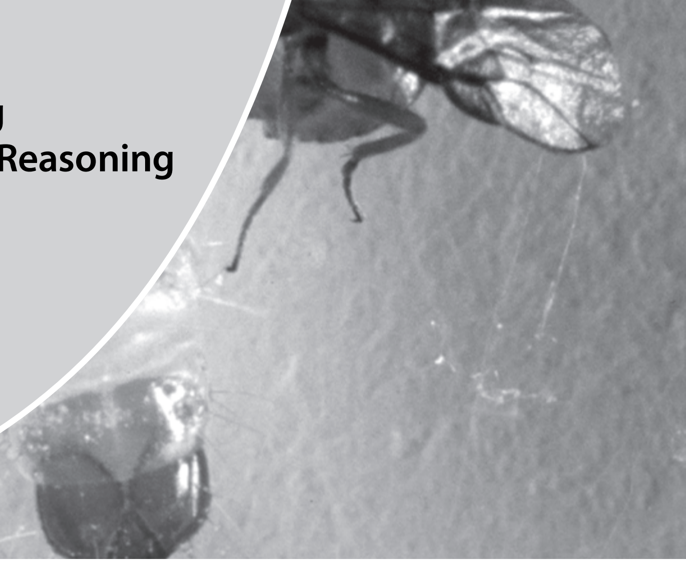
INQUIRY & INVESTIGATION

Competition for Limiting Resources: Quantitative Reasoning in Evolutionary Ecology



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Abstract

Teachers are charged with increasing students' scientific literacy, which involves interpreting evidence and making sense of patterns. However, teachers need access to – or must be able to generate – authentic datasets if they are to help their students develop quantitative reasoning skills. We describe an evolutionary ecology lesson focused on resource competition in a parasitic wasp. Students use datasets to generate graphs and test hypotheses on resource competition and fitness.

Key Words: *Quantitative reasoning; ecology; evolution; insects.*

Scientific thinking is grounded in reasoning and problem-solving strategies (National Research Council, 2012), skills necessary for designing experiments and analyzing data (Kuhn et al., 1988). To increase scientific literacy, science teachers are charged with improving students' abilities to (1) articulate their theoretical assumptions before designing their studies; (2) identify patterns in datasets and make inferences; (3) evaluate and discriminate which evidence supports, does not support, or provides inconclusive support for research questions/hypotheses; (4) construct evidence-based hypotheses or explanatory models of scientific phenomena and persuasive arguments; and (5) resolve uncertainty. Many of these skills require that students have knowledge about interpreting evidence, such as statistical techniques and measurement of error (Osborne, 2010). Moreover, teachers need access to, or must be able to generate, authentic datasets if they are to help their students develop their scientific and quantitative reasoning skills. Quantitative reasoning is central to the field of evolution; therefore, lessons centered on evolutionary ecology are ideal for students to explore both interdisciplinary content and scientific reasoning.

Evolution is an interdisciplinary field that draws conceptually from varied areas such as genetics, geology, climatology, ecology, conservation, and microbiology.

Here, we describe an evolutionary ecology lesson focused on resource competition in a parasitic wasp. The overarching objective of the lesson is to strengthen students' understanding of evolutionary processes and the nature of science through opportunities for making sense of quantitative data. To students, ecological and evolutionary studies may not at first seem related; however, understanding how ecological traits affect selection of organisms is central to evolutionary biology. Evolution is an interdisciplinary field that draws conceptually from varied areas such as genetics, geology, climatology, ecology, conservation, and microbiology. This lesson supports both *Next Generation Science Standards* (HS 4) in evolutionary biology and *Common Core State Standards* (CCSS.ELA-Literacy. RST.9-10.7) in quantitative literacy.

We taught this lesson in an advanced biology course and believe that it can be meaningfully integrated into the AP Biology curriculum (College Board, 2011, 2012). The following AP Biology curriculum learning objectives (LO) are addressed in our lesson: LO 1.3 and 1.4 within Big Idea 1, "The process of evolution drives the diversity and unity of life"; LO 3.4 within Big Idea 3, "Living systems store, retrieve, transmit, and respond to information essential to life processes"; and LO 4.11, 4.12, and 4.19 within Big Idea 4, "Biological systems interact, and these systems and interactions possess complex properties." Importantly, this lesson helps teachers meet the three objectives that are listed as part of AP Scientific Practice 5 ("The students can perform data analysis and evaluation of evidence"). This lesson is relevant in an undergraduate biology course, especially if implemented during recitation or laboratory sections in which problem-based learning activities are often taught. If undergraduate instructors use this lesson, we suggest that they implement the extension activity described below. We spent two class periods with assigned homework on this

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lesson; however, this will vary depending on the needs and levels of the students.

