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Effects of Humidity on Native and Non-Native Cavity Nesting Solitary Bees

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EFFECTS OF HUMIDITY ON NATIVE AND NON-NATIVE CAVITY NESTING SOLITARY BEES

by

Elleke Grace Kofford Manwill

Capstone submitted in partial fulfillment of the requirements for graduation with

University Honors

with a major in

Biology

in the Department of Science

Approved:

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Logan, UT

Spring 2024

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ABSTRACT

Invasive species are defined as those that are not native to an ecosystem but may cause harm to the environment or to human health. *Osmia cornifrons*, a species introduced to the United States, and *Osmia lignaria*, a native species, are cavity-nesting solitary bees. Although not officially classified as invasive, *O. cornifrons* presents competition for the niche that *O. lignaria* inhabits. *O. cornifrons* has established populations throughout the East Coast and the Pacific Northwest, while *O. lignaria* is found all throughout the contiguous United States. This interspecies difference in geographical range exists despite their similar temperature ranges. To determine if relative humidity (RH) was an influential factor in this difference, we placed 315 of both *O. cornifrons* and *O. lignaria propinqua* into one of three relative humidity treatments (10%, 50%, or 75%) and measured their weight change and survival. We expected to see *O. cornifrons* die more quickly and lose more weight in lower humidity conditions, with no apparent change in hours to death or weight change among *O. lignaria propinqua* groups. We found that females of both species died more quickly when subjected to a low humidity treatment than those at higher conditions. Female *O. cornifrons* in the 10% RH condition also lost a higher percentage of total body mass than those in either of the other RH groups. However, female *O. lignaria propinqua* showed only a difference between the 10% group compared to the 50% and 75% treatments. *O. lignaria* females outlived *O. cornifrons* females in every humidity treatment we tested. Males of both species showed no difference in percent weight loss or time to death between treatment groups. Our study showed that humidity is a limiting factor on *O. cornifrons* geographical range, and that *O. lignaria lignaria* is at higher risk of population decline due to niche overlap with *O. cornifrons* in the eastern U.S. With further research, our results indicate that *O. cornifrons* can be used safely as a managed pollinator in more arid

climates without risk of it becoming invasive in such regions. It could also indicate expansion of *O. cornifrons* geographical range in the U.S. if climate change increases relative humidity.

ACKNOWLEDGMENTS

First, I'd like to start with a thank you to Michael Syndergaard, who introduced me to the world of beekeeping and sparked my interest in bees. I'd also like to thank Dr. Theresa Singer, who was my delightful rugby coach and connection to the bee lab where I was able to complete this project. Thank you to Dr. Lindsie McCabe, who helped me form an idea for the experiment and experimental methods, then watch that experiment fail before it started, only to help me come up with another idea and get it started within two weeks. She was also so supportive of me as a scientist throughout the entire process and helped me to feel empowered as a leader of the project. A big thank you to Dr. Robert Schaeffer for agreeing to mentor me through this project, helping me learn how to write a research paper, and supporting me throughout the process. Thank you to Erica Brus, Dr. Mallory Hagadorn, and Ellen Klomps for agreeing to three straight days of experimental setup, and then to additional time checking on the experiment outside of normal working hours for weeks following. Thank you to my friends who are part of the Schaeffer Lab who were willing to help with whatever questions I had and who helped me practice presenting leading up to the Research Symposium. Thank you to the College of Science and the Department of Biology; I have greatly valued my entire education at Utah State and appreciate the knowledge I gained that allowed me to understand and complete this project. Thank you to the Honors Program for giving me the opportunity to complete a Capstone, it was a fantastic way to cement my ability to apply all the knowledge I've gained, earn some leadership experience, and springboard me into my next steps. Thank you to my fantastic parents for the constant emotional and financial support throughout my entire education. Lastly, thank you to my husband, Elijah Manwill, who was encouraging of my academic pursuits and patient with me through the weeks of stress and mild sleep deprivation leading up to the execution and

completion of this project while being a student himself. I couldn't have done it without all of you.

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INTRODUCTION

Invasive species pose a significant threat to biodiversity and ecosystem functioning. In the United States (U.S.), an invasive species is defined as a non-native species in an ecosystem whose introduction causes or may cause harm to the environment or to human health (U.S. Department of Agriculture, n.d.). Such harm can include the extinction or endangerment of competing native species, the potential to change a habitat (NOAA, n.d.), or introduction of a novel disease that an ecosystem and species within may have no prior exposure to (Beltrán-Beck et al., 2012). Reducing native biodiversity is harmful for several reasons, including threat to continued resilience of the ecosystem (Mata et al., 2021).

