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Research article

High Elevation Refugia for *Bombus terricola* (Hymenoptera: Apidae) Conservation and Wild Bees of the White Mountain National Forest

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Abstract

Many wild bee species are in global decline, yet much is still unknown about their diversity and contemporary distributions. National parks and forests offer unique areas of refuge important for the conservation of rare and declining species populations. Here we present the results of the first biodiversity survey of the bee fauna in the White Mountain National Forest (WMNF). More than a thousand specimens were collected from pan and sweep samples representing 137 species. Three species were recorded for the first time in New England and an additional seven species were documented for the first time in the state of New Hampshire. Four introduced species were also observed in the specimens collected. A checklist of the species found in the WMNF, as well as those found previously in Strafford County, NH, is included with new state records and introduced species noted as well as a map of collecting locations. Of particular interest was the relatively high abundance of *Bombus terricola* Kirby 1837 found in many of the higher elevation collection sites and the single specimen documented of *Bombus fervidus* (Fabricius 1798). Both of these bumble bee species are known to have declining populations in the northeast and are categorized as vulnerable on the International Union for Conservation of Nature's Red List.

Key words: Apoidea, Species of Greatest Conservation Need, Biodiversity, New England, New Hampshire

Bees are fundamental to a sustainable environment as they pollinate 90% of the world's flowering plants, which are essential to most functioning terrestrial ecosystems (Ollerton et al. 2011). Despite their significance as pollinators, research shows that bee populations are declining globally (Bartomeus et al. 2013, Burkle et al. 2013, Garibaldi et al. 2013, Potts et al. 2010, Kerr et al. 2015). Historically there were about 3,600 bee species recorded in the United States (Ascher and Pickering 2016, Wilson and Carril 2016) across 111 genera (Droege et al. 2016). These species span six different families, although the family Melittidae, comprised of 33 species in the United States with only 8 in the northeast, is rarely collected (Wilson and Carril 2016).

Of particular concern in the Northeast is the severe decline of several historically widespread bumble bee species, *Bombus affinis* Cresson 1863, *Bombus fervidus* (Fabricius 1798), *Bombus pensylvanicus* (DeGeer 1773), and *Bombus terricola* Kirby 1837 (Colla and Packer 2008, Grixti et al. 2008, Cameron et al. 2011, Colla et al. 2012, Bartomeus et al. 2013). These four species were listed as Species of Greatest Conservation Need (SGCN) in 2015 as part of the New Hampshire Fish and Wildlife Service Wildlife Action Plan (Normandeau 2015). With population ranges reduced by 87% (Cameron et al. 2011), *B. affinis*, is also listed as Critically Endangered by the International Union for Conservation of Nature (IUCN, Hatfield et al. 2015a). Populations of *B. fervidus* have shown significant declines in Guelph, Canada (Colla and Packer 2008), Vermont (McFarland et al. 2015, Normandeau 2015), New York (Giles and Ascher 2006, Normandeau 2015), while *B. pensylvanicus* has lost 23% of its historical range and is absent in much of its former northern and eastern territory (Cameron et al. 2011). Both species are listed as a vulnerable on the IUCN Red List (Hatfield et al. 2015b). Populations of *B. terricola* have suffered severe declines with historical range reductions as high as 31% (Cameron et al. 2011) and are listed for conservation priority by the Xerces Society for Invertebrate Conservation (Evans et al. 2008, xerces.org) and also as vulnerable by the IUCN (Hatfield et al. 2015c).

New England has the potential to support some of the highest levels of wild bee biodiversity in the Northeast with many protected areas and unique ecological niches (Chandler and Peck 1992, Goldstein and Ascher 2016, Koh et al. 2016). As recent studies in Massachusetts (Goldstein and Ascher 2016), Connecticut (Wagner et al. 2014), Maine (Bushmann and Drummond 2015), and New Hampshire (Tucker and Rehan 2016) have begun to document New England's wild bee biodiversity, many new state records, exotic introductions and species extirpations continue to be discovered in this relatively diverse and agriculturally important area. These prospective changes in New England biodiversity, along with the general global decline, emphasize the need for further surveys to monitor shifts in the wild bee community.

National parks and forests provide patches of protected habitat that can act as refuge to species in less than ideal environs sometimes leading to pockets of organisms rarely found elsewhere (Brown 1971, Dean 2000, Gillespie and Roderick 2002, Richards et al. 2011).The White Mountain National Forest (WMNF) contains 750,852 acres of protected land spanning three New Hampshire counties and over 100 miles of Appalachian Trail (USFS 2012) (Fig. 1). It is the largest alpine area in the eastern United States with its highest elevation at the peak of Mount Washington, which reaches 1,917 meters and classifies as tundra climate (Reiners and Lang 1979, Levesque and Burger 1982, Kimball and Weihrauch 2000, AMC 2016). The National Forest was first established in 1918, but has had few insect biodiversity assessments (McFarland 2003, Levesque and Burger 1982, McCall and Primack 1992, Chandler 1991) with little known about the wild bee fauna.

