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



ON THE COVER

Row one (left to right): *Bombus* on *Arnica* (NOCA), subalpine meadow on McAlester Trail (NOCA); Row two: bee bowl on Obstruction Point Rd. (OLYM), *B. occidentalis* on thistle (*Cirsium*; OLYM); Row three: Fireweed (*Chamerion*) above Ross Lake (NOCA), J. Freilich and J.D. Herndon collecting bees in OLYM

All photos by Jessica Rykken

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

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May 2018

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Rykken, J. 2018. Measuring and monitoring pollinator diversity along elevation gradients in Olympic and North Cascades National Parks. Natural Resource Report NPS/NOCA/NRR—2018/1634. National Park Service, Fort Collins, Colorado.

NPS 149/145006, 168/145006, May 2018

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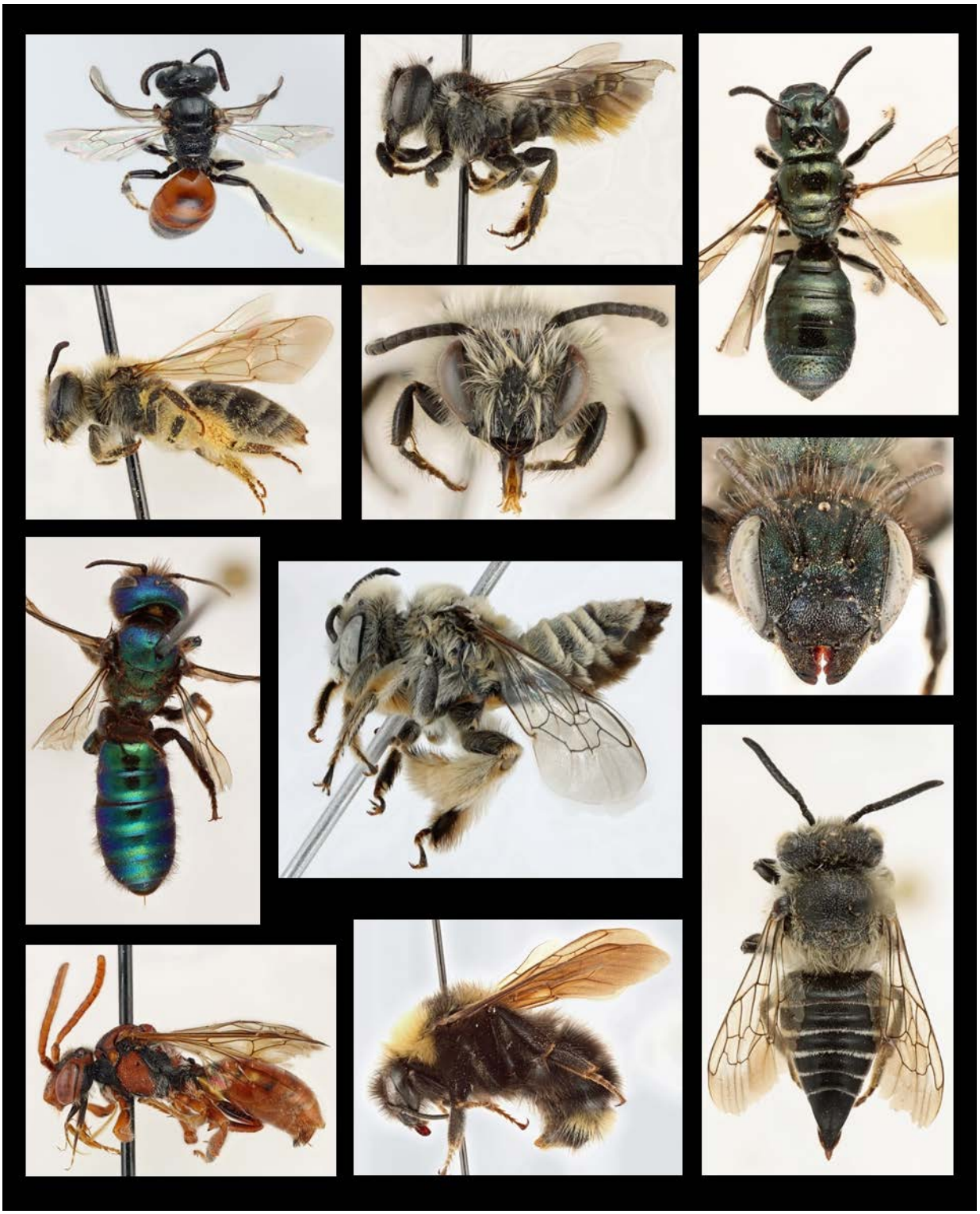
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Table 1. Location, habitat type, and collecting dates and methods for 86 pollinator sampling sites in North Cascades and Olympic in 2014. 6

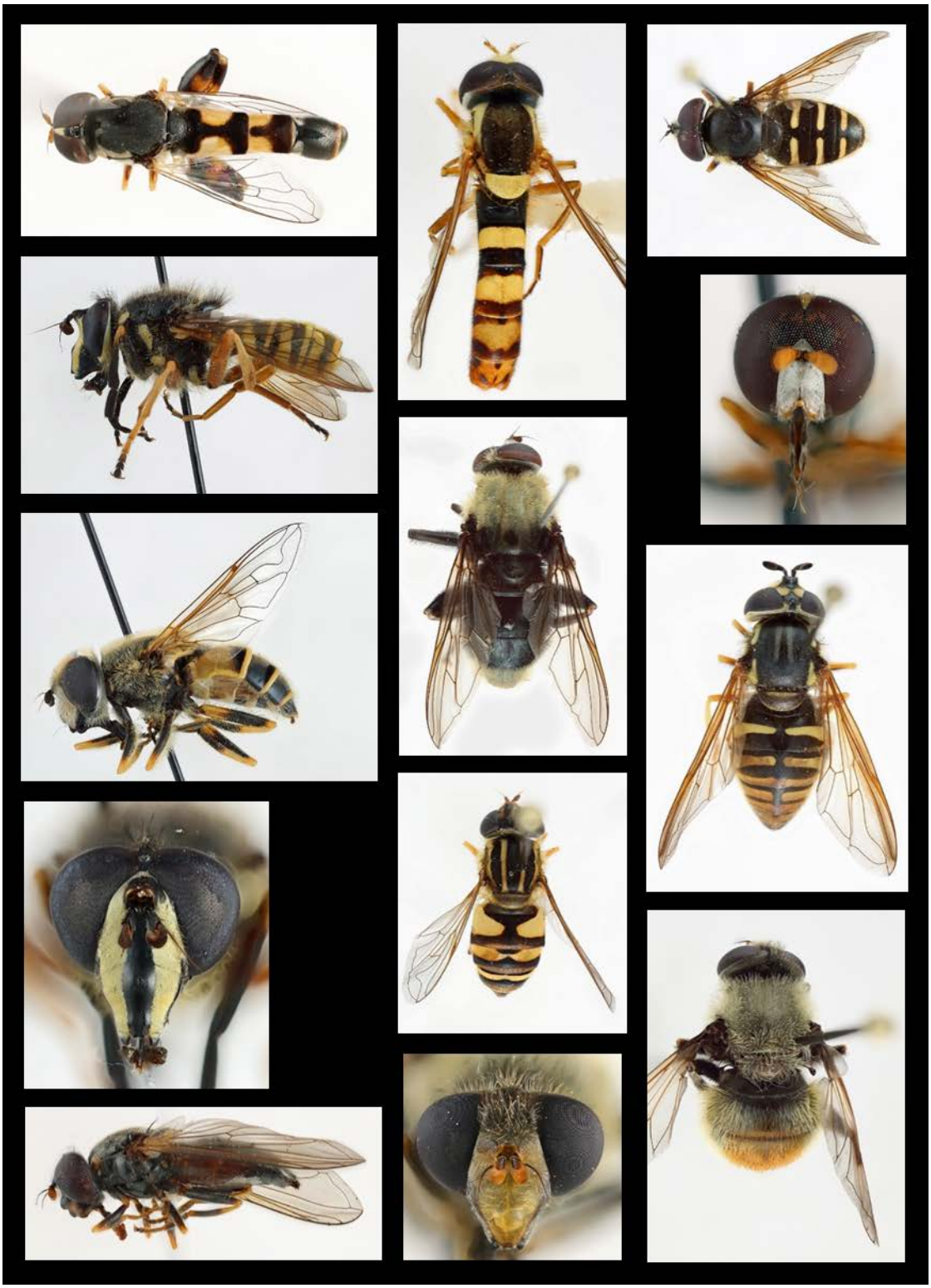
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Abstract

Insect pollinators, specifically bees and syrphid flies, are critical to maintaining functioning ecosystems. Despite their ecological importance and vulnerability to threats such as climate change, many of these pollinators remain unknown in Olympic and North Cascades National Parks. To address this knowledge gap, I conducted a pollinator survey in 2014 with three main objectives: (1) to document and compare the diversity and distribution of bees and syrphid flies in selected habitats along elevation gradients in both parks; (2) to develop protocols and suggest permanent sites for continued monitoring of these pollinators; and (3) to educate park staff and visitors about pollinators and threats to their health. Between June 28th and September 17th, 2014, I and several park staff and volunteers used insect nets and bee bowls to collect pollinators at 28 sites in North Cascades and 58 sites in Olympic, ranging in elevation from sea level to more than 2,000 m. We targeted areas of high floral diversity, including trails and roadsides, subalpine meadows, and edges of waterbodies. In all, we collected 1,890 bees and 298 syrphid flies across the two parks; these comprised 89 and 57 taxa, respectively. The dominant genus of bees in both parks was *Bombus*, comprising 14 species overall and 45% of the bee catch. Habitats above and below tree line shared 36-43% of their combined pollinator species in both parks, and while more taxa were collected in higher elevation habitats due to more intensive sampling, extrapolated rarefaction curves suggest that taxa richness may be as high or higher below tree line if sampling efforts were equal. Several species of bees and syrphid flies were strongly associated with higher elevations. Detailed sampling protocols were developed and permanent sites were suggested for future pollinator monitoring efforts. Park visitors, volunteers, and staff learned about insect pollinators through field trips, slide presentations, and a show-and-tell microscope session in a visitor center.



