MethodsX 12 (2024) 102571

Contents lists available at ScienceDirect

MethodsX

journal homepage: www.elsevier.com/locate/methodsx

Project-specific bumble bee habitat quality assessment ☆

Jason L. Robinson

Illinois Natural History Survey at Prairie Research Institute of the University of Illinois at Urbana-Champaign, Champaign, IL 61820, United States

A R T I C L E I N F O

Method name:
Bumble Bee Habitat Quality Assessment for Project Impacts

Keywords:
Bumble bee habitat
Rapid assessment
Endangered species
Habitat quality

A B S T R A C T

The listing of *Bombus affinis* Cresson 1863 (Rusty Patched Bumble Bee; RPBB) in 2017 under the Endangered Species Act (ESA) created a regulatory need for assessment methods, in order to limit take of this species by construction and development. As the first social insect listed under the ESA, the listing of RPBB has required new methods for biological assessment. This species has a complex life cycle requiring a mosaic of different habitat types, with each life cycle stage facing unique challenges and threats. I have established a method for separately assessing habitats critical to each vulnerable life history stage, using a combination of aerial photography, GIS maps and target-specific ground survey efforts. This method identifies factors that may potentially limit bumble bee colony success in each stage and provides project planners with facts about physical structures or plant communities that may have elevated importance to bumble bees during certain seasonal windows. Previous efforts to assess bumble bee habitat considered landscape features thought to be linked to bumble bee colony success. This effort extends these methods to estimate project specific impacts of construction and development projects, necessary for Section 7 Consultation with the United States Fish and Wildlife Service (USFWS) under the ESA.

- Systematic spatial assessment of landscape features linked to critical periods in the life history trajectory of a bumble bee colony across a season
- Construction and development project proponents can approach USFWS consultation with quantitative estimates of the area of a project area classified by habitat types and qualities
- Factors limiting bumble bee recovery may be inferred from the distribution and abundance of the constituent elements of quality bumble bee habitat

Specifications table

Subject area:	Environmental Science
More specific subject area:	Endangered Species Habitat Assessment
Name of your method:	Bumble Bee Habitat Quality Assessment for Project Impacts
Name and reference of original method:	Xerces Society for Invertebrate Conservation (2017) Rusty Patched Bumble Bee Habitat Assessment Form and Guide
Resource availability:	ArcGIS computer software

Method details

The problem- Ecological restoration and recovery efforts aimed primarily at simple features or processes may produce limited results [1]. The demographic and biogeographic declines of bumble bees implicate numerous complex and interacting factors that

☆ **Related research article:** None.

E-mail address: jrob@illinois.edu

https://doi.org/10.1016/j.mex.2024.102571
Received 28 October 2023; Accepted 14 January 2024
Available online 19 January 2024

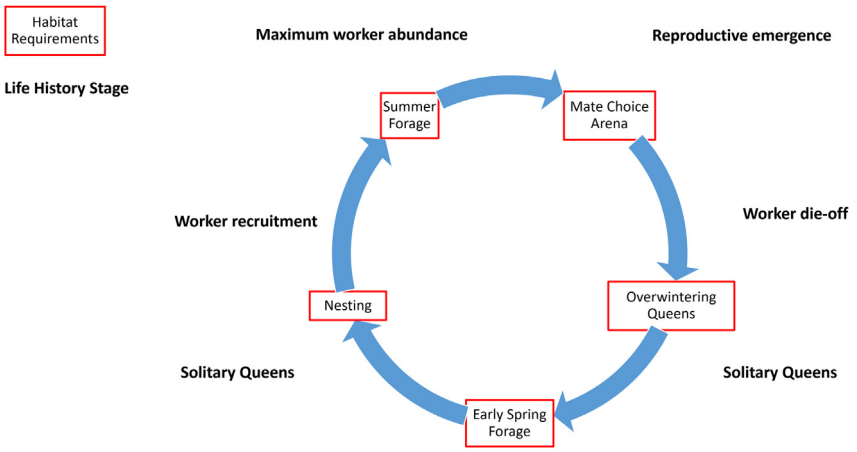

Fig. 1. The life cycle of a bumble bee colony relies on distinctly different habitat requirements over the course of a year or growing season.

elude simple correlation with land cover or habitat types [2,3]. Bumble bee (*Bombus*) species have complex life cycles requiring several somewhat independent dimensions of habitat quality [4]. The suitability of some area to provide habitat for bumble bees is, in part, a function of the local availability of the seasonal flowering of plants, demographic dynamics within and among colonies, and mate choice and dispersal dynamics facilitating the successful overwintering of mated queens. At critical periods in this life cycle, the fitness of the colony (reproduction and recruitment into the following year) can be impaired or precluded entirely. For the most part, these life cycle bottlenecks have distinct habitat requirements that may be useful to guide estimates of habitat quality in several dimensions (Fig. 1).