○ Evolutionary Ecology

The theory of biological evolution explains how the diversity of life arises. Evolutionary mechanisms (selection, mutation, gene flow, and genetic drift) result in changes in allelic frequencies within populations, resulting in organisms with genotypic and/or phenotypic modifications. Because the evolutionary history of organisms is affected by their interactions with other species and environmental variables, Futuyma (1998) described evolution and ecology as "sister fields." Therefore, by exploring how organisms interact with one another, students can develop a stronger understanding of how certain behaviors (e.g., reproduction or foraging) are advantageous and persist in populations. These studies fall within the field of evolutionary ecology.

Competition for limiting resources is a fundamental ecological concept and can be defined as the simultaneous demand by two or more organisms for a limited environmental resource, such as nutrients, living space, or light (Grover, 1997). All organisms require resources to grow, reproduce, and survive. Therefore, competition for limiting resources can be a powerful selective force that often regulates population dynamics within species and between coexisting species. Intraspecific competition (competition within a species) can regulate population dynamics (Benson, 1973; Svanback & Bolnick, 2007). Overcrowding can cause resources to become limited, and eventually individuals (often juvenile, senescent, or weak individuals) do not acquire enough resources to survive and reproduce. As a result, the population growth rate decreases. The evolutionary force of competition for limiting resources drives changes within and between species. Because the phenomenon of competing for resources is central to understanding evolution by natural selection, students must recognize that these principles and theories are supported by empirical studies.

○ Lesson Objectives

The purpose of the activity is for high school students to analyze data and use quantitative reasoning to make evidence-based claims. During this lesson, students will construct a scientific hypothesis, create graphical models from authentic data, and write an evidence-based conclusion.

○ Inquiry Activity

Before the activity, students should be familiar with the basic principles of competition. We engaged students through a video, *Parasitic Wasps and Aphids* (National Geographic, 2008). Most likely this will be students' first exposure to these unique organisms. Parasitic wasps lay their eggs in or on other insect species, after which the wasp larvae feed on host tissues. They are called "parasitoids" because they are similar to parasites; however, they eventually kill and consume their hosts, unlike most parasites. Some parasitoids live on the outside of their hosts (and are called "ectoparasitoids"), while others feed internally ("endoparasitoids").

Habrobracon hebetor is an ectoparasitoid of pyralid moths. Its hosts include the Indian meal moth, *Plodia interpunctella* (Lepidoptera: Pyralidae), a pest of stored grains that is often found in very high densities in grain warehouses (Ode et. al., 1998). The female wasp locates the host, injects venom into it, and induces complete and permanent paralysis within 15 minutes. Females lay about 10 eggs on an average-weight host (i.e., they are gregarious – more than one offspring successfully completes development on a host). Eggs are laid on, and larval wasps feed from, the outside of the host. Relevant information about the life histories of the parasitoid and host insects are provided in the printed handout that will be the framework for the rest of the lesson (Appendix A).

We introduced the activity by explaining that a research project had been half completed and that the data still need to be analyzed and described. Students should read the information on *H. hebetor* and participate in a class discussion so that the teacher can assess comprehension. The teacher should then pose the research question: "What do you predict will happen when two adult female wasps and their offspring compete for the same food resource?" The teacher should guide students to think about reproductive fitness and how it can be measured (e.g., number of eggs laid, number of offspring that hatch, proportion of offspring that survive). Through this discussion the teacher can help the students formulate a set of hypotheses as a class. Alternatively, the students can form small groups to explore the question and generate separate hypotheses.

