**Abstract**

**Introduction**

Long distance transport of managed pollinators for agricultural pollination, honey production, or both has been practiced by humans for centuries (REF). The practice is increasingly recognized for its potential to threaten the health, biodiversity, and abundance of wild pollinator communities (Goulson, 2003; Hooper et al., 2005; Page & Williams, 2023). Exotic pollinator introductions can negatively impact wild populations through a number of channels, including: exposure to wild populations to novel pests and pathogens (Arismendi et al., 2021; Cordes et al., 2012; Goulson et al., 2015; Graystock et al., 2016; Schmid-Hempel et al., 2014), competition for floral resources (Balfour et al., 2015; Bowers, 1985; Inoue & Yokoyama, 2010; Thomson et al., 1987), and competition for nesting sites (Inoue & Yokoyama, 2010; Miller et al., 2023). In addition, introduced pollinators could impact pollination of wild plant species, and provide pollination services to invasive weeds (Goulson 2003).

At the same time, not all species introductions result in negative impacts (e.g., ?). Introduced pollinators, for example, can provide critical pollination services in their introduced range (Downing & Liu, 2012; Groutsch et al., 2019; Rivest et al., 2023). The potential for negative impacts on wild pollinators, including competition, may depend largely on the degree of niche overlap between the introduced species and the native bee community (Osterman et al., 2021). ELABORATE HERE. A better understanding of the potential impact of introduced pollinators is necessary to inform management, conservation, and restoration efforts.

The common eastern bumble bee, *Bombus impatiens*, was approved for greenhouse pollination to the Lower Mainland of southwestern BC in 1998, after the native bee that was being managed for greenhouse pollination, *B. occidentalis*, experienced population collapse (Cannings, 2011; Evans et al., 2008; Ratti & Colla, 2010; Whittington & Winston, 2004). It has recently become clear that *B. impatiens*, whose queens, workers, and males regularly escape greenhouse captivity, has become naturalized throughout BC’s Lower Mainland, and has also been detected at low frequency on Vancouver Island and in Washington state, USA (Looney et al., 2019; Ratti & Colla, 2010; Sargent et al., unpublished data; Williams et al., 2014).

Little is known about the potential for *B. impatiens* to impact native pollinator and plant communities where it is introduced. A study from Mexico found that managed colonies of *B. impatiens* can act as a reservoir of novel parasites and pests (Sachman-Ruiz et al., 2015). Studies of field introductions of managed *B. impatiens* demonstrate that it frequently usurps other queens from their nests (Miller et al., 2023). Based on natural history records from its native range, *B. impatiens* tends to exhibit a late season phenology. For example, in southwestern Ontario, where it is native, abundance peaks early to mid-August and individuals are active well into October.

It is currently unclear how *B. impatiens* interacts with the existing bumble bee communities in its introduced range in southwestern BC. In terms of nesting, *B. impatiens* is a subterranean nester in the wild, nests are contained within boxes above ground when managed (Macfarlane et al., 1994; Williams et al., 2014). Subterranean nesting bumble bees depend on prebuilt holes in the ground, usually those made by rodents (Varner et al., 2023; Williams et al., 2014). Nest site competition from *B. impatiens* could impact the native bees *B. occidentalis* and *B. vosnesenskii* as both also rely on subterranean nesting spaces such as abandoned rodent dens (Macfarlane et al., 1994; Williams et al., 2014). Based on natural history observations, *B. impatiens*, similar to other bumble bees exhibits a generalist foraging strategy (Williams et al., 2014).

Within BC’s Lower Mainland region there are many introduced and invasive plant species that are popular foraging resources for bees, including *Hypericum radicata*, *Impatiens glandulifera*, *Lythrum salicara*, *Trifolium pratense*, and *Vicia cracca*. Many of these species exhibit a later flowering phenology than the native plant community of southwestern BC, which tends to flower early in the spring months (Sargent et al. unpublished data). If *B. impatiens* also exhibits a late season phenology in BC, it may be more often interacting with invasive species, possibly helping to support their populations (Lee-Mader et al., 2023; Williams et al., 2014).

Following the potential impacts of exotic bees outlined by Goulson (2003), we sought to explore the potential for *B. impatiens* to compete with native pollinators for floral resources and pollinate invasive plants in its introduced range in Vancouver, BC’s Lower Mainland region. Over two field seasons, we surveyed the phenology of *B. impatiens* along with four other *Bombus* species common to the area, in order to gather information about the potential for overlap in the timing of colony foraging activity. We also performed a set of surveys to establish the foraging preferences of these same species in order to establish the potential for temporal and floral resource niche overlap between *B. impatiens* and common native bumble bees in the region.

