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Native Pastures: Securing the Future of Farms and their Pollinators

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Jared Evan Gold

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Native Pastures: Securing the Future of Farms and their Pollinators

by

Jared Evan Gold

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Signature
Gerard Voos Ph. D.
Project Advisor
Director of the Asheville Graduate Center

____
Signature
Holly Iglesias, Ph. D.
MLA 680 Instructor

____
Signature
MLA Graduate Council

Date:______________________________

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Abstract

As a part of a unique and intricate matrix of natural processes, pollinators have existed for millennia. Through native diversity and evolutionary interdependence, this once robust system fosters health, balance and a resistance to invaders. However, as industrialized agriculture expands and disrupts overwhelmingly large parcels of habitat, the system shrinks and falters. This is due to a lack of habitat, the presence of invasive species, the use of synthetic inputs and species depopulation. The most critical example of ecosystem failure is found in declining pollinator populations. This includes wasps, stingless bees, social bees, flies, beetles, butterflies, moths and any other living creature that encounters the pollination process. The subsequent loss of crops, livestock, wild flowers and wild animals only emphasizes the problem.

Industrialized agriculture has temporarily mitigated the issue of general pollinator decline by further developing a dependence on the commercial honeybee industry. But, managed honeybees are now failing due to overuse, overexposure to chemicals, genetic hybridization and gene pool dilution.

A review of our approach to agriculture is necessary. In tailoring farms to incorporate native pollinator habitat within commercial borders, significant ecological and economic goals can be reached. A reduced dependency on the input of fertilizers and pesticides along with increased yields from a larger, more vigorous native pollination service has the potential to both offset the cost of sustainable design and remove the need for managed pollinator populations on open field farms.

Honeybees have allowed the farming industry to remain in an artificial state for decades. The initial disruption caused by adapting to passively managed pollinators cannot stand in the way of long-term improvements and innovation of the farm's design. And, the shift to a more sustainable organization of the industry does not necessitate hardship for the industry nor the individual farmer. Rather, it fosters security.

Introduction

For millions of years, flowering plants have produced pollen, nectar, oils, resins, fragrances and pheromones both as attractants and rewards for visiting pollinators.[1] Through pollination, flowering plants, or angiosperms, are able to produce seed, sometimes enclosed in an edible fruit. And, around 90% of angiosperms are dependent on animal pollinators.[2] Any animate creature that serves a role in the pollination service is an animal pollinator. With such a wide range of relevant flora and fauna, it is no surprise that humans have only a vague understanding of this complex relationship.

The concept of pollination was discovered about 3,500 years ago. This discovery was a result of diligent observation that related pollinator visitation with a change in flowering plants. A more complete understanding emerged in the 17th century firmly relating the pollination action with the propagation of seed.[3] Pollination occurs when pollen is transferred from the male to female sex organs of an angiosperm. More specifically, fertilization happens when pollen from the male anther comes in contact with the female ovule, which then forms into seed and fruit.[4] Some plants self-pollinate, but when considering animal pollinators, it is

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1 Pellmyr, Olle, and James Leebens-Mack. 1999. “Forty Million Years of Mutualism: Evidence for Eocene Origin of the Yucca-Yucca Moth Association.” *Proceedings of the National Academy of Sciences* 96 (August): 9178–9183.

2 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 53

3 Camerarius, Rudolf Jakob. 1694. *Ueber das geschlecht der pflanzen. (De sexu plantarum epistola.)*. Leipzig: W. Engelmann.

4 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 37.

specifically cross-pollination, or the transfer of pollen to the flower of a different plant, that is the goal.[5]

Today, scientists still struggle to understand the dynamic world of pollination beyond the principal events even as we split atoms in the next room. With that, the origin of angiosperms remains a mystery, with new theories eclipsing those of the past decade.[6] So, to honestly discuss pollination services and their impact on the world at large, it is necessary to appreciate just how limited our knowledge is.

The domestication of honeybees began in the Stone Age, as indicated by the presence of mesolithic rock paintings across the globe. This amounted to hunting, as primitive man sought out wild beehives for their honey. The Middle Ages saw the beginnings of organization as experienced beekeepers regularly harvested scattered wild colonies. Such beekeepers were known as beeman, or bortnik, at the time. Modern beekeeping was established in the 19th century upon the invention of modular hives, which allowed for cleaning, close observation and honey collection.[7] Agriculture, alongside wild lands and forests, opened its doors to the beekeeper as the burgeoning industry looked to produce varied flavors and styles of honey associated with different floral sources.

But, the world is in a much different era, one that was unforeseeable less than a century ago. Industry does not mix with natural processes and this is most apparent in attempts to work outside

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5 Ibid., 43.

6 Frohlich, Michael W., and Mark W. Chase. 2007. "After a Dozen Years of Progress the Origin of Angiosperms Is Still a Great Mystery." *Nature* 450 (7173) (December 20): 1184–1189. doi:10.1038/nature06393; Norstog, Knut. 1987. "Cycads and the Origin of Insect Pollination." *American Scientist* 75 (3) (June): 270–279.

7 Seeley, Thomas D. 1985. *Honeybee Ecology: A Study of Adaptation in Social Life*. Monographs in Behavior and Ecology. Princeton, N.J: Princeton University Press, 14-15.

nature's boundaries through intensification, genetic alteration and species importation. Yet, the natural world continues to have a significant impact on human civilization, whether it is acknowledged or not. So, as industry continues to push towards taming the land through manipulation, citizens are left to consider their choices.

And, while alternatives to active pollination by animals exist, in the form of hand and mechanical pollination, commercial operations are often found wanting. The cost is excessive and the results lacking. So, crops are genetically altered to become passive, or self-pollinating. It is hoped, that artificial intelligence and small, flying robots will be able to replace living pollinators should they fall by the wayside.[8] But, that is a significant technological influence on a natural order that almost 40% of plant-based food depends on.[9]

In the Sichuan Province of China, apple farmers are forced to hand-pollinate the mountainside orchards. Being one of the largest apple-producing regions in the world and the operation has decimated the local ecosystem, resulting in the collapse of native bees in the area.[10] And, with the high concentrations of pesticides, commercial honeybee keepers are unwilling to expose their hives to the orchards. The rest of

8 "Robotic Insects Make First Controlled Flight." 2013. Wyss Institute, Harvard University. http://wyss.harvard.edu/viewpressrelease/110/.

9 Klein, Alexandra-Maria, Bernard E Vaissière, James H Cane, Ingolf Steffan-Dewenter, Saul A Cunningham, Claire Kremen, and Teja Tscharntke. 2007. "Importance of Pollinators in Changing Landscapes for World Crops." *Proceedings of the Royal Society B: Biological Sciences* 274 (1608) (February 7): 303–313. doi:10.1098/rspb.2006.3721.

10 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 12.

the world is headed in that same direction as the loss and fragmentation of habitat continues alongside the use of pesticides and antibiotics.[11]

But, were an alternative method of pollination to be invented, what sort of disruption would this innovation cause? With such a limited understanding of pollination services, that could never be predicted. Perhaps the worst problem with fanciful technological solutions is their natural draw and distracting manner. Humans pine for invention and are ever hopeful that innovation can conquer nature. But, in complicating the problem, focus is lost and the consequences quietly sneak up on society. Furthermore, the dependance on technological innovation perpetuates an attitude that ecological problems can be fixed casually and abruptly once the appropriate technology has been developed.

Still, the agricultural industry is constantly trying to separate itself from the natural world. This movement appears in the form of synthetic chemicals, genetic modification and heavy machinery. However, for all the technological inputs, three-quarters of the world's flowering plants still depend on a natural agent that the agricultural industry has failed to replicate and replace – the animal pollinator.[12]

A wide range of financial analyses has put the value of annual

11 Ibid., 14.

12 National Research Council (U.S.), and National Academies Press (U.S.). 2007. *Status of Pollinators in North America*. Washington, D.C: National Academies Press, 1.

pollination between $150 million and $27 billion dollars within the commercial sector depending on the source.[13] Within those figures, an attempt has been made to validate native pollinator input within the commercial realm. A native pollinator is any animal pollinator that was naturally present or localized to a given area and, as such, could be sustained by native vegetation. As of 2006, non-managed pollination was deemed responsible for $3 billion dollars in crop yields per year.[14] However, Cornell University, in conjunction with the Xerces Society, increased the overall value of pollination to $27 billion annually. Fifteen percent of that total value, or $4 billion dollars, is the result of native, wild pollinator efforts.[15] Regardless of what source figures are drawn from, it has been succinctly established that pollination has an extraordinary intrinsic value.

However, the presence of non-indigenous and, often, invasive species has disrupted a significant number of ecosystems. The widespread use of non-native species to fill pollinator roles is commonplace within the annals of industrialized agriculture. One example is the importation and use of fig wasps in 1890s' California where a fundamentally false environment was created for profitable gain.[16] That aside, non-natives are typically used due to their generalist

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13 Ibid., 23.

14 Losey, John E., and Mace Vaughan. 2006. "The Economic Value of Ecological Services Provided by Insects." *BioScience* 56 (4) (April): 311–323.

15 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 6.

16 Swingle, Walter Tennyson. 1952. *The Fig in California*.

nature. Generalist pollinators will reliably gather from flowering plants of all kinds barring physical restrictions. However, some species of plants require specialized pollinators that have developed a unique relationship with the given plant through evolution, as with the fig and fig wasp.

Today's Farm

Industrial levels of crop productivity require significant modification of the plant and environment. Inputs, such as pesticide, kill not only the pests, but entire populations of beneficial invertebrates. Fertilizers are used in lieu of crop rotation and cover crops in order to maintain the immediate viability of cropland at the cost of long-term ecological sustainability. And, the design of modern agriculture requires significant alteration of the landscape. Monoculture farming, which turns enormous stretches of land into homogenous cropland, plays a large role in species decline worldwide.[17] Hundreds of thousands of acres turn into habitat-less zones barren of food for the majority of the year. These areas act as
barriers to the redistribution of native vegetation and pollinator populations. Furthermore,
large monocrops can affect migratory populations that depend on food

17 Marquard, Elisabeth J., Bernhard Schmid, Christiane Roscher, Enrica De Luca, Karin Nadrowski, Wolfgang W. Weisser, and Alexandra Weigelt. 2013. “Changes in the Abundance of Grassland Species in Monocultures versus Mixtures and Their Relation to Biodiversity Effects.” *PLoS ONE* 8 (9) (September): 1–10.

sources along their journey. Beyond that, the native predators that depend on said migratory species, are negatively affected by disruptions to their feeding cycle.[18]

The monoculture system is one of the most destructive practices in modern agriculture. In destroying large ranges of habitat, while establishing uniform fields of cash crops, farms are exposing themselves to a world of disease, fragility and limited pollination. Monocultures admittedly require the presence of managed pollinators, due to a lack of local habitat for native pollinators. In having homogenous fields with a limited bloom, native pollinators find themselves, for most of the year, in a food desert. Pollinator populations falter due to competition for a limited food source and either migrate or die off. With such uniformity, the risk of disease and infestation is increased due to an abundance of 'food' for a given disease or pest. This all while the soils are stripped bare due to overuse. In order for farmers to mitigate such risks while maintaining diminishing soils, a significant regiment of synthetic fertilizers and pesticides are required. However, in maintaining the short-term commercial profitability of the land, farmers are risking its long-term viability.

These agricultural tools seem primitive when put alongside high-

18 Doak, Patricia. 2000. “Population Consequences of Restricted Dispersal for an Insect Herbivore in a Subdivided Habitat.” *Ecology* 81 (7) (July 1): 1828–1841. doi:10.2307/177274.

paced industrial breeding where laboratories artificially inseminate queen bees in order to further specific genetic lines. And, whether such inputs and ideas come from United States factories or governmental experiments abroad, these actions and tools stand out within the exposed ecosystems as foreign invaders.

Regardless of collateral impact, modern farming works to achieve an understandable and admirable goal – feeding the world. However, doing so in an overtly industrial fashion is not without risk. The food distribution matrix is already weak. This matrix is made up of food, seed, fertilizer and chemical producers alongside distributors and consumers that span the globe. Such interdependence creates strength in a system not saturated with martial conflict and economic woes. However, the failure of one region to provide say, seed, to another, stands to disrupt the entire system. With the dependance of countless regions on imported sustenance, simply known as *food deserts*[19], any disruption can cause a crisis. As monocultures spread and a general dependence on farm inputs increases, the entire food matrix becomes more vulnerable to crop failure by way of epidemic, drought and soil collapse. And with the globalization of agriculture, families are dependent on far off regions. Civil, political and military strife can potentially disrupt trade routes, exposing the dinner table to conflict. More reliable agriculture at home will serve a number of purposes, including the independence of communities and countries.