The number of eggs laid by female wasps may depend on the competition treatment condition (one or two females), the size (weight) of the ovipositing (egg-laying) female(s), and the number (and weight) of the hosts presented to the competing females each day. Possible hypotheses include the following:

- If female wasps compete for limited host resources, the total number of eggs laid is expected to be greater when two females are present, but not twice that seen when only one female is laying eggs.
- The level of competition is expected to increase when competing female wasps are allowed access to fewer hosts (resources become more limiting, increasing the level of competition).
- The total number of eggs laid by competing female wasps should increase as the host resources (size and/or number of hosts) increase.

○ Making Sense of the Data

After students carefully read the rearing and experimental-setup descriptions (Appendix A), they should review the raw data (Table 1). Teachers should encourage students to reflect on how best to graph and interpret data by asking them to work with peers (think–pair–share) and then write in their science journals/notebooks about their conclusions. We found that teacher-led discussions centered on data collection strategies in research, including sample size, unit measurements, and which variables to measure were important. We found that it was helpful to remind our students to identify the independent (explanatory) and dependent (response) variables. Students should be asked to calculate the averages of each of the five replicates (i.e., the average number of eggs laid after four days when there was only one host per one wasp of the Oi strain, when there were two hosts per one wasp of the Oi strain, etc.). Students worked in pairs and

Table 1. Raw data collected for three experimental treatments (Oi, Wild, and Oi × Wild). Data for five replicates of each treatment (A–E) are included.

Treatment	Replicate	N Hosts	N Eggs Laid after 4 Days	Total Host Weights after 4 Days	Total Weight of Female Wasp(s)	Total Emerged Offspring
Oi strain	A	1	40	0.0436	1.2190	3
	A	2	55	0.0888	1.1146	13
	A	4	70	0.1778	0.9120	7
	A	8	60	0.3234	0.7140	10
	B	1	49	0.0534	0.9421	1
	B	2	56	0.0752	1.1025	0
	B	4	75	0.1637	1.2130	0
	B	8	80	1.0210	0.0862	0
	C	1	26	0.0509	0.5635	0
	C	2	44	0.0893	1.0335	3
	C	4	40	0.1828	1.2010	3
	C	8	51	0.3884	0.9660	0
	D	1	45	0.0466	1.0140	24
	D	2	55	0.1033	1.1272	11
	D	4	83	0.1624	1.1280	10
	D	8	86	0.3518	1.2310	9
	E	1	23	0.0747	1.0911	1
	E	2	55	0.1445	0.8250	6
	E	4	67	0.2726	0.8941	9
	E	8	112	0.4682	1.4737	6
Wild strain	A	1	21	0.1034	1.3560	2
	A	2	38	0.1023	1.3447	7
	A	4	63	0.1745	1.3965	5
	A	8	31	0.3166	0.8766	5
	B	1	50	0.0482	1.3345	5
	B	2	28	0.0834	1.1844	7
	B	4	56	0.1980	1.5278	3
	B	8	59	0.3639	1.3757	1
	C	1	42	0.0477	1.2601	3
	C	2	10	0.0916	0.5454	0
	C	4	47	0.5404	1.0688	4
	C	8	20	0.3974	0.5511	1
	D	1	41	0.0548	1.4748	8
	D	2	37	0.0926	1.1278	5

Table 1. Continued

Treatment	Replicate	N Hosts	N Eggs Laid after 4 Days	Total Host Weights after 4 Days	Total Weight of Female Wasp(s)	Total Emerged Offspring
	D	4	37	0.1589	1.1068	14
	D	8	30	0.3043	0.6673	1
	E	1	51	0.0591	1.0438	13
	E	2	26	0.0846	1.2920	10
	E	4	30	0.1660	1.2137	14
	E	8	32	0.3056	1.0315	14
Wild × Oi strain	A	1	60	0.0401	2.0569	2
	A	2	52	0.0929	1.4390	8
	A	4	75	0.1626	1.4902	9
	A	8	103	0.3479	2.5441	15
	B	1	76	0.0335	1.5187	2
	B	2	101	0.0918	1.9284	12
	B	4	122	0.1823	2.4861	9
	B	8	126	0.2756	2.6459	2
	C	1	77	0.0572	1.9868	6
	C	2	35	0.0797	2.2733	10
	C	4	100	0.1525	2.5258	2
	C	8	110	0.3664	2.1353	4
	D	1	42	0.0567	2.0996	19
	D	2	47	0.1049	1.7867	13
	D	4	55	0.1940	2.3033	28
	D	8	64	0.3749	1.2574	26
	E	1	51	0.0530	2.0996	11
	E	2	55	0.0948	1.7867	11
	E	4	57	0.1811	2.3033	18
	E	8	33	0.3083	1.5014	1

entered their data in Excel, and we reminded them to double-check that they entered their values correctly. Teachers can use the finished calculations (Appendix A: Table 2) as they guide students. They can also remind them that the independent variables are the number and size of hosts, and the dependent variable is the number of eggs laid by each female.

