The Effect of Nest Box Distribution on Sustainable Propagation of *Osmia lignaria* (Hymenoptera: Megachilidae) in Commercial Tart Cherry Orchards

N. K. Boyle¹,² and T. L. Pitts-Singer¹

¹Bee Biology and Systematics Laboratory, USDA-ARS-PIRU, 1410 N 800 E, Logan, UT 84341 (natalie.boyle@ars.usda.gov) and ²Corresponding author, e-mail: natalie.boyle@ars.usda.gov

Subject Editor: Sandra Rehan

Received 21 September 2016; Editorial decision 24 January 2017

Abstract

The blue orchard bee, *Osmia lignaria* (Say), is a solitary bee that is an excellent pollinator of tree fruit orchards. Due to the annual rising costs of honey bee hive rentals, many orchardists are eager to develop management tools and practices to support *O. lignaria* as an alternative pollinator. Establishing *O. lignaria* pollination as a sustainable industry requires careful consideration of both bee and orchard management. Here, we test the effect of artificial nest box distribution on in-orchard propagation of *O. lignaria* in Utah commercial tart cherry orchards. Two nest box distributions were compared across three paired, 1.2-ha plots. One distribution, traditionally employed by *O. lignaria* consultants, included a centrally located tote for mass-nesting with smaller, surrounding ‘satellite’ nest boxes at orchard margins. The other distribution was composed of smaller, more equally distributed nest boxes throughout the 1.2-ha plots. Significantly higher propagation of *O. lignaria* was observed in the latter nest box distribution, although all treatments resulted in bee return exceeding the number of bees initially released. These findings provide support for the use of *O. lignaria* in tart cherry orchards, and demonstrate how simple changes to bee set-up and management can influence propagation efforts.

Key words: blue orchard bee, commercial pollination, dispersal, *Prunus cerasus*, solitary bee

Recent declines in honey bee colonies (Seitz et al. 2016), combined with increasing demands for pollination services in agriculture (Aizen and Harder 2009), have elicited renewed enthusiasm to develop management strategies for alternative pollinators in many agricultural systems. The blue orchard bee, *Osmia lignaria* (Say) (Hymenoptera: Megachilidae), is a solitary, cavity nesting bee that has proven successful in providing pollination to spring-blooming orchard trees, including apple, pear, almond, and cherry (Torchio 1979, 1985; Bosch and Kemp 1999; Sheffield 2014). Native across most of the United States and Southern Canada (Rust 1974) adult *O. lignaria* females reside in naturally occurring tunnels located in wood or hollow stems, but will readily nest in various artificial substrates, including cardboard tubes, paper straws, and drilled wood laminates in agricultural settings (reviewed in Bosch and Kemp 2001; Fig. 1).

*Osmia lignaria* emergence can be manipulated to occur in synchrony with bloom through the use of standardized temperature-controlled incubation practices. The combined ease of in-orchard management and flexibility with timing adult bee emergence makes *O. lignaria* particularly attractive as a possible alternative, commercially managed pollinator (Bosch et al. 2000, Bosch and Kemp 2001). In almond orchards, the use of *O. lignaria* in combination with honey bees significantly increases fruit set, and provides measurable increases in nut yield (Artz et al. 2013, Brittain et al. 2013, unpublished data). Furthermore, *O. lignaria* show a strong preference for foraging on fruit trees (Bosch and Kemp 1999), highlighting great potential for this species to contribute to pollination in orchards.

