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Decline of bumble bees (*Bombus*) in the North American Midwest

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ABSTRACT

Declines in many bumble bee species have been documented in Europe raising several ecological and economic concerns. The nature and extent of bumble bee decline in North America is poorly understood due mainly to a lack of baseline and long-term data. Museum collections provide excellent sources of information on past and current species distributions, which can be used to infer changes in the composition of insect communities. Using the Illinois Natural History Survey's electronic database of Hymenoptera and a recent biodiversity survey of historically sampled localities, we were able to examine changes in the richness and distribution of the bumble bee fauna of Illinois over the last century. We found that bumble bee species richness declined substantially during the middle of the century (1940–1960). Four species were locally extirpated: *Bombus borealis*, *Bombus ternarius*, *Bombus terricola* and *Bombus variabilis*. The ranges of *Bombus affinis*, *Bombus fraternus*, *Bombus pensylvanicus* and *Bombus vagans* have also decreased in Illinois. Our analyses also indicated that current bumble bee diversity is highest in northern Illinois, where conservation efforts would be most productive. Our study demonstrates that half of the bumble bee species found historically in Illinois have been locally extirpated or have suffered declines, supporting observations of broader declines in North America. Major declines in the bumble bee fauna coincided with large-scale agricultural intensification in Illinois between 1940 and 1960. Attempts to conserve bumble bees in Illinois should involve wildlife-friendly approaches to agriculture, such as increasing agricultural land set-asides and hedgerows, and employing integrated pest management.

1. Introduction

Bumble bees (*Bombus*) provide the vital ecosystem service of pollination in both natural and managed systems (Corbet et al., 1991; Kevan, 1991; Buchmann and Nabhan, 1996; Goulson, 2003; Memmott et al., 2004; Pywell et al., 2006; Goulson et al., 2008), and declines in their abundance and distribution have serious ecological and economic ramifications (Corbet et al., 1991; Biesmeijer et al., 2006; Carvell et al., 2006). Numerous studies from Europe have documented recent declines in many species of *Bombus* (Williams, 1982, 1986; Carvell, 2002; Biesmeijer et al., 2006; Goulson, 2006; Rasmont et al., 2006; Fitzpatrick et al., 2007; Kosior et al., 2007), and such declines were often observed in areas where anthropogenic changes in habitats have occurred, such as agricultural intensification and urbanization (Pywell et al., 2006).

In North America, little is known about the status of native bumble bee species, hampering conservation efforts to

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protect these valuable pollinators (Committee on the Status of Pollinators in North America, 2007). Over the last decade, various North American entomologists have observed (some anecdotally) that some species of once-common bumble bees have declined in abundance and distribution (Thorp, 2005; Thorp and Shepherd, 2005; Colla and Packer, 2008). This prompted the Xerces Society for Insect Conservation to add several presumably declining bumble bees to their Red List of Pollinator Insects of North America (Thorp, 2005; Thorp and Shepherd, 2005). These species belong to a single subgenus (*Bombus sensu stricto* Latreille) (Williams, 1998; Cameron et al., 2007) and include the eastern *Bombus affinis* Cresson and *Bombus terricola* Kirby, and western *Bombus franklini* Frison and *Bombus occidentalis* Greene. In addition, the Committee on the Status of Pollinators in North America, (2007) also added two species from the subgenus *Thoracobombus* Dalla Torre (Williams et al., 2008), the eastern *Bombus pensylvanicus* (DeGeer) and western *Bombus sonorus* Say, to their list of bee species in decline. Potential causes cited for the decline of North American bumble bees include land-use changes in the form of urbanization and agricultural conversion (Kremen et al., 2002a,b; Greenleaf and Kremen, 2006; McFrederick and LeBuhn, 2006), extensive pesticide use (Gels et al., 2002; Marletto et al., 2003), and pathogen spillover from commercial bumble bee colonies that contain many parasites (Colla et al., 2006; Otterstatter and Thomson, 2008). A recent study has substantiated the decline in *B. affinis* in eastern North America, and documented declines in the diversity of the bumble bee fauna during the past 35 years over a small spatial scale (approximately 100 km^2) in southern Ontario, Canada (Colla and Packer, 2008). More data, especially over larger spatial and temporal scales, are needed to substantiate a decline of bumble bees in North America.