Though farms have faced obstacles in the past, the honeybee and pollinators of all

19 A food desert is an area of exclusion where residents face barriers when attempting to access healthy foods. Shaw believes that there are various food deserts with limitations based on physical, economic and attitudinal factors.
See: Shaw, Hillary J. 2006. "Food Deserts: Towards the Development of a Classification." *Geografiska Annaler. Series B, Human Geography* 88 (2) (January 1): 231–247. doi:10.2307/3878390.

kinds have continued, without fail, to provide pollination services. However, industrialized agriculture and the strain of human population expansion is a relatively new beast. Upon entering the modern age of agriculture, there was an expectation that Earth's resiliency would allow it to withstand an ever-expanding population's demands. Consequently, the honeybee species has been exploited to the point of abuse while native pollinators find their habitat and population declining.

Though Earth is, in and of itself, quite defensible and resilient, the impact of civilization on the planet's ecological systems has been far too abrupt. The planet's decline is evident in the loss of species, the disappearance of rivers and the disruption of age-old climate systems. However, the impact of pollinator loss stands to have, perhaps, the greatest effect on society – a decline in animal pollinators directly results in a decline of flowering plants and their yields.

The agriculture industry's decisions out in the field will heavily impact the individual on a personal level. The availability and diversity of food stands to be severely limited by the unavailability of pollination services. The consequences within the agricultural industry when put into dollars or more pointedly, jobs, cannot be overstated. With perhaps billions of dollars in lost crops, significant global malnutrition for the poor, bland diets for the affluent and an increasingly impoverished global population due to the collapse of an industry with significant employment numbers, modern institutions of agri-business and regulation will have to inevitably adjust their practices.

But, the design and action of industrial agriculture, while flawed, was not originally of malicious intent. Instead, the idea behind industrialism is to provide for all in an appreciable abundance while acting as a capitalist mechanism that supports growth and jobs. However, the “devil may care” attitude associated with the profitable management of corporate farming is not always considerate of ecology. In this, the public and private sectors are alike. Subjecting the earth to the whims of profit margins and algorithms seems ill-fitted in the long-term as the diversity, abundance and constancy associated with a healthy ecological system is compromised.

The Dust Bowl happened and soils worldwide continue to degrade.[20] Animal populations continue to decline. Some species, like the *Bombus Frankilini,* are extinct.[21] Others are greatly threatened. Fresh water sources are being harnessed at unprecedented rates with tracts of arable land facing desertification as the land simply dries up. And, with chemical contamination of land and water resources in countries from the United States to China, the global ecological landscape faces permanent alteration. The only way to ensure a legitimate agricultural future not threatened by instability is to improve the agricultural foundations on which the system stands. Finally, acknowledging private enterprise's influence on modern society, progressive change is possible when companies take on the values of their customers and set an example for the industry. So, corporate

20 Opie, John. 1992. “The Drought of 1988, the Global Warming Experiment, and Its Challenge to Irrigation in the Old Dust Bowl Region.” *Agricultural History* 66 (2) (April 1): 279–306. doi:10.2307/3743858.
21 Federman, Adam. 2009. “Plight of the Bumblebee.” *Earth Island Journal* 24 (3): 34–39.

abuses of the past cannot stain the customer's relationship with present and progressive companies. In supporting conservation-minded businesses, citizens are accelerating the pace of ecological recovery.

Still, as pollinator populations continue to decline it is difficult to predict the consequences.[22] The current, vague understanding of the symbiotic relationship between plant and pollinator does not provide the information necessary to prepare for a world without pollinators. But it is known that as animal pollinator populations fall, floral species will follow. And with them, food species and their predators further up the food chain.[23]

Honeybee Addiction

For the past 6,000 years, *Apis mellifera* was hunted throughout Eurasia for both its honey and wax.[24] Modern practices, however, are focused on the honeybee's role in pollination services. Honey and wax, while robust industries in and of themselves, are an afterthought resulting from agricultural necessity. But, with over 300,000 other animal pollinators in the world, the agricultural exclusivity which *Apis* retains is both staggering and

untenable in the long-term.[25] A diminishing reliance on the honeybee will allow both for

22 Mitchell, Randall J., and Tia-Lynn Ashman. 2008. "Predicting Evolutionary Consequences of Pollinator Declines: The Long and Short of Floral Evolution." *New Phytologist* 177 (3) (January 1): 576–579. doi:10.2307/30142252.

23 National Research Council (U.S.), and National Academies Press (U.S.). 2007. *Status of Pollinators in North America*. Washington, D.C: National Academies Press, 127.

24 Crane, Eva. 1983. *The Archaeology of Beekeeping*. Ithaca, N.Y: Cornell University Press, 27.

25 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 22.

the species' return to health and its tailored implementation in fields where it can be most effective.

But, every spring Maine sees more than 60,000 honey bee hives unloaded in its countryside. That is over one billion managed honey bees brought in to pollinate a number of crops, particularly blueberries. Their presence on commercial farms has played a significant role in the devastation of the 270 native bee species in the state. This sort of operation, however, seems to ignore that native pollinators evolved alongside commercial crops and are consequently superior pollinators. In Maine, specifically, a variety of pollinators evolved alongside wild blueberry plants and have been shown to outperform *Apis mellifera* in pollination services on commercial blueberry fields.[26]

Still, the most widely managed pollinator in the United States remains the *Apis mellifera L.*, or western honeybee. This species is non-indigenous to North America, being of northern European origin and having only arrived with colonists around 1620 CE.[27] The German *mellifera* , also known as the dark bee, was that first sub-species brought to North America. However, years of cross-breeding with Caucasian, Carniolan and Italian *mellifera* has caused the German genetic identity to be nearly lost, with a only a handful of colonies still retaining original German stock.[28] To scale things out, whatever traits the current hybrid honeybees share with the original *Apis mellifera*, found over 35 million years ago in Germany and France, will likely never be known.[29] With the pace of industrial breeding, the honeybee is subjected to a directed evolution that would have taken hundreds of generations

26 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 12.
27 Gojmerac, Walter L. 1980. *Bees, Beekeeping, Honey, and Pollination*. Westport, Conn: Avi Pub. Co., 13.
28 Ibid., 5.
29 Seeley, Thomas D. 1985. *Honeybee Ecology: A Study of Adaptation in Social Life*. Monographs in Behavior and Ecology. Princeton, N.J: Princeton University Press, 9.

to naturally manifest. And, that says nothing of the unnatural couplings of regional species that had an exceedingly low probability of ever crossing paths in the wild.

The more farmers utilize mono-cropping, the more they are dependent on honeybees for pollination services. This is due to the monoculture operation's scale which does not sacrifice any profitable land for pollinator habitat. Honeybees, however, can be transported from farm to farm. They have a resiliency against transport conditions, being subjected to heat, cold, vibrations, wind, sensory deprivation and overload with limited casualties for decades. But, the distance which honeybees are regularly transported to support commercial agriculture is staggering. It is likely that at this moment there are as many bees on the road as out in the fields. Honeybee keepers are resigned to those realities, consciously sacrificing a portion of their population with each trip.

However, travel subjects the honeybee to a much greater threat. Foreign lands. With exposure to new species within new climates, the non-native bee is subjected to new diseases and pests alongside predatory creatures that would never be present within the given bees' native land. Such diseases and pests are then transported across the country within the infected honeybees, spurring epidemics.[30] Furthermore, as managed honeybees travel foreign fields, inadvertent hybridization can occur when feral honeybees are encountered. Feral honeybees make up populations that have swarmed and left the boundaries of management, forming wild colonies in the area.

A virgin, queen bee briefly leaves the colony for fertilization. During that period, wild and undesirable, managed honeybee drones stand a chance of mating with her. This can

30 Virusleri, Orta Doguda Balarisi, Balarisi Hastaliklari, and Koloni Yonetimi. 2011. "Honey Bee Viruses, Diseases and Hive Management in the Middle East and Their Relation to the Colony Collapse Disorder and Bee Losses." *Uludag Bee Journal* 11 (1) (February): 17–24. 21.

and does dilute the gene pool of available managed species; the effects ranging from innocuous to life threatening. Hybrid species may inherit dominant genes more susceptible to pathogens in other regions that the honeybee will travel to, just as they may lose recessive genes that had previously protected them.[31]

Another consequence of importing *Apis mellifera* is the emergence of feral, or wild, populations within the North American landscape. Their presence has caused unknowable changes to the North American continent due a lack of monitoring. But, whatever the changes, so much time has passed as to alter the environment to the point of effectively localizing the non-native *Apis*.[32] These new, non-native populations compete with native species for habitat and food, compromising native populations to the point of permanently altering the makeup of North American ecosystems.

Plainly said, the presence of honeybees is having a significant and negative effect on native biodiversity. Exacerbating the consequences of monocropping, managed bees consume the limited food supply still available to native pollinators.[33] Beyond that, managed bees have developed a preference for certain plants due to their forced adaptation to monoculture.[34] In the absence of the native pollinators that have been pushed out, the local ecosystem will be further disrupted as native plants will go unpollinated. This will result in a significant loss of biodiversity within given ecosystems, resulting in a downward spiral as floral sources of food diminish alongside their pollinators. Speaking to the loss of native pollinators, the presence of honey bees has been correlated with a significant reduction

31 Michener, Charles D. 1973. "The Brazilian Honeybee." *BioScience* 23 (9) (September 1): 523–527. doi:10.2307/1296479, 524.

32 National Research Council (U.S.), and National Academies Press (U.S.). 2007. *Status of Pollinators in North America*. Washington, D.C: National Academies Press, 42.

33 Ibid., 89.

34 Goulson, D. 2003. "Effects of Introduced Bees on Native Ecosystems." *Annual Review of Ecology Evolution and Systematics* 34: 1–26. doi:10.1146/annurev.ecolsys.34.011802.132355.

in reproduction within nearby bumble bee colonies.[35] This is likely due to diminished sources of pollen and nectar.

Still, honeybees are the premier choice for commercial operations because of their vigorous and perennial nature. While, throughout the year portions of a given colony may die due to age, stress, changes in the weather, illness and predation, a healthy queen is able to regularly return the colony to a high-functioning state.[36] Colonies of up to 50,000 provide large numbers of generalist pollinators that could be moved between fields of entirely different crops without a loss in efficacy. Their body size, design, and proboscis – or tongue – length allow honeybees to pollinate a wide range of crops.[37] Furthermore, being relatively hardy, their pollination range is extensive. In order to collect pollen and nectar, honey bees will travel up to 11 kilometers if the quality of the source is worthwhile.[38] But, the mean distance is typically around two kilometers, or about 2,200 yards.[39] The greatest area of pollination efficiency, however, is within a 2-300 yard radius around a given colony.[40]

The positive effect *Apis* has on crops in the vicinity of the colony is a result of honeybees being evolutionarily designed with pollen in mind. The first two pairs of legs are modified to clean off the pollen gathered on the hairs of the body. The hairs on all bees

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35 Thomson, Diane. 2004. "Competitive Interactions between the Invasive European Honeybee and Native Bumblebees." *Ecology* 85 (2) (February 1): 458–470. doi:10.1890/02-0626.

36 Gojmerac, Walter L. 1980. *Bees, Beekeeping, Honey, and Pollination*. Westport, Conn: Avi Pub. Co., 6.

37 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 85

38 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 38; Gojmerac, Walter L. 1980. *Bees, Beekeeping, Honey, and Pollination*. Westport, Conn: Avi Pub. Co., 44.

39 Seeley, Thomas D. 1985. *Honeybee Ecology: A Study of Adaptation in Social Life*. Monographs in Behavior and Ecology. Princeton, N.J: Princeton University Press, 92.

40 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 94

retain a slight electrostatic charge developed during flight that causes more pollen to cling to the bee's body.[41] The final pair of legs each hold a pollen basket where pollen is stored after being combined with a drop of nectar and turned into a small pellet, called 'bee bread.'[42] This 'bread' is later used as a provision within the brood cell for the eggs being laid.[43] At three weeks of age the honey bee worker will begin foraging for pollen, nectar and water. They will adjust their focus and schedule to both the needs of the colony and the habits of the nearby plant species. Once attuned to a given area, 90% of honeybees will return to the colony with a homogenous pollen load. It is in their nature to choose the most abundant plants that satisfies the colony's needs and have been known to collect pollen from the same plant species for up to twenty days at a time.[44] Taking into account how much pollen is given up to pollinators, plants have adapted to make up for the losses. In some angiosperms, additional food stamen develop to provide nutritious, but sterile, pollen to distract from the plant's viable resources.[45]

A real concern with the use of honeybees is their tendency to focus on either pollen or nectar, often not completing the pollination cycle during their foraging. Native pollinators are typically far more efficient due to their physical makeup and character traits. That being said, with honeybees visiting sometimes over one thousand flowers on a single trip, their lack of pollination efficiency[46] is made up for by sheer effort.[47]

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41 Newman, Jay. 2008. *Physics of the Life Sciences*. New York: Springer, 378.

