National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Measuring and Monitoring Pollinator Diversity along Elevation Gradients in Olympic and North Cascades National Parks

Natural Resource Report NPS/NOCA/NRR—2018/1634






Introduction

The vast majority of flowering plants rely on insect pollinators for successful reproduction (Ollerton et al. 2011). Native bees (Hymenoptera: Anthophila) are among the most efficient and diverse pollinators, with 4,000 species known in North America (Mader et al. 2011), while syrphid or flower flies (Diptera: Syrphidae) are represented by approximately 870 Nearctic species (Vockeroth and Thompson 1987). Despite the ecological importance of these pollinators and their potential vulnerability to a variety of environmental threats, their diversity, distribution, and natural history has remained largely unknown to scientists, resource managers, and visitors in most national parks.

Bees and other pollinators are known to be at risk from various human-mediated threats such as habitat loss and alteration, invasive species, parasites, pesticides, and climate change (Potts et al. 2010; Goulson et al. 2015). Dramatic declines have been well-documented and publicized for honey bees (Natural Research Council 2006), but have also been observed among native bumble bees (Colla and Packer 2008, Cameron et al. 2011), and solitary bees (Burkle et al. 2013). Comparatively scant literature exists on the status of syrphid flies, although changes in species richness and composition pre-and post-1980 have been documented in Europe (Biesmeijer et al. 2006).

Climate change is predicted to pose a significant threat to native pollinator communities, with potential consequences including range shifts, phenological decoupling of plant-pollinator networks, and population declines (Bartomeus et al. 2011, Iler et al. 2013; Kerr et al. 2015). At particular risk are bee communities associated with habitats potentially most vulnerable to effects from warming temperatures and altered climates, such as alpine and subalpine areas (Dirnböck et al. 2011, Franzén and Öckinger 2012).

National parks provide a natural laboratory in which to measure patterns of pollinator diversity and to measure change in these patterns over time (Rykken and Farrell 2013*a*, Rykken et al. 2014, Koch et al. 2016, Rochefort and McLaughlin 2017). North Cascades and Olympic are iconic national parks that encompass low to mid-elevation montane forests as well as high-elevation subalpine and alpine habitats, and thus provide an ideal opportunity to establish baseline information on bee and syrphid fly species diversity and distribution along elevation gradients. Because impacts from climate change are presumed to be more pronounced at high elevations (Halofsky et al. 2011), pollinator communities in subalpine and alpine zones of these parks may be especially vulnerable to altered temperature and moisture regimes, and thus could serve as sentinels to monitor these changes and their effects on ecosystem health.

North Cascades and Olympic are also ideal parks in which to conduct pollinator inventory and monitoring work because there has been ongoing support for several other pollinator projects in the North Coast and Cascades Network (NCCN), including surveys of *Bombus* (bumble bees) in seven NCCN National and Historical Parks (Koch et al. 2016, 2017), and a butterfly monitoring program in North Cascades and Mount Rainier National Parks (Rochefort and McLaughlin 2017). I hope to be able to build on and contribute to this foundation of research.

The project was designed to collect pollinator biodiversity data from two mountainous parks that are relatively near each other but are geographically disjunct. By documenting patterns in both North Cascades and Olympic I hoped to determine if high elevation habitats above tree line, in which rare and endemic plants often reside, harbor a distinct community of pollinators that are different from the fauna in the lower and mid-elevation landscape matrix, and whether these patterns hold up across different mountain ranges. If high elevation pollinators do represent a distinctive fauna, then these areas can be targeted for future monitoring, and where appropriate, for active management.

Specifically, the primary objectives of this study were to:

1) Document and compare the diversity, species composition, and distribution of bees and syrphid flies in selected habitats along elevation gradients in Olympic and North Cascades National Parks, with a special focus on higher elevation habitats above tree line.
2) Suggest locations for permanent sites and develop protocols for continued monitoring of pollinators at different elevations by park staff, citizen scientists, or other researchers to detect future changes such as phenology or range shifts.
3) Educate park staff and visitors about pollinators and threats to their health through hands-on demonstrations, presentations, and field walks, including participation in BioBlitz activities at North Cascades.

Methods

Study Areas

North Cascades National Park Service Complex ("North Cascades" in this report) encompasses North Cascades National Park, Ross Lake National Recreation Area, and Lake Chelan National Recreation Area in northern Washington State (Figure 1). This 276,800 ha protected area spans the northern Cascade Range, including temperate rainforest on the western slopes, dry ponderosa pine forest on the eastern slopes, subalpine meadows near tree line, and numerous glaciers in alpine areas. Elevations range from 122 m in the Skagit River valley to more than 2,800 m on the highest peaks.

Figure 1. Relative locations of Olympic National Park and North Cascades National Park Service Complex (including North Cascades National Park, Ross Lake National Recreation Area, and Lake Chelan National Recreation Area) in northwestern Washington State.

Olympic National Park comprises approximately 373,120 ha on the Olympic Peninsula in northwest Washington State (Figure 1). The park encompasses the largest intact tract of temperate rainforest in the Pacific Northwest, 100 km of protected wilderness coastline, and is capped by numerous mountain glaciers and sub/alpine meadows. Forests on the western side of the park receive more than 350 cm rain per year, while eastern forests are somewhat drier. The park is known to harbor 35 endemic species or subspecies of plants and animals, largely a result of its isolation from the rest of the continent during previous glacial periods, and its location on a peninsula. Elevations range from sea level to 2,428 m on the summit of Mount Olympus.

Site Selection and Timing of Collections

With the help of park staff, I selected multiple sampling sites along elevation gradients in each park. The lowest sites were on ocean beach, managed lawns, and riparian areas of larger rivers (Hoh and Skagit Rivers); mid-elevation sites included various types of forest openings, including open trails, lake edges, and meadows; the highest elevation sites were subalpine meadows. Roadside sampling occurred at all elevations. Because I was interested in differences between habitats above and below tree line (which varies considerably in elevation depending on aspect, topography, and other factors), I also categorized each sampling site as “high meadow” or “high rocky area” if it was at or above tree line, or “forest opening” if below tree line (including open trails, riparian areas, beach), with the help of Geographic Information Systems (Google Earth Pro, version 7.1.5.1557). Disturbed sites (roadsides, lawns) were grouped in their own category, as were closed canopy forest sites.

Pollinator sampling in North Cascades occurred at 28 sites between August 4 and 18, 2014 (Figure 2, Table 1). General sampling areas included Newhalem area, sites near SR 20, and Desolation Peak in Ross Lake NRA; Maple Pass, Easy Pass, Cascade Pass, and Monogram Lake in the south unit of North Cascades NP; and McAlester Lake and South Pass in Lake Chelan NRA. Sampling site elevations ranged from 145 m on the Skagit River in Newhalem to 2,010 m at Easy Pass. In Olympic, a total of 58 sites were sampled between June 28 and September 17, 2014. These included 40 sites sampled by me (JR) between August 19 and 31, 2014, and 18 sites sampled by J.D. Herndon and/or J. Freilich earlier and later in the summer (Figure 3, Table 1). Sampling areas included Rialto Beach and Hoh River to the west; Crescent Lake, Seven Lakes Basin, and Hurricane Ridge in the northern part of the park; Grand Valley and Gray Wolf ridge in the east; the Quinault basin to the south; and Cushman in the southeast corner of the park. Focal habitats were similar to those in North Cascades. Sampling site elevations ranged from sea level at Rialto Beach up to 1,934 m on Lillian Ridge.

The process of site selection was constrained by the timing of sampling. Because the summer had been unusually hot and dry in 2014, and fieldwork was limited to the month of August (for JR), I targeted areas where I could find plants still in flower (based on recommendations by park staff), and this was mainly at higher elevations. Thus, there was a strong bias in my sampling towards higher elevation sites in both parks.