Native species displacement by an invasive can often stem from the two having a high degree of niche overlap. The niche is defined as the range of conditions that allow a particular organism to survive in an ecosystem, as well as the effect that organism exerts on the ecosystem (Polechová & Storch, 2018). Niche overlap is when species within the same ecosystem share some of their niche space (Tsafek et al., 2021), which could apply to diet, nesting strategies, predators, and other factors. When high niche overlap occurs, the species are competitive with one another. If a native species and a non-native species experience niche overlap, it could result in a decline of native species richness (Gaertner et al., 2009).

Bees are important insects that contribute to biodiversity and ecosystem functioning through the pollination services that they provide (Bascompte & Jordano, 2007). Bees are responsible for pollination as much as 2/3 of all cropping systems and 86% of all flowering plants (Garibaldi et al., 2016). Many species have been used as managed pollinators in an agricultural setting, *Apis mellifera* (honey bee), being a prime example (Weber 2012). However, honey bee populations alone are unable to keep up with the demand for managed

pollinators (Aizen & Harder, 2009). For this reason, solitary bees are being increasingly investigated for use as pollinators in agricultural systems (Sedivy & Dorn, 2014).

In the 1970s, *Osmia cornifrons*, the horned-face mason bee, was intentionally brought to the U.S. to serve as a commercial pollinator for apples and cherries (Batra, 1979). The natal range for this cavity nesting solitary species is restricted to far Eastern Asia, with the largest natal population in Japan. *O. cornifrons* is used as a major pollinator in apple orchards in its natal range (Sekita, 2001). *O. cornifrons* was first introduced to northern Utah, where the population stayed small and local and never truly established. An additional introduction was initiated in Pennsylvania (PA) around the same time; the population in PA established and spread rapidly throughout the East Coast (Gutierrez et al., 2023). It is likely through the selling and movement of *Osmia* species that *O. cornifrons* is now in the Pacific Northwest U.S. as well as Southeastern Canada, where populations have been on the rise since the early 2000s (MacIvor et al., 2022). *Osmia cornifrons* is not classified as an invasive species but is an introduced species who may inhabit the same niche as U.S. native species *Osmia lignaria*, the blue orchard mason bee.

This threat to *O. lignaria*, another cavity nesting solitary bee whose geographical range spans the entire U.S., with subspecies *O. lignaria lignaria* in the eastern half of the U.S. and *O. lignaria propinqua* in the western half of the U.S., is increasingly significant given its growing popularity as an alternative managed pollinator. *O. lignaria* is used primarily as a commercial pollinator for early spring orchard crops, such as almonds, cherries, pears, and apples (Arts 2014, Boyle 2019, McCabe 2024). Despite *O. cornifrons* and *O. lignaria* having similar temperature niches (Gutierrez, 2023), the geographical range of *O. cornifrons* is more limited. What factor affects this limitation remains unclear.

In this study, we wanted to determine if relative humidity influences the survivability of these two species, which could have an impact on their geographical range. Typical model projections, such as species distribution models, heavily rely on temperature to determine geographical range and/or suitable habitat of a species (Lee et al., 2018; Scalici et al., 2023; Kemp & Bosch 2005). However, variables like humidity are often excluded from these models and few climactic predictors even include them. Previous studies have examined the hygropreference of honey bees (Ellis et al., 2008). No such studies have been performed on solitary bee species. If we find that humidity is a determining factor of the region *O. cornifrons* can inhabit, we may see an increase in the region the bee is able to survive with a changing climate (Sherwood et al., 2010). We may also find that despite the bee being introduced to the U.S. and potentially invasive (LeCroy et al., 2020), it is safe to use as a managed pollinator in more arid climates. In particular, we expected that *O. cornifrons* survival would be lower in lower relative humidity environments. We also expected greater weight loss and a shorter lifespan in lower humidity treatments for this species. In contrast, we expected to see no variation in survival or weight loss depending on relative humidity treatment in *O. lignaria*.

MATERIALS & METHODS

Study System

The cocoons utilized included bees propagated in Washington orchard populations of *O. lignaria propinqua* and *O. cornifrons* sourced through Watts Bees, with the exception of 23 *O. cornifrons* (17 females, 6 males) who were propagated in an almond orchard in California the prior season.