42 Gojmerac, Walter L. 1980. *Bees, Beekeeping, Honey, and Pollination*. Westport, Conn: Avi Pub. Co., 26.

43 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 29.

44 Gojmerac, Walter L. 1980. *Bees, Beekeeping, Honey, and Pollination*. Westport, Conn: Avi Pub. Co., 44.

45 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 49

46 "Defined as the proportion of pollinated flowers relative to those that experienced pollen removal." See: Scopece, Giovanni, Salvatore Cozzolino, Steven D. Johnson, and Florian P. Schiestl. 2010. "Pollination Efficiency and the Evolution of Specialized Deceptive Pollination Systems." *The American Naturalist* 175 (1) (January): 99–105, 99.

47 Gojmerac, Walter L. 1980. *Bees, Beekeeping, Honey, and Pollination*. Westport, Conn: Avi Pub. Co., 45.

However, for all their numbers and flexibility, honeybees are somewhat sensitive to low temperatures and inclement weather. In temperatures below 54 degrees Fahrenheit and in windy, rainy weather, the honeybee cannot fly out to forage.[48] However, in extreme cases where colony health is at risk, honeybees will fly out in cold weather, periodically resting to heat their bodies.[49] Still, the healthy colonies found on farming operations are not likely to be that desperate. When temperatures reach around 100 degrees Fahrenheit, worker bees will forage for water for themselves and the colony, significantly limiting effective pollination rates.[50]

Another issue is that while honeybees are generalist pollinators, they have a preference for specific flowers with high sugar content – these tend to be wild, 'weed' plants. This is true of pollinators in general, and the overabundance of blossoming weeds near farming operations will have a negative effect on pollinator services.[51] Furthermore, foraging honeybees make firm decisions with respect to what flowers they are going to visit on a given trip. The individual forager will specialize in a specific flower species, with over 95% of pollen loads containing just one type of pollen. This is often considered a boon for the monoculture operator. However, honeybees will abandon a crop for sweeter pastures.

On a properly managed farm, this risk is significantly limited by offsetting the timing of native blooms with that of the crop. This allows the farm to still take advantage of the honeybee's ability to recognize and learn to forage healthy flowers of a given type, enhancing its efficiency.[52] Eventually, the honeybee will identify prime flowers with almost 100%

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48 Seeley, Thomas D. 1985. *Honeybee Ecology: A Study of Adaptation in Social Life*. Monographs in Behavior and Ecology. Princeton, N.J: Princeton University Press, 121.
49 Ibid., 122.
50 Gojmerac, Walter L. 1980. *Bees, Beekeeping, Honey, and Pollination*. Westport, Conn: Avi Pub. Co., 37.
51 Ibid., 122.
52 Seeley, Thomas D. 1985. *Honeybee Ecology: A Study of Adaptation in Social Life*. Monographs in Behavior and Ecology. Princeton, N.J: Princeton University Press, 103.

accuracy and be more likely to successfully trigger whatever pollination mechanism exists in order to receive the 'reward.'[53] This consistency also lends itself to successful pollination as pollen is not wasted on plants of other families.[54] This sort of intelligence, combined with a large colony population, allows the honeybee to compete in pollination efficiency with evolutionarily-specialized, native pollinators.

But, poor honeybee management has resulted in inadvertent hybridization due to the presence of feral honeybees and other managed colonies. This significantly dilutes the gene pool of the managed species as undesirable genes are introduced. With a managed species, control is important. However, it becomes difficult to contain tens of thousands of honeybees out in the field.

For decades now, laboratory hybridization and inbreeding has resulted in a consistent supply of perfected honeybees for commercial operations. Honeybee species are chosen for commercial breeding based on their towards handling, general hostility, honey production, colony design, pollination efficiency and a resistance to a particular disease or pest.[55] However, hybridization with dominant genes has resulted in the dilution of the available gene pool as recessive genes fall by the wayside. Inbreeding, in order to maintain certain genetic traits, has further damaged commercial queen stock and general population genetics. With the industry providing significant direction to the evolution of managed *Apis* species, the western honeybee is arguably a fundamentally artificial species.[56]

Amplifying the problem of gene dilution has been the shift from traditional breeding

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53 Ibid., 104.
54 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 88
55 Gojmerac, Walter L. 1980. *Bees, Beekeeping, Honey, and Pollination*. Westport, Conn: Avi Pub. Co., 110.
56 Seeley, Thomas D. 1985. *Honeybee Ecology: A Study of Adaptation in Social Life*. Monographs in Behavior and Ecology. Princeton, N.J: Princeton University Press, 16.

techniques to industrial ones. Modern industrial techniques have caused a directed and forced evolution of the honeybee. While with traditional breeding, which consists of manual insemination of available bee stock, the scale and existing diversity of that stock limited the negative impact of more specialized honeybee populations. With bees being chosen for specific traits, they are then bred over and over through artificial insemination with semen collected for the genes it possesses. In having become highly specialized, an exceeding number of bees have been bred off of a limited pool of genetic material. This creates a homogeneity that leans toward the realm of cloning. While this initially serves commercial operations well as large populations of efficient honeybees are widely available, the consequences are beginning to show themselves. Such homogeneity within honeybee genetics limits the species' resiliency against disease, creating the potential for exceedingly widespread epidemic amongst managed populations. Eventually, hybridization will eliminate enough recessive genes so as to limit the numbers of unique honeybee species worldwide. This limitation within the gene pool sets the stage for extinction.[57]

With over two million managed colonies in North America, *Apis mellifera* has been exposed to significant amount of trauma aside from genetic dilution.[58] Pesticides have weakened their neurological systems, hybridization and predation by newly-introduced species are destroying both colonies and gene pools, and the epidemic presence of parasitic mites, like the *Varroa destructor*, has been part of a population decline that has claimed almost 30% of managed bee populations.[59] Both the *Varroa* and Tracheal (*Acarapis woodi)*

57 Oxley, Peter R., and Benjamin P. Oldroyd. 2010. “Chapter 3 - The Genetic Architecture of Honeybee Breeding.” In , edited by Stephen J. Simpson, 39:83 – 118. Advances in Insect Physiology. Academic Press. http://www.sciencedirect.com/science/article/pii/B9780123813879000038.

58 National Research Council (U.S.), and National Academies Press (U.S.). 2007. *Status of Pollinators in North America*. Washington, D.C: National Academies Press, 18-19.

59 Ibid., 26-27.

mites' presence in North American bee colonies is a result of exposure to foreign species. *Acarapis woodi* mites entered North American *mellifera* populations by intermingling with Mexican bee populations.[60] *Varroa* emerged from Asiatic bee colonies of *Apis cerana* and entered the *mellifera* population when *cerana* was imported to North America. About $30 million is spent annually controlling *Varroa* mites, not including crop and honey losses.[61]

Other major health issues, like the pathogen known as American Foulbrood (AFB) – caused by *Paenibacillus larvae* – are simply a result of a strained system. AFB is, perhaps, the most serious and widespread disease facing the modern honeybee. The larvae of a given colony is infected by the disease spores, which germinate in the gut, stealing all nutrition. The *Paenibacillus* spores is spread further through the colony by worker bees as they clean up dead larvae and are often spread to other colonies by robber bees stealing honey from the weakened colony along with contaminated equipment.[62]

AFB is simply the result of poor beekeeping practices. The scale of management, over-demand and the presence of untrained beekeepers drives this issue to the point of epidemic. And, thanks to overuse and an overt dependance on medicine, the pathogen has become antibiotic-resistant since 1994. Each subsequent antibiotic has worked, but only for a short span of time as the mites become, again, resistant.[63] This is one of many factors setting the stage for a major collapse of the commercial beekeeping industry and,

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60 Eischen, F. A., W. T. Wilson, J. S. Pettis, A. Suarez, D. Cardoso-Tamez, D. L. Maki, A. Dietz, J. Vargas, C. Garza de Estrada, and W. L. Rubink. 1990. "The Spread of Acarapis Woodi (Acari: Tarsonemidae) in Northeastern Mexico." *Journal of the Kansas Entomological Society* 63 (3) (July 1): 375–384. doi:10.2307/25085193, 377.

61 Rucker, Randal R., Walter N. Thurman, and Michael Burgett. 2012. "Honey Bee Pollination Markets and the Internalization of Reciprocal Benefits." *American Journal of Agricultural Economics* 94 (4) (July 1): 956–977. doi:10.1093/ajae/aas031.

62 Genersch, Elke. 2010. "American Foulbrood in Honeybees and Its Causative Agent, Paenibacillus Larvae." *Journal of Invertebrate Pathology* 103, Supplement (0): S10 – S19. doi:http://dx.doi.org/10.1016/j.jip.2009.06.015.

63 National Research Council (U.S.), and National Academies Press (U.S.). 2007. *Status of Pollinators in North America*. Washington, D.C: National Academies Press, 79.

subsequently, much of industrial agricultural.

All this, however, is only being recently considered. The ease with which the honeybee has been managed and manipulated has allowed the industry to ignore its plight. It is then no surprise how involved we have become in the evolution of the honeybee; pollination by honey bees accounts for nearly one third of our food.[64] However, to reach this stage and scale, farmers have been forced to embrace a monocultural model, use an abundance of pesticides and remove all forms of native habitat from farmland.[65] But, this issue can be significantly mitigated by paying attention to a given plant's flowering characteristics.[66]

Tomorrow's Farm

With the industry so dependent on honeybees, a focus on 'bees' becomes a risk with respect to native pollinator incorporation. Many wasps are highly effective in the field as their life cycle and needs are similar to bees. Butterflies are particularly useful for floral crops, alongside flies and beetles. It is expected that any conservation efforts will benefit all of these species. However, flies and beetles in particular have few, if any, well-established conservation techniques.[67]

All of these creatures are working toward a goal, or better said, a reward. An important factor in making sustainable agricultural design work is understanding the reward mechanism of the pollination process.

64 Gojmerac, Walter L. 1980. *Bees, Beekeeping, Honey, and Pollination*. Westport, Conn: Avi Pub. Co., 120.
65 Ibid., 121.
66 Ibid., 122.
67 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, xi.

Rewards are quite varied in their nature and purpose. Bees seek out both nectar and pollen from angiosperms. Other pollinators are drawn to fragrances and pheromones.[68] An odd example being the variety of plant species that give off a rotten or excrement odor in order to attract fly pollinators.[69]

In commercial design, recognizing which plants provide no reward to pollinators is as crucial as recognizing that an overabundance of a given plant will cause pollinators to lose focus on the main crop, limiting fruit set.[70] Proper implementation serves to increase not only the health of the pollinator, but of the land and business.

It is difficult to determine the health and status of the wide range of native pollinating species. Without any sort of long-term monitoring in the United States, the fate of the 4,000 species of bees that exist in North America remains somewhat of a mystery. Monitoring is a critical part of the next phase of agriculture as the observations will aid in better tailoring recommendations, tools and techniques. Prescriptions for specific actions are difficult and the most logical step forward is simply to implement sound ecological practices as they relate to how the farm is setup and operated. For that to happen, the expectations society places on the agricultural industry and what society is willing to tolerate and risk in order to maintain the standard practices of modern farming must be addressed.[71]

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68 Dafni, Amots, Michael Hesse, and Ettore Pacini. 2000. *Pollen and Pollination*. Vienna: Springer Vienna.

69 Johnson, S. D., and A. Jürgens. 2010. "Convergent Evolution of Carrion and Faecal Scent Mimicry in Fly-Pollinated Angiosperm Flowers and a Stinkhorn Fungus." *South African Journal of Botany* 76 (4): 796 – 807. doi:http://dx.doi.org/10.1016/j.sajb.2010.07.012.

70 National Research Council (U.S.), and National Academies Press (U.S.). 2007. *Status of Pollinators in North America*. Washington, D.C: National Academies Press, 120.

71 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 27.

With that, a significant amount of field work has been done across the world, both in unmanaged and tailored pastures. This allows for a dense and academically satisfying analysis. In synthesizing all the available material, it becomes possible to discuss agricultural design from a position of merit. The augmentation of one successful technique with another within a commercial tract will provide exponential gains in terms of yield, consistency, crop security and ecological health. Furthermore, as this translates to a secure and increased profitability over the years, the economic health of the farming community can be repaired.

The most common native pollinator is the solitary bee. Bumblebees are included in this group even though they develop small, social colonies. Known for pollinating apples, alfalfa and strawberries on a large scale, solitary bees are a viable alternative to honeybees.[72] Coming in all shapes, sizes and demeanor, choosing the correct species for a given crop, as generalist and specialist solitary bees exist, is crucial.