Here we document the first faunistic survey of wild bees in the WMNF. The objectives of this study were to, 1) provide a contemporary survey and species checklist of the wild bees currently inhabiting WMNF, 2) document any new or introduced species not historically recorded for the area, and 3) record any *Bombus* species found that are listed as SGCN by the NH Fish and Wildlife Action plan.

Methods

Location and Collection

Wild bee collection was conducted at 16 sites in northern New Hampshire over an approximate 331,520-acre area in the WMNF (geographic coordinates in Table 1; map Fig. 1). This sampling area covered a broad spectrum of elevations ranging from a low of 118 m to a high of 1,160m on Mount Washington (Table 1). Sampling was conducted over a 2-day period on 26 and 27 June 2015 and comprised an estimated 60 concerted man-hours. Bees were sampled using standard pan traps and sweep nets. About 300 pan traps (New Horizons Support Services, Inc., Upper Marlboro, MD; 3.5 oz.) of alternating color (yellow, blue, and white) were filled soapy water and set out for ~8 h. The pan trap contents were poured through a sieve upon retrieval. Sweep netting was performed using collapsible aerial nets (Bioquip 7112CP; 30.5 cm in diameter, 12.7 cm aluminum handles) and sampled all possible flower blooms at collecting locations. Both pan trap and sweep netted specimens were labeled with collection information and placed in vials of 70% ethanol. Elevations of individual collection sites were estimated using the recorded GPS coordinates and freemaptool.com/elevation-finder.

Curation and Preservation

Ethanol preserved specimens were washed under running tap water for 1 min, dried with a traveling bee dryer (a section of PVC pipe covered with a fine screen that a hair dryer blows through; modified from devices in Droege 2015), pinned and labeled with locality information. All specimens were identified to species, or species-group where appropriate, using standard taxonomic literature (Mitchell 1960; 1962, Michener et al. 1994, Gibbs 2011, Rehan and Sheffield 2011, Williams et al. 2014) and the identification guides available on DiscoverLife.org. To determine species previously documented in the state of New Hampshire specimens were compared to distribution records on DiscoverLife.org and records compiled from Bartomeus et al. (2013) and Tucker and Rehan (2016). Exotic species introductions were identified using the Very Handy Manual (Droege 2015). Voucher specimens are deposited in the University of New Hampshire Insect Collection (Durham, NH), USGS Native Bee Inventory and Monitoring Lab collection (Beltsville, MD), and the National Museum of Natural History (Washington, DC).

Results

Diversity and Abundance

A total of 1,010 bee specimens were collected from pan trap and sweep net sampling (Table 2). Of the specimens collected, 137 species were identified, in 18 genera, representing five bee families. Halictidae was by far the most abundant family represented with 472 specimens collected compared with 231 Apidae and 212

Table 1. WMNF collection site information. Numbers correspond to those found on the map in Figure 1

Map number	Nearest Town	Latitude	Longitude	Elevation (m)	Bee Abundance	Bee Diversity
1	Milan	44.6	−71.2	334	18	16
2	Berlin	44.5	−71.3	434	194	63
3	Randolph	44.4	−71.3	892	68	28
4	Gorham	44.4	−71.1	349	119	43
5	Jefferson	44.4	−71.4	612	33	26
6	Whitefield	44.4	−71.6	390	8	7
7	Pinkham's Grant	44.3	−71.2	619	21	17
8	Mount Washington Area	44.3	−71.3	1160	157	40
9	Bretton Woods	44.3	−71.4	967	112	29
10	Bartlett	44.1	−71.3	343	68	26
11	Livermore	44.0	−71.4	419	13	7
12	Hart's Location	44.1	−71.4	783	2	2
13	Albany	44.0	−71.2	512	35	23
14	Conway	44.0	−71.1	184	111	35
15	Benton	44.0	−71.8	957	15	6
16	Hanover	43.7	−72.3	118	36	17
Total for all towns in survey					***1010***	***137***
*	Durham	43.1	−71.0	26	2297	118

Total abundance and diversity counts for this survey are in bold italics. Collection information for comparison purposes from the Tucker and Rehan (2016) study in Strafford County, NH is marked with an asterisk.

