POLLINATORS IN CANOLA IN THE INLAND PACIFIC NORTHWEST

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Pollinators in Canola in the Inland Pacific Northwest

By

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Abstract

Pollinators contribute widely to the growth and productivity of crops worldwide. Due to habitat loss, reduced food availability, increased parasite and pathogen pressure, and increased exposure to environmental toxins, these insects are facing steeply declining populations, which is causing global alarm. While a single approach to solving the pollinator crisis is unrealistic, canola grown in the inland Pacific Northwest region of the United States could have a major positive effect on wild bee populations. This region is exceptionally well suited for canola production, and canola provides extensive pollen and nectar food resources to bees. Canola production in the inland Pacific Northwest could aid bees—this region is dominated by cereal crops, which provide no food resources. At the same time, insect pollination from both wild bees and managed honey bees may increase canola seed yields, creating an economic boost for farmers. The aim of this article is to inform growers of the importance of pollinators in the canola growing region of the Inland Pacific Northwest and to provide crop management recommendations to facilitate habitat and food conservation for these pollinators.

Introduction

The Importance of Pollinators Globally

Insects are responsible for pollinating around 70% of the world's food, feed, and fuel crops, with bees serving as the primary group that provides these pollination services (Klein et al. 2007; Winfree et al. 2011). Bees live across a variety of landscape and habitat types on every continent except Antarctica (Michener 2007; Winfree 2010). Commercial honeybees, which are managed in large colonies, provide a considerable amount of pollination to many crops (Figure 1) (Goulson 2003). Other managed bees, such as some bumble bee species, are used in greenhouses or introduced to crop fields as primary pollinators (Macfarlane et al. 1994; Strange 2015). Other managed bees that provide pollination services include mason bees in orchards (Blitzer et al. 2016) and leaf cutter bees in alfalfa seed production (Pitts-Singer and Cane 2011). Notably, in the south-central region of Washington State, bee beds are maintained for alfalfa-pollinating alkali bees (Wine 2018).

Figure 1. Honey bee (*Apis mellifera* L.) visiting a canola flower. Photo courtesy of Megan Asche, www.macronature.com.

Alongside managed bees, wild bees can provide pollination services in many crops and in a variety of natural settings. Indeed, it has been shown that wild bees contribute pollination services that often complement managed bees, such that overall pollination increases when both managed and wild species are present in crop fields (Garibaldi et al. 2013; Klein et al. 2007; Kremen et al. 2007; Winfree et al. 2011). Many wild bee species, most of which are solitary species (unlike honey bees), are very well suited to provide vast pollination services, and they are adapted to the environments where they live. This contrasts with many types of managed bees which may be transported across the country or even internationally to pollinate specific crops (Winfree et al. 2011). As adults, bees consume nectar from flowers, and they collect pollen to feed to their developing offspring. Both pollen and nectar are critical food resources for bees and are becoming increasingly scarce as land is developed or converted to agriculture.

The Plight of Pollinators

Bees have been experiencing population declines across the world over the last half century (Fürst et al. 2014; Goulson et al. 2015; Lever et al. 2014). These declines have been caused by a number of factors, including declining food and habitat resources and increasing exposure to pesticides, parasites, and pathogens (Arce et al. 2017; Eiri et al. 2015; Fürst et al. 2014; Gill et al. 2012; Goulson et al. 2015; Morandin and Winston 2006; Thompson et al. 2014; Thomson 2016; Winfree 2010). While some of these factors can be managed by beekeepers, others withstand human intervention and spread beyond management to wild bee populations (Fürst et al. 2014). For example, the expansion of urban development and accompanying impermeable surfaces into natural habitats leads to a reduction in soil habitat—which some 70% of bee species (ground-nesting bees) use for nesting (Osgood 1972). Agricultural tilling and disturbance of the soil may also negatively impact bee nests (Wratten et al. 2012). These developments and disturbances also reduce the wildflower and prairie landscapes which provide food resources historically used by wild bees (Garibaldi et al. 2011; Hatten et al. 2013).

Pesticides have been a hotly debated topic in pollinator research. Pesticides undergo rigorous testing before being released for public use, and one aspect of that testing is aimed at the effects a pesticide will have on non-target individuals, such as insect pollinators. Many herbicides, fungicides, and even insecticides can be used in agricultural settings without detriment to pollinators, if the proper application guidelines are followed (Pickett et al. 1997). However, many others can have disastrous effects when improperly used, combined, or used over long term periods not studied by certifying agencies (Desneux et al. 2007; Gill et al. 2012). These damages can result in economic losses to beekeepers and also mortality or lower reproductive rates among wild bee populations (Brittain et al. 2010; Rundlöf et al. 2015; Wu et al. 2011).

Pathogens and parasites are also contributing to the global decline of pollinators, both managed and wild alike (Goulson 2010; Goulson et al. 2015; Graystock et al. 2013). Commercial beekeeping operations have suffered huge losses of colonies to Varroa mites (*Varroa destructor*) as well as diseases such as American Foulbrood, Chalkbrood, and Nosema (Fries and Camazine 2001; Fürst et al. 2014; Spivak and Reuter 2001). While beekeepers may have tools to combat some pathogens, the same cannot be said for the wild bees. Even more concerning is the knowledge that some of these pathogens and parasites can be spread across bee groups through direct or indirect transmission: for a bee, the act of visiting a flower could have similar repercussions as a human grasping an unclean door handle (Graystock et al. 2013).

These combined stresses, alongside limited conservation resources available on a large scale, highlight the importance of protecting pollinators from increased exposure to detrimental influences and maintaining their access to high quality food and habitat resources.