In recent years, a number of native species have been garnered for active management. Most prominently is the *Bombus*, or bumblebee, often found in greenhouses as honeybees are not suited for such conditions – they orientate themselves by the sun. Also, being one of the more prominent wild pollinators, bumblebees are heavily depended on in the fields, often unwittingly. Bumblebees are opportunistic and will generally not excavate a home, preferring to use deserted burrows and cavities under and

72 Mader, Eric, Mace Vaughan, Matthew Shepherd, and Scott Hoffman Black. 2010. "Alternative Pollinators: Native Bees." ATTRA, 3.

between debris, so their presence is not particularly apparent.[73]

Other generalist native bees like the alkali, mason and leafcutting are all being examined for potential use in commercial operations. For example, *Osmia lignaria*, the blue orchard mason bee, is now being used effectively for apple pollination.[74]

Some bees, such as *H. laboriosa*, fall into the *oligolectic* class. This designates that the bee collects pollen from a closely related group of plants. The propagation of specific *oligolectic* bees may be suitable for certain commercial operations that focus on a short list of appropriate crops. For instance, squash bees, or *Peponapis pruinosa*, specialize in squash and pumpkins specifically.[75] Their presence on the right farm can serve to ensure robust yields.

Bumblebees, however, remain perhaps the most viable and effective pollinator out in the fields. In both managed and wild form, they have a significant effect on farms due to their being the first bee active in the spring and last to go dormant in the fall.[76] Within the diverse group of native pollinators, the bumblebee seems to be the backbone of the system. Both the strength and versatility of the bumblebee allows it to act when other pollinators are incapacitated by various stressors. This ensures a minimum standard of pollination services and could be the difference between no yields and bringing *something* to market.

With longer tongues than honeybees, the bumblebee can more effectively pollinate a wider range of flowering plants. But, even more

73 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 158

74 Bosch, J., and W.P. Kemp. 2002. “Developing and Establishing Bee Species as Crop Pollinators: The Example of Osmia Spp. (Hymenoptera: Megachilidae) and Fruit Trees.” *Bulletin of Entomological Research* 92 (01) (February): 3–16.

75 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America’s Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 32.

76 Ibid., 45.

unique is the *Bombus'* ability to disconnect its wings from its flight muscles. Utilizing significant strength, the movement and flexing of the flight muscles creates a vibration that serves to "buzz-pollinate" a given flowering plant.[77] The more appropriate name for this action is sonication and the frequency of the vibrations is similar to the note middle C.[78] This technique effectively pollinates a number of crops including blueberries and peppers. And, with tomatoes, bumblebees are able to achieve nearly 100% pollination success.[79]

Flower constancy is a primary characteristic of the bee pollinator and remains an important factor for commercial operators. Bees have a natural inclination to repeatedly visit a particular plant type on a given foraging trip. The tendency allows for 'outcross' pollination, which is pollination by pollen from another flower within the same species. This provides for greater, healthier yields and seeds.[80] Bumblebees, after learning a flower's design, will focus on only one species of flower, provided there is enough of the given flower to sustain the colony.[81]

Diligence, however, is the true advantage of the bumblebee. They

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77 Javorek, S.K., K.E. Mackenzie, and S.P. Vander Kloet. 2002. "Comparative Pollination Effectiveness among Bees (Hymenoptera: Apoidea) on Lowbush Blueberry (Ericaceae: Vaccinium Angustifolium)." *Annals of Entomological Society of Ameirca* 95 (3) (May): 345–351.

78 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 45.

79 Luca, Paul A. De, and Mario Vallejo-Marín. 2013. "What's the 'buzz' about? The Ecology and Evolutionary Significance of Buzz-Pollination." *Current Opinion in Plant Biology* 16 (4): 429 – 435. doi:http://dx.doi.org/10.1016/j.pbi.2013.05.002.

80 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 22.

81 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 161

are two to four times more effective as a pollinator, per bee, than the honeybee. This is due to their strength, larger size which retains more pollen, proboscis length and resiliency against weather changes. Furthermore, the bumblebee is almost two times faster at working flowers than *Apis mellifera,* while working 50% longer days. However, the honeybee forages at a range two and three times that of the bumblebee. With the bumblebee only going as far as eight kilometers, this must be accounted for in design.[82] But, other native pollinators have even shorter ranges making it disingenuous to stretch the distance between attractive native vegetation when trying to implement an unmanaged pollinator service.

But, bumblebees have evolved into a number of sub-species designed particularly for a given area. Operations found in cold, northern regions may find the *Bombus polaris*, of great use. Found in Canada, Alaska and Greenland, the *polaris* has evolved to work during the entire 24 hours of daylight that occur in these regions during the short summer. More importantly, their hardiness with respect to cold weather makes them ideally suited for early-spring pollination of wildflowers and fruit crops.[83]

Studies have been done to keep tabs on the status of various pollinators across the world. Fieldwork during the mid-1990s

82 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 156.

83 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 45.

determined that *Bombus terricola* was the most abundant bumblebee in Wisconsin. Ten years later, *terricola* made up less than one percent of Wisconsin's bumblebee population. A western cousin, *Bombus occidentalis*, has met the

same fate while *Bombus franklini* has likely fallen into extinction.[84] This is *the* trend not only for bumblebees, but pollinators globally. While the expansion of industrialized agriculture has been varied, the industry has significantly impacted nearly every biome on Earth.

An often overlooked pollinator is the fly. Nearly half of the 120,000 species of flies are known to visit flowers and many of those act as pollinators.[85] Their effect is noticeable, particularly with strawberries, onions and carrots and has created a demand for novel management techniques.[86]

The butterfly is a well-known pollinator often seen in pleasure gardens. However, moths, of which there are ten times the variety of butterflies, play a unique and important role in the pollination matrix.[87] Consider that they are the only active pollinator at night. With some flowers blooming at night, specialized relationships have been formed with moths. Species of all kinds have adapted to one another in order to

84 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 11.

85 Ibid., 51.

86 Howlett, B. G. 2012. "Hybrid Carrot Seed Crop Pollination by the Fly Calliphora Vicina (Diptera: Calliphoridae)." *Journal of Applied Entomology* 136 (6): 421–430. doi:10.1111/j.1439-0418.2011.01665.x.

87 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 61.

facilitate survival. Over great lengths of time, both flora and fauna can develop specific organs in order to attract pollinators and pollinate specific flowers. The *Xanthopan morganii*, a hawk moth, has an extremely long proboscis that can reach over a foot in length. This allows the moth to

pollinate a particularly large orchid, 'the comet.'[88] Any disruption in this relationship and the comet orchid could not propagate, resulting in the decline of both species.

The dwarf bear poppy has also developed a specialized relationship with a certain pollinator. The Mojave poppy bee's partnership with the dwarf, makes the bee *monolectic.*[89] That is to say it depends entirely on a single plant for nectar and pollen. In this case, the poppy plant depends on this lone bee, as well, for pollination. This is a result of unique physical principles of both flora and fauna species that facilitate dual reward pollination.

With that, the reestablishment of pollinator populations is a critical issue facing not only commercial operations, but ecosystems worldwide. While the effects of pollinator decline may not be immediately tangible, over time species will come closer to extinction, creating a snowball effect. This is exactly the case with many bushes and trees which continue to flower for years, if not decades, without pollinators only to meet an abrupt and seedless decline.[90] Beyond the need for generalist pollinators within healthy habitats, specialists are of particular importance if biodiversity is to be maintained.

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88 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 63.
89 Ibid., 8.
90 Ibid., 7.

Making Room

Only 15% of the world's food supply is pollinated by domesticated honeybees, while 80% depends on wild bees and other wild pollinators. The other 5% of pollination occurs by passive means such as the wind or through mechanical and hand pollination.[91] With significantly less fanfare than the honeybee, a great number of insects work diligently day and night to pollinate flowers across the globe. They act in a range of tough conditions, working to form special relationships with countless plants. The challenge when depending on native pollinators is the effort necessary to finance, design and implement sustainable landscapes within a profitable agricultural operation.

Different locales must be defined properly so that effort is not wasted on the wrong species of plants and animals. That is to say native and localized plants known for providing pollinator habitat and forage must be initially identified for the region. Non-native plants will likely be less resilient to the conditions of the area and, not having developed with local pollinators, may be undesirable to them.

The typical advantage of the honeybee is its generalist, or *polylectic,*[92] nature. This makes it a simple and relatively efficient choice for commercial growers as the insect shows a willingness to pollinate any and all floral sources available to it. However, it becomes a matter of going one step further and identifying which species of pollinators have been evolutionarily designed through natural interactions for each flowering plant. Even with generalist pollinators, over time a symbiotic relationship is developed with regional plants

91 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 53

92 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 32.

allowing for more efficient pollination and greater floral rewards. By tailoring the farm's landscape, wasteland is planted with the correct plants so as to attract the most beneficial pollinating species for a given operation. A native species' correctness is determined by the crop itself along with the range and scale of the operation. The willingness of the farmer or business to invest in sustainable design will determine the diversity and abundance of pollinator attractants and, in so doing, determine the effectiveness of the native pollinator population.

A diversified portfolio of native vegetation will be necessary to provide consistent food sources for the given pollinator and will provide for a wide range of pollinators. Design will, perhaps, favor the populations of targeted species, but if properly thought-out should not create a significant imbalance. The pollinators that were not targeted by a given management plan will still benefit and their increased populations will serve to bolster pollination services overall. The increased competition for habitat and food within the operation will protect the ecosystem from species overpopulation and the consequent vulnerability to epidemic.

However, one of the issues with native bees has been their limited longevity. Most operate as active adults for only three to six weeks, creating a difficult management situation and inconsistent pollination patterns for commercial operations. It is no surprise that commercial operations often opt for managed honeybees due to their vigor and long life. Worker honeybees will remain active for months, as will drones. The queen, however, can survive for years.[93]

93 Gojmerac, Walter L. 1980. *Bees, Beekeeping, Honey, and Pollination*. Westport, Conn: Avi Pub. Co., 34.

Farmers and researchers have found stingless bees a particularly good option for commercial operations as they retain a number of the characteristics sought after in honeybees. They vary in size and design, making their wide range useful to almost all cultivators if appropriately chosen and by forming perennial colonies that are adaptable to changing crops, some stingless bees are viable use on a commercial level. Equally important is the relative ease with which they are handled. However, with stingless bees having a shorter foraging distance compared to *Apis*, considerations must be made when designing habitat and

colony layout. For this reason, as well as their limited resistance to cold, stingless bees are often used in greenhouses.[94]

Even so, range and longevity are not a concern in sustainable agricultural design as attractive pollinator features are heavily represented throughout crop fields that are passively managed. In providing the habitat, a significant diversity of pollinators remain present and healthy. With that, it has been established that passively managed pollinators can provide reliable pollination services. This is thanks to the ecosystem's flexibility where one species acts as a buffer when another species begins to die out for the season, much in the same way one flower takes on for another in order to provide a perpetual bloom and floral food source.

But, traditionally, specific operations call for specific operators. In the case of cherry orchards, the blue orchard bee (*Osmia lignaria*) has repeatedly shown itself to be a superior pollinator compared to the managed honeybee. In Utah, blue orchard bee-pollinated fields

94 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 141

produced double the average yield, while also producing a harvest-able crop during poor seasons when other farms were failing.[95] It will be a matter of observing managed non-*Apis* pollination efficiency against passive, native pollinators to determine the absolute ideal pollination scheme. However, management has shown itself to be a vulnerable practice and the long-term consequences of manipulating any species must be considered. That is not to say that species cannot be managed responsibly and used to augment the pollination services of native pollinators.

The availability of nesting habitat is the most common factor that limits the population, distribution and diversity of bee species.[96] Native vegetation has typically been viewed as wasteland within the agricultural world. Offering no valuable yields, these plants take up cropland. However, in understanding the significant benefits associated with the presence of native vegetation, the farmer may come to see the presence as the foundation of a reliable operation. But, on an over-manicured farm, native pollinator populations are severely limited. While this speaks to an imbalanced sustainable design, it is more so an acknowledgment of large-scale agricultural exercises in homogeneity.

But, even though passive management is to reflect nature, certain standards have been established to better attract pollinators to the farm and garden. For instance, flowers of any type that are being planted for attraction purposes have a larger impact when planted in clumps as opposed to individual plants strewn about the property.[97] More important than

95 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 26.

96 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 119

97 Mader, Eric, Mace Vaughan, Matthew Shepherd, and Scott Hoffman Black. 2010. "Alternative Pollinators: Native Bees." ATTRA, 6.

actual arrangement, however, is the diversity of the native wildflowers, trees and shrubs. Though many pollinators may show an inclination towards constancy with respect to pollinating a lone species at a time, this does not change the necessity of biodiversity within the environment. Pollinator corridors, islands, whatever you may call them, require a broad range of plants in order to feed a wide range of visiting species across a number of seasons.[98]

It is imperative that the native plants being used to passively manage pollinators on a given operation do not bloom during or just before the main cash crop. As was stated earlier, pollinators will abandon a crop in favor of wild plants with higher sugar concentrations. Consciously designing the native landscape to avoid competition is a must. Honey beekeepers are well aware of this and it is common practice to delay the introduction of managed pollinators until the main crop is beginning to blossom. This prevents the insects from being distracted by competing plants.[99] By avoiding this scenario altogether, the farmer is gaining precious days of pollination services.

