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Bee Nourished: How pollen nutrition shapes bee foraging habits and what it means for restoration

Hardworking bees are a familiar sight outdoors as they forage for nectar and pollinate flowers. Along with nectar, both wild bees and honey bees collect pollen to bring back to brooding areas, where it feeds developing larvae. From the bee's perspective, an important question arises: is all pollen nutritionally the same and, if not, how do bees get the nutrients they need?

U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station (RMRS) research scientist Anthony Vaudo has long studied the nutritional value of pollen and how bees choose flowering plants to forage for this sticky, nutritious substance. While traditional pollination ecology focuses on what attracts bees from a plant's perspective, Vaudo takes the bees' perspective, asking, "What do the plants have that bees need?" His research has shown that groups of bees preferentially select certain plants for pollen collection, and his recent work sheds light on why, with implications for habitat restoration at a time when pollinator decline is a pressing concern.

Nectar Fuels, But Pollen Builds the Future

Around 120 million years ago, a group of predatory wasps began eating pollen—instead of dead insects—and storing it in their nests for their brood to feed on, a behavior that eventually led to the evolution of bees. Now, bees are adapted to collect, transport, and consume pollen while also foraging for nectar and providing "pollination services" to plant communities. The carbohydrates in flower nectar may power the seemingly frenetic pace of life in adult bees, but the next generation of larvae also need the proteins, lipids, and micronutrients found in pollen to grow their bodies into adulthood.

Bees obtain most of their protein from pollen, the concentration of which can vary considerably

Bee visits to flowers for pollen collection are tied specifically to the quality of that pollen and its healthful benefits. USDA Forest Service photo by Anthony Vaudo.

between 2 and 60 percent across plant species. Pollen is also the main source for lipids in bee diets, in the form of sterols, triglycerides, and fatty acids, with concentrations ranging from 1 to 20 percent. This variability prompted Vaudo to investigate whether pollen nutrient content drives bee foraging behavior at the community level.

Vaudo recalls, “I thought we could do something positive for bee communities, and that launched an entire line of research that tries to link foraging behavior with health by looking at pollen nutrition content.”

Pollen Choice: A Balance of Protein and Lipids

Bees have specific nutritional needs and can adjust their foraging diet among many plants to meet these needs. Although the protein and lipid content varies considerably among species, researchers had not been able to show that bees consistently preferred high– or low–protein pollen when given a choice between different pollens. Vaudo found that the missing element in bee pollen foraging preferences is in the lipid content—specifically the ratio of protein to lipids in the pollen.

His early work with bumble bees showed that, when given a choice in a lab setting, bumble bees preferred diets with a high protein to lipid (P:L) ratio and that this translated into the bumble bees foraging preferentially in the field for plants with high P:L ratio. He explains, “Adding in lipid, or the fat component instead of just looking at protein in isolation was instrumental, because it wasn't just higher or lower protein, and it wasn't just higher or lower fat. It was the ratio between them that was so important in shaping their foraging behavior.”

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The Nutritional Landscape of Bees

Knowing that pollen nutrition was quite variable, Vaudo tried to figure out whether flowering plants with similar pollen nutrition share similar bee species—in other words, was there a relationship between bee species and the P:L ratio of the plants they visit? At his research sites in the Great Basin Desert and eastern Sierra Nevada Mountains of the western United States, he collected data on 4,500 bee visits to plants, representing at least 350 wild bee species and 145 plant species. At the same time, he collected pollen from the plants to analyze the P:L ratios to see if there was a relationship between these ratios and which species of bees were visiting these plants.

SUMMARY

Bees do more than buzz from flower to flower—they carefully select pollen to meet their nutritional needs. While nectar provides energy for adult bees, pollen is the primary source of protein and lipids needed by their larvae. USDA Forest Service Biological Scientist Anthony Vaudo has found that bees aren’t just looking for any pollen; they prefer specific plants based on the balance of protein and lipids (P:L ratio) in the pollen.