In Illinois, intensive farming and urban development over the last century have resulted in the loss of most of the state's once vast prairie, forest and wetland habitats (Iverson, 1988; Wang and Moskovits, 2001; Duram et al., 2004). As a result, Illinois ranks second to last of American states in the percentage of natural areas surviving (Jeffords et al., 1995); and nearly 95% of the northern two-thirds of the land area of Illinois is currently used for agricultural purposes (DeWalt et al., 2005). Given our knowledge of land-use changes and bumble bee decline in Europe, it would be expected that intensive farming and urban development in Illinois would have had a negative impact on the bumble bee fauna as a result of the loss of nesting habitat and continuous pollen and nectar sources. A study conducted in Iowa (Hines and Hendrix, 2005), a state with similar land-use changes to Illinois, found bumble bee diversity in prairie remnants to be strongly influenced by the availability of resources in the surrounding area, particularly in grasslands, which provide abundant pollen sources and nesting habitat for bumble bees (Svennson et al., 2000). Hines and Hendrix (2005) suggest that the resources that grassland habitats provide may be limited in agricultural landscapes as a result of mechanical disturbances over large areas. Bumble bees are susceptible to habitat loss due to their relatively limited flight range (Brian, 1954; Walther-Hellwig and Frankl, 2000), long colony cycle (commonly several months), and specific food and nesting requirements (Alford, 1975; Sakagami, 1976; Richards, 1978). Furthermore, bumble bees, like many other Hymenoptera, have complementary sex determination (van Wilgenburg et al., 2006; Heimpel and de Boer, 2008) which, in small populations, leads to the production of costly diploid males instead of females and this can substantially increase the risk of population extinction (Zayed, 2004; Zayed et al., 2004; Zayed and Packer, 2005).

Documenting the extent and possible causes of species declines requires both historical and current distribution and species richness data. Museum collections provide an excellent source of historical data, but most collections are not electronically catalogued, thus extracting specimen data is extremely time-consuming (Suarez and Tsutsui, 2004). The Illinois Natural History Survey (INHS, Champaign, Illinois) has captured its entire Hymenoptera (ants, bees and wasps) collection (approximately 360,000 specimens) into an electronic database and made them publicly available. A major strength of the Hymenoptera database is its bumble bee database, providing an invaluable source of information on the historical distribution of *Bombus* in Illinois. In this study, we use the state of Illinois as a model for assessing bumble bee decline over the last century across a state-wide scale (145,934 km^2). Illinois is ideal for such a study because it exemplifies a worst case scenario for loss of native habitat to farming and urban development. Further, Illinois has one of the best North American historical records of bumble bee diversity and distribution, dating back to the nineteenth century (e.g., Frison, 1919, 1921, 1923, 1926; Robertson, 1928; Waldbauer et al., 1977). These two factors allow us to examine whether and how the bumble bee fauna has changed in response to changes in habitat over the last century. We achieve this by integrating historical distributions and species richness from the INHS bumble bee database with current bumble bee distribution and species richness data obtained from our recent biodiversity survey.

2. Methods

2.1. *Bombus* biodiversity survey

In 2007, we conducted a survey of the bumble bee fauna at 56 sites in Illinois previously sampled between 1900 and 1949, 1950 and 1999, and 2000–2006 (Fig. 1, Table 1). Sites ranged in size from 0.05 acres to 2 acres, and were visited at least twice from early April to mid-October (between 9:00 a.m. and 4:00 p.m.). We employed an opportunistic sampling method in which a two-person team spent an average of 1.47 ± 1.09 SD person-hours per visit, and sampling time was increased based on the bumble bee activity observed at the site. We collected bumble bees with an aerial net on flowers or while in flight. We placed each collected specimen in a plastic vial and kept them alive in a cooler on ice until the end of the survey period. We identified the chilled bees to species, determined their caste (i.e. queen, worker or male) and recorded the number of individuals per species. A third of the captured workers and males were killed in cyanide vials for permanent deposition in the INHS insect collection and the remainder were released into the field to minimize destructive sampling of the *Bombus* fauna. We recorded the date,

