

**Effects of a parasitic mite on the competitive interactions between two
grasshopper species**

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ABSTRACT

To date, many studies that examine interactions between species have been limited to single interactions such as those between predators and their prey. Yet there is an increasing interest in integrating these traditionally separate fields with the goal of gaining the best understanding of the true interactions between organisms. One of the possible applications for increased understanding of natural interactions is in the development of effective Integrated Pest Management (IPM). In keeping with these themes, this study explored the effects of an ectoparasitic mite, *Eutrombidium locustorum* (Walsh), on the interspecific competition between two pest grasshopper species—*Ageneotettix deorum* (Scudder) and *Melanoplus sanguinipes* (Fabricius). We hypothesized that parasitism by *E. locustorum* would increase the grazing and competitive ability of infected grasshoppers. Field experiments were conducted to determine the effects of these combined interactions on the grasshopper species, while lab feeding trials were done to examine changes in feeding behavior caused by parasitism. The results of these experiments suggest that *E. locustorum* increases the competitive ability of host *M. sanguinipes* by increasing its grazing and competitive ability both in late instar and adult grasshoppers. While many studies have shown the potential of *E. locustorum* as biocontrol, the results of this study suggest that use of this mite should be considered more carefully, as the effects of the mite on grasshopper populations are not straightforward. Further research on this system is necessary and should focus on (1) the effects of a predator on the host-parasite interaction, (2) using parasitism to increase the competitive advantage that early season adult grasshoppers have over nymphs of late season pest species, (3) determining if observed differences in feeding behavior translate to more natural conditions in the field, (4) the long term effects of *E. locustorum* on grasshopper

populations, and (5) if *E. locustorum* densities can be economically increase in the field to maximize their effectiveness.

INTRODUCTION

To date, many studies on interactions between species have been limited to single interactions such as those observed between predators and prey, parasites and hosts, and competitors (Moller, 2008; Szuroczki and Richardson, 2009; Laws et al., 2009). This is surprising given that there is current interest in integrating different fields of research (Moller, 2008). Studying the different simultaneous interactions is important because this gives the best chance of truly understanding the focal interactions (Moller, 2008). Many studies that do examine multiple layers of interaction have been limited to how predators affect host-parasite interactions (*i.e.* Packer et al., 2003; Hall et al., 2005; Laws et al., 2009), while studies that specifically address parasitic affects on competition appear to be more rare and generally focused on intraspecific competition (*i.e.* Washburn et al., 1991; Branson, 2003). Theoretical papers have suggested that under the correct conditions, parasites can effectively regulate their host population, potentially altering competitive interactions (Anderson and May, 1978; May and Anderson, 1978). Additionally, experimental studies have demonstrated several effects of parasites on host populations that may alter the intensity of inter- and intraspecific competition experienced by potential competitors. Examples of these effects in insects include reduced survivorship (Lanciani, 1975; Washburn et al., 1991; Polak, 1996; Muñoz et al., 1998; Branson, 2003), changes in fecundity (Lanciani, 1975; Washburn et al., 1991; Polak, 1996; Muñoz et al., 1998; Branson, 2003), reduction in host hemolymph (Polak, 1996), changes in levels of host resource consumption (Slansky, 1978; Polak, 1996; Danyk et al., 2005), and measureable—sometimes drastic—changes in host behavior (*see review* Libersat et al., 2009). A better

understanding of the combined effects on organisms resulting from parasite-host and competitive interactions will give us insight into the complex interactions between organisms in the field as well as allow us to more efficiently manage pest species based on their natural ecology through Integrated Pest Management (IPM).

One group of pests of particular economic importance that may be better managed by understanding these relationships are grasshoppers (Orthoptera: Acrididae) (Belovsky, 1990; Belovsky et al., 1998; Branson, 2003). In western rangeland alone, grasshoppers can be responsible for the destruction of at least 21-23% of available range vegetation annually resulting in a yearly loss of approximately \$393 million if that vegetation had been available for livestock grazing (Hewitt and Onsager, 1983). Historic control methods relied mainly on chemical pesticides which have since been recognized to have a wide variety of unwanted side-effects, including decreases in biodiversity of non-target insects and arachnids that may actually be beneficial (Batory et al., 2012; Bundschuh, 2012). IPM attempts to minimize these harmful and unwanted side-effects by minimizing the use of pesticides and by supplementing them with other methods of control. One relatively new method of control, which shows promise, is the use of host-specific parasites (Belovsky et al., 1998). These ‘biocontrols’ effectively target the pest species without damaging other components of the ecosystem. While adding parasites or pathogens to control methods that already utilize natural predators may increase the effectiveness of this ‘biocontrol’ (Belovsky, 1990), careful consideration of other ecological factors that affect pest populations—such as competition for resources—are needed (Washburn et al., 1991).

