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SHORT COMMUNICATION

Does bird removal affect grasshopper grazing on *Juncus roemerianus* (black needlerush) marshes?

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Abstract Grazing on *J. roemerianus* (black needlerush), grasshopper abundance, and black needlerush plants was examined in the presence and exclusion of marsh birds. Birds were excluded using a PVC framed exclosure wrapped with bird netting that allowed free passage of marsh grasshoppers. These measurements were taken bi-monthly from April to August 2011 in a black needlerush marsh within the Grand Bay National Estuarine Research Reserve (Moss Point, MS, USA). Grazing metrics, grasshopper abundance, and plant health metrics showed no effect of bird exclusions across all sampling dates. In contrast to other marsh systems with strong trophic cascades (e.g., *Spartina alterniflora* on US east coast), these results suggest that the primary consumer (grasshoppers) is not affected by the presence of their dominant predator (birds) which leads to no change in the health of the primary producer (black needlerush). Information derived from this study furthers our understanding of the trophic relationships within black needlerush marshes in the northern Gulf of Mexico.

Keywords Gulf of Mexico · Salt marsh · Seaside sparrow · Grasshopper · Trophic cascade · Top-down

Introduction

Trophic cascades and their effects have been documented across many ecosystems (Pace et al. 1999 and references therein). Arguably the most well-known examples of trophic cascades are decreased wolf populations leading to increased deer populations, which in turn decrease the quantity of plants that these deer feed upon (Leopold 1949) and a similar relationship occurs with sea otters, sea urchins, and kelp forests (Estes and Duggins 1995). Interest in the effects of trophic cascades has recently heightened because of anthropogenic influence on these cascades (Daskalov 2002; Hebblewhite et al. 2005). Anthropogenic pressure on predators that prey upon first order consumers is a common underlying cause of extremes in trophic cascades (Pace et al. 1999; Ripple and Beschta 2006). In salt marshes, there have been documented declines in *Spartina alterniflora* (smooth

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cordgrass) marshes caused by increased grazing by marsh periwinkles (*Littoraria irrorata*; Silliman and Zieman 2001). Increased marsh periwinkle abundance can be attributed to the reduction of marsh periwinkle predator abundance, such as overfishing of the blue crab (*Callinectes sapidus*) and losses of terrapins (*Malaclemys terrapin*; Silliman and Bertness 2002). However, there have been no studies evaluating trophic cascades in *J. roemerianus* (black needlerush) marshes, which is a dominant marsh plant along the northern Gulf of Mexico coast (Eleuterius 1976).

The most prevalent grazers of black needlerush are several species of marsh grasshoppers (*Orthoptera: Tettigoniidae*; Parsons and de la Cruz 1980) and they are preyed upon by marsh birds (Pfeiffer and Wiegert 1981). The adult stages of these grasshoppers are typically found from April to August in the northern Gulf of Mexico (Smalley 1960; Davis and Gray 1966; Carrier 2013; Sparks and Cebrian 2015). During this time marsh grasshoppers are a significant contribution to the diet of many insectivorous marsh birds (Post and Greenlaw 2006). In the northern Gulf of Mexico, common birds that readily consume marsh grasshoppers include seaside sparrow, red-winged blackbird, and boat-tailed grackle (Mark Woodrey personal communication). In terrestrial grasslands and forests, birds have been documented to significantly decrease populations of insects, which led to a cascading effect on the primary producers that the insects grazed upon (Joern 1986; Bock et al. 1992; Marquis and Whelan 1994; Bridgeland et al. 2010). However, no studies have analyzed the extent of grazing pressure exerted on marsh grasshoppers by marsh birds in black needlerush marshes.

Populations of marsh birds along the Gulf of Mexico coast are experiencing a decline in abundance through natural and human induced processes (Rush et al. 2009). Declining marsh bird populations will inevitably alleviate grazing pressure on marsh grasshoppers. Higher abundances of marsh grasshoppers could lead to increased grazing on black needlerush marshes (Sparks and Cebrian 2015). Increased grazing could lead to reductions in plant biomass or plant stress; thereby, reducing the magnitude of ecosystem services provided by these marshes, such as habitat, shoreline stabilization, and nutrient filtration.