The Importance of Pollinators in the Inland Pacific Northwest

Since 1900, land use composition and plant species have shifted across 99% of the inland Pacific Northwest region including Washington and northern Idaho. The historic prairies dominated by bunchgrasses, wildflowers, and shrubs have been replaced by industrial agriculture and dominated by cereal crops (Black et al. 1998; Noss et al. 1995). Whitman County, Washington, in the heart of this region, has been one of the top wheat producing counties in the country since the late 1970s (USDA NASS 2019). While these changes have benefited farmers, the change in land use has had negative effects on pollinator resources. Increased access to mechanized farming tools leads to increased disturbance of ground-nesting pollinator habitat. The rolling wheat fields so familiar to the locals of the region provide immense food resources for humans and animals alike, but do not provide pollen or nectar resources for pollinators in the region. The variety of flowers available in the past likely allowed bees to gather food resources throughout the season. However, in 2018, 45% of the arable land in Washington State was being cultivated in a wheat rotation (WSDA 2018). Nearly all of this land is east of the Cascade mountain range and is considered part of the inland Pacific Northwest. Wheat is a self-fertilizing plant which rarely releases pollen that could be available for bees to collect. Because wheat has no need for pollinator assistance, wheat does not contain nectaries, thus this plant provides no nutritional resources for bees (Okada et al. 2018; Roulston and Cane 2000).

Legumes (Fabaceae) are the other major staple crop group grown in the Inland Pacific Northwest, in the form of pea, lentil, and chickpea, and while these plants do provide some pollen and nectar, many of these plants have adapted floral structures that can only be used by a small group of bees (Amaral-Neto et al. 2015; Bohart 1960). There are many legume seed crops grown throughout the Pacific Northwest region, most commonly in the form of clover and alfalfa, which are well known to provide nutrition for pollinators and contribute to bumble bee (Figure 2) and other wild bee diversity (Rao and Stephen 2009, 2010; Rundlöf et al. 2014). The majority of these crops are grown in the Walla Walla Valley and Columbia River Basin in Washington, central Oregon, and southern Idaho, while canola is more widespread throughout these states.

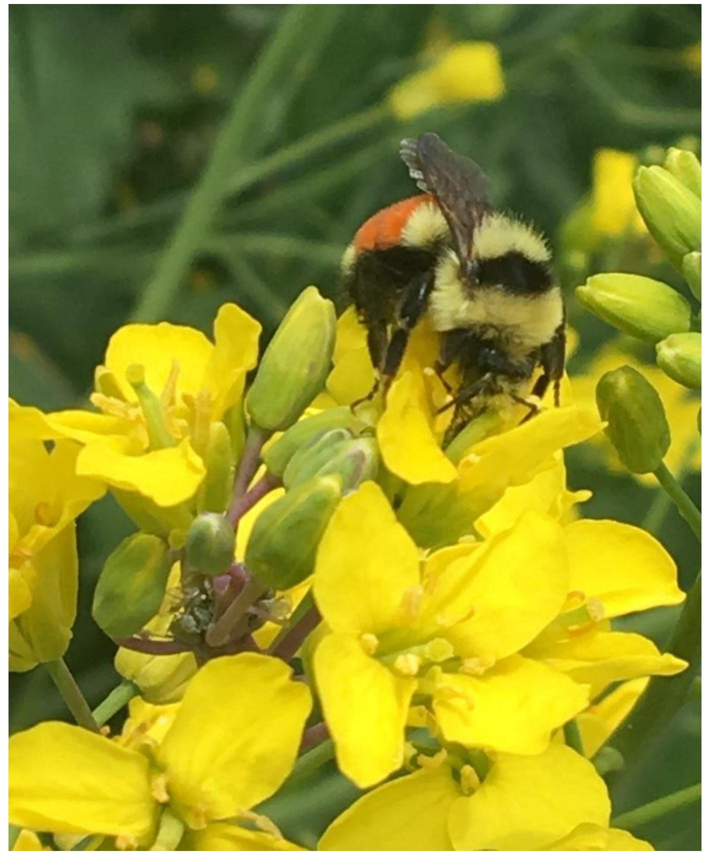

Figure 2. Bumble bee (*Bombus* spp.) visiting a canola flower. Photo by Rachel Olsson.

Declining resources for bees in the inland Pacific Northwest may be somewhat alleviated by the steady growth in canola acreage in the region since 2007 (USDA NASS 2019; WOCS 2017). In 2019, about 73,000 acres were planted to canola in Washington State, and 48,000 acres in Idaho. Acreage in both states is expected to increase in future years. Canola has proven to be a valuable crop in the inland Pacific Northwest, allowing growers to increase diversity in their agricultural rotations, offering a break in the pesticide and disease cycles, and allowing soils to recover after intensive cereal farming. Growers have also reported experiencing higher wheat yields after adding canola to a crop rotation (Pan et al. 2016). Notably, while providing value to wheat growers' rotations, canola markets are expanding in the region, making it an economically valuable crop on its own (WOCS 2017). Further, canola flowers produce a large amount of pollen and nectar, which is a valuable resource for bees (Carruthers et al. 2017; Holzschuh et al. 2013).

The Canola-Pollinator Relationship

Canola can provide a large amount of pollen and nectar to bees over the course of its flowering period. The inland Pacific Northwest is one of the few regions in the world where both winter and spring canola can be grown. This staggered cropping option, combined with variable soil moisture levels and microclimates across the region, results in canola blooming over a long period in the summer. Winter canola typically begins blooming in late April to mid-May, coinciding with the emergence of many early season bee species. This canola bloom can last four to five weeks, allowing for a long forage period for bees. Spring canola begins blooming in June and continues into early July, which continues to provide a stable source of food for adult and juvenile bees alike. For growers who are cropping both winter and spring canola, this long forage period can be extremely beneficial, sustaining populations through the majority of the season. However, if mass bloom crops are not followed by another flowering crop, this could lead to rapid early season colony or population growth followed by a food-scarce period, leading to reduced overall health of pollinator communities (Westphal et al. 2009). Growers can mitigate this food-scarce period by planting forage crops around fields that provide additional food resources and nesting habitat for bees (Galpern et al. 2017; Vickruck et al. 2019).