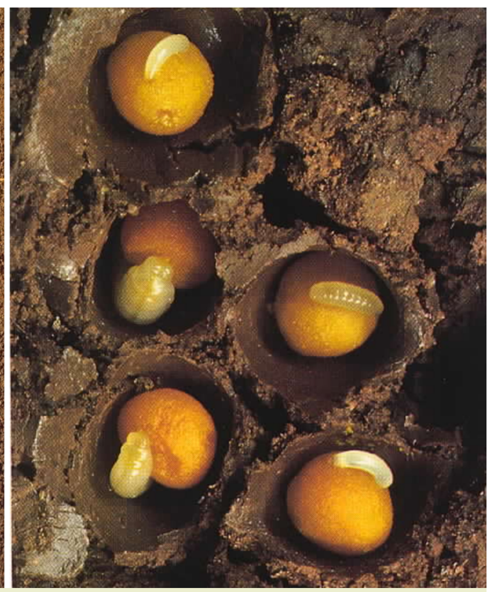
By analyzing over 4,500 bee visits to 145 plant species in the western United States, Vaudo and his co-authors demonstrated that bees collectively forage across a wide range of P:L ratios, meeting the diverse nutritional needs of their communities. Plants from the same family often have similar P:L ratios, helping explain patterns in plant-bee interactions. These findings reveal a “nutritional landscape,” where plant diversity directly supports pollinator biodiversity by providing complementary resources.

This research has significant implications for habitat restoration. To support pollinator populations, restoration projects can prioritize planting species with diverse P:L ratios to cater to the nutritional needs of various bee species. Integrating pollen nutrition into restoration planning could improve habitat quality and ensure long-term ecological resilience.

First, he found that the P:L ratios of the 145 plant species span the entire known distribution of protein and lipid concentrations (i.e., from 0.5:1 to 30:1), indicating that this area represents a complete "nutritional landscape" for the local wild bees. This nutritional diversity in the landscape provided a great opportunity to figure out how bees were going about meeting their nutritional needs. Vaudo explains, "These plants are complementary for supporting the entire bee community because we think that there are those that need the low P:L pollens, and those that need the high P:L pollens, and then there are bee species in the middle. All of these plants offering different rewards are equally important because they are supporting different groups of pollinators."

The flowering plants of the study sites represent the full range of known pollen protein to lipid ratios in plants and should be able to create a "nutritional landscape" that supports a wide variety of wild bee species. USDA Forest Service photo by Anthony Vaudo.

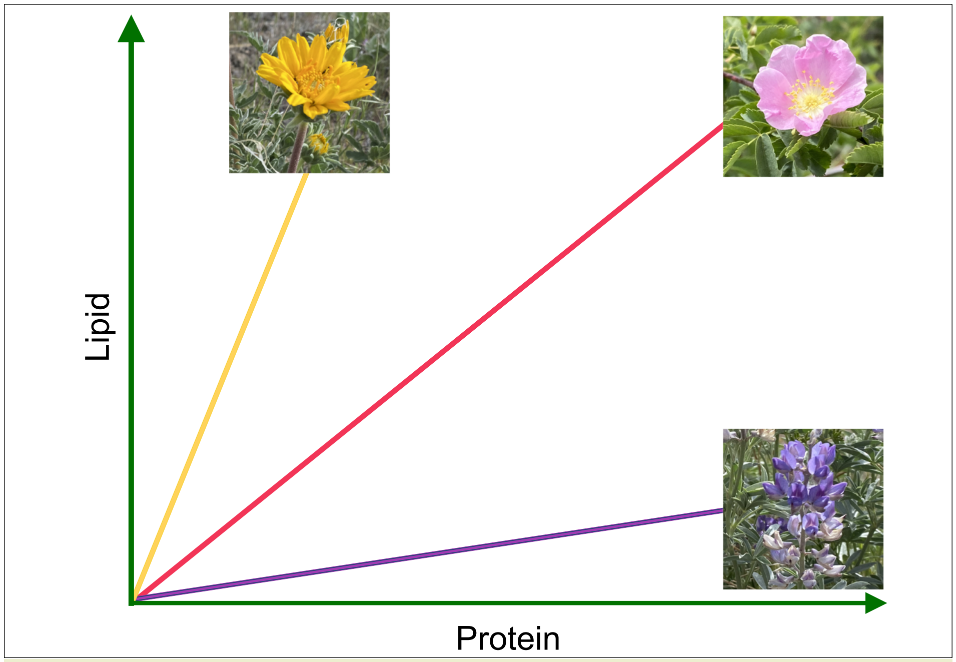
Also, P:L ratios are not distributed randomly across plant species, but