At present, current best management practices (BMPs) for using *O. lignaria* as pollinators of conventional, commercial orchards generally fail to provide details concerning how to optimally arrange nesting sites and deploy the bees, based on orchard structure and its management needs. For example, nesting site visibility and frequency may curtail the high rates of bee dispersal away from orchards, which limits the number of in-orchard nesting females and retrieval of bee offspring for use the following year. Consequently, orchardists typically do not recover the same number of bees that they initially release (Artz et al. 2013, 2014). Pollination using *O. lignaria* in orchards often requires that a new bee supply is purchased annually, which in most cases is not economically feasible at current costs. Developing BMPs that result in nesting rates that match or exceed the initial number of bees released in commercial orchards can dramatically decrease or eliminate the cost of...
replenishing annual *O. lignaria* populations. Identifying practices that improve annual in-orchard retention would have substantial implications for the economic viability of using this bee for commercial pollination. Furthermore, sustainable in-orchard management of bee populations would reduce the need to collect additional bees from native wildlands, which has unknown impacts on wild *O. lignaria* populations.

Presently, some solitary bee suppliers recommend providing nesting cavities for *O. lignaria* from a centrally located, corrugated plastic 'mail tote' (Cane 2006; Fig. 2a) along with smaller 'satellite' nest boxes (Artz et al. 2013; Fig. 2b) placed on the field margins of the space requiring pollination (J. Watts, personal communication). Previous studies that evaluate *O. lignaria* nesting in almond orchards report higher nesting rates when many nest boxes, partially filled with nest tubes, are placed uniformly throughout the orchard than when fewer nest boxes completely filled with nest tubes are uniformly provided (Artz et al. 2013, 2014). Nesting preference by *O. lignaria* females is also affected by other physical attributes such as nest box color, height, orientation, and nest cavity diameter (Bosch et al. 2000, Artz et al. 2014, Boyle et al., unpublished data). Thus, nest box style and distribution are simple and relatively inexpensive modifications that can have significant impacts on *O. lignaria* reproduction in orchard environments (Artz et al. 2013, 2014).

The purpose of this study was to evaluate the use of *O. lignaria* as an alternative pollinator of tart cherry orchards in Utah while also sustaining, or enhancing, in-orchard populations. More specifically, our interests were (1) whether *O. lignaria* populations can be sustainable in this system and (2) how changing the distribution of artificial nest boxes in cherry orchards can influence overall nesting success.

**Materials and Methods**

This study took place in a 101-ha tart cherry (var. Montmorency on Mahelab root) orchard in Santaquin, Utah (GPS: 39°59′28.84″N, 111°48′21.20″W). Within the orchard, two nest-box distributions (treatments; described below) were established across six 1.2-ha plots (treatments were paired across three geographically distinct ‘blocks’; Fig. 3). Because the typical foraging range of *O. lignaria* is about 60 m (Rust 1974) radius from the nest site, each treatment was separated by at least 75 m to minimize bee drift into neighboring experimental plots. Bees were provided by Watts Bees (Bothell, WA) in spring 2016 as loose-cell, overwintering adults in cocoons. They were stored at the USDA-ARS Pollinating Insects Research Unit in darkness at 4°C until their release. At the onset of bloom (15 April 2016), 825 female and 1,230 male just-emerging *O. lignaria* were released at the center of each plot from Styrofoam and plastic emergence boxes (40 × 25 × 20 cm), situated ~12 cm above ground. The emergence boxes each had a small, 2-cm exit hole at the bottom from which adult bees could crawl through and fly away. Plastic, corrugated nest boxes were distributed in one of two different layouts (or treatments) within each experimental block concurrently with *O. lignaria* bee releases: (1) A ‘Mail Tote/ Satellite’ (MTS) treatment and (2) a ‘Uniform’ (UF) treatment (Fig. 3). The MTS treatment consisted of a large, centrally located mail tote (described in Cane 2006; Fig. 2a) that supported 600 nesting cavities. This layout included four small corner satellite nest boxes as well (boxes described in Artz et al. 2013; Fig. 2b), each containing 100 cardboard nest tubes (15.3 cm in length × 7 mm inner diameter, each lined with paper straw inserts) and situated 86 m from the central tote. The UF treatment consisted of 10 small nest boxes, distributed evenly across two central rows within each replicate and containing 100 nesting cavities each (same as the previously described satellite boxes; Fig. 2b). All nest boxes were blue in color and installed at breast height with southeast-facing entrances. Both treatments provided the same number of cavities (n = 1000) to *O. lignaria* females in this experiment. A patented spray-on attractant (Pitts-Singer et al. 2015), which was identified from *O. lignaria* cocoons, was applied at a rate of 100 cocoon equivalents (105.77 µg active ingredient = one cocoon equivalent) per nest box by spritzing it directly onto the outer ends of the cardboard tubes. Composed of a free fatty acid mixed into an ethyl acetate solvent, this attractant has been demonstrated to increase nesting when sprayed onto vacant cardboard tubes (Pitts-Singer et al. 2015; unpublished data).