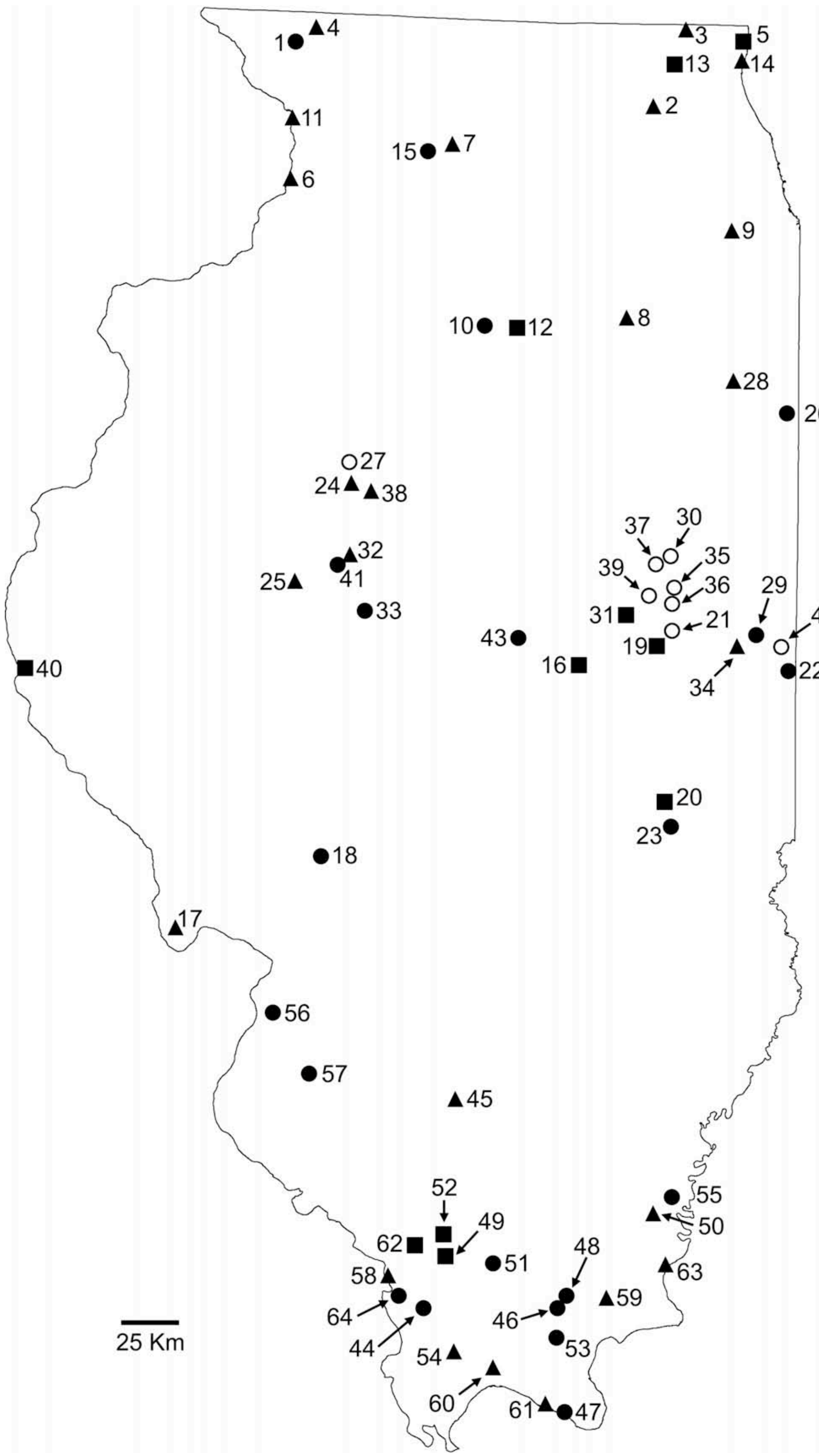

Fig. 1 – Bumble bee sampling sites in Illinois. Squares (■) indicate sites sampled in 1900–1949, 1950–1999 and 2000–2007. Triangles (▲) indicate sites sampled in 1900–1949 and 2000–2007. Closed circles (●) indicate sites sampled in 1950–1999 and 2000–2007. Opened circles (○) indicate sites sampled only in 2007. Site numbers correspond to those listed in Table 1.

Table 1 – Location of bumble bee sampling sites in Illinois.