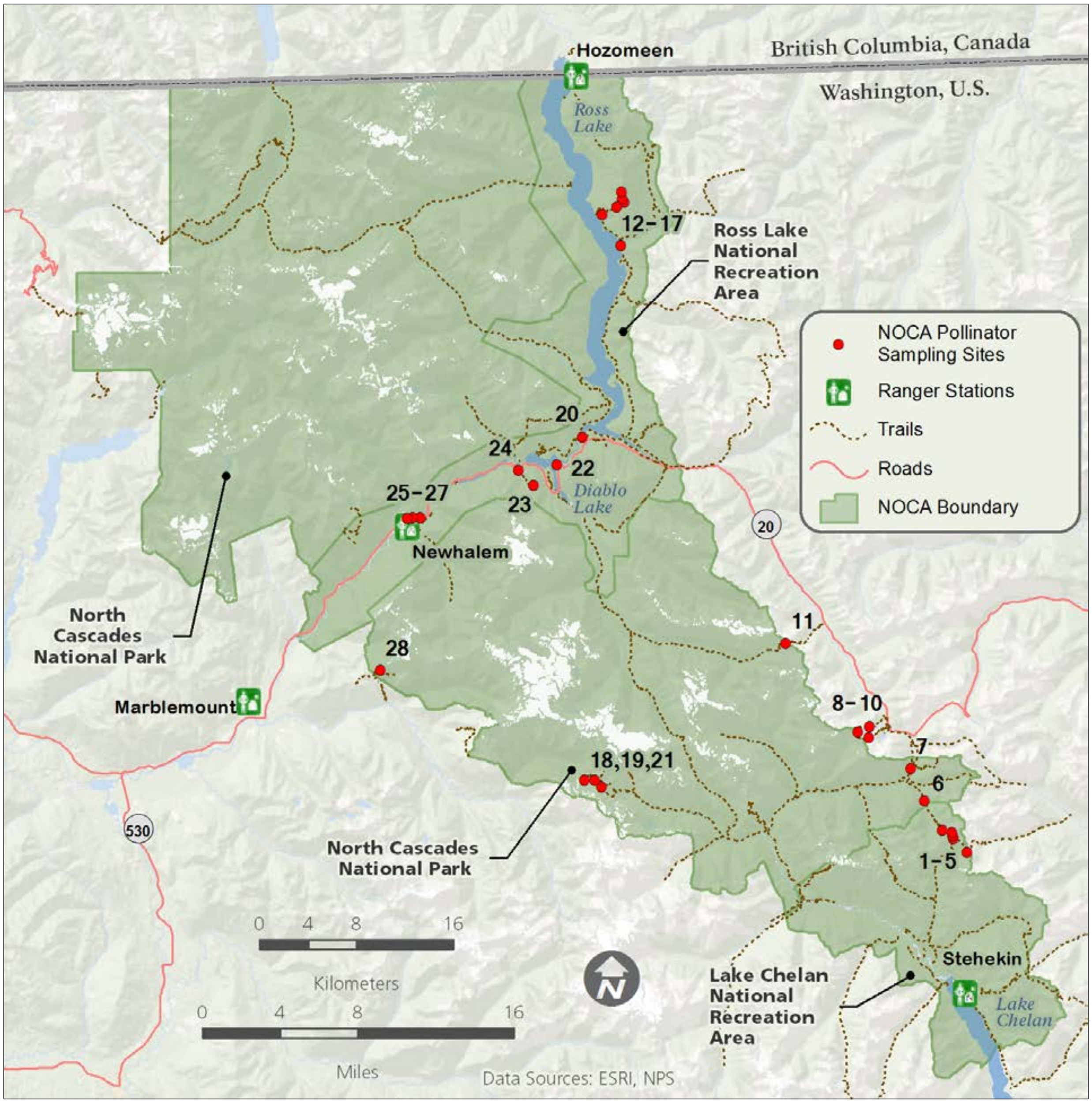

Figure 2. Approximate locations for pollinator sampling sites 1-28 (see Table 1) located in North Cascades National Park Service Complex.

Table 1. Location, habitat type, and collecting dates and methods for 86 pollinator sampling sites in North Cascades and Olympic in 2014. Site # refers to numbers on maps in Figures 2, 3. In tree line column: 1 = high meadow or rocky area at or above tree line; 2 = forest opening below tree line; 3 = closed forest; 4 = disturbed habitat.

Site #	Park	Locality	Latitude (N)	Longitude (W)	Elev (m)	Habitat	Tree line	Net	Bowl
1	NOCA	South Pass	48.4131	120.6486	1927	meadow	1	16-Aug	–
2	NOCA	McAlester Pass	48.4235	120.6637	1871	meadow	1	16-Aug	16-Aug
3	NOCA	McAlester Pass	48.4254	120.6644	1821	meadow	1	16-Aug	16-Aug
4	NOCA	Hidden Meadows Tr.	48.4283	120.6652	1808	open trail	2	16-Aug	–
5	NOCA	McAlester Lake	48.4300	120.6760	1745	lake edge	2	–	16-Aug
6	NOCA	McAlester Lake Tr.	48.4523	120.6952	1322	meadow	2	15, 17-Aug	–
7	NOCA	Bridge Creek Tr.	48.4766	120.7092	1200	open trail	2	17-Aug	–
8	NOCA	Maple Pass Tr.	48.5087	120.7539	1731	open trail	1	9-Aug	–
9	NOCA	Maple Pass	48.5005	120.7551	2023	meadow	1	9-Aug	–
10	NOCA	Maple Pass Tr.	48.5048	120.7670	1956	meadow	1	9-Aug	–
11	NOCA	Easy Pass	48.5722	120.8450	2010	meadow	1	9-Aug	–
12	NOCA	Desolation Peak Tr.	48.9041	121.0135	1668	meadow	1	6-Aug	–
13	NOCA	Desolation Peak Tr.	48.9066	121.0155	1793	open trail	1	6-Aug	–
14	NOCA	Desolation Peak Tr.	48.9114	121.0163	1857	meadow	1	6-Aug	–
15	NOCA	Lightning Creek Tr.	48.8719	121.0181	505	forest	3	5-Aug	–
16	NOCA	Desolation Peak Tr.	48.9006	121.0222	1281	open trail	2	6-Aug	–
17	NOCA	Desolation Peak Tr.	48.8949	121.0382	725	open trail	2	6-Aug	–
18	NOCA	Cascade Pass Tr.	48.4691	121.0558	1735	meadow	1	8-Aug	–
19	NOCA	Cascade Pass Tr.	48.4746	121.0631	1587	meadow	2	8-Aug	–
20	NOCA	Ross Dam, along dirt road	48.7299	121.0675	504	roadside	4	4-Aug	–
21	NOCA	Cascade Pass parking lot	48.4748	121.0748	1113	roadside	4	–	8-Aug
22	NOCA	SR-20, Diablo Overlook	48.7099	121.0971	476	roadside	4	4-Aug	–
23	NOCA	Pyramid Lake	48.6951	121.1236	938	lake edge	2	18-Aug	–

Table 1 (continued). Location, habitat type, and collecting dates and methods for 86 pollinator sampling sites in North Cascades and Olympic in 2014. Site # refers to numbers on maps in Figures 2, 3. In tree line column: 1 = high meadow or rocky area at or above tree line; 2 = forest opening below tree line; 3 = closed forest; 4 = disturbed habitat.

Site #	Park	Locality	Latitude (N)	Longitude (W)	Elev (m)	Habitat	Tree line	Net	Bowl
24	NOCA	Pyramid Lake Tr.	48.7064	121.1400	507	forest	3	18-Aug	–
25	NOCA	Newhalem, under powerlines	48.6730	121.2515	154	roadside	4	4-Aug	4-Aug
26	NOCA	SR 20, east of Newhalem VC	48.6732	121.2600	153	roadside	4	–	11-Aug
27	NOCA	Skagit River, Goodell Creek CG	48.6724	121.2665	145	riparian	2	–	11-Aug
28	NOCA	Monogram Lake Tr.	48.5598	121.3004	1511	meadow	1	11-Aug	–
29	OLYM	Wagonwheel Lake	47.5352	123.2971	1373	meadow	1	31-Aug	–
30	OLYM	Wagonwheel Lake	47.5330	123.2999	1320	lake edge	2	31-Aug	–
31	OLYM	Deer Park Rd.	47.9837	123.3165	857	roadside	4	1-Aug	–
32	OLYM	Cushman	47.5074	123.3204	244	lake edge	4	31-Aug	31-Aug
33	OLYM	Deer Park Rd.	48.0004	123.3206	605	roadside	4	1-Aug	–
34	OLYM	Grand Lake	47.8893	123.3451	1501	lake edge	2	22-Aug	–
35	OLYM	Badger Valley	47.9103	123.3467	1361	meadow	2	24-Aug	–
36	OLYM	Grand Lake	47.8899	123.3502	1535	meadow	1	–	23-Aug
37	OLYM	Moose Lake	47.8816	123.3507	1559	lake edge	1	–	23-Aug
38	OLYM	Between Moose and Gladys Lakes	47.8819	123.3536	1562	meadow	1	23-Aug	–
39	OLYM	Grand Lake	47.8981	123.3545	1670	open trail	1	22-Aug	–
40	OLYM	Gladys Lake	47.8781	123.3588	1669	meadow	1	5, 23-Aug	–
41	OLYM	Gladys Lake, above	47.8716	123.3591	1794	high rocky	1	5, 23-Aug	–
42	OLYM	Below Obstruction Pt.	47.9149	123.3621	1564	meadow	1	24-Aug	–
43	OLYM	Lillian Ridge Tr.	47.9116	123.3746	1934	meadow	1	4, 22-Aug	–
44	OLYM	Obstruction Pt.	47.9184	123.3831	1880	roadside	1	24-Aug	–
45	OLYM	PJ Lake and Tr.	47.9468	123.4150	1348	open trail	2	28-Aug	–
46	OLYM	Obstruction Pt. Rd., Waterhole SNOTEL	47.9450	123.4261	1545	forest	4	3-Jul, 20-Aug	–