Bees of North Cascades and Olympic: **Column 1** (top to bottom): *Sphecodes* sp.2, *Andrena w-scripta*, *Hoplitis fulgida*, *Nomada* sp.1; **Column 2**: *Megachile relativa*, *Colletes consors*, *Diadasia diminuta*; *Bombus flavidus*; **Column 3**: *Ceratina acantha*, *Osmia paradisica*, *Coelioxys sodalis*.



Syrphid flies of North Cascades and Olympic: **Column 1** (top to bottom): *Syritta pipiens*, *Sphecomyia pattonii*, *Eristalis hirta*, *Sphecomyia pattonii*, *Cheilosia tristis*; **Column 2**: *Sphaerophoria abbreviate/asymmetrica*, *Hadromyia grandis*, *Helophilus fasciatus*, *Sericomyia flagrans*; **Column 3**: *Sericomyia chalcopyga*, *Syritta pipiens*, *Chrysotoxum flavifrons*, *Sericomyia flagrans*.

Acknowledgments

Special thanks go to Regina Rochefort at North Cascades and Jerry Freilich at Olympic for their generous and enthusiastic support for this project.

I am very grateful for the help and companionship of Laura Larson, who proved to be a whiz at collecting bees and flies and also at handling many field logistics while we were in North Cascades. Tanner Humphries and Michelle Toshack, North Cascades butterfly technicians, were excellent guides.

In Olympic, I was fortunate to get out in the field with James (J.D.) Herndon and Gay Hunter, who both clearly love exploring the Olympics and catchin' bugs.

Many thanks to Michelle Locke at the American Museum of Natural History and Andrew Young at The Canadian National Collection of Insects, Arachnids and Nematodes, who took on the identification of the syrphid flies, and Robbin Thorp, professor emeritus from UC Davis, who happened to be passing through the MCZ collections at Harvard and took the time to look over many of the bumble bees from both parks. Also, I travelled with many "unknowns" to the USDA Pollinating Insects—Biology Management and Systematics Research Unit (Logan, UT), and several people there including Terry Griswold, Harold Ikerd, Jamie Strange, Jonathan Koch, Schuyler Burrows, and Brian Roznick generously contributed their time and expertise to identify these bees for me, to the extent possible.

Ana Casillas, Tara Chestnut, and Jamie Strange made helpful suggestions for improving the report.

This project was funded by the North Coast and Cascades Science Learning Network.

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.

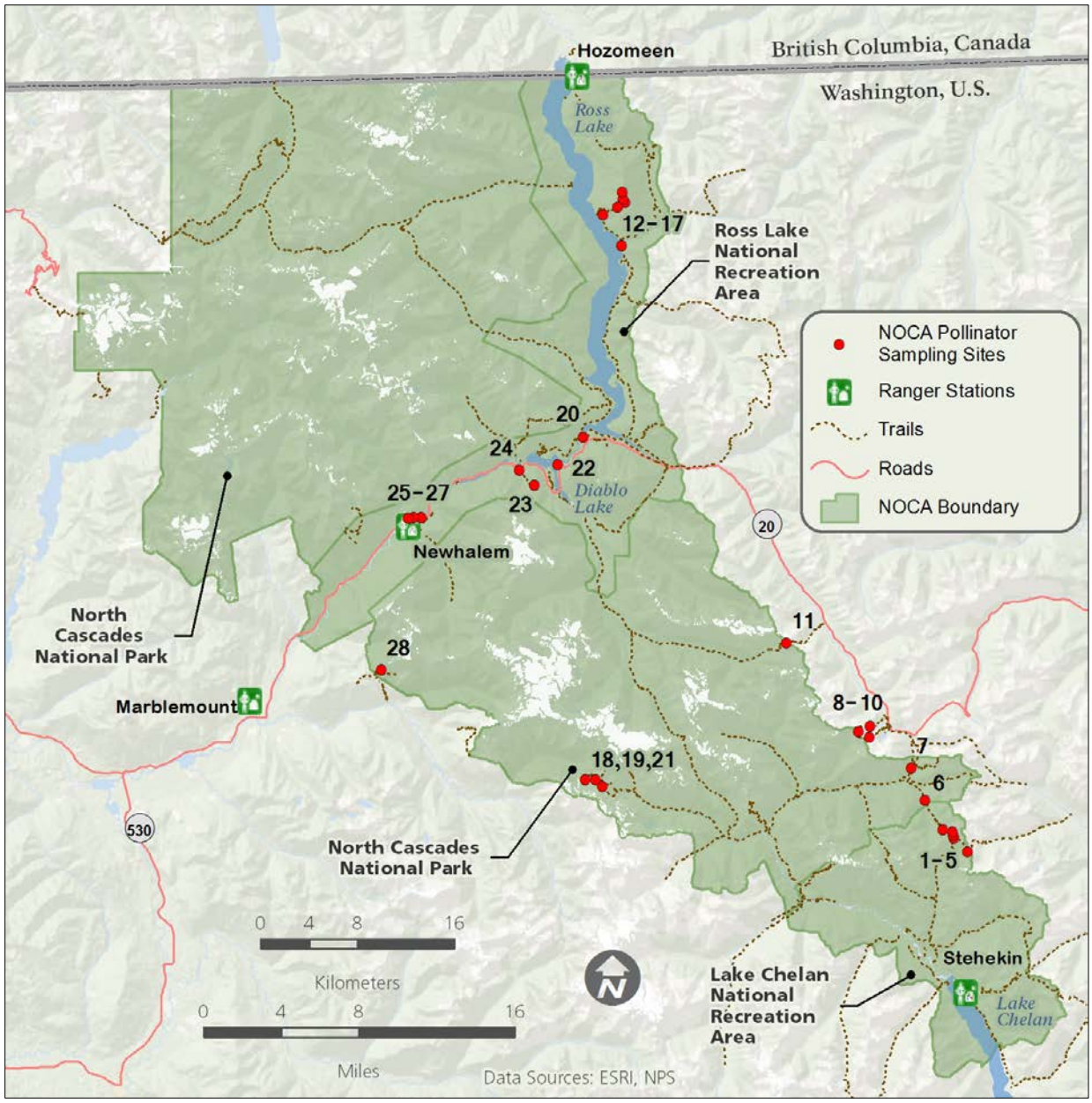


Figure 2. Approximate locations for pollinator sampling sites 1-28 (see Table 1) located in North Cascades National Park Service Complex.

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	–

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
47	OLYM	Obstruction Pt. Rd., Steeple Rock	47.9596	123.4530	1537	roadside	4	3-Jul, 28-Aug	28-Aug
48	OLYM	Switchback Tr.	47.9889	123.4603	1463	meadow	1	28-Aug	28-Aug
49	OLYM	Switchbck Tr.	47.9865	123.4608	1379	open trail	2	19-Aug	–
50	OLYM	Hurricane Ridge Rd.	47.9777	123.4751	1422	roadside	4	2-Aug	–
51	OLYM	Hurricane Ridge Rd.	47.9757	123.4762	1509	roadside	4	–	20-Aug
52	OLYM	Obstruction Pt. Rd., Cox Valley	47.9681	123.4807	1487	meadow	2	20-Aug	–
53	OLYM	Mt. Angeles Tr.	47.9763	123.4840	1635	open trail	1	24-Aug, 7-Sep	–
54	OLYM	Hurricane Ridge, Little River Tr.	47.9823	123.5222	1420	open trail	2	2-Aug	–
55	OLYM	Hurricane Hill	47.9833	123.5272	1609	meadow	1	–	29-Jul
56	OLYM	Hurricane Hill	47.9850	123.5279	1584	meadow	1	29-Jul	–
57	OLYM	Hurricane Hill	47.9830	123.5282	1630	meadow	1	3-Jul	–
58	OLYM	High Divide, near Bruce's Roost	47.9068	123.7270	1497	open trail	1	26-Aug	–
59	OLYM	Sol Duc Park	47.9194	123.7284	1274	meadow	2	27-Aug	–
60	OLYM	Heart Lake, above	47.9059	123.7314	1545	meadow	1	–	26-Aug
61	OLYM	Heart Lake	47.9108	123.7330	1452	meadow	1	27-Aug	–
62	OLYM	Silver Snag campsite	47.9061	123.7606	1527	meadow	1	–	26-Aug
63	OLYM	Silver Snag campsite	47.9064	123.7610	1565	meadow	1	26, 27-Aug	–
64	OLYM	Lunch Lake, Tarn #2	47.9103	123.7710	1458	lake edge	1	26-Aug	–
65	OLYM	Lunch Lake, Tarn #1	47.9126	123.7735	1450	meadow	1	26-Aug	–
66	OLYM	Lunch Lake	47.9175	123.7824	1398	meadow	1	26-Aug	–
67	OLYM	Pass to 7 Lakes Basin	47.9127	123.7906	1475	open trail	1	25-Aug	–
68	OLYM	Nature Bridge campus	48.0597	123.7940	215	lawn	4	–	21-Aug
69	OLYM	Between Deer Lake and 7 Lakes Basin	47.9140	123.8026	1409	open trail	1	1, 25-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
70	OLYM	Deer Lake	47.9255	123.8231	1092	lake edge	2	25-Aug	–
71	OLYM	Hoh, ranger quarters	47.8581	123.9318	228	lawn	4	21-Aug	–
72	OLYM	Hoh, parking lot	47.8224	124.0083	198	roadside	4	21-Aug	–
73	OLYM	Hoh River	47.8215	124.0095	121	riparian	2	21-Aug	–
74	OLYM	Rialto Beach	47.9204	124.6357	5	roadside	4	–	21-Aug
75	OLYM	Rialto Beach	47.9198	124.6375	1	ocean beach	2	21-Aug	21-Aug
76	OLYM	Happy Lake	48.0089	-123.6867	1489	lake edge	2	28-Jun	–
77	OLYM	Gray Wolf Ridge	47.8822	-123.1627	1470	forest	3	18-Aug	–
78	OLYM	Gray Wolf Ridge	47.8917	-123.1704	1799	meadow	1	18-Aug	–
79	OLYM	Ludden Peak	47.8546	-123.5346	1449	meadow	1	15-Aug	–
80	OLYM	Mt. Pulitzer	47.8195	-123.5728	1844	high rocky	1	13-Aug	–
81	OLYM	Lake Lacrosse	47.6665	-123.3608	1481	lake edge	1	10-Sep	–
82	OLYM	O'Neil Pass Tr.	47.6843	-123.3493	1154	meadow	2	11-Sep	–
83	OLYM	O'Neil campsite	47.6157	-123.4770	425	forest	3	12-Sep	–
84	OLYM	Mt. Hoquiam	47.5189	-123.5952	1402	meadow	1	25, 26-Aug	–
85	OLYM	Heather Lake	47.7915	-123.1770	1424	high rocky	1	3-Sep	–
86	OLYM	Mt. Bretherton	47.6271	-123.2060	1449	meadow	1	17-Sep	–