In insect surveys completed over 2018 and 2019, we found five families of bees visiting canola, on every variety we sampled during the flowering period, and in high numbers in fields. Bees, of course, are much more adept at collecting nectar than humans, and the canola flowers provide an excellent nectar resource over their long flowering period (Garibaldi et al. 2014; Morandin and Winston 2005). We saw that canola is an attractive food source for a diverse community of bees including honey bees, bumble bees, and small sweat bees (Figure 3). We found bees visiting both winter and spring canola, and we found bees in every variety we sampled (Figure 4). In our survey, observed nesting habitats included human-made structures (e.g. honey bees, some mason bees), and in the small cavities of hollow twigs or nearby

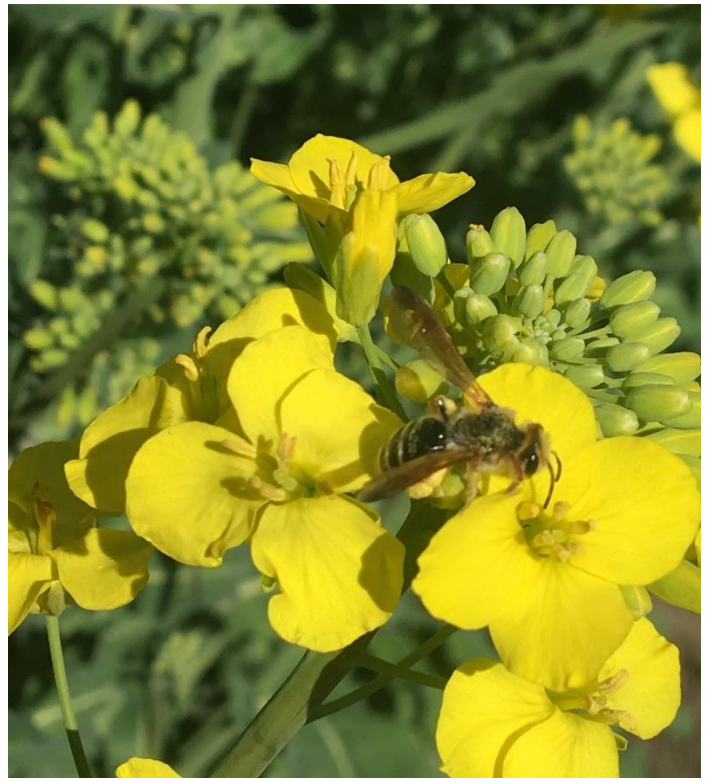

Figure 3. Mining bee (Andrenidae) visiting a canola flower. Photo by Rachel Olsson.

trees (carpenter bees, some sweat bees). The majority of bees observed in our study nest in compact soil between rows, on farm roads, and between plants (sweat bees, mining bees). In total, the bee specimens we collected comprised over a dozen genera (Figure 5).

Since pollinators are present in the canola system of the inland Pacific Northwest, it is key to understand how they fit into our ecosystem, how we might support them, and what services they can provide. Canola has been demonstrated to be an excellent food resource for pollinators in other regions, providing abundant supplies of both pollen and nectar, which can bolster the growth of honey bee colonies and solitary bees alike (Carruthers et al. 2017; Halinski et al. 2018; Holzschuh et al. 2013). In turn, insect pollination has been shown to improve canola yield by up to 30–40% (Winston and Morandin 2005; Zou et al. 2017). Many studies have documented this increase in yield around the world; however, very few studies have examined pollinators in canola in the inland Pacific Northwest, so this yield increase is currently speculative in this region.

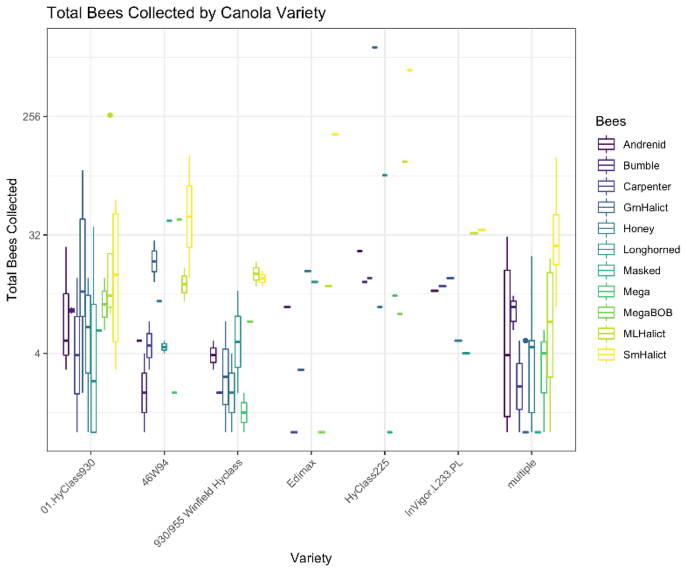

Figure 4. Bee abundances found on different canola varieties in 2018 and 2019. The y-axis has been log-transformed (log2). The horizontal line in each box represents the median abundance of each type of bee for each canola variety. Box boundaries represent the 25th and 75th percentiles, and whiskers extend to the most extreme data point that is no more than 1.5 times the length of the box.

