Title: **A Proactive Pest Control Calendar and Rearing Beneficial Insects**

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Abstract:

Morris Arboretum's greenhouses are home to several hundred different plant species. This makes scouting and controlling pests more challenging than in a typical greenhouse production system. There are six common greenhouse pest categories at Morris Arboretum: aphids, mites, mealybugs, scale, thrips, and whitefly. Danielle N. Novick, last year's plant propagation intern, created a guidebook to help with identifying, informing, and controlling common pests and diseases (Novick, 2015). To successfully control pests in the greenhouse, the next step is to have the proper timing and a proactive release plan for control options ready. A proactive year-round calendar and action plan were created to predict the timing for controlling pest with biocontrols. Since aphids, mealybug, and mites are the most common pests in the greenhouse, this project focuses on controlling these more proactively, because there are predators for them.

Biocontrols are readily available for controlling and reducing aphids and mites; however, mealybug biocontrols are less aggressive. Four different wasps for controlling aphids: *Aphidius abdominalis*, *A. colemani*, *A. ervi*, and *A. matricariae* were reared successfully for this project. A year round program for controlling mites was designed using predatory mites: *Neoseiulus (*previously known as *Amblyseius) fallacis, N. cucumeris, Amblyseius swirskii*, and *Stratiolaelaps scimitus*. Mealybug destroyers *Cryptolaemus montrouzieri* controls mealybug particularly citrus mealybugs, *Planococcus citri*, but this does not work well for longtailed mealybugs. The barley banker plant system was used to help disperse the aphid predators throughout the greenhouse in the late winter and early spring. To aid visual scouting, indicator plants have been incorporated into the greenhouses. Thus far, the proactive pest control plan appears to have the proper timing down, particularly with aphids and mites.

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INTRODUCTION

CHALLENGES IN THE GREENHOUSE

Good biocontrol always starts with proper identification of the pest and host plant. Creating a proactive plan for the Morris Arboretum greenhouse complex is particularly difficult because of the large variety and ever changing species of plants that are grown. While there are some plants like cherries (*Prunus*), oaks (*Quercus*), and maples (*Acers*) that are grown yearly, new plant species are constantly being introduced into the greenhouse environment. By focusing on the recurring greenhouse pests, it is possible keep pests under control using biocontrols. Morris Arboretum has six common greenhouse pest categories: aphids, mites, mealybugs, scale, thrips, and whitefly. Danielle N. Novick, last year's plant propagation intern, created a guidebook to help with identifying, informing, and controlling common pests and diseases (Novick, 2015). The natural next step is to have the proper timing and proactive release rates for the biocontrol available once the pest has been identified. A proactive year-round calendar and action plan was created to predict the timing for controlling pest with biocontrols. Since effective biocontrols exist for aphids, mealybugs, and mites in the greenhouse, this project focuses on controlling these more proactively.

PROACTIVE PEST CONTROL CALENDAR

Proactive planning is a crucial part of incorporating biocontrols into an integrated pest management (IPM) plan. At Morris Arboretum, the greenhouse staff works hard to increase the use of biocontrols into the IPM program. Over the past several years, they have been able to identify and utilize beneficial insects, mites, nematodes, and bio fungicides to help reduce the pest pressures on young plants. However, timing and proper release of beneficial insects has hindered the success of this program. In particular, mites, aphids, and longtailed mealybugs, *Pseudococcus longispinus*, have been a continuing problem. Part of the goal of this project was to summarize the historical occurrences of six of the most common greenhouse pests in order to predict the appearances of the pests. With this information in hand, a proactive pest control calendar was developed to help with the timing and releasing of commonly used biocontrols. This calendar can be used by greenhouse staff to proactively control and reduce the pests' populations.

A proactive pest control calendar can be useful in many different ways. It can help alert the greenhouse staff to recurring pest problems. It can be used as a reminder to staff of the proper timing of proactive pest control strategies. There are many different biocontrol options for some pests. However, the time of year and the time of release can greatly affect the success of these controls. As a result of doing research for this calendar, information on available biocontrols and release rates was gathered for later reference. In addition, depending on when and how the calendar is displayed, it should help the greenhouse staff notice patterns and plan for recurrent or yearly pest problems.