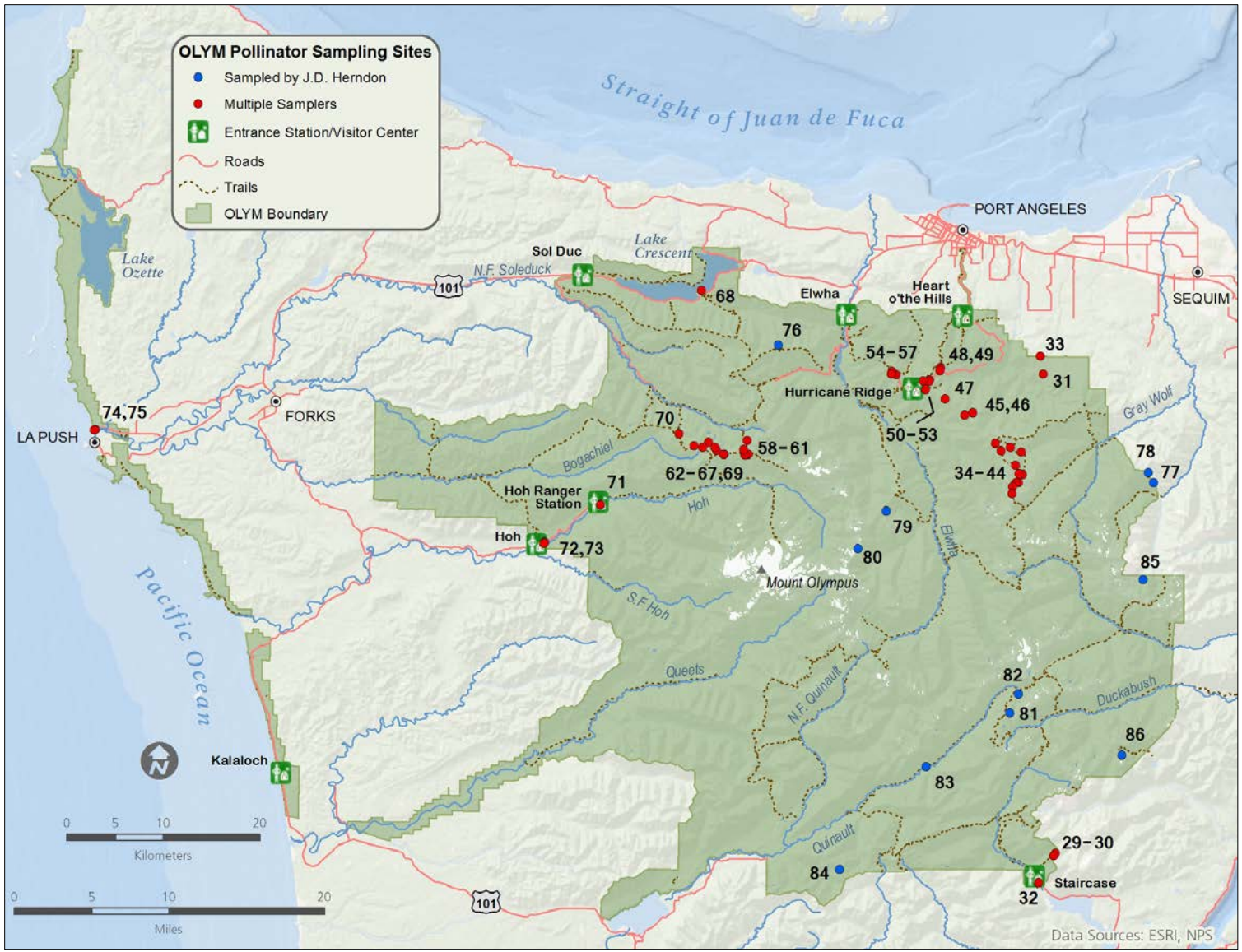


Figure 3. Approximate locations for pollinator sampling sites 29-86 (see Table 1) located in Olympic National Park. Red sites were visited primarily by J. Rykken and/or J. Freilich, J.D. Herndon; blue sites were visited only by J.D. Herndon.

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).

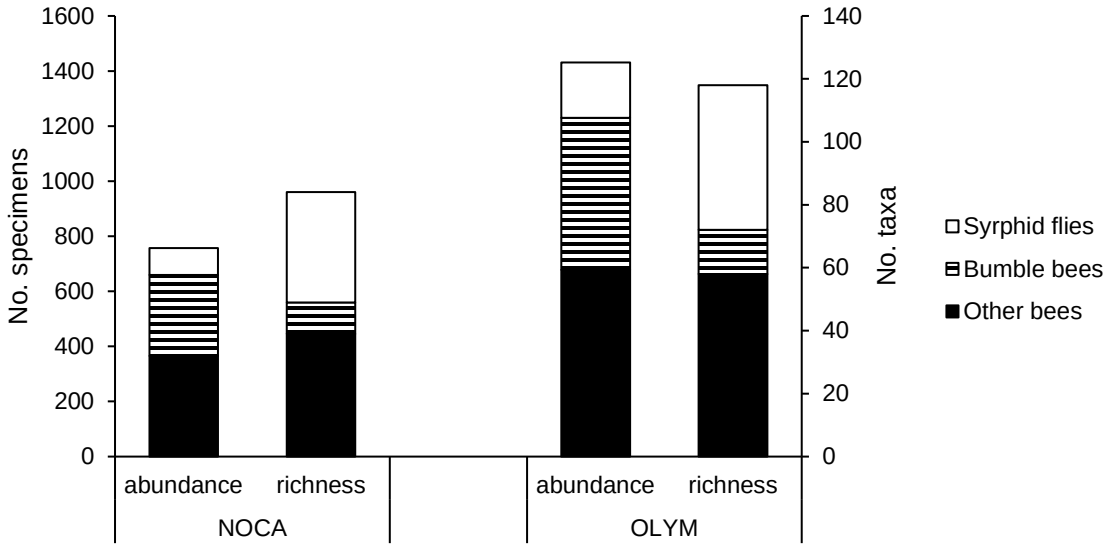


Figure 4. Abundance and taxa richness of syrphid flies, bumble bees (*Bombus*), and other bees collected in North Cascades and Olympic. Note left axis goes with abundance column and right axis goes with richness column.

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).