What the modern farmer must avoid when attracting pollinators is a dependance on any single crop. Even a native monoculture limits populations and diversity of species in the area. This sort of situation is untenable for a farm as pollinator populations are starved for a significant period of the year limiting their effectiveness in future growing seasons. Consequently, it is necessary to design pollinator habitats with a constant bloom in mind – the period of the main crop's bloom being factored in. Trees and shrubs provide shelter for nesting and overwintering while wildflowers provide the general diet. These can be a result of intentional plantings or through utilizing existing features on the land, particularly in the

98 Ibid., 7.
99 Gojmerac, Walter L. 1980. *Bees, Beekeeping, Honey, and Pollination*. Westport, Conn: Avi Pub. Co., 122.

form of 'set-asides,' or areas that are not to be mowed so that they remain as wild as possible.[100]

But, the first step in improving agricultural design is to make use of waste areas. Whether on the borders or in between the rows, available land must be planted or organized in order to support greater populations of pollinators. The effects of various ecological design features ranging in scale and result have been established, making design relatively straightforward. Options range from housing carpenter and mason bees in bamboo stalks and wooden blocks to providing sandy areas for burrowing solitary bees, or even leaving debris piles and old prairie dog holes for bumblebees. However, such novel habitats will likely be unnecessary within a properly designed farm as natural habitat is provided. Specific populations may be enhanced by implementing extra, tailored habitat, but the effect is potentially negligible within an already diverse pollination service. Regardless, the designer must be conscious of the operation's specific locale as this determines what options are available. One cannot expect *Bombus polaris* to be a presence on a Florida-based tomato operation.

When deciding on plants, perennials are desirable due to their hardiness and low maintenance requirements. Furthermore, it has been found that they tend to be more consistent with their blooms while being richer in nectar than their annual counterpart. Single flowers, as opposed to double flowers with their multiple layers of petals, are also better nectar sources. Regardless, by providing a variety of perennials, a dependable food source exists for a breadth of beneficial species.[101]

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100 Mader, Eric, Mace Vaughan, Matthew Shepherd, and Scott Hoffman Black. 2010. "Alternative Pollinators: Native Bees." ATTRA, 7.

101 Mader, Eric, Mace Vaughan, Matthew Shepherd, and Scott Hoffman Black. 2010. "Alternative Pollinators: Native Bees." ATTRA, 8.

But, there are a number of ways to implement passive pollinator management on farming operations. Varying in size and shape, vegetation is tailored to fit the land and resources available to the operator. Recognizing that many farming operations will be unable to fully implement passive design, let alone right away, the benefits of even partial implementation must be acknowledged. By introducing native plants to the farm's landscape at any scale, the operator is increasing the health of his property.

One concept for attracting native pollinating populations is the nectar corridor. These patches act as rest stops for the numerous species of migratory pollinators. The idea is to connect wider stretches of land by providing viable habitat for larger populations of migratory animals. Inherently local populations will benefit. But, the nectar corridor's goal is analogous to that of wildlife land crossings that address habitat fragmentation caused by roads. Regional ecological health can be improved by connecting currently isolated habitat.[102] But, connecting land-based habitat is far more costly and intensive of a process. This is due to the size, habitat demands and terrestrial nature of the targeted wildlife. Pollinator rest stops may be a more inviting project for government and non-profit environmental organizations to fund.

If commercial operations act to increase the general health of pollinating populations, farms worldwide will benefit. By diversifying the landscape of agriculture, pollinators are provided habitat that ensures the security of pollinator services season-to-season. This is an important concept in a world where pests and pathogens are now finding their way across the globe. The threat of epidemic for a range of species can be significantly reduced as passive management becomes worldwide. In a diverse system, there will not be any ecologically

102 Taylor, Brendan D., and Ross L. Goldingay. 2009. "Can Road-Crossing Structures Improve Population Viability of an Urban Gliding Mammal?" *Ecology and Society* 14 (2): 21.

weakened regions for diseases to find refuge where it can grow and spread from. Increasing the connectivity of pollinator habitat is a necessity when the fragmentation of habitat has been one of the major reasons for the dramatic population losses in migratory pollinators.[103] So, for farms that exist along migration routes, the presence of 'nectar corridors' will serve to attract hungry and vigorous populations of diverse pollinators and other beneficial insects. The implication being a reduction in pests and increased fruit set, which result in reduced input costs and increased yields.

To maintain the production of numerous commercial crops, the presence of animal pollinators is necessary from both a financial and practical standpoint. But, recognizing the strain currently being placed on the *Apis* genus, the question becomes whether other pollinators can step in and augment, if not replace the commercial dependance on managed honeybees. However, this requires a management style all its own and the analysis of trials

and studies is a significant step toward developing a theoretically sound method of agriculture on a worthwhile scale.

A large number of factors influence pollination services. For instance, proximity to plants has a tangible effect on pollinator efficiency. The nearer to a bee colony, the higher the fruit set. This is due to less energy being spent in flight, giving pollinators the chance to work blooms in a more vigorous fashion, often re-visiting flowers. This correlation has been established with

103 Mader, Eric, Mace Vaughan, Matthew Shepherd, and Scott Hoffman Black. 2010. "Alternative Pollinators: Native Bees." ATTRA, 5.

cherries, whose fruit sets grew exponentially as the distance to the apiary closed.[104] Strawberries are in a similar situation. However, honeybees of various kinds remain the primary pollinator of commercial strawberries.[105] Honeybee colonies within half a kilometer of the production field significantly improved yields. But, in doubling the distance to one kilometer, the impact of the bees' presence was negligible, having fallen by half. For the pollinator, a sense of motivation occurs. In having a shorter flight time, pollination vigor has been shown to increase. Specifically, foragers will, working harder, take a greater number of flights the closer the colony or nest is to a floral source.[106]

Large commercial fields of mango were modified to fit 'native flower compensation areas,' or NFCAs. The purpose of the field study was to dispel the farmer's apprehension over redesigning the farm's layout. Mango was chosen because of its nonspecialized flowers, allowing for a wide range of pollinators. Pollinator declines had been noted in the area due to heavy pesticide use and isolation from natural habitat. However, with the utilization of NFCAs, the negative impacts were mitigated.[107]

Specifically, a single 270 square foot NFCA of native vegetation was placed in the corner of each mango orchard. This patch was made up of two native species, intermingled. Neither ideally designed nor particularly diverse, the effort still had a significant effect on the commercial operation. Of note is the influence the presence of native pollinators had on managed honeybees. Honeybee visits to mango flowers more than doubled due to the

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104 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 59.

105 Ibid., 64.

106 Ibid., 98.

107 Carvalheiro, Luisa G., Colleen L. Seymour, Susan W. Nicolson, and Ruan Veldtman. 2012. "Creating Patches of Native Flowers Facilitates Crop Pollination in Large Agricultural Fields: Mango as a Case Study." *Journal of Applied Ecology* (49): 1373–1383. 1374.

presence of natural habitat and pollinators.[108] This is likely due to increased competition driving the honeybees to more actively forage. Native bees have also been known to simply disturb honey bees, preventing them from sitting idly on floral sites.[109]

Overall, production was found to be noticeably higher when near the NFCAs. In the case of the mango fields, a 1.5 kilogram increase was noticed in yield per mango tree per harvest.[110] An important factor to note is that the plants occurred naturally in the region, so no maintenance was required on the NFCAs – though they were impacted by the mango fields' flood irrigation system. Without consideration for reduced externalities, profitability was increased over $300 per hectare.[111]

On farming operations, a number of factors have been found to negatively affect pollinator populations. First, the distance from natural habitat limits growth due to a lack of diversity in a given pollinator's food supply along with the additional energy expended on foraging at a greater range. Pesticides, however, have the most significant impact, causing a 40% decline in pollinator diversity and populations within the observed mango fields.[112] With the implementation of nectar corridors, NFCAs and so on, standard practice is to minimize pesticide use as it has been consistently shown to negatively affect wildlife and biodiversity in the given area. Over time this could, if necessary, allow the reintroduction of

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108 Carvalheiro, Luisa G., Colleen L. Seymour, Susan W. Nicolson, and Ruan Veldtman. 2012. "Creating Patches of Native Flowers Facilitates Crop Pollination in Large Agricultural Fields: Mango as a Case Study." *Journal of Applied Ecology* (49): 1373–1383, 1376.

109 Brittain, Claire, Neal Williams, Claire Kremen, and Alexandra-Maria Klein. 2013. "Synergist Effects of Non-Apis Bees and Honey Bees for Pollination Services." *Proceedings of the Royal Society* 280 (1754) (March): 8.

110 Carvalheiro, Luisa G., Colleen L. Seymour, Susan W. Nicolson, and Ruan Veldtman. 2012. "Creating Patches of Native Flowers Facilitates Crop Pollination in Large Agricultural Fields: Mango as a Case Study." *Journal of Applied Ecology* (49): 1373–1383. 1378.

111 Ibid., 1379.

112 Carvalheiro, Luisa G., Colleen L. Seymour, Susan W. Nicolson, and Ruan Veldtman. 2012. "Creating Patches of Native Flowers Facilitates Crop Pollination in Large Agricultural Fields: Mango as a Case Study." *Journal of Applied Ecology* (49): 1373–1383, 1376.

managed *Apis* as the genus' health recovers. Their health speaks directly to the cost of pollination services as honeybee colony collapse and resulting shortages caused the cost of renting hives to rise threefold between 2003 and 2009.[113]

The effectiveness of the various vegetative management techniques can be correlated with size and distance. It is the expected that the combination of styles will create a more complete ecological matrix across the given agricultural operation as a diverse population is more likely provided for. And, with interspersed habitat within the farm, no longer will the effects of wildflower borders dwindle toward the interior of the crop field as pollinators will inhabit and migrate between corridors and pollinator islands throughout the landscape. The larger the implementation, the greater the expected site diversity, which corresponds directly to increased pollinator vigor. In addition, increased site number was directly correlated with an overall greater amount of nectar and pollen. Site number refers the how many unique pollinator attraction sites existed within the boundaries of the operation. As this number increased, pollinator populations also follow suit.

An effective pollinator habitat can provide the commercial operation with a reliable pollination system that will notably augment, if not supplant, commercial honeybee services. As importantly, the effectiveness and security of the native populations will continue to grow within the managed operation. This will eventually reach a plateau based on available forage and habitat, but further fieldwork is necessary to fully appreciate the strength of native pollinators as community growth likely continues for years on years.

Interdependence

113 Klein, Alexandara-Maria, Claire Brittain, Stephen D. Hendrix, Robbin Thorp, Neal Williams, and Claire Kremen. 2012. "Wild Pollination Services to California Almond Rely on Semi-Natural Habitat." *Journal of Applied Ecology* (49): 723–732. 724.

Sustainable agricultural design finds itself always returning to diversity. A variety of food supports a variety of creatures. Passive design builds upon a natural state, exaggerating certain features in order to attract larger, more varied populations of pollinators.[114] Diversity of food sources breeds resiliency in pollinator populations. As conditions change and food supplies of one kind dwindle, other sources emerge to fill in. Pollinators are never starved or forced to seek food outside of a designated region.

As for the implementation of NFCAs and other native vegetation designs, it is hypothesized that, as years pass, their effectiveness will grow as more invertebrates use the habitat for foraging and nesting. Migratory pollinators will further augment the various sites along their journey, returning year after year. And as perennial populations sustain themselves on reliable sources of food and habitat, they can be expected to grow, bolstering their services.[115]

When designing a landscape for pollinators, besides diversity, consistency is key. Food supplies must be available year-round, aside from periods of pollinator dormancy in certain climates. This is achieved by a perpetual bloom of various types of flowers, trees and shrubs. Native perennials serve admirably in this role. Again, however, pollinators should not be overwhelmed by the presence of these native flowers. Particularly, just before and during the main crop's bloom. As there is a significant risk that pollinators will ignore the main crop.

The given crop and financial situation of an operation will determine the scale of a corridor, island, NFCA or what have you. But, it has been shown that even small patches

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114 Carvalheiro, Luisa G., Colleen L. Seymour, Susan W. Nicolson, and Ruan Veldtman. 2012. "Creating Patches of Native Flowers Facilitates Crop Pollination in Large Agricultural Fields: Mango as a Case Study." *Journal of Applied Ecology* (49): 1373–1383. 1380.