This study will explore the influence of a parasitic mite, *Eutrombidium locustorum* (Walsh), on the competitive interactions of two grasshopper species—*Ageneotettix deorum* (Scudder) and *Melanoplus sanguinipes* (Fabricius). *Ageneotettix deorum* is a pest of rangeland

grasses and is often the dominant species in outbreaks on the mixedgrass prairie (Pfadt, 1994). The diet of *A. deorum* consists mainly of grasses and sedges (Pfadt, 1994). *Melanoplus sanguinipes* is a serious pest of both crops and grasslands causing more crop damage than any other grasshopper species in the United States (Pfadt, 1994). It is a mixed feeder of grasses and forbs (Pfadt, 1994). Despite its smaller size, Chase and Belovsky (1994) observed that *A. deorum* was competitively superior to *M. sanguinipes* when competing for inclusive resources due in part to its method of feeding.

Eutrombidium locustorum is a widely distributed grasshopper ectoparasite throughout much of the continental United States (Rees, 1973). Ectoparasitic larvae of this species consume grasshopper hemolymph by attaching to a susceptible host and piercing the integument beneath the wing pads or a vein of the wing, while adults and late stage nymphs consume grasshopper eggs (Rees, 1973). Branson (2003) found that parasitism by *E. locustorum* larvae reduced survivorship of adult *A. deorum* and reduced fecundity in both *A. deorum* and *M. sanguinipes* by negatively impacting current reproductive energy allocation while parasitized. The combination of grasshopper egg consumption, reduced survival in some parasitized species, and reduced fecundity independent of host density suggest that *E. locustorum* may be useful as a biological control of pest grasshopper species (Rees, 1973; Belovsky et al., 1998; Branson, 2003). This current study will aim to expand on the results of Branson (2003) by exploring the effects of *E. locustorum* on interspecific competition between *A. deorum* and *M. sanguinipes*.

This study consisted of two separate field experiments examining competitive interactions in field enclosures: the first stocked enclosures with adult *A. deorum* and parasitized and unparasitized late instar *M. sanguinipes* and the second stocked enclosures with adult *A. deorum* and parasitized and unparasitized adult *M. sanguinipes*. Feeding trials were also

conducted to determine if *E. locustorum* altered *M. sanguinipes* feeding behavior. Because young hosts are often more affected by ectoparasites (Lehmann, 1993), I hypothesized that in field experiment 1, parasitized late instar *M. sanguinipes* would experience higher levels of mortality than either *A. deorum* or unparasitized late instar *M. sanguinipes* and that survival of parasitized *M. sanguinipes* would be the lowest when paired with *A. deorum* due to its competitive advantage for shared resources (Chase and Belovsky, 1994). For field experiment 2, I hypothesized that survival of parasitized adult *M. sanguinipes* in single species treatments would not be lower than unparasitized adults of the same species (Branson, 2003). In mixed species treatments, I hypothesized that parasitized *M. sanguinipes* would have a greater impact on *A. deorum* survival than unparasitized *M. sanguinipes* because parasitized individuals should need to consume more food to compensate for nutrients removed by the parasite—increasing its competitive ability (Washburn et al., 1991; Chase and Belovsky, 1994; Polak, 1996). In feeding trials, I hypothesized that parasitized adult *M. sanguinipes* would consume the most because adult *M. sanguinipes* (♂ 240 mg, ♀ 277 mg) were larger than both late instar *M. sanguinipes* (♂ 165 mg, ♀ 151 mg) and adult *A. deorum* (♂ 103 mg, ♀ 216 mg) and because parasitized grasshoppers should have to consume more food to compensate for losses incurred from being parasitized. I also hypothesized that late instar *M. sanguinipes* should consume about the same amount of grass as *A. deorum* based on size, but that parasitized late instar *M. sanguinipes* should consume more resources than unparasitized late instar *M. sanguinipes*.