Sticky Boards

Sticky boards were used to hold gel capsules with bee cocoons in them during the x-ray and setup stage. These boards were made by lining one side of an 8½"x 12" plastic board with face-up masking tape. The tape was taped down along the edges of the plastic board with masking tape. A 7x7 grid was drawn on each sticky board, each sticky board was labeled with a unique board number, each column was labeled A-G, and each row was labeled 1-7, giving each cocoon a unique board and cell number (Figure 1a).

a **b** **c** **d**

Figure 1: a. Sticky board #8 with gel capsules containing *Osmia lignaria propinqua*, or Blue orchard bees (Hence "BOB"). b. Completed humidity chamber, top and bottom components parafilmed together. The label on top indicates this chamber is *Osmia lignaria* males, 75 percent humidity, the first replicate. c. All humidity chambers in place in the lab d. Possible color combinations each bee could be painted. Exactly one bee with each color combination would be placed in each humidity chamber.

Humidity Chambers

We constructed forty-two humidity chambers. The chambers were made using deli containers with a shallower bottom piece and a taller, transparent top piece (Figure 1b). The top of each top piece was cut out, and a transparent plastic sheet was taped to the top to act as a lid. The bottom compartment of each deli container held a temperature and RH data logger (HOBO Onset®) and a petri dish full of salt solution. The top compartment was where the bees would be released for the study and was separated from the bottom compartment by a layer of wire mesh so the effects of the salt solution on RH could be distributed through the whole chamber.

Methods using salt solutions to maintain RH in honey bee experiments have been standardized (Williams et al., 2015). The salt solutions we used were potassium hydroxide (KOH), magnesium nitrate [$Mg(NO_3)_2$], and sodium chloride (NaCl). At temperatures ranging from 16.67-21.67°C, these salts when in a saturated solution hold the humidity of their container around 10, 50, and 75 percent relative humidity (RH), respectively (The Engineering ToolBox n.d.; Young 1967). We used 26.5 g KOH and 10 mL water for each 10 percent RH solution, 26.5 g $Mg(NO_3)_2$ and 4 mL water for each 50 percent RH solution, and 26.5 g NaCl and 13.64 mL water for each 75 percent RH solution. After each salt solution was created and placed in the bottom compartment with a data logger, the top compartment and bottom compartment were parafilmed together (Figure 1b). The total volume of each humidity chamber was approximately 2000 cm^3.

Experimental Setup

Each cocoon was individually placed in a gel capsule, then all gel capsules of *O. lignaria* were mixed and placed in a random order on a sticky board. The same procedure was executed for *O. cornifrons*, except cocoons from Washington and cocoons from California were kept separate from each other. All sticky boards were X-rayed in a Faxitron X-ray MX-20 Specimen Radiography System at 28 kilovolts for 18 seconds to later determine fat body content of each bee used in the study.

To control for any effects emergence time may have on longevity, each bee was cut out of their cocoon. This also increased variation in what would have been the bees' natural emergence time within each treatment chamber in case of possible adverse effects once moved to treatment (i.e. failure of a salt solution to hold RH constant, corrosion of mesh wire). The bee was then sexed, placed in a tube, and the tube was labeled with the date and time the bee was cut

out of its cocoon. It was also labeled with the sex and board and cell number of the bee. The bee was then put on ice within its tube until sufficiently slowed down and photographed with a label containing sticky board position and sex to later determine intertegular distance (ITD) (Cane 1987; McCabe et al. 2021) of the bee and be able to link it to its X-ray. The bee was then painted a unique color combination (Figure 1d) and assigned a treatment box. This information was added to the tube label, and the time the bee was painted was recorded. Once the paint had dried, the bee was weighed, and the weight was recorded on the label. This process was repeated 14 more times for bees of the same species and sex, and once all fifteen bees had been weighed, they were placed in their assigned humidity chamber. This was repeated four times for each percent RH treatment for the females of each species, and three times for each percent RH treatment for the males of each species. The humidity chambers were labeled with the species and sex of the bees inside, the percent RH they were being held at and the number replicate that chamber was for that sex and species (Figure 1b).

All forty-two chambers were placed on the same table in the lab (Figure 1c). To simulate the natural rise and fall of temperatures during a 24-hour period, the chambers were not held at a constant temperature and were allowed to reach temperatures as low as 16.67°C during the night and as high as 22.78°C during the day. Once a humidity chamber was full of its fifteen bees, the chamber was checked every 3 hours from 5am-11pm each day. When a bee was found to be dead, which we defined as no apparent voluntary response to physical stimulus (i.e. being prodded in the abdomen with forceps) after a minimum of five minutes, the bee was weighed, and the weight and date/time of death was recorded in relation to the box label and color combination of the bee. Once only 10 percent of the total number of bees remained, checks were performed every three hours from 8am-8pm daily, and data on death time and weight for the

final 6 live bees, all *O. lignaria* females, was not recorded. At no point during the study were bees fed or watered.

