Proposal to rear and assess populations for the Hudsonian emerald (*Somatochlora hudsonica*), Mountain emerald (*Somatochlora semicircularis*), and American emerald (*Cordulia shurtleffi*) on multiple Boulder County Parks and Open Space sites.

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Abstract

Since 2017, the Butterfly Pavilion (BP) has been actively engaged in dragonfly conservation, initially focusing on the Hudsonian emerald dragonfly (*Somatochlora hudsonica*). Over time, our efforts expanded to include the American Emerald (*Cordulia shurtleffi*) and the Mountain Emerald (*Somatochlora semicircularis*). Despite targeted searches at Delonde Ponds and Duck Lake in Boulder and Ward, Colorado during 2022 and 2023, we have not located any females of *S. hudsonica* or *C. shurtleffi*. Our primary goals are to develop a population abundance index for annual monitoring of these three emerald dragonfly species and to collect eggs for captive rearing. The larvae will be used in a head-start program aimed at future reintroduction at Delonde Ponds, alongside identifying new sites supporting *S. hudsonica* and *C. shurtleffi*. In 2023, we collected and marked 32 males and 4 females of *S. semicircularis*, which oviposited 12, 221, 1, and 66 eggs respectively. By December 2023, 24 larvae had hatched and were reared using protocols similar to 2022, with added antifungal treatment (Methylene blue), increased water changes, and diet diversification; however, larval survival rates showed no significant improvement. In July 2025, 20 male and 2 female *S. semicircularis* were marked, with egg collections of a single egg and an estimated 50–80 eggs from the females. No *S. hudsonica* were observed during 2025 sampling, consistent with the 2024 absence of this species. In 2024, a record 36 *S. semicircularis* individuals were sampled (32 males and 4 females), compared to fewer marked individuals in 2025. Most 2025 activity occurred mid-July, with late-month egg-laying females indicating a reproductive phase. The continued absence of *S. hudsonica* may be linked to environmental changes such as shifting temperature and weather patterns, with cold and wet conditions in 2024 and a warmer or altered climate in 2025 potentially affecting habitat suitability or species behavior. We recommend expanding future surveys to include more diverse habitats, microclimates, and higher altitudes to improve detection chances and better understand population dynamics under changing environmental conditions. Looking ahead to 2026, we plan to initiate the first releases of lab-reared cohorts in April to supplement wild populations. These initial releases, though modest in number (details to be provided), will serve as a foundational step for scaling conservation efforts. Expanding study sites and refining monitoring techniques remain critical, particularly for elusive species like *S. hudsonica*. These efforts contribute to the overarching goal of conserving dragonflies, maintaining biodiversity, supporting ecosystem functions, and enhancing species resilience amid environmental change.

Introduction

In 2017 Butterfly Pavilion (BP) embarked on a multiyear investment in dragonfly conservation with support from Boulder County Parks and Open Space (BCPOS) and Regis University. Dragonflies remain poorly studied despite their outsized impact. Top-level invertebrate predators, dragonflies serve as indicators species of water quality and vegetation change as larvae, as keystone species that exert top-down pressures on their prey, and as habitat connectivity vectors as adults (Bried & Samways, 2015). And increasingly, fascinated odophiles (dragonfly-lovers) go dragonfly watching all over the world (Bried & Samways, 2015; Corbet, 1999; Paulson, 2009). Yet, we know surprisingly little about these animals. During a worldwide evaluation for 1,500 randomly chosen species, only 35% had adequate information to determine their level of threat (Clausnitzer et al., 2009). Of 453 species of North American odonata (dragonflies and damselflies), fewer than 20 have fully recorded life cycles (Tennessen, 2016). The Colorado Natural Heritage

Program and Colorado Parks and Wildlife published a list of sensitive dragonfly species in an addendum to their Wildlife Action Plan (2015). For most dragonfly species in the plan, the state listed lack of information as a threat to their survival. Lack of knowledge certainly characterizes the Hudsonian emerald (*Somatochlora hudsonica*), a dragonfly found in Boulder County and listed as Tier 2 Species of Greatest Conservation Need by Colorado Parks and Wildlife (CPW) and a sensitive species the United States Department of Agriculture Forest Service (Colorado Natural Heritage Program, 2015; Packauskas, 2005). Boulder County lists this as a Species of Special Concern in the Environmental Resource Element of the Boulder County Comprehensive Plan (Boulder County, 2020). In October 2020, BCPOS wrote a Draft Species Conservation and Recovery Plan to map action needed to protect populations of *S. hudsonica.*