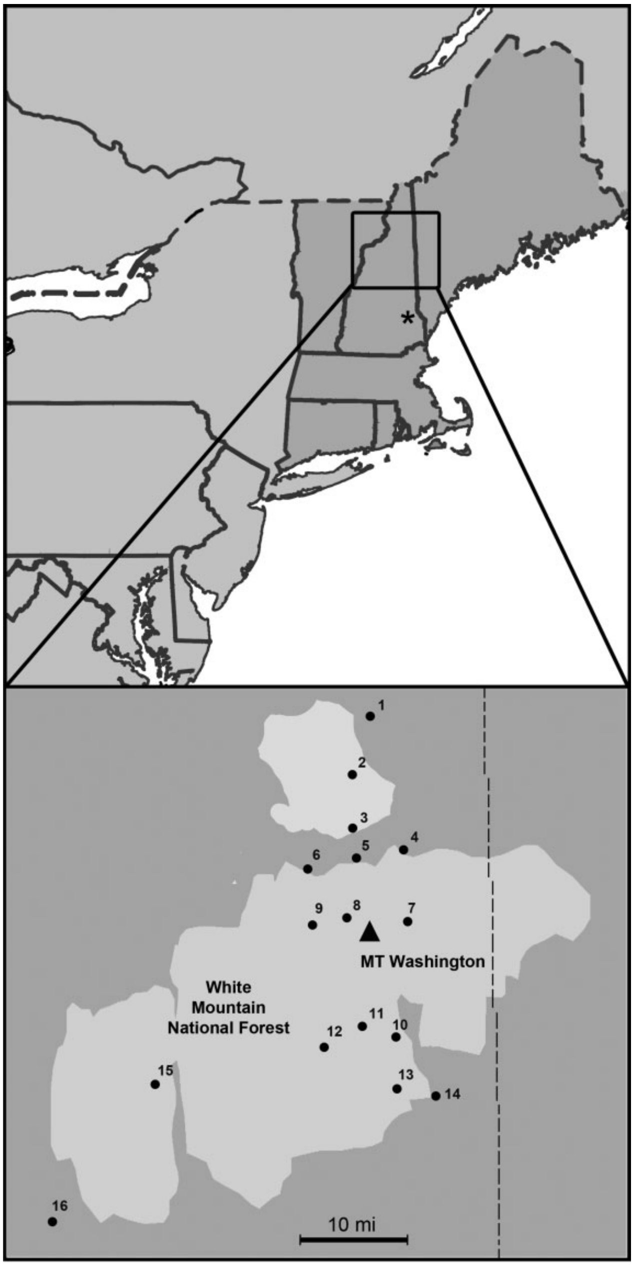

Fig. 1. Top: WMNF relative to the northeast. New England is shaded in darker gray. The asterisk marks Durham, Strafford County, NH. Bottom: An enlargement of WMNF in light gray with black dots representing collecting locations (Table 1). The black triangle denotes the peak of Mount Washington. The dashed line shows the New Hampshire and Maine state boundary.

Andrenidae. It was also the most diverse with 52 species followed by 33 Andrenidae, 23 Apidae, 21 Megachilidae, and 6 Colletidae species. The most abundant genera were *Lasioglossum* (301 specimens), *Andrena* (202 specimens) and *Bombus* (182 specimens). *Lasioglossum* was also the most diverse genera with 37 species and *Andrena* close behind with 31 species. Although Halictidae was both the most abundant and diverse family, the two most abundant species found were *Andrena wilkella* (Kirby 1802) (Andrenidae, 81 specimens) and *B. terricola* (Apidae, 73 specimens). Both the highest abundance and diversity of bees in the WMNF were found at an elevation of 434m near Berlin, NH (Table 1). We also found 73 species (Fig. 2, Table 2) in the WMNF that were not found at lower elevations (26 m) the previous year (2014) in Strafford County, New Hampshire, during a comprehensive bee biodiversity survey (Tucker and Rehan 2016).

New Records and Introduced Species

Three species were discovered for the first time in New England from this survey (*Andrena nigra*, Provancher 1895*; Lasioglossum hemimelas*, Cockerell 1901; *Lasioglossum seillean*, Gibbs and Packer 2013). Seven species were documented for the first time in New Hampshire (*Andrena accepta*, Viereck 1916*; Andrena heraclei*, Robertson 1897; *Hoplitis simplex*, Cresson 1864*; Hylaeus nelumbonis*, Robertson 1890*; Lasioglossum creberrimum*, Smith 1853*; Lasioglossum sagax*, Sandhouse 1924*; Sphecodes coronus*, Mitchell 1956; Table 2). Four introduced species (indicated by an asterisk in Table 2) were found in the WMNF (*A. wilkella, Anthidium manicatum*, (L.) 1758*; Anthidium oblongatum*, Illiger 1806*; Lasioglossum leucozonium*, Schrank 1781). All of these species have previously been recorded in the state of New Hampshire and, except for *L. leucozonium*, are relatively common species well established throughout the Northeast (Droege 2015).

The composition of the bee species recorded in the WMNF was also different than what has previously been recorded in other parts of New England. Of the 137 species recorded in the WMNF survey, 72 species were unique to the higher elevation area, while 54 of the 118 species previously documented in Stafford County (elevation 26 m; Tucker and Rehan 2016) were not found in WMNF and only 64 species were found in both areas (Fig. 2, Table 2).

Species of Concern

We found a relatively large population (73 specimens) of the New Hampshire species of concern *B. terricola* in the WMNF. Sampled sites near Bretton Woods, elevation 967 m, had the highest number of specimens recorded (20) with survey locations near Conway (elev. 184 m, 17 specimens) and Berlin (elev. 434 m) also containing many (12) specimens of *B. terricola*. One specimen of *B. fervidus* was discovered in Hanover (elev. 118 m). We did not find any specimens of the other two species of concern: *B. affinis* or *B. pensylvanicus*.