Site #, site name, county	Region	Site #, site name, county	Region
1. 4 mi E. Schapville, Jo Daviess	North	33. Mason City, Mason	Central
2. Algonquin, McHenry	North	34. Muncie, Vermilion	Central
3. Antioch, Lake	North	35. Near Tomlinson Cemetery[a], Champaign	Central
4. Apple River Canyon, Jo Daviess	North	36. Near Welles Cemetery[a], Champaign	Central
5. Beach, Lake	North	37. Paxton[a], Ford	Central
6. Fulton, Whiteside	North	38. Peoria/Airport region, Peoria	Central
7. Oregon, Ogle	North	39. Prospect[a], Ford	Central
8. Morris, Grundy	North	40. Quincy, Adams	Central
9. Palos, Cook	North	41. Sand Ridge State Park, Mason	Central
10. Peru, LaSalle	North	42. Vermilion River Observatory[a], Vermilion	Central
11. Savanna, Carroll	North	43. Weldon Springs, DeWitt	Central
12. Starved Rock, LaSalle	North	44. Alto Pass, Union	South
13. Volo, Lake	North	45. Ashley, Washington	South
14. Waukegan, Lake	North	46. Bell Smith Springs, Pope	South
15. White Pines, Ogle	North	47. Brookport, Massac	South
16. Allerton, Piatt	Central	48. Burden Falls, Pope	South
17. Brussels, Calhoun	Central	49. Carbondale, Jackson	South
18. Carlinville, Macoupin	Central	50. Cottonwood, Gallatin	South
19. Champaign-Urbana, Champaign	Central	51. Crab Orchard Wildlife Ref., Williamson	South
20. Charleston, Coles	Central	52. De Soto, Jackson	South
21. Collin Woods[a], Champaign	Central	53. Dixon Springs Ag. Center, Pope	South
22. Forest Glen, Vermilion	Central	54. Dongola, Union	South
23. Fox Ridge State Park, Coles	Central	55. Emma, White	South
24. Hanna City, Peoria	Central	56. Fairmont, St. Clair	South
25. Havana, Mason	Central	57. Freeburg, St. Clair	South
26. Iroquois Co. C. A., Iroquois	Central	58. Grand Tower, Jackson	South
27. Jubilee College State Park[a], Peoria	Central	59. Herod, Pope	South
28. Kankakee, Kankakee	Central	60. Karnak, Pulaski	South
29. Kickapoo State Park, Vermilion	Central	61. Metropolis, Massac	South
30. Loda[a], Iroquois	Central	62. Murphysboro, Jackson	South
31. Mahomet, Champaign	Central	63. Old Shawneetown, Gallatin	South
32. Manito, Mason	Central	64. Pine Hills, Union	South

a Indicates additional sites sampled in Illinois in 2007.

time, weather conditions, GPS coordinates and the floral host for each captured specimen. Species identifications made in the field were verified in the laboratory using the taxonomic keys of LaBerge and Webb (1962), Medler and Carney (1963) and, for subgeneric features, Williams et al. (2008).

2.2. *Databasing of Illinois bumble bees*

Approximately 3500 specimens of *Bombus* collected in Illinois and housed in the INHS insect collection had been determined and their locality databased (http://ctap.inhs.uiuc.edu/Insect/search_inhs.asp). Each record was re-examined for accuracy and identifications were confirmed or corrected. The collection localities were retrospectively georeferenced using printed (DeLorme Mapping Company, 2000) and internet-published atlases and geolocator databases (e.g., United States Geological Survey Geographic Names Information System: http://geonames.usgs.gov/, United States Geological Survey maps: http://www.topozone.com/, Google Earth software: http://earth.google.com/).

2.3. *Data analysis*

We examined changes in the richness and distribution of bumble bee species in Illinois across three time periods (1900–1949, 1950–1999, and 2000–2007). The 1900–1949 and 1950–1999 time periods were chosen because most of the bumble bee specimens from Illinois were collected between 1900 and 1940 and again between 1960 and 1980. The museum specimens included in our analyses were collected by both amateur and professional entomologists using opportunistic methods. It has been suggested that museum collections may over-represent the relative abundance of rare species as a result of collectors preferentially collecting rare over common species in a site, as found in museum collections of birds (Guralnick and Van Cleve, 2005). Although bumble bees may be more difficult than birds for the amateur collector to identify in the field, the potential for bias toward the collection of rare species still exists. Collector bias, however, is only expected to strongly affect relative abundance and not species richness (i.e. the number of species collected in a site); the latter can be biased only if collectors never collect one or more of the common species – an unlikely scenario. Nevertheless, to minimize collector biases that may have resulted at a given site in the historical dataset, we used only presence/absence data in our analyses and grouped sites together over a broad geographic and temporal scale (DeWalt et al., 2005).

We used resampling methods to examine changes in species richness between time periods, as implemented in the computer program ComRAND v 1.4 (Zayed and Grixti, 2005). Species richness is affected by the number of specimens collected (Magurran, 2004). We used ComRAND to randomly sample from the larger 2000–2007 dataset employing the smaller sample size of the historical datasets, in order to remove the confounding effect of sample size when making species richness comparisons. The 2000–2007 dataset mostly represented the 'randomly sampled' specimens collected in 2007 (see Section 2.1), satisfying ComRAND's assumptions. Sampling was conducted with replacement for 1000 iterations (Zayed and Grixti, 2005). For each iteration, species richness (Magurran, 2004) was estimated for the current dataset. To test the null hypothesis of no difference in species richness between the historical and current datasets, we generated *p*-values representing the number of iterations where species richness of the current dataset was equal to or more extreme than, the species richness observed in the historical dataset.