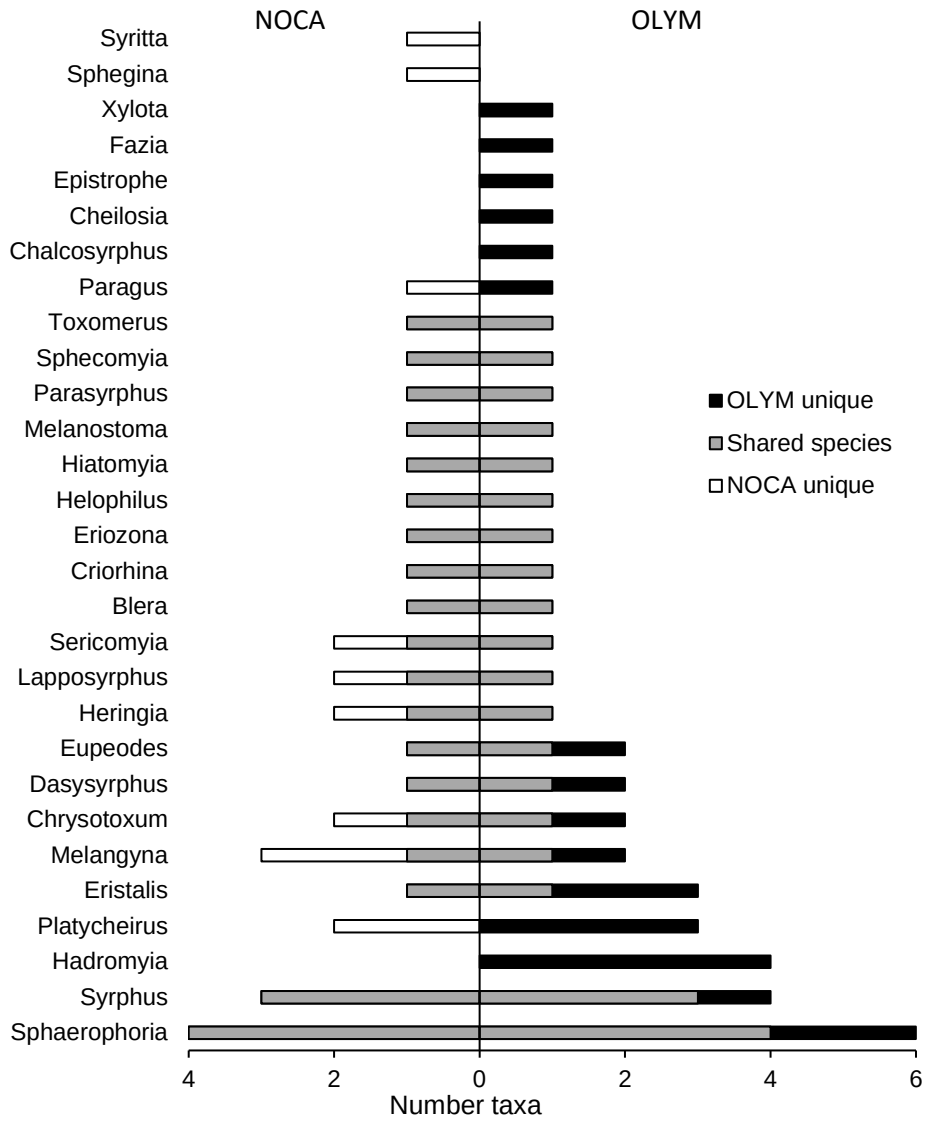


Figure 5. Taxa richness (including identified species, species groups, and genus-level taxa) among 29 syrphid fly genera collected in North Cascades (left bars) and Olympic (right bars). For each genus, color coding indicates unique species to each park, and species shared between both parks.

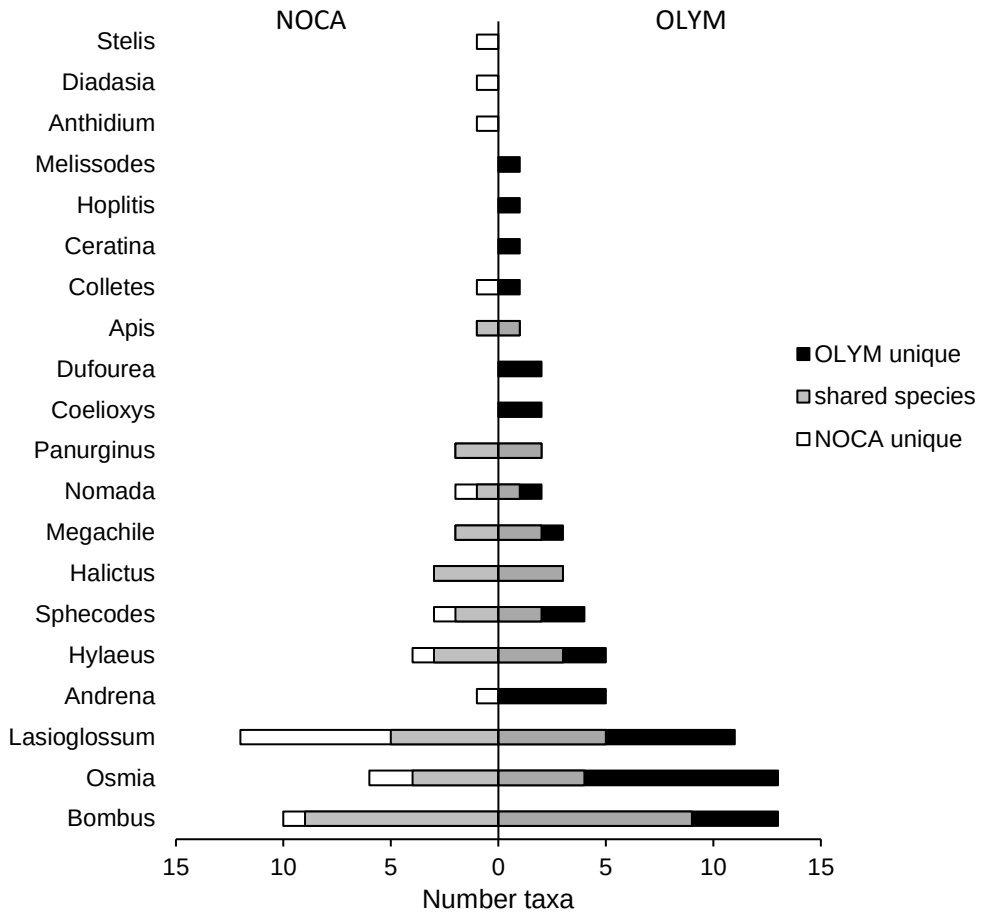


Figure 6. Taxa richness (including identified species, morphospecies, species groups, and genus-level taxa) among 20 bee genera collected in North Cascades (left bars) and Olympic (right bars). For each genus, color coding indicates unique species to each park, and species shared between both parks.

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).

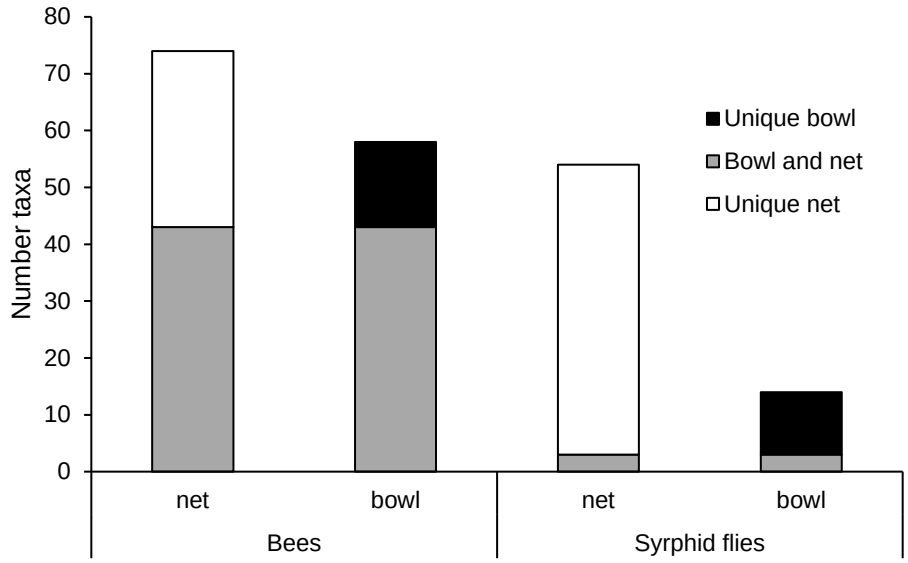


Figure 7. Comparison of collecting methods for bees and syrphid flies in North Cascades and Olympic. Gray areas in paired columns represent shared species collected by both bowl and net.

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

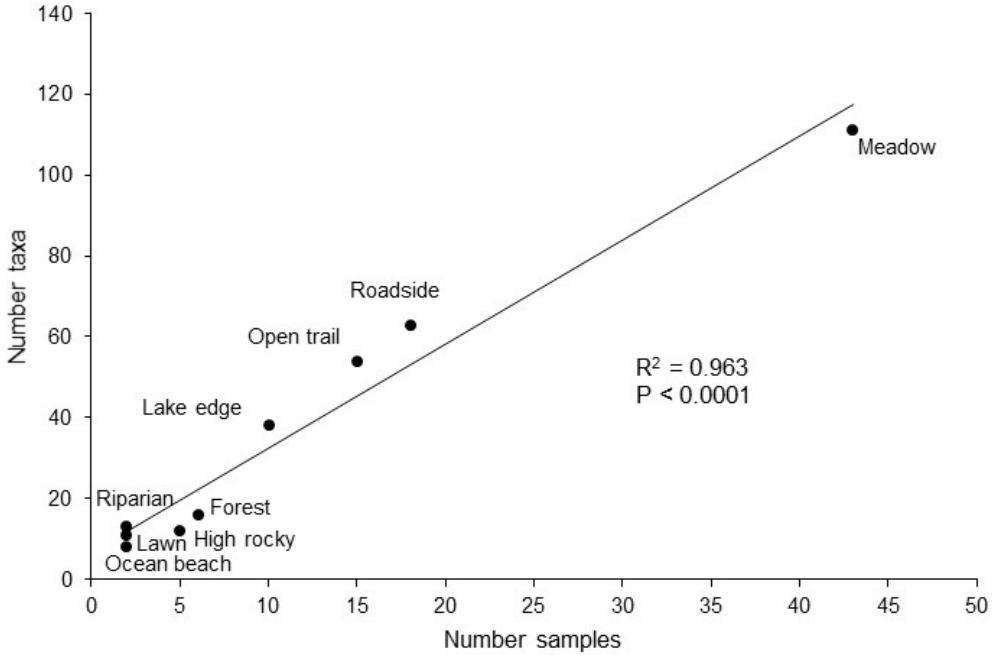


Figure 8. The relationship between sampling effort and the number of taxa collected across different habitats in North Cascades and Olympic. N = 9 habitats. The fitted regression line is shown.