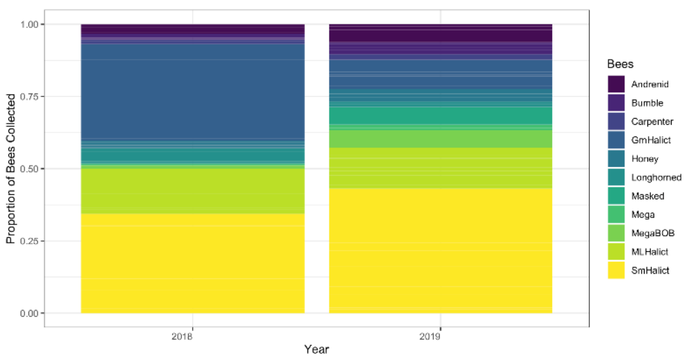

Figure 5. Proportion of bees grouped by morphotype in each sampling year. Morphotype codes: Andrenid = bees in the Andrenidae family. Bumble = bees in the *Bombus* genus, family Apidae. Carpenter = bees in the *Xylocopa* genus, family Apidae. GrnHalict = green bees in the family Halictidae, genera *Lasioglossum* and *Agapostemon*. Honey = European honey bees, *Apis mellifera*, family Apidae. Longhorned = bees in the *Melissodes* genus, family Apidae. Masked = masked bees, family Colletidae, typically genus *Colletes* and *Hylaeus*. Mega = bees in the Megachilidae family, not including the genus *Osmia*, genera *Megachile*, *Hoplitis*. MegaBOB = Megachilidae bees in the *Osmia* genus, also known as the Blue Orchard Bee. MLHalict = medium to large Halictidae bees that were not green, *Lasioglossum* and *Halictus* genera. SmHalict = small Halictidae bees, smaller than a honey bee, dark colored, *Lasioglossum* and *Halictus* genera.

Previously published works demonstrating canola seed yield in the presence of pollinators have relied on very high pollinator densities, in some cases requiring higher honey bee stocking rates than would be economically feasible (Sabbahi et al. 2005). Canola has been bred to many different varieties, each with unique characteristics (Canola Council of Canada 2017). Some of these characteristics may be more attractive to insect pollinators, such as large, showy flowers and the production of nectar (Carruthers et al. 2017; Thomson et al. 2012). However, differences in petal size, flower density, and the sugar concentration of nectar have all been shown to have influence on the number and species of bee using this flower resource (Carruthers et al. 2017; Jauker et al. 2016; Thom et al. 2018). With that in mind, it may be important to attract a number of different types of bees to canola in order to reap the benefits of these insect pollinators.

Honey Bees or Wild Bees?

Many western U.S. beekeepers place hives on canola during the later part of the flight season, typically between June and August, because canola in the inland Pacific Northwest blooms after almond in California and after apples, pears, and cherries in central Washington. At the end of the traveling season for these beekeepers, which ranges from mid-January to May, the canola bloom can provide a large amount of food for honey bees, reducing the amount of the year that beekeepers have to provide food supplements, thus reducing overall costs. Canola nectar is high in volume and sugar, making an excellent honey (Thom et al. 2016). If flowers are blooming when honey bees arrive, bees can contribute to pollination, increasing the overall seed weight and plant yield by up to 40% (Bjerke et al. 2019; Winston and Morandin 2005). This relationship between canola growers and beekeepers can be a mutually beneficial one. These benefits have yet to be tested in the PNW region, but published literature in other canola producing regions of the world show that the presence of honey bees can not only boost pollination but provide more timely pollination when bees are stocked at high density. This timeliness can encourage canola seed to develop more rapidly and at a more consistent rate across the entire field, reducing the amount of underdeveloped seed at harvest time. Finally, insect mediated pollination has been shown to increase overall seed weight and oil content by 18% (Bommarco et al. 2012).

As discussed above, honey bees are not the only bees able to provide pollination services, and in fact they may not be the most economical option for canola growers. Wild bees can contribute to pollination without the requirement of being brought to the field, because they are already present (Thom et al. 2018; Zou et al. 2017). In this region where the majority of crops do not produce nectar or pollen suitable for bees, the flush of resources available during the canola bloom can provide invaluable food for wild bees, which might otherwise starve (Carruthers et al. 2017; Thom et al. 2018).

How Growers Can Facilitate Pollinator Conservation and Reap the Benefits of Pollinators

Grow canola. The first step a grower in the inland Pacific Northwest region can take in supporting pollinators is to include canola in existing crop rotations when feasible. Many growers have found that canola is an excellent rotational crop, providing weed suppression, nutrient restoration, and a break in the pest and pathogen cycle (Esser and Hennings 2012). Canola can be farmed using the same equipment as wheat, so farmers who have already invested in the implements to grow wheat do not have to make major investments to overhaul their production (Pan et al. 2016), and the nearby canola crushing facility in Warden, Washington, allows growers to sell and transport the harvested seed easily without traveling long distances or across international borders to do so. Many local elevator companies also handle canola and ship to the Warden facility. In recent years, canola markets have exceeded wheat markets, with canola products (e.g., oil, meal, and seed) valued at more than three times as much as wheat products (Black and Thomsen 2019). It should be noted that although we compared the economics of these crops separately, one of the major benefits of growing canola is an improved wheat yield when wheat follows canola, thus resulting in a higher profit coming from wheat (Schillinger and Paulitz 2018).

Reduce tillage. Approximately 70% of wild bees nest in the soil. The queen (in the case of colony nesting bees) or the fertile female (in the case of solitary bees) will dig out a burrow into hard packed soil and lay her eggs over the season. The developing insects will then stay underground until they emerge as adults the following spring. Ground nesting bee nests can be disturbed or destroyed by tillage, so a no-till practice is the best method for preserving pollinator habitat. However, if no-till is not an option, avoiding fall plowing and delaying tillage until later in the season after bees have had the chance to emerge will greatly improve their likelihood of survival (Bjerke et al. 2019). Additionally, leaving areas uncultivated at field edges may provide beneficial refuge areas for pollinators. No-till farming using canola as a rotation crop also improves weed suppression in wheat systems, so the benefit for pollinators adds value to an already valuable option (Esser and Hennings 2012).

Use best management practices of pesticide application in canola. Pesticide applications, including herbicides, fungicides, and insecticides, are widely used in canola production. The majority of these pesticides are applied early in the canola season, before bees are present and feeding, so the likelihood of pollinators being affected by the applications is quite low. However, it is occasionally necessary to spray during the flowering period, when bees are present and active in the field. Before applying any spray, scout the canola field to determine if a pesticide application is needed, rather than relying on calendar sprays. If fields must be sprayed during bloom, it is important to follow these recommendations so as to limit any effect pesticide applications may have on bees: if a beekeeper has bees in or near fields to be sprayed, communicate with the beekeeper about spray plans several days ahead of time so they can move their hives away from the targeted area. If possible, reach out to area beekeeping associations, in case beekeepers have bees nearby that are unknown to the grower. On the day of pesticide application, if there are bees near the field, avoid spray drift onto hives, paying close attention to the direction of the wind. If possible, apply pesticides after sundown, when bees are no longer active in the field and the pesticide has time to act and begin degrading overnight (Bjerke et al. 2019).