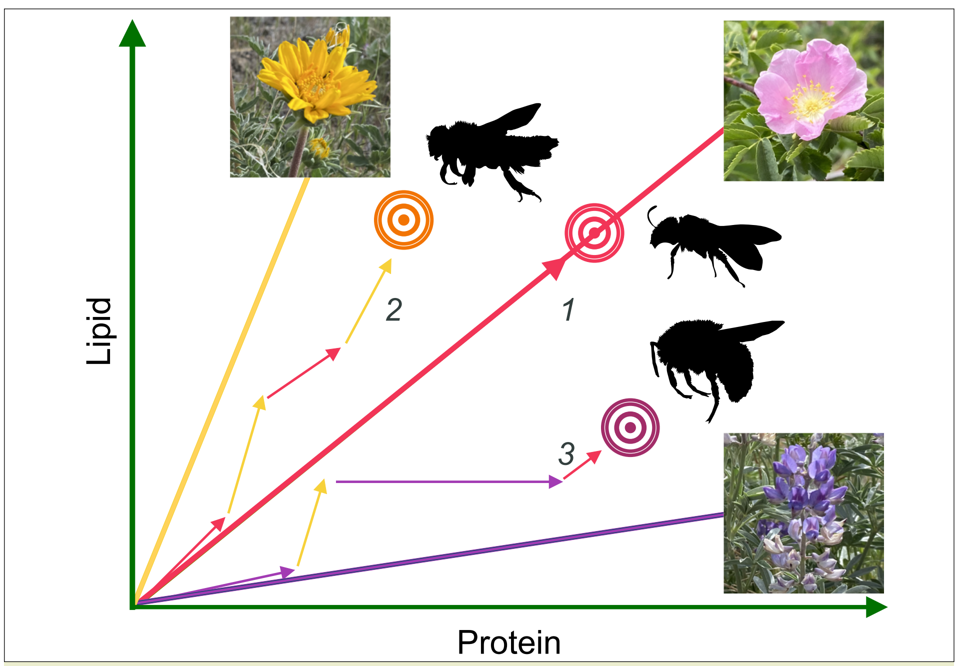
Bees are adapted to collect, transport, and consume pollen, foraging among a variety of plants to meet the nutritional needs of their developing larvae. USDA Forest Service photos by Anthony Vaudo (left). Courtesy photos by Robin Thorpe (middle and right).

tend to be similar within plant families, and even more so within genera. For example, lower pollen P:L ratios are associated with the large aster (sunflower) family, mid-range ratios are found in Rosaceae (rose family) and Apiaceae (celerey/carrot family), and higher ratios are found in Fabaceae (bean family) and Boraginaceae (borage family).

It makes a lot of sense that a diverse group like bees might adapt to different pollen diets over evolutionary time, because in doing so they occupy different ecological niches across the landscape, according to Vaudo. There are different strategies bees may use to obtain their optimal nutrition. They may not always be able to find a specific plant completely aligned with their needs, and so they can balance pollen collection from complementary food sources to reach their preferred target P:L ratios. In analyzing his data, he assigned bees and flowers to "modules", or sets of frequently interacting bees and plants, and compared distributions of P:L ratios to see if these associations existed. "Our data showed that there were some distinct differences in the plant nutrition offered within each module, both across the landscape and also over the season," says Vaudo, "indicating that there are nutritional niches for the wide diversity of wild bees in this landscape. Plants with similar pollen nutrition share similar groups of bee species."