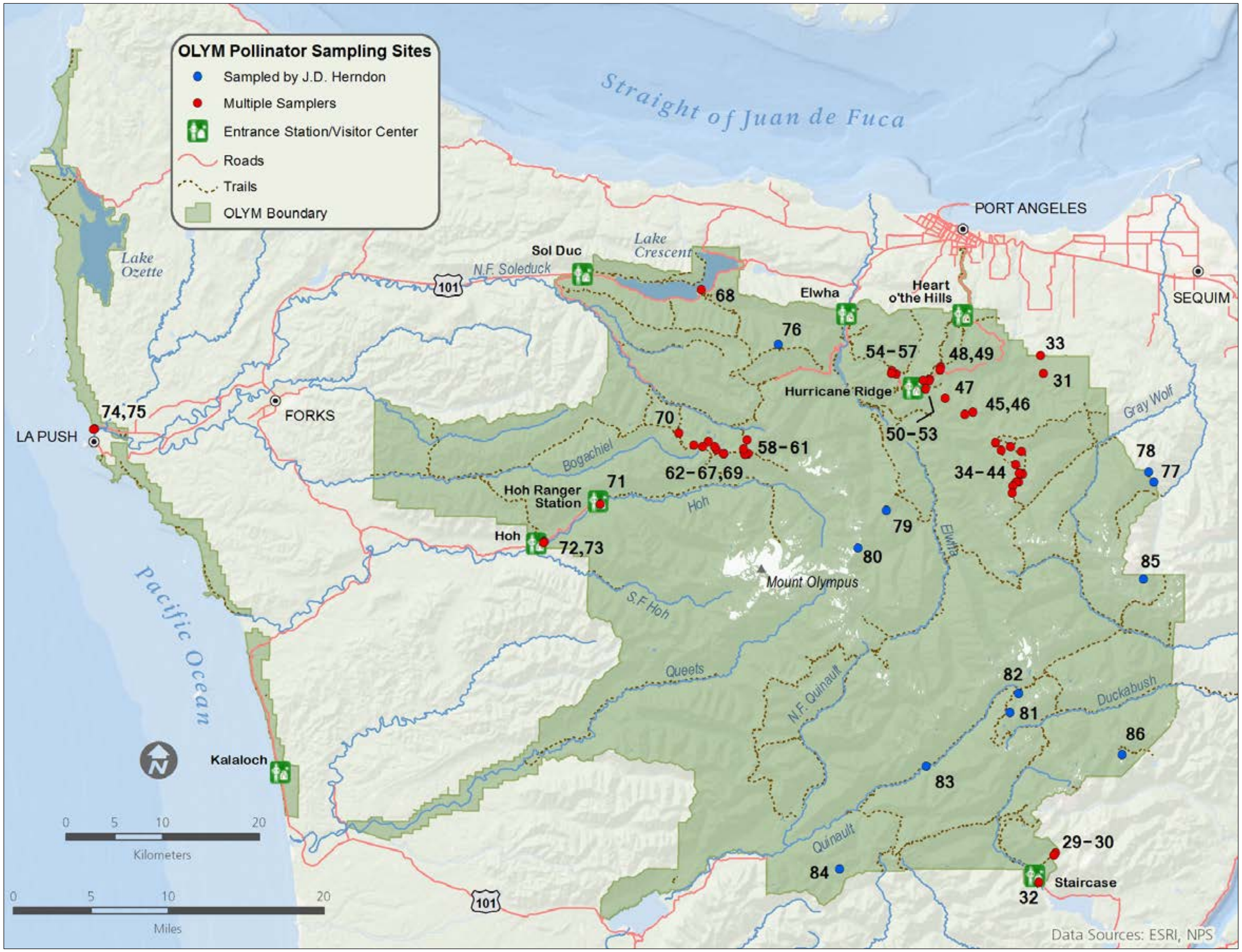

Figure 3. Approximate locations for pollinator sampling sites 29-86 (see Table 1) located in Olympic National Park. Red sites were visited primarily by J. Rykken and/or J. Freilich, J.D. Herndon; blue sites were visited only by J.D. Herndon.

Sampling techniques for pollinators

Because almost all bees and syrphid flies need to be examined with a microscope to make species level identifications, it was necessary to collect voucher specimens. The survey employed two methods for collecting insect pollinators: aerial insect nets and bee bowls. Nets allow active sampling of insects while they are in flight, feeding at flowers, or landed elsewhere. Netted specimens were killed with ethyl acetate in collecting jars. One net sample in this study represents a session (15 minutes to an hour) in one habitat type, in which multiple specimens were likely collected.

Bee bowls are passive traps that attract pollinators with color (mimicking floral blooms). Bee bowl transects were comprised of 30 plastic cups (Solo® 3.25 oz.) spaced 5 m apart. The cups were laid out in alternating colors: 10 blue, 10 yellow, and 10 white, and were filled approximately 3/4 full with a solution of 2 L water mixed with a few drops of non-scented dish-washing detergent to break the surface tension of the water. Bee bowl transects were generally set out by 10 am and kept open for six or more hours, ensuring that they were open during the warmest part of the day, when bees are most actively foraging. In Olympic, I placed small signs at either end of each transect, explaining the purpose of the bowls to help avoid disturbance by human visitors (Appendix B). At the end of the day, contents (i.e., drowned insects in soapy water) of all 30 bowls from each transect were poured into an 80 mm diameter tight-mesh kitchen strainer. The pooled insect catch from all bowls was then transferred from the strainer into a 4 oz. Whirl-Pak®. Because bee bowls must be left out in the field for several hours, this passive collecting method was used only in situations where I could revisit a site later in the day (e.g., on long one-day field trips or near basecamp). Thus many more net samples were collected overall than bee bowl samples.

With each sampling event (net or bowl), I recorded location and elevation with a GPS unit (Garmin® Oregon 600; datum WGS 84); general weather conditions; habitat description; and dominant plants in bloom. I also took photos of the site. For bee bowls, I recorded the time bowls were set out and picked up, and if there were any disturbances to the bowls (e.g., cups tipped over, missing, or otherwise disturbed).

I did much of the collecting on my own, but in both parks (especially North Cascades), I was fortunate to have assistance from park staff or volunteers at many of the sites. Thus, I will use the pronoun “we” in the rest of this report when referring to collecting activities.

Bee bowl sampling protocols were carefully documented so that they could be easily replicated by park staff, volunteers, or other researchers in the future, especially for pollinator monitoring.

Sample Processing and Specimen Identification

Specimens collected dry in nets were pinned or point-mounted during the field season at park facilities. Wet specimens from bee bowls were stored in 70% ethanol in Whirl-Paks® as explained above and brought back to the lab for further processing. Bees were washed in soapy water and then blown dry with a hand-held hairdryer according to methods described by Droege (2015). Once pinned and labeled with locality information, syrphid flies were sent to Michelle Locke at the American Museum of Natural History for identification. A subset of syrphid flies collected by J.D. Herndon was sent to Andrew Young at the Canadian National Collection of Insects, Arachnids and

Nematodes. Bumble bees (*Bombus* spp.) were identified primarily by J. Rykken, but more than one third of the total were identified (or identifications made by JR were confirmed) by Robbin Thorp from UC Davis, while he was visiting the Museum of Comparative Zoology at Harvard University. Most of the remainder of the bees were brought to the USDA Pollinating Insects—Biology Management and Systematics Research Unit in Logan, Utah, where species determinations were made by Terry Griswold, Harold Ikerd, James Strange, Jonathan Koch, Schuyler Burrows, and Brian Roznick. Even with expert help, many bees, especially in the genera *Lasioglossum*, *Sphecodes*, and *Nomada* could only be taken to genus, as species-level keys for many genera of solitary and parasitic bees in western North America are outdated or lacking altogether.

Specimen Deposition

Specimens from both parks were assigned Interior Collections Management System (ICMS) accession numbers (one number per park: NOCA-00933 and OLYM-00827), and unique catalog numbers. All bee specimens were deposited at the USDA-ARS National Pollinating Insect Collection in Logan, Utah; syrphid fly specimens were deposited at the National Museum of Natural History, Smithsonian Institution, Washington, D.C. A synoptic set of most bee and fly species were kept by each park.

Data Analysis

All specimen, sample, and associated data were entered into a Microsoft Access relational database; graphs were created with Microsoft Excel. I used the diversity software EstimateS version 9.1.0 (Colwell 2013) to generate sample-based rarefaction curves for comparing expected numbers of pollinator species collected in high meadows and rocky areas at or above tree line versus forest openings below tree line as a function of sample number. These curves were generated with data from actual collections in both habitats, but I was also able to extrapolate one of the curves (for lower elevation openings) to match the larger sample size for higher elevation meadows, using a technique described by Colwell et al. (2012). The slopes of these rarefaction curves also indicate how much more sampling is required to capture the full diversity of each habitat.

Outreach and Education

I used a variety of methods to educate park staff, visitors, and citizen scientists about native pollinator diversity, ecology, and health in the parks. These included public engagement, field work with volunteers and citizen scientists, creating and displaying informational signs, delivering presentations, and creating web content.

