

**THE EFFECT OF CATTLE GRAZING ON THE ABUNDANCE AND
DISTRIBUTION OF SELECTED MACROINVERTEBRATES IN WEST
GALVESTON ISLAND SALT MARSHES**

A Thesis

by

JENNIFER LYNN MARTIN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2003

Major Subject: Wildlife and Fisheries Sciences

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ABSTRACT

The Effect of Cattle Grazing on the Abundance and Distribution of Selected Macroinvertebrates in
West Galveston Island Salt Marshes. (August 2003)

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The effect of cattle grazing on the abundance and distribution of vegetation, burrowing crabs (*Uca rapax*, *Uca pugnax*, and *Sesarma cinereum*), marsh periwinkles (*Littoraria irrorata*), horn snails (*Cerithidea pliculosa*), and salt marsh snails (*Melampus bidentatus*) was evaluated over four seasons (summer 2000, fall 2000, winter 2001, and spring 2001) in grazed and ungrazed treatments. A Galveston Island salt marsh adjacent to Snake Island Cove was sampled at five elevations, from the water's edge to the high tidal flats. Data were analyzed for statistical differences using a two-way ANOVA in SAS. Cattle grazing may affect the vegetation and macroinvertebrate communities in salt marshes through trampling and herbivory. Vegetation resources available to other herbivores are decreased by the direct consumption of plant material by cattle. *Spartina alterniflora* and *Salicornia virginica* heights were significantly greater in ungrazed treatments than grazed for every season in the edge, upper, and middle elevation zones. Total aerial vegetative cover was also reduced significantly in grazed treatments, with the greatest impact in the edge and upper marsh. In the ungrazed treatments, *S. alterniflora* stem density was significantly greater in edge elevations, while both *S. virginica* percent cover and stem density in the edge elevation was greater. Burrowing crab populations were greater in the upper marsh and edge habitat of ungrazed treatments, while significantly greater in most of the middle marsh habitats of the grazed treatment. Size of burrowing crabs was generally significantly greater in ungrazed treatments. *Cerithidea pliculosa* size decreased in grazed treatments, but population had an overall increase in grazed treatments. *Littoraria irrorata* had very few differences between treatments, although few specimens were found. *Melampus*

bidentatus populations were too small to evaluate thoroughly. Macroinvertebrate populations could be used to assess the overall health of grazed salt marshes.

DEDICATION

This thesis is dedicated to my little girl, Jordan. She has shown me, through boundless energy and endless love, that I can attain my every desire as long as she's behind me, waiting at the end of the day with a sweet smile and hug.

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I wish to thank my committee members: Dr. Thomas Linton for taking a chance on me, and for encouraging me; Dr. William Wardle for his advice and guidance, for being an admirable mentor, for allowing me to gain a wealth of knowledge through teaching, and for help purchasing research supplies; and Dr. Webb for helping me design my project, enduring lengthy discussions on experimental design and statistics, and providing indispensable field experience working in coastal environments. Each was invaluable throughout my graduate career as teacher, friend, and advisor.

Thanks to everyone that helped me with my research. Specifically, I would like to recognize undergraduate students Michelle Swearer and Pete Golod. They never complained about the heat and cold, mosquitoes, and the back-numbing crouching required to sample. Their enthusiasm drove me forward.

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Thanks to my family for their support, encouragement, time, and faith. Special thanks to my parents, Gary and Deloris Martin, for raising me to believe that I really can accomplish anything I set my mind to.

Special thanks goes out to Nicholas Knowles. I would never have had the time and motivation to finish this thesis if he hadn't been there. He spent many days helping me learn to organize, giving pep talks, listening to my concerns, encouraging me, and even babysitting. Nick kept me on track and kept me going.

Lastly, I would like to thank Jordan Lynn Martin for inspiring me to be more than I am. Everything I am, I owe to her.

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CHAPTER I

INTRODUCTION

Approximately 70% of the world's population lives in coastal zones (Cherfas 1990), so the preservation of productive salt marshes has become increasingly difficult. As the human population continues to increase, some food sources are becoming scarce. Overall oceanic productivity is greatly enhanced by the presence of the marsh habitat that protects abundant larval and juvenile organisms that are important to commercial and recreational fisheries. The elimination of salt marsh nursery habitats could significantly decrease the annual fisheries catch.

The abundant nutrient rich salt marsh habitats along the Texas Coast serve a variety of vital purposes. The dense shallow water stands of smooth cordgrass (*Spartina alterniflora*) provide a nursery ground in which juvenile crabs, shrimp, and fish find refuge from predators. Resident birds find the relatively undisturbed vegetated areas ideal for nesting and feeding, while migrants are supplied with prime habitat for resting and overwintering (Melvin and Webb 1998).

The nutrient levels within a salt marsh are relatively high, as a result of decaying plants, animal excrement, and other forms of detritus present. Rivers that feed into bay systems also provide additional nutrients to the marsh, sometimes resulting in algal blooms. An abundance of nutrients is essential to the maintenance of the salt marsh ecosystem.

Primary productivity within the salt marsh system is centered around its uniquely adapted vegetation. Many studies have confirmed that zonation is present in coastal salt marshes, with plant communities changing in response to tidal levels, salinity (water and soil), waterlogging, nitrogen, iron, and sulfide concentrations, competition with other plant species, or physical disturbances (Jeffries 1977, Mendelsohn 1979, Webb 1983, Bertness 1991, Wilson and Whittaker 1995). The lowest zones of the marsh (which are submerged during high tide) are

This thesis follows the style and format of Ecology.

dominated by *Spartina alterniflora*, which is highly tolerant of water salinity and flooding (Bertness 1992). As elevation increases, the plant species become more varied in response to decreasing tidal flooding and increasing interstitial water salinity. Stands of plants present at the higher elevations include a mixture of *Spartina alterniflora* and species that are tolerant of high soil interstitial water salinity and less tolerant of tidal flooding, such as *Salicornia virginica* and *Batis maritima*, with the density of *S. alterniflora* decreasing steadily with increasing elevation (White et al. 1978, Mendelssohn 1979). Although *Salicornia virginica* and *Batis maritima* occur at middle to high elevations and at high salinities, they are inhibited from growth in tidal flat areas due to the high salinity present in the soil (Pennings and Callaway 1992).

Invertebrate populations within salt marshes are directly influenced by the presence (or absence), and type of vegetation. The burrowing activity of fiddler crabs (*Uca* spp.) helps to aerate and drain the soil around *Spartina alterniflora*, and the presence of the crabs has been shown to increase plant productivity. The root mass of the grass, in turn, provides structural support to crab burrows and the plants' shoots provide protection from predators (Bertness 1985, 1992, Nomann and Pennings 1998). *Uca* spp. concentrations, therefore, have been found to correlate positively with plant population density (Mouten and Felder 1996). Bertness (1985) suggested that *S. alterniflora* and *Uca* spp. are extremely dependent upon each other. The *S. alterniflora* would lose as much as 47% above ground biomass without the fiddler crabs, and in some soils, the crabs may not be able to maintain burrow integrity without the *S. alterniflora* root and rhizome mats as support.

The macroinvertebrate communities, much like the plants, have distinct areas of habitat preference. The snails *Cerithidea pliculosa* and *Melampus bidentatus* are usually both present on the marsh mud substrate. *C. pliculosa* can endure long periods of tidal submersion and may be present throughout the lower marsh, while the less submersion-tolerant *M. bidentatus* is restricted to the highest intertidal areas (Britton and Morton 1989). Another snail, *Littoraria*

irrorata, tends to avoid the ground and is usually found crawling or resting on *S. alterniflora* shoots (Britton and Morton 1989).

Although there are many possible reasons for salt marsh habitat loss, major contributors to the problem could be localized herbivory and vertebrate trampling. Feeding snow geese have been reported to cause a 66% loss of *Spartina alterniflora* in a middle Atlantic marsh (Smith 1983), while grazing nutria initiated a 30% loss in plants adjacent to Pearl River, Louisiana (Taylor and Grace 1995). Reimold et al. (1975) performed an experiment on ungulate herbivory in Georgia salt marshes and found that a natural marsh which was never grazed produced more than twice the amount of above ground biomass per unit area annually than a grazed marsh. They also determined that more fiddler crabs per unit area were present in the natural marsh than in the grazed marsh. Turner (1987) found that there were significantly fewer *Littorina irrorata* present after simulated trampling events. These findings suggest that cattle grazing has a negative effect on salt marsh flora and fauna.

Salt marshes provide a unique habitat that cannot be readily restored if damaged. Therefore, activities having negative effects on these areas should be identified and quantified. The macroinvertebrates and plant communities present are key indicators of the overall health and stability of a marsh, and any difference in these populations between a cattle-free natural marsh, and one with cattle activity should be determined.

STUDY SITE

The study was conducted on Texas A&M University at Galveston property located on the West End of Galveston Island, Galveston County, Texas. The study plots are directly adjacent to Snake Island Cove on the bayside of the island (Figure 1), at 29° 09' 02" N Latitude and 94° 49' 19" W Longitude. The property includes an uninterrupted expanse of historically cattle-grazed, intertidal salt marsh habitat, the dominant vegetation of which is *Spartina alterniflora*. The upper elevation of the marsh is vegetated by a mixture of *Spartina alterniflora*, *Salicornia virginica*, *Salicornia bigelovii* and *Batis maritima* and adjoins a non-vegetated high tidal flat.

OBJECTIVES

1. To determine the effects of cattle activity on height, percent cover, and stem density of salt marsh vegetation (*Spartina alterniflora*, *Salicornia virginica*, *Salicornia bigelovii*, and *Batis maritima*).
2. To determine the effects of cattle activity on population density and burrow size of fiddler and marsh crabs (*Uca* spp. and *Sesarma cinereum*).
3. To determine the effects of cattle activity on population density and body size of horn snails (*Cerithidea pliculosa*), marsh periwinkles (*Littoraria irrorata*), and salt marsh snails (*Melampus bidentatus*).

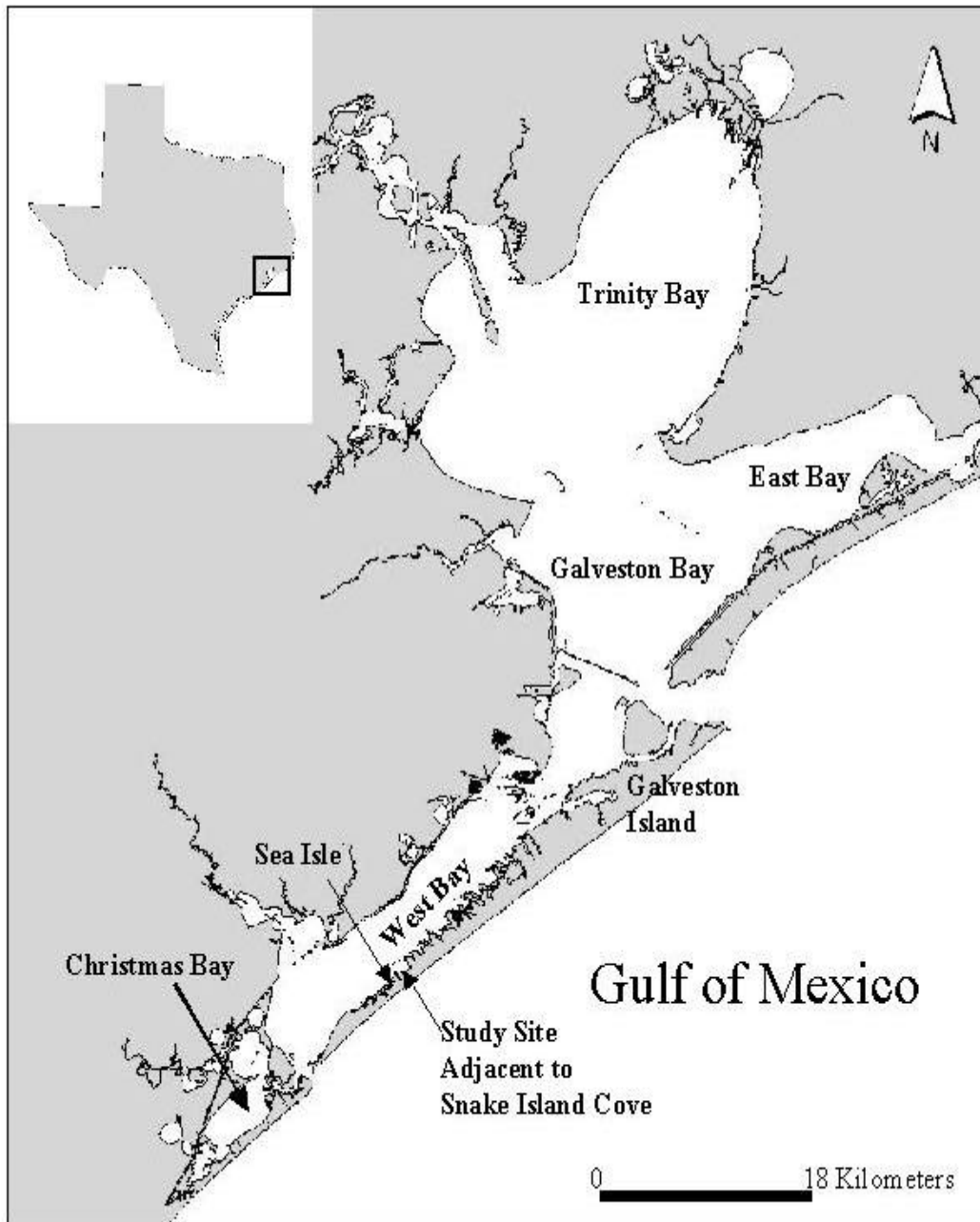


Figure 1. Location of the study site on the West End of Galveston Island, Galveston, Texas, adjacent to Snake Island Cove.

CHAPTER II

VEGETATION DIFFERENCES BETWEEN GRAZED AND UNGRAZED SALT MARSH ELEVATION ZONES

INTRODUCTION

Texas coastal salt marshes are dominated by *Spartina alterniflora* (smooth cordgrass) at lower tidal elevations and are typically inundated by water, with species mixing occurring as elevation increases to include *Salicornia virginica*, *Batis maritima*, and occasionally *Salicornia bigelovii* (Britton and Morton 1989). A high tidal flat with elevated soil salinity that does not encourage vegetation growth may separate the tidal salt marsh from the upland areas (Pennings and Callaway 1992). The combination of these habitats (tidal salt marsh, high tidal flats, and uplands) is a fragile and vital link in the estuarine ecosystem. The vegetation provides food, shelter, and substrate to many organisms, from the seasonal migrant bird to benthic microorganisms.

Macroinvertebrates like fiddler crabs (*Uca* spp.) and *Sesarma* spp. (marsh crabs) have been found to exist mutualistically with *S. alterniflora* (Mouten, Jr. and Felder 1996). Bertness (1992) conducted research on how crabs and mussels aid in cordgrass success. Crabs accelerate belowground debris breakdown, therefore nutrient input aboveground is not as vital for vegetation growth. In fact, when peat accumulates, soils become waterlogged, creating anaerobic conditions which stunt the growth of *Spartina*. Also, mussels and crabs provide nitrogen through feces, which the *Spartina* utilize by uptake through the roots (Montague 1980, Bertness 1992).

Fiddler crabs benefit from the structural support that *S. alterniflora* provides to their burrows which are excavated within and among the dense root mats (Bertness 1985, Bertness 1992, Nomann and Pennings 1998). Although marsh crabs are primarily herbivorous, they rely heavily on the marsh vegetation for nutritive needs (Seiple and Salmon 1982). In addition, the

snails *Littoraria irrorata*, *Cerithidea pliculosa*, and *Melampus bidentatus* utilize marsh vegetation for cover (to avoid predation and desiccation), direct feeding, feeding on other organisms attached to the plant surfaces, and as a substrate to escape, or limit, exposure to flooding during extremely high tides (Kerwin 1972, Hamilton 1976, Stiven and Hunter 1976, Price 1980, Warren 1985, Britton and Morton 1989, McGuinness 1994, Graca et al. 2000). Because these species of crabs and snails are highly dependent upon the presence of vegetation, maintenance of coastal marshes is necessary to ensure their survival.

A variety of studies have been conducted to assess the impacts of grazing within salt marsh ecosystems. One such study involved feral ponies in a coastal North Carolina salt marsh. The study suggests a significantly lower level of surface and subsurface deposit feeders in grazed areas in response to lower organic material input due to the uptake of nutrients by the ponies (Reader and Craft 1999). The same study revealed a significant decrease in aboveground biomass due to grazing.

Researchers investigated the impacts of clipping, burning, trampling, and grazing by feral horses on a *S. alterniflora* marsh on Cumberland Island National Seashore in Georgia (Turner 1987). Net aboveground primary productivity (NAPP) was not changed by clipping. It decreased 35% in response to burning and trampling, and decreased 25% when average grazing (kept at a moderate level through the year) occurred. Heavy grazing resulted in an almost 88% reduction of NAPP. The study indicates that not only is grazing an impact, but the rate of grazing is a key factoring in determining how the ecosystem is impacted by the presence of grazers. On Assateague Island, along the Maryland/Virginia coast, salt marsh vegetation diversity increased as grazing pressure by horses was introduced. A few of the newly introduced species were eliminated upon complete removal of the grazers, as community structures are driven by competition (Furbish and Albano 1994).

Long-term effects of grazing by cattle in salt marshes consists of increased plant diversity, movement of invertebrate deposit feeders to upper marsh areas, and reduced litter production (Andresen et al. 1990). Upon relief from intense grazing, it was theorized that the

invertebrate species that had been forced into higher than normal elevations would rapidly return to the lower marsh habitat in response to increased plant height and density.

Grazing by domestic sheep in Tasmania was shown to cause a significantly greater decrease in plant cover and vegetation species diversity when compared to natural grazers and rabbits, and recovery of the natural system was achieved most rapidly by complete removal of all grazers (Bridle and Kirkpatrick 1999). Bakker (1985) found that on the island of Schiermonnikoog in The Netherlands, cattle grazing and trampling stimulated plant species diversity from a single dominant species to 3 or more species. Litter decomposition was accelerated due to trampling, as well. When soil was bared during trampling events, new species were allowed easier access to colonize. Bakker also found that it takes about five to ten years for a lower marsh system that has had grazers removed to firmly retain dominance by a single plant species again. This suggests that heavily grazed systems can be returned to their natural state through proper management.

Ranwell (1961) found that in Bridgwater Bay, England, cattle grazing enhanced *Spartina* spp. cover due to tillering, which resulted often in plants being trampled into the soil by the cattle. However, this also allowed invasion by other species. He found that the ungrazed plots contained greater populations of *Atriplex hastate*, which grows well among *Spartina* wrack. The fact that *Spartina* wrack was greatly reduced in grazed areas is likely attributed to clipping as a result of herbivory. Therefore, not only does the vegetation respond to trampling through increased species diversity, but the ingestion of herbaceous material has the direct impact of removing the natural material that would eventually form *Spartina* wrack. This experiment allowed for equal seedling introduction as the experimental plots were small in contrast to the large available ungrazed system surrounding it. Lack of seed availability, therefore, was not the cause for species differentiation in experimental plots.

A previous graduate study conducted in the same area on Galveston Island used in the present study examined the effects of cattle grazing on vegetation and coastal avian species (Yeargan 2001). Significantly greater plant biomass, cover, and height were found within the

ungrazed treatments, suggesting that recovery of grazed salt marshes begins immediately after cattle grazing is excluded. The ungrazed treatments, established in previously grazed areas, appeared to have been effectively restored to their natural state by cattle exclusion.

Environmental factors constantly present, in conjunction with herbivory, afford challenges to survival of marsh plants as well. Simulated clipping in a Louisiana salt marsh, in conjunction with flooding by salt water, was shown to suppress plant growth and often resulted in death (Grace and Ford 1996). Patches of newly bared soil have been shown to quickly increase in soil salinity due to solar radiation on the exposed surface, as shading by plant cover is eliminated (Bertness et al. 1992). *Salicornia* spp. rapidly colonize bare patches (even those with extremely high soil salinity) due to ease of germination of the many seeds produced (Bertness 1992).