To examine potential declines in the distribution of the 16 species found historically in Illinois, we grouped sites according to Illinois' three major geographic regions (i.e. north, central and south), as defined by the United States Geological Survey, and estimated the proportion of historical regions that a species currently inhabits. This parameter was calculated by dividing the current number of geographic regions where a species is found by the number of geographic regions where the species was historically found. A value of 1 (or 100%) suggests a stable distribution, while a value of 0 suggests local extirpation. Values between 1 and 0 suggest declines in distribution, while values greater than 1 suggest expansion.

To quantify recent (i.e. 2007) bumble bee biodiversity patterns, we estimated species richness (*S*), the Shannon index (H') and species evenness index (*E*). H' represents a measure of biodiversity that takes into account both the number of species and their relative abundance, while *E* measures how evenly spread species are within a community (Magurran, 2004). We used ComRAND to estimate and statistically compare the three parameters between the different geographic regions (north, central and south) sampled in 2007. We also performed a rarefaction analysis, as implemented in BioDiversity Pro (McAleece et al., 1997), to examine if our sampling effort in 2007 was adequate for capturing the species richness of the bumble bee fauna of Illinois.

3. Results

Bumble bee species richness in Illinois declined over the last century despite increased sampling effort. Between 1900 and 1949, 16 species, comprising 1244 individuals were present in the INHS collection. The number of species declined to 11 between 1950 and 1999 as *Bombus borealis* Kirby, *Bombus perplexus* Cresson, *Bombus rufocinctus* Cresson, *Bombus ternarius* Say and *B. terricola* Kirby were absent among the 2674 individuals present in the collection for that time period. Between 2000 and 2007, 12 species were found among the 3763 individuals collected as *B. perplexus* and *B. rufocinctus* were present and *Bombus variabilis* (Cresson) was absent in that time period (Fig. 2). Rarefaction analysis of the 2007 bumble bee survey dataset indicated that we adequately sampled the species expected to be found in Illinois, as the species accumulation curve quickly reached an asymptote after approximately 25% of our total sampling effort (Fig. 3).

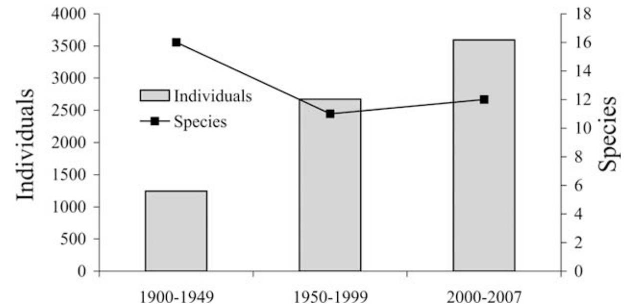

Fig. 2 – The number of bumble bee specimens (bars) and species (line) sampled over time in Illinois.

The declines in species richness over time despite increasing sampling effort indicate that the bumble bee declines are real and not simply an artifact of sampling. Using resampling methods to test the null hypothesis of no difference in species richness between the historic time periods and the current time period, after correcting for differences in sampling effort, species richness was significantly lower in 2000–2007 when compared to 1900–1949 (p-value < 0.001). Species richness in the 1950–1999 dataset was also significantly lower when compared to 1900–1949 (p-value < 0.001). However, species richness in 2000–2007 was not significantly different when compared to 1950–1999 (p-value = 0.473). Therefore, decreases in species richness occurred between the two major collecting periods (i.e. 1900–1940 and 1960–1980) in the historical dataset, between 1940 and 1960.