The most common observations of bumble bee species are probably workers foraging in summer floral resources, but other seasonal landscape features are integral to the success and persistence of bumble bee colonies across seasons (Fig. 1). Previous research has suggested that early spring floral resources are vital to the success of colonies [5], perhaps as vectors for nutritional support of newly emerged queens, or by providing the raw materials for the construction of nests and incubation cells required to rear more workers. In many biogeographical contexts, these early spring resources are disproportionately distributed in woodlands [6]. After the emergence of reproductive castes in late summer, some species have different mate-seeking behaviors [7–12] such as route cruising, perching and pheromone communications, that may potentially be influenced by local habitat features. Finally, post-reproductive queens seek deep leaf litter or mulch piles or other subterranean redoubts for overwintering habitat [13]. A meaningful assessment of bumble bee habitat quality at a site potentially impacted by a specific project should measure the area exhibiting a comprehensive set of factors attending the evolutionary fitness of the colony (i.e. “conditions appropriate for individual and population persistence” [14]).

The survey method- This method for bumble bee habitat assessment entails the explicit spatial mapping of the distribution of four different critical constituent elements in a project area. I have developed this method while conducting project impact surveys for the Rusty Patched Bumble Bee *Bombus affinis* Cresson 1863 in Northern Illinois, in anticipation of Section 7 consultation with the USFWS, but the general method would be modifiable to any bumble bee species in any region. The Xerces Society for Invertebrate Conservation [15] framed the problem of assessing bumble bee habitat as a task for conservation managers, but this did not address the issue of quantifying areas of habitat quality for impact assessment. I have modified and extended their approach here to facilitate rapid assessment of bumble bee habitats, particularly for the Federally Endangered Rusty Patched Bumble Bee *Bombus affinis.*

A surveyor approaching a project area will have prepared base maps of the boundaries under consideration, preferably satellite images or aerial photographs (Fig. 2). The aim of habitat assessment is to ascertain the extent of each constituent element of bumble bee habitat quality across the project area. This requires repeated observation throughout the growing season of floral resources. Rough consolidation of the project area into cover types (e.g. prairie planting, open woodland, mesic ravine) may be helpful for organizing field observations, but some habitat elements may be more patchily distributed within cover types. Careful photographic record keeping of the identity and date of blooming of forage plants, or the location of other physical habitat structures (mulch piles, embankments, cavities), will provide useful for mapping and report writing. Field notes for these observational surveys are then used in a GIS to construct a polygon of the extent of each constituent element of bumble bee habitat (Table 1).

No Habitat- Careful preliminary work from satellite images may enable the identification of “No Habitat” areas (e.g., impervious surfaces, open water, roofs and pavement) in a GIS or other computer mapping software, prior to visiting the site. These features should be verified by ground truthing, as water levels or the presence of structures may differ from photographs. Road embankments and flowered roadsides may provide habitat potential for foraging or nesting bees, so care should be taken to delimit only impervious surfaces with no floral resources as “No Habitat”.

Spring Habitat- The identification of floral resources requires some knowledge of local plant species. Careful photographic documentation of mystery plants, for later identification, can save valuable field time. A working familiarity with local flora and the preferences of target bumble bee species (if known) is important for accurate assessment. The distributions and abundances of particular plant and bumble bee species distributions are rarely concordant, but for *Bombus affinis* assessments there are several recent primary literature sources that provide surveyors with a basis for the floral assessment of habitat surveys [6,15–19]. In the Upper

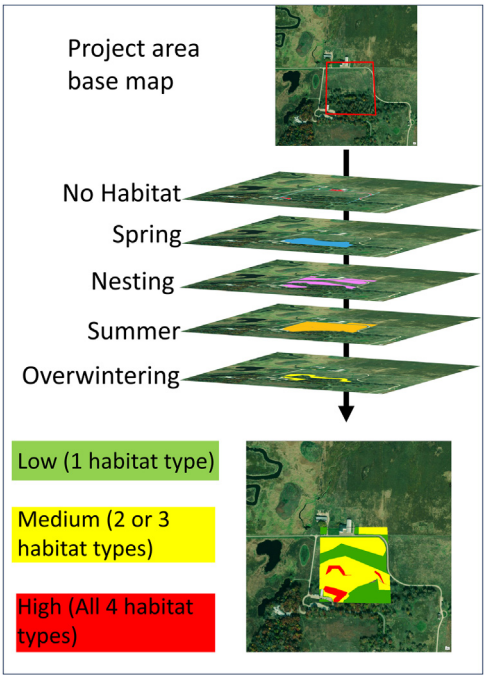

Fig. 2. Map algebra method of compiling GIS layers of the constituent elements of bumble bee habitat to derive a habitat quality index.

