Overwintering Habitat Assessment for *Anagrus* spp. (Hymenoptera: Mymaridae) in Northern California Vineyards

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ABSTRACT

Non-crop vegetation adjacent to vineyards provides important resources to *Anagrus* parasitoid wasps (Hymenoptera: Mymaridae) of grape leafhoppers, a key pest in California vineyards. Because grape leafhoppers overwinter as adults and larvae of *Anagrus* overwinter in leafhopper eggs, *Anagrus* must overwinter in the eggs of an alternate host found on non-crop vegetation. To identify and evaluate potential overwintering plant species suitable for *Anagrus*, I monitored 21 plant species from various non-crop habitat adjacent to eight vineyard sites throughout Napa and Sonoma counties, California during spring 2011. I monitored for the presence of *Anagrus* using yellow sticky traps placed in the canopy of each plant species. Average wasp abundance plotted throughout the sample period suggested the plant families: Asteraceae, Hippocastanaceae, Salicaceae and Betulaceae to be the likely locations of *Anagrus* refugia. Furthermore, coyotebrush (Baccharis pilularis), California buckeye (Aesculus californica), willow (Salix sp.), blackberry (Rubus sp.) and alder (Alnus spp.) showed high levels of *Anagrus* abundance. Overall, I found *Anagrus* to be associated with previously undocumented overwintering plant families and species. Counts varied on identified refugia throughout the sample period, suggesting that *Anagrus* utilizes a suite of plant types for their alternate hosts before it colonizes vineyards. Further research is required to identify the alternate hosts associated with overwintering habitat, and to further determine the influence of host and plant type preferences on *Anagrus* seeking overwintering habitat.

KEYWORDS

biological control, parasitoid, grape, leafhopper, alternate host, landscape heterogeneity

INTRODUCTION

By replacing natural plant diversity with homogenous plant types monoculture crops, such as grape vineyards, attract insect pests by concentrating available resources (Root 1973). Consequentially, harsh environmental conditions created by monocultures limit the effectiveness of the regulation of arthropod crop pests by removing food, overwintering habitat, and other necessary resources from naturally occurring enemies (Landis et al. 2000; Corbett and Rosenheim 1996a). To mitigate for the detrimental effects of monoculture, some ecologically-based management techniques diversify non-crop habitat surrounding vineyards. These techniques provide beneficial insects with the resources needed to colonize vineyards and control key pest populations (Geiger et al. 2009).

Biological control of grape leafhoppers (*Erythroneura* spp.), California's most common vineyard pest, started in the 1950s as a method of ecologically-based pest management (Flaherty et al. 1985). Species of *Anagrus*, a parasitoid wasp, were identified as an effective biological control agent of grape leafhoppers (Doutt and Nakata 1965, 1973). When *Anagrus*' larval stage develops within the egg of a host leafhopper the parasitoid effectively kills the pest before it has an opportunity to cause crop damage. However, because grape leafhoppers overwinter as adults, *Anagrus*, which can only parasitize host eggs, relies on the eggs of an alternate leafhopper species to diapause in during the winter months. Such alternate hosts are associated with plants near vineyards and are essential to *Anagrus*' ability to maintain populations throughout the overwintering season (Doutt and Nakata 1973). Thus, the viability of the *Anagrus* populations is jeopardized when non-crop vegetation is marginalized or destroyed by vineyard expansion.

Identification of alternate host-plant associations, dispersal patterns and the effect of pesticides on *Anagrus* can improve biological control efforts. Specifically, a better understanding of the overwintering habitat preferences of *Anagrus* addresses aspects of both alternate host-plant associations and dispersal patterns (Williams and Martinson 2000). Californian and North American studies have previously identified plants within the families *Rosaceae*, *Salicaceae*, *Betulaceae*, *Aceraceae*, *Ulmaceae*, *Vitaceae* and *Lamiaceae* as potential overwintering habitat sources for *Anagrus* (Lowery et al. 2007, Williams and Martinson 2000, Doutt et al. 1966, Kido et al.1984, McKenzie and Bierne 1972, Wright and James 2007, Prischmann et al. 2003). Only two identified overwintering plant species within these families, blackberry and French prune, have been adopted for use in ecologically based management. However, these plants were largely abandoned in California resulting from impracticalities in maintenance, disease control, and spatial requirements (Flaherty et al. 1985, and Baumgartner and Warren 2005). Therefore, many other untested and unidentified overwintering habitat types for *Anagrus* still exist (Wilson 1989). There remains a need to elucidate aspects of the life history of *Anagrus*, as well as improve biological control in vineyards.