The above recommendations are directed at pesticide application during canola bloom. However, best management practices also have recommendations for the rest of the season, summarized here following the recommendations of Bjerke et al. (2019):

- During the pre-planting phase, reduce flowering weeds that might attract foraging bees to the field. If pesticides are applied during the pre-planting phase, it is critical that bees are not present.

- During planting, if using treated seed, follow the manufacturer's guidelines to reduce dust drift during seeding. Neonicotinoid seed coatings are also a common insecticide in canola and have been hotly debated in the news and among researchers. Many studies have found that neonicotinoid insecticides, or "neonics" as they are commonly called, can have dramatic negative effects on honey bees and wild bees alike (Di Prisco et al. 2013; Lundin et al. 2015; Rundlöf et al. 2015; Scholer and Krischik 2014; Whitehorn et al. 2012; Xu et al. 2016). A few studies have found no adverse effects of neonics on certain bee species (Blacquière and van der Steen 2017; Cutler and Scott-Dupree 2007). However, given that the majority of canola seed is treated with a neonicotinoid insecticide, and it would be very difficult to avoid it, the best way to curb negative effects on bees is to follow the manufacturer's planting guidelines and reduce dusting-off during planting (Bjerke et al. 2019). In 2016, researchers from Washington State University published a two-year survey with results from neonicotinoid sampling across apiaries in Washington State and found very low levels of neonicotinoid residue, suggesting that neonicotinoid exposure was not of significant threat at that time (Lawrence et al. 2016). However, the increase in neonicotinoid-treated canola acreage since 2015 could increase the possibility of bee exposure to the pollen, so it is best to follow application guidelines and take precautions against dusting-off.
- During the prebloom period, be informed of hive locations, follow pesticide label instructions, avoid mixing chemicals, and minimize drift as much as possible.
- Once canola has bloomed and been harvested, it is still critical to be vigilant and maintain close contact with beekeepers. Encourage honey bees to be removed from the field as soon as flowering is over. If possible, avoid tillage of these fields in case wild bees are using them as nesting sites.

Leave patches of prairie and undisturbed soil. If your farm contains areas of natural land, such as forest or prairie, these patches can provide valuable refuge habitat for wild pollinators. If there are wildflowers or flowering shrubs in these areas, they may provide alternative floral resources outside of the canola flowering time, increasing the time that bees can access these food resources. These sites may also provide areas of undisturbed soil for ground nesting bees to establish their nests and safely overwinter.

Plant native shrubs and flowers. Many of the farms in the inland Pacific Northwest region are located on the rolling hillsides so iconic to the beauty of the area. While these hills are lovely to look at, some areas are too steep to farm. These areas, delightfully called "eyebrows," can be a source of frustration for growers, because they are taking up valuable space that might otherwise produce crops. However, these spaces can act as pollinator habitats and refuges, similar to undisturbed prairie areas. Planting native shrubs and flowers in these areas will provide long lasting habitat and floral resources for bees. Having these bee "islands" in the middle of a crop of canola can be very beneficial, as bees do not need to travel far to visit and provide their pollination services to the crop. Shrubs and flowers can also be planted along field edges, roads, and other borders to increase refuge zones for pollinators, thus improving the pollination in the crop fields. It is important, if these habitat areas are provided, to take every care to reduce pesticide exposure to these areas, so choose the locations wisely and plan according to both the current crop year and future years as well.

This investment of time and energy can go a long way to supporting pollination services for many years to come. The Native Plant Finder, hosted by the National Wildlife Federation (NWF 2020), provides location-specific information about different types of flowering plants and shrubs. There are many programs available through the USDA that can provide farmer assistance to install pollinator habitat. Two of the programs best suited for this type of assistance include the Environmental Quality Incentives Program (EQIP) which provides "up to 75% cost-share for installed conservation practices or 100% of forgone income…Special payment consideration for practices that promote pollinator habitat" (USDA NRCS 2021) and the Conservation

Reserve Program (CRP) which allows "50% cost-share for establishing permanent cover and conservation practices" (USDA Farm Service Agency 2021).

U.S. Canola Association and Honey Bee Health Coalition. The above recommendations closely align with recommendations by a collaboration between the U.S. Canola Association and the Honey Bee Health Coalition. The goal of this collaboration was to prepare a list of best management practices in canola that would conserve pollinators while also growing canola that is of high quality and competitive in the world market. The publication, titled *Best Management Practices (BMPs) for Pollinator Protection in Canola Fields*, was published in March 2019 by the U.S. Canola Association and is a great resource for finding more information on improving canola crop yield while maintaining pollinator health.

Summary

Pollinators around the world are experiencing declines at an alarming rate, but growers can help mitigate these losses. In the inland Pacific Northwest region, growers are adding canola to their wheat rotation and seeing large benefits, including increased wheat yields, reduced weed presence, and a diversified farm with lower economic risks. Canola is an excellent food resource for bees in all stages of their development, and it benefits in seed size and overall plant yield when insect pollinators are present. Honey bees use canola nectar to make high-value honey, and wild bees use the pollen and nectar to raise the next generation of their offspring. Growers can assist in pollinator conservation by implementing a few simple strategies in their farm plans, many of which might also benefit other crops. The relationship between growers and pollinators can be mutually beneficial and may help slow the decline of pollinators in our region.