Cherry bloom began 15 April 2016 and senesced around 30 April 2016. However, *O. lignaria* were permitted to mate and provision their nests in the orchard through post-bloom until 17 May 2016 so that delicate, immature larvae would be able to develop to less vulnerable stages prior to their removal (manipulation of early instar *O. lignaria* can dislodge them from their provision mass, resulting in mortality due to starvation; Bosch and Kemp 2001). No pesticide applications were made while the bees were nesting, and nest boxes were removed from the orchards prior to application of the first post-bloom nutritional spray (19 May 2016). In addition to introduced *O. lignaria*, honey bees were present in the orchard at a standard rate of one hive per acre for the duration of bloom.

Upon their removal in mid-May, nest boxes were disassembled and the cardboard tubes were evaluated immediately for occupancy by visual inspection. Fully or partially completed nests were determined to be ‘occupied’, and occupancy was compared between nest box distributions. Starting 9 June 2016, the nests with developing
bees in cocoons from each treatment were X-radiographed to determine the number of successfully completed live cells (or healthy cocoons), and offspring sex ratio (by visual inspection of nest position and size; Fig. 1). Statistical comparisons between treatments were conducted using one-way ANOVAs, blocked by replicate (JMP, SAS Institute 2015).

Results and Discussion
Despite the short bloom time of cherries (about 2 wk in this orchard), *O. lignaria* nested successfully and in large numbers. Regardless of treatment, reproduction of female *O. lignaria* surpassed the initial number of bees released into the orchard, resulting in a 1.6-fold increase in bees across treatments. In total, 19,336 live cells were created from the original 5,000 females released into the orchards. Overall, an average 1.11 male to female sex ratio was obtained, which did not vary significantly by treatment ($F = 0.78; \text{df} = 5; P = 0.47$). While cavity occupancy did not reveal significantly higher nesting between treatments ($F = 3.71; \text{df} = 2; P = 0.194$), we did observe significantly more live cells ($F = 18.79; \text{df} = 1; P = 0.0494$) produced in UF treatment over the MTS treatment (Table 1). This discrepancy results from a combination of a slightly higher number of cells per nest in the UF treatment (4.73 average cells per nest) over the MTS treatment (4.34 cells per nest) and numerically higher occupancy in UF (Table 1). Block did not affect nesting occupancy ($F = 1.34; \text{df} = 2; P = 0.43$) or live cell production ($F = 13.94; \text{df} = 2; P = 0.067$). In cherries, it appears best to distribute nest boxes uniformly throughout the orchard rather than rely on

![Fig. 2. Two types of corrugated plastic nest boxes were used in this study: (a) a large, centrally located mail tote in the MTS treatment (600 cavities) and (b) smaller nest boxes that comprised ‘satellite’ boxes in the MTS treatment and all boxes in the uniformly distributed (UF) treatment (100 cavities).](image-url)
a central nesting location with satellite boxes on orchard block margins.

Previous attempts to incorporate O. lignaria as cherry orchard pollinators have reported extremely successful nesting of in-orchard bee populations and significantly increased cherry yield where they are used (Bosch et al. 2006), although these earlier trials were limited to one small 1.4-ha orchard over several years. In addition, this smaller orchard received limited chemical inputs and was located in a semi-agricultural area. To our knowledge, our study is the first scientific report of successful O. lignaria propagation in conventional, commercially managed tart cherry orchards in Utah, suggesting that it could be an excellent target crop for future O. lignaria application.