The overall health of the salt marsh system hinges on the abundance and distribution of the types of vegetation found within it. Disruption to the natural functioning of salt marshes may cause damage throughout the entire ecosystem, as invertebrates depend on the vegetation for food, shelter, and habitat. Removal or change in diversity of vegetation may result in decreased or shifting populations of invertebrate communities and may impede the higher trophic levels that depend on these organisms (such as shorebirds, raccoons, fish, predatory crabs, etc.). The objective of this chapter is to determine the effects of cattle activity on salt marsh vegetation (*Spartina alterniflora*, *Salicornia virginica*, *Salicornia bigelovii*, and *Batis maritima*).

METHODS

Data were collected from August 2000 through April 2001. Sampling was conducted seasonally at low tide to facilitate data collection from the marsh surface. The seasons are defined for this area as: summer (July-September), fall (October-December), winter (January-March), and spring (April-June).

Cattle have been excluded by fencing some areas of the marsh, but not others. Barriers to cattle consist of fences of five-strand barbed wire, wooden posts, and metal t-posts constructed in the spring of 1998. Three paired plots, cattle (experimental, hereafter referred to as grazed)

and non-cattle (control, hereafter referred to as ungrazed) were established, each of which is approximately 50 meters wide (east to west) and varies from 100 to 200 meters in length (north to south) (Figure 2). The dimensions of the experimental plots (with cattle) were marked with wooden stakes. The following five marsh elevation zones were sampled in each plot: 1. high tide flats (areas of little or no vegetation), 2. marsh/tidal flat edge (intermediate zone between the tidal flats and upper-middle marsh, characterized by the greatest plant species diversity), 3. upper marsh (between the middle marsh and the marsh/tidal flat edge, characterized predominately as *Spartina alterniflora* and *Salicornia virginica* habitat), 4. middle marsh (predominantly *Spartina alterniflora*), and 5. lower marsh (areas above the line where the marsh meets the bay; usually only consisting of *Spartina alterniflora*). Four samples were taken seasonally within each of the five elevation zones of each plot, resulting in a total of 120 samples taken each season.

The cattle were removed during the winter season pending sale of the property. However, the hoofprints, feces, urine, etc. were evident throughout the study, therefore the study continued as the impacts due to grazing by cattle remained.

A 0.5 square meter (1.0 X 0.5 m) frame was placed at the northeast corner of each of four permanent wooden stakes in each elevation zone, to establish a sampling quadrat. Plant communities in each quadrat were characterized as follows: The five tallest plant heights, percent cover, and stem density (shoot population) of each plant species present was recorded for each quadrat in each of the five elevation zones and grazing treatments. The measurements for each species were combined for a total percent vegetation cover and stem density, and each plant species was analyzed as well.

Data were analyzed for each season by elevation zone using the null hypothesis that there was no difference in tallest plant heights, percent cover, and stem density of the target species in grazed and ungrazed treatments. A two-factor ANOVA (grazing treatment and site) was used to determine if there were significant differences ($\alpha=0.05$) in these measurements using the "Proc GLM" procedures in SAS to test the grazing treatment and site effects. The GLM model used was: "Dependent Variable" = Treatment Site Treatment X Site Error.

RESULTS

Maximum Vegetation Heights

The mean maximum heights of vegetation within each zone were calculated for each season (Table 1). All significant differences in heights for every season were due to greater

Table 1. Mean maximum heights \pm SE of vegetation at five elevations (high tide flats, edge, upper, middle, lower), by grazing treatments (grazed and ungrazed) in a Galveston Island salt marsh in summer and fall 2000, and winter and spring 2001, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$. n.p. = not present, * = significant at $\alpha=0.05$

VEGETATION TYPE BY ELEVATION	MAXIMUM HEIGHTS (SUMMER 2000)			MAXIMUM HEIGHTS (FALL 2000)		
	Grazed MEAN \pm SE	Ungrazed MEAN \pm SE	p-value	Grazed MEAN \pm SE	Ungrazed MEAN \pm SE	p-value
HIGH TIDE FLATS						
<i>Spartina alterniflora</i>	n.p.	14.5cm	p=N/A	10.3cm	n.p.	p=N/A
<i>Salicornia virginica</i>	13.0cm \pm 1.7cm	11.1cm \pm 1.0cm	p=0.418	13.7cm \pm 1.0cm	9.9cm	p=0.263
<i>Salicornia bigelovii</i>	n.p.	n.p.	n.p.	12.7cm \pm 1.3cm	12.0cm \pm 2.0cm	p=0.774
EDGE						
<i>Spartina alterniflora</i>	12.8cm \pm 1.5cm	37.0cm\pm4.0cm	p<0.001*	11.3cm \pm 1.6cm	30.0cm\pm4.5cm	p=0.001*
<i>Salicornia virginica</i>	15.2cm \pm 1.0cm	21.6cm\pm1.4cm	p<0.001*	13.7cm \pm 1.9cm	26.4cm\pm1.9cm	p<0.001*
<i>Salicornia bigelovii</i>	n.p.	n.p.	n.p.	14.1cm \pm 3.6cm	16.6cm \pm 0.7cm	p=0.590
<i>Batis maritima</i>	n.p.	22.2cm \pm 9.3cm	p=N/A	n.p.	17.7cm \pm 5.7cm	p=N/A
UPPER						
<i>Spartina alterniflora</i>	30.8cm \pm 1.6cm	56.7cm\pm3.0cm	p<0.001*	31.1cm \pm 1.3cm	47.9cm\pm2.7cm	p<0.001*
<i>Salicornia virginica</i>	28.8cm \pm 1.2cm	47.6cm\pm2.2cm	p<0.001*	30.0cm \pm 1.6cm	42.1cm\pm2.0cm	p<0.001*
<i>Salicornia bigelovii</i>	n.p.	32.3cm \pm 1.7cm	p=N/A	n.p.	32.0cm	p=N/A
<i>Batis maritima</i>	n.p.	6.8cm	p=N/A	n.p.	10.2cm	p=N/A
MIDDLE						
<i>Spartina alterniflora</i>	39.8cm \pm 1.9cm	51.2cm\pm4.8cm	p<0.002*	37.6cm \pm 1.7cm	50.1cm\pm5.9cm	p<0.001*
<i>Salicornia virginica</i>	34.3cm \pm 1.0cm	45.9cm\pm2.8cm	p<0.001*	33.5cm \pm 1.0cm	41.0cm\pm1.9cm	p=0.002*
LOWER						
<i>Spartina alterniflora</i>	48.0cm \pm 1.2cm	58.1cm \pm 5.9cm	p=0.053	49.2cm \pm 1.3cm	49.7cm \pm 5.6cm	p=0.935
<i>Salicornia virginica</i>	43.5cm \pm 6.7cm	52.3cm \pm 2.4cm	p=0.191	38.2cm \pm 4.6cm	50.1cm \pm 2.2cm	p=0.051

Table 1 Continued.

VEGETATION TYPE BY ELEVATION	MAXIMUM HEIGHTS (WINTER 2001)			MAXIMUM HEIGHTS (SPRING 2001)		
	Grazed MEAN±SE	Ungrazed MEAN±SE	p-value	Grazed MEAN±SE	Ungrazed MEAN±SE	p-value
HIGH TIDE FLATS						
<i>Spartina alterniflora</i>	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
<i>Salicornia virginica</i>	13.5cm±2.0cm	12.9cm	p=0.902	12.4cm±3.1cm	12.4cm	p=0.998
<i>Salicornia bigelovii</i>	10.8cm±3.0cm	11.2cm±3.2cm	p=0.931	8.4cm±1.4cm	11.8cm±2.2cm	p=0.254
EDGE						
<i>Spartina alterniflora</i>	10.8cm±1.8cm	26.6cm±2.1cm	p<0.001*	10.5cm±1.8cm	23.9cm±2.1cm	p=0.002*
<i>Salicornia virginica</i>	13.7cm±1.7cm	22.8cm±1.5cm	p=0.002*	10.8cm±1.7cm	22.7cm±1.5cm	p<0.001*
<i>Salicornia bigelovii</i>	18.1cm±0.8cm	14.3cm±1.4cm	p=0.060	14.5cm±0.4cm	14.3cm±2.1cm	p=0.871
<i>Batis maritima</i>	n.p.	15.2cm±2.7cm	p=N/A	n.p.	13.6cm±2.9cm	p=N/A
UPPER						
<i>Spartina alterniflora</i>	32.6cm±1.0cm	47.6cm±2.3cm	p<0.001*	40.1cm±1.2cm	47.5cm±1.5cm	p<0.001*
<i>Salicornia virginica</i>	29.6cm±1.7cm	49.3cm±5.1cm	p<0.001*	33.4cm±0.8cm	55.5cm±4.5cm	p<0.001*
<i>Salicornia bigelovii</i>	n.p.	1.5cm	p=N/A	n.p.	n.p.	n.p.
<i>Batis maritima</i>	n.p.	11.64cm	p=N/A	n.p.	14.7cm	p=N/A
MIDDLE						
<i>Spartina alterniflora</i>	36.5cm±1.6cm	45.9cm±4.6cm	p=0.005*	46.1cm±2.2cm	51.3cm±3.8cm	p=0.044*
<i>Salicornia virginica</i>	33.1cm±1.2cm	48.8cm±4.1cm	p<0.001*	37.5cm±1.2cm	56.1cm±3.7cm	p<0.001*
LOWER						
<i>Spartina alterniflora</i>	47.2cm±1.0cm	57.3cm±2.9cm	p=0.005*	52.7cm±1.0cm	62.3cm±2.2cm	p<0.001*
<i>Salicornia virginica</i>	37.5cm±2.4cm	44.0cm±6.6cm	p=0.544	35.1cm±2.2cm	47.5cm±5.5cm	p=0.187

heights in the ungrazed treatments. *Spartina alterniflora* and *Salicornia virginica* heights were significantly greater in the ungrazed treatments for every season in the marsh edge, upper marsh, and middle marsh. *Spartina alterniflora* heights were also significantly greater in the ungrazed treatments for the winter 2001 and spring 2001 seasons.

Percent Vegetation Cover and Stem Density

In summer 2000, statistically significant differences in grazed versus ungrazed treatments varied for total percent cover, total stem density, as well as the percent cover and stem density for each species (number of stems/m²) (Table 2). There was no significant difference in stem density between grazed and ungrazed treatments in the tidal flats, but the percent cover for total vegetation and *Salicornia virginica* were significantly greater in the grazed treatments. There were no significant differences for *Spartina alterniflora* even though *S. alterniflora* was not present in the grazed treatment. *Salicornia bigelovii* was not present in either treatment.

In the marsh edge, total vegetation and *Salicornia virginica* were significantly higher in the ungrazed treatment for both percent cover and stem density. *Spartina alterniflora* had significantly greater numbers of stems in the ungrazed treatment as well, however, the percent cover was not measurably different. No significant differences were found for *Batis maritima* even though *B. maritima* was not present in the grazed treatment. *Salicornia bigelovii* was not present in either treatment.

The upper marsh elevation zone had a significantly higher percent coverage for total vegetation in the ungrazed treatment, yet stem density was greater in the grazed treatment. The ungrazed treatment showed a significantly higher percent cover for *Spartina alterniflora*, but the stem density very closely mirrored that of the grazed treatment. There was no significant difference in either parameter for *Salicornia virginica*, *Salicornia bigelovii*, or *Batis maritima* in the upper marsh (with no *S. bigelovii* or *Batis maritima* in the grazed treatments).

The middle marsh contained significant differences in the percent coverage of the total vegetation and *Spartina alterniflora*, with significantly greater cover in the ungrazed treatments.

Table 2. Mean cover and stem density \pm SE of vegetation at five elevations (high tide flats, edge, upper, middle, lower), by grazing treatments (grazed and ungrazed) in a Galveston Island salt marsh in summer 2000, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$. n.p. = not present, * = significant at $\alpha=0.05$

VEGETATION TYPE BY ELEVATION	PERCENT COVER (SUMMER 2000)			STEM DENSITY (SUMMER 2000)		
	Grazed MEAN \pm SE	Ungrazed MEAN \pm SE	p-value	Grazed MEAN \pm SE	Ungrazed MEAN \pm SE	p-value
HIGH TIDE FLATS						
Total vegetation	2.8%\pm1.4%	0.8% \pm 0.4%	p=0.033*	10.2 \pm 5.0	6.2 \pm 4.0	p=0.373
<i>Spartina alterniflora</i>	n.p.	0.2% \pm 0.2%	p=0.331	n.p.	0.2 \pm 0.2	p=0.331
<i>Salicornia virginica</i>	2.8%\pm1.4%	0.6% \pm 0.4%	p=0.020*	10.2 \pm 5.0	6.0 \pm 4.0	p=0.354
<i>Salicornia bigelovii</i>	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
EDGE						
Total vegetation	21.9% \pm 4.8%	69.4%\pm6.2%	p<0.001*	186.6 \pm 51.8	894.6\pm160.8	p<0.001*
<i>Spartina alterniflora</i>	9.1% \pm 3.5%	18.1% \pm 6.3%	p=0.082	74.6 \pm 24.0	159.4\pm54.4	p=0.027*
<i>Salicornia virginica</i>	12.8% \pm 3.4%	50.3%\pm8.7%	p<0.001*	112.2 \pm 43.2	731.6\pm189.6	p<0.001*
<i>Salicornia bigelovii</i>	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
<i>Batis maritima</i>	n.p.	1.1% \pm 0.7%	p=0.146	n.p.	3.6 \pm 2.8	p=0.239
UPPER						
Total vegetation	60.0% \pm 5.3%	90.4%\pm2.1%	p<0.001*	726.6\pm77.4	596.6 \pm 46.2	p=0.045*
<i>Spartina alterniflora</i>	36.2% \pm 4.2%	60.8%\pm5.6%	p<0.001*	435.6 \pm 63.4	425.6 \pm 32.6	p=0.842
<i>Salicornia virginica</i>	23.8% \pm 7.3%	29.0% \pm 6.2%	p=0.308	290.8 \pm 107.8	169.4 \pm 66.8	p=0.092
<i>Salicornia bigelovii</i>	n.p.	0.6% \pm 0.4%	p=0.156	n.p.	1.4 \pm 1.0	p=0.174
<i>Batis maritima</i>	n.p.	0.1% \pm 0.1%	p=0.331	n.p.	0.2 \pm 0.2	p=0.331
MIDDLE						
Total vegetation	79.3% \pm 3.4%	95.5%\pm0.8%	p<0.001*	780.2 \pm 88.6	878.0 \pm 123.6	p=0.227
<i>Spartina alterniflora</i>	43.5% \pm 6.2%	63.7%\pm9.7%	p=0.006*	357.6 \pm 52.8	378.8 \pm 55.0	p=0.634
<i>Salicornia virginica</i>	35.8% \pm 8.6%	31.8% \pm 9.7%	p=0.563	422.6 \pm 133.4	499.2 \pm 174.0	p=0.466
LOWER						
Total vegetation	79.6% \pm 3.2%	85.3% \pm 2.5%	p=0.143	594.2 \pm 56.6	576.6 \pm 53.4	p=0.782
<i>Spartina alterniflora</i>	76.3%\pm3.1%	65.3% \pm 8.1%	p=0.022*	582.8\pm51.4	398.6 \pm 28.2	p=0.002*
<i>Salicornia virginica</i>	3.3% \pm 2.2%	20.1%\pm7.7%	p=0.006*	11.4 \pm 7.0	178.2\pm70.2	p=0.003*

The stem density was similar between treatments, however. No significant differences were found for *Salicornia virginica*.

The lower marsh elevation zone was significantly higher in percent cover and stem density of *Spartina alterniflora* for the grazed treatments, while *Salicornia virginica* was higher in percent cover and stem density for the ungrazed treatments. Total vegetation was not significantly different for either percent coverage or the number of stems for overall species.

For fall 2000, there were no significant differences between treatments for the high tide flats (Table 3). The marsh edge was significantly higher in the ungrazed treatment for total vegetation percent cover and stem density, *Salicornia virginica* percent cover and stem density, and *Spartina alterniflora* stem density. *Salicornia bigelovii* percent coverage was significantly greater in the grazed treatment, but the stem density was not significantly different. *Batis maritima* was not significantly different between treatments, even though *B. maritima* was not present in the grazed treatment. The percent cover of *Spartina alterniflora* was not measurably different between the treatments.

There were only two significant differences in the upper marsh. The total vegetation and *Salicornia virginica* percent cover were both higher in the ungrazed treatments. None of the stem densities was significant, nor were the percent cover measurements for *Spartina alterniflora*, *Salicornia bigelovii*, and *Batis maritima* (*Salicornia bigelovii* and *Batis maritima* were not present in grazed plots).

In the middle marsh, only the stem density for total vegetation was significantly greater in the ungrazed areas. No significant difference was revealed for percent coverage of any vegetation, nor for stem density of *Spartina alterniflora* or *Salicornia virginica*.

The lower marsh elevation zone was significantly higher in percent cover of total vegetation and *Salicornia virginica*, and stem density of *S. virginica*, for the ungrazed treatment. The grazed treatment was significantly higher in the number of *Spartina alterniflora* stems. There was no significant difference for *Spartina alterniflora* percent cover or the total vegetation stem density.

Table 3. Mean cover and stem density \pm SE of vegetation at five elevations (high tide flats, edge, upper, middle, lower), by grazing treatments (grazed and ungrazed) in a Galveston Island salt marsh in fall 2000, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$. n.p. = not present, * = significant at $\alpha=0.05$

VEGETATION TYPE BY ELEVATION	PERCENT COVER (FALL 2000)			STEM DENSITY (FALL 2000)		
	Grazed MEAN \pm SE	Ungrazed MEAN \pm SE	p-value	Grazed MEAN \pm SE	Ungrazed MEAN \pm SE	p-value
HIGH TIDE FLATS						
Total vegetation	2.5% \pm 1.4%	1.6% \pm 1.0%	p=0.501	9.8 \pm 6.6	6.0 \pm 3.6	p=0.549
<i>Spartina alterniflora</i>	0.04% \pm 0.04%	n.p.	p=0.331	0.4 \pm 0.4	n.p.	p=0.331
<i>Salicornia virginica</i>	1.5% \pm 1.0%	0.2% \pm 0.2%	p=0.153	7.0 \pm 5.2	2.0 \pm 2.0	p=0.331
<i>Salicornia bigelovii</i>	0.9% \pm 0.6%	1.4% \pm 0.9%	p=0.562	2.6 \pm 1.6	4.0 \pm 2.4	p=0.520
EDGE						
Total vegetation	20.9% \pm 4.4%	62.3%\pm5.2%	p<0.001*	163.6 \pm 55.4	860.8\pm139.6	p<0.001*
<i>Spartina alterniflora</i>	8.6% \pm 3.8%	17.5% \pm 6.1%	p=0.062	68.6 \pm 38.2	203.2\pm68.8	p=0.035*
<i>Salicornia virginica</i>	8.8% \pm 4.7%	41.8%\pm8.8%	p<0.001*	80.4 \pm 52.2	648.6\pm185.4	p=0.004*
<i>Salicornia bigelovii</i>	3.6%\pm1.6%	1.3% \pm 0.9%	p=0.023*	14.6 \pm 7.4	5.6 \pm 3.8	p=0.136
<i>Batis maritima</i>	n.p.	1.3% \pm 0.9%	p=0.174	n.p.	3.4 \pm 2.6	p=0.222
UPPER						
Total vegetation	66.5% \pm 5.0%	89.0%\pm2.4%	p<0.001*	703.2 \pm 98.0	813.2 \pm 38.2	p=0.064
<i>Spartina alterniflora</i>	41.1% \pm 6.1%	46.5% \pm 8.1%	p=0.477	358.6 \pm 63.8	425.0 \pm 78.4	p=0.388
<i>Salicornia virginica</i>	25.4% \pm 8.2%	42.1%\pm7.5%	p=0.025*	344.6 \pm 135.8	386.8 \pm 94.2	p=0.669
<i>Salicornia bigelovii</i>	n.p.	0.1% \pm 0.1%	p=0.331	n.p.	0.2 \pm 0.2	p=0.331
<i>Batis maritima</i>	n.p.	0.3% \pm 0.3%	p=0.331	n.p.	1.2 \pm 1.2	p=0.331
MIDDLE						
Total vegetation	45.7% \pm 44.9%	91.9% \pm 1.9%	p=0.332	750 \pm 94.6	1063.4\pm141.4	p=0.014*
<i>Spartina alterniflora</i>	43.6% \pm 8.0%	54.2% \pm 10.1%	p=0.206	389.2 \pm 78.0	442.6 \pm 78.2	p=0.385
<i>Salicornia virginica</i>	37.0% \pm 8.1%	37.8% \pm 11.0%	p=0.931	450.6 \pm 131.6	620.8 \pm 203.2	p=0.279
LOWER						
Total vegetation	83.2% \pm 2.5%	89.8%\pm2.3%	p=0.047*	730.8 \pm 47.2	772.6 \pm 73.2	p=0.583
<i>Spartina alterniflora</i>	80.8% \pm 1.9%	69.6% \pm 6.9%	p=0.083	723.6\pm45.0	536.6 \pm 62.4	p=0.005*
<i>Salicornia virginica</i>	2.3% \pm 1.4%	20.3%\pm7.3%	p=0.007*	7.2 \pm 4.4	235.8\pm105.0	p=0.009*