**Methods**

*Study sites*

We selected nine study sites from across BC’s Lower Mainland to survey bumble bee phenology and plant associations. All sites were established within regional parks managed by Metro Vancouver Regional Parks (<https://metrovancouver.org/services/regional-parks>). Sites were selected based on their location, vegetation, and whether they had confirmed sightings of foraging bumblebees (based on records from www.iNaturalist.org). Sites were required to be at least 2 km apart to ensure that the bumble bee communities at each park were independent, based on the average and maximum flight distances of *Bombus* species (Greenleaf et al., 2007). Information on the flowering plant community at a site and plant phenology was obtained through a combination of preliminary pollinator surveys performed in 2020, and through records discovered in iNaturalist (https://www.inaturalist.org). Study sites were also selected based on their vegetation to ensure a variety of flowering plants that represented a spectrum of bloom times from May to September. The information obtained online was confirmed through walk-throughs of sites during site selection. Once sites were selected, permission from the relevant permitting authorities was obtained (Appendix table A1).

*Bombus surveys*

Site surveys were performed twice per month from early or mid-May until the end of October in 2022 and 2023. After an initial walk through of the site, two 100 m subsections were chosen based on the presence of a relatively high density of floral resources. Transects were measured using a survey tape and the location was recorded using a sub-meter GPS (Trimble Geo 7X Handheld Data Collector). Bumble bee surveys took place between 10:00 am and 4:00 pm on days with less than 50% cloud cover, average wind speeds less than 10 km/h, and daily maximum temperatures of at least 8ºC (Williams et al., 2014).

‘Catch and release’ bumble bee surveys were performed along the established transects for a period of 30 minutes. Briefly, an observer chose a patch of floral resources close to one end of the transect, and then started a 5-minute timer. During this time, the observer stood close to the patch and watched for bumble bees foraging on a flower (defined as the bee touching the anthers and/or stigma). When a bumble bee was observed, we carefully captured it and stopped the timer. The bumble bee was placed in a vial and labelled with a unique number, date of capture, and the species of plant. If the plant could not be identified in the field, we took a photo of the flower(s), leaves, and whole plant for later identification. Captured bees were placed in a cooler for later identification, and the observer resumed the timer and continued observing the patch. After five minutes of observations, we chose another patch of flowers along the 100 m transect and repeated the process. After six patches of flowers had been observed within a transect and 30 total observation minutes had elapsed, we removed bees from the cooler and identified them to species and caste and then released them in the field. In cases where identification of the bee in the field was not possible, they were taken to the lab to be pinned and identified using microscopy and relevant keys.

*Plant surveys*

A vegetation survey was performed prior to (or following, depending on the time of day/weather) *Bombus* surveys at each site visit to quantify the available floral resources. Plants were surveyed along the same transect described above for bee surveys by placing a 1 m2 quadrat every 10 m along each transect. We then identified all species in flower and counted all open flowers within the quadrat. For flowering plant species with many inflorescences, the total number of flowers was estimated by counting five distinct inflorescences, estimating the average number of flowers per inflorescence, and multiplying by the number of total number of inflorescences (Guezen & Forrest, 2021).

*Statistical Analyses*

To explore whether *B. impatiens* exhibits a different phenology relative to other common native bumble bee species in Metro Vancouver, we developed a generalized mixed model (GLMM) with a Poisson distribution to model the bumble bee count data collected in 2022 and 2023. We restricted the count data to workers only, as males and queens exhibit distinct phenological patterns from workers, emerging earlier and later than workers on average, respectively (Williams et al., 2014). Where no bees of a species in our dataset were observed during a specific survey, the count was entered as ‘0’, in order to enable the estimation of the start and end of each species’ period of activity across sites. We ran a single GLMM using the lme4 package (v1.1-35; Bates et al. 2015), with bumble bee species count data as the response; Julian date, bumble bee species, and year (2022 or 2023) as fixed effects; and site as a random effect. A quadratic term (Julian date2) was also included in the model to better describe the pattern of seasonal bee abundances (Leong et al., 2016). We then fitted a phenology curve for each species using the coefficients resulting from the model (Figure ?).

