Wild Bees (Hymenoptera: Apoidea) of the Ossipee Pine Barrens

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Abstract - The pine barrens of the American Northeast is a globally rare and endangered landscape. The handful of pine barrens remaining in the Northeast provide valuable habitat to many threatened and endangered plant and animal (including insect) species, yet little is known about the bee fauna in this habitat. Here we present the results of the first faunal bee survey of the Ossipee Pine Barrens (OPB) in New Hampshire. We collected over 800 specimens from pan and sweep samples representing 95 species. We documented 1 species, *Megachile mucida*, for the first time in the state of New Hampshire and recorded 4 introduced species. In addition to general surveying, we surveyed landscapes with 4 different types of management for the OPB. Landscapes that incorporated both burning and mowing after burning into the management regime supported bee communites that had significantly greater abundance than all other treatments and greater species richness than all other landscapes, though not signficantly higher than those that were mowed without burning.

Introduction

Northeastern *Pinus* (pine) barrens are characterized by nutrient-poor, fire-dependent forest ecosystems dominated by *Pinus rigida* Mill. (Pitch Pine; Pinaceae) and *Quercus ilicifolia* Wangenh. (Scrub Oak; Fagaceae). These ecosystems are globally rare (G2-ranked community type: 6–20 occurrences worldwide) and only represented by a handful of forests scattered across the Northeast (Maine, New Hampshire, Massachusetts, New York, and Pennsylvania) (Bried and Dillon 2012, Bried et al. 2014, Howard et al. 2011, Patterson et al. 2016). Pine barrens are known to support habitat specialists and help sustain some rare and endangered plants and animals such as *Antrostomus vociferus* Wilson (Eastern Whip-poor-will), *Sylvilagus obscurus* Chapman, Cramer, Dippenaar, & Robinson (Appalachian Cottontail), *Plebejus melissa samuelis* Nabokov (Karner Blue Butterfly), and *Callophrys irus* (Godart) (Frosted Elfin Butterfly) (Bried et al. 2014, Leuenberger et al. 2016, NatureServe 2017, Swengel 1998).

Fire-dependent habitats, such as pine barrens, also have the potential to provide bee-friendly habitat (Bried and Dillon 2012). Forests and grasslands that are thinned periodically by burning provide more open ground for nesting sites, can stimulate growth of annual flowers and prolong flowering periods (Campbell et al. 2018, Grundel et al. 2010, Mola et al. 2018, Wrobleski and Kauffman 2003). In burned pine forest habitats in Greece, Turkey, and Finland, bee abundance was found to be significantly greater than in non-burned pine forest habitats (Potts 2006, Rodriguez and Kouki 2015). Similarly, in California grasslands, *Bombus*

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spp. (bumble bees) and floral abundance were also found to be greater in burned compared to non-burned sites (Mola et al. 2018). While burned pine forests and grasslands are not the same as pine barrens, they give some insight into the effect fire has on bees in fire-dependent ecosystems.

The Ossipee Pine Barrens (OPB) of New Hampshire is one of the largest pine barrens in New England and is considered an endangered landscape (Howard et al. 2011, The Nature Conservancy 2018). Consisting of about 1093 ha, it is situated across 5 towns in Carroll County, NH: Effingham, Freedom, Madison, Ossipee, and Tamworth (Howard et al. 2011, The Nature Conservancy 2018). Despite the potential to support rare and unique species, there is still little known about the pine barrens' wild bee community (Bried and Dillon 2012, Wheeler 1991). Here we document the first faunistic survey of wild bees in the (OPB). The objectives of this study were to: (1) provide a contemporary survey and species checklist of the wild bees currently inhabiting the OPB, (2) evaluate how bee species composition in the OPB varies from that in nearby regions, and (3) determine how wild bees are affected by different habitats and management regimes within the pine barrens.