Results

A total of 298 syrphid flies and 1,890 bees were collected across both North Cascades and Olympic National Parks between June 28th and September 17th, 2014 (Appendix A). These included 57 syrphid fly taxa (comprising 29 genera, including 47 identified species, 6 species groups, and 4 genus-level taxa) and 89 bee taxa (comprising 20 genera, including 60 identified species, 19 morphospecies, 2 species groups, and 8 genus or subgenus-level taxa).

Sampling effort was about twice as intense in Olympic as North Cascades (12 bee bowl samples and 60 net samples in OLYM versus 7 bee bowl samples and 26 net samples in NOCA), and not surprisingly, many more pollinator specimens and taxa were collected overall in Olympic than in North Cascades. However, the proportions of bees and flies—both in richness and abundance—collected in each park were similar (Figure 4).

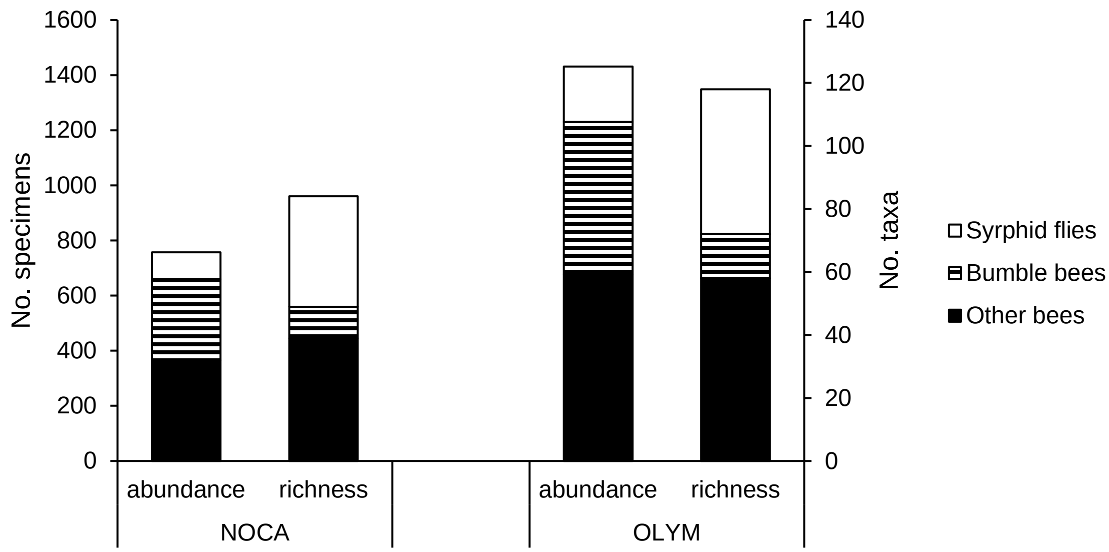

Figure 4. Abundance and taxa richness of syrphid flies, bumble bees (*Bombus*), and other bees collected in North Cascades and Olympic. Note left axis goes with abundance column and right axis goes with richness column.

Patterns of generic and species richness were fairly similar across the two parks. *Sphaerophoria* was the most diverse syrphid fly genus collected in both parks (Figure 5), although many specimens could only be identified down to species group. Among bees, bumble bees (*Bombus*), mason bees (*Osmia*), and the sweat bee genus *Lasioglossum* were the most diverse genera in both parks (Figure 6). Undoubtedly, many more *Lasioglossum* species remain unidentified. North Cascades and Olympic shared 24 species/taxa of syrphid flies, representing 42% of their total combined diversity (Figure 5; Appendix A). Among bees, 32 species were shared between parks, or 36% of the total diversity (Figure 6; Appendix A). Each park had several genera (represented by one or two species) that were collected only in that park, but Olympic had more unique genera of both syrphid flies and bees than did North Cascades (Figures 5 and 6).

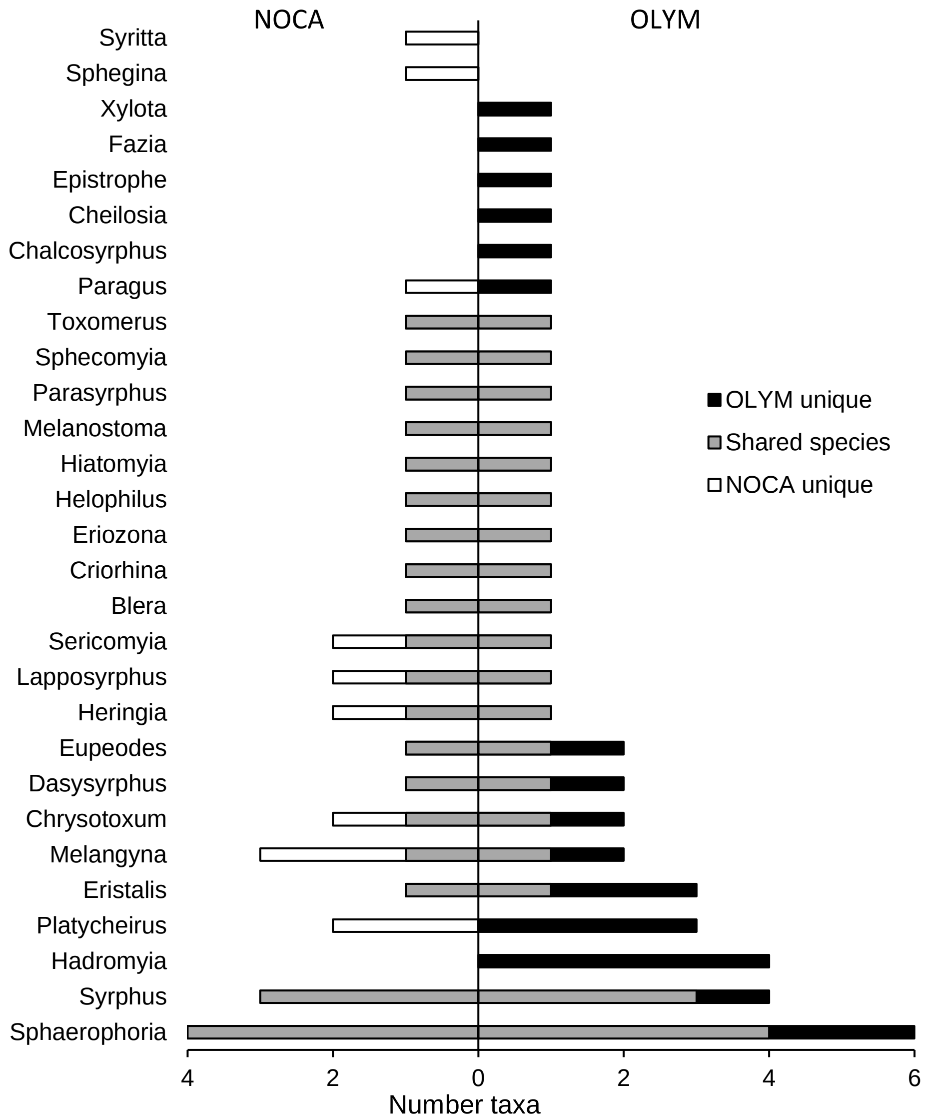

Figure 5. Taxa richness (including identified species, species groups, and genus-level taxa) among 29 syrphid fly genera collected in North Cascades (left bars) and Olympic (right bars). For each genus, color coding indicates unique species to each park, and species shared between both parks.

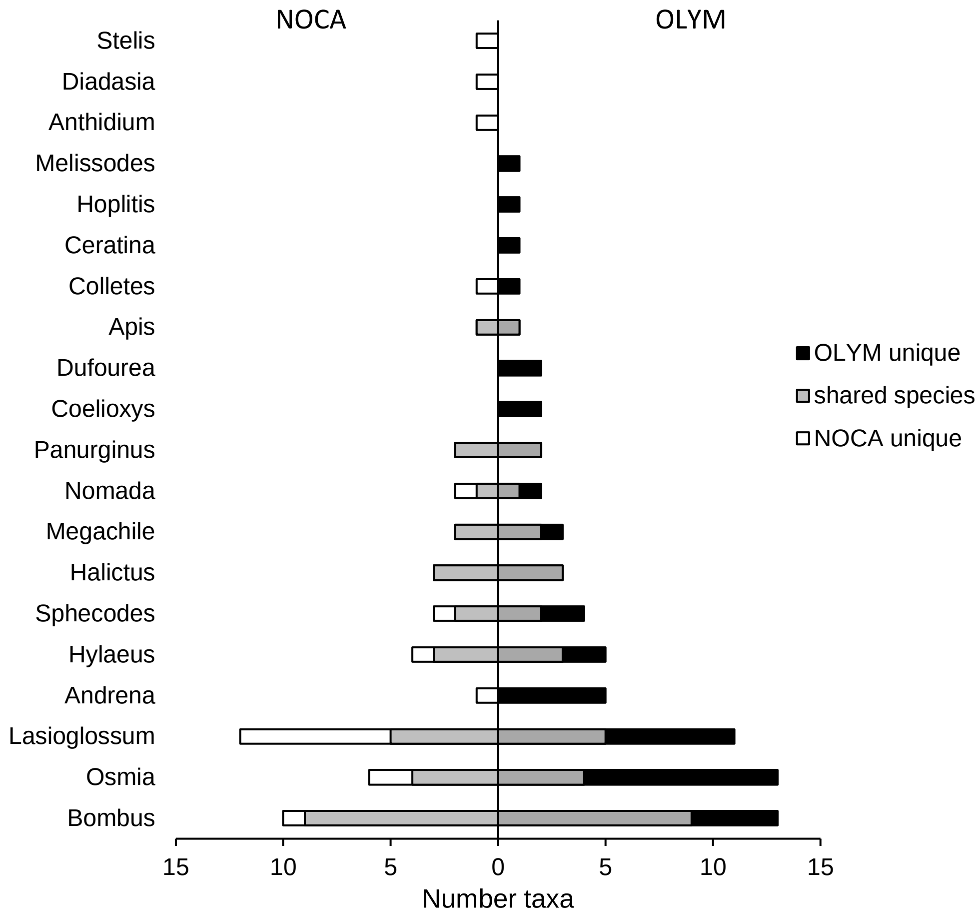

Figure 6. Taxa richness (including identified species, morphospecies, species groups, and genus-level taxa) among 20 bee genera collected in North Cascades (left bars) and Olympic (right bars). For each genus, color coding indicates unique species to each park, and species shared between both parks.