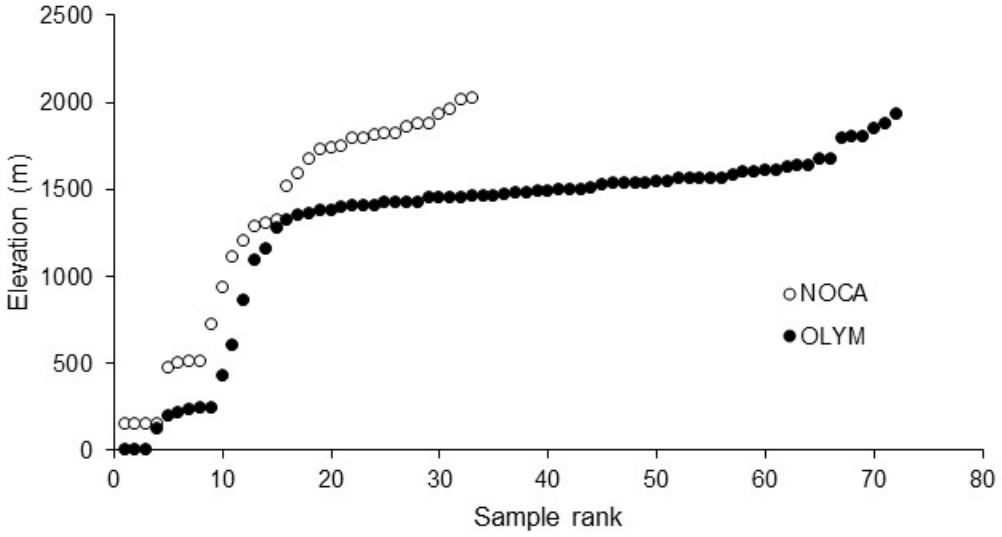


Figure 9. Distribution of pollinator sampling events from North Cascades and Olympic along elevation gradients. Each dot represents one pollinator sample (net or bee bowl).

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.

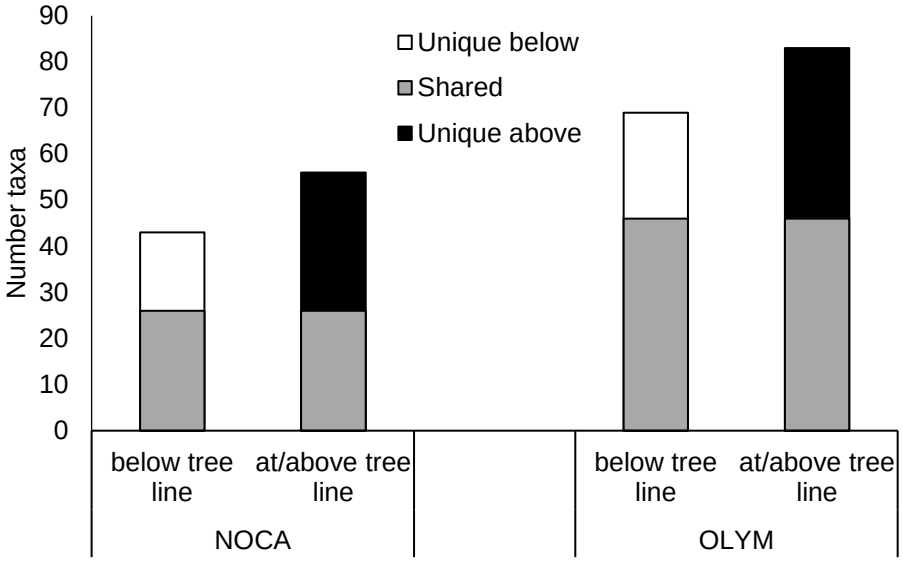


Figure 10. Comparison of taxa richness between habitats at or above tree line versus forest openings below tree line in North Cascades and Olympic. Grey portions of paired bars indicate shared taxa, collected both above and below tree line in that park.

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.

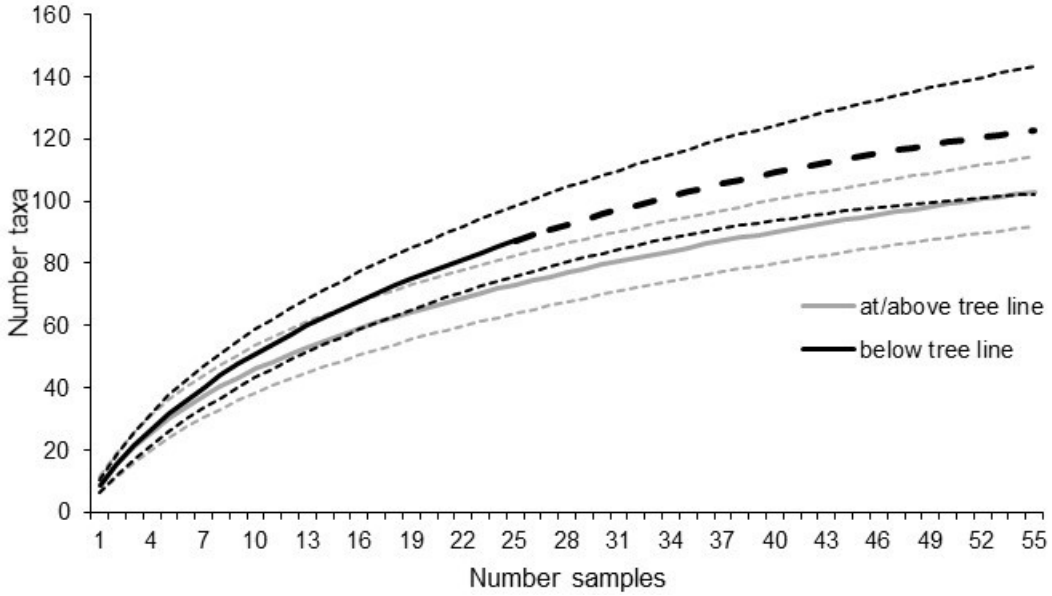


Figure 11. Rarefaction curves (bounded above and below with dotted lines representing 95% confidence intervals) for total numbers of pollinator taxa collected in meadows/rocky areas at or above tree line and forest openings below tree line in North Cascades and Olympic. Extrapolated rarefaction values (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).

Literature Cited

Bartomeus, I., J. S. Ascher, D. Wagner, B. N. Danforth, S. Colla, S. Kornbluth, and R. Winfree. 2011. Climate-associated phenological advances in bee pollinators and bee-pollinated plants. PNAS 108: 20645-20649.

Biesmeijer, J. C., S. P. M. Roberts, M. Reemer, R. Ohlemüller, M. Edwards, T. Peeters, A. P. Schaffers, S. G. Potts, R. Kleukers, C. D. Thomas, J. Settele, and W. E. Kunin. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science 313:351-354.

Burkle, L. A., J. C. Marlin, and T. M. Knight. 2013. Plant-pollinator interactions over 120 years: loss of species, co-occurrence, and function. Science 339:1611-1615.

Cameron, S. A., J. D. Lozier, J. P. Strange, J. B. Koch, N. Cordes, L. F. Solter, and T. L. Griswold. 2011. Patterns of widespread decline in North American bumble bees. PNAS Early Edition Available at: www.pnas.org/cgi/doi/10.1073/pnas.1014743108.

Cameron, S. A., H. C. Lim, J. D. Lozier, M. A. Duennes, and R. Thorp. 2016. Test of the invasive pathogen hypothesis of bumble bee decline in North America. Proceedings of the National Academy of Sciences 113:4386-4391.

Colla, S., M. C. Otterstatter, R. J. Gegear, and J. D. Thomson. 2006. Plight of the bumble bee: pathogen spillover from commercial to wild populations. Biological Conservation 129:461-467.

Colla, S. R., and L. Packer. 2008. Evidence for decline in eastern North American bumblebees (Hymenoptera: Apidea), with special focus on *Bombus affinis* Cresson. Biodiversity and Conservation 17:1379-1391.

Colla, S. R., and C. R. Ratti. 2010. Evidence for the decline of the western bumble bee (*Bombus occidentalis* Greene) in British Columbia. The Pan-Pacific Entomologist 86:32-34.

Colwell, R. K., A. Chao, N. J. Gotelli, S.-Y. Lin, C. X. Mao, R. L. Chazdon, and J. T. Longino. 2012. Models and estimators linking individual-based and sample-based rarefaction, extrapolation, and comparison of assemblages. Journal of Plant Ecology 5:3-21.

Colwell, R. K. 2013. EstimateS: Statistical estimation of species richness and shared species from samples. Version 9. User's Guide and application published at: http://purl.oclc.org/estimates.

Danks, H. V. 2004. Seasonal adaptations in arctic insects. Integrative and Comparative Biology 44:85-94.

Dirnböck, T., F. Essl, and W. Rabitsch. 2011. Disproportional risk for habitat loss of high-altitude endemic species under climate change. Global Change Biology 17:990–996.

Droege, S. 2015. The very handy manual: how to catch and identify bees and manage a collection. Available at: https://www.pwrc.usgs.gov/nativebees/Handy%20Bee%20Manual/The%20Very%20Handy%20Manual%20-%202015.pdf (accessed: 06 March 2016).

Evans, E., R. Thorp, S. Jepsen, and S. Hoffman Black. 2008. Status review of three formerly common species of bumble bee in the subgenus *Bombus*, *Bombus affinis* (the rusty patched bumble bee), *B. terricola* (the yellowbanded bumble bee), and *B. occidentalis* (the western bumble bee). The Xerces Society, Portland, OR. 63 pp.

Franzén, M., and E. Öckinger. 2012. Climate-driven changes in pollinator assemblages during the last 60 years in an Arctic mountain region in Northern Scandinavia. Journal of Insect Conservation 16:227-238.