115 Ibid., 1381.

will have a beneficial and financially-justifiable effect on the farm. When a monocrop is concerned, the presence of diverse flower patches before and during a monocrop's bloom has been shown to significantly increase the pollination rate of the main crop. Typically, those pollinators can only depend on the main crop and their health suffers. Consequently, their numbers and efficacy dwindle.

Some farms have attempted to naturalize their property by adding strips of natural habitat adjacent to their conventional orchards. As a result, almond flower visitation by wild pollinators significantly increased. However, this increase was predominantly confined to the orchard's borders. Furthermore, fruit set was not improved as a result. This was attributed to the strips lack of biodiversity and arguably, the non-organic operation itself. However, the strip technique was praised for increasing pest control within the orchards, acting as a natural barrier. As a note for design in general, the broad implementation of natural strips facilitates natural connectivity within agricultural borders and fosters biodiversity.[116]

But, in order for wild pollinators to have a role in commercial pollination services, they must prove themselves measurably. Managed honeybees have undergone significant observation and are an ideal comparison, entirely aside from their being the subject for potential replacement. If wild pollinators can be shown to significantly augment managed honeybee efforts, and they have been, there is potential for replacing managed populations.

116 Klein, Alexandara-Maria, Claire Brittain, Stephen D. Hendrix, Robbin Thorp, Neal Williams, and Claire Kremen. 2012. “Wild Pollination Services to California Almond Rely on Semi-Natural Habitat.” *Journal of Applied Ecology* (49): 723–732. 730.

But, unmanaged pollination services must be made comparable to existing services in order to establish an economic impact. As such, managed species have become the benchmark by which to assess the economic gain or loss of an unmanaged pollinator presence.[117]

Location plays a significant role, as native bees cannot be native to everywhere, as honeybees are treated. With native pollinators being dependent on local habitat and diversity, the habitual destruction of their food sources by industrialized agriculture correlates directly with declining populations. However, the diversity of pollinating animals creates a resiliency in the populations that can effectively respond to changes in the environment through migration, adaptability and stubborn constitution. This results in varied populations of a given taxa across numerous locales.[118] As certain food sources come and go, so do the populations of pollinators. The changing weather, a dwindling sun, both affect the presence of animal populations in general. By providing a diverse range of native habitat, farms are ensuring a home and meal for the whole range of pollinating insects that make up the pollination cycle of a given region. In so doing, robust pollination services throughout all the viable seasons should be expected.

Over four years (2005-2008), seven of the most abundant unmanaged pollinating insects were compared with managed *Apis mellifera.*[119] These eight pollinators account for nearly 80% of all flower visits. This was observed on over 36 large *Brassica rapa* fields across four distinct commercial operations.[120] Honeybees were found to be responsible for 40.6% of all flower visits, with the seven highlighted species accounting for 39.2%. Flower

117 Rader, Romina, Bradley G. Howlett, Saul A. Cunningham, David A. Westcott, and Will Edwards. 2012. "Spatial and Temporal Variation in Pollinator Effectiveness: Do Unmanaged Insects Provide Consistent Pollination Services to Mass Flowering Crops?" *Journal of Applied Ecology* (49): 126–134, 127.
118 Ibid., 127.
119 Ibid., 126.
120 Ibid., 128.

visits per minute were similar between the entire group, with no significant difference in amount of pollen deposited on stigmas.[121] An important factor, however, was remarked. Honeybees, outmatched the other seven pollinating insects when compared individually. However, on half of the fields, the seven unmanaged species as a group pollinated more effectively.[122] Speaking directly to the point of this work, diversity of pollinator correlates linearly with strength of pollination services.

The unmanaged pollinators were observed to have visited as many flowers and carry as much pollen as *Apis mellifera.* But, honeybees recorded more stigmatic contacts due, in particular, to their visitor abundance per open flower.[123] The sheer number of honeybees is quite advantageous in this respect. However, these results speak to potential pollination events, but do not imply success. With native pollinators, some have adapted to a regional plant and are more successful at triggering a pollination event while collecting their floral reward. A diverse presence of native pollinators means a diverse grouping of different sized bodies and styles of pollination approach. This makes natives highly effective pollinators, as a group, of general commercial crops. In light of the honeybee's tendency to orientate itself along rows of a singular cultivar, within an ill-designed orchard successful pollination may be significantly reduced.[124] This is due to certain crops requiring cross-pollination between varieties to produce fruit, such as apples – which are often orientated in rows composed of identical species.

121 Rader, Romina, Bradley G. Howlett, Saul A. Cunningham, David A. Westcott, and Will Edwards. 2012. "Spatial and Temporal Variation in Pollinator Effectiveness: Do Unmanaged Insects Provide Consistent Pollination Services to Mass Flowering Crops?" *Journal of Applied Ecology* (49): 126–134, 129.

122 Ibid., 130.

123 Ibid., 131.

124 Bosch, Jordi, and Marina Blas. 1993. "Foraging Behaviour and Pollinating Efficiency of Osmia Cornuta and Apis Mellifera on Almond (hymenoptera, Megachilidae and Apidae)". University of Barcelona, Animal Biology Dept., 2.

Despite limited stigmatic contact relative to *Apis*, the unmanaged group of wild pollinators provided adequate pollination services in all four years on the *B. rapa* fields. On two fields, *Apis mellifera* was actually outperformed.

These results could be important to almond orchards which are in a heightened state of crisis. Almonds depend exclusively on insects for pollination and consequently, so does California's almond industry. *Apis cerana indica*, the Asiatic bee, has been established as the ideal honeybee for almond management. Having a similar, if not superior, disposition and hardiness to the *mellifera*, *cerana* goes one step further in having an extended foraging period, though a slightly more limited range.[125] This is of particular importance to the commercial farmer and has likely influenced the direction of hybridization, queen stocks and, as we know from the *Varroa* epidemic, fueled the importation of non-native species. Recognizing that California accounts for 80% of almond production worldwide, the breadth of *Apis* management within that single state is massive.[126]

Apis almond services have been augmented most effectively by the wild carpenter bee, *Xylocopa* valga, the builder bee, *Osmia cornuta* and the sweat bee, *Lasioglossum spp*.[127] The industry, however, has still

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125 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 96.

126 Klein, Alexandara-Maria, Claire Brittain, Stephen D. Hendrix, Robbin Thorp, Neal Williams, and Claire Kremen. 2012. "Wild Pollination Services to California Almond Rely on Semi-Natural Habitat." *Journal of Applied Ecology* (49): 723–732. 724.

127 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer, 56.

failed to embrace the presence of native pollinator services. Even with the established superiority of *Apis cerana*, the industry still relies predominantly on *Apis mellifera* for managed pollination within almond orchards. So, whether *cerana or mellifera,* as honeybee populations falter almond production will come to a standstill on farms not sustainably managed or in proximity to natural habitat.[128]

The result of any fieldwork, however, depends heavily on the tailoring of the agricultural operation. Consider that, as a result of its body type and consequent style of foraging, *Osmia cornuta* was found to be far more effective at pollinating almond flowers than *Apis mellifera*. This even while honeybees have been shown to regularly outperform other pollinators in stigmatic contact. But, *Osmia cornuta* set a rate of 98.7% pollination success compared with *Apis mellifera's* 67.3%. It was established that three female *Osmia cornuta* per almond tree provided sufficient pollination services, significantly undermining honeybee requirements.[129] Japanese researchers followed up on these results within their own apple orchards and found that *Osmia cornuta* pollination was met with success at almost double the rate of *Apis mellifera.* [130] In any case, even where native pollinators are not evolutionarily designed for a foreign cash crop, a combined management program will yield a larger and more consistent fruit set.[131]

Other crops, watermelon specifically, have also been shown to be entirely self-

128 Klein, Alexandara-Maria, Claire Brittain, Stephen D. Hendrix, Robbin Thorp, Neal Williams, and Claire Kremen. 2012. “Wild Pollination Services to California Almond Rely on Semi-Natural Habitat.” *Journal of Applied Ecology* (49): 723–732. 724.

129 Bosch, Jordi, and Marina Blas. 1993. “Foraging Behaviour and Pollinating Efficiency of Osmia Cornuta and Apis Mellifera on Almofnd (hymenoptera, Megachilidae and Apidae)”. University of Barcelona, Animal Biology Dept., 3.

130 Ibid, 6.

131 Ibid., 3.

sufficient, with respect to pollination, based on nearby native habitat.[132] Blueberry producers also depend on a substantial presence of native pollinators as they are more effective than honeybees.[133] Specifically, it is the southeastern blueberry bee, *Habropoda laboriosa*, that is often found on these farms. It burrows deep underground and emerges just as the blueberry plants begin to flower. Whatever cue triggers this action remains unknown to researchers.[134]

The availability of specific floral sources drew certain pollinators. A variation in this group of pollinators was noted based on certain weather conditions or certain times of the day. With that, the diversity of vegetation served to provide for a wide range of pollinators that create resiliency within the dynamic pollination system. Unmanaged pollinators remain diverse and abundant on intensively-managed land provided appropriate habitat exists. And, unmanaged insects are capable of providing consistent pollination services in several locations over a period of years when there is consistent habitat.[135] Regardless of location, the varied pollinator populations strengthened the pollination service uniformly.

The reliability of this passive system lies in its flexibility. A given weather or seasonal condition will favor certain species. The presence

132 Winfree, Rachael, Neal M. Williams, Jonathan Dushoff, and Claire Kremen. 2007. "Native Bees Provide Insurance against Ongoing Honeybee Losses." *Ecology Letters* 10 (11) (November): 1105–1113, 1105.

133 MacKenzie, Kenna E., and George C. Eickwort. 1996. "Diversity and Abundance of Bees (Hymenoptera: Apoidea) Foraging on Highbush Blueberry (Vaccinium Corymbosum L.) in Central New York." *Journal of the Kansas Entomological Society* 69 (4) (October): 185–194.

134 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 30.

135 Rader, Romina, Bradley G. Howlett, Saul A. Cunningham, David A. Westcott, and Will Edwards. 2012. "Spatial and Temporal Variation in Pollinator Effectiveness: Do Unmanaged Insects Provide Consistent Pollination Services to Mass Flowering Crops?" *Journal of Applied Ecology* (49): 126–134. 132.

of a wide range of vegetative habitat will serve to make sure that those varying species are present throughout the growing seasons. The same condition of resiliency exists as it relates to population fluctuations due to natural and periodic disease and pest infestations along with weather cycles. On the fields of a monoculture, however, a significant population of homogenous honeybees exists alongside nearly perpetual fields of identical plants. Consequently, the operation is without any sort of natural defenses.

A significant amount of empirical evidence is available to the public that together presents a farming scenario in which managed pollinators are obsolete. Various styles of passive management have been tested over the years with varying crops, distances and conditions. They have all shown, either with respect to biological control or pollination services, an appreciable effect on the commercial operation by wild pollinator habitats. This is in regard both to increased commercial profits and ecological health of the targeted land. However, the variability of the situation requires sincere diligence by the agricultural designer when considering viability of a given system as well as the specific species planned for use.

Symptoms of Man

If the industry is to depend on passive management and its wild pollinators, the health of the system needs to be assured. As farms cultivate local pollinator populations, their overall numbers will increase. This inherently exposes the various species to more stressors.

Weakened species and threatening environments need to be addressed before pollination services can be depended on.

The overall health of worldwide pollinators has only been given cursory attention. Due to taxa population variations caused by a number of variables, industrial, environmental and otherwise, it becomes difficult to judge the status of any single unmanaged species. Consequently, completely understanding a given species' pollinating performance in a given region is difficult. While this may create issues of constancy within the academic realm, farmers can take away the higher and more consistent pollination rates as indications of a healthy, native population's impact. Outlying results may speak to contamination and extreme conditions, but wild pollinators have been consistently shown to be effective as commercial pollinators.

But, in light of pollution and pesticide exposure, all the passive pollinator management in the world will have a limited effect. During the past 20 years, the use of neonicotinoid pesticides has rapidly increased. Designed to aggressively target certain invertebrates, exposure to non-target pollinators has still had a negative impact due to the consumption of contaminated nectar and pollen. Both laboratory and field studies have shown that sub-lethal exposure to neonicotinoids resulted in behavioral changes in bees.[136]

These behavioral changes were caused by neonicotinoids targeting the mushroom bodies within the bee's brain. The bodies are a higher-order insect brain structure that integrates the senses and controls cognitive function. With these functions inhibited, the bee's memory and learning faltered along with navigation and foraging instincts. This is

136 Palmer, Mary J., Christopher Moffat, Nastja Saranzew, Jenni Harvey, Geraldine A. Wright, and Christopher N. Connolly. 2013. “Cholinergic Pesticides Cause Mushroom Body Neuronal Inactivation in Honeybees.” *Nature Communitcations* (March), 2.

directly correlated to a reduced survival rate.[137] Due to social bees having larger mushroom bodies, they are more significantly affected by the pesticides depressive effect on neurological responses.[138]

Of even greater concern is the exponential effect exposure to multiple kinds of pesticides has on invertebrates. Cholinergic and coumaphos pesticides act in a different way, but have the same negative affects on cognitive function. Consequently, with different pesticides depressing and shutting down different systems, the resiliency of the bee is further strained and pushed towards failure.[139] And, as pests become more resilient and farmers more desperate to combat them, the likelihood that combinations of these chemicals find their way onto fields worldwide increases.