Bumble bees (genus *Bombus*) were the most commonly collected pollinator in both parks, comprising 14 species overall, and 847 specimens (45% of all the bees). Also very common in both parks were sweat bees in the hyper-diverse and taxonomically challenging genus *Lasioglossum* (30% of the bee total; but most were identified only to subgenus or genus), and in the genus *Halictus*, which comprised only three species but made up 11% of the total bee catch.

Among the bumble bees, the most commonly collected species in North Cascades were *Bombus sylvicola, B. bifarius, and B. flavifrons* (115, 40, and 37 specimens, respectively), and in Olympic, there were four *Bombus* species with more than 30 specimens: *B. mixtus*, *B. flavifrons*, *B. sylvicola*, and *B. flavidus* (148, 99, 95, and 91 specimens, respectively). The sweat bee, *Halictus virgatellus* was also very abundant in both parks (44 in North Cascades, 88 in Olympic). Combined, these few abundant species in each park made up 36% of the entire bee catch in North Cascades, and 42% of the total in Olympic. By far the most abundant syrphid fly collected in Olympic was *Sericomyia chalcopyga* (47 specimens; 23% of total catch), while in North Cascades, the species complex *Sphaerophoria abbreviata*/*asymmetrica*/*philanthus* was most abundant (20 specimens, 21% of total catch). At the other end of the spectrum, 64 taxa (44% of all bee and syrphid fly taxa combined) were represented by just one or two individuals.

Net samples outnumbered bee bowl samples by 4.5 to 1 across the two parks, but collected only 1.5 times the number of specimens. More pollinator taxa were sampled with nets than with bowls (Figure 7). The difference in the number of taxa collected between the two methods was much greater for syrphid flies than for bees; almost four times as many syrphid taxa were collected with nets as with bowls, and very few syrphid taxa were shared between the two methods (Figure 7).

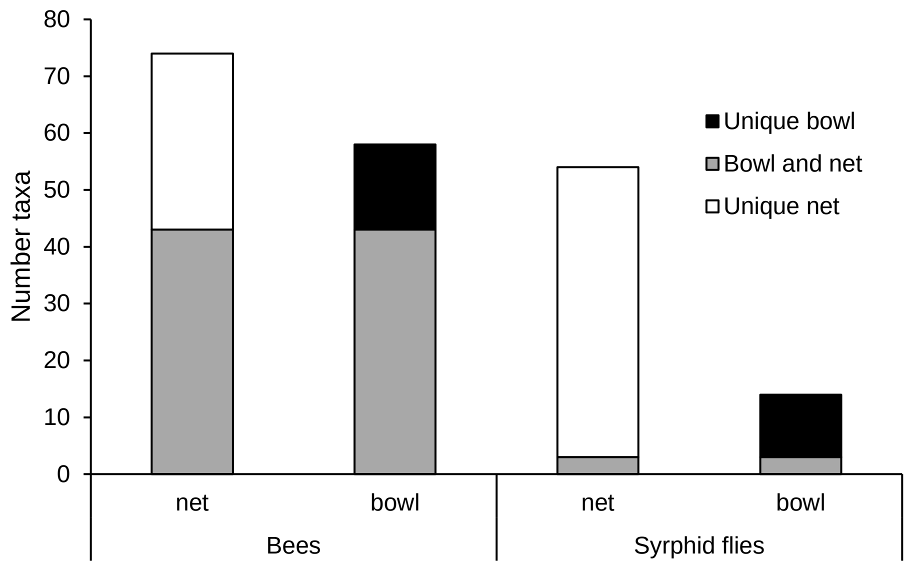

Figure 7. Comparison of collecting methods for bees and syrphid flies in North Cascades and Olympic. Gray areas in paired columns represent shared species collected by both bowl and net.

Sampling effort was not distributed evenly among habitats (Table 2). Meadows, mostly subalpine, made up 43% of the samples, and collected 55% of the total specimens. There was a significant positive relationship between sampling effort in a habitat and the number of taxa collected (Figure 8). Relative to tree line, high meadows and rocky habitats above tree line were sampled about twice as frequently as forest openings below tree line; the higher habitats yielded almost 2.4 times as many specimens, but only 1.2 times as many taxa (Table 2). Low to mid-elevation samples were under-represented (Figure 9). Across the two parks, just 26 samples were collected between 1 and 1,200 m, (yielding 250 specimens) while 79 samples were collected between 1,274 and 2,023 m (1,938 specimens). Samples taken under 1,200 m made up about one third of all samples in North Cascades, but only about one fifth of the samples in Olympic (Figure 9).

Table 2. Summary of habitats sampled for pollinators in North Cascades and Olympic, including number of samples, elevation range of samples, and abundance and taxa richness (including all identified species, morphospecies, species groups, and genus-level identifications) of pollinators in each habitat. Samples (n=105) are categorized in two ways: by general habitat type ("Habitat"); and by habitat relative to tree line ("Tree line"), with disturbed habitats in a separate category (numbers in parentheses refer to Tree line categories in Table 1).

Habitat	Tree line	# Samples	Elevation (m)	# Specimens	# Taxa
Forest	–	6	425-1545	41	16
High rocky	–	5	1424-1844	48	12
Lake edge	–	10	938-1745	171	38
Lawn	–	2	215-228	27	11
Meadow	–	45	1154-2023	1197	111
Ocean beach	–	2	1	13	8
Open trail	–	15	725-1808	243	54
Riparian	–	2	121-145	34	13
Roadside	–	18	5-1880	414	63
–	High meadow/rocky (1)	55	1373-2023	1217	103
–	Forest opening (2)	26	1-1808	510	89
–	Closed forest (3)	5	425-1470	20	11
–	Disturbed habitat (4)	20	153-1880	441	66

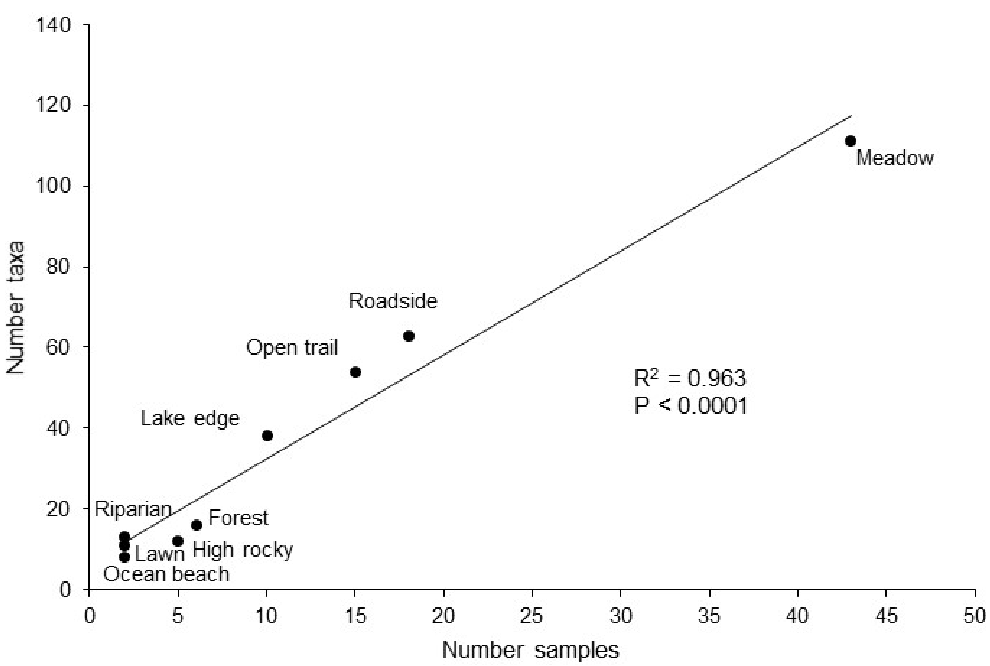

Figure 8. The relationship between sampling effort and the number of taxa collected across different habitats in North Cascades and Olympic. N = 9 habitats. The fitted regression line is shown.