To support the conservation and recovery of *S. hudsonica*, our goal is to target areas of research still needed in the BCPOS Species Conservation and Recovery Plan. Our first step to successfully measure the effectiveness of management strategies is to track the existing population sizes of *S. hudsonica.* In addition to *S. hudsonica* we propose studying the population sizes of two additional members of the Corduliid family found to use the same habitats as *S. hudsonica*. The American Emerald, *Cordulia shurtleffii*, a Boulder County wildlife Species of Special Concern (#96) due to dependence on a restricted or isolated habitat, and the more common Mountain emerald, *Somatochlora semicircularis*. Just like other species of dragonflies, are both vulnerable to population decline due to threats such as climate change, forestry practices, grazing practices, and other impacts to water quality (McCauley et al., 2018). All three species occur at the Delonde ponds at Caribou Ranch Open Space during the same flight season, July to August, allowing us to measure all three species with minimal additional effort. This will provide a more complete understanding of how environmental stressors affect the populations of species within this rarer family as a whole and if population trends vary by species or not.

The life history of *S. hudsonica* remains unknown, including the number of years for larvae to reach adulthood and if eggs overwinter. However, based on traits of congeners, Walker estimated that the larval phase of Hudsonian emeralds lasts two full seasons and eggs overwinter. He also estimated that adults live 1.5-2 months (Walker, 1925). Packauskas (2005) found all adult specimens in the region in July; the dragonflies probably started emerging in mid-June. During our work at BP (i.e., under human care), we found that it took the closely related mountain emerald 3 years for some larvae to emerge as adults, with the remaining individuals emerging in year four. Some larvae emerged from eggs prior to overwintering, while others overwintered for a season prior to emerging. We are currently summarizing the life history information we have for the mountain emerald.

In the wild, the years spent as larvae are the most dangerous. In shorter lived genera fewer than 10% of larvae survive to adulthood. Other corduliids have shown an even lower percentage of survivorship with 99.8% mortality over the five years spent as juveniles (Boulder County, 2020). Mortality in juvenile dragonflies most often results from predation pressure, so removing this factor can significantly increase survivorship. Rearing juveniles under human care (i.e., in a captive setting) to give them a head start may result in quicker population recovery by increasing the number of individuals able to emerge as adults and possibly re-establishing locally extirpated populations.

Odonates are readily collected in the field; however, laboratory rearing, and experimentation allows researchers to regulate environmental variables that are difficult to control in the field. Laboratory based experimental designs require large sample sizes of genetically related organisms at the same developmental stages. Controlled methods of large-scale rearing are needed for these designs. We therefore want to develop a population abundance index to permit annual monitoring of the three species of emerald dragonflies of interest: *S. hudsonica*, *C. shurtleffi*, and *S. semicircularis* and to collect eggs of *S. hudsonica, C. shurtleffi,* and *S. semicircularis* to rear under human care to enable use of the larvae in a head start program for subsequent reintroduction at Delonde Ponds as well as identify other sites that host *S. hudsonica* and *S. shurtleffi*.

In August 2021, we collected eggs from the mountain emerald after failing to obtain eggs of the Hudsonian emerald (or even finding a female; although we did find a male) during 3 trips to the mountains to search for them. The mountain emerald eggs developed overwinter and hatched in April 2022. We found that maturation of mountain emeralds took a minimum of three years, thus reintroduction efforts from the current cohort could not occur until 2024 or 2025. This timing provides us with the opportunity to monitor existing populations of mountain emeralds, Hudsonian emeralds, and American emeralds to assess the need for "head starting" (rearing young under human care through their most sensitive stages) of larvae.

We worked in 2021 to try to briefly capture adult female *S. hudsonica* from Boulder County Open Space properties, inducing those females to lay some eggs prior to releasing them back at their capture location (a process that takes just a few minutes), rearing the hatching larvae to their last instar or adulthood at Butterfly Pavilion, and then releasing those individuals back into the wild. Our plan was to maintain detailed records on the life history of *S. hudsonica*, information vital in case "head-starting" is warranted to help conserve the species and expand its range.

In 2022, researchers performed field collection of gravid females, again only coming across *S. semicircularis.* We did find more *S. hudsonica* in 2022 than 2021, though the number of field trips was increased to ten across the flying season to better understand utilization of habitat and seasonality of *S. hudsonica, S. semicircularis,* and *C. shurtleffii*.