In this study, I identify and evaluate potential *Anagrus* spp. overwintering habitat. I survey different, common plant species located within riparian, oak woodland, mixed oak woodland, agricultural and garden habitat types surrounding vineyards of Napa and Sonoma counties, California for populations of *Anagrus* spp. I hypothesize that *Anagrus* populations will be associated with common plant types of Napa and Sonoma which fall within previously assessed plant families. I also hypothesize that habitat type will have an effect on *Anagrus*-plant associations. This study forms the groundwork for future, more in-depth, *Anagrus* overwintering habitat assessments.

METHODS

Study sites

I conducted this study from February to June 2011 in the non-crop habitat of eight commercial vineyards in Napa and Sonoma counties, California. Each vineyard site was bordered by either riparian, oak woodland or mixed oak woodland plant communities, or any combination of the three. In addition to native habitat, we (Houston Wilson and I) included other agricultural and cultivated garden plant types of interest in the study because of their prominence on vineyard property and potential as overwintering plant species with novel, aesthetic and economic value.

Study species

The *Anagrus* spp. I sampled for were *A. Erythroneurae* and *A. daanei*, the most common parasitoids of the grape and variegated leafhoppers (*Erythroneura elegantula* and *Erythroneura* *variabilis*) in California (Triapitsyn 1998). In a vineyard system *Anagrus* generally begins to colonize vineyards and parasitizes leafhopper host eggs in March (Doutt and Nakata 1965, Williams 1984). *Anagrus* may also aggregate in vegetation near vineyards as late as June, before vineyard colonization. It continues to parasitize grape leafhoppers for several generations over the course of the grape-growing season with peak vineyard numbers occurring mid-season, July-August. However, by September *Anagrus* presence in vineyards dwindles, as the grape leafhopper begins to diapause in its adult form and cooling temperatures slow *Anagrus* development. In response, *Anagrus* seeks an alternate leafhopper host in non-crop vegetation whose eggs it parasitizes for reproductive diapause until it emerges the following spring (Williams and Martinson 2000).

Data collection

Vegetation selection

In February 2011 we qualitatively assessed the plant communities for uniform patches of species that could potentially serve as overwintering habitat, and tagged 37 individual plant types to include in our study. We sampled these plant types for *Anagrus* throughout the vineyard sites and recorded the habitat type in which it was found, either riparian, oak woodland, mixed oak woodland, agricultural or garden. With the aid of field guides and the UC Berkeley Jepson Herbarium, we identified each plant type to family and species.

Anagrus sampling

In March 2011, we began sampling vegetation for populations of *Anagrus* using yellow sticky traps (4” x 14”; Seabright Laboratories, Emeryville, CA). With methods adapted from Williams and Martinson (2000), we hung three yellow sticky traps on each of the 37 plant types, each of which folded out to expose a double-sided, 4”x7” yellow card coated in adhesive glue. We placed traps in areas exposed to as much green matter as possible, such as leaves and new growth, as *Anagrus*’ alternate hosts lay eggs on soft plant material. We exchanged exposed sticky traps with new traps in the same location on the plants at approximately two week intervals. We finished sampling with six complete sessions of traps collected. Poor weather conditions damaged some traps, which I later culled from the dataset.

I processed the collected sticky traps and recorded data manually and digitally. Each side of a sticky trap is divided into a 4”x5” grid whose outermost cells are not evenly coated in adhesive, so to maintain consistency; I performed insect counts on only the innermost set of six cells. Using a dissecting microscope to process each trap, I counted the number of *Anagrus* males, females and unknown sex, in addition to other beneficial arthropod species, and the two main leafhopper pest species in vineyards, *E. elegantula* and *E. variabilis*. I recorded counts first onto data sheets, and then input data digitally. I also recorded the average number of days each session of traps was left out and calculated insect count totals and averages per trap per day.

Data analysis

Anagrus-plant associations and abundance over time

I plotted cumulative average *Anagrus* counts per trap per day by plant family and plant species to visualize the trends in *Anagrus*-plant associations over the sample period. After identifying plant families and species which exhibited high average *Anagrus* abundances, I plotted average *Anagrus* counts over time in order to identify temporal trends associated those prominent plant families and species.

Generalized linear mixed model (glmm)

I fit a Poisson generalized linear mixed model to *Anagrus* counts using the lme4 package (Bates 2011) in R (R Development Core Team 2011). I used likelihood ratio tests and AIC values to test the importance of site, plant species, plant family, and habitat type on *Anagrus* counts. I considered each variable as both a fixed and random effect and ultimately chose a model with better interpretability and lower AIC values.