METHODS

Field Experiment—This study was conducted at the National Bison Range in northwestern Montana, USA at an elevation of approximately 800 m. The study site is a C₃ grass dominated Palouse prairie (Belovsky and Slade, 1995) with the most commonly occurring

grasses being *Poa pretensis* (Kentucky bluegrass) and *Pseudoroegneria spicata* (blue-bunch wheatgrass). Grasshoppers were stocked into experimental enclosures constructed from metal window screen and aluminum flashing with a basal area of 0.1 m² and a height of 0.9 m. Cages were placed over patches of vegetation that were similar in plant abundance and species composition. In order to maximize the interspecific competition between grasshopper species, forbs were avoided during the installation of cages to exclude potentially exclusive resources that *M. sanguinipes* could exploit during the study. The cage bases were buried into the ground and cage tops are closed with binder clips to prevent grasshopper escape. Similar cages have been used in previous studies with grasshoppers (Ritchie and Tilman, 1992; Joern and Klucas, 1993; Chase and Belovsky, 1994; Branson, 2003; Laws et al., 2009). This type of cage is particularly useful in grasshopper competition studies as it has minimal effects on microclimate (Belovsky and Slade, 1995) while eliminating the grasshoppers' ability to disperse to reduce the pressures of competition, which could result in competitive mortality (Chase and Belovsky, 1994).

We caught unparasitized adult *A. deorum* as well as late instar and adult *M. sanguinipes* with and without parasites at near-by field sites. The rate of infection for *M. sanguinipes* at this site was 57% and parasitized grasshoppers had an average of 2.5 larval mite ectoparasites attached (n=65). Grasshoppers were kept overnight in terrarium and fed *ad libitum* in order to insure that individuals injured during capture were not stocked. We conducted two competition experiments. Experiment 1 used adult *A. deorum* and late instar *M. sanguinipes*, and was started on July 14, 2013. Experiment 2 used adult *A. deorum* and adult *M. sanguinipes*, and was started July 27, 2013. Adult *A. deorum* were used in both experiments because *A. deorum* nymphs were in very low abundance when the experiments were run. In both experiments grasshoppers were stocked in the cages to create five treatments: (1) *A. deorum*, (2) parasitized *M. sanguinipes*, (3)

unparasitized *M. sanguinipes*, (4) *A. deorum* and parasitized *M. sanguinipes*, (5) *A. deorum* and unparasitized *M. sanguinipes*. Grasshoppers were stocked at a density of six grasshoppers per cage. In treatments with both species, three of each species was stocked at a sex ratio of 2:1 (female:male), while even sex ratios were used in single species treatments. An even number of each species was used in combined species treatments (treatments 4 and 5) because, despite *A. deorum*'s smaller body size, Chase and Belovsky (1994) showed that these two species have similar competitive abilities in their interactions with each other. Treatments were randomly assigned to cages with five replicates for each treatment. Survivors were counted every three days and dead grasshopper carcasses were removed to limit their potential as an alternative food source for surviving grasshoppers.

Feeding trials—Feeding trials were conducted to ascertain each species' feeding behavior and if parasitism by *E. locustorum* alters the feeding behavior of *M. sanguinipes* late instars and adults. Individual grasshoppers were placed in 0.5 L jars and grasshoppers were starved for 12-hours overnight. Following the starvation period, grasshoppers were offered 1 g of grass from the study site (predominately *P. spicata*) or 1 g organic romaine lettuce for a period of 6 h. Five controls without grasshoppers for each treatment allowed me to estimate the plant mass lost to desiccation during the feeding period. Remaining plant biomass was removed immediately following the feeding period, weighed, and corrected for desiccation. Grasshopper wet mass was also measured following lettuce feeding trials.

Statistical analysis—Survival data was analyzed for the eighth day—July 23 and August 5 respectively—for each field experiment using ANOVA followed by Tukey's post-hoc analysis if a significant difference was detected ($\alpha = 0.10$). The eighth day was used for analysis for two reasons: (1) in all instances, populations within each cage had reached an asymptote (Fig. 1) and

(2) this was the first date in both experiments in which *E. locustorum* was no longer attached to hosts (see Joern and Klucas, 1993; Branson, 2003). We used cage means as replicate values for all survival analyses. Feeding data was also analyzed using ANOVA followed by Tukey's post-hoc analysis if a significant difference was detected. The statistical program SYSTAT 13 (UNICODE) was used for all statistical analyses.