Discussion

Abundance and Diversity

In the intensive 60 man-hour collecting period we found 137 wild bee species in the WMNF, which is a remarkable amount of diversity compared with much longer studies. In a 1-year period 124 bee species were found in St. Catharines, Ontario (Richards et al. 2011) and 118 in Strafford County, New Hampshire (Tucker and Rehan 2016). Over a 2-year period only 54 species were found in Illinois (Burkle et al. 2013) and 64 species in Pennsylvania (Russo et al. 2013), with higher diversity found in Connecticut with 163 species (Wagner et al. 2016) and Massachusetts with 182 species (Goldstein and Ascher 2016). In three years, 133 bee species were recorded in Maine (Bushmann and Drummond 2015), yet only 54 species were documented during a 4-year survey and 104 species in a 6-year survey in New York (Matteson et al. 2008, Russo et al. 2015) with an even longer 10-year study in Ontario only finding 150 species (Onuferko et al. 2015).

Despite these concerted collecting efforts and variable duration of these studies, many species that are known to be in the area are still missed as historical state records estimate 400 species in Ontario (MacKay and Knerer 1979, Grixti and Packer 2006, Sheffield et al.

Table 2. Species checklist of all the wild bee species recorded in the WMNF in June, 2015 and previously published records for Strafford County, NH in 2014 (Tucker and Rehan 2016)

Family	Species	Species authority	New record	WMNF abundance	WMNF relative abundance	Tucker and Rehan abundance	Tucker and Rehan relative abundance
Andrenidae							
	Andrena accepta	Viereck 1916	yes	1	0.1%	–	–
	Andrena alleghaniensis	Viereck 1907		3	0.3%	1	0.04%
	Andrena asteris	Robertson 1891		–	–	6	0.26%
	Andrena bisalicis	Viereck 1908		–	–	1	0.04%
	Andrena braccata	Viereck 1907		–	–	3	0.13%
	Andrena brevipalpis	Cockerell 1930		2	0.2%	–	–
	Andrena canadensis	Dalla Torre 1896		1	0.1%	–	–
	Andrena carlini	Cockerell 1901		–	–	13	0.57%
	Andrena carolina	Viereck 1909		1	0.1%	1	0.04%
	Andrena ceanothi	Viereck 1917		2	0.2%	–	–
	Andrena commoda	Smith 1879		12	1.2%	3	0.13%
	Andrena confederata	Viereck 1917		2	0.2%	1	0.04%
	Andrena crataegi	Robertson 1893		21	2.1%	2	0.09%
	Andrena cressonii	Robertson 1891		5	0.5%	8	0.35%
	Andrena distans	Provancher 1888		–	–	4	0.17%
	Andrena dunningi	Cockerell 1898		–	–	4	0.17%
	Andrena erigeniae	Robertson 1891		–	–	6	0.26%
	Andrena erythronii	Robertson 1891		–	–	1	0.04%
	Andrena forbesii	Robertson 1891		2	0.2%	–	–
	Andrena fragilis	Smith 1853		–	–	1	0.04%
	Andrena frigida	Smith 1853		–	–	1	0.04%
	Andrena geranii	Robertson 1891		–	–	1	0.04%
	Andrena heraclei	Robertson 1897	yes	1	0.1%	–	–
	Andrena hilaris	Smith 1853		–	–	1	0.04%
	Andrena hippotes	Robertson 1895		2	0.2%	–	–
	Andrena hirticincta	Provancher 1888		–	–	3	0.13%
	Andrena ignota	LaBerge 1967		–	–	1	0.04%
	Andrena imitatrix	Cresson 1872		3	0.3%	1	0.04%
	Andrena kalmiae	Atwood 1934		1	0.1%	–	–
	Andrena krigiana	Robertson 1901		1	0.1%	1	0.04%
	Andrena mandibularis	Robertson 1892		1	0.1%	–	–
	Andrena mariae	Robertson 1891		1	0.1%	–	–
	Andrena milwaukeensis	Graenicher 1903		17	1.7%	–	–
	Andrena miranda	Smith 1879		4	0.4%	–	–
	Andrena miserabilis	Cresson 1872		2	0.2%	10	0.44%
	Andrena nasonii	Robertson 1895		–	–	1	0.04%
	Andrena nigra	Smith 1853	yes	1	0.1%	–	–
	Andrena nigrihirta	(Ashmead 1890)		5	0.5%	–	–
	Andrena nivalis	Smith 1853		8	0.8%	6	0.26%
	Andrena perplexa	Smith 1853		–	–	5	0.22%
	Andrena regularis	Malloch 1917		1	0.1%	1	0.04%
	Andrena robertsonii	Dalla Torre 1896		2	0.2%	1	0.04%
	Andrena rudbeckiae	Robertson 1891		–	–	1	0.04%
	Andrena rufosignata	Cockerell 1902		3	0.3%	–	–
	Andrena sigmundi	Cockerell 1902		–	–	2	0.09%
	Andrena simplex	Smith 1853		–	–	1	0.04%
	Andrena spiraeana	Robertson 1895		3	0.3%	–	–
	Andrena thaspii	Graenicher 1903		11	1.1%	–	–
	Andrena vicina	Smith 1853		–	–	2	0.09%
	Andrena w-scripta	Viereck 1904		4	0.4%	–	–
	*Andrena wilkella**	(Kirby 1802)		81	8.0%	13	0.57%
	Andrena ziziae	Robertson 1891		1	0.1%	–	–
	Calliopsis andreniformis	Smith 1853		7	0.7%	25	1.09%
	Calliopsis nebraskensis	Crawford 1902		–	–	2	0.09%
	Protandrena bancrofti	Dunning 1897		–	–	1	0.04%
Apidae							
	Anthophora terminalis	Cresson 1869		-	–	3	0.13%
	Bombus bimaculatus	Cresson 1863		8	0.8%	48	2.09%