Table 4. Mean cover and stem density \pm SE of vegetation at five elevations (high tide flats, edge, upper, middle, lower), by grazing treatments (grazed and ungrazed) in a Galveston Island salt marsh in winter 2001, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$. n.p. = not present, * = significant at $\alpha=0.05$

VEGETATION TYPE BY ELEVATION	PERCENT COVER (WINTER 2001)			STEM DENSITY (WINTER 2001)		
	Grazed MEAN \pm SE	Ungrazed MEAN \pm SE	p-value	Grazed MEAN \pm SE	Ungrazed MEAN \pm SE	p-value
HIGH TIDE FLATS						
Total vegetation	3.1% \pm 1.5%	1.4% \pm 0.9%	p=0.137	18.0 \pm 10.2	7.6 \pm 4.6	p=0.228
<i>Spartina alterniflora</i>	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
<i>Salicornia virginica</i>	1.7% \pm 1.2%	0.4% \pm 0.4%	p=0.264	7.6 \pm 5.2	3.6 \pm 3.6	p=0.497
<i>Salicornia bigelovii</i>	1.4% \pm 0.8%	1.0% \pm 0.6%	p=0.551	10.4 \pm 6.2	4.0 \pm 2.6	p=0.247
EDGE						
Total vegetation	23.5% \pm 4.7%	66.1%\pm5.0%	p<0.001*	242.6 \pm 59.2	1093.6\pm163.4	p<0.001*
<i>Spartina alterniflora</i>	4.7% \pm 2.4%	14.0% \pm 5.5%	p=0.061	90.6 \pm 53.8	157.6 \pm 61.4	p=0.307
<i>Salicornia virginica</i>	12.0% \pm 5.7%	49.0%\pm6.9%	p<0.001*	87.0 \pm 53.8	922.6\pm203.4	p<0.001*
<i>Salicornia bigelovii</i>	6.8%\pm3.1%	0.8% \pm 0.6%	p<0.001*	65.0\pm30.2	5.8 \pm 4.0	p<0.001*
<i>Batis maritima</i>	n.p.	2.3% \pm 1.4%	p=0.084	n.p.	7.6 \pm 4.2	p=0.096
UPPER						
Total vegetation	71.1% \pm 5.4%	92.3%\pm1.2%	p<0.001*	914.2 \pm 87.4	1060.6 \pm 91.2	p=0.081
<i>Spartina alterniflora</i>	46.7% \pm 3.9%	50.7% \pm 6.9%	p=0.596	540.8 \pm 60.4	504.2 \pm 71.2	p=0.632
<i>Salicornia virginica</i>	24.4% \pm 6.6%	41.2%\pm7.4%	p=0.038*	373.4 \pm 128.0	553.0 \pm 150.0	p=0.191
<i>Salicornia bigelovii</i>	n.p.	0.04% \pm 0.04%	p=0.331	n.p.	0.8 \pm 0.8	p=0.331
<i>Batis maritima</i>	n.p.	0.4% \pm 0.4%	p=0.331	n.p.	2.6 \pm 2.6	p=0.331
MIDDLE						
Total vegetation	86.8% \pm 1.3%	91.5%\pm1.4%	p=0.029*	1091.6 \pm 71.4	1333.4\pm100.0	p=0.010*
<i>Spartina alterniflora</i>	53.9% \pm 6.0%	58.8% \pm 9.4%	p=0.480	569.2 \pm 91.0	666.6 \pm 107.8	p=0.201
<i>Salicornia virginica</i>	32.9% \pm 5.8%	34.3% \pm 9.4%	p=0.855	522.4 \pm 153.6	666.6 \pm 197.8	p=0.336
LOWER						
Total vegetation	89.0% \pm 1.4%	86.9% \pm 2.2%	p=0.469	954.4 \pm 15.0	920.0 \pm 59.4	p=0.607
<i>Spartina alterniflora</i>	85.8%\pm1.7%	69.0% \pm 6.5%	p=0.012*	941.6\pm15.4	687.6 \pm 74.6	p<0.001*
<i>Salicornia virginica</i>	3.2% \pm 1.8%	17.9%\pm6.7%	p=0.033*	12.6 \pm 6.8	232.6\pm111.2	p=0.048*

In winter 2001, there were no significant differences in grazing treatments for the high tide flats (Table 4). For the marsh edge, the percent cover and stem density of the total vegetation and *Salicornia virginica* were significantly higher in the ungrazed treatment. *Salicornia bigelovii* was found to be significantly greater in grazed treatments for percent cover and stem density. There were no significant differences in percent cover or stem density for *Spartina alterniflora* or *Batis maritima* (*B. maritima* not present in grazed treatment).

For upper marsh, the percent cover for the total vegetation and for *Salicornia virginica* were significantly higher in the ungrazed treatment. No significance was found for any measurement of *Spartina alterniflora*, *Salicornia bigelovii*, or *Batis maritima* (*S. bigelovii* and *B. maritima* were not present in grazed treatments). There were also no significant differences in the stem densities of total vegetation or *S. virginica*.

For the middle marsh elevation zone, the total vegetation percent cover and stem density were significantly greater in the ungrazed treatments. There were no significant differences for *Spartina alterniflora* and *Salicornia virginica*.

The lower marsh was significantly different for *Spartina alterniflora* (greater in grazed treatment) and *Salicornia virginica* (greater in ungrazed treatment) in both percent cover and stem density. There were no significant differences for total vegetation.

Spring 2001 showed no significant differences for the high tide flats (Table 5). The marsh edge was significantly greater in percent cover and stem density in the ungrazed treatment for total vegetation, *Spartina alterniflora*, and *Salicornia virginica*. *Salicornia bigelovii* was greater in the grazed treatment for percent cover and stem density. There were no significant differences in treatments for *Batis maritima* (*B. maritima* was not present in grazed areas).

The upper marsh elevation zone was only significant in one measurement. The total vegetation percent cover was greater for the ungrazed treatment. The total vegetation stem density and all measurements for *Spartina alterniflora*, *Salicornia virginica*, and *Batis maritima* were not found to significantly vary between treatments. In the middle marsh, total vegetation cover was significantly greater in the ungrazed treatment (with no significant difference in the

Table 5. Mean cover and stem density \pm SE of vegetation at five elevations (high tide flats, edge, upper, middle, lower), by grazing treatments (grazed and ungrazed) in a Galveston Island salt marsh in spring 2001, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$. n.p. = not present, * = significant at $\alpha=0.05$

VEGETATION TYPE BY ELEVATION	PERCENT COVER (SPRING 2001)			STEM DENSITY (SPRING 2001)		
	Grazed MEAN \pm SE	Ungrazed MEAN \pm SE	p-value	Grazed MEAN \pm SE	Ungrazed MEAN \pm SE	p-value
HIGH TIDE FLATS						
Total vegetation	1.2% \pm 0.7%	1.2% \pm 0.7%	p=0.954	14.8 \pm 8.6	12.2 \pm 8.2	p=0.779
<i>Spartina alterniflora</i>	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
<i>Salicornia virginica</i>	0.8% \pm 0.5%	0.4% \pm 0.4%	p=0.588	9.4 \pm 6.4	6.6 \pm 6.6	p=0.761
<i>Salicornia bigelovii</i>	0.5% \pm 0.3%	0.8% \pm 0.4%	p=0.477	5.6 \pm 3.4	5.6 \pm 4.6	p=1.000
EDGE						
Total vegetation	14.0% \pm 3.8%	61.6%\pm6.2%	p<0.001*	212.8 \pm 69.0	1264.2\pm195.2	p<0.001*
<i>Spartina alterniflora</i>	2.5% \pm 0.7%	9.9%\pm3.9%	p=0.022*	17.2 \pm 7.4	133.4\pm53.2	p=0.004*
<i>Salicornia virginica</i>	8.1% \pm 4.2%	50.0%\pm8.2%	p<0.001*	139.0 \pm 74.8	1120.0\pm229.4	p<0.001*
<i>Salicornia bigelovii</i>	3.3%\pm1.5%	0.4% \pm 0.3%	p<0.001*	56.6\pm26.6	3.6 \pm 3.2	p<0.001*
<i>Batis maritima</i>	n.p.	1.3% \pm 0.8%	p=0.082	n.p.	7.2 \pm 4.6	p=0.109
UPPER						
Total vegetation	74.7% \pm 5.3%	90.6%\pm1.9%	p<0.001*	1078.6 \pm 184.8	1062.4 \pm 125.4	p=0.882
<i>Spartina alterniflora</i>	49.6% \pm 4.4%	54.3% \pm 7.0%	p=0.517	509.2 \pm 45.2	515.8 \pm 70.8	p=0.930
<i>Salicornia virginica</i>	26.6% \pm 8.2%	35.9% \pm 7.9%	p=0.210	569.6 \pm 207.8	542.2 \pm 183.8	p=0.863
<i>Batis maritima</i>	n.p.	0.4% \pm 0.4%	p=0.331	n.p.	4.4 \pm 4.4	p=0.331
MIDDLE						
Total vegetation	91.1% \pm 1.6%	94.2%\pm1.4%	p=0.036*	1259.2 \pm 155.4	1178.4 \pm 126.4	p=0.592
<i>Spartina alterniflora</i>	53.5% \pm 9.7%	56.3% \pm 11.5%	p=0.742	501.6 \pm 86.6	556.6 \pm 106.0	p=0.260
<i>Salicornia virginica</i>	37.6% \pm 8.6%	37.9% \pm 10.8%	p=0.969	757.6 \pm 237.6	621.6 \pm 200.2	p=0.475
LOWER						
Total vegetation	95.3% \pm 0.7%	94.3% \pm 1.9%	p=0.634	867.4 \pm 27.0	1004.4 \pm 112.8	p=0.095
<i>Spartina alterniflora</i>	93.3%\pm1.0%	72.2% \pm 7.3%	p=0.002*	855.0\pm26.0	633.4 \pm 65.4	p=0.002*
<i>Salicornia virginica</i>	1.9% \pm 1.0%	22.0%\pm7.8%	p=0.003*	12.4 \pm 8.4	445.2\pm184.8	p=0.003*

stem density). There were no significant differences for treatments found for any measurement of *Spartina alterniflora* or *Salicornia virginica*.

The lower marsh had two species with significantly higher percent cover and stem densities. *Spartina alterniflora* was greater in the grazed treatments while *Salicornia virginica* was greater in the ungrazed treatment for both measurements. There were no significant differences in the total vegetation percent cover or stem density.

Site Interactions

Site interactions occurred at several marsh elevation zones for each of the plant species. Summer 2000 site interactions for *S. alterniflora* cover were found in the edge ($p=0.0005$), upper ($p<0.0001$), middle ($p=0.0003$), and lower ($p<0.0001$) elevations, site interactions for the stem density of *S. alterniflora* were in the edge ($p=0.0003$), upper ($p=0.0008$), and middle ($p=0.0171$), while the site interactions for the maximum heights of *S. alterniflora* were in the upper ($p=0.0005$) and middle ($p=0.0031$) elevations. Site interactions for *S. virginica* cover were found in the flats ($p<0.0001$), edge ($p=0.0358$), upper ($p<0.0001$), middle ($p=0.0002$), and lower ($p=0.0007$) elevations, site interactions for the stem density of *S. virginica* were in the flats ($p=0.0002$), edge ($p=0.0245$), upper ($p<0.0001$), middle ($p=0.0002$), and lower ($p=0.0028$), while the site interaction for the maximum heights of *S. virginica* was in the upper ($p=0.0060$) elevation. Site interactions for the total percent vegetative cover were found in the flats ($p<0.0001$), upper ($p=0.0002$), and middle ($p=0.0197$) elevations, and total vegetative stem density site interactions were found in the flats ($p=0.0003$), edge ($p=0.0424$), upper ($p=0.0003$), middle ($p=0.0003$), and lower ($p=0.0079$) elevations.

Fall 2000 site interactions for *S. alterniflora* cover were found in the edge ($p<0.0001$), upper ($p=0.0007$), and middle ($p=0.0010$) elevations, site interactions for the stem density of *S. alterniflora* were in the edge ($p=0.0018$), upper ($p=0.0009$), and middle ($p=0.0002$), while the site interactions for the maximum heights of *S. alterniflora* were in the upper ($p=0.0076$) and middle ($p<0.0001$) elevations. Site interactions for *S. virginica* cover were found in the edge ($p=0.0389$), upper ($p<0.0001$), middle ($p=0.0011$), and lower ($p=0.0124$) elevations, site interactions for the

stem density of *S. virginica* were in the upper ($p < 0.0001$), middle ($p = 0.0054$), and lower ($p = 0.0102$), while the site interaction for the maximum heights of *S. virginica* was in the upper ($p = 0.0004$) elevation. Site interactions for *S. bigelovii* percent cover were found in the flats ($p = 0.0041$) and upper ($p < 0.0001$) elevations, and the stem density of *S. bigelovii* had site interactions in the flats ($p = 0.0031$) and edge ($p = 0.0004$), as well. Site interactions for the total percent vegetative cover were found in the flats ($p = 0.0012$), upper ($p < 0.0001$), and lower ($p = 0.0488$) elevations, and total vegetative stem density site interactions were found in the flats ($p = 0.0080$), upper ($p < 0.0001$), middle ($p = 0.0024$), and lower ($p = 0.0108$) elevations.

Winter 2001 site interactions for *S. alterniflora* cover were found in the edge ($p = 0.0044$) and middle ($p = 0.0003$) elevations, site interactions for the stem density of *S. alterniflora* were in the edge ($p = 0.0193$), upper ($p = 0.0046$), middle ($p < 0.0001$), and lower ($p = 0.0137$), while the site interaction for the maximum heights of *S. alterniflora* was in the middle ($p < 0.0001$) elevation. Site interactions for *S. virginica* cover were found in the flats ($p = 0.0451$), upper ($p = 0.0014$), and middle ($p = 0.0009$) elevations, site interactions for the stem density of *S. virginica* were in the flats ($p = 0.0405$), edge ($p = 0.0266$), upper ($p < 0.0001$), and middle ($p = 0.0003$), while the site interactions for the maximum heights of *S. virginica* were in the upper ($p = 0.0014$) and middle ($p = 0.0144$) elevations. Site interactions for *S. bigelovii* percent cover were found in the flats ($p = 0.0004$) and upper ($p < 0.0001$) elevations, and the stem density of *S. bigelovii* had site interactions in the flats ($p = 0.0046$) and edge ($p < 0.0001$), as well. Site interactions for the total percent vegetative cover were found in the flats ($p < 0.0001$) and upper ($p < 0.0001$) elevations, and total vegetative stem density site interactions were found in the flats ($p = 0.0014$), upper ($p < 0.0001$), and middle ($p = 0.0034$) elevations.

Spring 2001 site interactions for *S. alterniflora* cover were found in the edge ($p = 0.0069$), upper ($p = 0.0118$), middle ($p < 0.0001$), and lower ($p = 0.0202$) elevations, site interactions for the stem density of *S. alterniflora* were in the edge ($p = 0.0014$), upper ($p = 0.0267$), and middle ($p < 0.0001$), while the site interactions for the maximum heights of *S. alterniflora* were in the upper ($p = 0.0231$) and middle ($p < 0.0001$) elevations. Site interactions for *S. virginica* cover were found in the flats ($p = 0.0444$), edge ($p = 0.0116$), upper ($p < 0.0001$), middle ($p = 0.0004$), and lower

($p=0.0048$) elevations, site interactions for the stem density of *S. virginica* were in the edge ($p=0.0040$), upper ($p<0.0001$), middle ($p=0.0003$), and lower ($p=0.0139$), while the site interaction for the maximum heights of *S. virginica* was in the upper ($p=0.0005$) elevation. Site interactions for *S. bigelovii* percent cover were found in the flats ($p=0.0019$) and upper ($p<0.0001$) elevations, and the stem density of *S. bigelovii* had site interactions in the flats ($p=0.0273$) and edge ($p<0.0001$), as well. Site interactions for the total percent vegetative cover were found in the flats ($p=0.0006$), upper ($p<0.0001$), and middle ($p=0.0014$) elevations, and total vegetative stem density site interactions were found in the flats ($p=0.0028$), edge ($p=0.0128$), upper ($p<0.0001$), middle ($p=0.0038$), and lower ($p=0.0020$) elevations.

DISCUSSION

Spartina alterniflora and *Salicornia virginica* heights were significantly greater for every season in the ungrazed versus grazed treatments in the edge, upper, and middle marsh elevation zones. *S. alterniflora* was also significantly taller in the ungrazed lower marsh (versus grazed) for winter and spring 2001. These results were similar to those of a study at the same site in 1998-1999, in which significantly greater plant heights in ungrazed treatments were found (Yeargan 2001). These studies confirm that the heights of vegetation within a grazed system are significantly reduced by herbivory.

Few plants colonized in the high tide flats, and the only significant differences found were in the percentage cover of *S. virginica* (higher coverage in the grazed versus ungrazed) in summer 2000. The small percentage of cover and low stem densities across seasons were fairly consistent, and therefore likely the result of soil salinity effects rather than a grazing effect.

Too few *Batis maritima* stems were present throughout the sampling seasons to determine significant differences between grazed and ungrazed treatments. However, *B. maritima* was only found in ungrazed treatments. This illustrates a possible sensitivity to trampling, but with so few plants present, a definitive conclusion cannot be drawn.

Salicornia bigelovii was found in both treatments in the fall, winter, and spring. For each of these seasons, it had significantly greater percent coverage in the edge marsh elevation of

grazed treatments versus ungrazed (as well as higher stem densities in winter and spring). This is similar to the greater plant diversity found in grazed plots in previous research studies (Ranwell 1961, Bakker 1985, Andresen et al. 1990, Furbish and Albano 1994). Populations appear similar in the high tide flats, so it is theorized that grazing/trampling within the edge marsh stimulates growth of this particular species, while the tide flats are of equal opportunity to this high salinity colonizer.

The total percent coverage in the ungrazed treatment was almost twice that in the grazed treatments for the edge and upper marsh, indicating that grazing and trampling resulted in a marked decline in the plant cover of these plots. Though significantly greater in the middle elevation of ungrazed plots for summer, winter, and spring, the effect was not as great. Therefore, it is theorized that the impact of grazing and trampling upon overall percent vegetative cover is greatest at the edge and upper marsh. Andresen et al. (1990) found that reduced litter production occurred in cattle grazed marshes. This may have an overall effect of decreasing cover, as some of the nutrients normally available from detrital breakdown have been removed. A reduction in detritus may also result in fewer macroinvertebrates available to process what material there is. In a healthy marsh, mussels and burrowing crabs continually expel pellets rich in nitrogen that the plants may eventually absorb through their root systems (Montague 1980, Bertness 1992).

The upper and middle marsh had very few statistically significant measurements of *S. alterniflora* and *S. virginica* percent cover, and no significant differences in stem density between treatments. This appears to be the transition zone where impacts are starting to lessen slightly. However, the upper and middle marsh total vegetative cover was significantly greater in the ungrazed treatments, so the cumulative effects of grazing are significant, though differences in measurements amongst individual species were few.

The edge elevation *S. alterniflora* had a significantly greater stem density in the ungrazed treatments in summer, fall, and spring. This may be attributed to the prevalence of young stems present in the undisturbed plots, versus the grazed plots where seedlings of *Spartina* may find it more difficult to colonize. A study in a salt marsh by Grace and Ford (1996) showed that clipping

followed by inundation could inhibit growth or even kill vegetation. Upon introduction of cattle at the sensitive edge elevation, young plants would have multiple factors to contend with upon establishment. At the edge elevation, *S. virginica* was significantly greater in every season in the ungrazed versus grazed treatment in both percent cover and stem density. It appears that even though *S. virginica* has a high salinity tolerance, it does not have a high tolerance for physical manipulation.