Table 1
The constituent elements of bumble bee habitat quality, relevant to project impact assessment.

Bumble Bee Habitat Element	Description
No Habitat	Areas of open water, road surfaces, parking lots, building footprints and other impervious surfaces that offer no resources for bumble bees.
Spring Resources	Floral resources that develop to bloom during periods when queens are foraging for nest building materials or rearing small batches of workers, i.e. when queens are the primary individual bumble bees active in the landscape.
Nesting Resources	Soil voids, rodent burrows, bunch grasses, soil fissures, tree holes, debris piles, flowerpots and many other similar areas can provide enough sheltered refuge to allow bumble bees to create combs and rear larvae to adult worker and reproductive stages.
Summer Resources	Floral resources that provide nectar and/or pollen to bumble bees during the period of maximum bumble bee worker abundance, including preferred "superfood" or "immune system" forage species [15] that provide elevated nutritional value to bumble bees (e.g. *Monarda fistulosa, Eutrochium* spp., *Echinacea purpurea, Cirsium* spp., *Amorpha canescens, Impatiens* sp., *Helianthus* spp., *Chelone* spp., *Penstemon* spp.).
Overwintering Resources	Areas with substrates suitable for the survival of overwintering mated queens. These may include mulch piles, thick leaf litter, bunch grasses, or other structures (including bare soil near the natal colony site). Different species of *Bombus* may have different overwintering strategies [13], and for imperiled species the full extent of variation in this strategy may not be well known.

Midwest, spring ephemeral wildflowers in mature woodlands are primary spring habitats, while prairies and grasslands tend to bloom later. Non-native species can provide spring forage resources, sometimes in great abundance.

Nesting habitat- For many imperiled species of bumble bees, few observations of nest characteristics have been recorded in the scientific literature (Liczner and Colla 2019). Until recently, much of what has been known, or thought to be known, about the nesting habits of *B. affinis* was derived from the careful observational work of Otto Plath (1922, 1927) in the vicinity of Boston, Massachusetts. Boone et al. (2022) reported observations of 3 different *B. affinis* nests made in Minnesota and Wisconsin, each of which showed some evidence of association with rodent activity. For assessment purposes, we consider potential nesting habitat for *B. affinis* to include well drained slopes and embankments, bunch grass cover, anthropogenic structures and grasslands with legacy rodent burrows. Other imperiled bumble bee species may have different nesting proclivities, including ground, tree and cavity nestings.

Summer Habitat- Summer floral resources for bumble bees are primarily pollen and nectar products from flowers. Some floral resource species are more valuable to bumble bees than others, offering immune system benefits or particularly nutritious rewards to foragers [15]. Again, a working familiarity with local flora and the preferences of bumble bee species in the regional species pool will improve the quality of this habitat assessment. Key characteristics of prime summer floral resource quality are diverse assemblages of plants offering abundant floral foraging opportunities continuously throughout the summer, the presence of preferred plant species (including "superfood" or "immune system" species; [15]).

Overwintering Habitat- The overwintering behavior of queen bumble bees is largely unknown for many bumble bee species. In some species, mated queens seeking to overwinter will burrow in mulch or loose soil, sometimes near nests [13]. The behavior of

other species may be completely unobserved or inferred from the known behavior of close relatives. For *Bombus affinis*, we know of no published observations of overwintering habitat use and instead assume that forest duff, mulch piles, rodent burrows and anthropogenic debris may be used by overwintering queens.

Mating Habitat- Bumble bee mating behaviors vary across species and species groups. For some species, e.g. *B. pensylvanicus* (DeGeer 1773) mating may occur within the colony nest [11]. In other species, such as *B. griseocollis* (DeGeer 1773), males may perch on twigs or branches of trees and compete with other males for access to passerby queens (pers. obs.). To date, we ignore this dimension of habitat quality in our assessments of habitat quality for *Bombus affinis*, since we know so little about the mating strategies and behaviors of the bumble bees in Illinois. Should the state of knowledge on this aspect of bumble bee life history change, particularly for *B. affinis*, this habitat assessment framework could be used to map the spatial extent of mate choice arenas in a project area.