RESULTS

Vegetation and *Anagrus* sampling

I found that the 37 plant species sampled from for *Anagrus* represented 21 distinct species and 12 families (Table 1). *Anagrus* were counted on traps from all plant families and species. Average *Anagrus* counts per trap per day totaled across all sampling sessions by plant family ranged from 0 on Fabaceae, to 2.5 on Asteraceae. Total *Anagrus* counts over the sampling sessions by plant family ranged from 1 on Fabaceae to 306, on Hippocastanaceae (Table 2). Average *Anagrus* counts per trap per day totaled across all sampling sessions by plant species ranged from 0 on Bartlett pear, chaparral pea and English walnut, to 2.5 on coyotebrush. Total *Anagrus* counts over the sampling sessions by plant species ranged from 1 on Bartlett pear, chaparral pea, and English walnut to 306 on California buckeye (Table 3).

Table 1.Summary of plants sampled for *Anagrus*. Plants sampled were from non-crop vegetation adjacent to eight vineyard sites throughout Napa and Sonoma counties, California.

Plant Family	Plant Species	Common Name	Habitat Type	Site
Asteraceae	*Baccharis pilularis*	Coyotebrush	Oak Woodland	JPVH
Betulaceae	*Alnus spp.*	Alder	Oak Woodland Riparian	SL CSL
Caprifoliaceae	*Sambucus sp.*	Elderberry	Riparian	JPVR
Ericaceae	*Arbutus menziesii*	Madrone	Mixed Oak Woodland	LMR
	Arctostaphylos spp.	Manzanita	Oak Woodland	JPVH, MA
Fabaceae	*Pickeringia montana*	Chaparral Pea	Mixed Oak Woodland	LMR
Fagaceae	*Quercus kelloggii*	Black Oak	Oak Woodland	JPVH, SL
	Quercus douglasii	Blue Oak	Oak Woodland	MA
	Quercus agrifolia	Coast Live Oak	Oak Woodland Mixed Oak Woodland Riparian	JPVH, MA LMR JPVR, CSL, CSH, SL
	Quercus garryana	Oregon White Oak	Riparian	CSH
Hippocastanaceae	*Aesculus californica*	California Buckeye	Riparian	JPVR, CSL, HOC
Juglandaceae	*Juglans californica var. hindsii*	Black Walnut	Riparian	CSL
	Juglans regia	English Walnut	Agricultural	CSL

Lauraceae	*Umbellularia californica*	California Bay	Mixed Oak Woodland Riparian	LMR CSL, HOC
Oleaceae	*Olea europaea*	Olive	Agricultural	LMR, MA
	Fraxinus latifolia	Oregon Ash	Riparian	JPVR
Rosaceae	*Pyrus communis*	Bartlett Pear	Agricultural	HOC
	Rubus sp.	Blackberry	Riparian	LMR
	Rosa sp.	Rose	Garden	SL
	Heteromeles arbutifolia	Toyon	Oak Woodland Mixed Oak Woodland	JPVH LMR
Salicaceae	*Salix sp.*	Willow	Riparian	JPVR

Table 2. Summary of *Anagrus* counts by plant family. Counts were totaled across all six sample sessions and averaged per trap per day.

Plant Family	**Cumulative Average *Anagrus*/Trap/Day**	**Total *Anagrus***
Asteraceae	2.5	138
Betulaceae	0.9	98
Caprifoliaceae	0.4	19
Ericaceae	0.1	13
Fabaceae	0	1
Fagaceae	0.2	133
Hippocastanaceae	1.9	306
Juglandaceae	0.1	9
Lauraceae	0.1	19
Oleaceae	0.3	46
Rosaceae	0.4	102
Salicaceae	1.8	93

Table 3. Summary of *Anagrus* counts by plant species. Counts were totaled across all six sample sessions and averaged per trap per day.