Methods

Field-site description

We sampled wild bees from 27 sites across 7 towns (Fig. 1, Table 1) in northern New Hampshire in the OPB. These sites were concentrated in and around The Nature

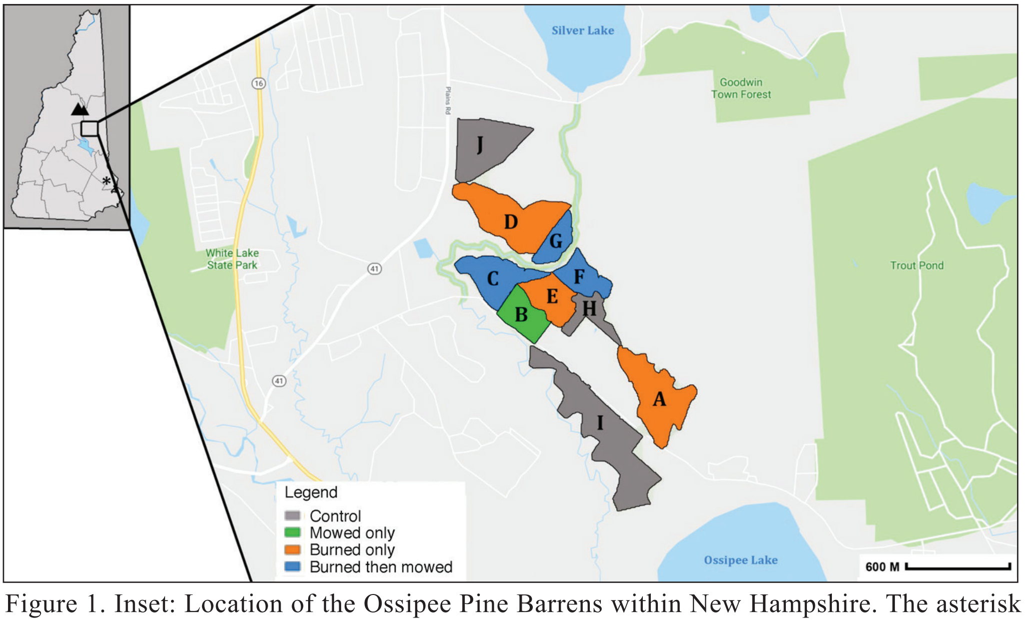

Figure 1. Inset: Location of the Ossipee Pine Barrens within New Hampshire. The asterisk marks Strafford County, NH, and the double triangles mark the White Mountains National Forest. The square indicates the location of the Ossipee Pine Barrens. Enlarged section: Map of the treatment areas sampled in the Ossipee Pine Barrens, with A–J corresponding to coordinates listed in Table 1 (treatment map provided by the Nature Conservancy). Burned and then mowed treatments are in blue, burned-only in orange, control in grey, and mowed-only in green.

Conservancy land (43.78°N, 71.10°W), covering an area of ~5.90 km² with an average elevation of 195 m. We assigned 9 of these sites to a specific treatment based on management regime information and maps provided by The Nature Conservancy (Fig. 1). Treatments and sample size (*n*) are as follows: burned then mowed (2), burned only (3), mowed only (1), and unmanaged wild areas designated as controls (3). The only control site to have any human management was Site H, which was a gravel pit and is now a restoration area that has been replanted since 2012–2013 with species that normally occur in in the understory of this pine barrens habitat, including Pitch Pine, Scrub Oak, and some *Vaccinium* (blueberry) and *Schizachyrium scoparium* (Michx.) Nash (Little Bluestem). It has not been mowed, burned, or otherwise altered except for replanting. All burned sites (including burned-only sites) underwent a single pre-burn mow to control fuel load and make the burn safer. Burned and then mowed sites were mowed again ~1 yr after the burn, with

Table 1. Ossipee Pine Barrens collection site information. Abund. = abundance, Rich. = richness, Elev. = elevation.