To test whether *B. impatiens* diet overlaps significantly with the diet of native *Bombus* species, we used non-metric multi-dimensional scaling (NMDS) to assess the similarity in the plant associations for each species of the five most common species of bumble bee from each site across the two years of surveys. Briefly, NMDS uses ordination to create a distance matrix of observations (Bakker, 2024). In ecological studies, the method is used to establish pairwise dissimilarity among community species lists. Here, we defined the set of plants each species of bumble bee was recorded foraging on as the bumble bee ‘community’, with the goal of illustrating the degree of dissimilarity in plant associations among the five most commonly observed bumble bees in my data set. Briefly, we created a matrix for each site, with the bumble bee species at each site as the columns, and the plant community as the rows. We populated the matrix with the abundance of interactions between a particular bee and plant species observed at that site over the two years of surveys. Using the vegan package in R and applying a Bray-Curtis distance metric (v2.6-4; Oksanen et al., 2022), plots were created to visualize the degree of overlap in the plant community observations for each of the five most common species of bumble bee in my data set, with the goal of establishing whether the species had distinct or overlapping foraging preferences. Explain the test STATS TEST HERE?

Finally, to test whether *B. impatiens* tends to preferentially interact with invasive plant species over native or naturalized species, we used logistic regression to model and compare the visitation behaviour of the five most common bumble bee species in the surveys (*B. impatiens*, *B. melanopygus*, *B. mixtus*, *B. flavifrons*, and *B. vosnesenskii*). Foraging observations included all recorded plant interactions between bumble bee workers, queens, and males for the listed species. In total, there were 3627 total bumble bee and plant interactions recorded. Flowering plants in my dataset were classified as invasive (or not) using the species list provided by the Invasive Species Council of BC (Invasive species council of BC, n.d.). Then, the proportion of the plants categorized as invasive at a site on a given survey date (and site) was calculated by dividing the total number of plants in the invasive category by the total number of plants recorded. Once the dataset was prepared, we ran a single logistic regression model, with the type of interaction (‘invasive’ or ‘native/naturalized’) as the response and the proportion of invasive plants and the species of bumble bee as fixed effects. We included an interaction between bumble bee species and the proportion of invasive plants in a given survey to test whether different species exhibited different relationships between the probability of visiting an invasive species and the plant species’ proportion in the overall population. Site was included as a random effect. The logistic regression was run in the lme4 package (v1.1-35; Bates et al. 2015). All statistical analyses and plots were generated in R (v4.2.3; R Core Team 2023).

**Results**

Over the two years, we performed 210 surveys and recorded a total of 3755 interactions between bumble bees and plants. *Bombus impatiens* was present at all sites and was also the most commonly observed species of bumble bees overall, making up 41.6% of all observations. The most common native species captured was *B. mixtus*, which comprised 24.6% of all observations. Out of all the bumble bees observed, the identity of six individuals could not be confirmed, and they were removed from the dataset. Also left out were *B. flavidus*, *B. huntii*, *B. insularis*, and *B. occidentalis* as we observed each only a single individual of each over the two years.

Bumble bees were recorded interacting with 73 different plant species across all sites and surveys. The notoriously bee-attractive invasive plant species *Impatiens glandulifera* made up 38.3% of the all recorded of plant-bumble bee interactions, consistent with other studies demonstrating its attractiveness to bees where introduced (Chittka & Schürkens, 2001). In total, nine invasive plant species (as defined by BC Invasive Species Council) were recorded over the two years.

*Phenological niche overlap*

We fit a generalized linear mixed model to the bumble bee count data in order to examine whether *B. impatiens* phenology overlapped with the four most common native bumble bee species: *B. flavifrons*, *B. melanopygus*, *B. mixtus*, and *B. vosnesenskii*. Bee species, Day of Year, and (Day of Year)2 were all significant predictors of the bee count data. In addition, there was a significant interaction between ‘Bee species’ and ‘Day of year’, and (Day of Year)2, indicating that different bee species phenologies exhibited significantly different functions (Table 2.1, Figure 2.1). Year also showed a positive effect (Table 2.1, p < 0.001), with a higher abundance of bumble bees collected in 2023 compared to the reference year of 2022 (Appendix). When examining the drivers of the significant interactions, it is clear that the timing and curvature of the functions describing the phenology of native bees differs from that of *B. impatiens* (Figure 2.1, Appendix). The most similar bee phenologically to *B. impatiens* is *B. vosnesenskii*, which tends to emerge at a similar time, and exhibits a very similar peak abundance (Figure 2.1).