RESULTS

Field Experiment 1—There was a significant effect of treatment (alone or with *M. sanguinipes*) on *A. deorum* density ($F_{2,12} = 6.000$, $P = 0.016$; Fig. 2). The number of *A. deorum* per cage was significantly lower when paired with *M. sanguinipes* without mites (Tukey's HSD, $P = 0.079$) and when paired with *M. sanguinipes* with mites (Tukey's HSD, $P = 0.014$) than when alone in the single species treatment (Fig. 2). However, there was no significant difference between the number of *A. deorum* per cage when paired with parasitized *M. sanguinipes* compared to when paired with unparasitized *M. sanguinipes* (Tukey's HSD, $P = 0.614$; Fig. 2). Comparing the densities of *M. sanguinipes* on day 9 reveals that there was no significant effect of treatment ($F_{1,16} = 0.111$, $P = 0.743$), but there is a trend for *M. sanguinipes* to have higher survival in cages where it is parasitized by *E. locustorum* than in those that it is not ($F_{1,16} = 2.788$, $P = 0.115$; Fig. 2). There was not a significant interaction term between treatment and the presence of the mite ($F_{1,16} = 1.000$, $P = 0.332$).

Field Experiment 2—There was a strong trend toward a significant effect of treatment on *A. deorum* ($F_{2,12} = 2.455$, $P = 0.128$; Fig. 3). Despite only approaching significance, I ran a Tukey's post-hoc test to explore the different treatment effects on *A. deorum*. The number of *A. deorum* per cage was not significantly different between the single species treatment and when paired with parasitized adult *M. sanguinipes* (Tukey's HSD, $P = 0.528$) or when paired with

unparasitized adult *M. sanguinipes* (Tukey's HSD, $P = 0.528$; Fig. 3). However, the density of *A. deorum* when paired with unparasitized adult *M. sanguinipes* was higher than when paired with parasitized adult *M. sanguinipes* at a level that approaches significance (Tukey's HSD, $P = 0.109$; Fig. 3). The number of *M. sanguinipes* per cage was not significantly different between treatments ($F_{1,16} = 1.220$, $P = 0.286$) or the presence or absence of *E. locustorum* ($F_{1,16} = 0.439$, $P = 0.517$; Fig. 3). The interaction term was also not significant ($F_{1,16} = 0.439$, $P = 0.517$).

Feeding Trials—In feeding trials where *M. sanguinipes* were offered grass, there was no significant effect of parasitism on amount consumed ($F_{1,28} = 0.004$, $P = 0.950$), but adult *M. sanguinipes* ate significantly more grass than late instar individuals ($F_{1,28} = 3.011$, $P = 0.094$). The interaction term was not significant ($F_{1,28} = 0.008$, $P = 0.929$). There was no significant difference between the amount of grass consumed by *A. deorum* and late instar *M. sanguinipes* with ($F_{1,14} = 0.005$, $P = 0.944$) or without the parasite ($F_{1,15} = 0.004$, $P = 0.949$). There was also no difference in the amount of grass consumed by *A. deorum* and adult *M. sanguinipes* with ($F_{1,15} = 1.081$, $P = 0.315$) or without the mite present ($F_{1,16} = 0.998$, $P = 0.333$).

In feeding trials where *M. sanguinipes* were offered organic romaine lettuce (*L. sativa*), there was no significant effect of parasitism on amount consumed ($F_{1,25} = 1.869$, $P = 0.184$), but adult *M. sanguinipes* ate significantly more grass than late instar individuals ($F_{1,25} = 16.853$, $P < 0.001$; Fig. 4). The interaction term was not significant ($F_{1,25} = 0.258$, $P = 0.616$). When grasshopper wet mass was considered, parasitized *M. sanguinipes* consumed more lettuce per grasshopper wet mass than unparasitized individuals ($F_{1,25} = 2.936$, $P = 0.099$), but life stage did not have a significant effect ($F_{1,25} = 2.185$, $P = 0.152$; Fig. 5). The interaction term was not significant ($F_{1,25} = 0.551$, $P = 0.465$).

DISCUSSION

The objective of this paper was to explore the effects of a parasitic mite, *E. locustorum* on the competitive interaction between two grasshopper species. While few of my results showed significant differences, strong trends were observed and can be used to infer the effects of *E. locustorum* on grasshopper competition. Important trends include: lower survivor rates for *A. deorum* when combined with parasitized *M. sanguinipes* than when paired with unparasitized *M. sanguinipes*, increased survival of late instar *M. sanguinipes* parasitized by *E. locustorum*, decreased survival of adult *M. sanguinipes* parasitized by *E. locustorum*, and that parasitized *M. sanguinipes* tended to consume more lettuce when parasitized than when not. Finally, conditions for interspecific completion were confirmed by the grass feeding trials which revealed no significant differences in the amounts of grass consumed between grasshoppers paired in the treatments.