(continued)

Table 2. continued

Family	Species	Species authority	New record	WMNF abundance	WMNF relative abundance	Tucker and Rehan abundance	Tucker and Rehan relative abundance
	Bombus borealis	Kirby 1837		2	0.2%	–	–
	Bombus fervidus	(F. 1798)		1	0.1%	1	0.04%
	Bombus griseocollis	(DeGeer 1773)		2	0.2%	4	0.17%
	Bombus impatiens	Cresson 1863		5	0.5%	423	18.42%
	Bombus perplexus	Cresson 1863		9	0.9%	1	0.04%
	Bombus sandersoni	Franklin 1913		16	1.6%	–	–
	Bombus ternarius	Say 1837		33	3.3%	–	–
	Bombus terricola	Kirby 1837		73	7.2%	–	–
	Bombus vagans	Smith 1854		33	3.3%	43	1.87%
	Ceratina calcarata	Robertson 1900		4	0.4%	33	1.44%
	Ceratina dupla	Say 1837		18	1.8%	16	0.70%
	Ceratina mikmaqi	Rehan and Sheffield 2011		7	0.7%	13	0.57%
	Ceratina strenua	Smith 1879		1	0.1%	–	–
	Melissodes druriella	(Kirby 1802)		–	–	4	0.17%
	Melissodes subillata	LaBerge 1961		–	–	5	0.22%
	Melissodes trinodis	Robertson 1901		–	–	1	0.04%
	Nomada articulata	Smith 1854		4	0.4%	3	0.13%
	Nomada australis	Mitchell 1962		1	0.1%	–	–
	Nomada bella	Cresson 1863		–	–	1	0.04%
	Nomada bidentate species-group			3	0.3%	–	–
	Nomada depressa	Cresson 1863		1	0.1%	–	–
	Nomada florilega	Lovell and Cockerell 1905		–	–	1	0.04%
	Nomada gracilis	Cresson 1863		1	0.1%	–	–
	Nomada lehighensis	Cockerell 1903		1	0.1%	–	–
	Nomada lepida	Cresson 1863		–	–	2	0.09%
	Nomada maculata	Cresson 1863		–	–	2	0.09%
	Nomada pygmaea	Cresson 1863		3	0.3%	–	–
	Nomada sayi	Robertson 1893		1	0.1%	–	–
	Nomada valida	Smith 1854		4	0.4%	–	–
	Peponapis pruinosa	(Say 1837)		–	–	3	0.13%
	Xylocopa virginica	(L. 1771)		–	–	25	1.09%
Colletidae							
	Colletes inaequalis	Say 1837		-	–	1	0.04%
	Hylaeus affinis	(Smith 1853)		-	–	8	0.35%
	Hylaeus affinis/modestus	(Smith 1853)/(Cockerell 1896)		7	0.7%	–	–
	Hylaeus annulatus	(L. 1758)		3	0.3%	1	0.04%
	Hylaeus basalis	(Smith 1853)		2	0.2%	–	–
	Hylaeus mesillae	(Cockerell 1896)		2	0.2%	1	0.04%
	Hylaeus modestus	Say 1837		9	0.9%	3	0.13%
	H. nelumbonis	(Robertson 1890)	yes	2	0.2%	–	–
Halictidae							
	Agapostemon sericeus	(Forster 1771)		8	0.8%	–	–
	Agapostemon texanus	Cresson 1872		2	0.2%	15	0.65%
	Agapostemon virescens	(F. 1775)		54	5.3%	410	17.85%
	Augochlora pura	(Say 1837)		4	0.4%	2	0.09%
	Augochlora aurata	(Smith 1853)		48	4.8%	161	7.01%
	Augochloropsis metallica	(F. 1793)		–	–	4	0.17%
	Halictus confusus	Smith 1853		13	1.3%	27	1.18%
	Halictus ligatus	Say 1837		25	2.5%	309	13.45%
	Halictus rubicundus	(Christ 1791)		7	0.7%	26	1.13%
	*Halictus tectus**	Radoszkowski 1876		–	–	1	0.04%
	Lasioglossum abanci	(Crawford 1932)		–	–	1	0.04%
	Lasioglossum achilleae	(Mitchell 1960)		–	–	1	0.04%
	Lasioglossum acuminatum	McGinley 1986		2	0.2%	–	–
	Lasioglossum admirandum	(Sandhouse 1924)		2	0.2%	21	0.91%
	Lasioglossum albipenne	(Robertson 1890)		–	–	10	0.44%
	Lasioglossum atwoodi	Gibbs 2010		–	–	1	0.04%
	Lasioglossum birkmanni	(Crawford 1906)		1	0.1%	–	–