#	Location	Treatment	Nearest town	Coordinates (°N, °W)	Bee Abund.	Bee Rich.	Elev. (m)
1	3 Plains Road	-	Tamworth	43.887, 71.178	2	2	246
2	Bear Camp	-	Ossipee	43.798, 71.158	15	7	179
3	Burke Field	-	Tamworth	43.896, 71.155	95	19	246
4	Camp area pasture	-	Tamworth	43.846, 71.257	57	13	246
5	Deer Hill Road	-	Tamworth	43.887, 71.184	20	11	246
6	Eaton swimming pond	-	Eaton	43.900, 71.044	1	1	285
7	Goodwin town forest	-	Madison	43.852, 71.153	80	29	187
8	Junction of Highways 28 and 153	-	Effingham	43.792, 71.035	18	10	151
9	Lily Pond	-	Madison	43.836, 71.187	26	16	187
10	Madison Lot	-	Silver Lake	43.866, 71.187	44	24	180
11	Mason Road	-	Ossipee	43.804, 71.056	18	11	179
12	McDonalds	-	Tamworth	43.820, 71.205	3	3	246
13	Ossipee Road	-	Ossipee	43.794, 71.054	5	3	179
14	Ossipee Valley Cemetery	-	Ossipee	43.832, 71.258	10	3	179
15	Pizza Barn	-	Ossipee	43.793, 71.178	12	9	179
16	Site A	Burned	Freedom	43.822, 71.162	34	21	139
17	Site B	Mowed	Freedom	43.831, 71.178	18	14	139
18	Site D	Burned	Madison	43.839, 71.182	5	4	187
19	Site E	Burned	Freedom	43.833, 71.173	29	13	139
20	Site F	Burned then mowed	Madison	43.837, 71.171	113	27	187
21	Site G	Burned then mowed	Tamworth	43.837, 71.173	32	18	246
22	Site H	Control	Freedom	43.831, 71.169	35	21	139
23	Site I	Control	Freedom	43.828, 71.175	2	4	139
24	Site J	Control	Madison	43.846, 71.185	3	3	187
25	Smith Flats	-	Tamworth	43.833, 71.236	119	21	246
26	Stillings Lane	-	Freedom	43.793, 71.066	16	10	139
27	Unamed road	-	Ossipee	43.829, 71.173	1	1	179

Site F having been burned in August 2009 and 2013 and Site G in September 2007 and October 2016. Of the burned-only sites, site A was burned in October 2013, while site D and E were burned in September 2010. The mowed-only site, Site B, was mowed in late fall 2016. We estimated site elevations with FreeMapTools (https://www.freemaptools.com/elevation-finder.htm) using the GPS coordinates of collection sites as input.

We conducted sampling on 24 June 2017 as part of the New England Bee Bioblitz annual event by 15 people for an estimated 45 working hours of sweep netting. It was an overcast morning and sunny afternoon. We employed about 300 standard pan traps for passive collection of bees. These traps were of alternating colors (white, yellow, blue), filled with soapy water, and set out 10 m apart in a transect line for ~6 h. Transect lines were in short vegetation or cleared areas to allow bees to find the traps. We also actively collected bees using standard Bioquip (Bioquip Pruducts, Inc., Rancho Dominguez, CA) collapsible aerial nets for sweeping. We sampled all possible flowering plant blooms throughout collecting locations. We excluded from analyses all *Apis mellifera* L. (Western Honey Bee; Apidae) specimens because the focus of the study was on unmanaged wild bees. We labeled with locality information and stored in vials of 70% ethanol specimens from both methods of collection.

Curation and preservation

We washed, dried, and processed all specimens, to each of which we assigned a unique QR code identification number following procedures in Droege (2015) and Tucker and Rehan (2017a, b). We identified all specimens to species using the following identification guides: Gibbs (2011) for metallic *Lasioglossum* (Halictidae), Mitchell (1960, 1962) for *Nomada*, Rehan and Sheffield (2011) for *Ceratina* (Apidae), and www.DiscoverLife.org (Ascher and Pickering 2017; referenced in DiscoverLife: Coelho 2004, Grigarick 1968, Laverty and Harder 1988, Michener 2000, Michener et al. 1994, Mitchell 1980, Ordway 1966, Plowright and Pallett 1978) for all other genera. To identify any potential new state records, we compared our lists to those of Bartomeus et al. (2013), Tucker and Rehan (2016, 2017a, 2018), www.DiscoverLife.org (Ascher and Pickering 2017), and the digital records available from the University of New Hampshire Insect Collection database (UNHC 2018). We used the *Very Handy Bee Manual* (Droege 2015) to identify introduced bee species. Voucher specimens and associated data are deposited in the University of New Hampshire Insect Collection (Durham, NH).