The remaining interpretation of the results of this study is best understood by explaining the observed trends in the context of a set of equations defining included niche competition (Schoener, 1974). These equations are:

$$dN_1/dt = R_1N_1[I_E/N_1 + I_O/(N_1 + \alpha N_2) - C_1] \quad \text{eqq. [1]}$$

for the species with the potential for exclusive resources (*M. sanguinipes* in this experiment) and

$$dN_2/dt = R_2N_2[I_O/(N_2 + \beta N_1) - C_2] \quad \text{eqq. [2]}$$

for the species with no exclusive resources (*A. deorum* in this experiment). Where N_i is the number of individuals of species i , R_i converts the per capita net resource intake for species i into mortality, C_i is species i 's per capita resource requirements for maintenance, I_E is the amount of

species 1's exclusive resource, I_0 is the amount of shared resource available, α converts species 2's resource use into an equivalent use by species 1, and β converts species 1's resource use into an equivalent use by species 2 (α and β are competition coefficients).

For field experiment 1, late instar *M. sanguinipes* parasitized by *E. locustorum* tended to survive better than unparasitized *M. sanguinipes*, suggesting that they were better competitors for food resources. This data suggesting that parasitized late instar *M. sanguinipes* were better competitors was also supported by the lettuce feeding trials where parasitized grasshoppers tended to consume more food per individual and per gram of grasshopper wet mass than their unparasitized counterparts. This perceived increase in competitive ability increases the competition coefficient β in equation [2], while simultaneously decreasing the competition coefficient α in equation [1] when *A. deorum* are paired with parasitized late instar *M. sanguinipes*. In theory, these changes in competition coefficients cause the nonlinear isocline for *M. sanguinipes* to shift upwards and the linear isocline for *A. deorum* to shift to the left (*isoclines available in Chase and Belovsky, 1994*). As a result, I should have observed lower survivorship for *A. deorum* when competing with parasitized late instar *M. sanguinipes*. In reality, the observed shift in survivorship was much milder than expected as survivorship was not significantly different for *A. deorum* when paired with parasitized or unparasitized *M. sanguinipes*.

For field experiment 2, the opposite trend was observed. Parasitized adult *M. sanguinipes* tended to do the same or slightly worse compared to unparasitized adult *M. sanguinipes* in terms of survival, suggesting a slight competitive disadvantage associated with parasitism as an adult. However, this was not supported by the lettuce feeding trials as parasitized adult *M. sanguinipes* appeared to consume more lettuce per individual as well as per gram of grasshopper wet mass

than unparasitized *M. sanguinipes*. A solution to this apparent conflict can be found in Branson (2003). Branson (2003) observed that *M. sanguinipes* adults parasitized by *E. locustorum* allocated resources away from reproduction in order to cope with the nutritional demands of the mite larvae. So while parasitized adult *M. sanguinipes* appeared to be superior competitors for food resources according to the lettuce feeding trials, the projected decrease in α in equation [1] was countered by an increase in the cost of maintenance (C_1) resulting in the observed survivorship rates for parasitized adult *M. sanguinipes*. This hypothesis is supported by the observation that *A. deorum* paired with parasitized adult *M. sanguinipes* had lower survival rates than when paired with unparasitized adult *M. sanguinipes*, suggesting a larger β value in equation [2]. The overall effects on the included niche competition equations are that increased feeding by parasitized *M. sanguinipes* increases the competition coefficient β in equation [2], decreases the competition coefficient α in equation [1], and that increased cost of maintenance resulting from parasitism results in an increase of C_1 in equation [1]. These changes add up to a slight shift downward in the nonlinear isocline for parasitized adult *M. sanguinipes* and a shift to the left for the linear isocline of *A. deorum* when paired together.