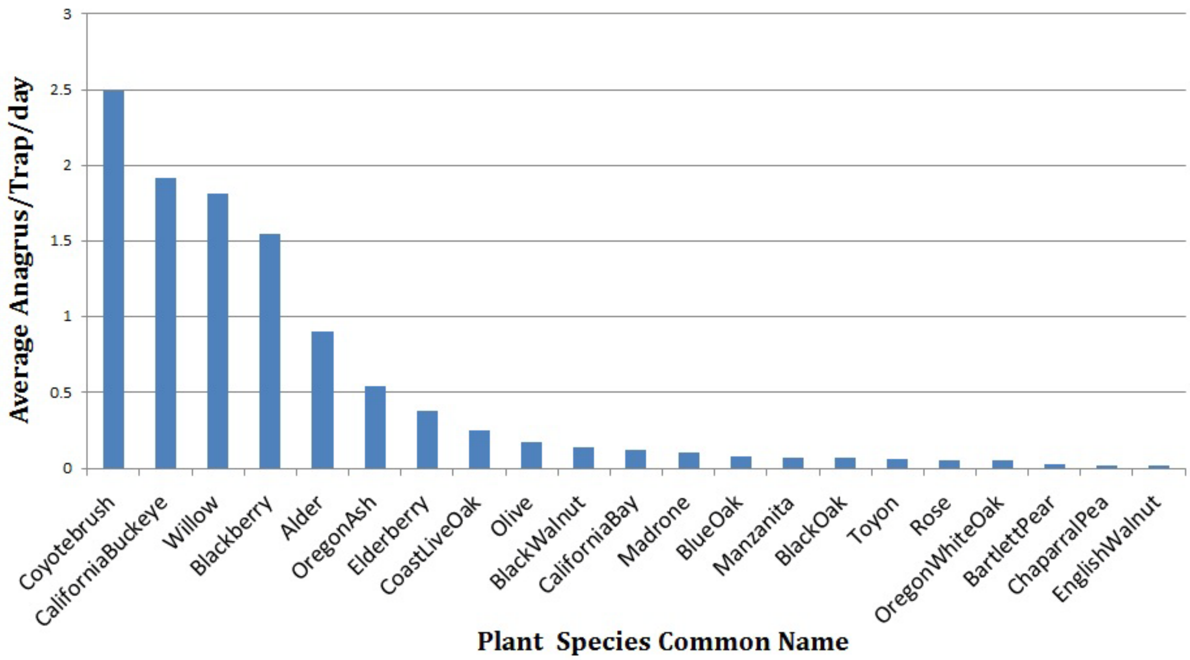
Plant Species	**Cumulative Average *Anagrus*/Trap/Day**	**Total *Anagrus***
Alder	0.9	98
Bartlett Pear	0	1
Blackberry	1.5	91
Black Oak	0.1	9

Black Walnut	0.1	8
Blue Oak	0.1	4
California Bay	0.1	19
California Buckeye	1.9	306
Chaparral Pea	0	1
Coast Live Oak	0.3	118
Coyotebrush	2.5	138
Elderberry	0.4	19
English Walnut	0	1
Madrone	0.1	6
Manzanita	0.1	7
Olive	0.2	16
Oregon Ash	0.5	30
Oregon White Oak	0.1	2
Rose	0.1	3
Toyon	0.1	7
Willow	1.8	93

***Anagrus*-plant associations and abundance over time**

I found that the plant families Asteraceae, Hippocastanaceae, Salicaceae and Betulaceae had the highest cumulative average *Anagrus* counts, ranging from 0.9-2.5 individuals per trap per day, on Betulaceae and Asteraceae respectively (Fig. 1). Furthermore, the plant species coyotebrush, California buckeye, willow, blackberry and alder had the highest cumulative average *Anagrus* counts, ranging from 0.9 -2.5 individuals per trap per day, on alder and coyotebrush respectively (Table 3; Fig 1). These plant family and species associations are the most likely to serve as potential overwintering habitat.

a)



b)