Students can use Excel to graph the total number of eggs that the female in each *resource treatment* laid over four days. Students should examine the relationship between resource availability and egg-laying decisions (which determine the level of competition expected) to determine whether there are any patterns. Remind students to plot all three *competition treatments* (single wild type, single ivory eye, and one of each) on one graph, enabling comparison of results using the same scale. Because not all students recognize the importance of making comparisons on the same scale, we suggest that the teacher pose this question to the class. Using their graphs, students should then evaluate their hypotheses regarding resource limitation and competition. We used the following guiding questions: How are the *resource treatments* different from each other? How are the *competition treatments* different from each other? What patterns do students observe?

As a guide for instructors, we constructed an example report that presents a scientific argument supported by evidence and explanation

(Appendix B). The graphs (Figures 1–4 in Appendix B) are provided for teachers as a reference. Teachers should remind students of the importance of making evidence-based claims using graphical data. Students may also need reminders about the importance of labeling graphs and including units. In addition, remind students that graphs (and their accompanying legends) should be interpretable as stand-alone documents.

Evidence-based arguments are in line with the claims–evidence–reasoning framework described in the *Next Generation Science Standards* (NGSS Lead States, 2013). Depending on the level of the class, instructors may ask students to use statistical analyses to determine whether the data support or refute the hypothesis. Most students should be able to calculate the standard error of the mean for their bar graphs so that they can gain a sense of the expected amount of variation around each of the means they have calculated.

○ Discussion

After analyzing the data for the ivory eye-color strain, students will likely discover that as the number of hosts (*P. interpunctella*) increases, the number of eggs laid by the wasp (*H. hebetor*) increases. Predictions of a direct correlation between host resources and parasitoid eggs are supported by the data. However, the results from the wild-type females are less conclusive. Biological differences between strains may explain the results. Females in the competition treatment involving females of both eye-color strains consistently laid a higher number of eggs than the single-female treatments. Although more total eggs were laid when a wild-type female and an ivory eye-color female were present than when either type of female was alone, the number of eggs was not twice as great. This suggests that competition for limiting host resources interferes with the total number of eggs that were laid. These findings are important because, too often, we present students with no anomalous data, which, unfortunately, perpetuates the myth that there are "good" or "right" datasets that they are trying to collect. Rather, the data presented here provide the opportunity to initiate discussions with students about data that provide only inconclusive support for the original hypotheses (Chinn & Brewer, 1998).

○ Extension

The lesson can be extended in multiple ways, which we believe will be appropriate if this lesson is used in an undergraduate biology course. Students can use data measurements other than the number of eggs laid over four days. The results can be compared to the conclusions made from the original activity. For example, graphing "total emerged offspring" versus "host number" helps illustrate that the competitive Oi × wild-type treatment resulted in consistently higher survivorship. However, despite having twice as many wasps in the competition treatment, females did not lay twice as many offspring as when they were by themselves, which suggests that competition for host resources limits per capita egg production. Encourage students to participate in peer review and evaluate each other's scientific arguments. This models how scientists engage in peer review when they submit journal articles.

○ Assessment

We suggest that each student complete the research-paper discussion by interpreting his or her graphs. Students should be clear about what their claims are and that these should be evidence based. Study limitations should also be described. Teachers can decide if they want their students to draw on other literature to cite in their discussion section of their laboratory papers. Guiding questions for the discussion might include

- Were there competitive pressures present in the experiment?
- How were the hypotheses supported or refuted?
- What evidence supports your argument? How?
- How did you choose which data to use? Why?
- How could the experiment be improved? How could more conclusive results be obtained?
- What other experiments would strengthen the research and the conclusions you can draw?
- What new questions arose from the research results?