(continued)

Table 2. continued

Family	Species	Species authority	New record	WMNF abundance	WMNF relative abundance	Tucker and Rehan abundance	Tucker and Rehan relative abundance
	Lasioglossum boreale	Svensson, Ebmer and Sakagami 1977		1	0.1%	–	–
	Lasioglossum bruneri	(Crawford 1902)		–	–	2	0.09%
	Lasioglossum cinctipes	(Provancher 1888)		1	0.1%	3	0.13%
	Lasioglossum coeruleus	(Robertson 1893)		–	–	1	0.04%
	Lasioglossum coriaceum	(Smith 1853)		29	2.9%	65	2.83%
	Lassioglossum creberrimum	(Smith 1853)	yes	2	0.2%	–	–
	Lassioglossum cressonii	(Robertson 1890)		52	5.1%	67	2.92%
	Lasioglossum ephialtum	Gibbs 2010		8	0.8%	–	–
	Lasioglossum fuscipenne	(Smith 1853)		2	0.2%	11	0.48%
	Lassioglossum hemimelas	(Cockerell 1901)	yes	1	0.1%	–	–
	Lasioglossum heterognathum	(Mitchell 1960)		–	–	1	0.04%
	Lasioglossum hitchensi	Gibbs 2012		1	0.1%	2	0.09%
	Lasioglossum imitatum	(Smith 1853)		16	1.6%	1	0.04%
	Lasioglossum inconditum	(Cockerell 1916)		2	0.2%	–	–
	Lasioglossum laevissimum	(Smith 1853)		2	0.2%	17	0.74%
	Lasioglossum leucocomum	(Lovell 1908)		10	1.0%	2	0.09%
	*Lassioglossum leucozonium**	(Schrank 1781)		10	1.0%	5	0.22%
	Lasioglossum lineatulum	(Crawford 1906)		–	–	5	0.22%
	Lasioglossum macoupinense	(Robertson 1895)		2	0.2%	–	–
	Lasioglossum nigroviride	(Graenicher 1911)		10	1.0%	–	–
	Lasioglossum nr. tenax	(Sandhouse 1924)		5	0.5%	–	–
	Lasioglossum nymphaerum	(Cockerell 1916)		5	0.5%	5	0.22%
	Lasioglossum oblongum	(Lovell 1905)		6	0.6%	–	–
	Lasioglossum oenotherae	(Stevens 1920)		6	0.6%	–	–
	Lasioglossum paradmirandium	(Knerer and Atwood 1966)		5	0.5%	4	0.17%
	Lasioglossum pectorale	(Smith 1853)		17	1.7%	6	0.26%
	Lasioglossum pilosum	(Smith 1853)		37	3.7%	89	3.87%
	Lasioglossum planatum	(Lovell 1905)		4	0.4%	–	–
	Lasioglossum quebecense	(Crawford 1907)		–	–	2	0.09%
	Lassioglossum sagax	(Sandhouse 1924)	yes	11	1.1%	–	–
	Lassioglossum seillean	Gibbs and Packer 2013	yes	1	0.1%	–	–
	Lasioglossum smilacinae	(Robertson 1897)		1	0.1%	–	–
	Lasioglossum sp.			8	0.8%	6	0.26%
	Lasioglossum subversans	(Mitchell 1960)		5	0.5%	–	–
	Lasioglossum subviridatum	(Cockerell 1938)		1	0.1%	–	–
	Lasioglossum taylorae	Gibbs 2010		2	0.2%	–	–
	Lasioglossum tegulare	(Robertson 1890)		17	1.7%	69	3.00%
	Lasioglossum truncatum	(Robertson 1901)		–	–	1	0.04%
	Lasioglossum versans	(Lovell 1905)		9	0.9%	3	0.13%
	Lasioglossum versatum	(Robertson 1902)		5	0.5%	84	3.66%
	Lasioglossum viridatum	(Lovell 1905)		2	0.2%	–	–
	*Lasioglossum zonulum**	(Smith 1848)		–	–	1	0.04%
	Sphecodes antennariae	Robertson 1891		–	–	1	0.04%
	Sphecodes clematidis	Robertson 1897		–	–	2	0.09%
	Sphecodes coronus	Mitchell 1956	yes	2	0.2%	–	–
	Sphecodes cressonii	(Robertson 1903)		1	0.1%	–	–
	Sphecodes johnsonii	Lovell 1909		–	–	2	0.09%
	Sphecodes levis	Lovell and Cockerell 1907		2	0.2%	1	0.04%
	Sphecodes minor	Robertson 1898		1	0.1%	–	–
	Sphecodes prosphorus	Lovell and Cockerell 1907		1	0.1%	–	–
	Sphecodes sp.	–		1	0.1%	1	0.04%
	Sphecodes species_A	–		1	0.1%	–	–
	Sphecodes species_D	–		1	0.1%	–	–
Megachilidae							
	*Anthidium manicatum**	(L. 1758)		1	0.1%	1	0.04%
	*Anthidium oblongatum**	(Illiger 1806)		3	0.3%	8	0.35%
	Coelioxys porterae	Cockerell 1900		1	0.1%	–	–
	Coelioxys sayi	Robertson 1897		1	0.1%	–	–
	Coelioxys sodalis	Cresson 1878		3	0.3%	–	–