The pesticide, coumaphos, is used to combat *Varroa* mites and its extreme toxicity and regularity of use makes it a potent neuromodulator of the insect brain. However, as *Varroa* develops further resistance to coumaphos, use will dwindle. Regardless, an important

factor to take away is the exponential impact exposure to multiple pesticides has on invertebrate neurological systems.[140]

Another threat to invertebrates is heavy metal pollution, with heavy metals like iron, copper, and mercury being toxic elements of a high density. This polluation has had an

137 Ibid., 2.
138 Ibid., 5.
139 Ibid., 6.
140 Palmer, Mary J., Christopher Moffat, Nastja Saranzew, Jenni Harvey, Geraldine A. Wright, and Christopher N. Connolly. 2013. "Cholinergic Pesticides Cause Mushroom Body Neuronal Inactivation in Honeybees." *Nature Communitcations* (March), 7.

impact on wild bees specifically, resulting in population declines and consequent yield losses.[141] It is particularly noteworthy how heavy metal exposure impacts the issues of habitat loss and fragmentation, pesticide use, non-native invasive species, competition with managed *Apis*, pathogen spread and genetic introgression. With consideration for the complicated interactions in nature, there is concern that heavy metal pollution will eliminate certain species in favor of more pollutant-resistant species. Heavy metals are described by specialists in the field as the 6th worst stressor of the bumblebee decline.[142]

Fieldwork looking for a correlation between metal concentrations and bee health was conducted near lead and zinc smelters where concentrations in the soil were of a significant level.[143] The average number of bee species was found to have decreased with increasing metal concentrations in the soil. Specifically, polluted fields often have no bees compared to four and five types in unpolluted fields. This was found in two geographically distinct locations, advancing the conclusion that there is a negative relationship between heavy metal pollution and bee community size.[144]

Population decline resulted from individual bees expending their energy on detoxification instead of their intended purpose. Local flowering plants remain unpollinated resulting in a decline in diversity and abundance, thus reducing available forage for the bees in the future. This is particularly concerning for specialized pollinators as generalists may

141 Moron, Dawid, Irena M. Grzes, Piotr Skorka, Hajnalka Szentgyorgyi, Ryszard Laskowski, Simon G. Potts, and Micha Woyciechowski. 2012. "Abundance and Diversity of Wild Bees along Gradients of Heavy Metal Pollution." *Journal of Applied Ecology* (49): 118–125, 118.

142 Ibid., 119.

143 Ibid., 119.

144 Ibid., 121.

travel outside of a polluted area for forage.[145]

Only native pollinators are to be introduced into polluted landscapes as invasive species may have their typical impacts severely augmented due to the ecological weakness of the area. Conservationists suggest that polluted areas are to be sown with native, wild flowers in order to attract growth and diversity in native pollinator populations.[146] Native plants are more attuned to the given area and have demands balanced to what is available making them better able to compete within the polluted, local environment. Furthermore, in drawing up nutrients through the roots and dispensing it through dead matter, native plants are a key part of a cycle that can return the land to health.

Given the impact of chemicals and metals on contaminated fields, the organic management of farm land can serve to mitigate these issues. It has been determined that organic management of fields resulted in increased flower visitation by hover flies and, likely, tachinid flies. However, only when farms were near native habitat were wild bees positively impacted.[147] Wild bees cannot be expected to positively impact agricultural landscapes without any nearby natural habitat.[148] These results supported earlier hypotheses that stated clear, intensified landscapes have little to gain from pollinators with organic farming alone. Even so, a significant amount of evidence is available supporting the need for a reduction, if not elimination, of synthetic pesticides and herbicides due to emerging consequences.

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145 Moron, Dawid, Irena M. Grzes, Piotr Skorka, Hajnalka Szentgyorgyi, Ryszard Laskowski, Simon G. Potts, and Micha Woyciechowski. 2012. "Abundance and Diversity of Wild Bees along Gradients of Heavy Metal Pollution." *Journal of Applied Ecology* (49): 118–125, 122.

146 Ibid., 123.

147 Klein, Alexandara-Maria, Claire Brittain, Stephen D. Hendrix, Robbin Thorp, Neal Williams, and Claire Kremen. 2012. "Wild Pollination Services to California Almond Rely on Semi-Natural Habitat." *Journal of Applied Ecology* (49): 723–732. 728.

148 Ibid., 730.

That being said, the large cost of operating at or near an organic standard cannot be disregarded. The initial labor and capital costs often act as a barrier to sustainable agriculture, let alone organic. Within a more vigorous economy, government and business alike would be wise to create an incentive for today's farmer.

As it stands, the agricultural industry continues to strip land of native vegetation, significantly impacting native pollinator populations. And, with the widespread use of pesticides necessary to curb populations of various pests and pathogens, a large number of honeybee colonies have been destroyed alongside millions of native and feral pollinators. Pollination effort, however, is not the only useful characteristic native insects possess. Without the natural defenses of a diverse environment, the homogeneity of monocultures allow pests and pathogens to thrive.[149] However, when properly managed vegetative habitats support beneficial insect populations, there is a measurable and positive effect in terms of natural biological control over cropland pests. Therefore, in providing native pollination services to farmland, the farmer is also effectively protecting his crops against pests and disease through diversity and natural predators. Growing populations of beneficial, predatory insects acting as agents of biological pest control will provide a significant boon ecologically and commercially in an era of rising costs and hardened pests. And, the diversity of species prevents the overabundance of a single food source for pests, again, limiting their populations.

Wasps, the closest relative of the bee, use their carnivorous nature to agriculture's advantage. Potter wasps, of which there are numerous North American varieties, prey upon

149 National Research Council (U.S.), and National Academies Press (U.S.). 2007. *Status of Pollinators in North America*. Washington, D.C: National Academies Press, 80.

caterpillars, alfalfa weevil and other pests.[150] Other species, such as tachinid flies and lady bugs, either eat or prey upon agricultural pests through parasitism. Parasitism refers to the action of some parasitoid wasps and flies that lay eggs inside of a host insect, eventually killing the host. The presence of these insects within an agricultural operation curbs the population of pests and is common practice within greenhouses.[151]

Habitat stability and diversity are key features of natural biological pest control, something that is severely lacking in annual cropping systems. This opens up monocultures to pest and disease outbreaks due to the regular disruptions of insect community development and the subsequent suppression of natural pest enemies. From a commercial standpoint, additional crop security and a reduced dependence on pesticides directly correlates with increased profits.[152]

The diversity of tachinid flies was used to express the effect of semi-wild perennial vegetation cover on agricultural land. Being that the various species of tachinids have different roles, some pollinate and some control pests, increased health of these populations will invariably be beneficial to farmland. Furthermore, considering the diversity of tachinid roles, what benefits them likely benefits a wide range of other insects that share these roles.

Japanese researchers developed a strong connection between the abundance of native

150 Hunt, James H. 2007. *The Evolution of Social Wasps*. New York, New York: Oxford University Press, 32.

151 Higaki, Morio, and Ishizue Adachi. 2011. "Response of a Parasitoid Fly, Gymnosoma Rotundatum (Linnaeus) (Diptera: Tachinidae) to the Aggregation Pheromone of Plautia Stali Scott (Hemiptera: Pentatomidae) and Its Parasitism of Hosts under Field Conditions." *Biological Control* 58 (3): 215 – 221. doi:http://dx.doi.org/10.1016/j.biocontrol.2011.05.009.

152 Letourneau, Deborah K., Sara G. Bothwell Allen, and John O. Stireman III. 2012. "Perennial Habitat Fragments, Parasitoid Diversity and Parasitism in Ephemeral Crops." *Journal of Applied Ecology* (49): 1405–1416. 1406.

vegetation around annual crop fields and tachinid fly health.[153] Their fieldwork suggested that persistent vegetation promoted the biodiversity of beneficial insects. With the four most commonly captured tachinid species being known to prey on common pests of farmland, as their populations increase, passive biological control over pests can be expected to increase in effectiveness.[154] Furthermore, the utilization of complex landscapes provides insurance over contingencies associated with environmental variability as varied populations ebb and flow in order to maintain a diverse balance.[155]

A Reliable Future

Large agricultural operations are the primary concern due to their concentrated, yet far-reaching effect on the environment. Their practices must be adapted to the modern ecological world and this will require unique solutions. In saying that, unique need not mean complicated.

The passive management of native pollinators appears to be a profound answer to commercial pollination problems, but the landscape will have to be altered to some extent. However, that is not to say passive management will be overtly disruptive.[156] Farmers are likely quite knowledgeable about the native vegetation in the region. Their years of observation provides them with an idea of the micro-climate their farm operates in, adding

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153 Letourneau, Deborah K., Sara G. Bothwell Allen, and John O. Stireman III. 2012. "Perennial Habitat Fragments, Parasitoid Diversity and Parasitism in Ephemeral Crops." *Journal of Applied Ecology* (49): 1405–1416, 1409.

154 Ibid., 1413.

155 Ibid., 1414.

156 Vaughan, Mace, Matthew Shepherd, Claire Kremen, and Scott Hoffman Black. 2011. *Farming for Bees: Guidelines for Providing Native Bee Habitat on Farms*. Portland, OR: The Xerces Society for Invertebrate Conservation, 8.

even greater specificity with respect to plant choices and pollinator expectations. Still, adapting agriculture to a sustainable model will be a team effort. Fieldwork must be continued in order to better establish the relationships formed between pollinators and angiosperms. Concise numbers need to be established with respect to the financial gains associated with passive pollinator management on commercial farms. Universities and governments have to take greater steps to support academic agricultural departments while also improving the physical and political infrastructure agriculture depends on.

Currently, farmers are inclined to believe that taking steps to ensure pollinator habitat on their commercial farmland is too costly of a measure. To be convincing, design has to be backed up with measurable evidence of increased yields, field health, profits and a reasonable rate of returned investment.[157]

A number of case studies developed tangible evidence of the positive effects of native floral sources near or within commercial operations. Yields of pollinator dependent crops are shown to decline as they are further isolated from natural habitat. The greater issue here is that as the productivity of agricultural land falls due to pollinator decline, more land must be converted to cropland to maintain the output required. A cycle is perpetuated as a further reduction in wildlife habitat will result in lower efficiencies on cropland, which will then require more conversion of wildland into crop land. Invariably, this will lead to a collapse of the animal pollinator system.[158]

The general protection, preservation and re-introduction of native habitat is the only way to maintain healthy populations of native pollinators and, consequently, protect

157 Carvalheiro, Luisa G., Colleen L. Seymour, Susan W. Nicolson, and Ruan Veldtman. 2012. "Creating Patches of Native Flowers Facilitates Crop Pollination in Large Agricultural Fields: Mango as a Case Study." *Journal of Applied Ecology* (49): 1373–1383, 1373.

158 Ibid., 1374.

indigenous flora. Perennial vegetation and cover crops serve to protect the condition of soils while adding nutrients from deep in the soil and humus, which is the organic material in soil formed from decomposed plant matter. The soil is stabilized for future years, having not been stripped of nutrients by harvested crop and laid bare for the off-season. For a commercial operation this speaks to reduced erosion and leaching of soil nutrients, while also addressing issues of run-off.[159] In providing for native pollinators, the farmer is also investing in the future of his or her soil and this addresses a key point associated with passive pollinator management. The farmer, in providing for diversity, enjoys many benefits beyond that of pollination services.

As honeybee availability declines, commercial farms will come to depend more heavily on native pollinators. Their presence is currently driven by the existence of nearby wildland and, to a lesser extent, the availability of wasteland on a commercial tract. However, as the worldwide decline of pollinators continues, agriculture is running out of animal pollinators altogether. Currently, 185 species of pollinators have been deemed threatened or extinct by the World Conservation Union.[160]

As farms continue to expand, so must native habitat in order to provide adequate pollination services through passive management. Losing farm-able land and investing in perpetual, passive management over bee rentals may be untenable for farms already facing thin margins. However, capital and room must be made.

Even farmers that remain too skeptical to fully implement passive management will see significant benefits. In taking small steps towards sustainability, farmers will be

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159 Xerces Society. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. North Adams, MA: Storey Pub, 8.

160 Mader, Eric, Mace Vaughan, Matthew Shepherd, and Scott Hoffman Black. 2010. "Alternative Pollinators: Native Bees." ATTRA, 2.

augmenting their hard work and that of their *Apis* populations. Perhaps that will be enough motivation for future changes.