The final assignment includes the comprehension questions, graph, and evidence-based discussion (written as a scientific paper). Teachers may find that asking students to first review scientific papers in journals to make sense of the format will help them in developing their own scientific reports.

○ Evaluation of the Activity

This activity not only teaches students about the ecological theory of competition for limiting resources but, more importantly, it demonstrates an authentic research experiment that reinforces the notion that quantitative reasoning is the hallmark of data analysis and scientific argumentation – both of which are central to scientific investigations. It is not always practical for classroom educators to have the time or resources to generate data to be examined by their students. Hence, datasets such as that presented are valuable for educators. We tested this lesson in two zoology classes for seniors (n = 50) at a public high school. We ensured that there were several breakout sessions so that students could engage in small-group discussion as they completed the lesson. We discovered that students greatly benefited by discussing the reading in depth before proceeding with data analyses. Although we found that our students were comfortable with basic graphing skills (knew about independent, dependent variables, labeling axes, etc.), we expect that some teachers may need to spend more time reviewing these skills. By the end of the class period, students were able to describe the purpose of the study and the experimental design.

One month later, students were asked on an open-prompt assessment what they remembered about the lesson and its difficulty. Our team categorized student responses and found that among 45 responses, the majority (40%) described "creating graphs" to be the most challenging. About a quarter of the students (24%) indicated that "understanding the research enough to make conclusions" was also challenging. Although the readability of our text measures at grade level 9.3 (using the Flesch-Kincaid tool in Microsoft Word), we believe that many students still struggle to make sense of scientific jargon and expository writing. Another 24% claimed that they did not remember the assignment well enough after a month to evaluate it, and 11% claimed that it was not difficult. On student assessments, we noted that they struggled most with explaining *how* the data supported or refuted their hypothesis. Many even added that it was because they do not like graphing or that they are "bad" at graphing. We suggest that beyond graphing, students struggle with developing scientific arguments, as others have noted (Duschl et al., 2007). More robust arguments clearly identify theoretical assumptions, reasoning used, and refutation of other possible arguments (Erduran et al., 2004). The results of the activity show the need for more quantitative analysis skills and how this project can successfully help teachers incorporate authentic data-analysis lessons in ecology and evolution units.

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Appendix A. Parasitoid Research Project

A scientist researching parasitic wasps has collected data, which still need to be analyzed. Your task will be to familiarize yourself with the research project and then analyze the data with the use of graphs. You will make a final conclusion after interpreting the graphs. Read the following information on the research organism, *Habrobracon hebetor*.

Research Organism

We designed an experiment to study the effects of competition for limiting resources using *Habrobracon hebetor*, a species of parasitic wasp (parasitoid) (Hymenoptera: Braconidae) that has been reared in the laboratory. Parasitic wasps lay their eggs in or on other insect species, which serve as hosts to the developing parasitoid offspring. After hatching, the wasp larvae feed on host tissues. They are called "parasitoids" because they are similar to parasites in that they require only a single host to complete their own development; however, they eventually kill and consume their hosts, like predators.

H. hebetor is a parasitoid of pyralid moths, including the Indian meal moth (*Plodia interpunctella* (Lepidoptera: Pyralidae). *P. interpunctella* is a pest of stored grains and is often found in very high densities in grain warehouses (Ode et al., 1998). The female wasp locates the host and injects venom, which induces complete and permanent paralysis within 15 minutes. Females then lay about 10 eggs on an average-weight host (i.e., they are gregarious – more than one offspring successfully completes development on a host). Eggs are laid on the outside of the host, and larval wasps feed from the outside of the host (i.e., they are ectoparasitoids). When reared at 27°C, parasitoid eggs hatch in 2 days, develop through four larval instars, pupate in a group next to the consumed remnants of the host, and emerge as adults approximately 12 days after oviposition. Females are distinguished by their shorter antennae and a visible ovipositor protruding from the abdomen. Often the ovipositor is called a stinger, although in *Habrobracon*'s case, it is only used to paralyze moth larvae and to lay eggs, not to sting people.