*Diet breadth overlap*

Using NMDS, we examined the flowering plant species visited by the five most common *Bombus* species over the two survey years. There was high overlap in terms of the plant species present in the diet of the surveyed bumble bees (Figure x). EXPAND

*Association with invasive plant species*

We fit a logistic regression model to examine the predictors of plant choice (invasive or not) for the five most common bumble bee species over the two years. Not surprisingly, the proportion of plants in flower that were invasive at the time of survey was a significant predictor of choice (Table 2.2, p < 0.001), indicating that bumble bees foraging choices tend to match the local abundance of invasive flowering plants. The significant ‘Species’ term indicates that different bumble bee species tend to have different preferences for invasive species when they are rare (i.e., at the intercept). Specifically, *B. flavifrons* and *B. mixtus* were significantly less likely to visit invasive flowering plant species when they are rare compared to *B. impatiens*, while *B. melanopygus* and *B. vosesenskii* exhibited plant choices similar to *B. impatiens*. The significant interaction term between the proportion of invasive flowering plant species and bumble bee species indicates there are differences in the shape of the function for different species (Figure x). A summary model (Appendix) found that *B. flavifrons* and *B. melanopygus* exhibited significantly different curves to *B. impatiens, B. vosnesenskii,* or *B. mixtus*. Specifically, the latter three species tend to visit invasive species more often than *B. flavifrons* or *B. melanopygus*, given a particular proportion of invasives in the population. This is consistent with the hypothesis that different species might have different preferences or visitation patterns to invasives, for example, by seeking them out even when they are rare.

**Discussion**

Our study quantified phenological and foraging niche overlap between the introduced bumble bee, *B. impatiens*, and other common native *Bombus* species in BC’s lower mainland region, with the goal of exploring the potential for *B. impatiens* to compete with native bee species for critical resources. We also estimated the potential for *B. impatiens* foraging preferences to promote the spread of invasive plant species in our region. To our knowledge, this is the first dedicated set of surveys of *B. impatiens* abundance, phenology and foraging at this scale in natural or semi-natural areas since its accidental introduction to the environment in the late 1990s.

Surprisingly, we found that *B. impatiens* was the most abundant bee species across our surveys, although its abundance varied widely across the nine sites (Appendix). We found strong evidnece that *B. impatiens* has a distinctly later phenology relative to many common native bumble bees, but that its phenology clearly overlaps with another common regional bumble bee, *B. vosnesenskii*. NEED A PARA OR TWO DESCRIBING WHAT THIS MEANS AND WHY IT MATTERS FOR COMPETITION.

The late season phenology of *B. impatiens* workers is consistent with its described phenology in its home range, where it is known to forage well into the fall months (Williams et al., 2014). Late season activity in bumble bees has not been studied extensively, but it has been shown that the availability of floral resources for late season foraging can influence bumble bee colony density in agricultural systems (Timberlake et al., 2021). The fact that worker activity in *B. impatiens* tends to peak later in the year than other local *Bombus* species could indicate that it imposes weaker competition on native bumble bees that tend to peak earlier in the season, including *B. flavifrons*, *B. melanopygus*, and *B. mixtus*.

Early season foraging is predictive of colony success in bumble bees (Malfi et al., 2019). Due to the mild, maritime-influenced climate in southwestern BC, the flowering phenology of the native flora tends to peak relatively early in the season, relative to other North American locations at a similar latitude (REF?). Consistent with this, bumble bee species native to this region tend to exhibit a phenology that more or less matches this bloom time (Williams et al., 2014). At the same time, the later phenological timing of *B. impatiens* workers could be detrimental to emerging young queens from earlier peaking species, whose foraging opportunities in late summer predict their ability to successfully survive the winter and reproduce the following spring (Williams et al., 2014). We did not attempt to track late season emerging queens and, at this point in time, but this would be an important potential source of competition that future studies should examine.

Our investigation of the plant associations for the most abundant bee species surveyed, *B. flavifrons*, *B. impatiens*, *B. melanopygus*, *B. mixtus*, and *B. vosnesenskii*, revealed no clear pattern of distinction in terms of the plant species utilized, suggesting competition for foraging resources is possible, especially under resource limitation. Finally, an analysis of whether *B. impatiens* is more likely to interact with invasive plant species than native bumble bees found that, consistent with their overlapping foraging and phenology data, *B. impatiens* and *B. vosnesenskii* tended to interact somewhat more frequently with invasive plants as a proportion of the visit total, relative to other common surveyed bumble bees.