There is wide variation in the protein to lipid ratios of pollen in flowering plants. The ratios tend to be similar within families and even more so within genera. USDA Forest Service graphic by Anthony Vaudo.



Plant species offer a variety of protein to lipid ratios within the nutritional landscape. Bee species may have specific pollen nutritional targets that can be met by foraging from a single plant species (as in species 1), or by foraging among different plants species (as species 2 and 3). Plants with similar pollen nutrition share similar groups of bee species. USDA Forest Service graphic by Anthony Vaudo.

Bees have several ways of collecting pollen, based both on the bee species and on the morphology of the flower. Some bees use their front legs and scrape them as though they're digging the pollen from the anthers of the flowers. Other bees, like mason bees for example, tap their abdomen against the anthers where pollen sticks to their hairs. Bees also forage for nectar as they collect pollen, binding the pollen into packets with the nectar. In doing so, bees may also pick up a lot of pollen from flowers that they are not actively foraging pollen from.

Because bees seem to be foraging for pollen with specific P:L ratios, but also passively picking up other pollen while collecting nectar, Vaudo and collaborators wondered what the P:L ratios were of the pollen that was on the legs of the bees returning to their brood, and whether it would match what was expected based on pollen foraging visits. As part of the study, they painstakingly collected these pollen sacs from the bees' legs and analyzed the P:L ratio in the lab. They found that the P:L ratio of the pollen collected by the bees did in fact match that of the plants that they were visiting specifically to forage pollen from, and pollen that they picked up inadvertently did not contribute greatly to the P:L ratio of what was delivered to the brood.

Plant ecologists working in these arid western ecosystems are hoping to collaborate with Vaudo to answer some questions that might have bearing on their work. Sarah Barga,

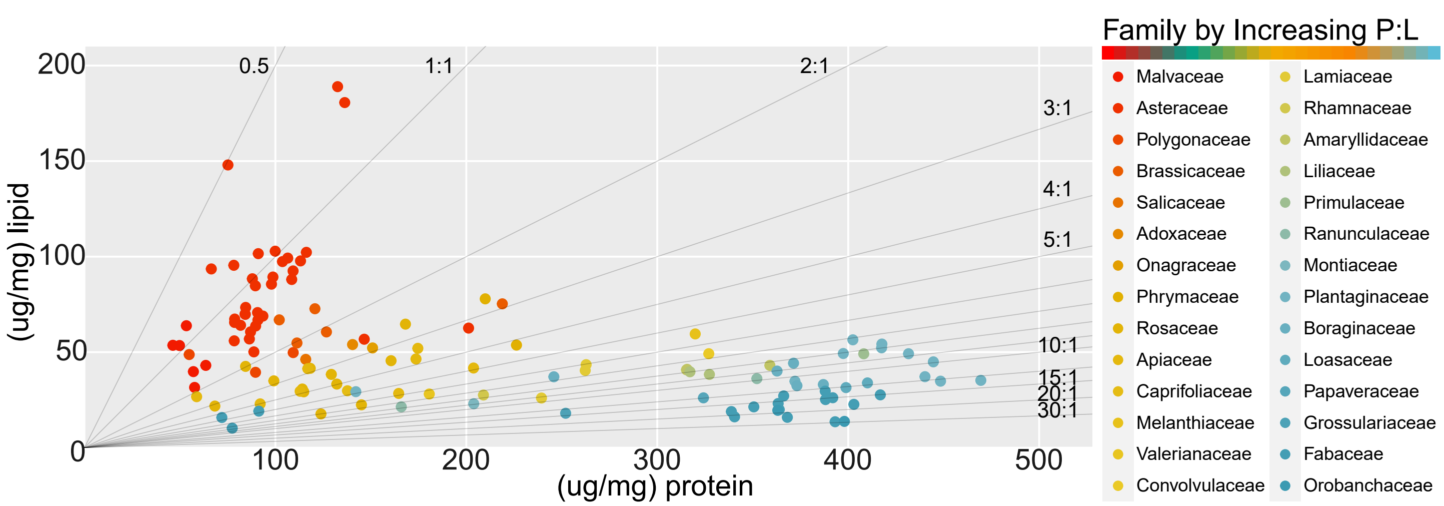
Plants in a landscape should be thought of as complementary and equally important in bee nutrition. Diversity in plants at the family level creates the nutritional diversity needed for bees to self-select their diet and should be a consideration in restoration. USDA Forest Service photo by Anthony Vaudo.