In the present study, the only grazed plots that had a significantly greater stem density for *S. alterniflora* were in the lower marsh elevation (for every season). The results may be attributed to an increase in stem density as the biomass and height decrease for *S. alterniflora*.

The findings of this study were similar to those of Reimold et al. (1975) which found that *Salicornia virginica* represented a greater percentage of the plant species present in ungrazed marshes (in February, May and December), while in grazed marshes *S. alterniflora* maintained its' position as the dominant species present throughout the year. This may explain the unexpected results in the lower marsh where it was found that significantly greater cover and stem density occurred for *S. alterniflora* in grazed treatments while a significantly greater percent coverage and stem density occurred for *S. virginica* in ungrazed treatments.

Reimold (1975) also suggested that recovery from intensive grazing could occur in as little as one year. However, his study was conducted 30 years ago, with no follow-up studies, so further research must be conducted to validate that assumption thoroughly. Bakker (1985) found that it takes five to ten years for a marsh to attain natural conditions again, so there are many differing results depending upon vegetation makeup, type of grazer, and geographical location of the marsh.

Bertness (1992) observed the rapid colonization by glasswort when bare spots were opened up by *Spartina alterniflora* drift. Plants in some of the lower marsh sampling sites were damaged by *S. alterniflora* wrack, which may also account for the frequency of occurrence of *S. virginica* within ungrazed plots. The fencing around the ungrazed plots would occasionally act as a barrier to removal of wrack by tides. Brewer et al. (1998) also observed that *Salicornia* spp. were prevalent in areas that were subject to gaps in vegetation as a result of drift, but were not as

commonly found in areas that were disturbed repeatedly. Therefore, the presence of *S. virginica* in the ungrazed plot, as a response to wrack burial, is not uncommon.

The importance of stem density is illustrated by a study on sediment retention of *S. alterniflora* in response to wave action. The study found that the greatest stem densities ($108/\text{m}^2$) rendered the largest accumulations of sediment (Gleason et al. 1979), therefore, the more dense the vegetation along a shoreline, the less likely for high erosion rates to occur as sediments are trapped and retained more easily.

Though this study did not assess statistical significance between seasons, an overall look at the stem density of *S. alterniflora* showed an increase from summer (when stem density was the lowest) to fall, peaking in winter, and a slight drop in spring. A study addressing non-destructive techniques to assess salt marsh primary productivity in a South Carolina salt marsh had similar findings in that the stem densities of *S. alterniflora* tended to peak in late fall and winter, and were lowest in the summer sampling (Morris and Haskin 1990). Though total cumulative stem density was significantly greater in some zones, it is not a reliable measure, as a relatively high number of *S. virginica* stems without a very high percent cover could skew that statistic.

A simulated grazing study revealed that stem density of *Spartina alterniflora* was greater in each of the simulated grazed plots versus the control (ungrazed) plot (Reimold et al. 1975). However, biomass was greater in the ungrazed plot than a recently grazed plot. Conversely, the biomass of a previously grazed area was found to exceed that of the control, and the height of the plants exceeded that of the control as well. This leads one to conclude that strict management of light grazing activity in a marsh system may actually stimulate growth and enhance the overall health of a salt marsh.

Andresen et al (1990) suggest that a grazing rate not to exceed $0.5 \text{ cattle ha}^{-1}$ would be an appropriate management practice for areas that shall be continually grazed. It has been theorized by Reimold et al. (1975) that a cattle management program involving grazing once every three years within a marsh system would allow sufficient time for the marsh to recover. The

monetary gain of using salt marsh habitat as cattle-producing grazing land may help to protect them from residential and commercial development.

The effects of various forms of grazing should be assessed for each salt marsh being managed, as vegetation types, invertebrate populations, vertebrate communities, avian residents and migrants, sediment composition, salinity, tidal inundation, and many other factors are ever changing. The diversity that comes with grazing may not be optimal for that particular marsh. If low level to moderate grazing practices are being utilized to manage for vegetation diversity, an analysis of management needs must first be conducted.

In addition to grazing management, uninterrupted expanses of smooth cordgrass marsh are increasingly difficult to protect from development, pollution, and installation of bulkheads and piers due to the increased human population along coastal areas and increased building to accommodate recreational activities. Salt marsh vegetation is a precious commodity necessary in the life cycles of many marine invertebrates, fishes, and birds. Impact studies should be conducted to assess the long-term effects of all these activities to better understand the ramifications of development.

Any site interactions that were present are likely attributed to the fact that this research was conducted in a recovering marsh system that had once been grazed entirely. Cattle were excluded two years prior to experimentation. Differences may be due to the resultant compaction, differences that may have been created in edge habitat, encroaching tidal creeks formed by cattle paths, or differential flow from uplands that supplied some areas with more urine and feces (increased nutrients/eutrophication). This experiment sought to investigate changes over time, and these plots were established to measure those changes. The unpredictable nature of the environment at large leads to interactions that cannot always be assessed or accounted for.

CHAPTER III

FIDDLER CRAB (*UCA* SPP.) AND MARSH CRAB (*SESARMA CINEREUM*) POPULATION DENSITY AND SIZE DIFFERENCES BETWEEN GRAZED AND UNGRAZED SALT MARSH ELEVATION ZONES

INTRODUCTION

Uca rapax, *Uca pugnax* (Malacostraca: Ocypodidae) and *Sesarma cinereum* (Malacostraca: Grapsidae) have overlapping distributions within the Galveston Bay system. *Uca rapax* has the greatest distribution range for fiddler crabs in the western Gulf of Mexico (Britton and Morton 1989). *Uca* spp. and *Sesarma reticulatum* are territorial, semi-terrestrial, crabs that reside within burrows during high tide. Some burrows are extended above the substrate in funnels or mud porches (Warner 1977), while the depth of the intertidal burrows are typically between 10 and 30 cm (Bertness 1992). In contrast to *Uca* spp. and *Sesarma reticulatum*, *Sesarma cinereum* are highly mobile while feeding, and tend to maintain one shelter among dense stands of *Spartina* and wrack, only occasionally constructing solitary burrows (Seiple 1979, Britton and Morton 1989, Seiple and Mueller 1992).

Uca spp. are primarily detritivores, though some have suggested that direct herbivory occurs on occasion (Montague 1980, Seiple 1981, Britton and Morton 1989, Currin et al. 1995). *Sesarma cinereum* is primarily herbivorous, relying predominantly upon *S. alterniflora* for nutritive needs (Seiple 1981). *S. cinereum* prefers a substrate with more sand than silt, dense *Spartina* spp. and *Salicornia* spp. stands, relative high salinity (~27.9 ppt), and higher elevations within the marsh (Seiple 1979). Typically, these crabs are found beneath wrack or debris within an area at or just beneath the mean high water. *S. reticulatum* prefers a milder salinity (10-25 ppt), therefore would likely not be found within the same habitat as *S. cinereum*, *U. rapax*, and *U. pugnax*, which can survive within the relative high salinities of west end salt marshes in Galveston, Texas (Britton and Morton 1989). *Uca pugnax* prefers a substrate of mud versus sand and exists throughout the elevational zones of the marsh (Teal 1958).

Invertebrate populations in salt marshes are directly influenced by the abundance (or lack) of vegetation. The macroinvertebrate communities, much like the plants, have distinct areas of habitat preference. Fiddler crabs (*Uca* spp.) have been found to exist mutualistically with *Spartina alterniflora*. The crabs help aerate and drain the soil around the vegetation, and their presence has been shown to increase plant productivity. The root mass of the grass, in turn, provides structural support to crab burrows and the shoots provide protection from predators (Bertness 1985, Bertness 1992, Nomann and Pennings 1998). *Uca* spp. distributions, therefore, have been found to correlate positively with plant population density (Mouton, Jr. and Felder 1996).

Bertness (1985) has suggested that *S. alterniflora* and *Uca* spp. are extremely dependent upon each other. The *S. alterniflora* would lose as much as 47% aboveground biomass without the fiddler crabs, and in some soils, the crabs may not be able to maintain burrow integrity without the root and rhizome mats as support. Once established, the burrows within areas of dense mats may be maintained and protected for years (Montague 1980). The same researcher found that the material deposited at the surface from burrow excavation allowed organic material to decay, which increased the amount of detritus available to the crabs and prevented overaccumulation of peat adjacent to plant roots. Another advantage to the plants is that they may directly absorb waste nitrogen expelled into the burrows by fiddler crabs. An additional suggestion as to the affinity of fiddler crabs for *S. alterniflora* habitat is the lack of limitation on food supplies, as there is an abundance of algae and detritus consistently available (Kerwin 1971).

The diameter of burrow openings has been determined to be an accurate estimation of the carapace width of crabs and population estimates may be made from burrow counts (Kerwin 1971, Bertness and Miller 1984, Mouton and Felder 1996, Lourenco et al. 2000). Abandonment of a burrow results in rapid degradation and collapse of the structure due to the need for continual maintenance. Therefore, the incidence of overestimation would be minimal. This type of sampling allows researchers to make size determinations without the destructive means of sampling used in the past that consisted of excavating entire sample plots or individual burrows. Both of these practices may lead to the inadvertent destruction of crabs. Surface removal of

crabs for measurement could also result in possible stress and requires a much greater expenditure of time on the part of the researcher. An observation study, by continuous viewing versus rapid scanning, of *Uca* spp. in a mangrove system as an estimate of population (Nobbs and McGuinness 1999) would not be prudent in a *Spartina* marsh system. Continual observation by researchers takes time and the abundance of hiding places within dense *Spartina* marsh vegetation would make detection of crabs extremely difficult, thereby resulting in inaccuracies.

There are very few studies of the effects of cattle grazing on salt marshes invertebrates. Many grazing studies focus on soil salinity changes, nutrient levels, and vegetation reactions to herbivory and trampling. Reimold et al. (1975) found that there was a significantly greater density of fiddler crabs in ungrazed versus grazed, and assumed that the decrease could mainly be attributed to trampling by cattle. However, the crabs were only sampled over one season, and within grazed, ungrazed, and previously grazed marshes; no distinction was made between elevational zones. The distribution of crabs throughout the intertidal zones with respect to grazed systems has not been adequately studied. The objective of this chapter is to determine the effects of cattle activity on fiddler and marsh crabs (*Uca* spp. and *Sesarma cinereum*) in a salt marsh dominated by *Spartina alterniflora* and *Salicornia virginica* and on a high unvegetated zone (tidal flat).

METHODS

Grazed and ungrazed treatments established in spring 1998 (as described in the methods section of chapter II) were used to examine the effects of cattle grazing on fiddler and marsh crabs. Crab population (burrow) density (n/m^2) and burrow size were measured within each quadrat. As *S. cinereum* does not continually burrow, few burrows likely contained this species. However, they are included in the instance that they may take residence within a recently abandoned burrow, or for the occasional burrower. Burrows were counted as an estimation of the number of crabs, and the inside diameter of each burrow was measured to the nearest 1/10 mm using calipers. The burrow diameter was used as an estimate of crab size. The population density and mean size of crab burrows were calculated for each of the quadrats by

elevation zone (high tide flats, marsh edge, upper marsh, middle marsh, and lower marsh) and grazing treatment (grazed, ungrazed).

Data were analyzed by elevation zone using the null hypothesis that there was no difference in population density and the size of individuals of the target species in grazed and ungrazed treatments. A two-factor ANOVA (grazing treatment and site) was used to determine if there were significant differences ($\alpha=0.05$) in these measurements using the "Proc GLM" procedures in SAS to test the grazing treatment and site effects. The GLM model used was: "Dependent Variable" = Treatment Site Treatment X Site Error.

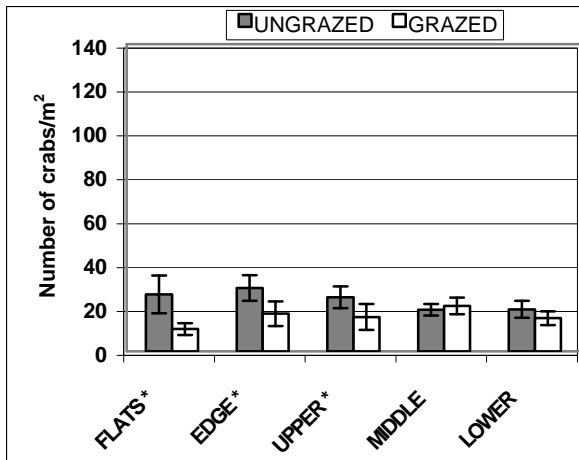
RESULTS

Burrowing Crab Population Density

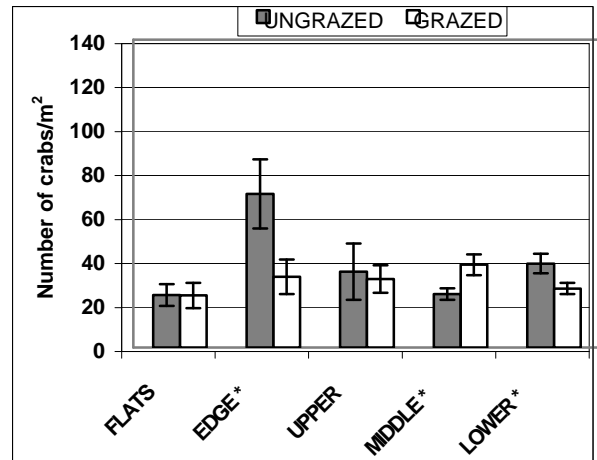
Summer 2000 population density for fiddler and marsh crabs showed significant differences between treatments for three elevation zones (Figure 2). All three zones had higher populations in the ungrazed treatments. The high tide flats had a mean of 26 crabs/m² \pm 8.58 for the ungrazed treatment and 10.16 crabs/m² \pm 2.74 for the grazed ($p<0.001$). The marsh edge ungrazed mean was 28.84 crabs/m² \pm 5.8 and the grazed mean was 17.16 crabs/m² \pm 5.6 ($p=0.016$). The upper marsh had an ungrazed mean of 24.66 crabs/m² \pm 4.92 and a grazed mean of 15.66 crabs/m² \pm 5.90 ($p=0.010$). There were no significant differences for the middle marsh or lower marsh elevation zones.

Fall 2000 also showed significant differences between treatments for three zones. The middle zone had a significantly larger population ($p=0.012$) in the grazed treatment (37.66 crabs/m² \pm 4.76) than the ungrazed treatment (24.34 crabs/m² \pm 2.62). In the other two zones, crab density was significantly greater in the ungrazed treatment. The marsh edge ungrazed mean (69.84 crabs/m² \pm 15.74) was higher than the grazed mean (32.16 crabs/m² \pm 7.86) ($p=0.007$). The lower marsh had an ungrazed mean at 38.16 crabs/m² \pm 4.44 and a grazed mean of 26.84 crabs/m² \pm 2.52 ($p=0.007$). There were no significant differences between grazing treatments for the high tide flats or the upper marsh elevation zones.

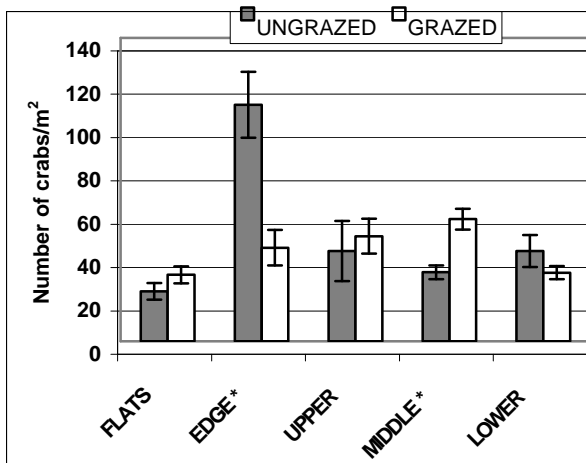
a. Summer 2000



b. Fall 2000



c. Winter 2001



d. Spring 2001

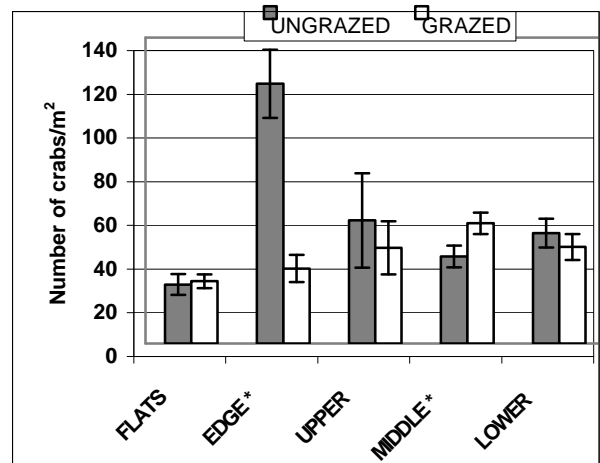


Figure 2. Population density of burrowing crabs (Mean \pm SE) for four seasons (summer 2000, fall 2000, winter 2001, and spring 2001), at five elevations (high tide flats, edge, upper, middle, and lower) in a Galveston Island salt marsh, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$.

In winter 2001, only two zones were found to differ significantly. The middle marsh population density was higher in the grazed treatment with a grazed mean of $56.34 \text{ crabs/m}^2 \pm 4.76$ and an ungrazed mean of $31.84 \text{ crabs/m}^2 \pm 3.22$ ($p < 0.001$). The marsh edge had a higher population density for the ungrazed treatment with an ungrazed mean of $109.16 \text{ crabs/m}^2 \pm 15.24$ and a grazed mean of $43.16 \text{ crabs/m}^2 \pm 8.2$ ($p < 0.001$). There were no significant differences for the high tide flats, upper marsh, or lower elevation zones.

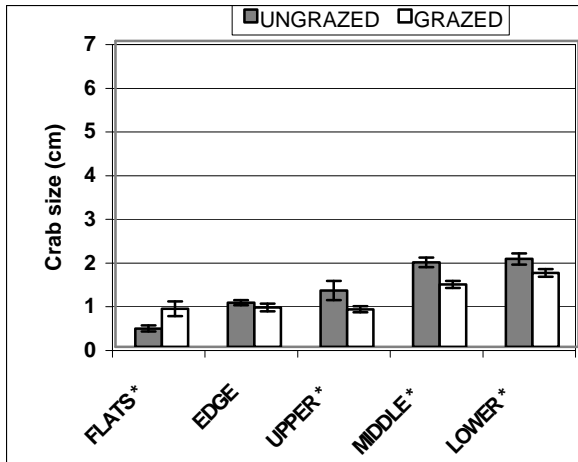
In spring 2001 the same two zones differed significantly as were found in the winter sample. The middle marsh population density was higher in the grazed treatment with a grazed mean of $55.00 \text{ crabs/m}^2 \pm 4.86$ and an ungrazed mean of $39.84 \text{ crabs/m}^2 \pm 4.96$ ($p = 0.014$). The marsh edge had a higher population density for the ungrazed treatment with an ungrazed mean of $118.84 \text{ crabs/m}^2 \pm 15.62$ and a grazed mean of $34.34 \text{ crabs/m}^2 \pm 6.2$ ($p < 0.001$). There were no significant differences for the high tidal flats, upper marsh, and lower marsh elevation zones.

Burrowing Crab Size

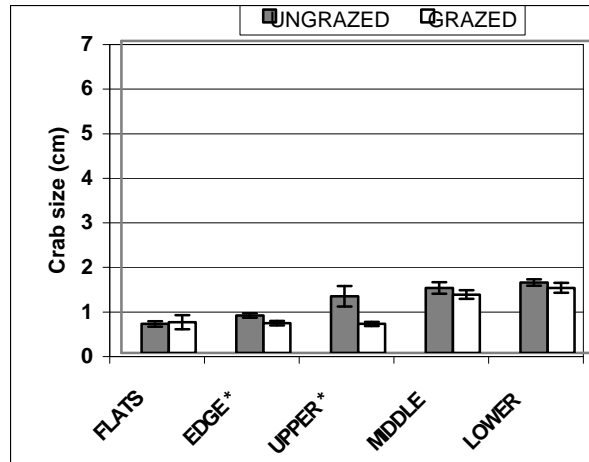
In summer 2000 the burrowing crab size was found to be significantly different between treatments at four elevation zones (Figure 3). For the high tide flats, the grazed mean of $0.87 \text{ cm} \pm 0.17$ was significantly higher than the ungrazed mean of $0.42 \text{ cm} \pm 0.07$ ($p = 0.028$). The other three zones had significantly larger burrow sizes in the ungrazed treatments. The upper marsh zone had an ungrazed mean of $1.29 \text{ cm} \pm 0.22$ and a grazed mean of $0.86 \text{ cm} \pm 0.07$ ($p = 0.003$). The middle marsh had an ungrazed mean of $1.93 \text{ cm} \pm 0.11$ and a grazed mean of 1.43 ± 0.08 ($p < 0.001$). And the lower marsh had an ungrazed mean of 2.01 ± 0.13 and a grazed mean of 1.69 ± 0.09 ($p = 0.020$). There were no significant differences for the marsh edge elevation zone.