If surveyors seek to assess the habitat quality in some project area, it is important that habitat assessments be conducted without regard to the observed rates of visitation by bumble bees. High quality habitat is not necessarily highly used habitat; there is an inherent circularity of using organismal abundance as a proxy for habitat quality [20,21]. This problem can be avoided by assessing habitat quality solely on the basis of the structural components given in Table 1, and disregarding observations or capture of bumble bees during habitat assessment.

The analysis method- An important product of this project specific assessment of bumble bee habitat quality is a map of the distribution of habitat quality, and the acreage occupied by each category of habitat quality, across the project area. Depending on the needs of the surveyor or others that might utilize these maps for decision-making, additional information about the content of these polygons may be stored in the GIS. For example, a map depicting the extent of "Summer Foraging Habitat" as a polygon might contain additional information about the species composition in different subpolygons similarly classified as summer foraging habitat. Similarly, observations of bumble bee species or relevant environmental data and field notes are also potentially stored in the tables accompanying a GIS map of a project area habitat assessment.

In Illinois, I classify bumble bee habitat quality in 4 categories: No Habitat, Low, Medium and High Quality. I consider areas where none of the constituent elements of bumble bee habitat occur to be No Habitat for bumble bees. Areas with only 1 element of bumble bee habitat are Low Quality (e.g., lawns and roadsides with intermittent spring or summer forage). Areas with 2 or 3 elements are considered Medium Quality habitats, without respect to which elements are present. Areas where all 4 elements occur are considered High Quality. A GIS is used to merge the individual polygons of each constituent element of bumble bee habitat to create a single map layer where the total area of each cover type, or habitat quality, can be calculated separately (Fig. 2).

Project specific habitat assessments should take pains to document the extent of occurrence of important plant species and physical structures associated with potential nesting and overwintering habitat. Mitigations or other commitments intended to reduce potential impacts may be assigned not only by land cover types, but also the total area of each habitat quality in the project area. A full assessment of spring and summer floral forage typically requires several visits to the site, and an eye for documenting species that may bloom ephemerally outside of these visits (e.g., by identifying spent blooms, or dead stems from the last year's growth). The reduction of a multi-dimensional habitat assessment problem to map algebra offers the rapid conceptualization and estimation of project impacts to habitats known to be associated with critical periods in the life history of bumble bee colonies.

I have suggested a possible fifth constituent element of quality bumble bee habitat with potential to limit the year-to-year success of bumble bee colonies: courtship arenas where mate choice and mating occur. However, variation in the mating behavior among *Bombus* species precludes a generalized description of such habitat, and so the potential contribution of a project area to provide mating arena habitat should be considered for each species separately. For example, Boone et al. (2022) observed *Bombus affinis* courtship and mating behaviors approximately 5 m from a known nest. For some species, possibly including *Bombus affinis*, courtship habitat may occur within or overlap with nesting habitat completely. For other species (e.g. *B. auricomus*), courtship may occur a much greater distance from a nest [22]. *B. griseocollis* males establish and defend perches, from where they compete for the attention of queens seeking mating opportunities (author, personal observation). Nesting, overwintering and courtship habitat requirements are the least well understood aspects of bumble bee life history, and the uncertainty around which behaviors are normative for target species currently limits the utility of exploiting this habitat requirement dimension in project assessment. Nonetheless, as more is learned about the ecology and behavior of bumble bees, this spatial framework for project specific habitat assessment can easily accommodate the consideration of new habitat features as new map layers.

Funding

This work was supported by Illinois Department of Transportation, through the Illinois Natural History Survey at the University of Illinois at Urbana-Champaign.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgments

Jason Bried and K.C. Carter provided invaluable feedback on the use and development of this method. Several iterations of undergraduate and graduate students have also been instrumental in working out a standardized method for habitat assessment, including Maria Niemerg, Alma Schrage, Jack Caldwell, Casey Fry, Breanna Owens and Moshe Piltz.