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 347:1255957.

Grundel, R., K. J. Frohnapple, R. P. Jean, and N. B. Pavlovic. 2011. Effectiveness of bowl trapping and netting for inventory of a bee community. Environmental Entomology 40:374-380.

Halofsky, J. E., D. L. Peterson, K. A. O'Halloran, C. Hawkins Hoffman, eds. 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. Gen. Tech. Rep. PNW-GTR-844. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 130pp.

Iler, A. M., D. W. Inouye, T. T. Høye, A. J. Miller-Rushing, L. A. Burkle, and E. B. Johnston. 2013. Maintenance of temporal synchrony between syrphid flies and floral resources despite differential phonological responses to climate. Global Change Biology 19:2348-2359.

Kearns, C. A., and J. D. Thomson. 2001. The natural history of bumblebees: a sourcebook for investigations. The University Press of Colorado, Boulder, CO.

Kerr, J. T., A. Pindar, P. Galpern, L. Packer, S. G. Potts, S. M. Roberts, P. Rasmont, O. Schweiger, S. R. Colla, L. L. Richardson, D. L. Wagner, L. F. Gall, D. S. Sikes, and A. Pantoja. 2015. Climate change impacts on bumblebees converge across continents. Science 349:177-180.

Koch, J. B., C. Looney, W. S. Sheppard, and J. P. Strange. 2016. Range extension of two bumble bee species (Hymenoptera: Apidae) into Olympic National Park. Northwest Science 90:228-234.

Koch, J. B., C. Looney, W. S. Sheppard, and J. P. Strange. 2017. Patterns of population genetic structure and diversity across bumble bee communities in the Pacific Northwest. Conservation Genetics 18:507-520.

Mader, E., M. Shepherd, M. Vaughan, S. Hoffman Black, and G. LeBuhn. 2011. Attracting native pollinators: protecting North America's bees and butterflies. Storey Publishing, North Adams, MA. 371 pp.

Michener, C. D. 2007. The bees of the world. The Johns Hopkins University Press. Baltimore, MD. 953 pp.

Miller-Struttmann, N. E., J. C. Geib, J. D. Franklin, P. G. Kevan, R. M. Holdo, D. Ebert-May, A. M. Lynn, J. A. Kettenback, E. Hedrick, and C. Galen. 2015. Functional mismatch in a bumble bee pollination mutualism under climate change. Science 349:151-1544.

Natural Research Council. 2006. Status of pollinators in North America. The National Academies Press, Washington, D.C. 312 pp.

Ollerton, J., R. Winfree, and S. Tarrant. 2011. How many flowering plants are pollinated by animals? Oikos 120:321-326.

Potts, S. G., J. C. Biesmeijer, C. Kremen, P. Neumann, O. Schweiger, and W. E. Kunin. 2010. Global pollinator declines: trends, impacts and drivers. Trends in Ecology and Evolution 25: 345-353.

Rochefort, R. M. 2017. The Cascades Butterfly Project: Survey routes, standard operating procedures, and field forms. North Cascades National Park Service Complex. Sedro-Woolley, WA. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2240163.

Rochefort, R. M, and J. F. McLaughlin. 2017. The Cascades butterfly project: A protocol for monitoring subalpine butterflies and plant phenology in the Cascade Mountains of Washington. Natural Resource Report. NPS/NOCA/NRR—2017/1440. National Park Service. Fort Collins, CO. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2240282.

Rykken, J. J., and B. D. Farrell. 2013*a*. Developing a pollinator monitoring program for Boston Harbor Islands National Recreation Area: A pilot study. Natural Resource Report. NPS/BOHA/NRR—2015/950. National Park Service, Fort Collins, CO. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2221699.

Rykken, J. J., and B. D. Farrell. 2013*b*. Discovering the microwilderness in parks and protected areas. Pages 306-322 *in* R. H. Lemelin (Ed.). The management of insects in recreation and tourism. Cambridge University Press, New York, NY.

Rykken, J., A. Rodman, S. Droege, and R. Grundel. 2014. Pollinators in Peril? A multipark approach to evaluating bee communities in habitats vulnerable to effects from climate change. Park Science 31:84-90.

Sheffield, C. S., A. Pindar, L. Packer, and P. G. Kevan. 2013. The potential of cleptoparasitic bees as indicator taxa for assessing bee communities. Apidologie 44:501-510.

Strange, J. P, J. B. Koch, W. S. Shepherd, B. Hopkins, J. Long, E. Lichtenberg, and C. Looney. 2013. Bumble bee community composition and population genetic diversity in the North Cascades and Coast Network. National Park Service Progress Report. 20 pp.

Thorp, R., D. S. Horning, Jr., and L. L. Dunning. 1983. Bumble bees and cuckoo bumble bees of California (Hymenoptera: Apidae). Bulletin of the California Insect Survey 23:1-79.

Vockeroth, J. R. 1992. The flower flies of the subfamily Syrphinae of Canada, Alaska, and Greenland (Diptera: Syrphidae). The insects and arachnids of Canada, Part 18. Research Branch, Agriculture Canada, Ottawa, ON. 456 pp.

Vockeroth, J. R, and F. C. Thompson. 1987. Syrphidae. Pages 713-744 *in* J. F. McAlpine, B. V. Peterson, G. E. Shewell, H. J. Teskey, J. R. Vockeroth, and D.M. Wood (Eds.). Manual of Nearctic Diptera, Volume 2. Research Branch Agriculture Canada, Monograph no. 28.

Wcislo, W. T. 1987. The roles of seasonality, host synchrony, and behaviour in the evolutions and distributions of nest parasites in Hymenoptera (Insecta), with special reference to bees (Apoidea). Biological Reviews 62:515-543.

Williams, P., R. Thorp, L. Richardson, and S. Colla. 2014. Bumble bees of North America. Princeton University Press, Princeton, NJ, 208 pp.

Appendix A. Pollinator taxa collected in North Cascades (NOCA) and Olympic (OLYM) National Parks between June 28th and September 17th, 2014.

For each taxon: number of individuals collected in each park and elevation range at which each taxon was collected. Species noted with asterisk (*) are non-native.

Order	Family	Subfamily	Species	NOCA	OLYM	ELEV. (m)
Diptera	Syrphidae	Eristalinae	*Blera scitula* (Williston)	2	12	1348-2010
	Syrphidae	Eristalinae	*Chalcosyrphus nemorum* (Fabricius)	0	4	244
	Syrphidae	Eristalinae	*Cheilosia tristis* Loew	0	5	1348-1562
	Syrphidae	Eristalinae	*Criorhina coquilletti* Williston	1	1	1489-1511
	Syrphidae	Eristalinae	*Eristalis arbustorum* (Linnaues) *	0	1	1799
	Syrphidae	Eristalinae	*Eristalis hirta* Loew	3	2	121-2010
	Syrphidae	Eristalinae	*Eristalis tenax* (Linnaeus) *	0	2	244-1487
	Syrphidae	Eristalinae	*Hadromyia crawfordi* (Shannon)	0	1	1536
	Syrphidae	Eristalinae	*Hadromyia grandis* Williston	0	5	1397-1794
	Syrphidae	Eristalinae	*Hadromyia opaca* (Shannon)	0	1	1489
	Syrphidae	Eristalinae	*Hadromyia pulchra* (Williston)	0	2	1536
	Syrphidae	Eristalinae	*Helophilus fasciatus* Walker	1	1	1322-1487
	Syrphidae	Eristalinae	*Hiatomyia plutonia* (Hunter)	4	4	1487-1808
	Syrphidae	Eristalinae	*Sericomyia chalcopyga* Loew	3	47	1347-2010
	Syrphidae	Eristalinae	*Sericomyia flagrans* (Osten Sacken)	2	0	1871-1927
	Syrphidae	Eristalinae	*Sphecomyia pattoni* Williston	1	1	1489-1511
	Syrphidae	Eristalinae	*Sphegina* sp.	1	0	1511
	Syrphidae	Eristalinae	*Syritta pipiens* (Linnaeus) *	2	0	154
	Syrphidae	Eristalinae	*Xylota naknek* Shannon	0	1	1489
	Syrphidae	Syrphinae	*Chrysotoxum fasciatum* (Muller)	0	2	1487
	Syrphidae	Syrphinae	*Chrysotoxum flavifrons* Macquart	1	0	1281

Appendix A (continued). Pollinator taxa collected in North Cascades (NOCA) and Olympic (OLYM) National Parks between June 28th and September 17th, 2014. For each taxon: number of individuals collected in each park and elevation range at which each taxon was collected. Species noted with asterisk (*) are non-native.