For fall 2000 only two zones had significant treatment differences. Both zones had significantly higher burrow diameters in the ungrazed treatment. The marsh edge had an ungrazed mean of $0.84 \text{ cm} \pm 0.05$ and a grazed mean of $0.67 \text{ cm} \pm 0.05$ ($p = 0.006$), while the upper marsh was $1.27 \text{ cm} \pm 0.23$ for the ungrazed treatment and $0.65 \text{ cm} \pm 0.05$ for the grazed plots ($p = 0.001$). There were no significant differences for the high tide flats, middle marsh, and lower marsh elevation zones.

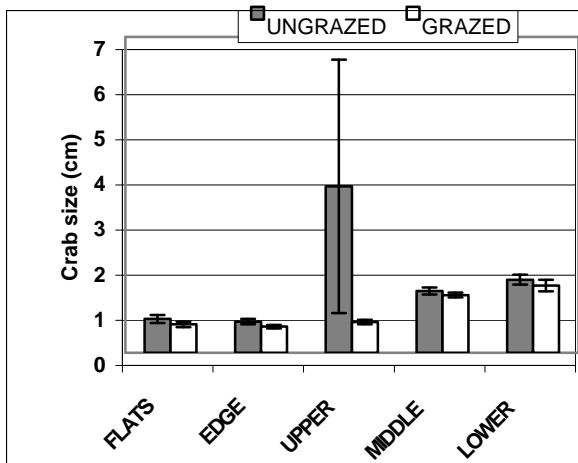
a. Summer 2000



b. Fall 2000



c. Winter 2001



d. Spring 2001

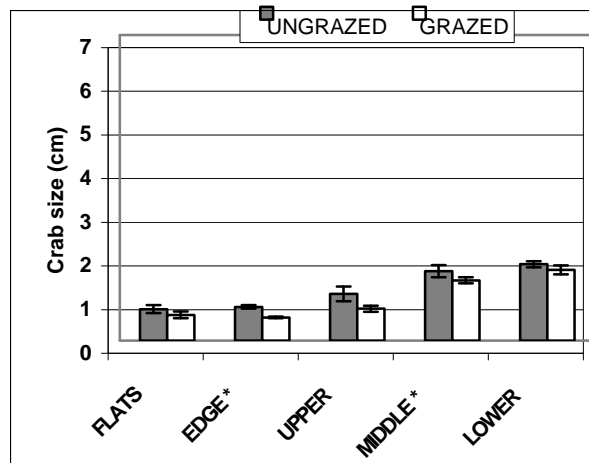


Figure 3. Size of burrowing crabs (Mean \pm SE) for four seasons (summer 2000, fall 2000, winter 2001, and spring 2001), at five elevations (high tide flats, edge, upper, middle, and lower) in a Galveston Island salt marsh, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$.

Winter 2001 measurements were taken and calculated, however, there were no significant differences between treatments for any of the zones.

There were two zones with significant differences in spring 2001, both with greater size in the ungrazed treatments. The marsh edge had an ungrazed mean of $0.77\text{cm} \pm 0.04$ and a grazed mean of $0.53\text{cm} \pm 0.02$, while the middle marsh had an ungrazed mean of $1.59\text{cm} \pm 0.14$ and a grazed mean of $1.38\text{cm} \pm 0.07$ ($p=0.043$). There was no significant difference in any other zone.

Site Interactions

Site interactions occurred at several marsh elevation zones for the crabs. Summer 2000 site interactions for crab densities were found in the high tidal flat ($p<0.0001$) and upper ($p=0.0118$) elevations, and the site interactions for the size of crabs were in the edge ($p=0.0180$), upper ($p=0.0010$), and lower ($p=0.0036$). In Fall 2000, site interactions for crab densities were found in the high tide flats ($p=0.0005$), edge ($p=0.0018$), and upper ($p<0.0001$) elevations, and the site interactions for the size of crabs were in the upper ($p=0.0336$) and lower ($p=0.0005$). Winter 2001 site interactions for crab densities were found in the flats ($p=0.0011$), edge ($p=0.0343$), and upper ($p<0.0001$) elevations, and the site interactions for the size of crabs were in the flats ($p=0.0002$), middle ($p<0.0001$), and lower ($p=0.0143$). Spring 2001 site interactions for crab densities were found in the flats ($p<0.0001$), edge ($p=0.0016$), and upper ($p<0.0001$) elevations, and the site interactions for the size of crabs were in the flats ($p<0.0001$), edge ($p=0.0021$), middle ($p=0.0010$), and lower ($p=0.0405$).

DISCUSSION

Just as found in the study by Mouton and Felder (1996), the lowest density of burrows was found in the summer, while the greatest were in winter and spring. The edge marsh had a significantly greater burrowing crab density in the ungrazed treatment for every season (versus grazed). This may be due to the significantly greater coverage of vegetation in the ungrazed treatment, as well as a response in the grazed treatment to trampling, which may either cause

direct mortality or may make it too costly for the crabs to maintain burrows in the much frequented edge zone. As fiddler crabs are among the first to colonize created marshes, the marsh edge crab population in the grazed treatments may rapidly approach the ungrazed measurement upon elimination of grazers (Levin et al. 1996).

Typically, as one moves from the water landward, the size of the burrows increases as the sediment size and root mass increase (Bertness and Miller 1984). However, in the present study, the larger burrows were found lower in the marsh, with the size decreasing as elevation increased. This may be a result of higher sand content within the sediments overall, compared to the high silt content within most east coast salt marshes.

The lowest levels in the marsh (closest to the water's edge) are avoided by *Uca pugnax*, likely in response to the lack of cover, exposing them to predation (Teal 1958). Therefore, it is assumed that the main inhabitant of this zone must be *Uca rapax*. In a study comparing wetland functions in grazed versus ungrazed salt marshes, it was theorized that a reduction in deposit feeders was also directly linked to the removal of nutrients by feral ponies. The vegetation they consumed from the system would have otherwise been broken down and assimilated into the detrital food web (Reader and Craft 1999). As the fiddler and marsh crabs are dependent upon detrital and vegetative resources for food, removal by cattle may have been an overall limiting factor in population densities. As vegetation impacts from grazing lessened closer to the water's edge, noticeable increases in densities of crabs in the grazed treatments occurred as well.

Montague (1980) has suggested that the fiddler crab not only aids in support of marsh vegetation but by nature of its' activities, provides structure and food to maintain itself within its' environment. The interactions of the fiddler and marsh crabs amongst the vegetation and sediments of the marsh is an interwoven lattice that is disrupted by cattle grazing. The trampling that occurs during grazing causes vegetation shifts, soil compaction, and direct mortality of crabs. When population densities decrease, not only are the plants affected, but predators of the crabs as well. Fiddler crabs are a favored resource by many coastal shorebirds, which raises the issue of whether grazing may impact not only invertebrate populations, but their avian predators, as well. Less cover from vegetation may result in greater predation, and decreases in crab

populations may significantly increase competition among their predators. Yeargan (2001) observed significantly greater numbers of wading birds in the grazed salt marsh when compared to the ungrazed salt marsh, with feeding on macroinvertebrates the primary activity observed in the grazed marsh.

A study in 1975 by Reimold et al. suggested that management of salt marsh grazing systems by limiting exposure to one year of grazing every three years to allow the habitat to recover. Further research should be conducted to assess the recovery of invertebrate populations when submitted to rotational grazing practices. When alternative grazing sites are not available, a management technique that minimizes the long-term effects may be a viable option.

Any site interactions that were present are likely attributed to the fact that this research was conducted in a recovering marsh system that had once been grazed entirely. Cattle were excluded two years prior to experimentation. Differences may be due to the resultant compaction, differences that may have been created in edge habitat, encroaching tidal creeks formed by cattle paths, or differential flow from uplands that supplied some areas with more urine and feces (increased nutrients/eutrophication). This experiment sought to investigate changes over time, and these plots were established to measure those changes. The unpredictable nature of the environment at large leads to interactions that cannot always be assessed or accounted for.

CHAPTER IV

**HORN SNAIL (*CERITHIDEA PLICULOSA*) POPULATION DENSITY AND SIZE
DIFFERENCES BETWEEN GRAZED AND UNGRAZED SALT MARSH
ELEVATION ZONES**

INTRODUCTION

Cerithidea pliculosa Menke (Gastropoda: Potamididae), the horn snail, prefers to inhabit the muddy marsh surface. Only rarely do they exhibit climbing behavior. Greater numbers of *Cerithidea pliculosa*, *Cerithidea californica*, and *Cerithidea scalariformis* are found in zones dominated by *Salicornia* than are found in zones dominated by *Spartina* or *Juncus* (Houbrick 1984). McGuinness (1994) found that *Cerithidea anticipata* climb not for predator avoidance (as often seen in species of littorinids), but to attempt to escape the stress of inundation by high tides. Rao and Sukumar (1981) found a preference for substrates of mixed particle size versus strictly sand or fine mud by *Cerithidea cingulata*. They found that population density did not correlate with the amount of organic content in the sediments and they observed that horn snails tend to be buried during high tide and feed on the substrate during low tide.

Race (1981) studied a population of *C. californica* in San Francisco Bay marsh pans. The snails overwintered beneath *Salicornia* cover from November to March, during which time they remained virtually inactive (hibernating within their shells). They resumed normal activity in the spring. *C. californica* was found to attain populations of 1000/m² in the summer, with an even distribution of age groups. Dispersal appeared to originate at the fringe areas of the marsh pans, and snails became distributed into creeks and tidal flats, limited to only one to two months each spring due to competition with the mud snail, *Ilyanassa obsoleta*. Little to no growth (0-0.01mm/month) occurred in winter, with nearly all growth taking place during summer. Juveniles (<20mm) grew rapidly ~1-4mm per month. Small adults (20-25mm) grew ~1mm per month in the summer, while adults over 25mm grew in the summer as well, but only slightly.

The resources consumed by *C. californica* only occasionally consist of vascular plants, with the greatest ingestion consisting of diatoms. The size of ingested diatoms was a function of snail size, with much smaller diatoms being ingested by juvenile snails (Whitlatch and Obrebski 1980). An enclosure study by Byers (2000) showed a tendency towards even dispersal of juvenile horn snails independent of feeding resources, which were heterogeneously distributed. The larger adults concentrated around resource centers initially but dispersed evenly as limited resources were consumed.

C. californica, which is closely related, genetically, to *C. pliculosa*, has predators, which are mainly crabs and shorebirds. Sousa (1993) showed that crabs exhibit little size preference for prey horn snails, while willets tended to feed exclusively upon small juvenile snails, apparently being unable to consume larger adults. It was also noted that many living snails were found within the fecal pellets of willets. Survival in fecal pellets acts as a form of dispersal, which rapidly extends the snail population over more of the marsh surface.

The effects of cattle grazing on the biology and habitat of *C. pliculosa* have not been previously investigated. Therefore, the objective of this chapter is to determine the effects of cattle grazing on horn snails (*Cerithidea pliculosa*) in a salt marsh dominated by *Spartina alterniflora* and *Salicornia virginica* and on a high unvegetated zone (tidal flat).

METHODS

Grazed and ungrazed treatments established in spring 1998 (as described in the methods section of chapter II) were used to examine the effects of cattle grazing on horn snails (*Cerithidea pliculosa*). Population density (n/m^2) and size were recorded within each quadrat. Each shell was examined to verify the presence of a live snail. Empty shells and those occupied by hermit crabs were excluded from the study. The snails were counted and the length of each individual was measured to the nearest 1/10 mm with calipers. The population density and mean size was calculated for each of the quadrats by elevation zone (high tide flats, marsh edge, upper marsh, middle marsh, and lower marsh) and grazing treatment (grazed, ungrazed).

Data were analyzed by elevation zone using the null hypothesis that there was no difference in population density and the size of individuals of the target species in grazed and ungrazed treatments. A two-factor ANOVA was used to determine if there were significant differences ($\alpha=0.05$) in these measurements using the “Proc GLM” procedures in SAS to test the grazing treatment and site effects. The GLM model used was:
 “Dependent Variable” = Treatment Site Treatment X Site Error.

RESULTS

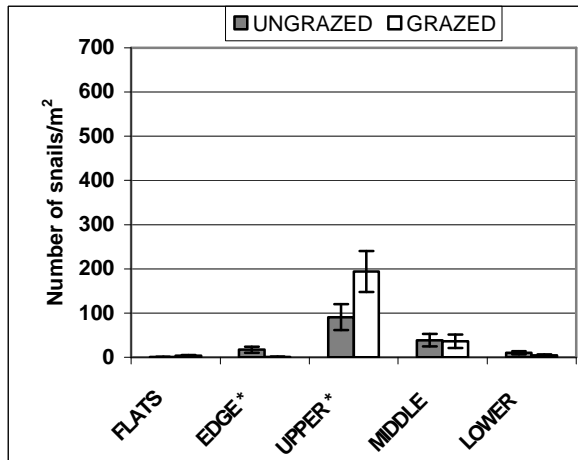
Horn Snail (Cerithidea pliculosa) Population Density

For summer 2000, the population density of horn snails showed significant differences between treatments at two elevation zones (Figure 4). The upper zone contained more individuals in the grazed treatment with a mean of $194/m^2 \pm 46.2$ versus an ungrazed mean of $90.8/m^2 \pm 29.3$ ($p<0.001$). The edge zone was significantly different with the ungrazed treatment having a more dense population with a mean of $17.2/m^2 \pm 6.8$ and the grazed treatment with a mean of $0.8/m^2 \pm 0.5$ ($p=0.015$). There was no significant difference in any other zone.

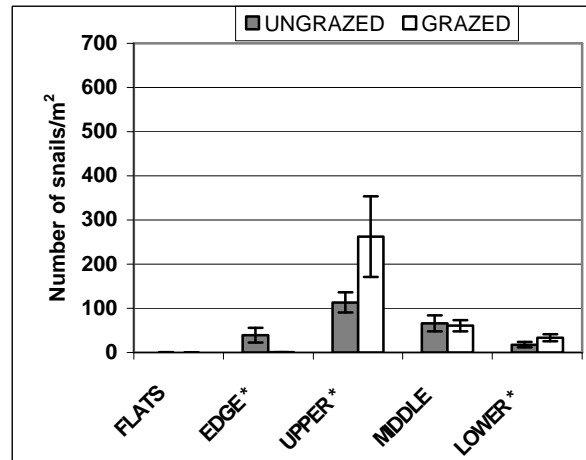
Fall 2000 showed three zones with significantly different horn snail populations. In the upper and lower zones, population densities were significantly higher in the grazed treatments. In the upper zone, the grazed mean was $262.2/m^2 \pm 91.3$ while the ungrazed mean was $113.2/m^2 \pm 22.8$ ($p=0.021$). The lower zone had a mean of $33.3/m^2 \pm 7.8$ versus the ungrazed mean of $17.7/m^2 \pm 6.0$ ($p=0.020$). The edge zone had a significantly higher population in the ungrazed treatment with a mean of $39.2/m^2 \pm 16.8$ in comparison to the grazed mean of $0.7/m^2 \pm 0.4$ ($p=0.004$). There was no significant difference in any other zone.

In winter 2001, there were three zones with significantly different horn snail population densities. The grazed treatments had significantly higher populations in the upper and middle zones. The upper zone had a grazed mean of $511.3/m^2 \pm 174.1$ and an ungrazed mean of $99.7/m^2 \pm 19.7$ ($p<0.001$). The middle zone had a grazed mean of $101.7/m^2 \pm 18.1$ and an ungrazed mean of $66.5/m^2 \pm 16.9$ ($p=0.024$). Significantly higher populations were found in the ungrazed treatment in the edge zone with an ungrazed mean of $25.5/m^2 \pm 10.8$ and a grazed

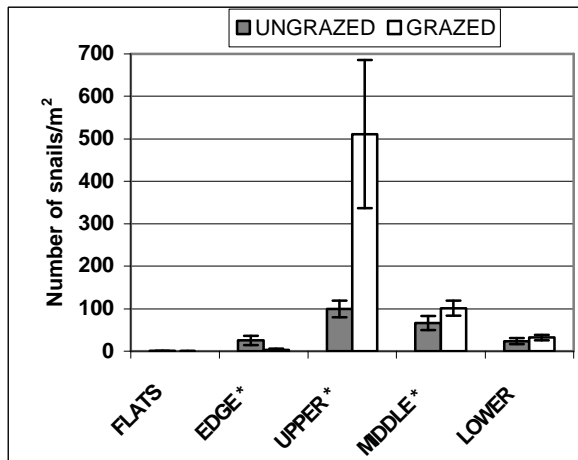
a. Summer 2000



b. Fall 2000



c. Winter 2001



d. Spring 2001

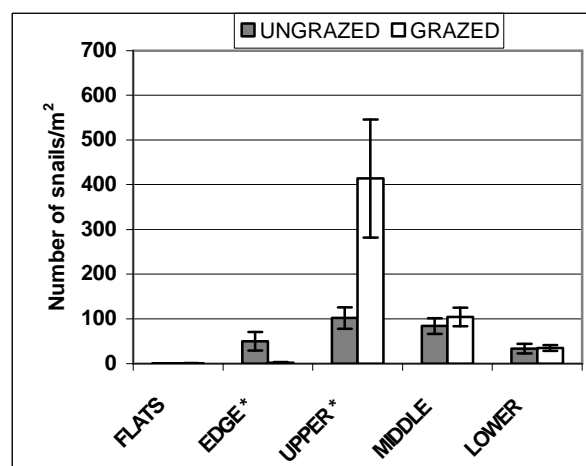


Figure 4. Population density of *Cerithidea pliculosa* (Mean \pm SE) for four seasons (summer2000, fall 2000, winter 2001, and spring 2001), at five elevations (high tide flats, edge, upper, middle, and lower) in a Galveston Island salt marsh, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$ (=*).

mean of $3.3/\text{m}^2 \pm 2.5$ ($p=0.007$). There was no significant difference in any other zone.

Spring 2001 showed significant differences in two zones. The upper zone had higher populations in the grazed treatment with a grazed mean of $413.7/\text{m}^2 \pm 131.8$ and an ungrazed mean of $101.8/\text{m}^2 \pm 24.3$ ($p<0.001$). The edge zone had a significantly higher density of horn snails in the ungrazed treatment with $49.3/\text{m}^2 \pm 20.9$ while the grazed mean was $2.5/\text{m}^2 \pm 0.9$ ($p=0.001$). There was no significant difference in any other zone.

Horn Snail (Cerithidea pliculosa) Size

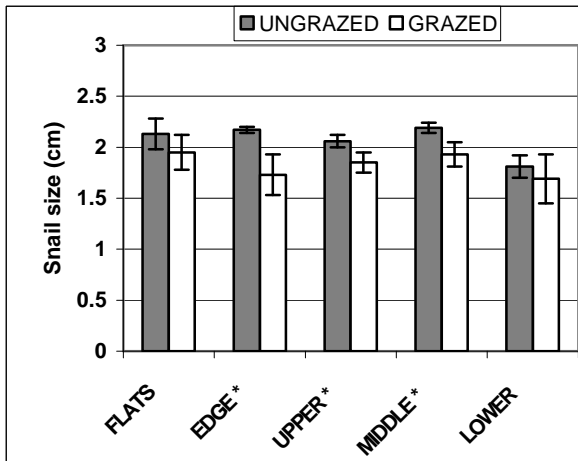
In summer 2000, three elevation zones showed significantly greater sizes in the ungrazed treatments (Figure 5). The edge zone had an ungrazed mean of $2.17\text{cm} \pm 0.03$ and a grazed mean of $1.73\text{cm} \pm 0.2$ ($p=0.010$). The upper zone had an ungrazed mean of $2.06\text{cm} \pm 0.06$ and a grazed mean of $1.85\text{cm} \pm 0.1$ ($p=0.016$) and the middle zone had an ungrazed mean of $2.19\text{cm} \pm 0.05$ and a grazed mean of $1.93\text{cm} \pm 0.12$ ($p=0.030$). There was no significant difference in any other zone.