H. hebetor is well suited to test predictions of competition for limiting resources. This organism paralyzes its host before oviposition resulting in a well-defined, easily measured host resource (i.e., weight of the host). That offspring emerge in approximately 12 days provides a quick and visible life cycle. Eggs are deposited on the outside of the host organism, which allows for ready identification and counting using a stereomicroscope. Laboratory colonies of both insect species are fairly easy to maintain.

Research Question: *What do you predict will happen when two females compete for the same food resource?*
How will this affect reproductive fitness?

- How will this affect the number of eggs they lay?
- How will this affect the number of offspring that hatch?

Why might it be important to know the weight of the female?

Class Hypothesis:

Methods

Rearing Organisms

To monitor the outcome of the competition experiments, two different populations (wild-type and eye-color mutant, Oi) of wasps were maintained in the laboratory. The wild-type wasps have black eyes. Oi wasps have ivory-colored eyes. Both populations were maintained on their *P. interpunctella* hosts in 100 × 15 mm Petri dishes in separate incubators. Five to eight wasps of each population were presented with approximately 20 *P. interpunctella* larvae in each dish. Each day female wasps were transferred to new Petri dishes with unparasitized host larvae. *P. interpunctella* were maintained in glass Mason jars half-filled with cornmeal food mixture. The wasp and moth colonies were kept in two incubators set at 27°C and a 16L:8D photoperiod.

Experimental Design

To determine whether the parasitic wasp experienced competitive pressures when resources were limited, we presented female wasps with a varying number of hosts (1, 2, 4, or 8) in a 100 × 15 mm Petri dish arena in one of three treatment conditions. Two control treatments consisted of a single Oi female or a single wild-type female in each dish. The experimental treatment consisted of one Oi female and one wild-type female in each dish. For each treatment, the female wasp was transferred to a new dish with the corresponding number of hosts for four consecutive days. Each treatment was replicated five times. We recorded the number of eggs laid and weight of hosts in grams. The females were frozen on the fifth day, after which their weights were recorded to the nearest milligram. We counted the number of eggs laid on the outside of the host each day using a stereomicroscope. Paralyzed larvae were gently rolled so that we could examine all the eggs without damaging them. We calculated the total number of eggs laid over four days because adult female wasps gradually increase their daily egg output over the first four days of their adult life. The Petri dishes were kept in incubators set at 27°C until the offspring began emerging, approximately

10 days after oviposition. Oi treatments emerged more quickly than wild-type treatments. Date of emergence was recorded. Once all offspring had emerged, Petri dishes were frozen and the number of offspring was recorded.

Data/Analysis

Using the data in Table 2, create a graph that illustrates the relationship between the number of hosts and the average numbers of eggs laid over four days. Use different colors for the three different strains. One graph will include all the three treatments. Be sure to label the axis and title your graph. Before you begin, identify the following:

Independent variable: ______________________________
Dependent variable: ______________________________

Table 2. Three treatment conditions (Oi strain alone, wild strain alone, and Oi × wild strain) of female *Habrobracon hebetor* presented with varying numbers of hosts over four days.

Oi Strain

N Hosts	Average N Eggs Laid over 4 Days	Average Weight of Hosts after 4 Days	Average Weight of Female Wasp	Average N Emerged Adults
1	40	0.05384	0.96594	6
2	53	0.10022	1.04056	6.6
4	67	0.19186	1.06962	5.8
8	78	0.51056	0.89417	5

Wild Strain

N Hosts	Average N Eggs Laid over 4 Days	Average Weight of Hosts after 4 Days	Average Weight of Female Wasp	Average N Emerged Adults
1	41	0.06264	1.29385	6.2
2	28	0.0909	1.09886	5.8
4	47	0.24756	1.26272	8
8	35	0.33756	0.90044	4.4

Oi × Wild Strains

N Hosts	Average N Eggs Laid over 4 Days	Average Weight of Hosts after 4 Days	Average Weight of Female Wasp	Average N Emerged Adults
1	61	0.0481	1.95232	8
2	58	0.09282	1.8428	10.8
4	89	0.1745	2.222	13.2
8	87	0.3346	2.017	9.6

Conclusion

What trends are noticeable in your graph? What interpretations can you make from your graph?

Do the findings support or refute your hypothesis? Explain how.

What is your final claim? Write the conclusion to finish the research project. How do your data support your claim?