References

[1] R.H. Hildebrand, A.C. Watts, A.M. Randle, The myths of restoration ecology, Ecol. Soc. 10 (1) (2005) 19 http://www.ecologyandsociety.org/vol10/iss1/art19/.
[2] S.A. Cameron, J.D. Lozier, J.P. Strange, J.B. Koch, N. Cordes, L.F. Solter, T.L. Griswold, Patterns of widespread decline in North American bumble bees, Proc. Natl. Acad. Sci. 108 (2) (2011) 662–667 www.pnas.org/cgi/doi/10.1073/pnas.1014743108.
[3] D. Goulson, G.C. Lye, B. Darvill, Decline and conservation of bumble bees, Annu. Rev. Entomol. 53 (1) (2008) 191–208.
[4] A.R. Liczner, S.R. Colla, One-size does not fit all: at-risk bumble bee habitat management requires species-specific local and landscape considerations, Insect Conserv. Divers. 13 (6) (2020) 558–570.
[5] C. Carvell, A.F.G. Bourke, S. Dreier, S.N. Freeman, S. Hulmes, W.C. Jordan, J.W. Redhead, S. Sumner, J. Wang, M.S. Heard, Bumblebee family lineage survival is enhanced in high-quality landscapes, Nature 543 (2017) 547–549, doi:10.1038/nature21709.
[6] J.M. Mola, J. Hemberger, J. Kochanski, L.R. Richardson, I.S. Pearse, The importance of forests in bumble bee biology and conservation, Bioscience 71 (12) (2021) 1234–1248, doi:10.1093/biosci/biab121.
[7] J. Alcock, J.P. Alcock, Male behavior in two bumblebees, *Bombus nevadensis auricomus* and *B. griseocollis* (Hymenoptera: Apidae), J. Zool. 200 (4) (1983) 561–570, doi:10.1111/j.1469-7998.1983.tb02816.x.
[8] D. Fairchild, O.W. Barrett, Notes on the copulation of *Bombus fervidus*, Proc. Entomol. Soc. Wash. 8 (1-2) (1906) 13–14.
[9] H.J. Franklin, The bombidae of the new world, Trans. Am. Entomol. Soc. 38 (1912) 177–486.
[10] H.J. Franklin, The bombidae of the new world (continued), Trans. Am. Entomol. Soc. 39 (2) (1913) 73–200.
[11] T.H. Frison, A contribution to the knowledge of the bionomics of *Bremus americanorum* (Fabr.) (Hymenoptera), Ann. Entomol. Soc. Am. 23 (4) (1930) 644–665.
[12] E.M. Villalobos, T.E. Shelly, Observations on the behavior of male *Bombus sonorous* (Hymenoptera: Apidae), J. Kans. Entomol. Soc. 60 (4) (1987) 541–548.
[13] O.E. Plath, Notes on the hibernation of several North American bumblebees, Ann. Entomol. Soc. Am. 20 (2) (1927) 181–192, doi:10.1093/aesa/20.2.181.
[14] L.S. Hall, P.R. Krausman, M.L. Morrison, The habitat concept and a plea for standard terminology, Wildl. Soc. Bull. 25 (1) (1997) 173–182.
[15] Xerces Society for Invertebrate ConservationRusty Patched Bumble Bee Habitat Assessment Form and Guide, Xerces Society for Invertebrate Conservation, 2017 https://www.xerces.org/sites/default/files/2018-05/17-010_01_HabitatAssessmentFormGuideByXercesForRPBB.pdf.
[16] M.P. Simanonok, C.R.V. Otto, R.S. Cornman, D.D. Iwanowicz, J.P. Strange, T.A. Smith, A century of pollen foraging by the endangered rusty patched bumble bee (*Bombus affinis*): inferences from molecular sequencing of museum specimens, Biodivers. Conserv. 30 (2020) 123–137 https://link.springer.com/article/10.1007/s10531-020-02081-8.
[17] Smith T.A. 2017. Plants favored by Rusty Patched Bumble Bee, https://www.fws.gov/sites/default/files/documents/PlantListRPBBJune2017.pdf.
[18] A.T. Wolf, J.C. Watson, T.J. Hyde, S.G. Carpenter, R.P. Jean, Floral resources used by the endangered rusty patched bumble bee (*Bombus affinis*) in the Midwestern United States, Nat. Areas J. 42 (4) (2022) 301–312, doi:10.3375/22-2.
[19] T.J. Wood, J. Gibbs, K.K. Graham, R. Isaacs, Narrow pollen diets are associated with declining Midwestern bumble bee species, Ecology (2019) e02697, doi:10.1002/ecy.2697.
[20] M.D. Johnson, Measuring habitat quality: a review, Condor 109 (2007) 489–504.
[21] B. VanHorne, Density as a misleading indicator of habitat quality, J. Wildl. Manag. 47 (4) (1983) 893–901.
[22] T.H. Frison, Notes on bombidae, and on the life history of *Bombus auricomus* Robt, Ann. Entomol. Soc. Am. 10 (1917) 277–288.