For fall 2000, four elevation zones showed significantly greater sizes in the ungrazed treatments. The edge zone had an ungrazed mean of $2.17\text{cm} \pm 0.02$ and a grazed mean of $1.17\text{cm} \pm 0.39$ ($p=0.004$) and the upper zone had an ungrazed mean of $2.08\text{cm} \pm 0.05$ and a grazed mean of $1.87\text{cm} \pm 0.1$ ($p<0.001$). The middle zone had an ungrazed mean of $2.23\text{cm} \pm 0.02$ and a grazed mean of $1.95\text{cm} \pm 0.08$ ($p<0.001$) and the lower zone had an ungrazed mean of $1.89\text{cm} \pm 0.09$ and a grazed mean of $1.63\text{cm} \pm 0.09$ ($p=0.024$). There was no significant difference for the high tide flats zone.

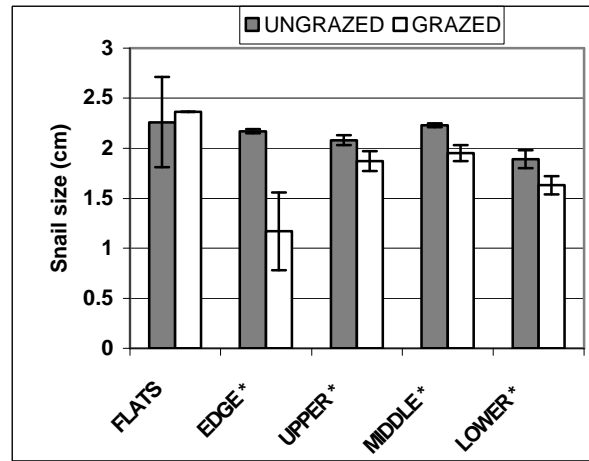
In winter 2001, the ungrazed treatment was significantly higher for the upper and middle zones. The upper zone ungrazed mean was $2.04\text{cm} \pm 0.04$ while the grazed mean was $1.83\text{cm} \pm 0.1$ ($p<0.001$) and the middle zone ungrazed mean was $2.17\text{cm} \pm 0.02$ while the grazed mean was $1.87\text{cm} \pm 0.07$ ($p<0.001$). There was no significant difference in any other zone.

For spring 2001, the upper zone had significantly greater snail size with the ungrazed mean at $2.07\text{cm} \pm 0.05$ while the grazed mean was $1.95\text{cm} \pm 0.1$ ($p=0.014$) and the middle zone's significantly larger size had an ungrazed mean of $2.2\text{cm} \pm 0.02$ while the grazed mean

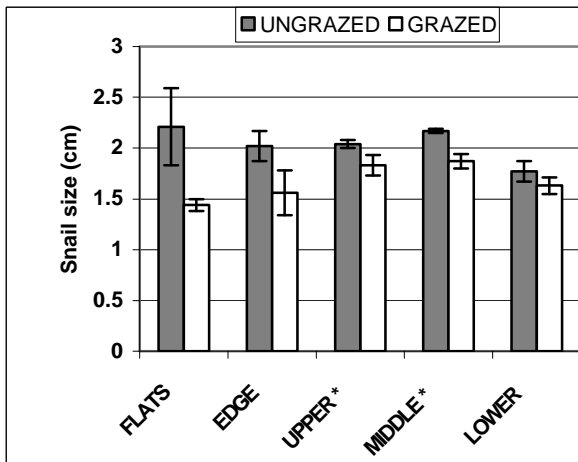
a. Summer 2000



b. Fall 2000



c. Winter 2001



d. Spring 2001

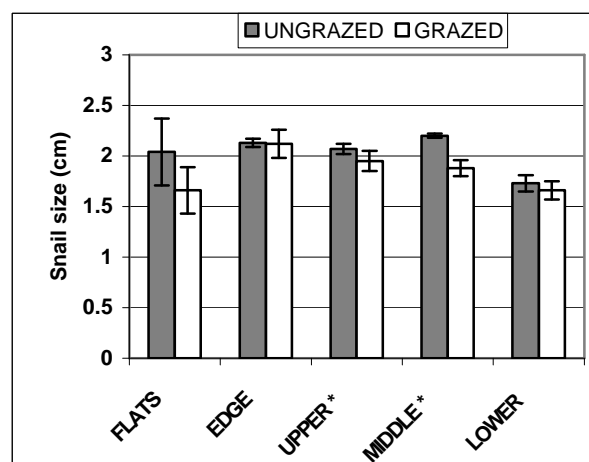


Figure 5. Size of *Cerithidea pliculosa* (Mean \pm SE) for four seasons (summer 2000, fall 2000, winter 2001, and spring 2001), at five elevations (high tide flats, edge, upper, middle, and lower) in a Galveston Island salt marsh, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$ (*). Lack of error bar indicates single observation.

was $1.88\text{cm} \pm 0.08$ ($p < 0.001$). There was no significant difference in any other zone.

Site Interactions

Site interactions occurred at several marsh elevation zones for the horn snail. Summer 2000 site interactions for snail densities were found in the upper ($p < 0.0001$) and middle ($p = 0.0022$) elevations, and snail size had site interactions in the upper ($p = 0.0072$). In Fall 2000, site interactions for snail densities were found in the edge ($p = 0.0050$), upper ($p = 0.0002$), and middle ($p = 0.0206$) elevations, and snail size had site interactions in the upper ($p < 0.0001$), middle ($p = 0.0013$), and lower ($p = 0.0180$). Winter 2001 site interactions for snail densities were found in the edge ($p = 0.0009$), upper ($p < 0.0001$), and middle ($p < 0.0001$) elevations, and snail size had site interactions in the upper ($p < 0.0001$) and the middle ($p < 0.0001$). Spring 2001 site interactions for snail densities were found in the flats ($p = 0.0012$), edge ($p = 0.0005$), upper ($p < 0.0001$), middle ($p = 0.0004$), and lower ($p = 0.0467$) elevations, and snail size had site interactions in the edge ($p = 0.0054$), upper ($p < 0.0001$), middle ($p = 0.0428$), and lower ($p = 0.0041$).

DISCUSSION

Unlike Race (1981), who found that horn snails virtually hibernate between November and March, the snails were observed actively feeding throughout the present study in both treatments (personal observation). Overall size throughout the seasons appears consistent within treatments, though the ungrazed treatment usually had a mean size of > 2.0 cm in all zones, while the horn snails in the grazed treatment average between 1.5-2.0 cm. Race (1981) describes horn snails from 2.0-2.5 cm as small adults, while those below 2.0 cm are classified as juveniles. Thus, it was found that the ungrazed treatments contained small adults, while juveniles were predominant in the grazed treatment.

While the population density of horn snails was significantly greater in the grazed upper zone, the size was significantly smaller within that elevation. In fact, whenever significant differences in size occurred, values were greater in ungrazed treatments. Algal mats were

observed during sampling primarily in the upper zone of each treatment, but the greatest density of algal accumulations observed was in the grazed treatment. This may be due to excessive nutrient input by cattle feces and urine, as well as retention of the nutrients in depressions made by cattle footprints. The number of snails present may be a product of increased availability of nutrition in the form of the algal mats, which allowed the populations to increase significantly as feeding success increased.

The study by Byers (2000) indicates that juveniles should disperse evenly within the marsh, as long as resources (i.e. diatoms, macroalgal accumulations, organic material in mud, and vascular plants) are homogeneously distributed. However, the greatest populations within the grazed treatments, which are predominantly juveniles, are centered within the upper zone. Hence, grazing seems to concentrate the snails in the upper zone. Trampling may also result in a snail population shift from the edge zone to the upper zone. Individuals in the ungrazed treatments have a higher population within the upper zone as well, but are much more evenly distributed between the edge, upper, and middle zone than their grazed treatment counterparts.

The abundance of juvenile snails in the grazed upper zone may attract willet predators, which have difficulty ingesting adult snails, which dominate ungrazed treatments (Sousa 1993). Through an intensive literature search, Sousa (1993) found that of all shorebirds in Pacific coast salt marsh systems, willets are usually the primary consumers of *Cerithidea californica*. As *C. californica* is closely related to *C. pliculosa*, and the sample site affords habitat for a large population of willets (Yeargan 2001 and personal observation), similar predation likely occurs here.

The significantly greater size of snails in the ungrazed upper and middle zones for each season may be attributed to reduced predation on juveniles by willets, which may have difficulty locating prey due to greater vegetation heights in the ungrazed plots, thereby allowing snails to survive to adulthood. Another factor that snails in the ungrazed treatment are not subjected to is trampling, which could stunt growth due to stress, or crush the snails.

Overall population densities are greatest in the edge, upper, and middle zones in both treatments, which indicates their preference for the mixed sediment particle size in these zones,

as found by Rao and Sukumar (1981). The lower zone, however, consists of finer mud, and the tidal flats are primarily sand. In the ungrazed treatment (which serves as a natural control treatment), the upper zone has the greatest population density, with slightly lower values occurring in both the edge and middle zone. The snails exhibit a preference for the upper zone elevation, which may be attributed to vegetation cover, the elevation itself, or even a response to sediment size.

The significantly greater snail population density in the edge zone in the ungrazed treatment in every season is likely due to the significantly greater *Salicornia virginica* stem density, height, and percent cover found there at the edge treatments in all seasons. Though the grazed part of the upper zone had a greater number of snails each season, it did not have overall greater vegetation density, height, or percent cover. Within the upper zone elevation, snail population is greatest in the grazed treatment when the total vegetation cover is between 25-40%. However, it appears that the horn snails are less dependent on this apparent vegetation association in the lower zones of the marsh for either treatment.

This study shows that in West End Galveston salt marshes, *C. pliculosa* populations are affected in several ways by cattle activity. Snail population densities increase significantly, primarily in the upper zone in grazed treatments, while the horn snails in ungrazed marshes attain overall greater size. The differing responses are due to a change in total vegetation cover and *Salicornia virginica* cover. Population densities in the upper zone increase when there is less cover and greater algal accumulation, while size seems to be dependent upon increased vascular plant cover. These differences in cattle grazed treatments may be advantageous to predators such as willets, however predation by crabs is not size specific. If the entire marsh were grazed, the shift in populations to juveniles versus adults may cause a shift in predators, and the overall ecosystem could be altered by this apparently simple change. As populations of willets increase in response to the greater small snail availability, animals dependent upon adult horn snails, however, would be negatively affected.

Any site interactions that were present are likely attributed to the fact that this research was conducted in a recovering marsh system that had once been grazed entirely. Cattle were

excluded two years prior to experimentation. Differences may be due to the resultant compaction, differences that may have been created in edge habitat, encroaching tidal creeks formed by cattle paths, or differential flow from uplands that supplied some areas with more urine and feces (increased nutrients/eutrophication). This study sought to investigate changes over time, and these plots were established to measure those changes. The unpredictable nature of the environment at large leads to interactions that cannot always be assessed or accounted for.

CHAPTER V

MARSH PERIWINKLE (*LITTORARIA IRRORATA*) POPULATION DENSITY AND SIZE DIFFERENCES BETWEEN GRAZED AND UNGRAZED SALT MARSH ELEVATION ZONES

INTRODUCTION

Littoraria irrorata Say (Gastropoda: Littorinidae) tends to prefer substrates other than the ground and is usually found crawling on vegetation (Murty and Rao 1977, Britton and Morton 1989). A study of macrobenthos in a *Spartina alterniflora* salt marsh in Sao Paulo State, Brazil revealed that *Littorina angulifera* tended to dominate the populations in tall-form, sparsely populated *S. alterniflora* plots in the winter and spring, and short-form, densely populated *S. alterniflora* plots with the population density also peaking in the spring (Flynn et al. 1996). In a similar study by Harlin and Rines (1993), *Littorina littorea* was found in the salt marsh stations sampled with a frequency of 91%, but with only ~10% plant cover in the marsh. Plant cover was low due to rapid consumption of the plant substrate. Lana and Guiss (1992) showed that *Littorina flava*, which was found in crevices between plants and adjacent to structures below-ground, responded significantly to the below-ground *Spartina alterniflora* biomass versus the aerial cover. It appeared that detrital build-up and pressure from predators were driving forces in habitat selection, with aerial cover chosen least.

Feeding preferences vary among species, however, the diet of littorinid snails consists of various organic material, including *Spartina alterniflora* litter. A study that evaluated stable isotope values of C, N, and S in *Littoraria irrorata* showed that the snail primarily feeds on fungal growth on dead standing *S. alterniflora* shoots, and microalgae associated with detrital matter on the mud substrate (Currin et al. 1995). The low N isotope values reported rule out major contributions by phytoplankton, living *S. alterniflora*, or benthic macroalgae. Other nutritional investigations reveal a preference for dead *Spartina alterniflora* litter by *Littorina saxatilis* (Barlocher and Pitcher 1999), and that *Littorina littorea* consume great amounts of young

Enteromorpha spp. versus *Ulva* spp. (Chlorophyta, Ulvales) among mussel beds (Wilhelmsen and Reise 1994).

Predator and injury avoidance, as well as escape from tidal inundation, is achieved by *Littoraria irrorata* by climbing upward on plant shoots (Hamilton 1976, Warren 1985). Additionally, young snails take cover within folds of *Spartina alterniflora* leaves to avoid detection (Stiven and Hunter 1976). Another behavioral adaptation for predator avoidance is chemical detection of danger. *Littorina littorea* was shown to chemically recognize potential predatory crabs that were fed a *L. littorea* diet, and the chemical elicited a quick fleeing response in the snails that did not occur when exposed to crabs fed a diet of fish (Jacobsen and Stabell 1999). Similarly, Duval et al. (1994) revealed that *Littoraria irrorata* has behavioral responses to odors. Positive or neutral movements were recorded for familiar plants, grass shrimp, *Uca*, and other littorinids while a negative reaction occurred when odors were released which corresponded to those of plants found outside their distribution range, minced littorinid meat, or predators (blue crabs, carnivorous gastropods). Intense negative responses to blue crabs only occurred when the crab's diets consisted of *L. irrorata*.

The effects of catastrophic storms, habitat degradation and destruction, and trampling on populations of littorinid snails have been investigated, though not thoroughly. Trussell (1997) found that *Littorina obtusata* had shorter overall length and smaller aperture sizes on exposed, wave-beaten shores after a major storm while snails on protected shores maintained previously recorded measurements. The unexpected smaller aperture size was explained as an adaptation to fitting into smaller openings to hold on to the substrate more effectively. *Littorina saxatilis* has rapidly adapted to changes in natural habitat availability in the Wadden Sea, from rapidly degrading seagrass beds to habitats dominated by *Spartina anglica* and green algae (Wilhelmsen 1999). *Littoraria irrorata* populations had not shown recovery in the four years following a pipeline installation near Charleston, SC, although the *Spartina alterniflora* had replenished rapidly (Knott et al. 1997). Grazing events have been shown to similarly suppress *L. irrorata* populations in a Georgia salt marsh due to a reduction in *Spartina alterniflora* stem density (Turner 1987).

Littoraria irrorata and *Littorina littorea* show promise as bioindicators of chemical and biological disturbance. PAH (polycyclic aromatic hydrocarbon) contamination of sediments in Pass Fourchon, LA can be monitored by recording the feeding activity/intensity of *L. irrorata* (Bennett et al. 1999) and *Littorina littorea* can be analyzed to determine exposure to metallothionein, Cd, and Zn (Leung and Furness 1999). Mortality occurs more quickly in *Littorina* spp. than fish when exposed to toxic algal blooms such as *Gymnodinium nagasakiense*, which could forewarn of other fisheries impending die-offs. *Littorina littorea* may be used as a bio-antifoulant on mussel beds as a result of their affinity for algal mats (Wilhelmsen and Reise 1994). This illustrates another important role of *Littoraria irrorata* within the marsh system, that of controlling filamentous algae. Such control may prevent mass mortality of *Spartina alterniflora* due to the effects of eutrophication. The objective of this chapter is to determine the effects of cattle grazing on marsh periwinkles (*Littoraria irrorata*) in a salt marsh dominated by *Spartina alterniflora* and *Salicornia virginica* and on a high unvegetated zone (tidal flat).

METHODS

Grazed and ungrazed treatments established in spring 1998 (as described in the methods section of chapter II) were used to examine the effects of cattle grazing on marsh periwinkles, *Littoraria irrorata*. Population density (n/m^2) and size were recorded within each quadrat. Each shell was examined to verify the presence of a live snail (empty shells were excluded). The snails were counted and the length of each individual was measured to the nearest 1/10 mm with calipers. Additionally, the substrate was noted (mud or vegetation), and the height on plants was recorded to the closest millimeter for snails found on vegetation. The population density and mean size of each snail were calculated for each of the quadrats by elevation zone (high tide flats, marsh edge, upper marsh, middle marsh, and lower marsh) and by grazing treatments within each zone (grazed and ungrazed).

Data were analyzed by elevation zone using the null hypothesis that there was no difference in population density, the size of individuals of the target species, or height location on plants in grazed and ungrazed treatments. A two-factor ANOVA was used to determine if there

were significant differences ($\alpha=0.05$) in these measurements using the “Proc GLM” procedures in SAS to test the grazing treatment and site effects. The GLM model used was:

“Dependent Variable” = Treatment Site Treatment X Site Error.

RESULTS

Marsh Periwinkle (Littoraria irrorata) Population Density

No significant population density differences were detected in any zones during the summer, fall, or winter. The only significant difference between grazed and ungrazed plots was found in spring 2001 in the middle marsh (Figure 6), when the grazed treatment was higher with a mean of 2.0 snails/m² \pm 0.66 versus an ungrazed mean of 0.34 snails/m² \pm 0.22 ($p=0.012$). Very few individuals were present throughout the study sites. None was ever observed in the high tide flats and few were observed in the edge.

Marsh Periwinkle (Littoraria irrorata) Size

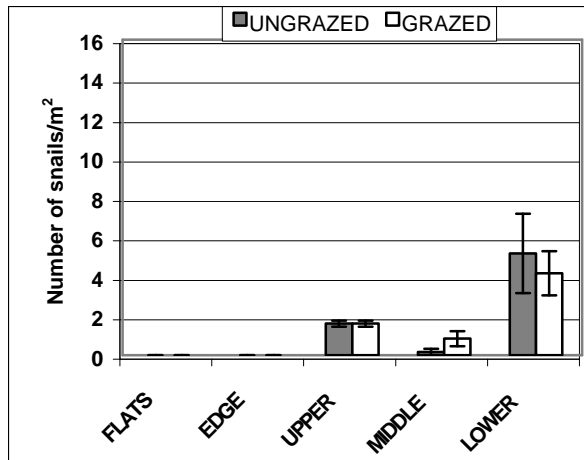
No significant differences in overall size between grazed and ungrazed plots were detected in any zone in any season (Figure 7).

Marsh Periwinkle (Littoraria irrorata) Height of Attachment to Vegetation

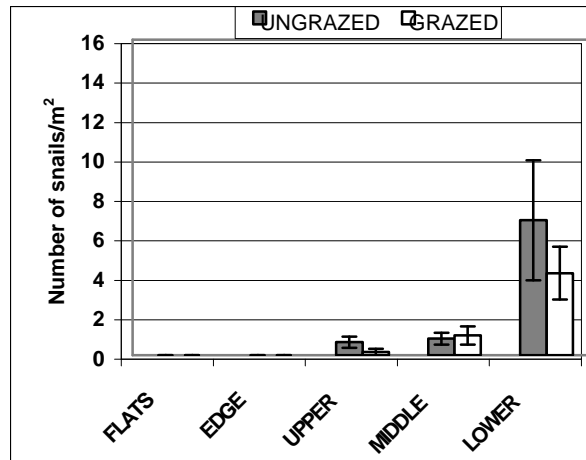
In summer 2000 there was one zone in which there was a significant difference between grazed and ungrazed plots for marsh periwinkle height of attachment to vegetation (Figure 8). The middle zone had a significantly greater height in the ungrazed treatments with a mean of 20.2cm \pm 0 and a grazed mean of 6.59cm \pm 3.14 ($p=0.011$). There was no significant difference for any other zone.

For fall 2000, only the lower marsh elevation zone had significant differences between treatments. Elevation was greater in the grazed treatment with a mean of 9.56cm \pm 2.69 and an ungrazed mean of 3.28cm \pm 0.79 ($p=0.006$). There was no significant difference in any other zone.