Analyses

We compiled datasets to compare species richness variation among the OPB, the White Mountain National Forest (WMNF; Tucker and Rehan 2017a), and long-term surveys conducted in Strafford County, NH (Tucker and Rehan 2017b, 2018; UNHC 2018). We employed the interactive tool VENNY (Oliveros 2007) to visualize variation in species coexistence and exclusivity in relation to different habitats.

We compiled additional datasets to examine abundance and richness variation of bee species for management regimes in the OPB. We used generalized linear models (GLM) with bee abundance and bee species as variables under a Poisson distribution and performed statistical analyses in R (R Core Team 2015) with the associated packages 'ggfortify' (Horikoshi and Tang 2015) and 'multcomp' (Hothorn et al. 2008). We subsequently performed a post-hoc Tukey analysis on any significant results.

Results

Bees of the OPB

Pan trap and sweep net samples collected a total of 815 bee specimens. These specimens represented 5 families, 19 genera, and 95 species (Table 2). Halictidae was the most abundant and diverse family, with 405 specimens representing 33 species. Abundance of Halictidae was largely comprised of *Halictus ligatus*, with 104 specimens. Andrenidae was the next most abundant family, with 182 specimens representing 19 species, and Megachilidae was the second most diverse, with 22 species represented in the 94 specimens collected. We collected 112 specimens of Apidae representing 16 wild bee species. We collected 5 species and 22 specimens of Colletidae, all in the genus *Hylaeus*. In the OPB, bees were most abundant in Smith Flats, while we detected the greatest richness in Goodwin Town Forest (Table 1).We recorded the species *Megachile mucida* for the first time in the state of New Hampshire during the course of this survey. Additionally, we found 3 introduced bee species, *Andrena wilkella*, *Lasioglossum leucozonium,* and *Anthidium oblongatum* (Table 2).

OPB bee similarity to nearby regions

Despite the relative close proximity of OPB to the WMNF (~48 km), bee species composition varied greatly between the 2 regions. Tucker and Rehan (2017a) sampled bees from the WMNF with similar protocols at about the same time of year. Of the 95 species collected in the OPB, we found 30 species exclusively in the OPB and 65 species in both regions (Fig. 2). Species composition was also notably different than in Strafford County, NH (~97 km south of OPB), where thorough long-term bee surveys have been conducted (Tucker and Rehan 2017b, 2018). In comparison to Strafford County, we found 7 bee species sampled only at the OPB and 88 species present in both Strafford County and the OPB (Fig. 2). In comparison with both the WMNF and Strafford County, 5 species were only found in the OPB (Andrenidae: 1, Megachilidae: 2, Apidae: 2; Fig. 2). There were 2 species of Andrenidae—*Andrena brevipalpis* and *Andrena ceanothi*—found in the OPB and WMNF, but not in Strafford County despite extensive surveying in that area (Fig. 2).

Management regime effects

We collected a total of 271 bees representing 59 species from 9 samples, across 4 treatments (Table 1; Sites A–J). Bee abundance was significantly affected by management regime (χ^2 = 129.33, df = 5, *P* = <0.001; Fig. 3). Post-hoc analyses examining management revealed that burned and then mowed treatments had significantly more bees than any others. Control treatments had the lowest bee

Table 2. Species checklist for all bees species recorded in the Ossipee Pine Barrens (OPB) during this study. Species previously found (+) in the White Mountain National Forest (WMNF; Tucker and Rehan 2017a) and Strafford County, NH (Tucker and Rehan 2017b, 2018), are also listed. * = introduced species; † = a new species record for the state of NH. [Table continued on following page.]