(continued)

Table 2. continued

Family	Species	Species authority	New record	WMNF abundance	WMNF relative abundance	Tucker and Rehan abundance	Tucker and Rehan relative abundance
	Heriades carinata	Cresson 1864		1	0.1%	2	0.09%
	Hoplitis producta	(Cresson 1864)		13	1.3%	–	–
	Hoplitis simplex	(Cresson 1864)	yes	1	0.1%	–	–
	Hoplitis spoliata	(Provancher 1888)		1	0.1%	1	0.04%
	Hoplitis truncata	(Cresson 1878)		2	0.2%	–	–
	Megachile centuncularis	(L. 1758)		–	–	2	0.09%
	Megachile gemula	Cresson 1878		8	0.8%	–	–
	Megachile inermis	Provancher 1888		–	–	4	0.17%
	Megachile latimanus	Say 1823		2	0.2%	–	–
	Megachile melanophaea	Smith 1853		12	1.2%	–	–
	Megachile relativa	Cresson 1878		6	0.6%	1	0.04%
	Osmia albiventris	Cresson 1864		1	0.1%	–	–
	Osmia atriventris	Cresson 1864		3	0.3%	3	0.13%
	Osmia bucephala	Cresson 1864		2	0.2%	–	–
	Osmia collinsiae	Robertson 1905		1	0.1%	–	–
	*Osmia cornifrons**	(Radoszkowski 1887)		–	–	1	0.04%
	Osmia proxima	Cresson 1864		5	0.5%	–	–
	Osmia georgica	Cresson 1878		–	–	1	0.04%
	Osmia inermis	(Zetterstedt 1838)		–	–	9	0.39%
	Osmia inspergens	Lovell and Cockerell 1907		–	–	6	0.26%
	Osmia pumila	Cresson 1864		2	0.2%	–	–
	Osmia tersula	Cockerell 1912		1	0.1%	–	–
	*Osmia taurus**	Smith 1873		–	–	1	0.04%
Melittidae							
	Melllita eickworti	Snelling and Stage 1995		–	–	1	0.04%

New records are the first documentation of a species for the state of New Hampshire. Species with asterisk are introduced species.

2011), about 325 in New Hampshire (Discoverlife.org), 296 in Illinois (Marlin and LaBerge 2001), 371 species historically in Pennsylvania (Donovall and vanEngelsdorp 2010), at least 355 species in Connecticut (discoverlife.org), 377 documented in Massachusetts (Goldstein and Ascher 2016), 329 in Maine (discoverlife.org), and 447 species historically in New York (Ascher et al. 2014).

Obtaining accurate documentation of a region's diverse bee fauna is not an easy task (Russo et al. 2015). Documentation of bee community diversity is exasperated by its inclusion of many rare and few abundant species that often exhibit significant annual variation and cryptic morphologies (Olesen and Jordano 2002, Wilson et al. 2008, Grundel et al. 2011, Russo et al. 2011). Both short term intensive surveys spanning many locations as well as long term studies conducted in the same location are required for representative species monitoring and documentation.

Where we found *A. wilkella* (an introduced species) and *B. terricola* (a species of concern) to be the dominant presence (Fig. 2, Table 2), other studies have found *Bombus impatiens* (Cresson 1863) to be dominant (Matteson et al. 2008, Russo et al. 2011, Tucker and Rehan 2016) as well as *Augochlorella aurata* (Smith 1853) (Wagner et al. 2014, Goldstein and Ascher 2016) and *Lasioglossum cressonii* (Robertson 1890) (Bushmann and Drummond 2015). The high abundance of *A. wilkella* found in the WMNF is, however, concordant with recent bee surveys, which also found this species to be widely distributed and abundant in Massachusetts (Goldstein and Ascher 2016). For a complete species list of the WMNF or New Hampshire in general, long-term surveys are needed as highlighted by the difference in species composition (Fig. 2) found in this study compared with that of Tucker and Rehan (2016). Although some differences in species composition may be attributed to different habitat or elevations between collection sites, much is likely due to the short-term nature of both studies (2 days and 1 year; Minckley et al. 1999; Grixti and Packer 2006) as many species found in just one of the two habitats are only represented by a few specimens (Table 2).