After all bees had died, all females from the first replicate of their kind were placed on sticky boards with two 3x5 grids on them, rows labeled with the bee's primary color and columns with the secondary color (Figure 1d). These were x-rayed to determine post-death fat-body content with the thought that if the bees had died from dehydration rather than exhaustion, they may still have fat bodies (Bosch et al., 2010). Bees were then dried at room temperature over the course of several weeks and re-weighed to determine dry weight. Relative humidity data from the data loggers was examined in order to determine how constant the humidity was to ensure the data we collected was accurate.

Data Analysis

The date and time of emergence and date and time the bee was found dead were recorded for each bee. Time to death was calculated by determining the number of hours between emergence time and death time. To determine the difference in survivability within species between humidity treatments and between species within humidity treatments, we ran an analysis of variance model (ANOVA) with time to death being the response variable and sex, species, and humidity treatment as the predictor variables.

The pre-treatment live body mass (mg) and post-mortem body mass (mg) at approximate time of death were recorded for each bee. Percent body loss was calculated by finding the change from pre-treatment weight to post-mortem weight and dividing by pre-treatment weight. To determine the difference in weight loss between humidity treatments and between species within the same humidity treatments, we ran an ANOVA with percent body weight loss being the response variable and sex, species, and humidity treatment as the predictor variables.

Using mass as a predictor of body size, we analyzed the correlation between body size and survivability. We ran a linear regression comparing pre-treatment body weight (mg) to longevity (hours). All data analyses were performed in R 4.1.2 (R core team).

RESULTS

O. cornifrons female survival was 30% lower in lower relative humidity. *O. cornifrons* females in the 10% RH treatment (7.0 ± 1.6 days) died 33.6 hours before those in the 50% RH (8.4 ± 2.3 days) and 24 hours before those in the 75% RH (8.0 ± 2.8 days) treatments ($p < 0.001$, Figure 2). The average percent weight loss of *O. cornifrons* in 10% RH treatment (38.1 ± 6.0%) was 1.1x times greater than those in 50% RH (33.3 ± 6.5%) ($p = 0.003$) and 1.4x greater than those in the 75% RH (27.7 ± 9.2%) treatments ($p < 0.001$) (Figure 4). The average weight loss of *O. cornifrons* in the 50% RH was 1.2x greater than those in the 75% RH treatment ($p < 0.001$)

O. lignaria female survival was lower in lower relative humidity as well. *O. lignaria* females in the 10% RH treatment (8.0 ± 1.9 days) died 42 hours before those in the 50% RH (9.8 ± 2.7 days) or 75% RH (10.5 ± 3.2 days) treatments. The average percent weight loss of *O. lignaria* in 10% RH treatment (34.4 ± 7.2%) was 1.2x greater than those in the 50% RH treatment (28.7 ± 5.46%, $p = 0.001$) or 75% RH treatment (29.3 ± 5.54%, $p = 0.010$) (Figure 4). However, there was no significant difference in percent weight loss between those in the 50% RH and 75% RH treatments ($p = 0.998$, Figure 4).