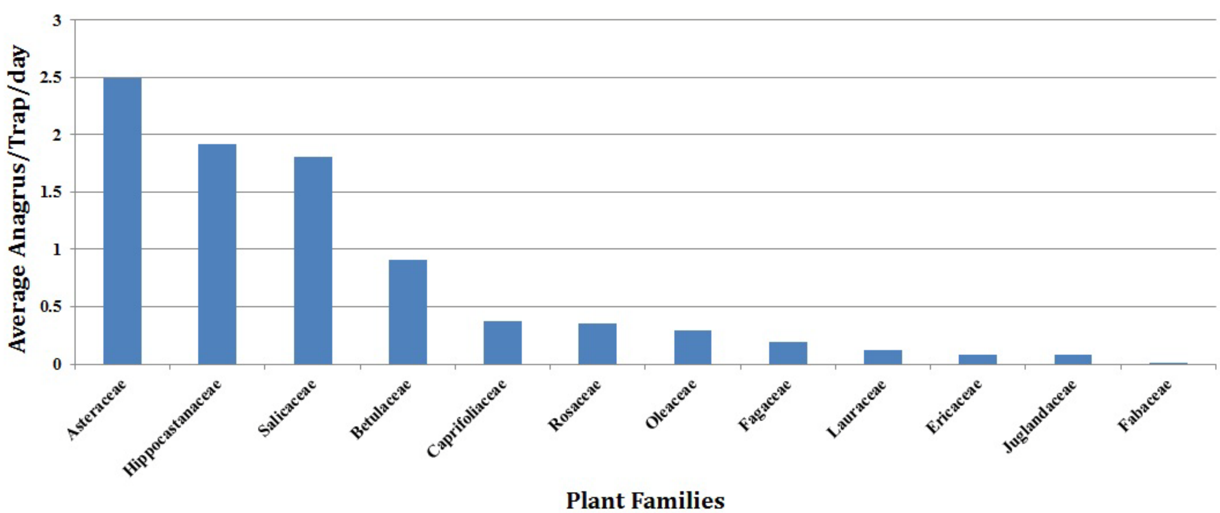
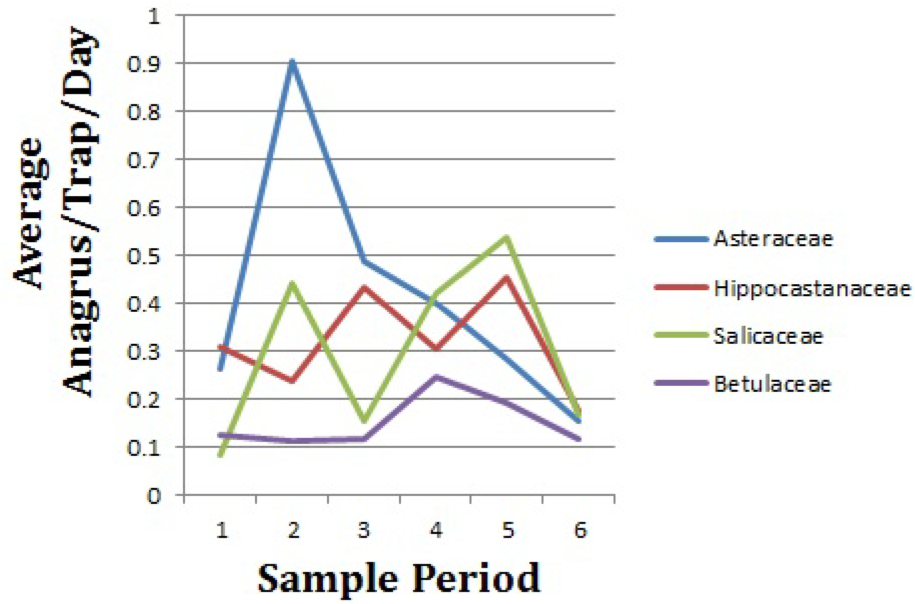


Figure 1.a) *Anagrus* plant family associations. Cumulative average counts of *Anagrus* per trap per day by plant family for entire sample period. b) *Anagrus* plant species associations. Cumulative average counts of *Anagrus* per trap per day by plant species for entire sample period.

Of these prominent plant families and species *Anagrus* counts peaked and troughed several times throughout the sample period, displaying no clear pattern of plant association. On both plots of plant family and species abundance, however, *Anagrus* counts were seen to decrease and converge by the final sample session date, with the exception of alder (Fig. 2).

a)



b)