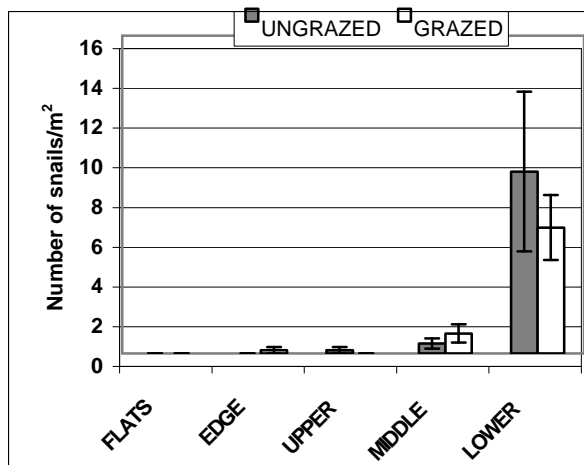
a. Summer 2000



b. Fall 2000



c. Winter 2001



d. Spring 2001

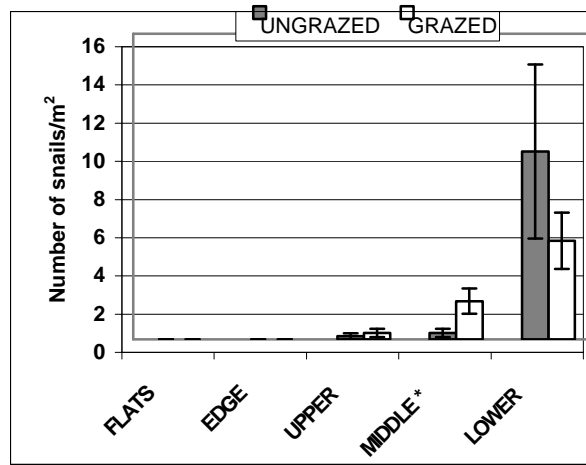
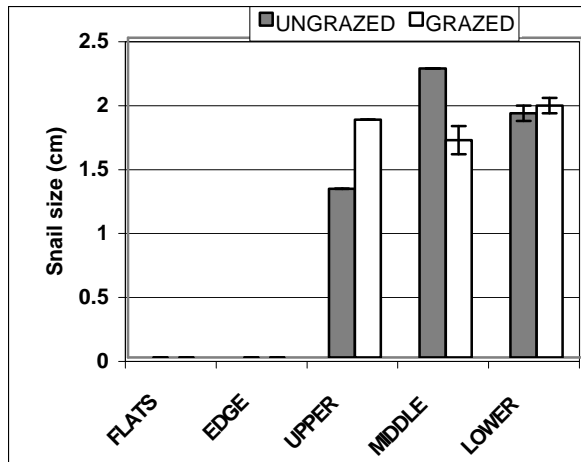
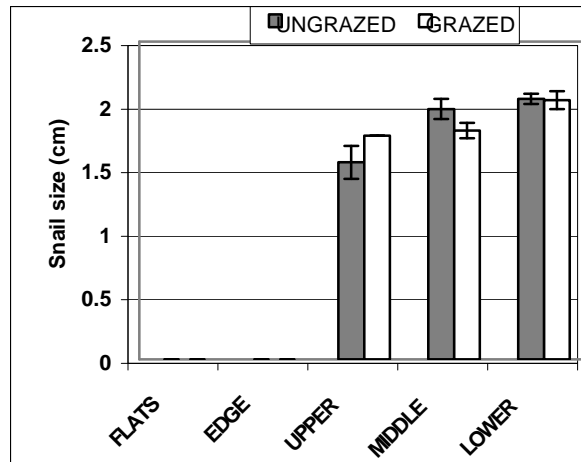


Figure 6. Population density of *Littoraria irrorata* (Mean \pm SE) for four seasons (summer 2000, fall 2000, winter 2001, and spring 2001), at five elevations (high tide flats, edge, upper, middle, and lower) in a Galveston Island salt marsh, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$ (=*).

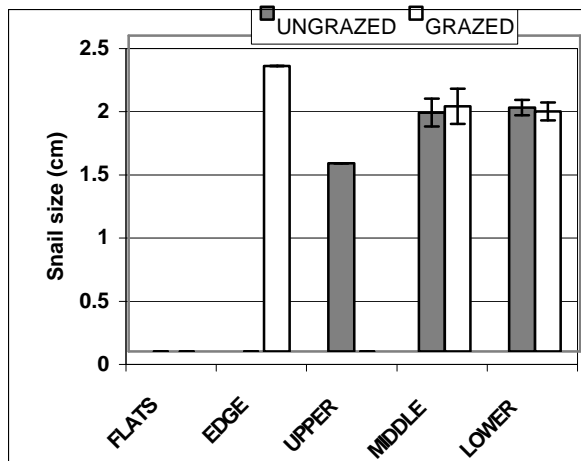
a. Summer 2000



b. Fall 2000



c. Winter 2001



d. Spring 2001

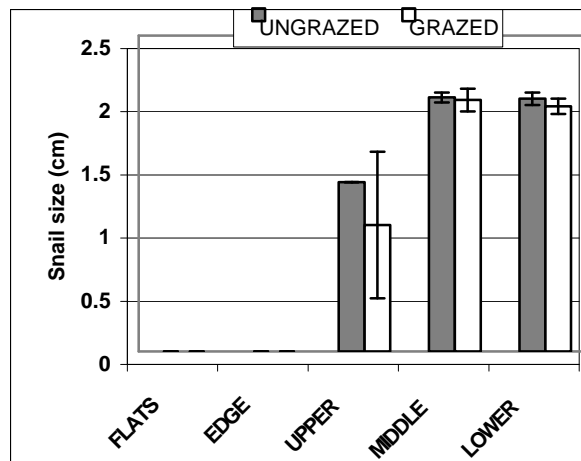
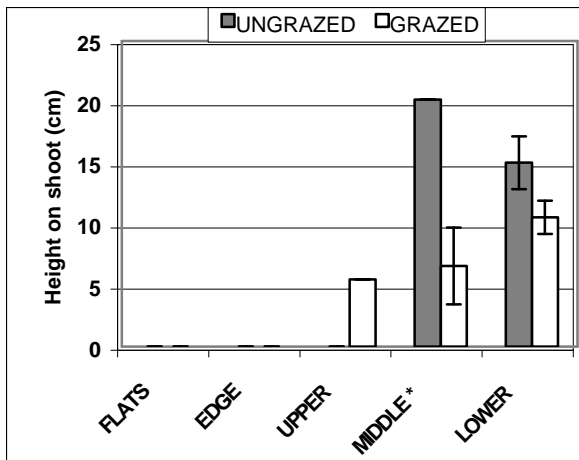
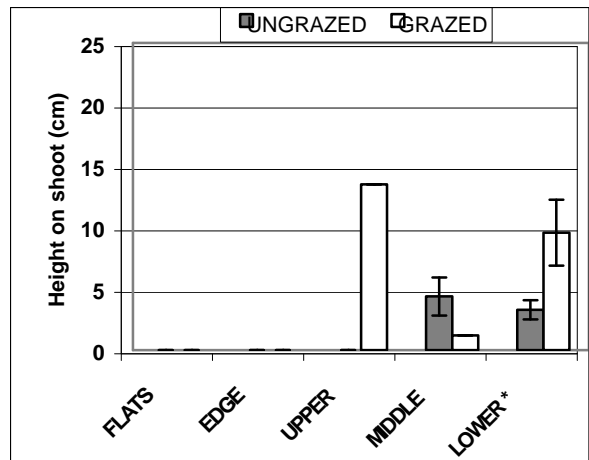


Figure 7. Size of *Littoraria irrorata* (Mean \pm SE) for four seasons (summer 2000, fall 2000, winter 2001, and spring 2001), at five elevations (high tide flats, edge, upper, middle, and lower) in a Galveston Island salt marsh. No significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$ (=*) were found. Lack of error bar indicates single observation.

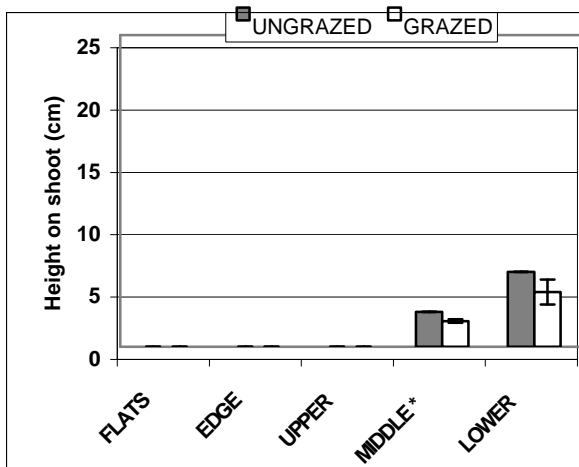
a. Summer 2000



b. Fall 2000



c. Winter 2001



d. Spring 2001

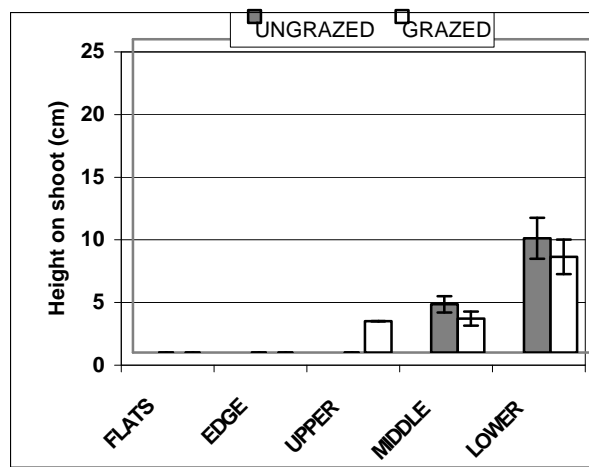


Figure 8. Height of *Littoraria irrorata* on vegetation (Mean \pm SE) for four seasons (summer 2000, fall 2000, winter 2001, and spring 2001), at five elevations (high tide flats, edge, upper, middle, and lower) in a Galveston Island salt marsh, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$ (=*).

In winter 2001 the middle marsh elevation zone was significantly different in height of snails on vegetation. The ungrazed mean was $2.8\text{cm} \pm 0$ while the grazed mean was $2.06\text{cm} \pm 1$ ($p=0.028$). There was no significant difference in any other zone.

Spring 2001 snail height values for ungrazed and grazed treatments were quite similar. Therefore, there was no significant difference in any zone.

Site Interactions

Site interactions occurred at several marsh elevation zones for the marsh periwinkles. Summer 2000 site interactions for snail densities were found in the lower ($p=0.0136$), for snail size in the lower elevation ($p=0.0186$), and height on vegetation in the middle ($p=0.0195$) elevation. In Fall 2000, site interactions for snail densities were found in the lower ($p=0.0021$), for snail size in the lower elevation ($p=0.0366$), and height on vegetation in the lower ($p=0.0023$) elevation. Winter 2001, site interactions for snail densities were found in the lower ($p=0.0004$), and for snail size in the lower elevation ($p=0.0007$). Spring 2001, site interactions for snail densities were found in the upper ($p=0.0404$) and lower ($p=0.0009$), and snail size had a site interaction in the lower ($p=0.0248$) elevation.

DISCUSSION

The only significant difference between treatments for marsh periwinkle density was spring 2001 in the middle zone, in which the grazed treatment was greater than the ungrazed. This may have been due to movement of snails from the lower elevation to the middle as spring tides forced individuals to climb vegetation to avoid submersion and crab predation. Since the threat of water inundation in the middle zone is not as great as in the lower, the snails may have been anticipating the beginning of the feeding season for young blue crabs (May-October) by moving to slightly higher ground (Hamilton 1976). Kim and DeWreede (1996) found a greater density of *Littorina* sp. (snail species undescribed at time of press) in a salt marsh habitat in British Columbia, Canada, in the summer and fall, with declines through the rest of the year. Present findings do not reflect this for the Galveston marsh system. The western Gulf Coast is

not subject to the same set of climatic conditions as are northern regions. Galveston air temperatures rarely decline to freezing. Therefore, snails may not be stressed sufficiently from one season to another to result in a population decrease. *Littorina angulifera* was found to reach highest densities in the winter and spring in a *Spartina alterniflora* marsh in Brazil (Flynn et al. 1996). In the present study, the greatest densities of snails in either treatment were found in the lower zone, also in winter and spring, so it appears that neither trampling nor herbivory reduce the population at this elevation.

No significant differences were detected for the size of marsh periwinkles in grazed versus ungrazed plots through any of the seasons sampled. The food sources were not a limiting factor due to the density of *L. irrorata* being relatively low. Dangers of trampling could have been minimized due to climbing behaviors, therefore cattle grazing apparently did not affect the overall size of marsh periwinkles. Since *Littoraria irrorata* feed primarily on dead *Spartina alterniflora* (59%), the detritus mixed with marsh sediments (37%), live *S. alterniflora* (4%), and algal mats when available, cattle grazing within the marsh may actually increase the available nutrient load by knocking down living and dead stems for the snails to feed on. Filamentous algal mats may increase due to nutrients released during decomposition of cattle urine and feces deposition (Alexander 1979).

The height of positioning on shoots by marsh periwinkles was significantly different between grazed and ungrazed treatments in the middle zone for summer 2000 and fall 2000 (higher in the ungrazed treatments), and the lower elevation for winter 2001 (in the grazed treatment). No difference in height was found in the edge. In the upper zones, only the grazed treatments had one climbing individual apiece for summer, fall, and spring. Climbing appears to be primarily a function of predator avoidance. As tides come in, predatory snails (conchs, whelks, moon snails), blue crabs, and other aquatic predators are able to access the littorinid habitat, and will actually climb the stalks to reach periwinkles just above the water line (Hamilton 1976, Warren 1985). As vegetation becomes scarce, the periwinkles tend to move to more vegetated patches, because in thin vegetation they lose the ability evade these predators. Climbing in littorinids has been shown to provide avoidance, rather than escape from predation, as the snails move too slowly to flee an

attack in progress (Warren 1985). The same researcher found that in areas of stunted, sparse vegetation, snails would actually pile atop each other on the few remaining blades. Most of these areas had few snails, either due to emigration or to being eaten as the habitat thinned. Jacobsen and Stabell (1999) found that *Littorina littorea* would climb above the water line when chemical cues were received that warned of advancing predators, which had recently consumed other members of their species. Failure to ascend shoots may be tied to prevention of water loss that occurs when exposed to air and direct sunlight (Jones and Boulding 1999). These researchers found that large snails seem to prefer more risky, exposed habitats than their younger counterparts, as they can withstand a greater degree of dehydration and benefit from the underutilized microhabitat for feeding.

The density, size, and height on shoots from the present study show that *Littoraria irrorata* in this West End salt marsh ecosystem could have been impacted by the presence of cattle, as Turner (1987) may have predicted. However, statistically significant differences did not occur in most samples. Since the sample plots had only been enclosed for 2 years prior to the experiment, the snail populations may not have had sufficient time to make a full recovery from the grazed to the natural state. This view is supported by the reported problems with repopulating the pipeline disturbance in habitat in South Carolina, which had not recovered in 3-4 years time (Knott et al. 1997).

Any site interactions that were present are likely attributed to the fact that this research was conducted in a recovering marsh system that had once been grazed entirely. Cattle were excluded two years prior to experimentation. Differences may be due to the resultant compaction, differences that may have been created in edge habitat, encroaching tidal creeks formed by cattle paths, or differential flow from uplands that supplied some areas with more urine and feces (increased nutrients/eutrophication). This experiment sought to investigate changes over time, and these plots were established to measure those changes. The unpredictable nature of the environment at large leads to interactions that cannot always be assessed or accounted for.

CHAPTER VI

**SALT MARSH SNAIL (*MELAMPUS BIDENTATUS*) POPULATION DENSITY
AND SIZE DIFFERENCES BETWEEN GRAZED AND UNGRAZED SALT
MARSH ELEVATION ZONES**

INTRODUCTION

Melampus bidentatus Say (Pulmonata: Ellobiidae), the salt marsh snail, is a pulmonate possessing lungs instead of gills. It usually occurs on the marsh mud substrate and is restricted to the highest intertidal areas, which extend from the high marsh zones, made up of stands of *Spartina patens* and *Distichlis spicata* (*Distichlis sporobolus* in some regions), downward to the *Spartina alterniflora* short-form marsh. The snails are typically found among decaying organic litter under vegetative cover, and upon algal accumulations (Kerwin 1972, Price 1980, Britton and Morton 1989). Communities dominated by *Salicornia virginica* tend to have the lowest populations of *M. bidentatus*, in comparison to those composed of *S. patens* and *D. spicata* (Joyce and Weisberg 1986). The ability of the snails to withstand desiccation and submersion permits them to occupy the high intertidal habitat. Adult *M. bidentatus* (>8mm) can endure up to 30 hours of desiccation, and while these pulmonate snails are generally regarded as being terrestrial, they require a salt water medium for dissemination of their planktonic larvae (Price 1980). *M. bidentatus* can tolerate submersion for up to 48 hours, and can survive intermittent flooding for up to 10 days at 20°C, and temperatures down to -12°C for several days (Price 1980, Capaldo 1983). Price (1980) showed that the larger the snails, the more tolerance they have to cold temperatures and submersion.

Joyce and Weisberg (1986) found that smaller, juvenile snails occurred more often in the higher marsh while large, adult snails were more prevalent in the lower marsh. This was interpreted as an adaptation to avoid fish predation, since *Fundulus heteroclitus* (mummichog) prefers snails <7mm due to its small gape size. They found that the average snail population density remained consistent in pens with natural fish population densities, and that there were

more snails in pens with a decreased fish density. The snail population declined by over 50% in overstocked fish pens.

Melampus bidentatus is opportunistic in its feeding habits, eating whatever organic matter it encounters. Approximately 60% of a typical salt marsh snail's gut content is made up of *Spartina alterniflora* and *Spartina patens*. Much of this material is indigestible and is excreted directly back into the environment (Thompson 1984). Spelke et al. (1995) found that *M. bidentatus* preferred *S. alterniflora* and forb clippings over *Spartina patens*, and had a significantly greater growth rate when associated with the former. The snail's activity in winter is greatly reduced, with no feeding and little movement occurring (Grandy 1972, Thompson 1984).

M. bidentatus shows promise for use as a chemical pollution indicator species. Fitzpatrick and Sutherland (1978) added temephos and chlorpyrifos (used to control mosquito larvae) in granular form to experimental plots with salt marsh snails to determine harmful effects by measuring population density changes. The only plots in which a decline in population density occurred were those subjected to repeated constant application. The populations recovered rapidly and completely, however, upon removal of the treatments. As yet, no studies have been published that address the possible effects of cattle grazing on the population dynamics of *M. bidentatus* (due to trampling and vegetation reduction). Further studies upon the predators of *M. bidentatus* may reveal additive food web interactions, as the snails consume the primary producers that form the base of the food chain, and are in turn fed upon by larger species. Studies on the ecology of marshes and the environmental factors that control dispersal, population densities, reproductive strategies, etc. may lead to the use of *M. bidentatus* as an indicator species to gauge the health of marshes. The objective of this chapter is to determine the effects of cattle activity on salt marsh snails (*Melampus bidentatus*) in a salt marsh dominated by *Spartina alterniflora* and *Salicornia virginica* and on a high unvegetated zone (tidal flat).

METHODS

Grazed and ungrazed treatments established in spring 1998 (as described in the methods section of chapter II) were used to examine the effects of cattle grazing on salt marsh

snails. Population density (n/m^2) and *Melampus bidentatus* size were recorded within each quadrat. Each shell was examined to verify the presence of a live snail (empty shells were excluded). The snails were counted and the shell length of each individual was measured to the nearest 1/10 mm with calipers. The density and mean size of each snail population was calculated for each of the quadrats by elevation zone (high tide flats, marsh edge, upper marsh, middle marsh, and lower marsh) and grazing treatments (grazed and ungrazed).

Data were analyzed by elevation zone using the null hypothesis that there was no difference in population density and the size of individuals of the target species in grazed and ungrazed treatments. A two-factor ANOVA was used to determine if there were significant differences ($\alpha=0.05$) in these measurements using the “Proc GLM” procedures in SAS to test the grazing treatment and site effects. The GLM model used was:

“Dependent Variable” = Treatment Site Treatment X Site Error.