Due to the time needed to reach sexual maturity for all three species, the impact of reintroductions using head starting programs will take several years. This latency makes it imperative to begin recovery efforts now and collect yearly cohorts to ensure the future of these populations over the next several decades. Climate change may well force all the emerald dragonfly species into higher altitude habitat over the next several decades. Refining head starting programs now could prove crucial if assisted dispersal of these species becomes necessary.

Methods

Field Collection

Specimen collection was performed from July 2025 at Delonde Ponds on Caribou Ranch Open Space (Fig 1) in Boulder County, CO under a research permit from Boulder County Parks and Open Space allowing for the collection of *S. semicircularis, C. shurtleffi* and *S. hudsonica*. We followed previously approved procedures for capturing adult female *S. semicircularis.* Adult *S.*

semicircularis were captured with a soft aerial net in marsh surrounding the ponds identified as historical oviposition sites for emerald species by researchers at Butterfly Pavilion (Voss and Loewy, 2017, Stevens and Reading, 2021, Stevens and Reading, 2022). All specimens were held gently by their wings folded behind the carapace to examine the last abdominal section for sexing.

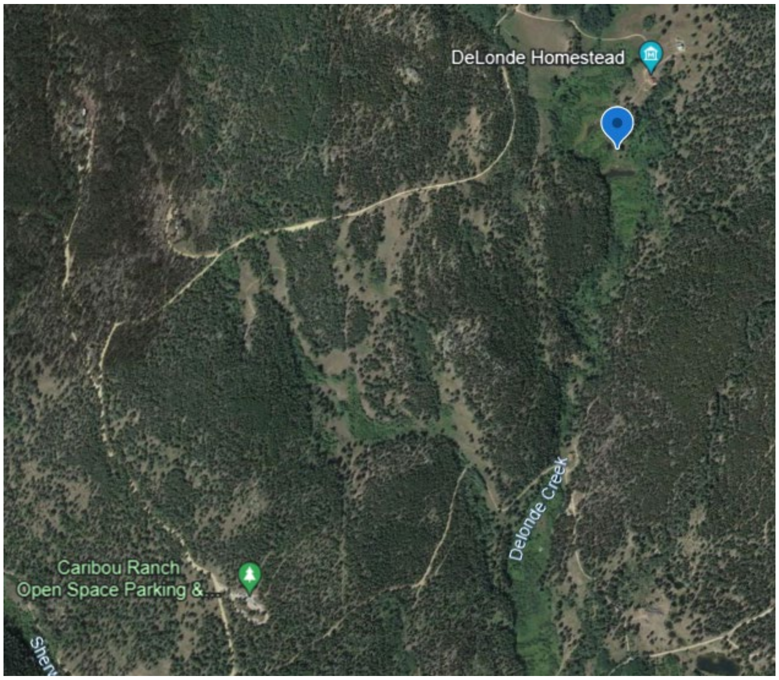

Figure 1. Location of the Delonde Ponds in the Caribou Ranch Open Space, Boulder County**. 39**°59'23" N, 105°31'48" W

For females, we induced ovipositing of eggs into plastic vials (20 mL Clear Polystyrene Plastic Vials with White Caps; Freund Container and Supply, Lisle, IL, USA) of prepared RO/DI water re-mineralized with Equilibrium (Seachem, USA) to induce oviposition. Before release, we marked captured females from which we collected eggs unobtrusively on the carapace to help avoid additional collection.

In addition, any males captured of *S. hudsonica* were marked with Sharpie, silver on the ventral side of the abdomen to reduce impact on survivability and ensure individuals weren't counted twice.

We counted eggs using a microscope at X40 magnification (OMAX) and then transferred them to plastic vials ¾ full of reverse osmosis, deionized water treated with Equilibrium (Seachem, Madison, GA, USA) in groups of no more than 50 eggs per vial. We are maintaining labeled vials with eggs in submerged water on temperature and photoperiod-controlled larva shelves that we check bi-weekly.

Rearing set up.