Order	Family	Subfamily	Species	NOCA	OLYM	ELEV. (m)
Diptera (continued)	Syrphidae	Syrphinae	*Chrysotoxum ventricosum* Loew	6	1	1281-2010
	Syrphidae	Syrphinae	*Dasysyrphus intrudens* (Osten Sacken)	2	4	507-1821
	Syrphidae	Syrphinae	*Dasysyrphus venustus* Meigen	0	1	1799
	Syrphidae	Syrphinae	*Epistrophe grossulariae* (Meigen)	0	4	1347-1563
	Syrphidae	Syrphinae	*Eriozona laxus* (Osten Sacken)	8	9	1-2010
	Syrphidae	Syrphinae	*Eupeodes americanus/fumipennis/pomus*	2	2	121-1927
	Syrphidae	Syrphinae	*Eupeodes fumipennis* (Thomson)	0	1	1564
	Syrphidae	Syrphinae	*Fazia micrura* (Osten Sacken)	0	3	121-1487
	Syrphidae	Syrphinae	*Heringia rita* (Curran)	1	0	2010
	Syrphidae	Syrphinae	*Heringia* sp.	1	2	5-2023
	Syrphidae	Syrphinae	*Lapposyrphus aberrantis* (Curran)	3	0	1322-2010
	Syrphidae	Syrphinae	*Lapposyrphus lapponicus* (Zetterstedt)	3	8	505-2010
	Syrphidae	Syrphinae	*Melangyna fisherii* (Walton)	1	0	1511
	Syrphidae	Syrphinae	*Melangyna labiatarum* (Verrall)	2	0	1587
	Syrphidae	Syrphinae	*Melangyna subfasciata* (Curran)	0	1	1608
	Syrphidae	Syrphinae	*Melangyna umbellatarum* (Fabricius)	1	1	1361-1927
	Syrphidae	Syrphinae	*Melanostoma mellinum* (Linnaeus)	1	3	504-1564
	Syrphidae	Syrphinae	*Paragus haemorrhous* Meigen	2	0	504-1793
	Syrphidae	Syrphinae	*Paragus* sp.	0	1	1562
	Syrphidae	Syrphinae	*Parasyrphus relictus* (Zetterstedt)	4	4	507-1956
	Syrphidae	Syrphinae	*Platycheirus atra/lutepennis*	0	1	1535
	Syrphidae	Syrphinae	*Platycheirus ciliatus* Bigot	1	0	1511
	Syrphidae	Syrphinae	*Platycheirus confusus/sabulicola*	0	1	1564
	Syrphidae	Syrphinae	*Platycheirus stegnus* (Say)	3	0	1322

Appendix A (continued). Pollinator taxa collected in North Cascades (NOCA) and Olympic (OLYM) National Parks between June 28th and September 17th, 2014. For each taxon: number of individuals collected in each park and elevation range at which each taxon was collected. Species noted with asterisk (*) are non-native.

Order	Family	Subfamily	Species	NOCA	OLYM	ELEV. (m)
Diptera (continued)	Syrphidae	Syrphinae	*Platycheirus trichopus* (Thomson)	0	7	1481-1799
	Syrphidae	Syrphinae	*Sphaerophoria abbreviata/asymmetrica*	10	5	1361-2010
	Syrphidae	Syrphinae	*Sphaerophoria abbreviata/asymmetrica/philanthus*	10	2	1322-2010
	Syrphidae	Syrphinae	*Sphaerophoria brevipilosa/longipilosa*	0	3	1379-1537
	Syrphidae	Syrphinae	*Sphaerophoria novaeangliae* Johnson	0	1	1537
	Syrphidae	Syrphinae	*Sphaerophoria* sp.	2	1	1487-1745
	Syrphidae	Syrphinae	*Sphaerophoria sulphuripes* (Thomson)	2	1	1361-1871
	Syrphidae	Syrphinae	*Syrphus attenuatus* Hine	0	1	1537
	Syrphidae	Syrphinae	*Syrphus opinator* Osten Sacken	1	8	1-1821
	Syrphidae	Syrphinae	*Syrphus ribesii* (Linnaeus)	7	16	504-2010
	Syrphidae	Syrphinae	*Syrphus torvus* Osten Sacken	2	16	1372-1821
	Syrphidae	Syrphinae	*Toxomerus occidentalis* Curran	1	1	243-1113
Hymenoptera	Andrenidae	Andreninae	*Andrena columbiana* Viereck	0	1	1
	Andrenidae	Andreninae	*Andrena knuthiana* Cockerell	0	1	1545
	Andrenidae	Andreninae	*Andrena thaspii* Graenicher	0	1	1609
	Andrenidae	Andreninae	*Andrena trevoris* Cockerell	1	0	1281
	Andrenidae	Andreninae	*Andrena washingtoni* Cockerell	0	1	1609
	Andrenidae	Andreninae	*Andrena w-scripta* Viereck	0	3	1545
	Andrenidae	Panurginae	*Panurginus atriceps* (Cresson)	22	1	1113-1806
	Andrenidae	Panurginae	*Panurginus ineptus* Cockerell	4	10	1527-1669
	Apidae	Apinae	*Apis mellifera* Linnaeus *	2	2	1511-1630
	Apidae	Apinae	*Bombus appositus* Cresson	2	14	1319-1821
	Apidae	Apinae	*Bombus bifarius* Cresson	40	13	145-2023
	Apidae	Apinae	*Bombus caliginosus* (Frison)	0	6	605-1584

Appendix A (continued). Pollinator taxa collected in North Cascades (NOCA) and Olympic (OLYM) National Parks between June 28th and September 17th, 2014. For each taxon: number of individuals collected in each park and elevation range at which each taxon was collected. Species noted with asterisk (*) are non-native.

Order	Family	Subfamily	Species	NOCA	OLYM	ELEV. (m)
Hymenoptera (continued)	Apidae	Apinae	*Bombus flavidus* Eversmann	12	91	154-1871
	Apidae	Apinae	*Bombus flavifrons* Cresson	37	99	1-1934
	Apidae	Apinae	*Bombus insularis* (Smith)	15	0	725-2023
	Apidae	Apinae	*Bombus melanopygus* Nylander	17	24	1281-1934
	Apidae	Apinae	*Bombus mixtus* Cresson	29	148	153-2023
	Apidae	Apinae	*Bombus occidentalis* Greene	0	5	1361-1562
	Apidae	Apinae	*Bombus rufocinctus* Cresson	0	2	1487
	Apidae	Apinae	*Bombus sitkensis* Nylander	26	19	145-1745
	Apidae	Apinae	*Bombus* sp.	0	13	1154-1639
	Apidae	Apinae	*Bombus sylvicola* Kirby	115	95	1113-2023
	Apidae	Apinae	*Bombus vandykei* (Frison)	2	21	215-1880
	Apidae	Apinae	*Bombus vosnesenskii* Radoszkowski	0	2	244-1565
	Apidae	Apinae	*Diadasia diminuta* (Cresson)	3	0	153-154
	Apidae	Apinae	*Melissodes* sp.	0	1	605
	Apidae	Nomadinae	*Nomada* sp. 1	2	2	1113-2054
	Apidae	Nomadinae	*Nomada* sp. 2	0	1	228
	Apidae	Nomadinae	*Nomada* sp. 3	1	0	1113
	Apidae	Xylocopinae	*Ceratina acantha* Provancher	0	1	243
	Colletidae	Colletinae	*Colletes nigrifrons* Titus	5	0	1587-2010
	Colletidae	Colletinae	*Colletes consors* Cresson	0	6	1584
	Colletidae	Hylaeinae	*Hylaeus annulatus* (Linnaeus)	10	12	1113-2010
	Colletidae	Hylaeinae	*Hylaeus coloradensis* (Cockerell)	0	2	1409-1537
	Colletidae	Hylaeinae	*Hylaeus episcopalis* (Cockerell)	0	3	1487-1537
	Colletidae	Hylaeinae	*Hylaeus modestus* (Cockerell)	8	3	1-1537

Appendix A (continued). Pollinator taxa collected in North Cascades (NOCA) and Olympic (OLYM) National Parks between June 28th and September 17th, 2014. For each taxon: number of individuals collected in each park and elevation range at which each taxon was collected. Species noted with asterisk (*) are non-native.

Order	Family	Subfamily	Species	NOCA	OLYM	ELEV. (m)
Hymenoptera (continued)	Colletidae	Hylaeinae	*Hylaeus nevadensis* (Cockerell)	3	0	1322
	Colletidae	Hylaeinae	*Hylaeus wootoni* (Cockerell)	2	3	1322-1537
	Halictidae	Halictinae	*Halictus confusus* Smith	4	27	145-1635
	Halictidae	Halictinae	*Halictus rubicundus* (Christ)	18	24	154-1871
	Halictidae	Halictinae	*Halictus virgatellus* Cockerell	44	88	145-1934
	Halictidae	Halictinae	*Lasioglossum anhypops* McGinley	1	0	1871
	Halictidae	Halictinae	*Lasioglossum Dialictus* sp.	34	107	1-1871
	Halictidae	Halictinae	*Lasioglossum egregium* (Vachal)	2	0	504
	Halictidae	Halictinae	*Lasioglossum Evylaeus* sp.	0	58	1154-1799
	Halictidae	Halictinae	*Lasioglossum Evylaeus* sp.1	0	2	1537-1564
	Halictidae	Halictinae	*Lasioglossum Evylaeus* sp.2	1	0	1871
	Halictidae	Halictinae	*Lasioglossum Evylaeus* sp.3	1	1	1564-1745
	Halictidae	Halictinae	*Lasioglossum Evylaeus* sp.4	0	1	1537
	Halictidae	Halictinae	*Lasioglossum Evylaeus* sp.5	1	0	1745
	Halictidae	Halictinae	*Lasioglossum Evylaeus* sp.6	0	2	1537-1564
	Halictidae	Halictinae	*Lasioglossum niger* complex	11	16	1452-1871
	Halictidae	Halictinae	*Lasioglossum nigroviride* (Graenicher)	1	0	1200
	Halictidae	Halictinae	*Lasioglossum ?nigrum* (Viereck)	79	53	1361-2010
	Halictidae	Halictinae	*Lasioglossum ruidosense* (Cockerell)	0	10	1463-1584
	Halictidae	Halictinae	*Lasioglossum* sp.	79	96	228-2010
	Halictidae	Halictinae	*Lasioglossum trizonatum* (Cresson)	1	0	504
	Halictidae	Halictinae	*Lasioglossum zonulum* (Smith) *	0	15	5-228
	Halictidae	Halictinae	*Sphecodes* sp.	1	12	1-1799
	Halictidae	Halictinae	*Sphecodes* sp. 1	0	7	1402-1562

Appendix A (continued). Pollinator taxa collected in North Cascades (NOCA) and Olympic (OLYM) National Parks between June 28th and September 17th, 2014. For each taxon: number of individuals collected in each park and elevation range at which each taxon was collected. Species noted with asterisk (*) are non-native.