REARING BENEFICIAL INSECTS

There are several reasons to rear one's own insects including availability, cost, and use. At the Morris Arboretum greenhouse, the three common pest groups are aphids, mites, and mealybugs. Mealybug is a soft scale that usually spreads more quickly than other scale. In particular, Morris Arboretum has green aphids, black aphids, broadmite (*Polyphagotarsonemus latus*), two spotted spider mite (*Tetranychus urticae* Koch), and longtailed mealybug (*Pseudococcus longispinus*). Mite predators are often very small and hard to keep track of, so they generally do not make good greenhouse rearing subjects for pest control. However, there are predators for aphids and mealybugs that have been successfully reared by others. The aphid banker plant system is a fairly common system that is used to rear predatory wasps for aphid control. The mealybug destroyers (*Cryptolaemus montrouzieri*) or crypts for short are much more difficult to rear. Large companies and a few horticulturists and entomologists have been able to rear crypts, but success is rare and rearing is expensive. It was thought worthwhile to see if Morris Arboretum could rear crypts since crypts are costly to order every month, and crypts eat two common pest categories aphids and mealybugs.

SCOUTING AND IDENTIFYING THE PEST AND THE PREDATOR

Locating and properly identifying pests as soon as possible greatly reduces pest damage and the cost of pest control. When caring for so many different plants, it can be hard to keep track of things and scout for possible pest problems on every plant. Methods have been developed to get plants to help in the scouting process. Often plants that show the symptoms of the pest early on or have a greater attraction to the pest are used to aid scouters. The plants are called indicator, trap, banker, habitary or insectary, and guardian plants. Indicator plants are plants that are already grown or especially grown because they are highly attractive to some pests. Trap plants are often indicator plants that are thrown away when the pest is found on the plant. Banker plants are rearing grounds for predators and often have both the pest and predator on them at the same time. Habitary/insectary plants are generally pollen or nectar sources that attract and/or feed the beneficial predator adult and/or young. Finally, guardian plants have two or more of the above traits: indicator, trap, banker, and habitary or insectary (Sullivan and Skinner, 2013).

METHODS

PROACTIVE PEST CONTROL CALENDAR GUIDELINES

The calendar shows the months in which the insects are historically present in the greenhouse. Based on this information a chart was created to predict the pest level of occurrence in the greenhouse and if possible the hoophouses. This would allow the viewer to anticipate the pest problems and give him or her sufficient time to order the insects before the problems get out of control.

There are two particular situations where this calendar can be very useful. The first is for short term pest population explosions; a good example of this is aphids. Aphids are generally

able to quickly reproduce in a short period of time. As a result, the window of opportunity is small for using biocontrols to control this pest. Any hesitation or delay in controlling this pest can quickly lead to overwhelming pest populations that are nearly impossible for beneficial insects to take care of in a timely manner. The second situation has to do with early or untimely pests emerging. Mites are a good example of this. Traditionally, mites are a problem in dry weather conditions or on succulent new growth; however, by the time humans can spot them or their symptoms, the infestation is out of control and the damage is done. In the greenhouse controlling mites involves monthly releases of predators year-round, increasing to weekly releases when pest are known to be a major problem. While outside in the hoophouses, controlling mites in the spring begins by proactively releasing several different predators in the fall. The predators reduce the existing populations and overwinter on-site and emerge with the surviving pests. A proactive calendar can be used to help with the timely ordering and releasing of biocontrols.