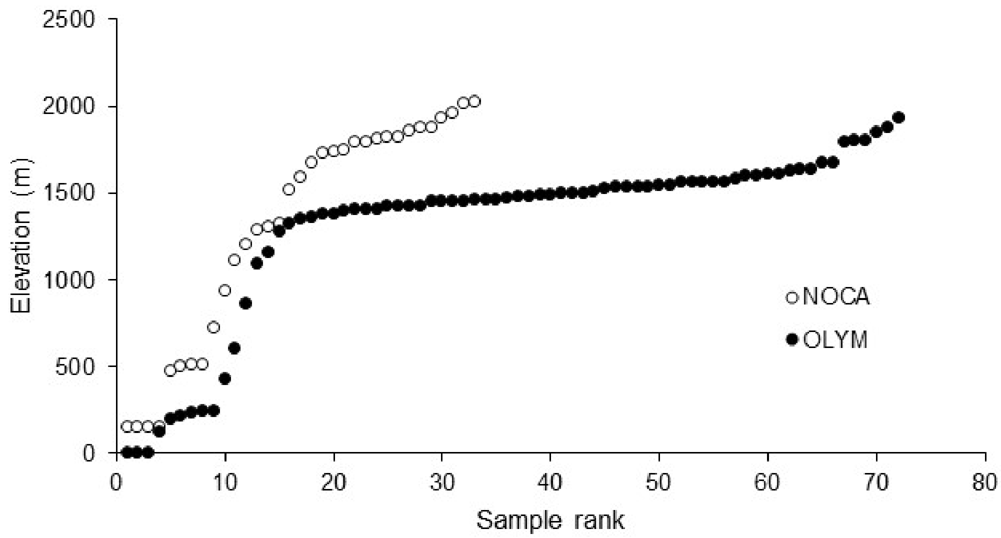

Figure 9. Distribution of pollinator sampling events from North Cascades and Olympic along elevation gradients. Each dot represents one pollinator sample (net or bee bowl).

Within each park, samples from habitats at or above tree line yielded more taxa (collectively) than samples from forest openings below tree line (Figure 10). Habitats above and below tree line within a park shared 36% of their combined pollinator taxa in North Cascades, and 43% of their combined taxa in Olympic (Figure 10). Comparing habitats only above tree line between the two parks (i.e., right hand columns of each pair in Figure 10) showed a similarity of 35% shared species of the combined total.

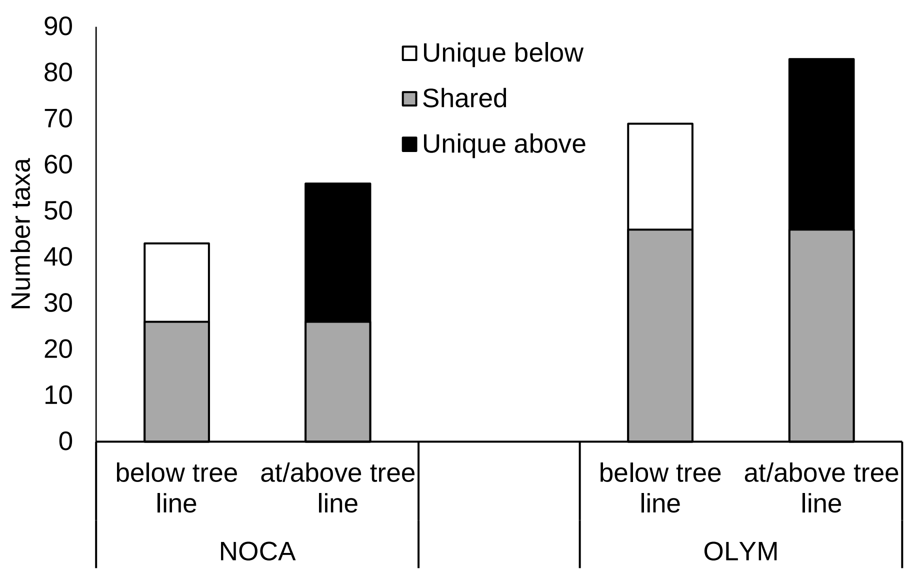

Figure 10. Comparison of taxa richness between habitats at or above tree line versus forest openings below tree line in North Cascades and Olympic. Grey portions of paired bars indicate shared taxa, collected both above and below tree line in that park.

Rarefaction curves indicated that additional sampling in forest openings below tree line could yield more taxa than were found in high meadows and rocky areas for the equivalent number of samples, although overlapping confidence intervals suggested no significant difference in richness between the habitat types (Figure 11). The upward trajectories of both of the rarefaction curves suggest that additional sampling would yield many more species in both habitats.

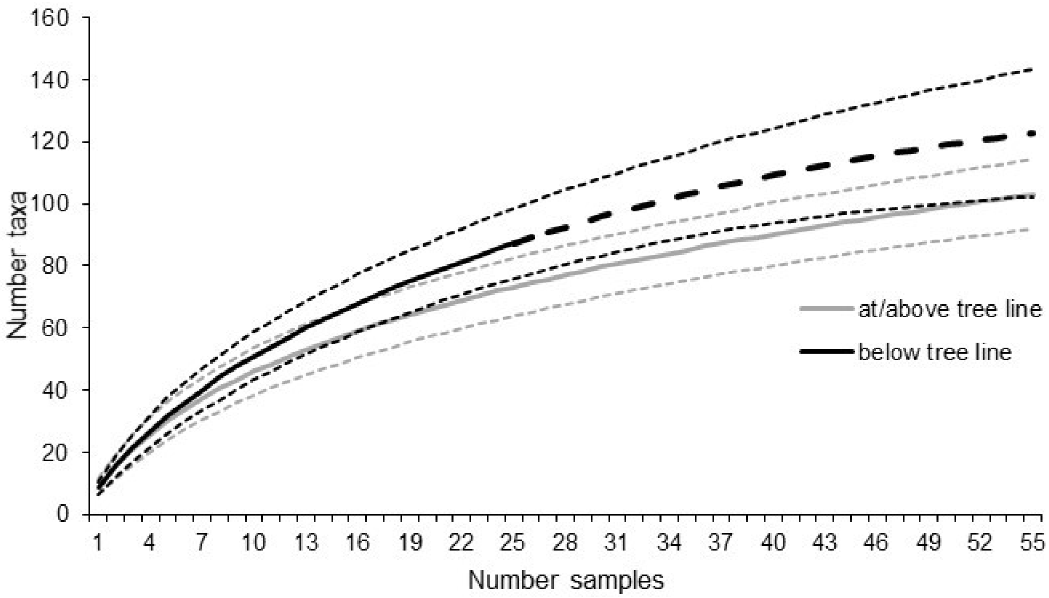

Figure 11. Rarefaction curves (bounded above and below with dotted lines representing 95% confidence intervals) for total numbers of pollinator taxa collected in meadows/rocky areas at or above tree line and forest openings below tree line in North Cascades and Olympic. Extrapolated rarefaction values (beyond the 26 samples actually collected) for the below tree line curve are indicated by a black dashed line (see Methods for explanation).

I conducted several outreach activities in August 2014:

1) engaged with park visitors while doing fieldwork, explaining the focus and importance of the research and talking about pollinators
2) created and then displayed informational signs (Appendix B) near transects of bee bowls to explain their purpose, and the purpose of the study
3) participated in the BioBlitz at North Cascades by spending time in the field with citizen scientists to document pollinators
4) co-hosted (with J. Freilich from Olympic) a "show-and-tell" session inside the Hurricane Ridge visitor center with a microscope and pinned specimens to give visitors a magnified view of the diversity of bees and syrphid flies, as well as answering questions and sharing information about pollinators
5) presented day and evening slide programs for NPS staff and visitors about pollinator diversity, natural history, conservation concerns, monitoring strategies, and the importance of pollinator research in national parks

Follow-up activities, concluded after the 2014 field season, included taking high resolution stacked macro images of 42 bee and syrphid fly species, and producing summary articles, photo galleries, and pollinator species lists for the North Coast and Cascades Research Learning Center website (https://www.nps.gov/rlc/northcoastcascades/pollinators.htm).

Discussion

Pollinator diversity

Bumble Bees (Bombus Species)

Bumble bees made up almost half (45%) of the bees in the survey. Bumble bees are well-adapted to the adverse climates of high latitudes and altitudes because of their comparatively large body size, long, dense pelage, and ability to warm their thoracic muscles through "shivering" which allows them to fly at lower temperatures than most insects (Kearns and Thomson 2001). Bumble bees are typically generalist foragers with relatively long tongues and these traits are also beneficial in alpine systems where the flowering season is compressed. Only the newly-mated queens from bumble bee colonies overwinter, the rest of the colony (the founding queen, workers, males) perish at the end of the growing season.