The results of this study suggest that use of *E. locustorum* as ‘biocontrol’ as a part of an effective IPM should be considered more carefully, as the effects of the mite on grasshopper populations are not straightforward. Mites have a high potential to aid in the control of pest grasshopper species because (1) they consume a relatively larger number of grasshopper eggs during its lifetime in order to reproduce (males require 3 eggs, females require 7-8 eggs; Rees, 1973), (2) they reduce the fecundity of parasitized females by a significant amount (Branson, 2003), and (3) they can potentially reduce survivorship of some hosts when at high enough parasite loads (Belovsky et al., 1998; Branson, 2003). However, this current study suggests that

parasitism by *E. locustorum* increases the grazing and competitive ability of host species which could result in increased damage to economically important cropland or rangeland. Given that interspecific competition among grasshoppers might not be intense under field conditions even when food resources are scarce (Evans, 1992), increased resource consumption rates due to parasitism by *E. locustorum* in the absence of competitive mortality could be devastating during outbreaks of pest species. Another possible problem with using *E. locustorum* as a ‘biocontrol’ agent is that instead of lowering the grazing effectiveness and survivorship of immature grasshoppers—the most important and economical period for grasshopper control (Hewitt and Onsager, 1983)—these rates were both higher for parasitized immature *M. sanguinipes* in this study.

Further research is required to determine if *E. locustorum* can be used as an effective biocontrol. This research should pay special to five components of the *E. locustorum*-grasshopper system. (1) Does the addition of a predator to the system, such as arachnids or birds, increase the effectiveness of the biocontrol? Previous studies of the effects of predators on the parasite-host interaction have shown that predators selectively feed on individuals of lower fitness caused by infection (Hudson et al., 1992). (2) Can *E. locustorum* be used on early season adult grasshoppers to increase their competitive advantage over late season grasshopper nymphs? Belovsky (1990) suggests that competition between early season grasshopper adults and late season grasshopper nymphs could increase the mortality of late season grasshoppers and that sufficient precipitation remains during and after early season grasshopper die-off that recovery of vegetation could effectively negate the increase in consumption by parasitized early season grasshoppers. (3) Further field assessment of the perceived increase in feeding rate is needed in order to determine if this also occurs under field conditions. (4) Does the mite have the predicted

long term effect on grasshopper populations? This may be difficult to assess given that the life cycle of *E. locustorum* is not well understood and observation of late stage nymphs and adults in the soil is difficult. (5) Can *E. locustorum* densities be economically increased in the field? If the costs of this control method outweigh its benefits to effective IPM, then *E. locustorum*'s use as a control agent will be severely limited. This study highlights the complexities of multiple level interactions and the need to further investigate the effects of potential biocontrol agents, such as *E. locustorum*, before they can be effectively implemented by IPM in the control of pest species.