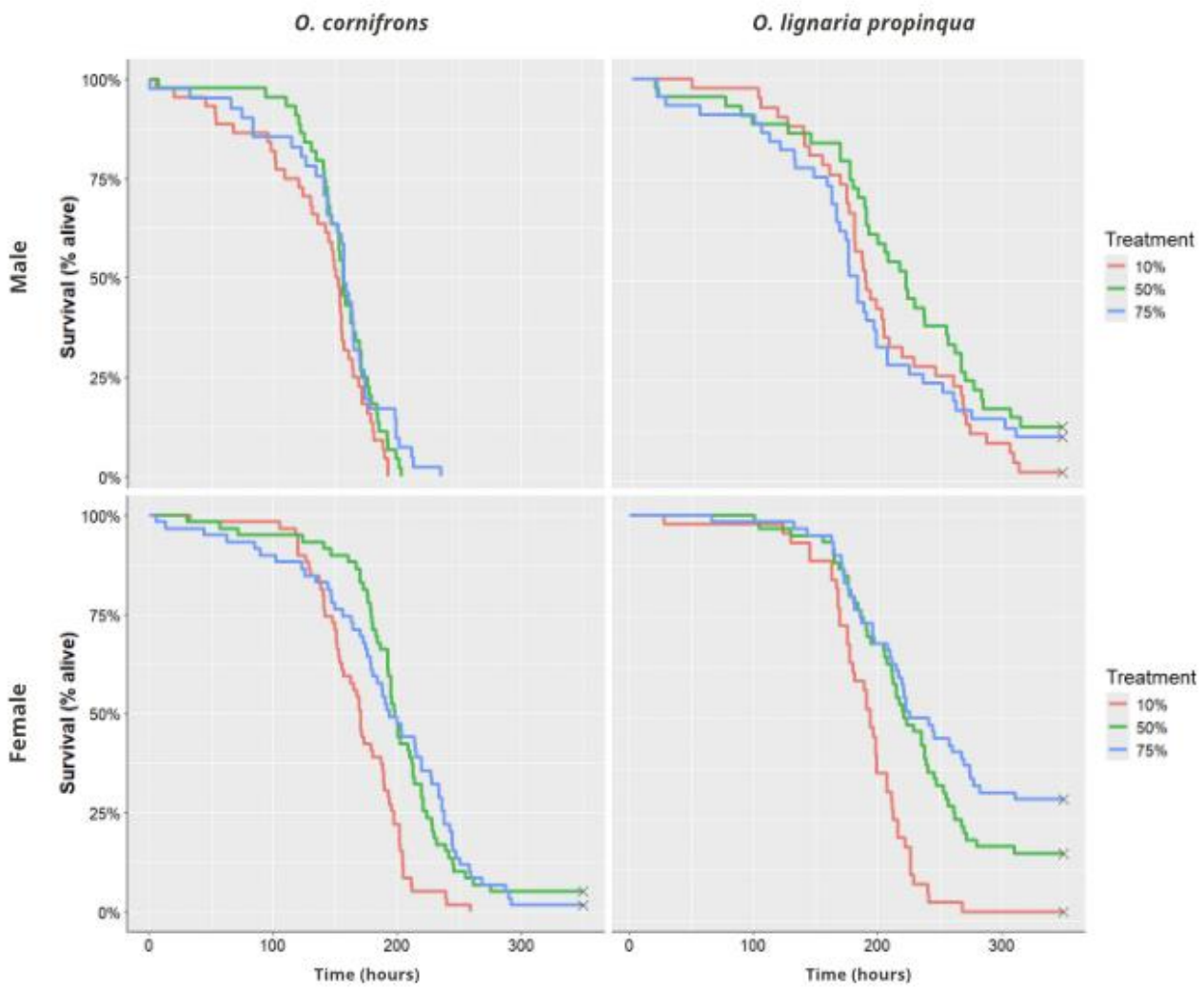

Figure 2: Mortality curves for each species and sex, divided by humidity treatment.

Additionally, *O. lignaria* females outlived *O. cornifrons* females in every RH treatment. In 10% RH treatment, *O. lignaria* females (8.0 ± 1.9 days) lived on average 24 hours longer than *O. cornifrons* females (7.0 ± 1.6 days, $p = 0.003$). In 50% RH treatment, *O. lignaria* females (9.8 ± 2.7 days) lived on average 33.6 hours longer than *O. cornifrons* females (8.4 ± 2.3 days, $p = 0.003$). In 75% RH treatment, *O. lignaria* females (10.5 ± 3.2 days) outlived *O. cornifrons* females (8.0 ± 2.8 days) by 60 hours ($p < 0.001$).

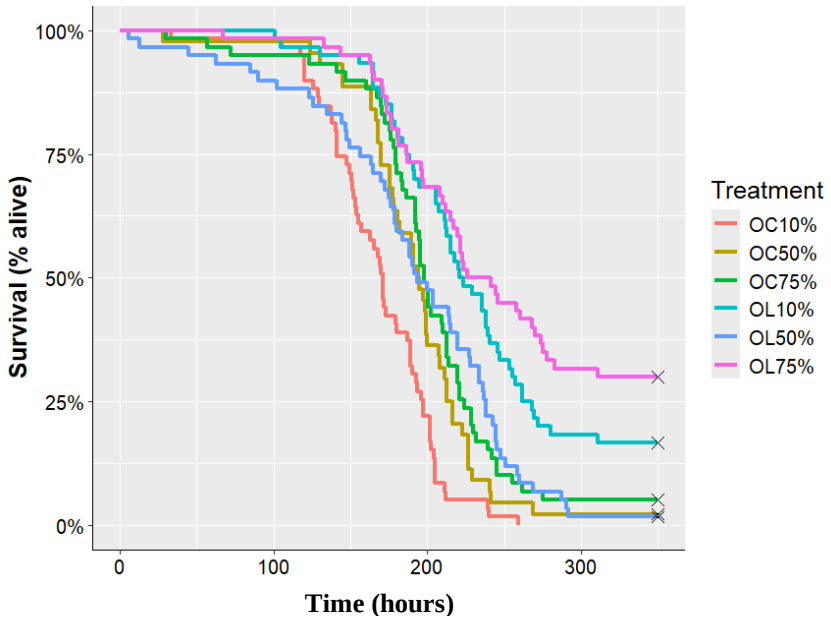

Figure 3: Mortality curves for female *O. cornifrons* and *O. lignaria*, divided by RH treatment.