The rearing setup to support dragonfly eggs and larvae has successfully reared *S. semicircularis* from eggs to general emergence in three to four years. The rearing system to support eggs through emergence is built on a metal shelving unit. Three central shelves hold hydroponics trays (0.6m by 1.2m by 11.4 cm), Chlorophyll, Denver, CO, USA). A bottom shelf holds a sump tank that contains a Eflux DC Flow pump (Current, Vista, CA, USA) in addition to the intake pump/hose and outtake hose for a ¼ HP chiller (JBJ Arctica; TransWorld Aquatic Enterprises Inc., Inglewood, CA, USA). PVC pipes connect the trays to each other and to the pump. Three 91.4 cm Trulumen Pro LED strips 12000 K (Current, Vista, CA, USA) on photoperiod timers light the three central shelves. We update timers periodically to reflect sunrise and sunset times in Colorado for accurate simulation of photoperiod. The system is connected to a chiller (JBJ Artica; TransWorld Aquatic Enterprises Inc., USA) to maintain temperature. The setup receives ample daylight from large windows and maintains a natural photoperiod outside of facility operating hours from 7am-5pm, during which fluorescent room lighting is on. Eggs were slowly raised from 62-63°F to 65.8°F and observed every other day for hatching.

Once hatched, larvae were separated into individual 20ml glass vials to avoid risk of cannibalism and allow for independent monitoring. The vials are set in 0.15 L plastic cups. The cups nest securely into trimmed cup bases affixed with silicon into 10 in (25.4 cm) plastic underwater planter baskets (Pond Boss, West Palm Beach, FL, USA). The planter baskets sit, partially submerged, in the trays. This permits temperature-controlled water to circulate around the cups without water exchange and therefore without the risk of losing a larva into the larger system or of exposing hatchlings to the scent of larger larvae.

We used RO water that was re-mineralized using Seachem's Equilibrium at ¼ tablespoon per 5 gallons to reach approximately 0.3 KH and pH 7. Due to the small volume of each vial, the water changed from each condition was collected into a cup and tested collectively by trial condition each week to monitor water quality. In different to last years, water changes were performed 3 times a week to every other day, with as close to 100% volume changed as possible without leaving larvae dry.

The vials of larvae and eggs are maintained in the same system. The larvae were fed from cultured prey items (Table 1). Once a week, we performed water tests (Red Sea Fish Pharm Ltd., United Kingdom) to ensure that ammonia levels were maintained below detectable levels. In winter we lowered temperatures to 38 °F mimicking seasonal temperature fluctuations and induced natural diapause, temperatures were slowly lowered from their peak at 65.8°F to 38°F by lowering 1°F every other day after feeding. After reaching 38°F in December, both larvae and eggs will slowly be raised back up to around 65°F in mid to late June to match normal habitat cycles. At around 50 days post-hatching (mean 48.2) and significant enough growth to easily visualize larvae, a 1inch sprig of Java moss (*Vesicularia dubyana*) was added to each vial to reduce stress and hopefully aid in molting.

This methodology differs from that used by Butterfly Pavilion to raise *S. semicircularis* in 2022 by increasing water changes and water quality monitoring, diversifying prey items, and cooler maximum temperatures. Additionally, 4 of 6 vials of eggs of the divided clutch of 210 laid by Female 2 (n=133) received diluted methylene blue for treatment of an apparent fungal outbreak.

Use of blue methylene to avoid fungal growth

Results

2025 Field collection

During July, a total of 20 male and 2 female *S. semicircularis* were marked. Among the females, we collected a single egg and 50–80 eggs from the other one respectively. Notably, no *S. hudsonica* were observed during this sampling period.

Table summarizing results from fieldwork collection of the Mountain Emerald dragonfly *Somatochlora semicircularis* in July 2025.

Date (July)	Males Marked	Females Marked and eggs collected
9	5	–
10	4	–
15	4	–
22	4	1 (with 1 egg)
23	1	–
30	1	–
31	1	1 (seen, not marked; 50–80 eggs)
1 (Aug)	0	0

2025 Husbandry (Reyna to edit)

All eggs were kept with their initial clutch in the original collection vial. Each vial was labeled with a color in order to track what animals came from which clutch. The vial was partially submerged in a hydroponics tray (0.6 m x 1.2m x 11.4cm) (Chlorophyll, USA) using a pond basket (Pond Boss, USA).

Fertility was determined by examining eggs under a dissecting microscope (40x) at least 48 hours post-oviposition to visualize development. Fertilization rates were consistent with previous findings at 94.8% (Table 3) (Voss and Loewy, 2017, Stevens and Reading, 2021, Stevens and Reading, 2022).

Discussion (including past year results)

Cohort 2022

We adjusted our methods to incorporate a late summer period with eggs being kept at room temperature 72 °F. Adjustments included starting eggs at room temperature to mimic late summer temperatures and allow for a fall hatching group to the hatch group in 2017. In addition, we moved to lab-cultured food with *Paramecium aurelia* and *Paramecium multimicronucleatum* for instars 1-3, and copepods and *Moina spp* for subsequent instars. We also addressed water quality issues by increasing water changes occurring at feeding from 30% total water volume to 50-80% total water volume, dependent on detritus build up. These three changes increased survivorship in early instar development from 2.68% to 38.46% with mortality dropping to zero after 45 days post hatch. In addition, based on previous rearing in 2017, viable eggs may still hatch in spring 2023.