Family/OPB species list	Abundance	Relative abundance	WMNF	Strafford
Andrenidae				
Andrena alleghaniensis Viereck	1	0.12%	+	+
Andrena brevipalpis Cockerell	1	0.12%	+	
Andrena carlini Cockerell	17	2.09%		+
Andrena ceanothi Mitchell	23	2.82%	+	
Andrena cressonii Robertson	1	0.12%	+	+
Andrena dunning Cockerell	5	0.61%		+
Andrena erigeniae Robertson	1	0.12%		+
Andrena imitatrix Cresson	2	0.25%	+	+
Andrena krigiana Robertson	9	1.10%	+	+
Andrena melanochroa Cockerell	1	0.12%		+
Andrena morrisonella Viereck	1	0.12%		+
Andrena nivalis Smith	1	0.12%	+	+
Andrena robertsonii Dalla Torre	4	0.49%	+	+
Andrena rugose Robertson	1	0.12%		+
Andrena vicina Smith	7	0.86%		+
Andrena virginiana Mitchell	1	0.12%		
Andrena w-scripta Viereck	1	0.12%	+	+
**Andrena wilkella* Kirby	95	11.66%	+	+
Calliopsis andreniformis Smith	10	1.23%	+	+
Apidae				
Bombus bimaculatus Cresson	40	4.91%	+	+
Bombus griseocollis De Greer	13	1.60%	+	+
Bombus impatiens Cresson	5	0.61%	+	+
Bombus perplexus Cresson	3	0.37%	+	+
Bombus sandersoni Franklin	23	2.82%	+	+
Bombus ternarius Say	8	0.98%	+	+
Ceratina calcarata Robertson	3	0.37%	+	+
Ceratina dupla Say	1	0.12%	+	+
Ceratina mikmaqi Rehan & Sheffield	3	0.37%	+	+
Nomada articulata Smith	3	0.37%	+	+
Nomada cf. *bethunei* Grote & Robinson	2	0.25%		
Nomada cressonii Cockerell	2	0.25%		+
Nomada depressa Cresson	2	0.25%	+	+
Nomada illinoensis Robertson	1	0.12%		
Nomada lepida Cresson	2	0.25%		+
Nomada maculata Cresson	1	0.12%		+
Colletidae				
Hylaeus affinis Smith	1	0.12%	+	+
Hylaeus annulatus L.	3	0.37%	+	+
Hylaeus illinoisensis (Robertson)	1	0.12%		+
Hylaeus mesillae (Cockerell)	2	0.25%	+	+
Hylaeus modestus Say	15	1.84%	+	+
Halictidae				
Agapostemon texanus Cresson	14	1.72%	+	+
Agapostemon virescens (Fabricius)	14	1.72%	+	+
Augochlora pura (Say)	1	0.12%	+	+
Augochlorella aurata (Smith)	24	2.94%	+	+

Table 2, continued.

Family/OPB species list	Abundance	Relative abundance	WMNF	Strafford
Augochloropsis metallica (Fabricius)	3	0.37%		+
Halictus confusus Smith	11	1.35%	+	+
Halictus ligatus Say	104	12.76%	+	+