When comparing percent weight loss between species in each RH treatment, only the 50% RH treatment is significant. In the 50% RH condition, *O. cornifrons* lost on average 4.6% more of their body mass than *O. cornifrons* (p = 0.010, Figure 4).

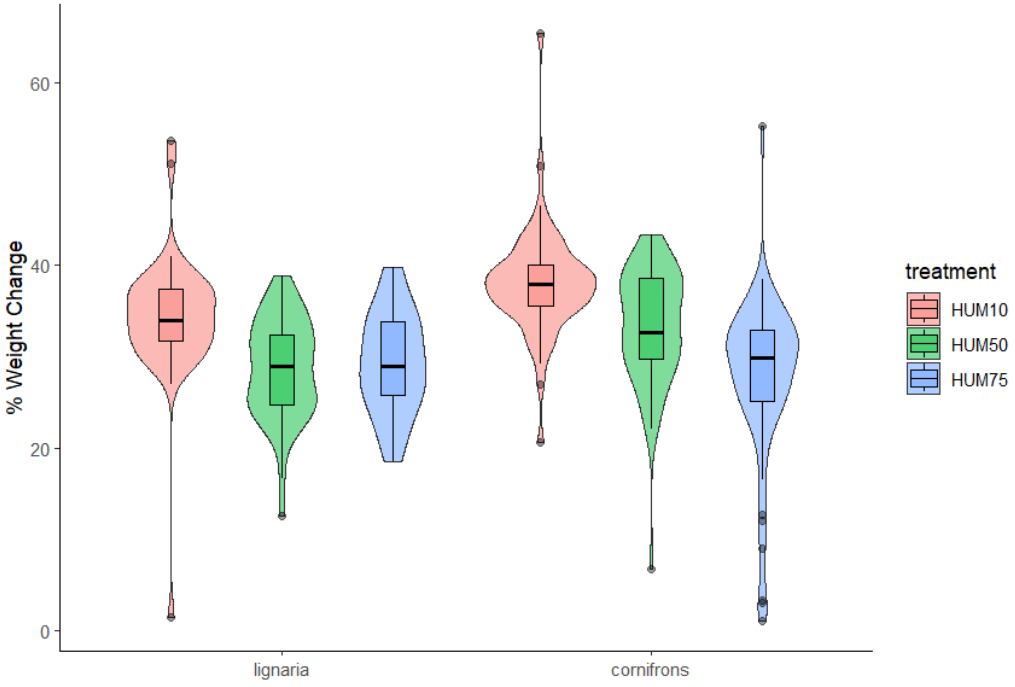

Figure 4: Violin plots of percent weight loss of females in each species, divided by humidity treatment.

There was no significant difference in lifespan (p = 0.659) or average weight loss (p = 0.703) in males of either species.

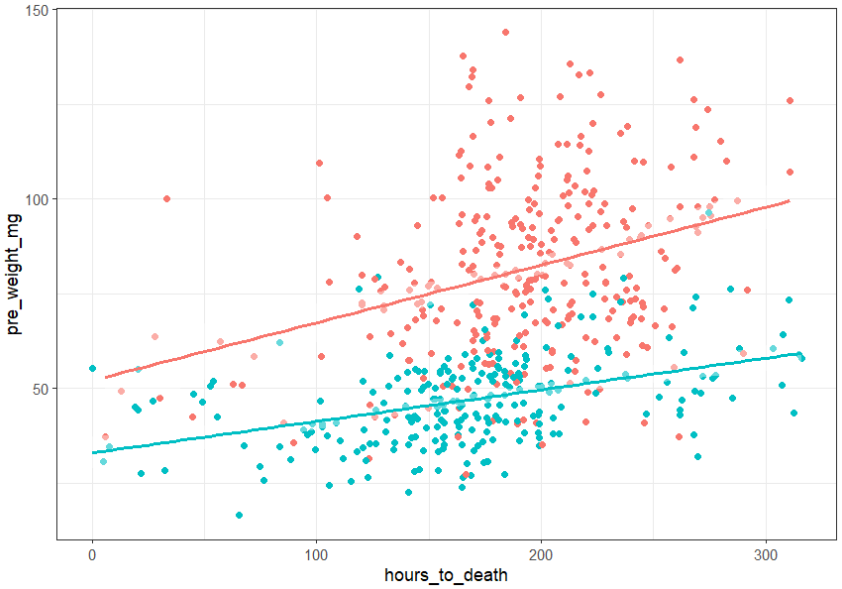

Figure 5: Correlation of survival time to body mass. Red is *O. lignaria*, blue is *O. cornifrons.*

Using mass as a predictor of body size, we saw no correlation between body size and hours to death (p = 0.061, Figure 5) within either of the two species. Data using fat bodies and intertegular distance will be used at a later time to determine whether the size of the bee or the fat body reserves of the bee had an effect on the survivability. In the sample of females that were X-rayed to examine post-mortem fat body content, fat bodies were absent in all specimens of either species.