Appendix B. Example of Completed Report

We hypothesize the number of eggs laid by females will depend on the competition treatment condition (one or two females), the size (weight) of the ovipositing female(s), and the number (and weight) of the total number of hosts presented each day in the following ways: (1) If females are competing for limited host resources, the total number of eggs laid is expected to be greater when two females are present, but not twice that seen when only one female is ovipositing. (2) The level of competition is expected to increase when females are allowed access to fewer hosts. (3) Larger females are expected to lay more eggs. The effect of number of females (competition treatment), body size of females, and number of host presented on the total number of eggs laid was analyzed with a series of analyses of covariance (ANCOVAs) treating female weight as a covariate. Data were analyzed with JMP 10.0.2.

Results

The number of Oi eggs laid significantly increased as the number of hosts increased ($F_{4,19} = 3.30$, $P = 0.03$; Figure 1). Weight of the ovipositing female did not influence the number of eggs laid (partial-$F_{1,19} = 0.30$, $P = 0.59$). The number of wild-type eggs laid did not show a pattern based on number of hosts (partial-$F_{3,19} = 1.80$, $P = 0.18$); however, the number of eggs laid was positively correlated with the body weight of the ovipositing female (partial-$F_{1,19} = 5.50$, $P = 0.03$; Figure 2). The number of eggs laid when Oi and wild-type females were present (competition). While not significant (partial-$F_{3,25} = 0.63$, $P = 0.60$), the mean number of eggs laid by the two females was larger when these females encountered more hosts (Figure 3). More eggs were laid when wild-type females were larger (partial-$F_{1,25} = 7.06$, $P = 0.01$; Figure 4). No such relationship was found between Oi female weight and the number of eggs laid (partial-$F_{1,25} = 0.64$, $P = 0.43$).

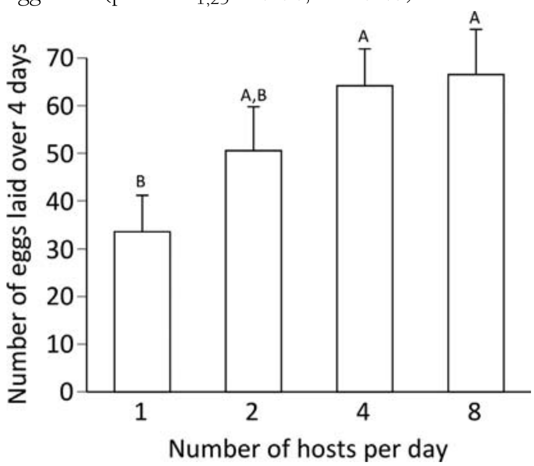

Figure 1. The number of Oi eggs laid significantly increased as the number of hosts increased ($F_{4,19} = 3.30$, $P = 0.03$). The weight of the ovipositing female did not influence the number of eggs laid (partial-$F_{1,19} = 0.30$, $P = 0.59$).

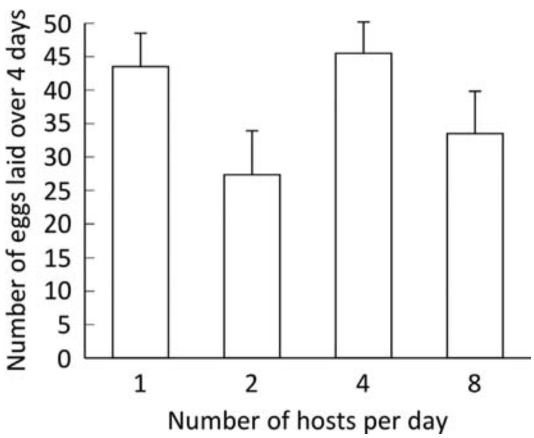

Figure 2. The number of wild-type eggs laid did not show a pattern based on the number of hosts (partial-$F_{3,19} = 1.80$, $P = 0.18$); however, the number of eggs laid was positively correlated with the body weight of the ovipositing female (partial-$F_{1,19} = 5.50$, $P = 0.03$).