Halictus rubicundus (Christ)	1	0.12%	+	+
Lasioglossum abanci (Crawford)	1	0.12%	+	+
Lasioglossum acuminatum McGinley	15	1.84%	+	+
Lasioglossum admirandum (Sandhouse)	2	0.25%	+	+
Lasioglossum birkmanni (Crawford)	2	0.25%	+	+
Lasioglossum cressonii Robertson	47	5.77%	+	+
Lasioglossum ephialtum Gibbs	29	3.56%	+	+
Lasioglossum imitatum (Smith)	4	0.49%	+	+
Lasioglossum leucocomum (Lovell)	3	0.37%	+	+
**Lasioglossum leucozonium* Schrank	2	0.25%	+	+
Lasioglossum nigroviride (Graenicher)	2	0.25%	+	+
Lasioglossum nymphaearum (Cockerell)	3	0.37%	+	+
Lasioglossum oblongum (Lovell)	3	0.37%	+	+
Lasioglossum pectoral (Smith)	47	5.77%	+	+
Lasioglossum pilosum (Smith)	15	1.84%	+	+
Lasioglossum planatum (Lovell)	6	0.74%	+	+
Lasioglossum quebecense (Crawford)	1	0.12%		+
Lasioglossum tegulare (Robertson)	1	0.12%	+	+
Lasioglossum timothyi Gibbs	21	2.58%		+
Lasioglossum versans (Lovell)	1	0.12%	+	+
Lasioglossum versatum (Robertson)	23	2.82%	+	+
Lasioglossum vierecki Crawford	1	0.12%		+
Sphecodes banksii Lovell	1	0.12%		+
Sphecodes persimilis Lovell & Cockerell	1	0.12%		+
Sphecodes prosphorus Lovell & Cockerell	1	0.12%	+	+
Sphecodes ranunculi Robertson	1	0.12%		+
Megachilidae				
**Anthidium oblongatum* (Illiger)	2	0.25%	+	+
Heriades carinata Cresson	2	0.25%	+	+
Heriades leavitti Crawford	1	0.12%		+
Hoplitis producta (Cresson)	14	1.72%	+	+
Hoplitis spoliata (Provancher)	1	0.12%	+	+
Hoplitis truncate (Cresson)	17	2.09%	+	+
Megachile gemula Cresson	4	0.49%	+	+
Megachile latimanus Say	5	0.61%	+	+
Megachile melanophaea Smith	14	1.72%	+	+
Megachile mendica Cresson	2	0.25%		+
†*Megachile mucida* Cresson	1	0.12%		
Megachile relativa Cresson	2	0.25%	+	+
Megachile texana Cresson	3	0.37%		+
Osmia atriventris Cresson	5	0.61%	+	+
Osmia bucephala Cresson	3	0.37%	+	+
Osmia collinsiae Robertson	1	0.12%	+	+
Osmia distincta Cresson	1	0.12%		+
Osmia felti Cockerell	3	0.37%		
Osmia georgica Cresson	1	0.12%		+
Osmia pumila Cresson	5	0.61%	+	+
Osmia virga Sandhouse	3	0.37%		+
Stelis labiate (Provancher)	4	0.49%		+