In addition to competition for foraging resources, *B. impatiens* may compete with native species for nesting sites. *Bombus* nesting sites are hypothesized to be finite because bumble bees do not dig their own nests. Instead, they mostly utilize pre-existing holes in the ground, such as those dug by rodents (Williams et al., 2014). In addition to competing for nest space indirectly, *B. impatiens* could compete for nest space with native subterranean nesters directly through nest usurpation, a known behavior of this species (Miller et al., 2023). Further research on nesting site limitation and nest usurpation among bumble bee species would both be important avenues for better understanding the impacts of *B. impatiens* on nesting in native species.

Our finding that species of *Bombus* are foraging on a similar set of flowering plant species also raises the concern of increased opportunities for parasite and pathogen transmission. Managed bees have previously been identified as a source of increased pathogen risk (REF), and flowers are a well-established source of parasites and pathogens (Burnham et al., 2021; Figueroa et al., 2019). Our data on the regional occurrence of *B. impatiens* strongly suggests that managed bees continue to regularly escape greenhouses (Ulrich et al., *in preparation*). Pathogen transfer could be higher between managed *B. impatiens* and native bumble bee species as *B. impatiens* has been shown to act as a reservoir for infectious diseases previoulsy (Sachman-Ruiz et al., 2015). Studies on the impact of managed bees on the diet and transmission of pests and pathogens continue to emerge; our findings of strong flowering plant choice overlap suggest that future studies should examine pathogen transfer at foraging sites as a potential impact of *B. impatiens* on native bees.

Consistent with the hypothesis that introduced bees can facilitate the spread of exotic or invasive species (Goulson 2003), we found that *B. impatiens* tended to preferentially interact with invasive species, visiting them at a higher frequency than other *Bombus* species, relative to their frequency in the local plant community. We also found that *B. flavifrons* and *B. melanopygus* were a less likely to ‘switch’ to foraging on an invasive plant species, even as their frequency as a proportion of all floral resources increased. *Bombus mixtus* and *B. vosnesenskii*, on the other hand, tended to forage on invasive species at about the same rate as *B. impatiens*.

Previous studies have demonstrated that the presence or proportion of invasive plants can alter bumble bee foraging behavior and resource utilization patterns. For example, it has been shown that the notorious invasive plant species, *I. glandulifera*, a common fall-blooming species in our region, is preferred and used highly by bumble bees due to its exceptionally high nectar rewards (Chittka & Schürkens, 2001; Tanner & Gange, 2020). Introduced plant-pollinator interactions can have positive as well as negative ecosystem effects; Gibson et al. (2019) demonstrated that invasive flowering plants can support endangered species of bumble bees. (Richardson et al., 2010). and recent work has shown that native hoverflies and butterflies benefit from invasive plants in at-risk ecosystems on Vancouver Island (Kovács-Hostyánszki et al., 2022; Rivest et al., 2023). At present, it is not possible to generalize the role of invasive plant species in supporting native or introduced species, but this is an area of active research and debate (Rivest et al., 2023)

Although longitudinal survey data is lacking, occurrence data from iNaturalist suggest that there has been a considerable amount of turnover in the most common *Bombus* species in BC’s lower mainland in recent decades. For example, *B. occidentalis*, then *B. vosnesenskii….* Interestingly, *B. vosnesenskii* is itself a relative newcomer to this region in terms of its occurrence/abundance, with surveys indicating it was initially rare prior to the late 1990s, after which it became more prevalent, and is now one of the most common species of *Bombus* observed in metro Vancouver and on Vancouver Island (Ulrich et al. in prep??). This could explain why it tends to have lower phenological niche overlap with native species that have long been established in this region (e.g., *B. melanopygus*, *B. flavifrons* and *B. mixtus*). Future studies should consider the relatively new status of *B. vosnesenskii* in our region when considering the importance of niche overlap in the success of introduced species.

Overall, our study provides clear evidence that *B. impatiens*, introduced to our region as a greenhouse pollinator in YEAR, first escaped in the late 1990s and has now naturalized across the BC’s lower mainland. It has become so successful in this region that it is now one of the most frequently identified bee species detected in surveys throughout the region (Ulrich et al., *in preparation*). The rapid expansion of *B. impatiens* in our region and its niche overlap with regional *Bombus* species underscores the urgency of understanding the ecological implications of its introduction, especially with respect to its potential to compete, or even outcompete, native bees for foraging and nesting opportunities. Our findings emphasize the importance of proactive management strategies to reduce the potentially harmful impacts of introduced bumble bee species on native ecosystems. Future studies should focus on testing the degree to which competition for floral and nesting resources and pathogen transmission are impacting wild plant-pollinator communities.