By demonstrating the effectiveness of native pollinator habitats within the borders of commercial agricultural operations, the stage is set to re-diversify and invigorate the countryside. Some operations will be able to entirely replace their managed *Apis* populations, others will find that wild pollinators can effectively augment *Apis* efforts resulting in greater yields and lower rental costs. Beyond that, farms can expect a significant reduction in pests if natural habitat is provided. The extent to which biological control of pests can be achieved will depend on the scale and diversity of native vegetative habitat available. So, between increased yields, reduced bee rental costs, crop security and consistency, reduced pesticide use and the consequent reduction in the cost of unrealized externalities, farms can expect native habitat management to have an appreciably positive effect on their commercial agricultural operations.

Still, the scale and diversity of implementation, as well as location, yield expectations and crop choice will impact both the effect and cost. Farms will have to individually assess their crop and land so as to design accordingly. Micro-climates, which are small areas with weather patterns unique to the surrounding area, are particularly important. Due to the presence of natural constructs, like mountains which trap moisture and temperature, these areas are able to grow crops often unusual to the region at large. Being aware of a farm's micro-climate will allow for a more effective implementation of passive management by using plants specialized for the locale. So, while specific guidelines exist and ideal species may be highlighted for a given region, the diversity of Earth will not allow for concrete standards. Success will depend on the diligence of the designer.

But, this is an industrial world that is looking to circumvent the animal pollinator. Severe and abrupt actions within large-scale ecological systems risks significant disruption of agriculture as it has come to be. Being that novel pollination solutions serve to complicate matters, actions may have consequences that cannot be ecologically reversed. So far, efforts to replace animal pollinators have either failed or been insufficient and costly, as with hand-pollination. Perhaps if we had more time, innovation could offer a technical and more complicated solution than the one before us by way of artificial intelligence and robotics. However, such solutions as the 'robobee' arguably utilize energies better spent on addressing the degradation and abuse of natural resources.

Wild pollinator presence was found to correlate with increased ecological health and pollination rates within commercial farming borders. The greatest efficacy revolved around natural habitat and colonies, dramatically diminishing as distance from cropland increased. However, the group efficiency of wild pollinators could not be questioned and was often found superior to that of managed *Apis*. Furthermore, biological control of crop pests was significantly bolstered by the presence of natural vegetation and inhabitants. The initial cost of sustainable design and implementation is offset by increased yields and a reduced dependency on outside inputs. The pace of and capital return on investment (ROI) is determined by characteristics unique to each individual agricultural operation.

The effective implementation of sustainable design will better allow for a copacetic relationship between man and nature. The continued expansion of industrial agriculture, as we now know it, will force a push back, in the form of drought, crop failure or environmental disaster. But, a prime example of this scenario is alfalfa, a bee-pollinated crop. Alone it has an annual value of $109 million. However, the $4.6 billion a year livestock industry depends heavily on a bumper crop of alfalfa year after year.[161] Were animal pollinators to fail, the alfalfa crop would be all but eliminated with enormous consequences for the livestock industry. So, when one looks beyond the primary relationships between flora and pollinator, the real consequences of declining pollinator services become clear.

However, in the pursuit of protecting the environment one cannot lose sight of the needs of mankind. Man will place himself above plants. So, the demand on the environment will only increase. Steps must be taken to limit man's impact and increase the efficiency of industrial operations. The challenge is that neither of these goals can be reliably attained independently of the other. Increased efficacy resulted in a Green Revolution that significantly damaged the ecological health of the planet by way of soil erosion, habitat destruction, water contamination and so on. Yet, without raising efficiencies, a reduction in man's impact results in reduced yields and thus, less supply for a growing demand.

Native pollinator management can reduce the ecological impact of agricultural operations while improving and protecting croplands. And, the utilization of vegetative alleys and corridors along with intermittent pollinator islands within large-scale monocultures could potentially mitigate the disruption of habitat and return biodiversity to the fields. By extending the range of natural habitat, a significant agent of agriculture is again utilized. Both in terms of the biological control of pests and pollination, wild insects

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161 Abrol, D. P. 2010. *Pollination Biology: Biodiversity Conservation and Agricultural Production*. Life Sciences. Dordrecht ; New York: Springer.

already play a large, if not dominant role throughout the varying regions of modern agriculture. This is in light of the obstacles placed in their way by the agricultural industry. Native pollinators are a significant natural force with extraordinary potential within the commercial realm.

With biological pest control, the reduced need for pesticides will not only benefit a farm's checkbook, but the health of local flora and fauna. Recognizing the heavy impact pesticides and pollution has on an insect community's strength, any decrease in their levels will likely increase community strength. Over time, there is the potential that a measurable cyclical correlation between pesticide reduction and increased beneficial populations could be observed. That is to say, increased populations drive down pesticide use, which, in turn, drives up populations more and reduces pesticide use again. This will have the side effect of benefiting pollinating populations, possibly increasing their vigor and efficacy over time as well.

In order to provide habitat and a food supply for pollinators, some land now in use for commercial agricultural purposes must be appropriated for pollinator ecology projects. However, the concept of land-sharing is a difficult compromise for farmers who are used to steely contracts and thin margins. Still, empirical data favors agricultural land-sharing. It has been established that an increase in pollinator presence results in an increase in yield as repeated pollination serves to increase yield. Both size and weight of blooms are affected by the pollination action with plants producing deformed blooms if the number of pollination events is insufficient.

The expansion of pollinator habitats will increase the abundance and longevity of native pollinators. And, their diverse presence ensures pollination services in spite of weather and environmental changes. However, the use of too few or an overabundance of any single plant species will serve the local ecological system poorly. In lacking diversity, such landscapes act as monocultures, providing an overabundance of food to the pollinators for a specific and short length of time. Furthermore, it must be highlighted that the biodiversity of these habitats protects both the investment in the habitat and in the main crop when faced with a pathological or pest crisis. One pollinator will pick up when another fails on a rainy, cloudy or cold day or night or when disease and predators strike. The same cannot be said of honey bees, of which are becoming highly susceptible to epidemics and shortages.

Diversity serves the pollinator populations in a number of ways that, overall, is analogous to the checks and balances of modern government. A greater density of foodstuffs throughout the year allows for population expansion as the environment is able to support a greater number of pollinators. This both swells the ranks of various species and allows smaller, weaker species to take a minority foothold within the system – furthering the resiliency of the system through diversity while also invigorating pollination services. Varying species, being specialized for different locales and plants are further specialized to battle the pests associated within local habitat. In a diverse system nothing grows too strong, large or widespread.

Monoculture, chemicals and habitat erosion due to human development, however, all disturb the balance as varying species artificially waver where others grow. Any of those factors can serve to destroy one population while bringing another to a strength and influence unprecedented within a given ecosystem. This is evident in resistant diseases and pests, herbivore overpopulation threatening crops and globally declining pollinator numbers. As such, diversity also serves to prevent crop infestation without the use of pesticides, organic and otherwise, as a wider range of resilient species and natural predators will inhabit the area. The less inputs into a given agricultural system, the less likely a foreign agent, plant, animal or otherwise, is to infiltrate the operation.

Agricultural design that is beneficial to pollinators is in no way restricted to new operations. Current operations can be adapted during times of harvest and rotation or during times of commercial dormancy due to climate or lacking demand. However, without thoughtful design and follow-through, all the time, effort and money invested will be wasted within the year as weeds overtake altered lands. Specific species must be appropriated for specific areas, serving to strengthen the natural bonds of the land through interdependence. A landscape that fosters such an interdependence will have the strength to fend off invasive species, pests and climatic changes while providing robust pollination services.

For the farmer to take advantage of the given strengths of varying regions, he or she must thoroughly understand his micro-climate and the flora and fauna indigenous to it. On larger operations, a micro-climate may not exist and a more broad strategy must be considered in light of a varied landscape. However, the more detailed the initial design, the better it will perform. Local officials, conservationists and extension services will be invaluable to the designer. Their knowledge of the local species and climate will be key in developing a symbiotic relationship between native and commercial lands. Within this relationship, agriculture can become a productive member of both human society and the environment.

Passive management will depend on the combination of old and new agricultural systems with pollinator features large and small. Sustainable farms must be incorporated into a larger ecological system designed to sustain pollinator life globally. It incorporates efficiency by its use of space and retains an inherent aesthetic value associated with floral diversity and density. In recognizing the specificity with which nature evolves over long spans of time, pollinator design reflects the decisions of nature.

As said before, the flora and fauna available to an operation depends on the purpose, scale, season and expected yield of a given operation. For many regions, the prospect of year-round pollinators is an impossibility whether due to extreme temperatures, winds or other weather events. This is a non-issue however, as the growing season itself is similarly limited. Still, the planting of the appropriate perennial and re-seeding annual plant species will provide a welcoming habitat for large pollinator populations and, consequently, result in a vigorous growing season regardless of length. This limits the expense of rental pollination services for short seasons and in remote regions.

To implement these changes, the amending of soil and removal of invasive species may be necessary. These costs will add up, especially for struggling operations looking to make their margins and the risks associated with capital investment have to be understood and moderated if possible. The longevity of a given operation, financing and profitability will determine for many commercial enterprises whether the implementation of pollinator gardening within their borders is viable at this moment. But, it must be acknowledged that, in the long term, the cost of maintaining the status quo will be far greater than adapting to a more sustainable approach. For this reason, state and federal grants, along with pay-back programs and financing, must be considered by governments in order to re-modernize their agricultural sector. Corporations are no different and those that employ hundreds of family farms should be inclined to provide incentives to farms that adopt sustainable practices in order to secure crop yields into the future.

The initial costs and shifts in practice can be unmanageable in the short-term for a farmer left to his or her own devices. And, the idea of relinquishing cropland to cultivate native species will likely seem absurd in this era of farming debt and hyper-efficiency. To push away from pesticides and other synthetic inputs so as to encourage pollinator populations will be difficult for farmers so used to the vulnerability of their monocrops. But, with inputs both organic and conventional becoming more costly, arable land more scarce and pests and diseases more resilient, farmers have to take major steps to ensure their future. Moreover, as commercial honeybee rental rates continue to rise due to shortages and increased demand, it will be important to retain a native pollinating population to ensure yields and lower costs in times of honeybee scarcity. If action is not taken now, farmers can expect to see their fields sparsely pollinated in the years to come as pollination services, wild and managed, fail.

Conclusion

Agriculture is not an independent or omnipotent operation. It depends on a natural cycle that has evolved over countless years. The highly complex, global food matrix that feeds the world population rests on the presence of healthy pollinators. A large number of crops require pollination in order to fruit in general or yield a crop of any significance. And, a large number of animals depend heavily on these crops. Consequently, the agriculture sector is reporting losses and is predicting extensive crop failures in the coming years as pollinator populations continue to fall at an accelerating pace.

Understanding the intricacies of the growth cycle allows the amateur and commercial farmer to increase yields by providing ideal habitat for a given species. This is common sense and common practice. At least that has been true with temperature and soil nutrients, moisture and sunlight. The agriculture sector, however, cannot stop there. Whatever hard work done in the fields is meaningless in the face of diminishing pollination rates.

Bolstering pollinator insect diversity and population has repeatedly resulted in more robust crops. This benefits everyone. Beyond that, native plant and insect populations curb invasive plants, disease and pests, thereby acting as insurance against crop failure and as a natural replacement for costly pesticides. In the long run, biological controls may be even more valuable than increased yields. With a diverse pollinator crop selection, re-invigoration of native habitat can serve local wildlife, local feedlots and local soils.

In taking the commercial perspective, these management techniques serve to optimize and secure the processes of agriculture. The practicality of native pollinators by way of costs and benefits is clearly established. However, it is up to the industry to embrace that fact. The expansion of pollinator habitat, whether in the form of bee islands or hedgerows, inter-cropping or wasteland cultivation, will both protect and instill vigor in the land. New farm and expansion design will be more thoughtful, practical and economical when looking to establish an efficient operation in the long-term.

While the resiliency of Earth cannot be overstated, neither can the doggedness with which the human species spreads in an increasing density. This is not going to end. Already, the face of this planet has changed dramatically and the presence of countless species has dwindled. Every step of the way, agriculture must be looking to innovate and adapt. The revolutionary, Green grace period is over and we are now facing its consequences. Similar mistakes cannot be made in the future. Just as horticulturists mimic the natural environment in its ideal form to grow a particular flower, let farmers mimic and optimize the natural pollination services life has depended on for millenia.

Pollinator havens may be able to act as a profound solution to an immense problem. In the daunting face of unpollinated fields, corporations, governments and citizens have to take steps to provide habitat for beneficial invertebrates. In that vein, the expectation that pollinators will be here tomorrow has to end today.

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