Cohort 2023

We adjusted our methods to try to increase larval survival by using methylene blue on the egg clutches, diversifying the diet, and doing full water changes of each vial. We ran *t*-tests for each of these changes and found that none of the changes significantly impacted survival from last year, which suggests that larval mortality might be related to a genetic bottle neck or some other environmental factors that we have not tried yet. We, however, are still successful at rearing a good number of eggs to adulthood, which is still a very good result compared to the wild populations. For future trials, we want to try using filamentous algae for larva to use as substrate and be able to grasp on. Past studies have shown that transparent containers work well because sunlight promotes algal growth, and emerging adults are easily seen. The presence of algae in rearing containers appeared to decrease mortality, and they showed that most mortality occurred in containers with little to no filamentous algae. Therefore, we aim to trial this and show a significance in survivability of the larvae.

This season we found the most emerald dragonflies that we have ever sampled. We captured 36 individual *S. semicircularis*, 32 males and 4 females. We, however, did not find any *S. hudsonica* or *C. shurtleffii* during field collection trips. A possible explanation of these changes was that this year was a particularly cold and wet year that could have influenced the change of dragonfly populations.

In July we collected eggs from *S. semicircularis* early in the season and observed the first hatching within 21 days of oviposition, incubating at 72 °F. In Cohort 2023, 24 individuals hatched since collection. Per previous trails with rearing *S. semicircularis* we found that survivability increases significantly after day 100 post-hatch. It seems water quality is a critical component to ensuring survivability in early instars. In addition, early instar larvae do seem to show preferences in food choices with ostracods proving an unviable food source. *Paramecium* and *Moina* have proven the most reliable food sources for *Somatochlora* larvae. With these changes we increased survivability by 35.78%.

Attempts were made to survey *Somatochlora* species at Duck and Barron Lakes twice in August of 2023. We ran into barriers accessing the lakes using the existing access easement used by Boulder County Parks and Open Spaces.

Overall, due to not finding any S. *hudsonica* or *C. shurtleffii* at identified sites, contrary to increases seen in populations of *S. semicirularis,* we recommend genetic analysis to identify if population fluctuation is due to genetic drift, interspecies competition, or climate impact.

S. hudsonica typically inhabits elevations above 1500 m in still water (lentic) habitats. The lentic habitats have been described as sedge-bordered, boggy lakes, ponds and streams with nearby or adjacent forest for foraging and mating (Voss and Loewy, 2017). Increasing the amount of preferred habitat may support recruitment or survivability of *S. hudsonica* along Delonde Creek.

In addition, previous mitochondrial sequencing of *S. hudsonica* in the literature provides a solid foundation for looking at genetic diversity and estimation of population size through sequencing.

We are also aiming to increase reintroduction releases of late-stage instars to increase wild populations in Delonde Ponds or surrounding areas.

Cohort 2024

Eggs from the 2024 field season did not hatch, most likely attributed to the system temperatures being too cool (65F) to encourage fall hatching.

Second year offspring from the 2022 cohort

Cohort 2025

Fieldwork

Comparing the results from 2024 and 2025 reveals some notable differences and consistent patterns in S. semicircularis populations. In 2024, a record number of emerald dragonflies were sampled, totaling 36 individuals (32 males and 4 females). In contrast, 2025 showed a smaller number of marked individuals, with 20 males and 2 females recorded.

Most marked individuals of 2025 were recorded between July 9–17, suggesting peak male activity in mid-July. The presence of egg-laying females later in the month (July 22 and 31) could have indicated a seasonal shift toward reproductive behavior.

Somatochlora hudsonica was not observed during field collections in either 2024 or 2025. A likely explanation for this absence may be related to environmental changes, including shifting temperature and weather patterns. The notably cold and wet conditions in 2024, followed by a potentially warmer or altered 2025 climate, could be impacting *S. hudsonica*'s habitat suitability or activity patterns. For future studies, we recommend expanding sampling sites in future surveys to include a wider range of habitats and microclimates, maybe sampling at higher altitudes. This strategy will improve the chances of detecting *S. hudsonica* and provide better insight into its population status and habitat preferences under changing environmental conditions.