REARING MEALYBUG DESTROYERS

Morris Arboretum has reoccurring longtailed mealybug (*Pseudococcus longispinus)*. Mealybug destroyer or crypts for short can be used to help reduce the population of mealybugs. A monthly release of mealybug destroyers in the greenhouse and fernery would be ideal. In the fernery it may be possible to establish a population of mealybug destroyers, if the female predators would lay eggs. However, female crypts traditionally lay their eggs on mealybug egg masses. Longtailed mealybugs give birth to live young and do not have an egg mass. If one were able to get the crypts to lay eggs, a crypt population could be established in the fernery more readily. Several experimental attempts were made to get the female crypts to lay eggs on other materials. Longwood Gardens and other smaller operations have said they were able to get mealybugs destroyers to occasionally lay eggs on cotton balls or paper shreds (Schnaitman, 2015).

Two different methods were used to try and control crypts this year. The first method was used at Longwood Gardens. Rachel Schnaitman an IPM technician at Longwood Gardens recommended a protocol written by Neil Cunningham. It suggests rearing crypts in petri containers. Each crypt is fed about a gram of pea aphids and kept at 73-78 F for about 21 days. They were able to get the female crypts to lay yellow eggs on the cotton balls. Larvae hatch about six to seven days afterwards and are dispersed onto mealybug infested plants. It takes about eight to twelve days for the crypts to pupate. Fresh food, optimal temperature, and females/males are needed for egg production (Cunningham, 2009).

A second method for rearing crypts in trash cans was found through a blog discussion. This method consists of placing mealybug infested material in a can every week. The can is covered with an insect screen held on by bungie cord preventing crypts and mealybugs from escaping (Jody Fetzer, personal communication AERGC form, June 13, 2015). The can is then checked once a month for adult crypts that crawl to the top. One could also try putting in a mealybug infested coleus plant every week to make things more sanitary (Deb Shubat, personal communication AERGC, June 15, 2015). These are the two methods that were attempted.

APHID BANKER PLANT SYSTEM

A common way to control aphids is with predatory wasps and banker plants. This system involves growing barley (*Hordeum vulgare*) until it is at least an inch high. At this point, bird cherry-oat aphids (BCOA) are released onto the barley in an insect proof tent. When the barley plants are covered from twenty-five to fifty percent with aphids, a barley plant covered with aphids is moved into another tent where the predatory wasps are introduced. The parasitic wasps infect the aphids causing aphid mummies to form. The wasp larvae feed inside the aphid, eventually killing the aphids. About one to two weeks later, the barley plant with aphid mummies can then be moved from the tent into a greenhouse that has un-mummified aphids in it. The predatory wasp will then emerge from the mummies and seek out more aphids to parasitize. This provides aphid protection for about a month (IPM Laboratories Inc. 2015).

There are currently four predatory wasps that go after many different aphid species: *Aphidius abdominalis, Aphidius colemani*, *Aphidius ervi*, and *Aphidius matricariae*. The *Aphidius abdominalis* goes after smaller aphids and typically creates black mummies (Beneficial Insectary Inc., 2015). The more aggressive hunter, *Aphidius colemani*, turns its host into tan mummies; its common hosts include green peach aphid *Myzus persicae*, melon aphid or cotton aphid *Aphis gossypii*, pea aphid *Acyrthosiphon pisum*, and many other species, mostly aphids (University of California Agriculture and Natural Resources, 2014). Then there is the *Aphidius ervi*, which often parasitize potato aphid *Macrosiphum euphorbiae* and foxglove aphid *Aulacorthum solani*, turns the host into grey or brown mummies (Mahr, 1998). *Aphidius matricariae* makes light brown to silvery-gold mummies out of green peach aphids, which can be white, yellow, or green; these aphid mummies often fall off the plant soon after parasitization (Capinera, 2015). Since aphids have been a particular problem, all four of the wasps are used.

For the insect rearing, two different setups were used: *A. colemani* only, and a combination of all four wasps. On November 12th, the banker plants arrived with bird cherry-oat aphids (*Rhopalosiphum padi* or BCOA) already on them. The sample plants were divided into six pots and placed in the white Bugdorm 2 from Bugdorm.com. The plants were watered about once a week or as needed. For the first five weeks an additional barley plant was added into the tent in either a four or six inch pot. At which point the tent was full. Three traditional barley plants (*Hordeum vulgare*) and squirrel tail grass barley plants (*Hordeum jubatum*) were added. The aphids spread to the newly introduced plants; however, they appeared to like the plain barley plants better. Some random aphids that appeared in the greenhouse in December on some of the elephant ear, some small ferns, and succulent plants were placed in a black insect tent.