In addition to social bumble bees, we documented two species of social parasites, *Bombus insularis* (a new record for North Cascades) and *B. flavidus*. These bees do not build nests of their own, nor do they have a worker caste. Instead, a female bee will invade the nest of a host (social) species, kill the queen, and usurp the nest, so that host workers will raise her young. Thus, the female bees do not collect pollen and nectar for the nest, and have no special structures on their legs (corbiculae) for pollen transport. Known hosts for *Bombus insularis* include *B. flavifrons* and *B. appositus*, and suspected hosts for *B. flavidus* include *B. occidentalis*, *B. rufocinctus*, and *B. appositus* (Williams et al. 2014).

Bumble bees were previously surveyed in both parks (Strange et al. 2013 and historical records), but this study documented three new vouchered species records for North Cascades (*Bombus appositus*, *B. insularis*, and *B. vandykei*), and two new vouchered records for Olympic (*Bombus appositus* and *B. rufocinctus*).

Other Bees

World-wide, the greatest bee diversity is found among solitary nesting species and social bees other than *Bombus* (Michener 2007). Although bumble bees dominated many of the habitats sampled in this study, over half the pollinators we collected in both parks were solitary, cuckoo, or other social bees, from all habitats and elevations. These comprised bees in five families including soil-nesting mining bees (e.g., *Andrena*, *Panurginus*, *Halictus*, *Lasioglossum*, *Colletes*), stem and twig-nesting small carpenter bees (*Ceratina*) and masked bees (*Hylaeus*), leafcutter bees (*Megachile*), other mason bees (*Hoplitis*, *Osmia*), and several genera of cuckoo or cleptoparasitic bees (*Nomada*, *Sphecodes*, *Coelioxys*, *Stelis*).

Most of these bees are solitary, with each female building and provisioning her own nest, although some species nest in aggregations. The two sweat bee genera, *Halictus* and *Lasioglossum*, include many social species, with a division of labor among generations. Cuckoo bees, also called cleptoparasites, lay their eggs in the nest of a host solitary bee. After the egg is deposited in an individual nest cell, the developing cuckoo larva kills the host egg or larva and eats their nectar and pollen provisions. The cuckoo lifestyle is not uncommon among bees; a summary of surveys conducted in various regions of the U.S. suggests that parasitic bees make up between 10 and 25% of bee communities (Wcislo 1987). Because their success depends on healthy populations of host bees, cleptoparasites can serve as good indicators of the overall health of bee communities for pollinator monitoring programs (Sheffield et al 2013).

Syrphid Flies (Syrphidae)

Syrphid flies made up just 13-14% of the pollinator catch in both parks, but 40-42% of the total taxon diversity. Generic diversity for syrphid flies was considerably higher than for bees in both parks. We collected syrphid flies in two subfamilies, Syrphinae and Eristalinae. Adults of both subfamilies visit flowers to feed on pollen and nectar, and thus effect pollination. Their mobile larvae, however, lead very different lives. Larval Syrphinae are predators, feeding mainly on aphids and other soft-bodied homopterans, and some have been used for biocontrol of aphid pests in agriculture. Larval Eristalinae are more varied in their habits. *Cheilosia* larvae feed on fungi or plant tissue, while *Eristalis* and *Sericomyia* larvae live in stagnant, organic water (Vockeroth and Thompson 1987). As adults, syrphid flies are quite conspicuous while feeding on flowers, and their mimicry of stinging bees and wasps is believed to be a defensive strategy against predators (Vockeroth and Thompson 1987).

The contribution of syrphid flies as pollinators has received less attention than bees, but one study compared pollination performance between a relatively hairless *Hylaeus* bee and a syrphid fly, and found the bee to be much more efficient at transferring pollen, even though the two taxa made similar numbers of visits to the plants (Bischoff 2013). Thus, per-visit effectiveness is important to consider in addition to visitation rate when comparing pollinator contributions. Flower fly species also likely vary in their pollen transfer effectiveness, with hairy species such as *Eristalis* or *Hadromyia* carrying more pollen than relatively smooth flies like *Toxomerus*.

Taxonomic Challenges and Resources

Both syrphid flies and bees presented significant taxonomic challenges. The family Syrphidae is represented by more than 870 Nearctic species. Species-level identifications require considerable expertise and I was fortunate to have the assistance of two syrphid specialists, Michelle Locke and Andrew Young, to make species determinations for 85% of the 298 syrphid flies. The remainder of the flies were identified to genus or multispecies-group because of the poor physical condition or sex of the specimens (some species are described only from male genitalia, thus females cannot be identified).

The bees, comprising six families in the Nearctic, include more than 3,600 described species, with several hundred additional species still undescribed. Diversity is far higher in the western U.S. than in the east, and while the bumble bees (*Bombus*) are relatively well known, the taxonomy of many other western bees is extremely challenging, including the hyper-diverse sweat bee genus *Lasioglossum*, and parasitic genera such as *Sphecodes* and *Nomada*. For numerous western bee groups, there are no up-to-date taxonomic keys available, thus the only way to make accurate identifications is with the help of reference collections (and specialist expertise) at various institutions. We collected 1,043 non-*Bombus* bees across both parks, and with the generous assistance of many taxonomists at the USDA Pollinating Insects—Biology Management and Systematics Research Unit in Logan, UT, I identified almost half (423) of those to valid species. As with the syrphid flies, the remainder of the bees were identified to species groups, morphospecies, or genus level.

All bee specimens were deposited in the USDA-ARS National Pollinating Insect Collection in Logan, UT, and thus will serve as a valuable reference collection to support further pollinator work in Pacific Northwest parks. The syrphid flies were deposited in the National Museum of Natural History at the Smithsonian Institution in Washington, D.C., contributing to a globally significant syrphid fly collection, while also providing an invaluable resource for future pollinator work in the northwest.

Pollinator Distributions Across Elevation Gradients

While some bees and syrphid flies appeared to respond to elevation gradients, bumble bee species richness did not differ between habitats above and below tree line. Bumble bees comprised more than half (54%) of the total bee abundance in lower habitats, versus 37% of total bee abundance above tree line. As both Olympic and North Cascades are northern parks, it is not surprising that the diversity and abundance of bumble bees is relatively high even at lower elevations. Moving southwards into California, some of these species are confined to higher elevations (Thorp et al. 1983).

A few individual species were abundant enough that they could be more reliably associated with higher elevations. The bumble bee *Bombus sylvicola* occurred between 1,113 and 2,023 m in both parks, and it is known to be a boreal/alpine species; in California, it occurs primarily above 2,400 m (Williams et al. 2014). The tiny masked bee, *Hylaeus annulatus*, was far less abundant but occurred at 17 sites within the same elevation range as *B. sylvicola.* Among syrphid flies, *Sericomyia chalcopyga*, *Blera scitula*, *Syrphus torvus*, and the *Sphaerophoria abbreviata/asymmetrica* group were also restricted to higher elevations in this study (and occurred in at least 7 samples). The genus *Platycheirus* is primarily a boreal northern/high elevation genus (Vockeroth 1992), but we found too few specimens of each *Platycheirus* species to conclude anything definitive about their distribution in the parks (all individuals occurred between 1,322 and 1,799 m).

Many of the common species we collected occurred across a broad elevation range, for example, the syrphid flies, *Eriozona laxus* (1-2,010 m), and the cosmopolitan *Syrphus ribesii* (504-2,010m). All of the commonly collected sweat bee species in the genus *Halictus* were also widespread across elevations (145-1,934 m), as were half of the bumble bees (*Bombus bifarius*, *B. flavidus*, *B. flavifrons*, *B. insularis*, *B. mixtus*, *B. sitkensis*, and *B. vandykei*).

Given the limitations and biases of this study (i.e., short duration, primarily unstandardized sampling techniques (net collecting), relatively small samples, and unequal sampling intensities among habitats and parks), strong distributional patterns would be difficult to discern even if present. Based on extrapolation of the lower habitat samples it appeared that if sampling effort was equal above and below tree line, habitats above tree line may be somewhat less diverse than lower elevation openings. However, I observed that above tree line habitats had a higher proportion of unique species than the lower elevation openings in both parks. It is worth noting that many of the unique species either above or below tree line were represented by just one or a few individuals, so these patterns may be partially an artifact of under-sampling.

Efficacy of Sampling Methods

All insect collecting methods have benefits and biases, and inventories are best accomplished using a combination of active and passive (i.e., trapping) approaches (Grundel et al. 2007). Net-collecting is the simplest method, and in this survey was used in all habitats, especially in remote sites. The drawbacks of netting include that it provides only a snapshot of what is active at the time of sampling, it is not easily repeatable, and, depending on the skill of the sampler, there may be a bias towards more obvious, larger, and/or slower insects. Pan-trapping (in this case, "bee bowls") is a relatively simple passive collecting technique, and complements net-collecting by allowing a longer window of sampling (which can result in relatively high capture rates), and is also easily repeatable by anyone, regardless of skill. On the negative side, bee bowls also have biases in their catch (generally towards smaller insects), and they are less ideal for remote sites because they must be set out and then collected several hours later, all the while vulnerable to disturbance from curious wildlife or park visitors. We sampled with bee bowls primarily in more accessible sites, such as along roadsides, trails, and river gravel bars, and in alpine meadows only when working from a remote basecamp.