In this short communication, we evaluate grazing of black needlerush by marsh grasshoppers with and without the presence of birds, through measurements of marsh grazing metrics, relative grasshopper abundances, and plant health metrics. The results from this study will further our understanding of how anthropogenic influences, such as predator removal, can influence marsh health along the northern Gulf of Mexico coast.

Materials and methods

Experimental methodology and sampling

The study site was situated in the marsh off of Maddie Clark Bayou (Fig. 1) within the Grand Bay National Estuarine Research Reserve (GBNERR). The climate at the GBNERR is warm subtropical with mean summer temperatures of 27 °C and mean monthly summer rainfall of 16 cm (Rush et al. 2010). Maddie Clark Bayou is predominately polyhaline with a small tidal amplitude (<1 m; Dardeau et al. 1992). The marsh in this area is dominated by black needlerush with fringing smooth cordgrass (Rush et al. 2010). This study site was chosen because it is relatively undisturbed (no major development within 4.5 km radius) and surveys throughout the GBNERR showed Maddie Clark Bayou had the highest concentration of insectivorous birds (A. J. Lehmicke unpublished data). Additionally, insectivorous birds were observed feeding on marsh grasshoppers within the study site, throughout the experiment. Choosing a site with a high concentration of insectivorous birds maximizes the probability of observing an effect of excluding birds.

At the study site, there were 4 blocks of 2 treatments (Fig. 1; Open and Exclusion). Each of the 8 plots were 10 m inland from a tidal creek and spaced 10 m from each other. Each plot was 2 m × 2 m (4 m^2) with the Open plots having corners marked with PVC poles and the Exclusion plots composed of bird exclosures. The exclosures covered the entire plot with a cube shaped PVC frame wrapped with Dalen Bird-X netting with a mesh size of 1.91 cm × 1.91 cm to a height of 2 m. The largest observed grasshoppers, in this area, had a maximum body diameter of approximately 1 cm; thus this mesh allowed for free passage of grasshoppers into and out of the plots while excluding birds. Reduction of photosynthetically active radiation (PAR) caused by the exclosures was tested, with a LICOR-LI1400 light meter, throughout the day of project initiation (March 1, 2011). The mesh reduced PAR by less than 5 %.

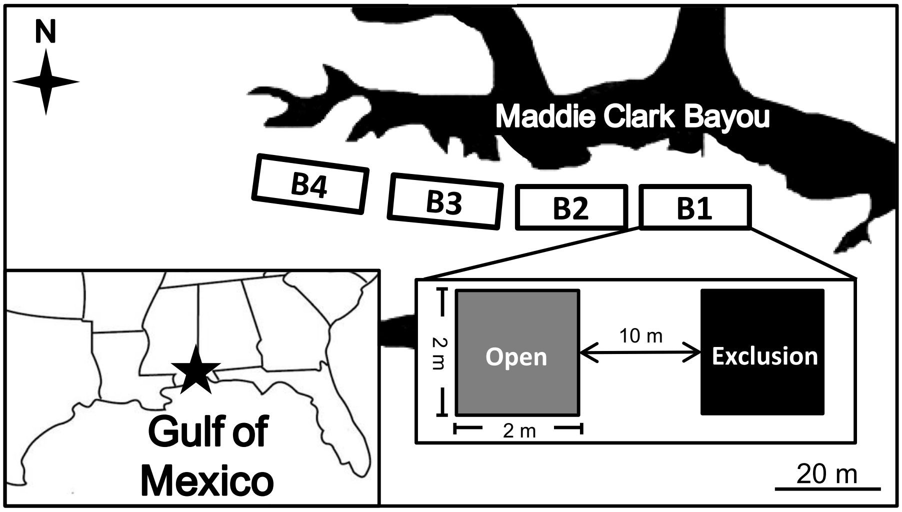

Fig. 1 Schematic of experimental layout. The center of the experimental layout is at the coordinates: 30°24′5.5″N, 87°24′27.5″W. The *dark coloration* on the primary map indicates open water and the *light coloration* is black needlerush marsh. Individual blocks are notated by B1–B4, with each block containing an open and bird exclusion treatment

Bi-monthly from April to August 2011, plant samples were taken by throwing two 15 cm × 15 cm quadrats randomly within each plot. All vegetation within the quadrat was clipped at the sediment surface, transported back to the laboratory, and frozen. After thawing, individual leaf lengths were measured in addition to several grazing metrics (% of leaves grazed, grazing per meter of leaf, longest scar length, leaf grazing degree and breakage probability) following the methodology of Sparks and Cebrian (2015). After taking these measurements, leaves were separated into living and senesced (brown, dead) portions. These samples were dried and weighed with living, senesced, and total biomass calculated for each quadrat.