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FIGURES

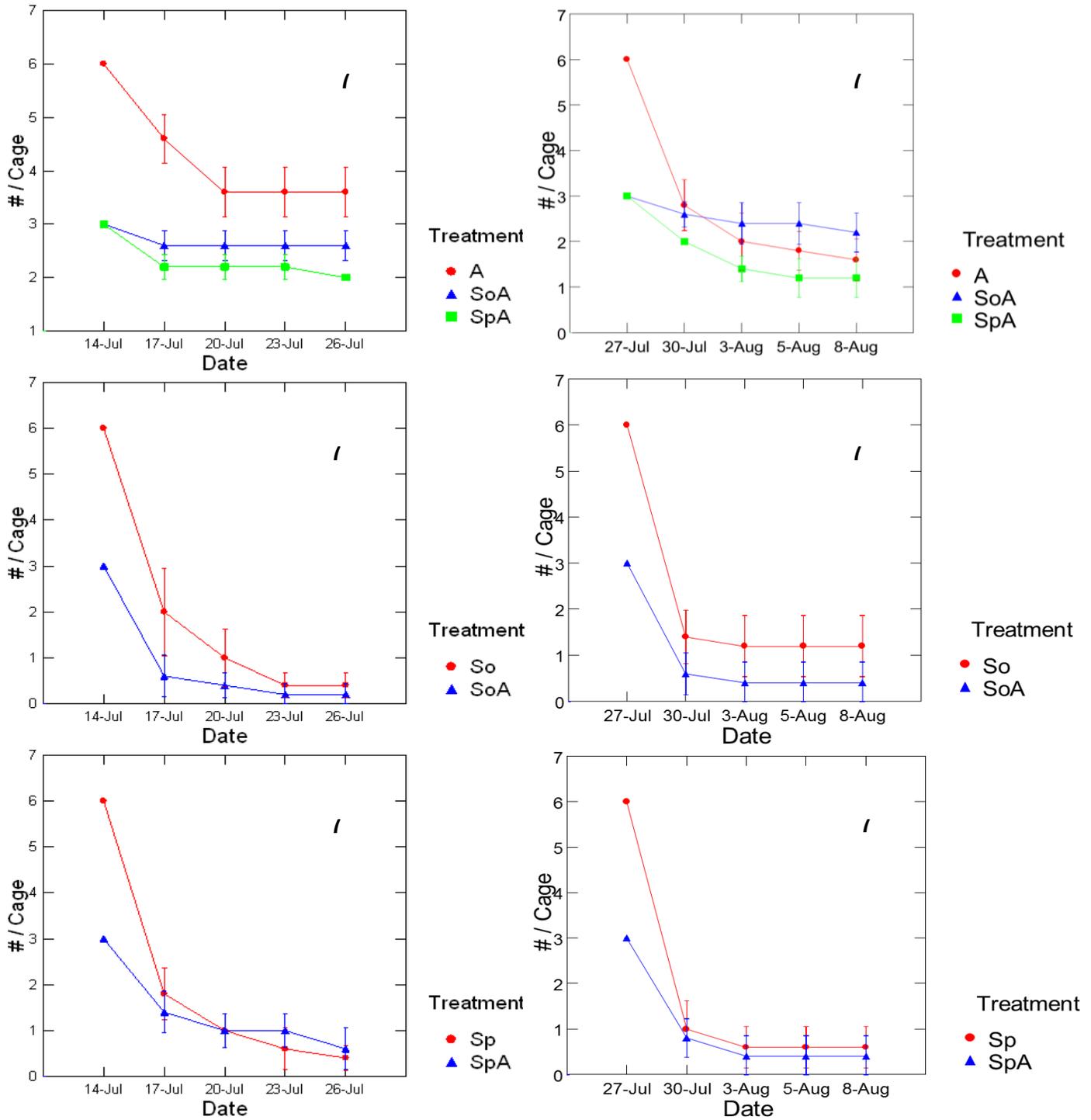


Figure 1. Time series mean (\pm SE) grasshopper densities for each species stocked in cages for field experiment 1 (a. *A. deorum* adults, b. unparasitized *M. sanguinipes* late instar, and c.

parasitized *M. sanguinipes* late instar) and for field experiment 2 (**d.** *A. deorum* adults, **e.** unparasitized *M. sanguinipes* adults, and **f.** parasitized *M. sanguinipes* adults).

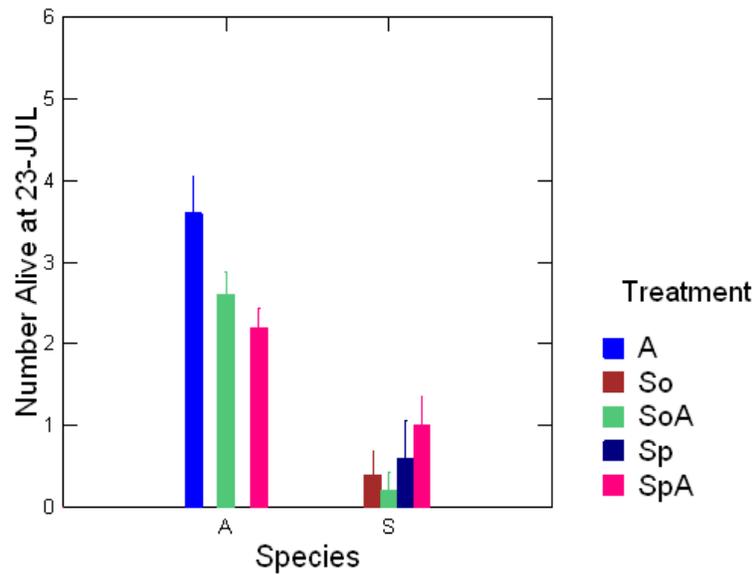


Figure 2. Cage densities for field experiment 1 on 23 July, 2013. There was a trend for lower survivorship of *A. deorum* adults when paired with parasitized late instar *M. sanguinipes* than when paired with unparasitized late instar *M. sanguinipes*. There was also a strong trend for increased survivorship of parasitized late instar *M. sanguinipes* when compared to unparasitized late instar *M. sanguinipes*.