abundance, although not significantly lower than the mowed-only or burned-only treatments. Bee richness was also significantly affected by management regime, with post-hoc analyses revealing that burned-then-mowed treatments contained significantly greater bee richness than all other treatments except the mowed-only

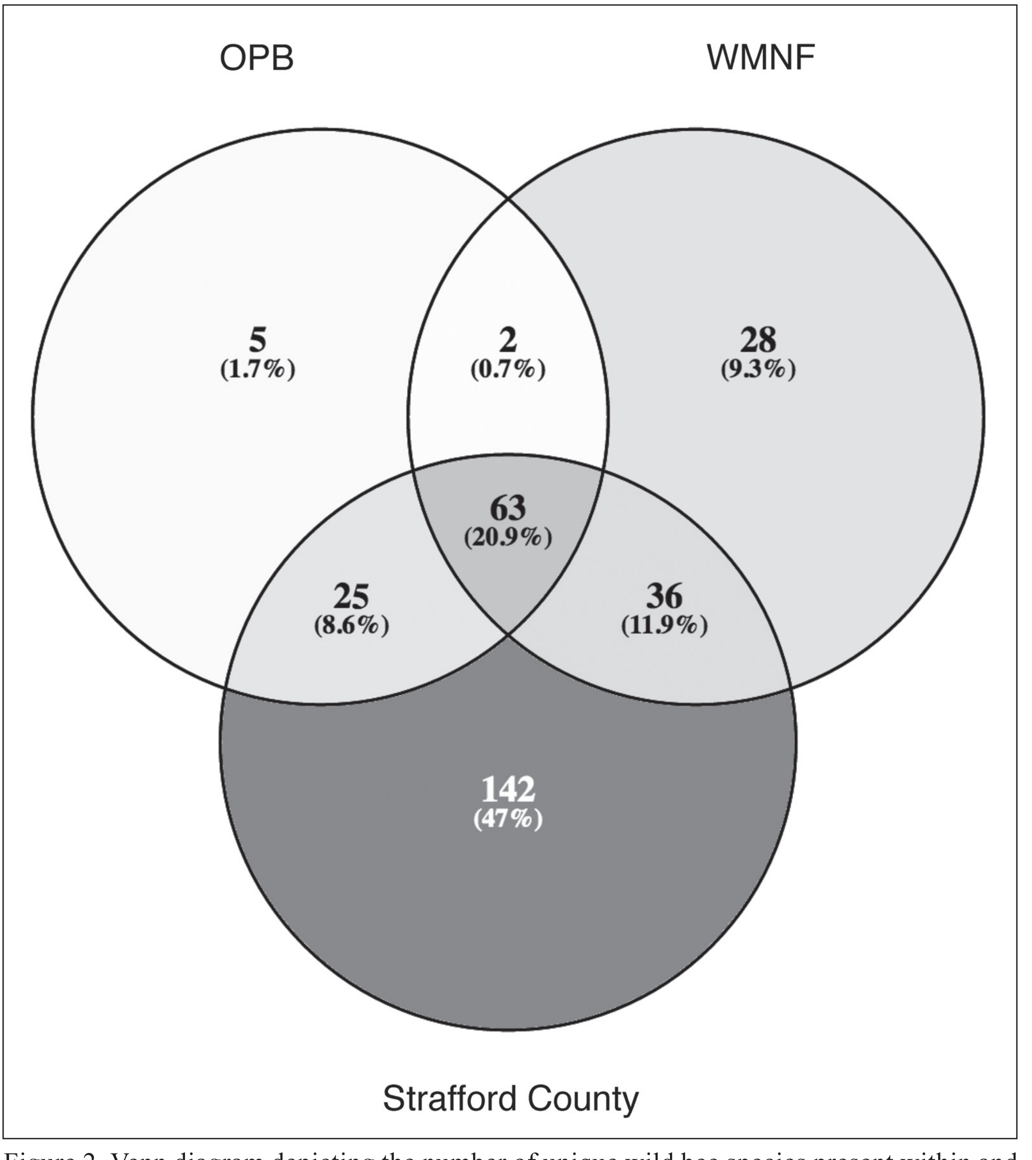

Figure 2. Venn diagram depicting the number of unique wild bee species present within and shared among the Ossipee Pine Barrens (OPB; this study), the White Mountain National Forest (WMNF; Tucker and Rehan 2017a), and Strafford County, NH (Tucker and Rehan 2017b, 2018). The relative number of species collected at a site compared to all species collected at all sites is given as a percent in parentheses. Note that the Strafford County samples were accumulated over a longer period of time and throughout the active bee season, whereas, those from the OPB and WMNF are based on single-day collection events. Differences in unique species per surveyed area can in part be explained by unequal sampling effort.

treatment ($\chi^2 = 14.38$, df = 5, $P = 0.002$). Of the 59 bee species collected, 15% (9 species) were found in all management regimes and 55% (33 species) were exclusive to a single treatment.

Discussion

Bees of the OPB

This study documents the first survey of wild bees in the OPB. We document the wild bee *Megachile mucida* for the first time in the state of New Hampshire. Although previously recorded in Maine, Massachusetts, Connecticut, and other nearby states, the species had yet to be documented in New Hampshire (Ascher and Pickering 2017, UNHC 2018). We also found 4 other species (Table 2) that while previously recorded for NH and neighboring states, have not been recorded in either Strafford County or the WMNF (Ascher and Pickering 2017, Tucker and Rehan 2017b, 2018). These findings demonstrate that there is still much need for research on the New Hampshire bee fauna (Koh et al. 2016). We also confirmed 3 introduced bee species in the OPB (see Table 2). Although not previously documented in the OPB, these introduced species have been recorded in the state and are commonly found throughout the Northeast (Droege 2015). The presence of