On January 21, the *A. colemani* and the four wasp mix order from IPM Laboratories arrived. The *A. colemani* was placed in a Bugdorm 1 with a regular barley and BCOA. In another Bugdorm, a fern with unknown aphids on it was introduced to about 100 of the four wasp mix. Then about 650 of the four wasp mix were released into the big black tent. As of February 11, the aphids in the big black tent and the Bugdorm 1 w/ *A. colemani* had been successfully mummified. Some of the parasitic wasps have even escaped from the black tent and infected some random aphids on a few barley plants surrounding the black tent. The second generation of wasps was already beginning to emerge.

SETTING UP INDICATOR PLANTS

Three plants were selected to aid the scouting and biocontrol program. Yellow marigold was selected because it attracts thrips, which are hard to spot (Sullivan and Skinner, 2013). Not only are thrips hard to spot, but it only takes a few of them to become a problem. There are also very few control methods for this pest, most of which involve destroying the plant or using chemicals to suppress thrip development. Ornamental pepper was selected for their habitary trait of providing nectar. Beans were selected for their habitary and indicator traits. Mites are very attracted to beans and mite symptoms are easy to spot on beans. Beans also provide food for pollinators and humans (Sullivan and Skinner, 2013). These plants were grown in addition to checking more valuable plants that are very prone to pest problems.

RESULTS

As of March 1, 2016, the proactive pest control calendar and insect rearing project is mostly complete. The proactive pest control calendar has been created and formatted in ways that should make it useful and easy to update as needed. The insect rearing projects of predatory wasp and crypt breeding experiments have been completed. Three tools were created for the proactive pest control plan for the greenhouse: these include a calendar, a graph, and a chart. The calendar is a detailed overview of all six common pests in the greenhouse, hoop houses, and medicinal house. It also lists how and when to use about three different predators of each pest in the greenhouse when available. The graph shows a monthly projection of the pest pressure that faces the greenhouse (See Figure 1). The graph can be applied to the outdoors when the temperatures are above 50 degrees F. The chart is a quick reference of the month, ratio, rate, and how the biocontrols can be used both proactively and reactively. For the insect rearing farm, the banker aphid wasp system was successful, but the crypts systems were unsuccessful. The wasp successfully parasitized some of the unknown aphids in Morris Arboretum's greenhouse. The crypts are able to survive but we were not able to get them to reproduce.

DISCUSSION

PROACTIVE PLAN FOR CONTROLLING APHIDS

Proper application and timing are important when controlling aphids. Aphid populations can grow very quickly. Having an action plan network already laid out for commonly occurring aphid populations can help keep the problem from getting out of control. For example, *A. colemani*, commonly found in many parts of the world, takes about four to five days to complete its life cycle, and parasitizes about 388 aphids per female wasp (Mahr, 1998). However, if this species is not effective there are at least three other wasps to choose from. If the aphid species is unknown, it is recommended that the wasp mix be purchased to try to figure out the pest solution by process of elimination.

PROACTIVE PLAN FOR CONTROLLING MEALYBUGS

Rearing crypts as a control agent for long tailed mealybugs did not work. It did not work in the petri dishes or in the trash cans. In the petri dishes, the mealybugs died off before laying any eggs. In the trash cans, the mealybugs continued to multiply while the crypts were nowhere to be seen. A different control method should be tried. The predatory *Lindorus lophanthae* may work better as it goes after mealybugs and other scale.