a research botanist at the RMRS lab in Cedar City, Utah says that Vaudo and she have discussed sampling the pollinator communities at the RMRS Desert Experimental Range in southwestern Utah and looking at how pollinator resources might change along an elevation gradient or a disturbance gradient. "We would look at the differences in the pollinator communities along a gradient and see perhaps how the nutritional resources provided by the plant communities might shift based on the pollinators they're interacting with," she says.

Bryce Richardson, a plant research geneticist at the RMRS Moscow lab, says that pollen P:L ratios are "something we need to start paying attention to in our studies." He explains, "We need to home in on specifically, whether the ratio varies within plant species and see if there is a genetic component. If Vaudo collected the pollen and figured out what the ratios were in, for example, rabbitbrush, where we have some hybridization, we would have a whole set of genetic data we could use for comparisons."

Looking Ahead: The Role of Pollen and Plant Families in Restoration

With concerns about declines in wild bee populations, one important question for restoration efforts is which species should be planted for bees? Justin Runyon, RMRS research entomologist and colleague of Vaudo's, has developed "[pollinator scorecards]" that land managers in the Northern Rockies can use to help choose plant species that will best support local bee species. The list was developed by collecting information on the timing and bloom duration of 24 focal plant species and both the number of bees and bee species that visited the plants. They ranked the plants across each of these metrics and developed a scorecard that managers can use to select pollinator-friendly seed mixes based on budget, habitat type, or plant availability. According to Runyon, Vaudo's work helps to fill a void in the understanding of what makes a particular plant valuable



When managers are planning restoration projects, they can create the most nutritionally diverse landscape by choosing plants from families across the spectrum of protein to lipid ratios. The plant families above were present in the Sierra Nevada and Great Basin research sites and are listed from lowest to highest protein to lipid ratios. USDA Forest Service graphic by Anthony Vaudo.

to a given bee species. He explains, "When we ranked these pollinator-friendly plants, one huge missing gap is nutrition-wise, are they indeed valuable?"

Runyon imagines that the pollinator scorecards he and his colleagues developed could be revised to include Vaudo's findings. He explains, "It's eye-opening to me that he found that the protein to lipid ratio explained a lot of preferences by the bees. Based on this, we can create subsets on our list to make sure we get plants that are preferred by all the different bee groups."

The pollinator friendliness scorecards started with a list of native plant species that is available for the Forest Service to use. "Seed is unavailable for most native plant species. No one's ever grown them," says Runyon, "So we started with this list of 35 plant species whose seeds are available for use in restoration. What a manager might do now is make sure they include seeds from plants in different families to get the diversity in the nutrition and protein:lipid ratios as well. And we may add a category for protein to lipid ratio onto the scorecard."

Even though the availability of native plants for restoration in the arid West is constrained, Vaudo is anticipating that managers will start adding the importance of pollen resources to their thought process when selecting which species they will use. He explains, "If we can start thinking about how pollen resources are important, then we can take it a step further and acknowledge the need for nutritional diversity and think about whether there is representation across nutritional niches for pollinators." He acknowledges that this may not happen overnight. "When I present these ideas to people, the first reaction is usually that they didn't know pollen was even eaten by bees, so it may take some time to get there, but I am hopeful."

KEY RESEARCH FINDINGS

- Bees forage for pollen to meet their nutritional needs for protein and lipids. Different species of plants have different ratios of protein to lipids, which creates nutritional diversity on the landscape and shapes the bees' foraging behaviors.
- Pollen protein to lipid ratios are similar within plant families, and even more similar within genera.
- Wild bees are "nutritionally specialized", meaning that they may prefer pollen from plants that are unrelated but have similar nutritional value.
- Observations of interactions between plants and bee species suggests that there are "nutritional niches", or groups of frequently interacting bees and plants delineated by pollen nutritional quality.
- Plants with varying pollen protein to lipid ratios should be considered complementary and equally important for wild bee populations.