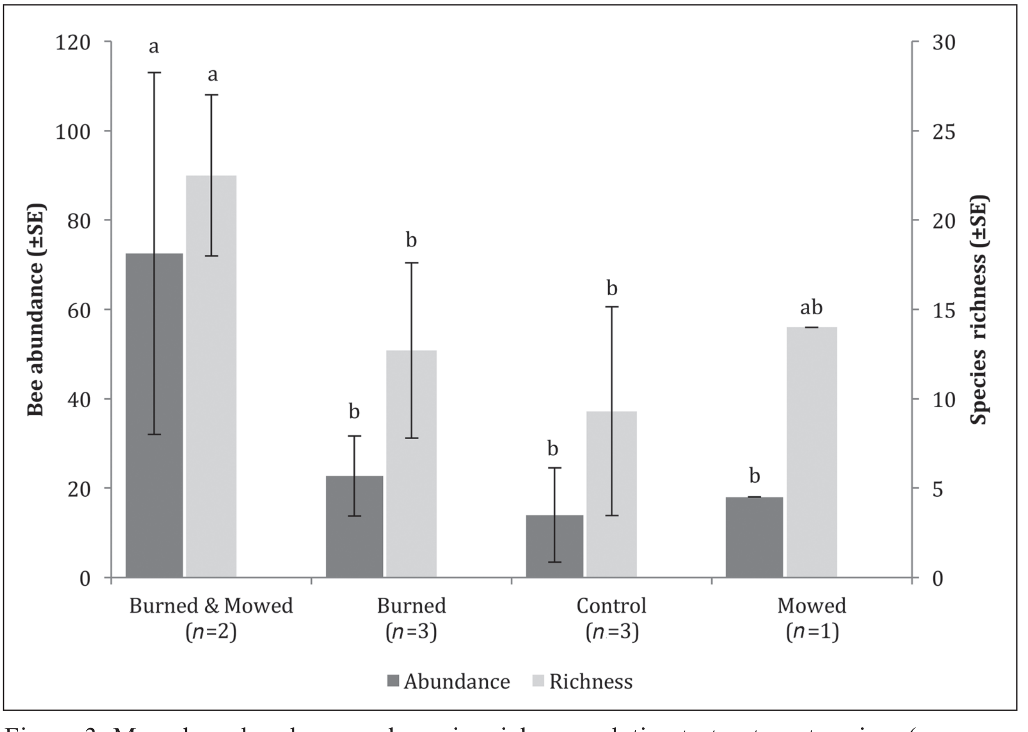

Figure 3. Mean bee abundance and species richness relative to treatment regime (*n* = number of samples per treatment). Treatment significantly affected both bee abundance (dark grey bars) and richness (light grey bars) based on GLM results. Post-hoc analyses showed abundance, as well as richness, were significantly greatest in the burned and then mowed treatment (significant differences are indicated by letters in order from left to right).

introduced species in an already fragile ecosystem could indicate an impending decline in bee species dependent on this habitat (Gibbs and Sheffield 2009, Morales et al. 2013, Paini 2004).

OPB bee similarity to nearby regions

Despite being relatively close to the WMNF, we found OPB to have a very different wild bee composition, with 30 species not found in the WMNF (Tucker and Rehan 2017a). Further studies will be required to determine how species composition varies between these habitats due to floral resource or nesting site availability, elevation, or land management; other studies have found many unique and rare insect species in pine barrens (Bried et al. 2014, Grand and Mello 2004, Leuenberger et al. 2016, NatureServe 2017, Swengel 1998). Thorough and regionally specific studies are important to not only account for high levels of landscape specificity, but also ecological fluctuations and species turnover between years and seasons (Oertli et al. 2005, Rollin et al. 2015). The OPB bee community was similar to the Strafford County bee community: we found only 7 species in the OPB not recorded in Strafford County (Tucker and Rehan 2017b, 2018). Considering that the duration of the survey in Strafford County was much longer (3 years compared to 1 day), the difference in species composition is likely due to habitat differences. Some of these differences in species composition may also be attributed to the time of year sampled, as many species have limited flight periods, and OPB sampling would have missed many early spring, late summer, and fall species. We expect that additional surveying of the OPB will expand the species list, increasing both the number of unique species and species found in both habitats.

Management regime effects

In our survey, we found significantly greater bee abundance and richness in the burned-then-mowed sites than in the other sites. These results are consistent with bee surveys conducted in other fire-dependent habitats that found early successional habitats caused by burning supported larger bee communities (Campbell et al. 2018, Mola et al. 2018, Potts 2006, Rodriguez and Kouki 2015). Our findings that bee abundance in the mowed treatments did not significantly differ from those in our control sites were also similar to results from a comparable study on bees in the pine barrens of New York. In that study, Bried and Dillon (2012) found no significant differences in bee abundance and richness between fire-prone sites that were mowed and treated with herbicides compared to those that were unmanaged and fire-prone. In addition to greater bee abundance and richness in burned-then-mowed sites, we found a high species–site exclusivity. While some of these species may truly only be associated with the specific management regime sampled, based on the high number of singleton species collected, it is likely some of the site exclusivity can be attributed to only collecting on a single day and the resulting small sample size. These results suggest that wild bees may benefit from periodic burning and infrequent mowing. Combined, these land-use management regimes may reduce the growth of non-flowering forbs and increase open ground for nesting sites. In addition to providing the first wild bee survey in the OPB, this study highlights the need for long-term and repeated surveys of wild bees across the highly varied landscapes of New England and beyond.

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