Within each plot an insect trap was deployed to quantify relative grasshopper abundance. These traps were designed and sampled according to the methodology of Sparks and Cebrian (2015). In this experiment, traps were sampled 3 times per month from May to August with the CPUE (i.e. catch per unit effort, individuals trap^{-1} d^{-1}) calculated for each plot for every sampling event. The timing for plant and grasshopper sampling (April–August) was chosen to encompass the peak in grasshopper abundance and grazing (Smalley 1960; Davis and Gray 1966; Carrier 2013; Sparks and Cebrian 2015).

Statistical analyses

We recognize that this sampling design has low power due to the small sample size. However, we chose to have low replication of larger plots (4 m^2) rather than high replication of smaller plots, since larger plots are more representative of bird exclusion. Additionally, we obtained mean values from each plot on each sampling date (i.e., average of 2 quadrat clippings). Using large plots (i.e., more representative) and mean values in our analyses counteract the limitations of low power associated with low replication.

Leaf length, biomass values, and metrics of herbivory intensity were calculated for each quadrat. Means of the two quadrats from the same plot were averaged for each sampling time. All three grasshopper abundance samples within the same month were averaged for each plot. Those means served as replicates in the statistical analysis. We ran a Repeated Measures ANOVA (RMANOVA) with block, exclusion (among-subject factor), and time (within-subject factor) for each site and variable. No grazing occurred during April; therefore, that month was excluded from the analysis for grazing metrics. Block was never significant and, thus, we pooled all blocks and reran the RMANOVA with only exclusion and time to increase the chance of finding significant effects by

Table 1 Results of RMANOVA for Treatment, Time, and interaction of Treatment × Time for all measured response variables

Response variable	Treatment		Time		Treatment × Time	
	F value	P value	F value	P value	F value	P value
Leaves grazed (%)	0.271	0.621	68.172	**<0.001**	0.046	0.837
Scars m^{-1}	0.422	0.540	100.220	**<0.001**	2.970	0.136
Longest scar	0.241	0.641	22.922	**0.003**	0.434	0.535
Leaf grazing degree	0.314	0.595	119.686	**<0.001**	2.081	0.199
Breakage probability	0.533	0.493	0.489	0.510	1.369	0.286
Hopper CPUE	0.126	0.732	5.241	**0.027**	0.597	0.635
Leaf length	0.029	0.869	14.931	**<0.001**	1.354	0.295
Biomass	0.041	0.846	1.566	0.249	0.889	0.436
Living biomass (%)	3.104	0.129	6.125	**0.015**	3.046	0.085

Bold P values indicate significance ($P < 0.05$)

these factors (Quinn and Keough 2002). All statistical tests were done with R (version 3.0.2) and significance for all tests was considered at $p < 0.05$.

Results

As expected from the cumulative nature of grasshopper grazing, most grazing metrics significantly increased through time (Table 1; Fig. 2). The only grazing metric that did not show a time effect was breakage probability (Table 1). Time was also a significant factor for relative grasshopper abundance (Table 1) with peak abundance in June (Fig. 3). Two of the three plant metrics (mean leaf length and % of living biomass) showed significant increases through time (Table 1; Fig. 2d, f); whereas, aboveground biomass remained similar from April–August (Fig. 2e).

There were no significant effects of bird exclusion on any of the grazing metrics measured for black needlerush (Table 1). However, the percent of leaves grazed, scars per leaf meter, length of the longest scar, and leaf grazing degree displayed elevated values in exclosures in relation to open plots in August (Table 1; Fig. 2), although these differences were not statistically significant. Similarly, relative grasshopper abundance showed no effect of bird exclusion (Table 1), but higher grasshopper abundances were found within the exclosures than in the open treatment in August (Fig. 3). As expected from the lack of significant differences in grazing metrics between open and exclusion plots, we found no significant effect of bird exclusion on the measured plant metrics (Table 1; Fig. 2).