Grundel et al. (2007) found that the most common species in their bee surveys were collected by both nets and bee bowls, but uncommon species were often only collected with one method or the other, and thus concluded that both netting and pan-trapping were necessary for a complete survey of diversity at their sites. In the Olympic and North Cascades surveys, there was much more redundancy in bee species between the two collecting methods than in syrphid fly species, suggesting that for syrphid flies especially, using both active and passive sampling techniques improves detection rates. Among the rarely collected taxa, of 64 pollinator species for which only one or two specimens were collected overall, 26 species were collected only in bee bowls, and 47 species only with nets.

Species of Concern

We collected five specimens of *Bombus occidentalis* in Olympic, a species known to be in dramatic decline throughout the Pacific Northwest (Evans et al. 2008, Colla and Ratti 2010, Cameron et al. 2011). *Bombus occidentalis* was common on the west coast of the U.S. until the mid-1990's, after which sightings dropped precipitously, despite intensive surveys (Cameron et al. 2011). It is hypothesized that the primary cause for its decline was infection by a microsporidian fungus, *Nosema bombi* (Evans et al. 2008). In the late 1990's, *B. occidentalis* queens were sent to Europe for commercial rearing, where it is thought cultured bees were exposed to exotic pathogens before being shipped back to the United States (Evans et al. 2008). The pathogen from the cultured bumble bees working in greenhouses may have spilled over into surrounding wild bee populations from shared use of flowers (Colla et al. 2006). However, this hypothesis is not scientifically supported and has been debated by some (Cameron et al. 2016).

I collected *B. occidentalis* specimens in Badger and Grand Valleys, in the northeast section of the park, and J.D. Herndon collected one specimen at Heather Lake in the southeastern region of the park. Koch et al. (2013) documented *B. occidentalis* in Royal Basin, and more recently, near

Obstruction Point (pers. comm). These collections point to Olympic being a potential refugium for this at-risk species.

Non-native pollinators collected in the two parks included three common and cosmopolitan syrphid flies (*Eristalis arbustorum*, *Eristalis tenax*, and *Syritta pipiens*) and two bees (the honey bee, *Apis mellifera*, and the sweat bee, *Lasioglossum zonulum*).

Threats to Pollinators and the Need for Monitoring

Insect pollinators are intimately linked to their host plants in complex ecological networks, and thus they may serve as effective indicators of ecosystem integrity. One of the most urgent threats facing montane ecosystems in protected areas is climate change. Species in environments with compressed growing seasons and extreme climates have evolved a variety of complementary physiological adaptations and behaviors to survive such conditions, and thus responses to changes in temperature and moisture may be complex and difficult to predict (Danks 2004, Miller-Struttmann et al. 2015). A predicted response is that host plants and their pollinators will respond to climate change at different rates, so that the timing of flowering will no longer coincide with pollinator emergence, particularly detrimental in climates with shorter growing seasons, or for bees with a narrower range of host plants (Bartomeus et al. 2011, Iler et al. 2013). Climate change may also drive shifts in geographical ranges of pollinators, especially northwards in latitude or upwards in elevation. For instance, Kerr et al. (2015) showed that southern range limits for many northern bumble bee species in Europe and North America have shifted northwards (compressing the overall range), and southern species have moved upward in elevation over the last century. As the body of research looking at effects of climate change on pollinator distribution and diversity grows, especially in alpine and northern ecosystems, one common conclusion is that structured survey and monitoring on both local and global scales is imperative to track pollinator responses.

One of the objectives for this project was to develop a set of detailed sampling protocols as well as suggest locations for a network of permanent sites for future monitoring, as has been done for the Cascade Butterfly Project (Rochefort 2017, Rochefort and McLaughlin 2017). To achieve this goal, I provide sampling protocols that will enable consistent, replicated pollinator sampling by park staff, citizen scientists, or other researchers in a monitoring program (Appendix B). Site selection will be an ongoing process. In North Cascades, collaborating with the ongoing Cascade Butterfly Project would be ideal, and sites would include Easy Pass, Maple Pass, and Cascade Pass, all of which yielded a diversity of pollinators. Because we did not sample many lower elevation sites in North Cascades, more sampling effort is needed to identify appropriate comparison sites. In Olympic, high elevation sampling sites could be established in Seven Lakes Basin, Grand Valley, Royal Basin, and/or Hurricane Ridge. All of these sites have high visitor use, which can pose a heightened risk of disturbance to bee bowl transects that will be left unattended for 8 or more hours, however, visibility to visitors also affords an opportunity for outreach and educations. For instance, signage that explains the purpose of the bee bowls and pollinator monitoring can be posted with the bee bowl transects (see Appendix B).

In addition to selecting sampling locations and developing sampling protocols, for a monitoring program to be successful it will need to be statistically robust with enough power to detect relatively subtle trends in pollinator abundance or diversity over time. The number of sites, timing and intervals of sampling, and suite of metrics to measure are decisions that will require careful consideration and planning (Rykken and Farrell 2013*a*). The data collected in this initial survey will help inform these decisions by providing information on catch rates for bee bowl transects in different habitats.

Educating Park Staff and Visitors about Pollinators

An important goal of the survey was to foster awareness and appreciation of insect pollinators to park staff and visitors. North Cascades and Olympic boast an impressive diversity of vertebrate fauna that visitors come to view and learn about, however, as in most national parks, the far vaster diversity of the "microwilderness" has thus far received little attention (Rykken and Farrell 2013*b*). In large part, this is because invertebrate wildlife is tiny and challenging to view, and also because accessible information is scarce. Additionally, insects and other invertebrates often evoke feelings of revulsion and/or fear among the general public, and a bee's potential to sting a visitor may receive more attention than its role as a pollinator in a complex ecosystem.

Engaging with the public at the visitor center and providing access to a microscope so that people could see the fascinating and beautiful attributes of pollinators up close, proved to be a successful way to generate curiosity and enthusiasm about Olympic's "other fur bearers" (i.e., bumble bees) and their relatives. Photo-rich and 3-D presentations to the general public at the North Cascades Visitor Center in Newhalem and in the amphitheater at Heart o' the Hills campground near Port Angeles were well received by participants. The ongoing BioBlitz at North Cascades presented several opportunities for engaging with volunteers in the field. To reach a wider audience, I am developing content including pollinator articles, photo galleries, and species lists for the North Coast and Cascades Research Learning Center website.

Conclusions and Recommendations

Four weeks of intensive sampling towards the end of the growing season in an unusually hot and dry year were far from sufficient to complete a comprehensive survey of pollinators in North Cascades and Olympic. It was necessary to focus on higher elevation sites to find a diversity of host plants in bloom, as flowers at lower elevations had mostly gone to seed, with the notable exception of roadside plants. Rather than implement a structured, standardized sampling design based on passive trapping (i.e., bee bowls) that would allow sample-based community analysis, we spent much of our time roaming far up into the high country to find patches of pollinators, and thus relied extensively on active net collecting. Acknowledging these biases towards higher elevation sites, and more opportunistic samples, the survey did successfully begin to explore patterns of pollinator diversity along elevation gradients.

Clearly, there is still much work to be done in North Cascades and Olympic in order to gain a more comprehensive understanding of the current pollinator fauna and how it is distributed along various environmental gradients, and also to prepare for monitoring changes in diversity, species composition, abundance, phenology, and range shifts over time.

Future priorities should include:

1) Continue inventory work in Olympic and North Cascades for pollinators, especially earlier in the growing season and at lower elevations. Expand inventories in both parks to get better coverage and include a greater variety of habitats, including the Stehekin area in Lake Chelan NRA, and the north unit of North Cascades NP. In Olympic, there are many lower elevation areas and habitats of interest, including the Ozette prairies and open gravel bars along some of the larger rivers draining to the west (e.g., Hoh, Queets, Bogachiel, Quinault). Expanding our knowledge of the lower elevation fauna will also help determine the uniqueness of fauna in high elevation meadow habitats.
2) Expand pollinator inventory work to include Mount Rainier NP (also included in the Cascades Butterfly Project).
3) In collaboration with the USDA Pollinating Insects—Biology Management and Systematics Research Unit in Logan, UT, continue to inventory and monitor populations of *Bombus occidentalis*, the western bumble bee, in Olympic National Park, and search for *B. occidentalis* populations in other northwestern parks.
4) Work toward establishing a network of mid-elevation and high elevation meadow sites that can serve as long-term pollinator monitoring plots. Combine efforts with the Cascades Butterfly Project in North Cascades and Mount Rainier where possible.
5) Build on pollinator outreach and education materials for parks in the North Coast and Cascades Network with products such as field guides, visitor center displays, or multi-media web content (for an example in Denali National Park and Preserve, see: http://nps.maps.arcgis.com/apps/MapJournal/index.html?appid=ce8f10facd424e45983830bcf6e88ba9).

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