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References

Amaral-Neto, L.P., C. Westerkamp, and G.A.R. Melo. 2015. From Keel to Inverted Keel Flowers: Functional Morphology of "Upside Down" Papilionoid Flowers and the Behavior of Their Bee Visitors. *Plant Systematics and Evolution* 301(9): 2161–2178.

Arce, A.N., T.I. David, E.L. Randall, A. Ramos Rodrigues, T.J. Colgan, Y. Wurm, and R.J. Gill. 2017. Impact of Controlled Neonicotinoid Exposure on Bumblebees in a Realistic Field Setting. *Journal of Applied Ecology* 54(4): 1199–1208.

Bjerke, J., B. Caldbeck, D. Crowder, C. Dalley, D. Epstein, J. Gunter, C. Hiatt, et al. 2019. Best Management Practices (BMPs) for Pollinator Protection in Canola Fields. U.S Canola Association and The Honey Bee Health Coalition.

Black, A.E., J.M. Scott, E. Strand, P. Morgan, C. Watson, and G. Wright. 1998. Biodiversity and Land-Use History of the Palouse Bioregion: Pre-European to Present. In *Land Use History of North America*.

Black, J.D., and F.L. Thomsen. 2019. Agricultural Prices. In *USDA Agricultural Counts*.

Blacquière, T., and J.J.M. van der Steen. 2017. Three Years of Banning Neonicotinoid Insecticides Based on Sub-lethal Effects: Can We Expect to See Effects on Bees? *Pest Management Science* 73(7): 1299–1304.

Blitzer, E.J., J. Gibbs, M.G. Park, and B.N. Danforth. 2016. Pollination Services for Apple Are Dependent on Diverse Wild Bee Communities. *Agriculture, Ecosystems and Environment* 221: 1–7.

Bohart, G.E. 1960. Insect Pollination of Forage Legumes. *Bee World* 41(3): 57–64.

Bommarco, R., L. Marini, and B.E. Vaissière. 2012. Insect Pollination Enhances Seed Yield, Quality, and Market Value in Oilseed Rape. *Oecologia* 169(4): 1025–1032.

Brittain, C.A., M. Vighi, R. Bommarco, J. Settele, and S.G. Potts. 2010. Impacts of a Pesticide on Pollinator Species Richness at Different Spatial Scales. *Basic and Applied Ecology* 11(2): 106–115.

Canola Council of Canada. 2017. History of Canola Seed Development.

Carruthers, J.M., S.M. Cook, G.A. Wright, J.L. Osborne, S.J. Clark, J.L. Swain, and A.J. Haughton. 2017. Oilseed Rape (*Brassica napus*) as a Resource for Farmland Insect Pollinators: Quantifying Floral Traits in Conventional Varieties and Breeding Systems. *GCB Bioenergy* 9(8): 1370–1379.

Cutler, G.C., and C.D. Scott-Dupree. 2007. Exposure to Clothianidin Seed-Treated Canola Has No Long-Term Impact on Honey Bees. *Journal of Economic Entomology* 100(3): 765–772.

Desneux, N., A. Decourtye, and J.-M. Delpuech. 2007. The Sublethal Effects of Pesticides on Beneficial Arthropods. *Annual Review of Entomology* 52: 81–106.

Di Prisco, G., V. Cavaliere, D. Annoscia, P. Varricchio, E. Caprio, F. Nazzi, G. Gargiulo, and F. Pennacchio. 2013. Neonicotinoid Clothianidin Adversely Affects Insect Immunity and Promotes Replication of a Viral Pathogen in Honey Bees. *Proceedings of the National Academy of Sciences* 110(46): 18466–18471.

Eiri, D.M., G. Suwannapong, M. Endler, and J.C. Nieh. 2015. *Nosema ceranae* Can Infect Honey Bee Larvae and Reduces Subsequent Adult Longevity. *PloS One* 10(5): e0126330.

Esser, A., and R. Hennings. 2012. Winter Canola Feasibility in Rotation with Winter Wheat. *Washington State University Extension Publication* FS068E. Washington State University.

Fries, I., and S. Camazine. 2001. Implications of Horizontal and Vertical Pathogen Transmission for Honey Bee Epidemiology. *Apidologie* 32(3): 199–214.

Fürst, M.A., D.P. McMahon, J.L. Osborne, R.J. Paxton, and M.J.F. Brown. 2014. Disease Associations between Honeybees and Bumblebees as a Threat to Wild Pollinators. *Nature* 506(7488): 364–366.

Galpern, P., S.A. Johnson, J.L. Retzlaff, D. Chang, and J. Swann. 2017. Reduced Abundance and Earlier Collection of Bumble Bee Workers under Intensive Cultivation of a Mass-Flowering Prairie Crop. *Ecology and Evolution* 7(7): 2414–2422.

Garibaldi, L.A., L.G. Carvalheiro, S.D. Leonhardt, M.A. Aizen, B.R. Blaauw, R. Isaacs, M. Kuhlmann, et al. 2014. From Research to Action: Enhancing Crop Yield through Wild Pollinators. *Frontiers in Ecology and the Environment* 12(8): 439–447.

Garibaldi, L.A., I. Steffan-Dewenter, C. Kremen, J.M. Morales, R. Bommarco, S.A. Cunningham, L.G. Carvalheiro, et al. 2011. Stability of Pollination Services Decreases with Isolation from Natural Areas despite Honey Bee Visits. *Ecology Letters* 14(10): 1062–1072.

Garibaldi, L.A., I. Steffan-Dewenter, R. Winfree, M.A. Aizen, R. Bommarco, S.A. Cunningham, C. Kremen, et al. 2013. Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance. *Science* 339(6127): 1608–1611.

Gill, R.J., O. Ramos-Rodriguez, and N.E. Raine. 2012. Combined Pesticide Exposure Severely Affects Individual- and Colony-Level Traits in Bees. *Nature* 491(7422): 105–108.

Goulson, D. 2003. Conserving Wild Bees for Crop Pollination. *Food, Agriculture & Environment* 1: 142–144.