A total of four species found in the historical time periods were not collected between 2000 and 2007: *B. borealis*, *B. ternarius*, *B. terricola* and *B. variabilis*. Furthermore, we found that

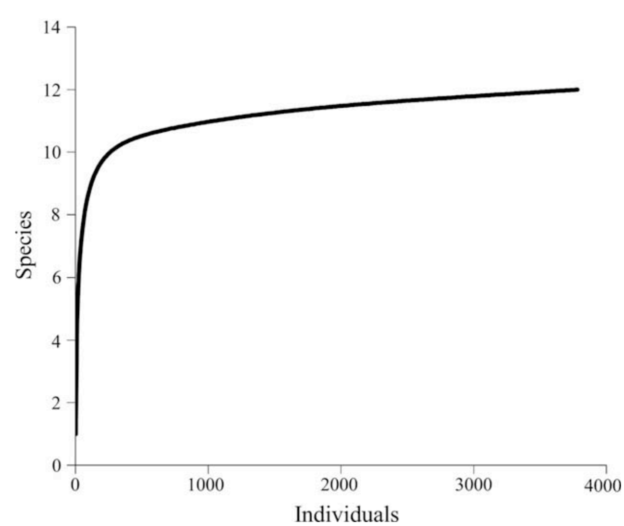

Fig. 3 – Rarefaction analysis on the 2007 bumble bee survey data indicated that sampling effort was adequate for characterizing the species richness of the bumble bee fauna of Illinois. The species accumulation curve rapidly reached an asymptote with increasing sampling effort.

Table 2 – List of bumble bee species collected from the 56 revisited sites in Illinois, with their presence (+) or absence (–) in the INHS collection.

Species	Ecological Traits		Presence (+ or –) and relative abundance[c] (%)				Distribution[d]		Distribution remaining[e] (%)
	Timing[a] E/I/L	Tongue Length[b] S/M/L	1900–1949	1950–1999	2000–2007	2007[f]	Past	Current	
B. affinis Cresson	E	S	+(0.6)	+(0.3)	+(1.4)	50	3	2(N, C)	67
B. auricomus (Robertson)	I	L	+(6.9)	+(3.6)	+(8.9)	332	3	3	100
B. bimaculatus Cresson	E	M	+(5.9)	+(7.1)	+(14.7)	547	3	3	100
B. borealis Kirby	L	L	+(0.6)	–(0.0)	–(0.0)	0	1(N)	0	0
B. citrinus (Smith)	L	S	+(0.6)	+(0.5)	+(0.7)	27	3	3	100
B. fervidus (Fabricius)	I	L	+(8.3)	+(1.0)	+(2.5)	95	2(N, C)	2(N, C)	100
B. fraternus (Smith)	E	S	+(1.9)	+(0.2)	+(0.2)	4	3	2(N, C)	67
B. griseocollis (DeGeer)	E	M	+(7.8)	+(7.4)	+(29.3)	1118	3	3	100
B. impatiens Cresson	E	M	+(10.9)	+(52.5)	+(34.7)	1330	3	3	100
B. pensylvanicus (DeGeer)	L	L	+(28.1)	+(23.0)	+(4.4)	160	3	2(C, S)	67
B. perplexus Cresson	E	M	+(0.1)	–(0.0)	+(0.0)	1	1(N)	1(N)	100
B. rufocinctus Cresson	L	S	+(1.3)	–(0.0)	+(0.8)	27	1(N)	1(N)	100
B. ternarius Say	E	S	+(0.2)	–(0.0)	–(0.0)	0	1(C)	0	0
B. terricola Kirby	E	S	+(1.2)	–(0.0)	–(0.0)	0	2(N, C)	0	0
B. vagans Smith	L	M	+(11.3)	+(3.5)	+(2.5)	91	3	2(N, C)	67
B. variabilis (Cresson)	L	S	+(14.3)	+(0.8)	–(0.0)	0	3	0	0

The proportion of the historical distribution remaining was measured by dividing the current distribution by the past distribution. A species is considered to have declined in distribution, if the proportion of the historical distribution remaining is less than 100%.

a E = early emerging, I = intermediate emerging, L = late emerging. Emergence times (i.e. when the first queen of the flight season is observed for a species) were obtained by Medler and Carney (1963).

b S = Short tongue, M = medium tongue, L = long tongue. Tongue lengths were obtained by Medler (1962).

c Relative abundance data was not used in our analyses.

d N = northern region, C = central region, S = southern region.

e Proportion of historical distribution remaining.

f Number of individuals of bumble bees observed from both the 56 revisited sites and eight additional sites.

Table 3 – Current species richness (S), diversity (H′), evenness (E) and sample size (N) for each geographic region in Illinois.