PROACTIVE PEST CONTROL CALENDAR PLAN

Under each month the level of pest pressure that may occur that month is listed. For best results, at the beginning of each month or earlier, the calendar and graph should be consulted for the appropriate proactive predator for a pest that may occur. The calendar also lists some predatory options that mostly cover the whole calendar year so that one can select the control that will work best. It also lists the temperature, humidity, rate, and dispersal method that should be used in the greenhouse (or in the hoophouse in the summer). The graph is designed to help remind everyone when the pests are likely to be a problem and plan for things to happen. Out of the six pest groups, aphids, longtailed mealybug, mites, scale, thrips, and whitefly, aphids, mites, and whitefly have sufficient biocontrol options. The calendar plan should be updated yearly (See FIGURE 1).

USING INDICATOR PLANTS

The use of indicator or guardian plants in the greenhouse seems to be promising, but more documentation needs to be done. The marigolds were successfully used to track down thrips and were then treated as trap plants and discarded. A similar strategy is anticipated for the bean plants. The pepper plants appear to be working as well. However, it may be more helpful to know when plants are more prone to have aphids on them. It may be helpful in the future to have a running list of common or favorite valuable plants that may also inadvertently become indicator plants for the six pest categories. For example, *Brugmansia* and *Prunus* species appear to get mites quite readily and should be scouted more often, particularly when they are in the cutting stage. In this way, scouting can be aided, timing can be improved, and biocontrol releases can be managed.

CONCLUSION

Despite the challenges created when diverse plants are kept in the same area and when there are a variety of pest solutions, the proactive pest control calendar plan was implemented. This calendar is being put to the test in the long term by using it to control mites. In the short term, the aphid banker plants were successfully reared to control aphids. The mealybug destroyer project was unsuccessful. It is highly encouraged that the proactive calendar be updated about once a year to help bridge any gaps or changes in the growing conditions. With the proper identification and timing of releasing biocontrols, beneficial insects can greatly enhance the Morris Arboretum's integrated pest management system in the greenhouse.

ACKNOWLEDGEMENTS

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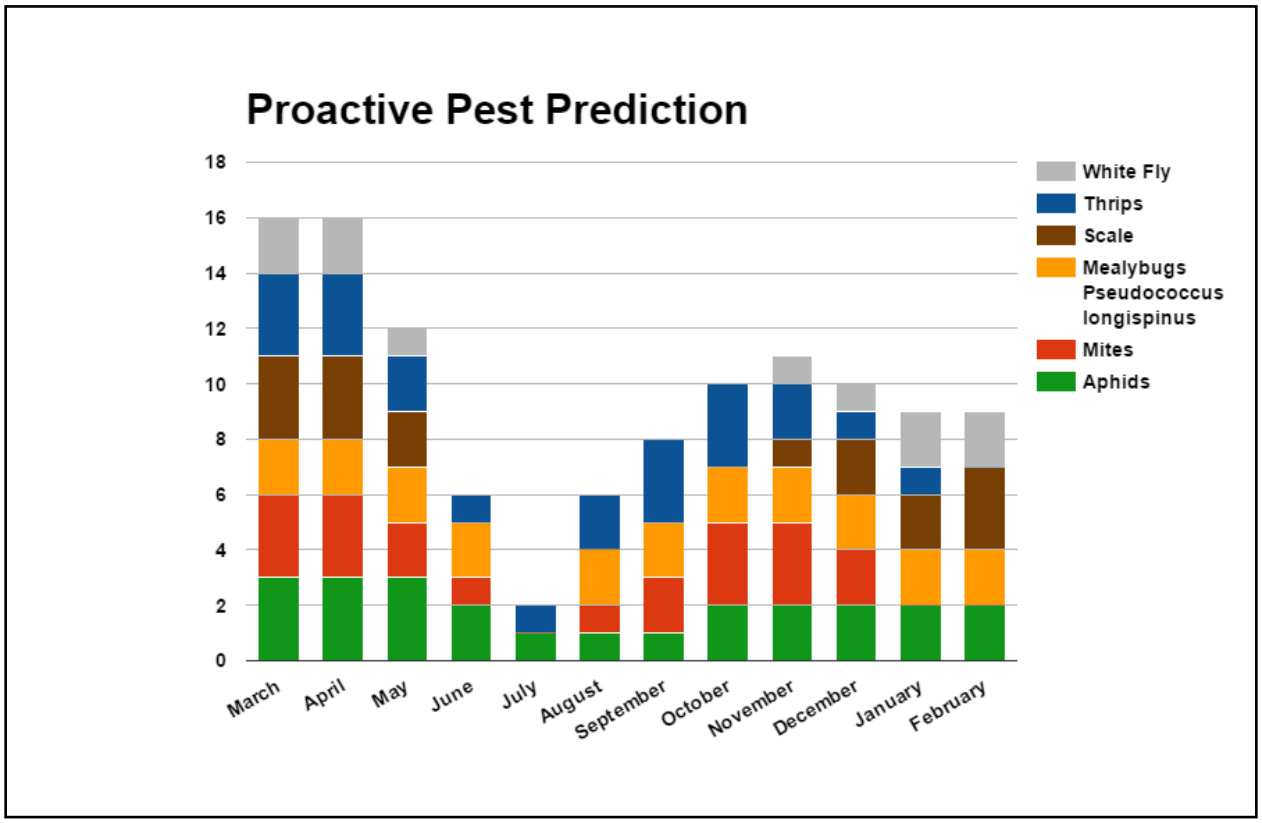
APPENDIXES