RESULTS

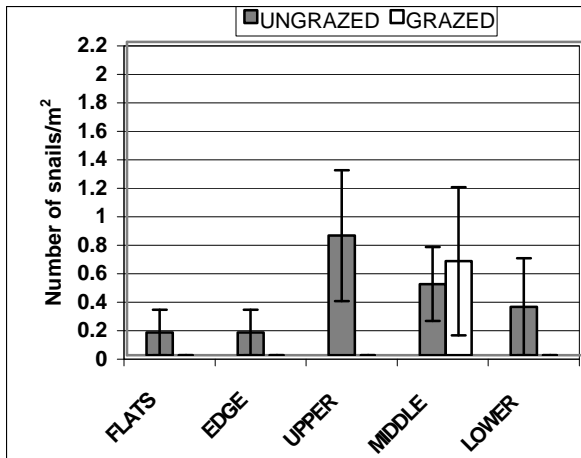
Salt Marsh Snail (Melampus bidentatus) Population Density

In summer 2000, the numbers of salt marsh snails in the grazed treatment were too low to permit effective comparison of the treatment populations (Figure 9). Therefore, there were no significant population density differences between grazed and ungrazed plots in any zone.

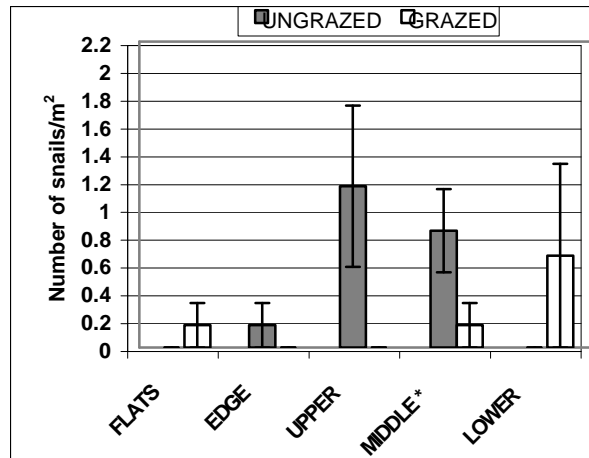
In fall 2000, only the middle marsh elevation zone showed significant differences in population density. There was a significantly higher population density for the ungrazed treatment with a mean of $0.84 \text{ snails}/m^2 \pm 0.30$ versus a grazed mean of $0.16 \text{ snails}/m^2 \pm 0.16$ ($p=0.042$). There were no significant differences between treatments in any of the other zones.

In winter 2001, only the upper marsh zone was significantly different for treatment. There was a significantly higher population density in the ungrazed treatment, with a mean of $1.50 \text{ snails}/m^2 \pm 0.66$ compared to the absence of *Melampus bidentatus* in the grazed treatment ($p=0.029$). There were no significant differences between treatments in any other zone.

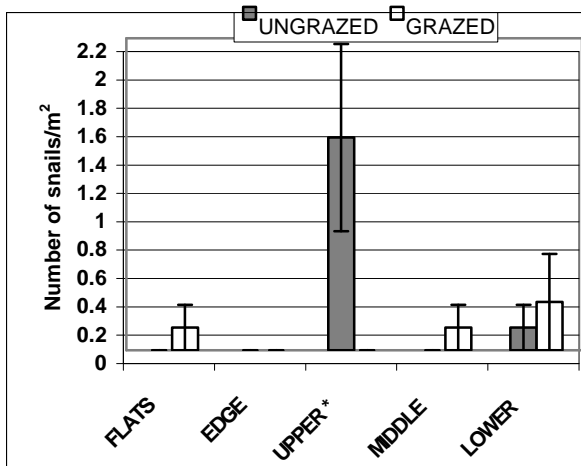
a. Summer 2000



b. Fall 2000



c. Winter 2001



d. Spring 2001

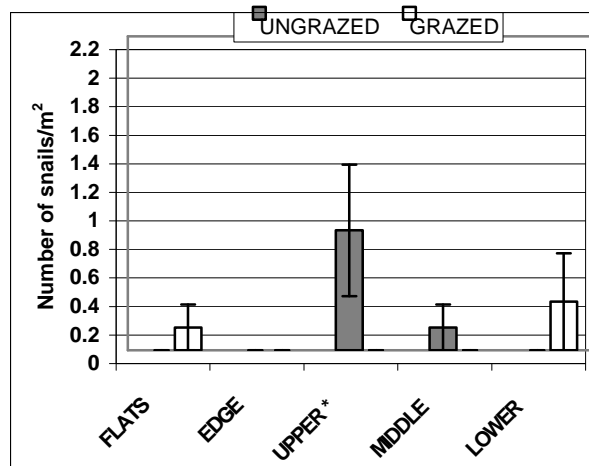
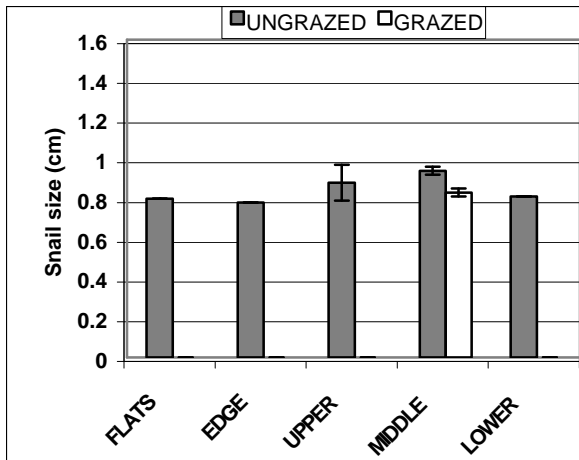
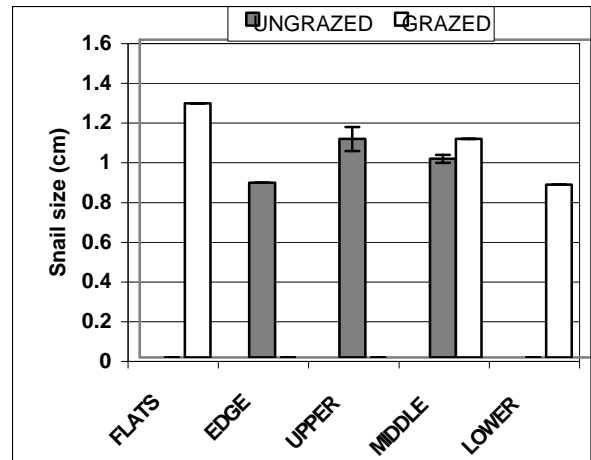


Figure 9. Population density of *Melampus bidentatus* (Mean \pm SE) for four seasons (summer 2000, fall 2000, winter 2001, and spring 2001), at five elevations (high tide flats, edge, upper, middle, and lower) in a Galveston Island salt marsh, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$ (=*).

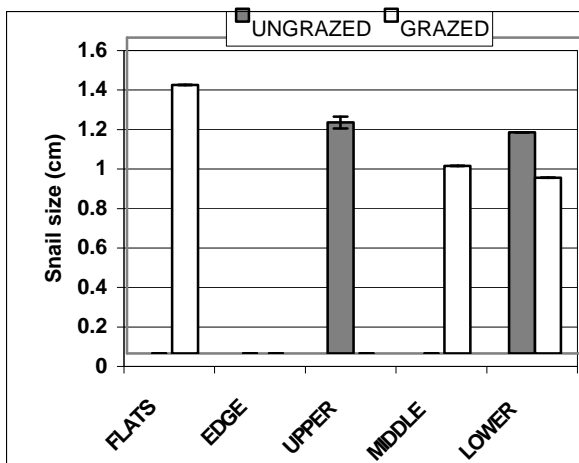
a. Summer 2000



b. Fall 2000



c. Winter 2001



d. Spring 2001

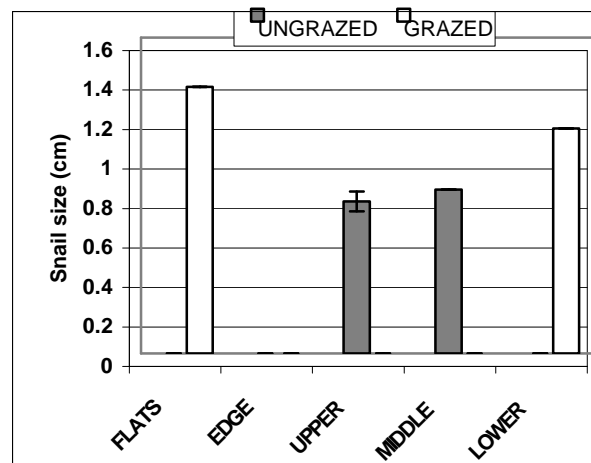


Figure 10. Size of *Melampus bidentatus* (Mean + SE) for four seasons (summer 2000, fall 2000, winter 2001, and spring 2001), at five elevations (high tide flats, edge, upper, middle, and lower) in a Galveston Island salt marsh, testing for significant differences by grazing treatment (grazed and ungrazed) at a significance level of $\alpha=0.05$. No significant differences were detected. Lack of error bars indicates single observation.

For spring 2001, the upper marsh was the only zone significantly different for treatment. The ungrazed treatment was higher in population density in the upper marsh with a mean of 0.84 snails/m² \pm 0.46 compared to an absence of *Melampus bidentatus* in the grazed treatment ($p=0.018$). There were no significant differences in any other zone.

Salt Marsh Snail (Melampus bidentatus) Size

Because of the absence of snails in the grazed treatment, too few measurements were obtained to permit an accurate comparison of treatments by elevation zone for salt marsh snail size. Therefore, no statistically significant differences were detected in any zone. However, the values of the snail sizes that were observed are reported in Figure 10.

Site Interactions

Site interactions occurred at several marsh elevation zones for the salt marsh snail. In Fall 2000, the only site interactions were for snail density in the middle elevation ($p=0.0484$). Spring 2001 only had site interactions for snail density in the upper elevation ($p=0.0062$).

DISCUSSION

The greatest populations in these disturbed marshes appear to reside in the upper and middle marsh elevation zones that are predominantly inhabited by *Spartina alterniflora* short-form and are inundated infrequently by high salinity salt water. This situation was also found elsewhere by others (McMahon and Russell-Hunter 1981, Fell and Williams 1985, Burnham and Fell 1989, Peck et al. 1994). Although the snails require salt water for their reproductive stages, they are otherwise semi-terrestrial, so the central elevations within the marsh are optimal for growth and survival. The periodic submersion provides moisture and soil salinity is high.

The general lack of significant differences between treatments of salt marsh snail density for summer 2000 could be attributed to the lower tides and lack of freshwater addition to the marsh system as little rain occurred. Though the snails prefer higher soil salinity, they also need occasional inundation to avoid desiccation and to produce their planktonic veliger larvae, which

require a salt water medium (Price 1980, McMahon and Russell-Hunter 1981, Burnham and Fell 1989).

The only significant difference in grazing treatments for the density of salt marsh snails in the fall was the middle marsh elevation, while the winter and spring each had significant differences in the upper marsh only. Though the overall number of snails was low, significantly greater numbers occurred in the ungrazed treatments of these zones. This indicates a slight reduction in the population of *M. bidentatus* due to the presence of cattle. In general, the population distributions found in the ungrazed treatment of the current study are similar to the results found in restored marsh systems, as compared to stable, undisturbed marshes (Fell et al. 1991, Peck et al. 1994).

As tides encroach, a few adult snails may climb vegetation to escape imminent submersion, but they descend immediately after the water recedes (Price 1984). This behavior has not been observed in juveniles, and may also be one of the factors limiting the presence of juvenile snails in the present study, as they were probably in higher regions of the marsh that weren't sampled.

No significant differences in shell length were found between treatments for salt marsh snails, with relatively consistent sizes occurring in all elevation zones and seasons. The presence of cattle does not appear to have a negative effect on the overall growth of *M. bidentatus*. However, the individuals sampled were all ~ 8mm or greater and thus classified as adults. The small size of the juveniles may have caused them to have been occasionally overlooked. However, juvenile horn snails of similar size were present and those were accounted for, so it is not likely that *Melampus bidentatus* juveniles were overlooked. Juveniles have also been shown to move into higher marsh elevations, and adults into the lower marsh in response to predation (Joyce and Weisberg 1986). Historic grazing in the research site may have left all the sample plots with channels that allow predatory fishes to move further into *M. bidentatus* habitat, thereby increasing the amount of predation in the higher marsh elevations and limiting the prevalence of young snails. It is possible that the lack of juveniles is a direct correlation to the trampling and habitat removal by cattle, as well as pollution by feces and urine. Trampling of the

snails by livestock may have limited the population to snails large enough to withstand the physical constraints of trampling. Developing juveniles may simply not be able to endure the pressure of the hooves or the burial within sediment that occurs when trampled. The predominance of snails of larger size could also be attributed to cattle presence, through which an influx of nutrients from urine and feces deposition may have afforded the snails a greater food source due to extra fertilization for growth of algae and marsh grasses (Peck et al. 1994).

Salt marsh snails are typically found beneath the cover of plants and debris during the heat of the day, and they move more freely during the night (Holle and Dineen 1957). In the present study, most snails were also retrieved from beneath, or on, *Spartina alterniflora* and *Salicornia virginica* during the daytime sampling.

The ungrazed treatments in the present study appear to show impacts from previous grazing. Comparisons of the population density and snail size between an undisturbed marsh in close proximity to a marsh with newly introduced grazers would be a good baseline measurement to allow for modeling of how the species will adapt to different intensities of grazing. This technique could then be expanded to model environmental impacts other than grazing, which may allow for construction of a model to determine the rate of success of newly established marshes, and the rate of recovery in disturbed marshes.

Any site interactions that were present are likely attributed to the fact that this research was conducted in a recovering marsh system that had once been grazed entirely. Cattle were excluded two years prior to experimentation. Differences may be due to the resultant compaction, differing edge habitats, encroaching tidal creeks formed by cattle paths, or differential flow from uplands that supplied some areas with more urine and feces (increased nutrients/eutrophication). This study sought to investigate changes over time, and these plots were established to measure those changes. The unpredictable nature of the environment at large leads to interactions that cannot always be assessed or accounted for.

CHAPTER VII

SUMMARY

The height of vegetation in a West End Galveston salt marsh was significantly greater for *Spartina alterniflora* and *Salicornia virginica* in ungrazed areas than in those that were continually grazed by cattle. This confirms that the heights of vegetation within a grazed system are significantly reduced by herbivory and trampling.

Salicornia bigelovii usually had significantly greater percent coverage and higher stem densities in the edge marsh elevation zone of grazed treatments in winter and spring. Populations were similar between treatments in the high tide flats, so it is hypothesized that grazing/trampling in the edge marsh zone stimulates growth of this species. Conversely, the high salinity colonizer did not require such stimulation in the tide flats and occurred in similar numbers between treatments. *S. virginica* appeared to be very sparse in the high tide flats probably as a result of high soil salinity rather than grazing.

Total percent vegetative cover in the ungrazed treatments was almost twice that found in the grazed treatments for the edge and upper marsh, indicating that grazing and trampling resulted in a marked decline on the aerial coverage of these plots. Although cover in the ungrazed middle zone was significantly greater for three seasons, the difference was not as great. It seems the impact of grazing and trampling upon overall percent vegetative cover is greatest at the edge and upper marsh.

The upper and middle marsh had very few statistically significant measurements of *S. alterniflora* and *S. virginica* percent coverage, and no significant differences in stem density between treatments. However, the upper and middle marsh total vegetative cover was significantly greater in the ungrazed treatments, so the cumulative effects of grazing are significant, though measurements among individual species were few.

The edge elevation *S. alterniflora* had a significantly greater stem density in the ungrazed treatments in summer, fall, and spring. This may be attributed to the prevalence of young stems in the undisturbed plots, versus the grazed plots where seedlings of *Spartina* may find it more

difficult to colonize. Upon introduction of grazers at the sensitive edge elevation, young plants would have multiple factors to contend with upon establishment. At the edge elevation, *S. virginica* percent cover and stem density was significantly greater in every season in the ungrazed treatment versus grazed. It appears that even though *S. virginica* has a high salinity tolerance, it has low tolerance for physical manipulation.

Significantly greater cover and stem density of *S. alterniflora* occurred in lower marsh grazed treatments while a significantly greater percent coverage and stem density occurred for *S. virginica* in ungrazed treatments. This increase in *S. virginica* is likely a response to *S. alterniflora* wrack damage to plants, which doesn't occur as often in grazed marshes because the cattle consume the vegetation that would otherwise become wrack.

Stem density of *S. alterniflora* increased from a summer low to fall, peaking in winter, with a slight reduction in spring. Stem density is an important factor in reduction of shoreline erosion.

The edge marsh had a significantly greater burrowing crab density in the ungrazed treatment for every season. This may be due to the significantly greater coverage of vegetation in the ungrazed treatment, as well as a response to trampling in the grazed treatment. Trampling may make it too costly for the crabs to maintain burrows in the grazed edge zone, and direct mortality from trampling may occur as well.

Removal of detrital and vegetative cover by cattle may have been a limiting factor in population densities of fiddler and marsh crabs since they utilize these resources as food and habitat. As grazing impacts to vegetation decreased close to the water's edge, noticeable increases in densities of crabs in the grazed treatments occurred as well.

The interactions of fiddler and marsh crabs amongst the vegetation and sediments of the marsh are disrupted by cattle grazing. The trampling that occurs during grazing causes vegetation shifts, soil compaction, and direct mortality of crabs. When crab population densities decrease, not only are the plants affected, but predators of the crabs are affected as well. Less cover from vegetation may result in greater predation, and decreases in crab populations may significantly increase competition among predators.

Cerithidea pliculosa communities are affected in several ways by cattle activity. Population densities increase significantly, primarily in the upper zone, in grazed treatments, while the horn snails in ungrazed marshes attain overall greater size. Grazed treatments were dominated by juveniles between 1.5-2.0cm, while the ungrazed treatment contained small adults >2.0cm. The ungrazed edge zone may have a greater density of snails due to significantly greater *S. virginica* stem density, heights, and percent cover.

Population density and snail size for *Littoraria irrorata* were not significantly reduced between treatments in response to current cattle activity. The relatively low number of measurements in the ungrazed treatment may be due to previous activity prior to cattle exclusion, and the system simply hasn't had enough time to recover.

Melampus bidentatus was found to primarily reside in the upper and middle marsh zones dominated by *S. alterniflora* short-form. Decreases in population density were detected in response to cattle grazing, and although snail size was not significantly different between treatments, no juveniles were found in any samples. The snail size measurements were similar to those found in recovering marshes, therefore the ungrazed treatment still appears to show lingering effects from the grazing that occurred prior to the construction of the enclosures. This indicates that *M. bidentatus* is sensitive to habitat disturbance, and populations may take many years to return to natural levels.

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GRADUATE EXPERIENCE

Graduate Teaching Assistant – Laboratory instructor for courses in Marine Botany and Biology II

Graduate Research Assistant – Conducted beach elevational surveys to determine loss/gain in slope. Transplanted vegetation into a created dune system, set up experimental plots to assess growth and survival of transplants, and helped maintain a coastal plant nursery. Supervised placement of alignment stakes for a geotube project to minimize the impact on the natural dune vegetation line. Conducted beach and street elevational surveys to assess what impact natural flow and drainage systems within the community would have on the artificial dune system. The project was mapped with the use of GIS, involving ArcView and Microsoft Excel software

Sea Camp and Galveston Graduate Student Association (GGSA) Instructor – Instructed children and college students for Texas A&M's SeaCamp Program, and for GGSA Field Trips, covering various biological topics (dissections, coastal flora and fauna, dune habitats, fishing trawls, marsh seine tows, and ecology lectures).

OTHER PROFESSIONAL EXPERIENCE

Undergraduate Research Assistant – Performed phytoplankton tows to assess the quality and quantity of phytoplankton in Galveston, Texas. Used photographic analysis of species to construct a detailed identification guide to local organisms. Performed population counts.

Undergraduate Independent Research - Performed dissections on coastal birds that died within the care of wildlife rehabilitation stations or local veterinary hospitals to determine probable cause of death, and to quantify parasite load. Parasites were identified, and preserved for future analysis.

National Marine Fisheries Service, Biological Technician - Assisted in bay sampling of flora and fauna present at dredge spoil island habitats, and natural seagrass beds in Corpus Christi, TX and Galveston Bay, TX. Performed analysis of organisms (i.e. fish, crabs, shrimp, seagrasses) caught within drop samples, sediment cores, and various experimental frame techniques. Conducted biomass determinations.