Discussion

To our knowledge, this is the first study to analyze the trophic relationships of insectivorous birds, marsh grasshoppers, and black needlerush. In this study, we opted to have fewer larger scale replicates than many small scale replicates since the effect of bird exclusion is more representative at larger scales. Our overall findings were that bird exclusion did not have an impact on grazing of black needlerush or grasshopper abundance over the one sampling year. However, low statistical power limits the interpretive capabilities of these data and it is possible that there may be significant effects of bird exclusions on grasshoppers and/or marsh grazing that are not detectable with the low replication of this study. We did observe some suggestive evidence of possible bird exclusion effects that should be further evaluated with more replication over a longer duration.

The exclusion of marsh birds did not lead to significant increases in grazing of black needlerush by marsh grasshoppers during this study. Interestingly, most grazing metrics showed higher values at the end of the grazing season (August) in plots where birds were excluded, although these results were not significant (Fig. 2a, b, c). These suggestive data should be further evaluated with more replication over multiple years to determine if bird exclusion does indeed have an effect on grazing metrics of black needlerush. Other studies have documented grazing by marsh grasshoppers at other sites within the GBNERR, during the same time period (August 2011), and found higher percentages of grazed leaves (≈70–95 %; Carrier 2013; Sparks and Cebrian 2015) than we found in this study (≈65–70 %). Possibly, the

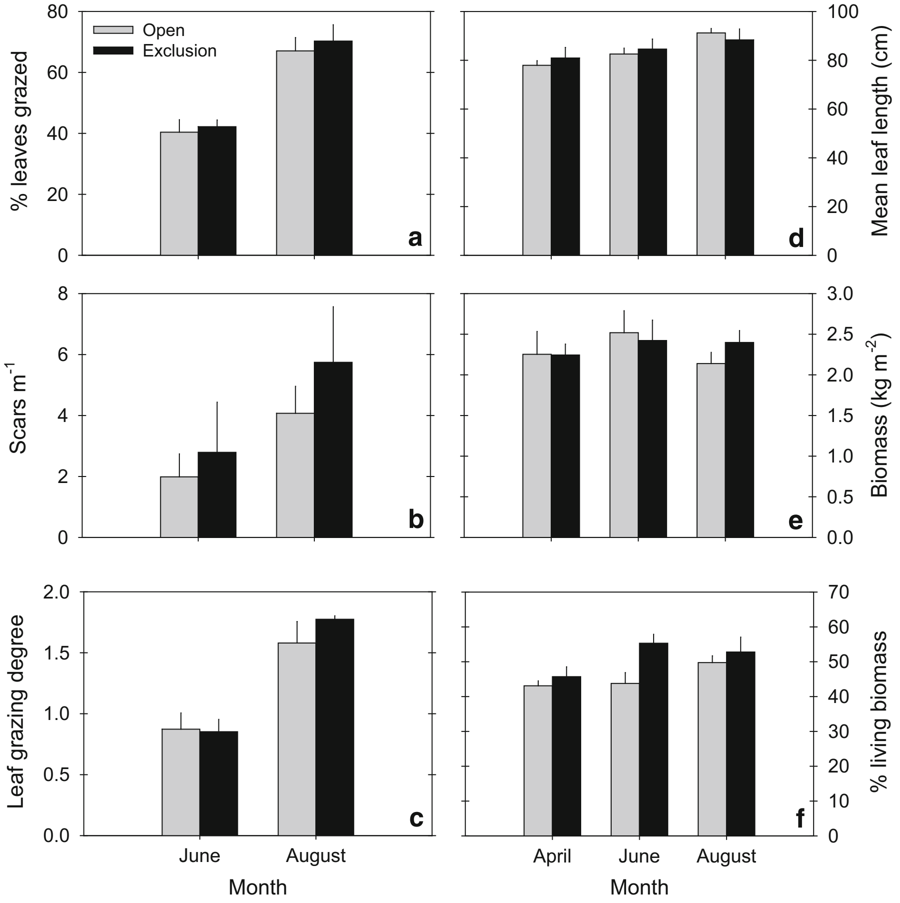

Fig. 2 Grazing and plant metrics through time for open and bird exclusion treatments. Grazing metrics include (**a**) percentage of leaves grazed, (**b**) scars per meter of leaf tissue, and (**c**) leaf grazing degree. Plant health metrics include (**d**) mean leaf length, (**e**) aboveground biomass, and (**f**) percentage of living aboveground biomass. *Error bars* indicate ± 1 SE