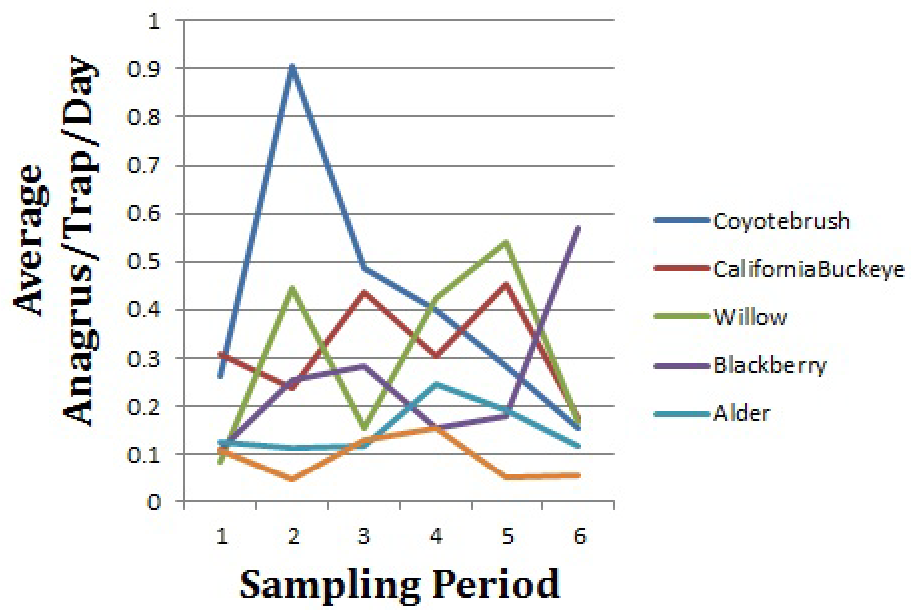


Figure 2. *Anagrus* abundance over time. a) Average *Anagrus* per trap per day by sample session for prominent plant family associations. b) Average *Anagrus* per trap per day by sample session for prominent plant species associations. Sample sessions range from March to June, 2011.

Model selection

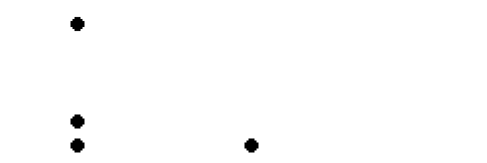
Using a combination of likelihood ratio tests and AIC values, I ultimately selected a generalized linear mixed model with a fixed effect for habitat type and random effects for site, sample session, and plant species. Both likelihood ratio tests and AIC values indicated that plant family and plant species were not both needed for the model. Ultimately I chose plant species rather than family to include in the model due to a lower AIC value for its model.

Sampling and habitat type effects on *Anagrus* counts

Site and session were both significant in the model, implying that sampling did have an important effect on *Anagrus* counts. Habitat type was still significant in addition to these sampling effects, however. Riparian and mixed oak woodland habitat types had the highest expected mean *Anagrus* counts (Table 4). When summarized, riparian habitat types had higher *Anagrus* counts compared to other habitat types and had many large outliers from select plant families and species. Oak woodland habitat types generally had low *Anagrus* counts, but had many high outliers from select plant families and species (Fig. 3)

Table 4. Mean number of *Anagrus* by habitat type. Model results for habitat type as fixed effect. Displays expected mean numbers of *Anagrus* to be caught on a given sample date for each habitat type.

Habitat type	**Agricultural**	**Garden**	**Oak Woodland**	**Mixed Oak Woodland**	**Riparian**
Expected *Anagrus*	0.12	0.17	0.07	1.20	1.02



Plant Species effect on *Anagrus* counts

Plant species was significant in the model, implying that it had an effect on *Anagrus* counts. Riparian Alder, blackberry, California buckeye, mixed oak woodland coast live oak, coyote brush and willow all had high expected mean values of *Anagrus* counts. Expected means ranged from 1.29 *Anagrus* on coast live oak, to 6.39 *Anagrus* on alder (Table 5).

Table 5. Mean number of *Anagrus* by plant species and habitat type. Model results for species as random effect by habitat. Displays expected mean values of *Anagrus* to be caught on a given sample date for each plant species by habitat type. Marked values refer to means associated with species as they occur in their respective sample habitat types. All other values are invalid.

Plant Species	**Habitat Type**				
	Agricultural	Garden	Oak Woodland	Mixed Oak Woodland	Riparian
Alder	0.07	1.07	0.44	7.54	6.39
Bartlett Pear	0.18	0.18	0.07	1.25	1.06
Blackberry	0.28	0.68	0.28	4.75	4.03
Black Oak	2.20	0.31	0.13	2.20	1.86
Black Walnut	0.59	0.10	0.04	0.70	0.59
Blue Oak	0.01	0.17	0.07	1.19	1.01
California Bay	0.07	0.07	0.03	0.48	0.41
California Buckeye	0.28	0.69	0.28	4.82	4.09
Chaparral Pea	0.10	0.01	0.01	0.10	0.09
Coast Live Oak	1.09	0.18	0.08	1.29	1.09
Coyotebrush	0.42	6.39	2.63	44.84	38.01
Elderberry	0.07	0.07	0.03	0.47	0.39
English Walnut	0.05	0.13	0.05	0.92	0.78
Madrone	0.30	0.04	0.02	0.30	0.25
Manzanita	0.95	0.16	0.07	1.12	0.95
Olive	0.02	0.32	0.13	2.23	1.89
Oregon Ash	0.10	0.10	0.04	0.69	0.58

Oregon White Oak	0.03	0.07	0.03	0.49	0.41
Rose	1.30	0.18	0.08	1.30	1.10
Toyon	0.26	0.04	0.02	0.30	0.26
Willow	0.02	0.30	0.12	2.11	1.79