APPENDIX I

Figure 1. Proactive Pest Prediction based on the past 5 years (2010-2015)



Rating Scale	
0	Usually not a problem
1	Proactive 1 a month control recommended
2	Regular Proactive Release
3	Major Pressure Continue Releasing

APPENDIX II

Figure 2: Calendar Sample Aphid and Mite Control Plan

SEASON	Spring			Summer			Fall			Winter		
MONTH	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
Common Pest Present: Aphids					Data Inferred							
Green Aphids Timeline												
Biocontrol: Aphidius colemani for Aphis gossypii (cotton aphids), green aphids & Myzus persicae (peach aphids)	proactive-1 predatory wasp/60 ft sq.; infestation- 7 predatory wasp/60 ft. sq Action 0.5 - 1 Aphidius/m²/week for 3 weeks											
Black Aphids Timeline												
Biocontrol: Aphelinus	Release every 8 weeks (5-10 aphids per day- 40-80 aphids per 8 weeks)											
Biocontrol: Aphidoletes aphidimyza (Midge larvae) for 60 species of aphid	One larva needs a minimum of 7 aphids in order to complete the life cycle, but it may eat as many as 80; (end of summer may induce diapause);											
Biocontrol: Chrysopa (Lacewing)	Any time of year: lacewing release every two weeks until pest population ratio											
Common Pest Present: Mites (most likely **Tetranychus urticae Koch (Two Spotted Spider Mites) or TSSM**)												
Biocontrol: Neoseiulus (Amblyseius) fallacis for Tetranychus urticae (two-spotted spider mite) , Panonychus ulmi (European red mite), Oligonychus ununguis (Spruce spider mite) , Oligonychus ilicis (southern red mite), Schizotetranychus celarius (bamboo mite)	Spring, Summer, Fall, (Winter if above 64F)- Proactive once a month, Every 2-3 (high pest pop) to 2-4 weeks (low pest pop), 1-5 fallacis per 10 sq. ft with dense plant canopy / clean up; proactive- 25 predatory mites/m² (9ft) every 3 weeks; curative treatments, introduce 100 to 200 predatory mites/ m² in the hot spots; Adults eat 5 prey a day or pollen"											
Biocontrol: Stratiolaelaps scimitus (previously known as Hypoaspis miles)	- At a low infection pressure and/or a longer length of time 50 to 500 mites/m² are introduced. - At a high infection pressure and/or a short length of time 500 to 1000 mites/m² are introduced. - Does well in the soil and may control soil insects and other organisms particularly thrip pupae and whitefly larvae;											