MANAGEMENT IMPLICATIONS

- Diversity in plants at the family level creates the nutritional diversity needed for bees to self-select their diet.
- Managers can consider the protein:lipid ratio in plants when choosing species for restoration.
- Because different bee species have different pollen protein:lipid ratio needs, no one plant will support the entire bee community.
- Healthy landscapes are comprised of plants covering the widest range of pollen protein to lipid ratios.

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- Justin Runyon

FURTHER READING

Vaudo, A.D.; Dyer, L.A.; Leonard, A.S. 2024. Pollen nutrition structures bee and plant community interactions. Proceedings of the National Academy of Sciences. 121: e2317228120. https://doi.org/10.1073/pnas.2317228120

Vaudo, A.D.; Tooker, J.F.; Grozinger, C.M.; [et al.]. 2015. Bee nutrition and floral resource restoration. Current Opinion in Insect Science. 10: 133-141. https://doi.org/10.1016/j.cois.2015.05.008

Vaudo, A.D.; Lin, E.; Luthy, J.A.; [et al.]. 2024. Do past and present abiotic conditions explain variation in the nutritional quality of wildflower pollens for bees? Evolutionary Ecology. 38: 941-945. https://doi.org/10.1007/s10682-024-10313-4

Vaudo, A.D.; Tooker, J.F.; Patch, H.M.; [et al.]. 2020. Pollen protein: Lipid macronutrient ratios may guide broad patterns of bee species floral preferences. Insects. 11(2): 132. https://doi.org/10.3390/insects11020132

Copeland, S.; Schroeder, V.; Agneray, A.; [et al.]. 2024. Sagebrush wildflowers: From bloom to seed. PNW 779. Pacific Northwest Extension Publishing. Corvallis, OR: Pacific Northwest Cooperative Extension. 9 p. https://extension.oregonstate.edu/sites/extd8/files/catalog/auto/PNW779.pdf

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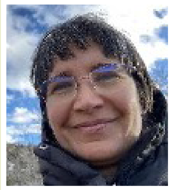
The following individuals were instrumental in the creation of this Bulletin.

Anthony Vaudo is a post-doctoral Biological Scientist with the USDA Forest Service's Rocky Mountain Research Station in Moscow, Idaho. He earned his M.S. in Entomology from the University of Florida, and his Ph.D. in Entomology from Pennsylvania State University. His research takes a holistic and integrative approach to ecological restoration and conservation of native plant-pollinator communities, with a particular interest in how bees' nutritional needs drive their perception of reward quality and how they forage among host-plants to balance their nutritional intake.

Bryce Richardson is a Plant Research Geneticist with the USDA Forest Service's Rocky Mountain Research Station in Moscow, Idaho. He earned his M.S. in Forest Resources from University of Idaho, and his Ph.D. in Plant Pathology from Washington State University. His research focuses on understanding plant population evolutionary relationships, adaptive genetic variation, and its application to restoration.



Sarah Barga is a Research Botanist with the USDA Forest Service's Rocky Mountain Research Station lab in Cedar City, Utah. She earned her M.S. and Ph.D. in Biology and Ecology, Evolution, and Conservation Biology (respectively) from the University of Nevada, Reno. She performs a variety of work to support the use of native forbs in restoration, including involvement in a large-scale forb common garden study for native plants of interest for use in restoration across the Great Basin.

Justin Runyon is a Research Entomologist with USDA Forest Service's Rocky Mountain Research Station in Bozeman, Montana. He earned his M.S. in Entomology from Montana State University, and his Ph.D. in Entomology from Pennsylvania State University. His research focuses on plant-insect chemical ecology and he has projects on assessing "pollinator-friendliness" of native plants for restoration.

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