	North	Central	South
S	10	10	7
H′	1.73	1.46	1.46
E	0.75	0.64	0.75
N	1357	1861	564

four bumble bee species were found in fewer geographic regions during the current period when compared to the historical time periods: *B. affinis*, *B. fraternus* (Smith), *B. pensylvanicus* and *Bombus vagans* Smith (Table 2). This suggests that these species have declined in distribution. Although we do not use relative abundance data in our analyses of bumble bee declines because of the concern that it may be biased in museum datasets (Guralnick and Van Cleve, 2005), most of the species which declined in distribution also declined in apparent relative abundance (Table 2). For example, the historically common *B. pensylvanicus* (28.1% of all bumble bees sampled between 1900 and 1949) represents only 4.4% of the current (2000–2007) bumble bee fauna. *B. affinis* declined in distribution, although its relative abundance increased in 2000–2007 (from 0.6% to 1.4%). The increase in relative abundance of *B. affinis* is, however, misleading because 90% of the 50 workers sampled in 2000–2007 were collected from the same site during the same survey. Finally, eight species were found in all geographic regions in which they were previously recorded: *B. auricomus* (Robertson), *B. bimaculatus* Cresson, *B. citrinus* (Smith), *B. fervidus* (Fabricius), *B. griseocollis* (DeGeer), *B. impatiens* Cresson, *B. perplexus* and *B. rufocinctus* (Table 2).

In 2007, we found that the highest diversity of bumble bees in the state were observed in northern Illinois (Table 3). Species diversity (H') was significantly higher in the northern region, when compared to the central ($p < 0.001$) and southern regions ($p < 0.001$). Species richness (S) was significantly higher in the northern region when compared to the southern region ($p < 0.001$), but not the central region ($p = 0.66$). Species evenness (E) was not significantly different between the northern and southern regions ($p = 0.468$), but both were significantly higher than the central region ($p = 0.002$ and $p = 0.049$, respectively).

4. Discussion

Bumble bee species, with their varying tongue-lengths (Medler, 1962; Inouye, 1980), ability to forage at lower temperatures (Corbet et al., 1993), and capacity to buzz pollinate (Kevan et al., 1991; King, 1993), are one of the most effective pollinators of wild plants and crops (Goulson, 2003). A large number of wildflowers are pollinated exclusively or predominately by bumble bees (Corbet et al., 1991) and recent work has shown that bumble bees act as important 'hubs' or central connectors in pollination networks (Memmott et al., 2004; Olesen et al., 2007). Therefore, bumble bee declines are expected to have devastating effects on pollination and ecosystem functioning (Memmott et al., 2004; Goulson et al., 2005, 2008; Olesen et al., 2007). Here, we provide quantitative evidence for declines of multiple North American bumble bee species over a large geographic area. Half of the bumble bee species found historically in Illinois have been either locally extirpated or showed declines in distribution. Our findings of declines are similar to those of a study conducted in eastern Canada over a smaller geographic area (Colla and Packer, 2008), as well as those of several European studies (e.g., Berezin et al., 1995; Sarospataki et al., 2005; Kosior et al., 2007), suggesting that bumble bees are declining globally. Our findings confirm previous concerns over the status of *B. affinis*, *B. terricola* and *B. pensylvanicus* in eastern North America (Thorp, 2005; Thorp and Shepherd, 2005; Committee on the Status of Pollinators in North America, 2007; Colla and Packer, 2008); these species have experienced declines in their distribution over time in Illinois.

Three possible reasons have been cited for the decline of bumble bees in North America (Thorp and Shepherd, 2005): (1) habitat loss due to urban and agricultural growth (Kearns and Inouye, 1997); (2) the extensive use of pesticides, such as organophosphates, carbamates, and pyrethroids, (Kevan, 1975; Johansen, 1977), and more recently, neonicotinoids (Marletto et al., 2003); and (3) the spread of pathogens, such as *Nosema bombi* Fantham and Porter and *Crithidia bombi* Lipa and Triggiani from managed greenhouses to foraging bees nearby (Otterstatter et al., 2005; Colla et al., 2006; Otterstatter and Thomson, 2008) (i.e. 'pathogen spillover').

In Illinois, bumble bee richness declines occurred principally between 1940 and 1960, a period that coincided with major agricultural intensification in the Midwest, during which technological advancements in mechanization and agrichemicals lead to the expansion of existing farms in central and southern Illinois (Mattingly, 1987; Iverson, 1988; Duram et al., 2004). During that time, farms that grew a variety of crops, including temporary and permanent pastures containing wildflowers, switched to growing corn and soybeans (Newman et al., 2003). This conversion resulted in a loss of wildlife habitat within Illinois' agricultural landscape. In Britain and Ireland, it has been suggested that the widespread decline in wildflowers traditionally associated with hay meadows, pasture and hedgerows may have contributed to the decline in British bumble bees (Williams, 1986, 1988; Fitzpatrick et al., 2007) and reports from Europe also suggest that bumble bee declines may be linked to habitat loss and fragmentation, mostly due to urbanization and the intensification of farming practices (Williams, 1986; Goulson, 2003; Goulson et al., 2008). Agricultural intensification may have contributed to the local extirpation and decline of *Bombus* species in Illinois, where similar land-use changes have taken place.