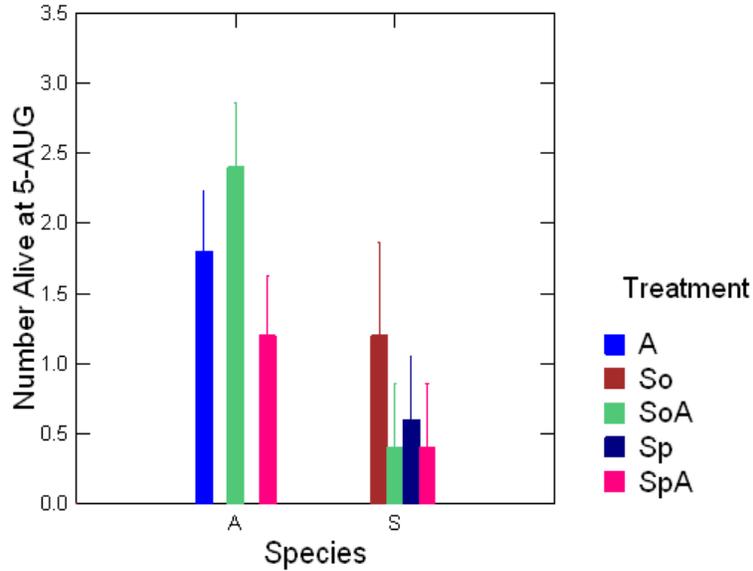


Figure 3. Cage densities for field experiment 2 on 5 August, 2013. *Ageneotettix deorum* had a significantly lower survivorship when paired with parasitized adult *M. sanguinipes* than when paired with unparasitized adult *M. sanguinipes*. There was also a trend for lower survivorship of *M. sanguinipes* adults when parasitized by *E. locustorum* than when not parasitized.

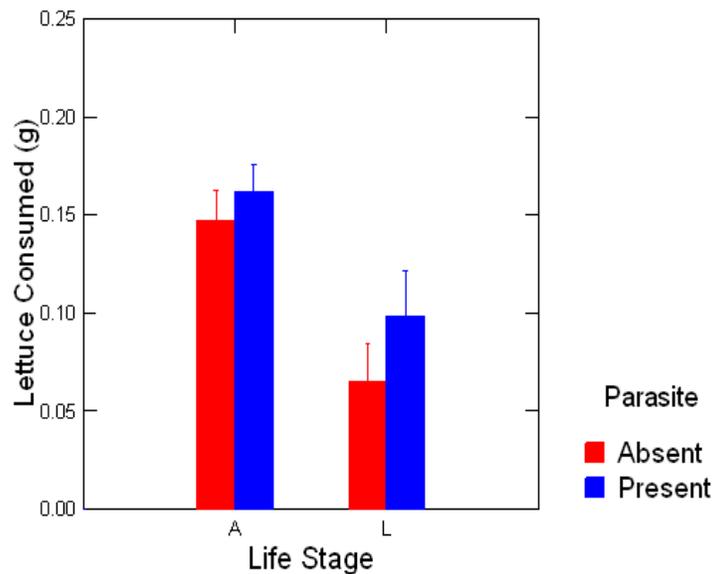


Figure 4. Adult *M. sanguinipes* consumed significantly more lettuce per individual grasshopper compared to late instar *M. sanguinipes*. There was no significant difference in lettuce consumed per individual between parasitized and unparasitized *M. sanguinipes*.

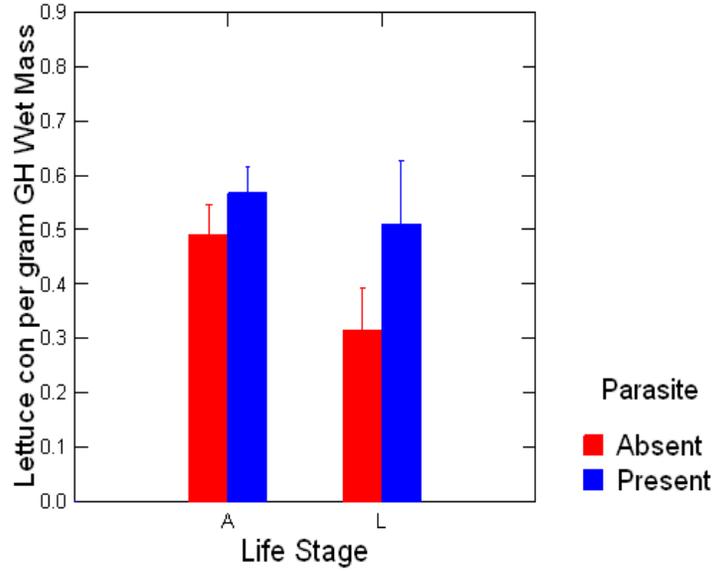


Figure 5. Parasitized *M. sanguinipes* consumed significantly more lettuce per gram of grasshopper wet mass than unparasitized *M. sanguinipes*. There was no significant difference in the lettuce consumed per gram of grasshopper wet mass between late instar and adult *M. sanguinipes*.