DISCUSSION

This study revealed the effect of RH on survivability and percent weight loss in *O. lignaria* and *O. cornifrons*. We saw that females of both species died faster in very low RH treatments relative to their cohorts in higher RH conditions, but that *O. lignaria* lived significantly longer than *O. cornifrons* when comparing RH treatments across species. This

suggests that in a scenario where more arid conditions occur after *O.cornifrons* and *O. lignaria* have emerged, *O. lignaria* can survive the conditions for a longer period of time, giving them a higher chance of outlasting the conditions or additional days to reproduce and therefore establish.

When comparing percent weight loss across treatments, *O. cornifrons* females in the 10% RH treatment lost a higher percentage of their body weight than those in the 50%, and those in the 50% lost a higher percentage of body weight than those in 75% RH treatment. Meanwhile, *O. lignaria* females in the 10% RH treatment lost more weight than those in the 50% or 75% treatments, but there was no difference in percent weight loss between the 50% and 75% treatments. These results indicate that *O. lignaria* has a greater RH range in which they can maintain body mass, which is likely to lead to an increase in health and reproduction (Bosch 2010). Overall, all results point to humidity being a factor in *O. cornifrons'* geographical limitations in the U.S.

Because *O. cornifrons* appears to be limited by humidity, and subspecies *O. lignaria lignaria* is found on the eastern half of the U.S. where most of the U.S. *O. cornifrons* population is found, *O. lignaria lignaria* may be more at risk of high niche overlap with *O. cornifrons* and subsequent decreases in population (LeCroy et al., 2020; Centrella 2019). At a broader level, our results join studies such as Papanikoloau et al. (2018) in indicating that humidity can have an effect on species distribution and should be considered more often in insect species distribution models.

This study was the first to consider RH effects in solitary bees and on *Osmia*, and it provides a solid baseline understanding of how RH impacts cavity nesting solitary bees. Future experiments can determine a more specific RH range for *O. cornifrons* and *O. lignaria*, which can be done by selecting more salts that hold at a wider range of RHs. It is likely that neither

species would experience RH as low as 10% in their natural habitats. Humidity for *O. lignaria* during foraging time ranges between 25% - 85% RH, while *O. cornifrons* natal humidity range is usually between 75% - 100% RH. Thus, it is likely that *O. lignaria* is more acclimated to lower humidity ranges but not as low as 10% RH, which is why we are showing a decline in survivability and weight loss at 10% RH. *O. cornifrons* on the other hand has a much narrower band of RH in natal range and our results show they are less amenable to RH below the 50% RH.

Our study did not determine the level of activity, such as mating or foraging, the bees are capable of within different humidity treatments. Using salts that hold similar RH and attempting to replicate our results can determine whether the salts, particularly potassium hydroxide (Waller 1972), acted as a confounding variable by having an adverse effect on the bees other than changing RH and causing a decrease in longevity themselves. Future studies might also consider the effects of humidity on the developmental stages of both *Osmia* species examined in this study to determine whether the bees could establish and propagate in various RH conditions. In our study, we examined the effect of humidity on the bees, and the bees were not given the option to move freely between different humidity conditions. A comparative hygropreference study could be done of *O. lignaria* and *O. cornifrons*, similar to Ellis et al. (2008), where honey bees were placed in connected chambers and given the choice of where to lay their brood.

With *O. cornifrons* being an introduced species, it is imperative that we are cautious about dispersion. Our study suggests that due to the shorter lifespan of *O. cornifrons* in more arid conditions, there is a low likelihood of establishment of the species in drier regions. This suggests that *O. cornifrons* could be safely used as a managed pollinator for crops in more arid climates (i.e. California almonds), with low likelihood of establishment of permanent populations. Because this effect was seen in females, it is even more likely that they will not

establish in low humidity environments. Additionally, this could mean an expansion in the geographical range of *O. cornifrons* with climate change.

Word count: 3,570

REFLECTIVE WRITING

Completing this Capstone was one of the most stressful and most rewarding experiences of my undergraduate career. Because I only had three school years to complete a project, it was on my mind from the beginning of my freshman year in 2019, but when COVID-19 hit, I hadn't made many meaningful connections with people who I felt comfortable asking for guidance or to serve as a mentor. The classes within my major that I had taken up to that point all took place in large lecture halls with audiences of over 200. For the remainder of my freshman year and much of the following year, I felt mostly alone when it came to my academic pursuits, but I finally had an idea that I was passionate about for a Capstone project and took matters into my own hands.