Goulson, D. 2010. Impacts of Non-native Bumblebees in Western Europe and North America. *Applied Entomology and Zoology* 45(1): 7–12.

Goulson, D., E. Nicholls, C. Botías, and E.L. Rotheray. 2015. Bee Declines Driven by Combined Stress from Parasites, Pesticides, and Lack of Flowers. *Science* 347(6229): 1255957.

Graystock, P., K. Yates, B. Darvill, D. Goulson, and W.O.H. Hughes. 2013. Emerging Dangers: Deadly Effects of an Emergent Parasite in a New Pollinator Host. *Journal of Invertebrate Pathology* 114(2): 114–119.

Halinski, R., C.F. Dos Santos, T.G. Kaehler, and B. Blochtein. 2018. Influence of Wild Bee Diversity on Canola Crop Yields. *Sociobiology* 65(4): 751–759.

Hatten, T.D., C. Looney, J.P. Strange, and N.A. Bosque-Pérez. 2013. Bumble Bee Fauna of Palouse Prairie: Survey of Native Bee Pollinators in a Fragmented Ecosystem. *Journal of Insect Science* 13(26): 26.

Holzschuh, A., C.F. Dormann, T. Tscharntke, and I. Steffan-Dewenter. 2013. Mass-flowering Crops Enhance Wild Bee Abundance. *Oecologia* 172(2): 477–484.

Jauker, F., M. Speckmann, and V. Wolters. 2016. Intra-specific Body Size Determines Pollination Effectiveness. *Basic and Applied Ecology* 17(8): 714–719.

Klein, A.-M., B.E. Vaissière, J.H. Cane, I. Steffan-Dewenter, S.A. Cunningham, C. Kremen, and T. Tscharntk. 2007. Importance of Pollinators in Changing Landscapes for World Crops. *Proceedings of the Royal Society B* 274(1608): 303–313.

Kremen, C., N.M. Williams, M.A. Aizen, B. Gemmill-Herren, G. LeBuhn, R. Minckley, L. Packer, et al. 2007. Pollination and Other Ecosystem Services Produced by Mobile Organisms: A Conceptual Framework for the Effects of Land-Use Change. *Ecology Letters* 10(4): 299–314.

Lawrence, T.J., E.M. Culbert, A.S. Felsot, V.R. Hebert, and W.S. Sheppard. 2016. Survey and Risk Assessment of *Apis mellifera* (Hymenoptera: Apidae) Exposure to Neonicotinoid Pesticides in Urban, Rural, and Agricultural Settings. *Journal of Economic Entomology* 109(2): 520–528.

Lever, J.J., E.H. van Nes, M. Scheffer, and J. Bascompte. 2014. The Sudden Collapse of Pollinator Communities. *Ecology Letters* 17: 350–359.

Lundin, O., M. Rundlof, H.G. Smith, I. Fries, and R. Bommarco. 2015. Neonicotinoid Insecticides and Their Impacts on Bees: A Systematic Review of Research Approaches and Identification of Knowledge Gaps. *PLoS ONE* 10(8): 1–20.

Macfarlane, R.P., K.D. Patten, L.A. Royce, B.K.W. Wyatt, and D.F. Mayer. 1994. Management Potential of Sixteen North American Bumble Bee Species. *Melanderia* 50: 1–12.

Michener, C.D. 2007. *Bees of the World* (2nd ed.). Johns Hopkins University Press.

Morandin, L.A., and M.L. Winston. 2005. Wild Bee Abundance and Seed Production in Conventional, Organic, and Genetically Modified Canola. *Ecological Applications* 15(3): 871–881.

Morandin, L.A., and M.L. Winston. 2006. Pollinators Provide Economic Incentive to Preserve Natural Land in Agroecosystems. *Agriculture, Ecosystems and Environment* 116: 289–292.

Noss, R.F., E.T. LaRoe, III, and J.M. Scott. 1995. Endangered Ecosystems of the United States: A Preliminary Assessment of Loss and Degradation.

NWF (National Wildlife Federation). 2020. Native Plant Finder.

Okada, T., J.E.A.R.M. Jayasinghe, M. Nansamba, M. Baes, P. Warner, A. Kouidri, D. Correia, V. Nguyen, R. Whitford, and U. Baumann. 2018. Unfertilized Ovary Pushes Wheat Flower Open for Cross-Pollination. *Journal of Experimental Botany* 69(3): 399–412.

Osgood, E. 1972. Soil Characteristics of Nesting Sites of Solitary Bees Associated with the Low-Bush Blueberry in Maine. *Maine Agricultural & Forest Experiment Station* TB59. The University of Maine.

Pan, W.L., F.L. Young, T.M. Maaz, and D.R. Huggins. 2016. Canola Integration into Semi-arid Wheat Cropping Systems of the Inland Pacific Northwestern USA. *Crop and Pasture Science* 67(3–4): 253–265.

Pickett, J.A., L.J. Wadhams, and C.M. Woodcock. 1997. Developing Sustainable Pest Control from Chemical Ecology. *Agriculture, Ecosystems and Environment* 64(2): 149–156.

Pitts-Singer, T.L., and J.H. Cane. 2011. The Alfalfa Leafcutting Bee, *Megachile rotundata*: The World's Most Intensively Managed Solitary Bee. *Annual Review of Entomology* 56: 221–237.

Rao, S., and W.P. Stephen. 2009. Bumble Bee Pollinators in Red Clover Seed Production. *Crop Science* 49(6): 2207–2214.

Rao, S., and W.P. Stephen. 2010. Abundance and Diversity of Native Bumble Bees Associated with Agricultural Crops: The Willamette Valley Experience. *Psyche: A Journal of Entomology* 2010: 354072.

Roulston, T.H.H., and J.H.H. Cane. 2000. Pollen Nutritional Content and Digestibility for Animals. *Plant Systematics and Evolution* 222(1–4): 187–209.