It has been argued previously that bumble bees that exhibit diet and/or habitat preferences may be more susceptible to anthropogenic changes. One hypothesis proposes that species that exhibit food-plant specialization (e.g., long-tongued species forage primarily on long corolla flowers, such as legumes) are susceptible to declines when losses of the preferred food-plant occur (Goulson and Darvill, 2004; Goulson et al., 2005; Kleijn and Raemakers, 2008). Another hypothesis proposes that niche specialization, including preferred climate and habitat, may interact with food-plant availability to make species at the edge of their distribution more vulnerable to declines (Williams, 1985, 2005). Both specialized diet and habitat are expected to reduce levels of genetic diversity in bee populations (Packer et al., 2005; Zayed et al., 2005), which can increase the risk of extinction from the 'diploid-male production vortex' (Zayed and Packer, 2005). However, a recent study by Fitzpatrick et al. (2007) conducted in Ireland found no evidence of a relationship between rarity and decline in Irish bumble bees and diet specialization. Our study found that both long and short tongued bees were either absent or in decline in Illinois. In our study, lack of a large number of species exhibiting the different natural history traits (e.g., long versus short tongue, and early versus late emerging) precluded statistical testing of the influence of food-plant specialization and declines in the bumble bee fauna. However, most of the species that were locally extirpated or declined were rare and/or at the edge of their distribution (Mitchell, 1962; Milliron, 1971). For example, *B. borealis*, *B. ternarius*, *B. terricola* and *B. affinis* were both rare and at the edge of their distribution in Illinois. *B. fraternus* is rare but not at the edge of its distribution. Although the locally extirpated *B. borealis* (eight bees collected from three sites between 1917 and 1930) and *B. terricola* (15 bees collected from three sites between 1894 and 1929) were rare in Illinois, they were historically recorded from multiple geographic regions and/or multiple years indicating that they were not transient species. The locally extirpated *B. ternarius* was very rare (two bees collected from a single site between 1927 and 1929) and may represent a transient species.

The decline and local extirpation of historically common species is of particular concern. *B. vagans* and *B. pensylvanicus* are no longer found in southern and northern Illinois, respectively, while *B. variabilis*, the social parasite of *B. pensylvanicus*, is locally extirpated in Illinois. *B. vagans* was last recorded in southern Illinois in 1975, while *B. pensylvanicus* was last recorded in northern Illinois in 1996. *B. variabilis*, which was historically recorded in all geographic regions, was last recorded in Illinois in 1980. These dates indicate that declines in these common species occurred in Illinois more recently due to novel causes arising later on in the century, and/or due to delayed responses to the earlier land-use changes discussed above.

It is likely that multiple factors are responsible for the decline of these and other bumble bee species in North America. Species-specific resource requirements may explain why we found some species to have declined, while others like *B. impatiens* and *B. bimaculatus* continue to persist. Until we gain a better understanding of these resource requirements, efforts to set aside diverse patches of natural habitat for bees throughout Illinois are needed. Because three-quarters of the state is covered by cropland, any attempt at conserving bumble bees must involve a more wildlife-friendly approach to agriculture, including increasing the amount of interspersed or adjacent semi-natural habitat patches, rotating row crops with small grains, grasses and legumes, and employing integrated pest management strategies (Newman et al., 2003). Additional strategies include farm land restoration, use of hedgerows, and agricultural land set-asides.

Our study demonstrates the importance of using museum specimen data – an otherwise underutilized resource – to examine changes in biodiversity over time (Favret and DeWalt, 2002; Suarez and Tsutsui, 2004; DeWalt et al., 2005; Beck and Kitching, 2007; Kleijn and Raemakers, 2008). Museum collections contain valuable baseline data on species distribution and richness (Beck and Kitching, 2007; Tsoar et al., 2007) over large geographic and temporal scales. Once databased, these collections can be used to examine how anthropogenic causes such as habitat destruction and global climate change affect biodiversity (Parmesan et al., 2003; Suarez and Tsutsui, 2004). Our study shows that museum collections, combined with current biodiversity surveys, provide an irreplaceable resource for conservation biology.

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