I wanted to start a chapter of a summer camp for children who have had a parent with cancer. It was a camp I grew up attending and had meaningful experiences at, so I wanted to give more access to more children in that position and felt that Utah State students would be a great fit for the program. I began talking to the people who run the non-profit and help students start chapters, I found someone who was willing to be my mentor, and I began contacting nurses, community members, and students who I felt may have interest in the cause.

This was out of my comfort zone at the time because I wasn't very comfortable cold-calling strangers to ask them for help. I also didn't know exactly what I was doing, but I continued forward anyway, just doing the best I could to explain to people what expectations would be for them if they became involved and what being involved could mean for them and for the people they would serve. As I contacted more people and had more of these conversations, I became more comfortable with the idea and made substantial progress on gathering all the materials and people I needed to apply to start a chapter of the camp.

As I was doing this work, I was also preparing to serve a mission for the Church of Jesus Christ of Latter-Day Saints. I didn't know how all these plans would fit together, but I felt that if I continued to ask others for help, things would work out. Fortunately, I found another student who was willing to continue the work I had started on my behalf while I took my leave of absence.

At some point while I was away, this other student reached out to me and let me know that the year we had intended to apply, application requirements had changed, and they were going to be more intentional about spacing these camps out to ensure that more children were within reasonable distance of these camps. Since there are already multiple schools that have chapters within Utah, Utah State would not be considered. This put me back in square one, which left me feeling nervous about being able to complete a project at all. I would only have two semesters once I returned and I knew that most students typically have more time than that to complete their capstone projects, so I felt very behind.

Luckily, I had joined the university's women's rugby club team during the 2020-2021 school year and had an amazing coach, Dr. Theresa Singer. She had been so encouraging, patient, and kind to me during one of the hardest times in my life. I also knew that she was an entomologist who worked with bees, in which I had minimal interest at the time I was on the rugby team. However, in the short couple of months between finishing that spring semester and departing for my mission, I had learned how to keep honey bees from a neighbor of mine and became fascinated by them, as well as by bees in general. When I returned from my mission, I knew that Dr. Singer had retired and moved away, but reached out thinking she might still have contacts that she could recommend to me. By her recommendation, I found Dr. Lindsie McCabe, who was willing to take me on and teach me some of the things she knew. With her, I was able

to formulate a project that I was excited about. She also helped me find a faculty mentor through her connections.

From there, the road was not smooth. I had to change my research plans again due to the first part of the experimental setup failing; the plants we had growing in the greenhouse were killed by a fungus, rendering the project incompletable. It was nice to know I had a mentor and committee member who were willing to help me redirect and had the confidence in me to complete another project on time that would still be meaningful.

This project was so different from my original plan but felt so much more like a suitable capstone to my undergraduate education. The summer camp would have been fantastic for different reasons, but being able to put the knowledge I had gained within my degree into practice was a better fit for the definition of what a capstone project should be. Completing this project has helped me feel more confident in my ability as a scientist to formulate and execute an experiment. I learned so much just about the scientific method in general. It has also opened doors for eventual publication, which will look good on my eventual medical school applications. Had I not had this experience, I wouldn't have had any research experience that I felt passionate about and may have left this chapter of my education thinking I just didn't like research.

This project also opened my eyes to the importance of ecology and being able to apply ecological knowledge, even though it hasn't been my primary area of study. I've realized the importance, especially in agricultural communities, of pollinating species. I had never felt so involved in the research process in general, either. It was fun to see a project all the way through and to discover how flexible research can be. I even enjoyed presenting my findings at the spring

research symposium and felt that experience greatly improved my ability to communicate my research.

This experience as a whole broadened my experience across disciplines in many ways. For one, I led research in an area of biology that isn't my primary interest and learned so much while doing it. In the process of deciding what I would do for my project, I learned perseverance and trust in others. At many points, I was out of my comfort zone in contacting people, many of whom were strangers, and asking for help. Because of these experiences, I'm much more comfortable talking to people. I believe that's one of the most important things I've gained from completing this project, which is also a way that I've become more engaged in my community. Doing research on a pollinating insect has helped me to connect with my community as well, as Logan has a big agricultural scene.

I'll forever be grateful for the trajectory that completing this capstone project has set me on. I feel like I've accomplished something hard, added information of value to my area of research, made meaningful connections with others, and learned valuable skills that will continue to be of worth as I carry on in my pursuit of knowledge. There's nothing more I could have asked for in this process.

Word count: 1262

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