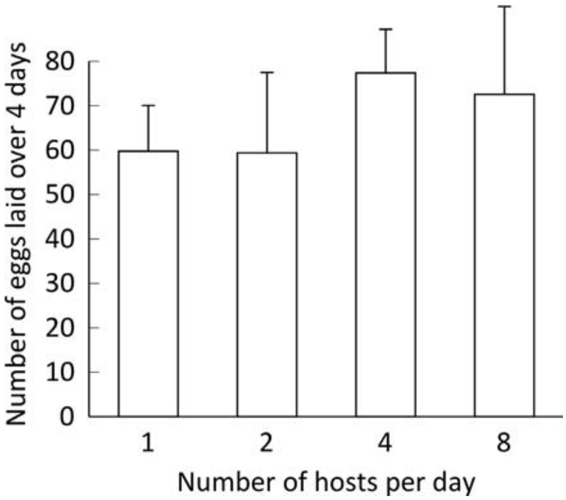

Figure 3. Number of eggs laid when Oi and wild-type females were present (competition). While not significant (partial-$F_{3,25}$ = 0.63, P = 0.60), the mean number of eggs laid by the two females was larger when these females encountered more hosts. More eggs were laid when wild-type females were larger (partial-$F_{1,25}$ = 7.06, P = 0.01). No such relationship was found between Oi female weight and the number of eggs laid (partial-$F_{1,25}$ = 0.64, P = 0.43).

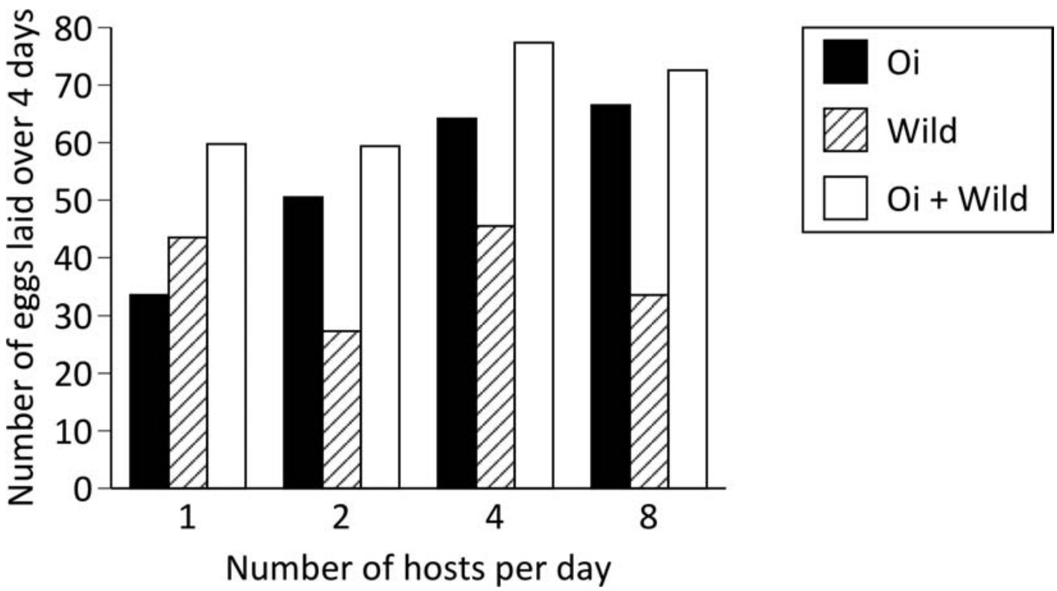

Figure 4. More eggs were laid in the competition treatment than the two controls regardless of the number of hosts presented (partial-$F_{2,68}$ = 12.64, P = 0.001), although not twice as many eggs.

Discussion

As the number of hosts (*P. interpunctella*) increased, there was a significant increase in the number of eggs laid by the wasp, *H. hebetor*. These results support our predictions. However, the results of the wild-type females were less clear. Inconsistency in experimental methods or biological differences between strains may explain the results. The increase in the total female wasp weight was correlated with an increase in the number of eggs laid. The competitive treatment trials had two wasps that consistently laid a high number of eggs. Despite having twice as many wasps, the competitive treatments did not result in twice as many eggs laid. Therefore, competitive pressures likely reduced the number of eggs laid by each female. An examination of the total host weight and individual female wasp weight also was not conclusive. Further testing and more data are needed to draw more definitive conclusions about the relationships between host weight and female wasp fitness.