DISCUSSION

My study assessed the potential of common plant types found throughout non-crop habitat of vineyards in northern California to serve as overwintering habitat for the biological control agent, *Anagrus*. I identified prominent *Anagrus*-plant associations by comparing cumulative average *Anagrus* counts for samples collected on each plant type from spring to early summer, when *Anagrus* typically begins to emerge from overwintering and migrates to vineyards. I hypothesized that prominent *Anagrus*-plant associations would confirm previously identified associations, and that habitat type would effect *Anagrus*. *Anagrus*-plant associations were found for several known plant species and families, in addition to several new plant families and species, supporting my hypothesis and broadening knowledge of *Anagrus*' overwintering habitat preferences. *Anagrus* abundance over time on these prominent plant associations fluctuated over time, suggesting *Anagrus* utilizes not just one plant type for its alternate hosts, but several. Habitat type, in addition to sample session and vineyard site, were also seen to have an effect on *Anagrus*, however further research is needed to determine the extent of their effect, as it is likely a complex of ecosystem interaction that creates an ideal habitat for *Anagrus*.

***Anagrus*-plant associations and abundance over time**

Anagrus was found to be associated with all plant families and species, however high abundances associated with the plant families: Asteraceae, Hippocastanaceae, Salicaceae and Betulaceae, and plant species: coyotebrush, California buckeye, willow, blackberry and alder suggest *Anagrus* utilizes these plants as overwintering habitat for their associated alternate hosts (Fig 1). While, Rosaceae exhibited overall low *Anagrus* counts over the course of the sample period, it must also be considered for its potential as overwintering habitat due to the extremely high counts of blackberry, a species within this family (Fig 1).

Known *Anagrus*-plant associations exist for Salicaceae and Rosaceae, in addition to *Rubus* spp. (blackberry) and *Salix* spp. (willow) (Lowery et al. 2007, Williams and Martinson 2000, Doutt et al. 1966, Kido et al.1984, McKenzie and Bierne 1972, Wright and James 2007, Prischmann et al. 2007). Furthermore, known alternate host associations exist for blackberry, *Alnus* spp., and *Salix* spp. (Doutt and Nakata 1965, and Orzos 2008). These confirmed overwintering plant and host associations further suggest that *Anagrus* utilizes these plants for their alternate hosts, and support my findings.

Blackberry is a documented overwintering plant species associated with the blackberry leafhopper (*Dikrella cruentata*), a known alternate host of *Anagrus*. However, Flaherty et al. (1985) showed it did not consistently support *Anagrus* populations for biological control of grape leafhopper despite harboring high levels of *D. cruentata*. Furthermore, blackberry was identified as a host for the glassy-winged sharpshooter (Cicadellidae: *Homalodisca vitripennis*), which is a vector for Pierces Disease, a disease deadly to grapevines (Baumgartner and Warren 2005). Due to these impracticalities, blackberry was abandoned as a prime candidate for use in habitat manipulation to promote biological control of grape leafhoppers. Since this discovery, few overwintering plant species have been identified for practical use in vineyard management.

Asteraceae, Hippocastanaceae, Betulaceae, coyotebrush and California buckeye are previously undocumented *Anagrus*-plant associations that warrant further research, as they exhibited some of the highest abundances over the course of the sample period (Fig 1). In fact, unpublished data (Wilson, personal communication) show high emergence of *Anagrus* from vegetative clippings taken from coyotebrush, confirming the plant's association with a viable alternate leafhopper host of *Anagrus*. Coyotebrush and California buckeye are also California native plant species, which makes them ecologically important when seeking to manipulate habitat as part of a restorative management plan.

Throughout the course of the sample period *Anagrus* did not exhibit clear patterns of consistent habitat association. As seen in Figure 2, average counts fluctuate on the identified potential plant families and species between each sample period. These patterns may be due to abiotic factors, such as wind speed and direction, as *Anagrus* is thought to be dependent on wind for dispersal (Corbett and Rosenheim 1996b). This may also suggest the movement of *Anagrus* between plant types as it utilizes multiple alternate hosts associated with nearby plants, or begins to colonize vineyards. If this biotic influence is true, this suggests *Anagrus* relies on a suite of overwintering plants for their associated alternate hosts. Interestingly, prior research shows that *Anagrus* is likely to have some degree of preference for alternate host species, as well as host plant type (Al-Wahaibi and Walker 2000). Despite fluctuation of *Anagrus* abundance throughout the sample period, counts generally decreased and converged by the final sample session, spanning May and June. This pattern may be explained by *Anagrus*' movement away from refugia as it has been seen to aggregate in non-crop vegetation before it colonizes vineyards (Williams and Martinson 2000).