Husbandry (Reyna)

Vials containing eggs were checked regularly. These vials did not require food or water replacement; however, when newly hatched larvae were observed, each specimen was transferred to a new vial containing at least 5 mL of clean water and labeled with a number and the designated color rubber band to match the egg vial.

Newly hatched larvae that were less than a millimeter in size were fed two to three drops of water from the Paramecium culture. The microscope was used to confirm that the prey was present in sufficient numbers (>20 per field) before feeding with their designated pipette. Approximately 3–4 times a week during the summer season, hatchlings were fed. When temperatures were cooler

(<50 °F), they were fed twice a week. Feeding occurred after a 50% water change. For vials with new hatchlings, the larva was always visualized prior to pipetting. A 25–50% water change was performed using the designated pipette (marked with red and blue dots). Any bacterial accumulation at the bottom of the vial was removed and replaced with fresh dragonfly water. During the summer season, water in each vial was replaced approximately 3–4 times per week. When temperatures were below 50 °F, water was replaced twice weekly.

For the older cohort of larva, 1 full California Blackworms (Lumbriculus variegatus) were fed out. When the chiller temperature was maintained near 50 °F, at least two of the larger prey items were offered 3–4 times per week. Feedings dropped down to twice a week when temperatures fell below 48 °F. Feeding occurred after a 50% water change. Water replacement occurred 3–4 times per week during the summer and twice weekly when temperatures were below 50 °F. The larva was visualized prior to pipetting. Fecal pellets, uneaten prey, and shed molts were removed with a pipette, while any Java moss present was left in place. Fifty percent of the water was removed by slowly decanting the deli cup into a disposal bowl, ensuring the larva remained submerged throughout the process.

Individuals were checked 3-4 times a week to make sure the specimen is making attempts to right itself from the jostling of the water change or otherwise demonstrating signs of life. Any deceased animal was noted in TRACKS and any molt was recorded in the animal's file.

Next steps

For next year, we aim to begin the first releases of lab-reared cohorts, planned for April 2026. These cohorts, currently being raised in our lab facilities (2022: 13 individuals, 2026: 22 individuals), are intended to supplement wild populations. Although the initial numbers might seem low, this pilot release serves as a foundation for future scaling.

Expanding our study sites and refining monitoring methods will also be priorities to better capture population dynamics, especially for species like *S. hudsonica* that remain hard to find in the wild (Boulder County). Ultimately, these efforts contribute to the broader goal of dragonfly conservation, maintaining biodiversity, supporting ecosystem function, and ensuring the resilience of these species.

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Prey item	Size of prey	Source	Appropriate size of Odonata larva	Amount per feeding
Paramecium multimicronucleatum	50-300µm	CBS	Hatchling (≤0.5mm) to 1mm	In excess, 0.5mL at density of >20 per field at 40x magnification
Philodina sp.	Up to 500µm	CBS	Hatchling (≤0.5mm) to 1mm	In excess, 0.5mL at density of >20 per field at 40x magnification
Artemia sp. (nauplii)	400- 570µm	CBS	1-2mm	6-10 individuals
Moina sp.	<400 – 1,000µm	CBS	1-2mm	6+ individuals, depending on size
Daphnia sp.	220µm (nauplii) to 5mm (adult)	Wild- caught	1.5-10mm	4-6+, depending on size
Cyclops sp.	78 - 245µm (nauplii) 0.5-5mm (adult)	CBS and wild-caught	1-2mm	6-10 individuals
Drosophila melanogaster (larvae)	2-20mm	CBS	3-10mm	1-2 individuals

Table 1. Prey items used to feed larval *S. semicircularis*, quantities listed per each dragonfly larvae. CBS stands for Carolina Biological Supplies, cultured.

	S. semicircularis		*S. hudsonica*	
	Male	Female	Male	Female
2021	0	1	1	0
2022	16	1	4	0
2023	32	4	0	0

Table 2. Specimens collected at Delonde Ponds field site.

Date collected	Vial ID	Fertilized Eggs	Unfertilized Eggs	Total eggs	Fertilization Rate
7/26/2023	23.1	12	0	12	1
7/26/2023	23.2	200	10	210	0.952380952
8/8/2023	23.3	1	0	1	1
8/10/2023	23.4	65	5	70	0.928571429
Total		278	15	293	**0.948805461**

Table 3. Fertilization rate across all eggs collected during 2023 season. Total fertilization is determined by the total number of fertilized eggs over total number of unfertilized eggs, rather than an average of rates between clutches.