As with many tart cherry varieties that are commercially produced, Montmorency cherries are not entirely reliant on insect pollination, as they are partially self-compatible and capable of setting fruit without cross-pollination. However, this variety, along with many others that are grown commercially in the United States do benefit substantially from bee visitation (Lansari and Iezzoni 1990), which is why honey bee hives are frequently interspersed throughout these orchards. Considering the use of an optional (Scott-Dupree et al. 1999) stocking rate of one hive per acre, O. lignaria may be a viable alternative or complimentary candidate for providing pollination services in this system. However, due to the sensitivity of O. lignaria to pesticide exposure (e.g., Biddinger et al. 2013, Artz and Pitts-Singer 2015) and the practicalities concerning the timing of nest removal from orchards, the use of this pollinator requires care in cases where pesticides are routinely applied during or just after bloom.

Because the native range of O. lignaria overlaps with our study site, there is a possibility that some of the bees nesting in these orchards were from local, wild populations. However, due to the intensive management strategies employed in conventional commercial orchards (including frequent agrochemical applications) and short cherry bloom window, it is improbable that the local environment would be capable of sustaining large, stable populations of O. lignaria over time.

On the day of nest removal from the orchard, no adult O. lignaria were observed. This is likely a consequence of limited available forage to the bees immediately following bloom. In the presence of alternative floral resources (combined with careful pesticide use), the foraging window for O. lignaria can extend beyond crop bloom, which has been shown to have positive impacts on bee propagation (Sheffield et al. 2008, unpublished data).

Presently, the greatest challenge in using O. lignaria for commercial pollination is their limited supply. O. lignaria are primarily obtained by wild trapping, in which ‘trappers’ place artificial nest cavities in regions where they are known to aggregate (predominantly in high elevation areas of Utah, Idaho, and Washington). At the end of nesting, wild-caught bees are sorted and processed for storage at 3–5°C over the winter months as adults in cocoons. Subsequently, they are sold and distributed to local farm stores or directly to orchardists. Management practices to date are labor-intensive and expensive, which results in impractically high retail

| Table 1. Mean (± SE) nest occupancy and live cell count of O. lignaria reproduction by treatment |
|-----------------------------------------------|
| N | Mean nest occupancy, % ± SE | Mean live cells, ± SE | Average cells per nest |
|-----------------------------------------------|
| Uniform treatment | 3 | 80.6 ± 8.2 | 3,812.0 ± 562.5 | 4.73 |
| MTS treatment | 3 | 60.7 ± 2.1 | 2,633.3 ± 501.6 | 4.34 |

Percent occupancy is a total percentage of all nest straws available at each site (n = 1,000 per site). Male-to-female ratio did not vary between treatments.
prices of *O. lignaria* for pollination (typical 2016 costs were upwards of $1 per female USD; J. Watts, personal communication) on a commercial scale. With a suggested stocking rate of 250 females per acre (618 females per ha) (*Bosch and Kemp 2001*), commercial *O. lignaria* pollination will only be economically feasible if sustainable year-to-year reproduction within orchards is achieved. This study provides the kind of nuanced detail in *O. lignaria* management needed for improving BMPs that will lead to sustainable *O. lignaria* reproduction within tart cherry orchards. Overall, results obtained from this study are provocative, and further evaluation to examine pollination efficacy of *O. lignaria* in commercial cherry orchards is needed.

**Acknowledgments**

This study would not have been possible without incredible support and assistance provided by Jim Watts, who provided the bees and the premise for this study, and Ray Rowley who allowed us to work in his cherry orchards. We would also like to thank ARS laboratory technicians and science aids, Ellen Klomps, Jenna Hanson, Hannah Jarvis, Penina Meatoga, and Matthew Treasure for help in executing the study and processing much of the data discussed in this manuscript.

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