Model selection

Site, session, and plant species were treated as random effects for both philosophical and pragmatic reasons. I did not choose the levels of these variables while sampling, and thus redundancies occurred when only one plant species was sampled per plant family. By using these random effects I retained statistical power for testing habitat type effects, treated as a fixed effect, as there were 21 different species, and because I was not specifically interested in the values of site or session.

Sampling and habitat type effects on *Anagrus* counts

Site and session both had significant effects on *Anagrus* counts. Some vineyard sites were more diverse than others in the number of habitat types, plant families and species they contained, suggesting that *Anagrus* is likely associated with certain sites-specific characteristics. Habitat types, plant composition, and regional location of a vineyard site could all play a part in determining preferable *Anagrus* habitat. Sample session likely had an effect due to warming temperatures throughout the sample period, which spanned from March to June. *Anagrus* development increases as the number of degrees days necessary for development increases into spring and summer (Williams 1984).

Riparian and mixed oak woodland habitat types had the highest expected mean *Anagrus* counts (Table 4) and riparian habitat types had the highest overall *Anagrus* abundance (Fig 3).

The riparian habitat type was certainly the most diverse in terms of plant species composition (Table 1), which may have offered *Anagrus* more opportunities, in comparison to other habitat types, to find suitable overwintering habitat with viable alternate hosts-associations. However, the riparian habitat was also the most heavily sampled in terms of the number of plant species sampled, which may over-represent the numbers of *Anagrus* recorded for this habitat. Very few *Anagrus* counts were recorded for the garden and agricultural habitat types, which also had very few sampled plant species. This may under-represent the number of *Anagrus* recorded in these habitats. More uniform sampling of plant species and habitat types would produce more accurate predictions of the true extent of sampling and habitat type on *Anagrus*.

Plant Species effect on *Anagrus* counts

Riparian Alder, blackberry, Californian Buckeye mixed oak woodland coast live oak, and coyote brush and willow all have high expected mean counts of *Anagrus* in their respective habitat types (Table 5). Each of these plant species, with the exception of coast live oak, was also identified as prominent overwinter plant association (Fig 1). Coupled with the fact that plant species had a significant effect on *Anagrus* counts, this makes these plant-associations the most suitable overwintering habitat I assessed. However, focusing future research on just these plant types would be ill-founded, as it may be the larger ecosystem that allows for a viable alternate host of *Anagrus* to establish on a particular plant type. As my finding suggest, *Anagrus* may utilize a suite of plant types for their associated alternate hosts.

Study limitations and future direction

This study served to identify prominent *Anagrus*-plant associations; however *Anagrus* counts may be caused by chance encounter with the vegetation at the time of sampling. To address this concern future research must answer the question of what alternate hosts are associated with those prominent *Anagrus*-plant associations. Ideally, leafhopper data would have been collected from the sticky traps used to collect *Anagrus* data which would have led to identification of complimentary prominent leafhopper-associations. Future studies should further focus efforts on confirming plant-associations by rearing *Anagrus* from vegetative clippings and identifying the leafhopper species from which *Anagrus* emerges.

To fully identify temporal trends in *Anagrus* abundance on overwintering habitat sampling should last for the length of the growing season, however due to time constraints and lack of resources this was not possible. Additionally, only dominant plant species were sampled for *Anagrus*; however "dominance" in a habitat type was qualitatively determined which introduces bias. A sampling method such as this, based on ease of access to sample plants may over-represent species that seem dominant in comparison to other plant species.

Ultimately, this study lays the groundwork for further overwintering habitat research, which if better understood will lead to elucidation of other aspects of *Anagrus*' life history, such as viable alternate hosts, as well as host and plant preferences. This study especially broadens knowledge of the life history of *Anagrus* by identifying new overwintering plant associations. Overwintering habitat is just one factor to account for when practicing ecologically-based vineyard management to promote biological control programs.

Broader implications

Anagrus spp. are prominently used as biological control agents in vineyard pests throughout North America, and any ecologically-based vineyard management plan seeking to use *Anagrus* to control pests should take into account it's habitat preferences, in addition to its other required resources and life history. For instance, Corbett and Rosenheim (1998) stress the importance of identifying dispersal mechanisms of *Anagrus* which should then be paired with habitat augmentation to promote informed biological control of grape leafhoppers. This research, while broad in nature, serves as the foundation for future *Anagrus* overwintering studies, particularly in the Napa and Sonoma wine-grape growing regions of California.

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