New Records and Introduced Species

Other species of note that were collected in the WMNF were three singleton specimens: one andrenid and two halictids. *A. nigra* is primarily a western species with few records east of the Rocky Mountains (DiscoverLife.org). *L. hemimelas* typically ranges throughout the Midwest, while the specimen of *L. seillean* represents the southern most record of this northern species that is reported to be restricted to high altitudes (Gibbs et al. 2013). *L. seillean* has been recorded as far south as Michigan, but is typically found from the Northwest Territories to Newfoundland and south to New Brunswick (DiscoverLife.org, Gibbs et al. 2013). It is possible that these specimens may predict future range expansions for these species; however, more data would certainly be needed to support this conjecture. The other seven species representing new state records were somewhat expected as they have previously been found in the northern New England region, but not previously documented in New Hampshire.

Species of Concern

There was a relatively high abundance of *B. terricola* (40% of collected *Bombus*) found in the WMNF. A low abundance of this species (1% of collected *Bombus* records) was recently found in Maine (Bushmann and Drummond 2015), but this species is not reported in any of the other bee faunal studies in New England (Wagner et al.

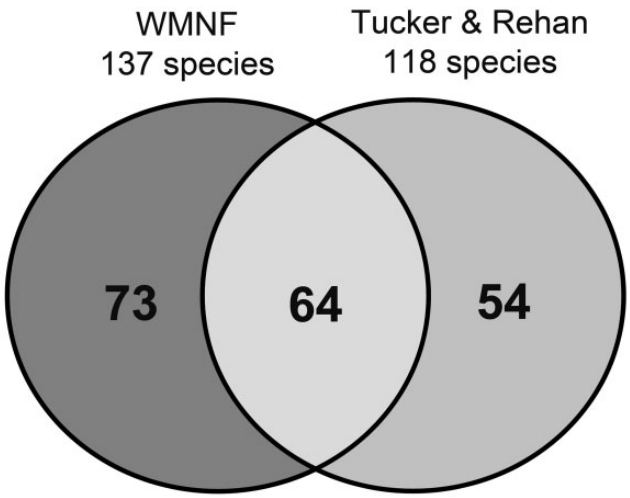

Fig. 2. Venn diagram depicting the species of overlap (light gray) between wild bees surveyed in the WMNF (dark gray) and those documented by Tucker and Rehan (2016) in the same state at a much lower elevation in Strafford County, NH (medium gray).

2014, Goldstein and Ascher 2016, Tucker and Rehan 2016). This high abundance of *B. terricola* does however corroborate some findings suggesting populations may still be enduring, but relegated to areas of higher elevation (Colla et al. 2012, Hatfield et al. 2015c). The seeming relegation of *B. terricola* populations to higher elevation refugial habitats may lead to evolutionary consequences detrimental to the species long-term persistence (Cameron et al. 2011). Bees tend to be particularly vulnerable to genetic threats, reducing community fitness and species potential viability, especially in small population sizes (Zayed 2009). If populations of *B. terricola* become isolated in these high elevation refugia, reduced gene flow between populations could contribute to further species decline (Cameron et al. 2011).

A single specimen of *B. fervidus* was collected during this survey. Only a single specimen of this species was found in the recent Massachusetts survey (Goldstein and Ascher 2016), with two specimens (0.2% of total *Bombus*) found in Maine in 2010 (Bushmann and Drummond 2015). An additional 14 specimens were found in Connecticut between 2005 and 2006, but this still only made up 4% of all the *Bombus* collected during that study (Wagner et al. 2014). We did not find any specimens of the two other bumble bee species of concern, *B. affinis* and *B. pensylvanicus*. What was historically a common species throughout eastern North America (Millrion 1971, Hatfield et al 2015a), *B. affinis*, is now believed to be on the brink of extinction and is closely related to *B. terricola* (Cameron et al. 2007). Based on data from the University of New Hampshire Insect Collection (UNHC) the last time *B. affinis* was documented in New Hampshire was 1993 when one specimen was discovered in Durham. There was however a single specimen sighted in Maine and one in Connecticut in 2015 (BumbleBeeWatch.org). It is even longer since *B. pensylvanicus* has been recorded in New Hampshire, although it was seldom documented historically in the state, with only six records (out of 1,246 total *Bombus* records, >0.1%) between 1899 and 1965 (UNHC). The last record of *B. pensylvanicus* in the state of New Hampshire was in Durham in 1965 (UNHC) and since then appears to be locally extirpated.

Conclusions

Protected areas such as national parks and forests can provide safe havens for vulnerable and endangered species of concern. This survey found the WMNF to be an excellent example of a terrestrial refuge for wild bees with its broad diversity of species being more speciose than other areas in the Northeast including relatively nearby habitats in the same state. Despite our thorough sampling of the WMNF, it is likely there are many more species residing and taking refuge in the WMNF as most ecosystems have a high species composition turnover and we sampled during a single two-day collection period. In addition to the high species diversity, the WMNF also appears to be a sanctuary for a considerable abundance of *B. terricola*, a species of particular concern in North America. The presence of *B. terricola*, as well as *B. fervidus* and numerous new state records including several species far outside their historical geographic range, underscores the importance of protected land areas in invertebrate conservation and the need for further bee biodiversity studies throughout New England.

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