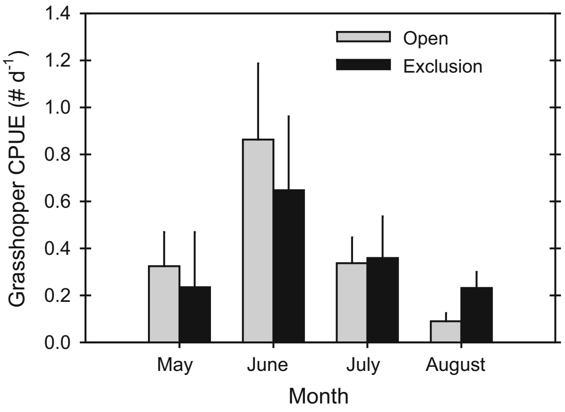

Fig. 3 Relative grasshopper abundances through time for open and bird exclusion treatments. *Error bars* indicate ± 1 SE

movement of marsh grasshoppers to this study site was regulated by a relatively high abundance of marsh birds (A. J. Lehmicke unpublished data) and/or the marsh birds altered the behavior of the grasshoppers through non-consumptive effects in both treatments (i.e., less plant consumption due to fear of being predated; Grabowski and Kimbro 2005; Preisser et al. 2007).

We also found no difference between exclusion and open treatments for relative grasshopper abundance. This result was not surprising because of the lack of differences between treatments for grazing metrics. Grasshopper abundance has been associated with the magnitude of grazing at other sites within the GBNERR (Sparks and Cebrian 2015). As expected with no differences between treatments for grazing and relative grasshopper abundance, we found no differences in plant health over the duration of the study. Another finding that warrants further study, with more replication, is that we trapped slightly more grasshoppers in bird exclusion plots than open plots in August. This finding coincides with the slightly elevated August grazing metrics in bird exclusion plots discussed in the previous paragraph.

Anthropogenic influences, particularly development, decrease the carrying capacity of areas for birds through reductions of nesting and feeding habitat (Rush et al. 2009). The marsh bird population may not be large enough, even in pristine areas, to effectively control marsh grasshopper populations. The pristine condition of the GBNERR decreases the chances of bird limitation; however, it cannot be completely dismissed since areas surrounding the GBNERR are developed and many marsh birds migrate or occupy large ranges (Dunn and Alderfer 2011). Our study does not have enough statistical power to make firm conclusions on the effects of bird presence on black needlerush marsh health. Studies similar to this, but with larger exclosures, more replicates, and sampling over multiple years are necessary to decisively determine if reduction in bird abundances could result in harmful grazing levels of black needlerush marsh.

In other systems strong trophic cascades have been documented with a change in predator abundance cascading down the food web to alter primary production (Leopold 1949; Estes and Duggins 1995; Pace et al. 1999; Silliman and Bertness 2002). Wootton (1995) conducted a 2 year bird exclusion study with a similar design to ours and found there was a strong trophic cascade associated with birds, sea urchins, and algae. However, sea urchins graze year round; whereas, the adult stages of marsh grasshoppers are only present in late spring through summer (Smalley 1960; Carrier 2013). The grazing span for marsh grasshoppers could be a limiting factor for the potential strength of a bird-grasshopper-black needlerush trophic cascade, as biological characteristics of herbivores has been a primary factor for trophic cascade strength in other systems (Borer et al. 2005). Additionally, the strongest trophic cascades have been observed in lentic and marine benthic habitats with the weakest occurring in terrestrial food webs (Shurin et al. 2002). Pairing the limited time grasshoppers graze with typically weaker trophic cascades associated with more terrestrial food webs makes it difficult to detect if a strong bird-grasshopper-black needlerush trophic cascade exists. This study, although limited in statistical power, provides some insight into the dynamics of this potential trophic cascade and provides considerations for future research regarding trophic interactions in black needlerush marshes.

Conclusion

In summary, these results indicate that marsh birds did not exert strong grazing pressure on marsh grasshoppers over the one year duration of this study. This lack of strong grazing pressure was evident through the similar estimates of grasshopper grazing on black needlerush, relative grasshopper abundance, and black needlerush plant health whether birds were excluded or not. However, this experiment had low replication and was conducted for only one grazing season (April–August) at one site. Longer studies at more sites should be conducted to reach more conclusive results.

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