Rundlöf, M., G.K.S.S. Andersson, R. Bommarco, I. Fries, V. Hederström, L. Herbertsson, O. Jonsson, et al. 2015. Seed Coating with a Neonicotinoid Insecticide Negatively Affects Wild Bees. *Nature* 521(7550): 77–80.

Rundlöf, M., A.S. Persson, H.G. Smith, and R. Bommarco. 2014. Late-Season Mass-Flowering Red Clover Increases Bumble Bee Queen and Male Densities. *Biological Conservation* 172: 138–145.

Sabbahi, R., D. De Oliveira, and J. Marceau. 2005. Influence of Honey Bee (Hymenoptera: Apidae) Density on the Production of Canola (Crucifera: Brassicacae). *Journal of Economic Entomology* 98(2): 367–372.

Schillinger, W.F., and T.C. Paulitz. 2018. Canola versus Wheat Rotation Effects on Subsequent Wheat Yield. *Field Crops Research* 223: 26–32.

Scholer, J., and V. Krischik. 2014. Chronic Exposure of Imidacloprid and Clothianidin Reduce Queen Survival, Foraging, and Nectar Storing in Colonies of *Bombus impatiens*. *PLoS ONE* 9(3).

Spivak, M., and G.S. Reuter. 2001. Resistance to American Foulbrood Disease by Honey Bee Colonies *Apis mellifera* Bred for Hygienic Behavior. *Apidologie* 32: 555–565.

Strange, J.P. 2015. Variable Responses in Population Genetic Structure to Climate Change within Bumble Bee Communities of the Pacific Northwest.

Thom, M.D., C.A. Eberle, F. Forcella, R. Gesch, and S. Weyers. 2018. Specialty Oilseed Crops Provide an Abundant Source of Pollen for Pollinators and Beneficial Insects. *Journal of Applied Entomology* 142(1–2): 211–222.

Thom, M.D., C.A. Eberle, F. Forcella, R. Gesch, S. Weyers, and J.G. Lundgren. 2016. Nectar Production in Oilseeds: Food for Pollinators in an Agricultural Landscape. *Crop Science* 56(2): 727–739.

Thompson, C.E., J.C. Biesmeijer, T.R. Allnutt, S. Pietravalle, and G.E. Budge. 2014. Parasite Pressures on Feral Honey Bees (*Apis mellifera* sp.). *PLoS ONE* 9(8): 1–8.

Thomson, D.M. 2016. Local Bumble Bee Decline Linked to Recovery of Honey Bees, Drought Effects on Floral Resources. *Ecology Letters* 19(10): 1247–1255.

Thomson, J.D., J.E. Ogilvie, T.T. Makino, A. Arisz, S. Raju, V. Rojas-Luengas, and M. Tan. 2012. Estimating Pollination Success with Novel Artificial Flowers: Effects of Nectar Concentration. *Journal of Pollination Ecology* 9(14): 108–114.

U.S. Canola Association. 2019. Best Management Practices (BMPs) for Pollinator Protection in Canola Fields.

USDA Farm Service Agency. 2021. Conservation Reserve Program.

USDA NASS (National Agricultural Statistics Service). 2019. Crop Production 2018 Summary.

USDA NRCS (Natural Resources Conservation Service). 2021. Environmental Quality Incentives Program.

Vickruck, J.L., L.R. Best, M.P. Gavin, J.H. Devries, and P. Galpern. 2019. Pothole Wetlands Provide Reservoir Habitat for Native Bees in Prairie Croplands. *Biological Conservation* 232: 43–50.

Westphal, C., I. Steffan-Dewenter, and T. Tscharntke. 2009. Mass Flowering Oilseed Rape Improves Early Colony Growth but Not Sexual Reproduction of Bumblebees. *Journal of Applied Ecology* 46(1): 187–193.

Whitehorn, P.R., S. O’Connor, F.L. Wackers, and D. Goulson. 2012. Neonicotinoid Pesticide Reduces Bumble Bee Colony Growth and Queen Production. *Science* 336(6079): 351–352.

Wine, E.H. 2018. Long-Term Population Census and Nest Site Characterization of Managed Alkali Bee Population in Alfalfa Seed Production in South Central Washington (master's research). Washington State University.

Winfree, R. 2010. The Conservation and Restoration of Wild Bees. *Annals of the New York Academy of Sciences* 1195: 169–197.

Winfree, R., B.J. Gross, and C. Kremen. 2011. Valuing Pollination Services to Agriculture. *Ecological Economics* 71: 80–88.

Winston, M.L., and L.A. Morandin. 2005. Wild Bee Abundance and Seed Production in Conventional, Organic, and Genetically Modified Canola. *Ecological Applications* 15(3): 871–881.

WOCS (Washington Oilseed Cropping Systems Project). 2017. Annual Report.

Wratten, S.D., M. Gillespie, A. Decourtye, E. Mader, and N. Desneux. 2012. Pollinator Habitat Enhancement: Benefits to Other Ecosystem Services. *Agriculture, Ecosystems and Environment* 159: 112–122.

WSDA (Washington State Department of Agriculture). 2018. Agricultural Land Use.

Wu, J.Y., C.M. Anelli, and W.S. Sheppard. 2011. Sub-lethal Effects of Pesticide Residues in Brood Comb on Worker Honey Bee (*Apis mellifera*) Development and Longevity. *PLoS ONE* 6(2).

Xu, T., D.G. Dyer, L.L. Mcconnell, S. Bondarenko, R. Allen, and O. Heinemann. 2016. Clothianidin in Agricultural Soils and Uptake into Corn Pollen and Canola Nectar after Multiyear Seed Treatment Applications. *Environmental Toxicology and Chemistry* 35(2): 311–321.

Zou, Y., F.J.J.A. Bianchi, F. Jauker, H. Xiao, J. Chen, J. Cresswell, S. Luo, et al. 2017. Landscape Effects on Pollinator Communities and Pollination Services in Small-Holder Agroecosystems. *Agriculture, Ecosystems and Environment* 246: 109–116.

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