Order	Family	Subfamily	Species	NOCA	OLYM	ELEV. (m)
Hymenoptera (continued)	Halictidae	Halictinae	*Sphecodes* sp. 2	1	0	154
	Halictidae	Halictinae	*Sphecodes* sp. 3	0	1	1379
	Halictidae	Halictinae	*Sphecodes* sp. 4	5	20	1-1821
	Halictidae	Rophitinae	*Dufourea campanulae* (Cockerell)	0	4	1527-1559
	Halictidae	Rophitinae	*Dufourea maura* (Cresson)	0	2	1402-1799
	Megachilidae	Megachilinae	*Anthidium tenuiflorae* Cockerell	1	0	2010
	Megachilidae	Megachilinae	*Coelioxys rufitarsis* Smith	0	1	1487
	Megachilidae	Megachilinae	*Coelioxys sodalis Cresson*	0	7	1535-1799
	Megachilidae	Megachilinae	*Hoplitis fulgida fulgida* (Cresson)	0	6	1487-1584
	Megachilidae	Megachilinae	*Megachile melanophaea* Smith	0	14	1527-1799
	Megachilidae	Megachilinae	*Megachile perihirta* Cockerell	1	5	121-1871
	Megachilidae	Megachilinae	*Megachile relativa* Cresson	1	4	1200-1487
	Megachilidae	Megachilinae	*Osmia coloradensis* Cresson	0	3	1537
	Megachilidae	Megachilinae	*Osmia densa* Cresson	1	2	145-1527
	Megachilidae	Megachilinae	*Osmia dolerosa* Sandhouse	1	1	1322-1564
	Megachilidae	Megachilinae	*Osmia Melanosmia* sp.	1	0	1113
	Megachilidae	Megachilinae	*Osmia Melanosmia* sp. 1	0	3	1487-1584
	Megachilidae	Megachilinae	*Osmia Melanosmia* sp. 2	0	4	1463-1535
	Megachilidae	Megachilinae	*Osmia odontogaster/obliqua*	0	4	1348-1799
	Megachilidae	Megachilinae	*Osmia paradisica* Sandhouse	8	0	725-2010
	Megachilidae	Megachilinae	*Osmia* aff. *penstemonis*	0	1	1564
	Megachilidae	Megachilinae	*Osmia penstemonis* Cockerell	0	2	1487-1608
	Megachilidae	Megachilinae	*Osmia ?phaceliae* Cockerell	0	3	1487-1564
	Megachilidae	Megachilinae	*Osmia pusilla* Cresson	1	1	1527-1793

Appendix A (continued). Pollinator taxa collected in North Cascades (NOCA) and Olympic (OLYM) National Parks between June 28th and September 17th, 2014. For each taxon: number of individuals collected in each park and elevation range at which each taxon was collected. Species noted with asterisk (*) are non-native.

Order	Family	Subfamily	Species	NOCA	OLYM	ELEV. (m)
Hymenoptera (continued)	Megachilidae	Megachilinae	*Osmia simillima* Smith	0	1	1501
	Megachilidae	Megachilinae	*Osmia subaustralis* Cockerell	0	13	1348-1670
	Megachilidae	Megachilinae	*Osmia tristella* Cockerell	2	3	1200-1821
	Megachilidae	Megachilinae	*Stelis* sp.	1	0	1821

Appendix B. Resources for pollinator monitoring program: field sampling protocol for bee bowl trapping; sampling data sheet, and signage for bee bowl transects.

Setting out bee bowls

(Deploy bowls before 10 am)

Equipment (per transect):
30 painted bee bowls (10 each color)
One half gallon water plus a few drops of unscented dishwashing soap
5-10 orange flags
2 bee monitoring signs
Camera/smartphone
Data sheet
Pencil

1) Mark one end of a 145 m transect with an orange flag and/or sign (so that it's visible to passers-by). Ideally, the transect should be in an open area, and traps should be placed to avoid shade as much as possible.
2) Fill out first two sections of data sheet, including weather and a general description of the transect location.
3) Fill each bee bowl with soapy water to about ¾ mark (not too full or insects may crawl out, try to avoid excessive suds). Place bowl on level ground. Avoid tall vegetation. If you can't see the bowl, chances are pollinators can't either.
4) Place the first bowl at the end of the transect, then measure another 5 m (about 5 paces) and fill the next bowl, repeat process above. Colors should alternate along transect.
5) At every 5th bowl, or if the bowl is in an odd or hidden place, mark with orange flag (also if transect bends).
6) Transect does not have to be straight, it can bend to avoid shady areas. Or you can run two parallel shorter transects, at least 15 m apart.
7) When you reach the far end of the transect, put in another sign and/or flag
8) Fill in the time (Time set out) on data sheet, and the number of bowls set out (30).
9) Take a photo of the transect from each end, make note of these on data sheet (in second section).
10) Walk back along transect (or have other people do this while you are setting bowls) and record the presence/absence of flowering plants (excluding graminoids) in a one meter band to the left and then the right of the transect in the interval between one cup and the next. You will record presence/absence in 58 sections total for one transect. See data sheet.

Bringing in bee bowls

(Retrieve bowls after 4 pm)

Equipment (per transect):
Whirl-Pak
Plastic funnel
Strainer
Forceps or tweezers
Ethanol (can use 70% ethanol or isopropyl alcohol from drugstore)
Data sheet
Pencil (NOT PEN!)
Ziploc bag for collecting bowls

1) Swirl contents of each bowl to get insects in suspension and then swiftly pour contents into strainer. If any insects remain in bowl, you can pick out with forceps if necessary (or just rap bowl on side of strainer to dislodge). Combine contents of ALL 30 bowls into the strainer.
2) Once all bowls are emptied (count them to make sure you didn't miss any), mark down time on data sheet (Time brought in).
3) Note down on data sheet any bowls that were empty either because they were tipped over or trampled/eaten/missing etc.
4) Tear top off of Whirl-Pak and pull tabs to open the mouth of the bag, then blow inside the bag to open it up. Place the plastic funnel tip inside the bag (you can hold the Whirl-Pak and the bag securely in one hand) and then, with your other hand, rap the strainer upside down on the funnel a few times to dislodge all insects into the funnel. If there are a lot of bugs, the hole of the funnel will get clogged, but you can gently shake the funnel and they should start to move down. Rinsing the sides of the funnel with ethanol will get the last specimens down into the Whirl-Pak.
5) Once you have all the insects in the Whirl-Pak, wash down any that are stuck to the sides of the bag so that they go down to the bottom with the rest. Make sure there is enough ethanol to cover the insects, but no excess.
6) **Tear off and add label. Label instructions are on the data sheet. Label goes INSIDE THE BAG with the insects. Use pencil. THIS IS THE MOST CRITICAL STEP!!!**
7) Get all the air out of the Whirl-Pak, then fold down the wire top several times, until you have folded down to where the insects are. Bend the two ends of the wire until you can twist them together.
8) Pick up flags and signs.
9) Check over data sheet to make sure everything is complete.

North Cascades/Olympic Insect Pollinator Monitoring Datasheet

Date: **Samplers:**

Site name/location:

Weather (cloud cover, wind, humidity etc.):

Air temp. (high projected for day):

Describe condition of transect location: (dominant plant species in bloom (if known), grass mowed, etc.)

Photos taken?

Number of bowls set out: **Time set out:** **Time brought in:**

Condition of bowls at pick-up: "all okay" (circle if true, or fill out below)

 # tipped over, destroyed, or dry:

 # bowls disappeared:

Explain disturbances if you can: humans, birds, other animals, wind??

Label for Sample (WRITE IN PENCIL, LABEL GOES INSIDE WHIRL-PAK)

Write the sample code (see below) + sampling date + initials of samplers

Sample code = OLYM-BB-xx or NOCA-BB-xx

(OLYM = park code; BB = bee bowl; xx = site identifier)

Example:

NOCA-BB-05

July 3, 2015

JR, LL

Write out two identical labels: leave the top one on the data sheet →

tear the bottom one off and place in Whirl-Pak ↓

More on back side

Bloom density next to transect:

Walk down transect from Start to End, and look an arm's length (~1m) left and right of transect. Record presence (√) or absence (0) of blooming flowers in interval between one cup and the next.

Count up total # of segments with blooming flowers (x/58):

Cup interval	Left side	Right side
1-2		
2-3		
3-4		
4-5		
5-6		
6-7		
7-8		
8-9		
9-10		
10-11		
11-12		
12-13		
13-14		
14-15		
15-16		
16-17		
17-18		
18-19		
19-20		
20-21		
21-22		
22-23		
23-24		
24-25		
25-26		
26-27		
27-28		
28-29		
29-30		

Example of a sign for putting at either end of a bee bowl transect to explain the purpose of the traps and to discourage disturbance.

Pollinators of Olympic National Park



Bumble bee



Mining bee



Flower fly

We are conducting a pollinator survey in the park focused on native bees and flower flies, two abundant and diverse groups of insects.

What are these colored bowls?



Bee bowls are painted blue, yellow, and white to resemble flowers and attract pollinators. They are laid out in transects of 15-30 bowls on warm, sunny days, when bees and flies are active. After a few hours, the bowls are collected and the insects are removed from the water.

PLEASE LEAVE THE TRAPS IN PLACE!

To learn more about this project, contact Jerry Freilich at Jerry_Freilich@nps.gov, 360-565-3082

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 149/145006, 168/145006, May 2018



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