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Reithrodontomys Raviventris: microhabitat associations in a diked marsh

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***REITHRODONTOMYS RAVIVENTRIS*:**

MICROHABITAT ASSOCIATIONS IN A DIKED MARSH

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ABSTRACT

REITHRODONTOMYS RAVIVENTRIS: MICROHABITAT ASSOCIATIONS IN A DIKED MARSH

By Gretchen Padgett-Flohr

I used a random trapping technique to determine the distribution of salt marsh harvest mice, *Reithrodontomys raviventris,* across a diked pickleweed marsh and to test the null hypothesis that this species' distribution is not associated with the microhabitat variables of pickleweed salinity, sympatric rodent species nor the site location (peripheral versus interior). This study spanned the pre-breeding, breeding and post-breeding phases of the annual cycle. In the pre-breeding phase, salt marsh harvest mice were randomly dispersed. However, in the breeding and post-breeding phases, the population was clumped and associated with sites of mid-range salinities in pickleweed. I found salt marsh harvest mice throughout the marsh and detected no preference for interior versus peripheral sites. No significant relationships were detected between salt marsh harvest mice and sympatric rodent species: California meadow vole, *Microtus californicus*, western harvest mouse, *R. megalotis* and the non-native house mouse, *Mus musculus*.

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INTRODUCTION

Successful conservation of an endangered species such as the salt marsh harvest mouse, *Reithrodontomys raviventris*, (SMHM) requires detailed knowledge of its habitats and microhabitats as well as its biology, as many species are endangered due to the loss of habitat or a decline in habitat quality. The failure to adequately examine and describe specific microhabitat features may lead to misunderstanding a species' habitat requirements and potentially could result in inappropriate management decisions.

Salt marsh harvest mice are endemic to the salt and brackish marshes of the San Francisco Bay (Fisler 1965, Dixon 1908) but suitable habitat is declining. To date, 313 mi^2 (80%) of the historic tidal marshes have been destroyed through filling, diking or subsidence (Shellhammer *et al.* 1982). Sixty percent of the remaining habitat is now diked (Nichols and Wright 1971, Shellhammer *et al.* 1988) resulting in highly altered, disjunct and isolated patches of former habitat.

Pickleweed is the dominant halophytic vegetation in most tidal salt marshes (Mason 1957). Numerous scientists have concluded that the optimal macrohabitat of SMHM is one dominated by pickleweed (*Salicornia virginica*) (Fisler 1965, Wondollek *et al.* 1976, Shellhammer *et al.* 1982, Shellhammer *et al.* 1988, Johnson and Shellhammer 1988); especially when thick stands are heterogeneously mixed with other marsh species *e.g.*: alkali heath, *Frankenia grandifolia*, (Shellhammer *et al.* 1988). However previous research was restricted largely to pickleweed patches within entire marshes and did not address the distribution of SMHM within these patches nor the specific microhabitat requirements of the mouse.

A few studies have been conducted to examine salinity as one potentially important microhabitat requirement for SMHM. Fisler (1963, 1965), Zetterquist (1977) and Geissel *et al.* (1988) concluded that SMHM are well adapted to hypersaline environments. Zetterquist (1977) and Geissel *et al.* (1988) had the greatest capture success of SMHM in areas of high salinity. Fisler documented the dietary habits of SMHM and found that they ingest salt through both food and water. Pickleweed is the main component of the diet of *R. raviventris raviventris* and the mice of that subspecies will also preferentially drink saline water slightly less concentrated than seawater, even if offered fresh water (Haines 1944, Fisler 1963, 1965). However, since salinity intake is a limiting factor for many species, including SMHM (Fisler 1965), it seemed appropriate to investigate possible associations between salinity in pickleweed and the distribution of the mice. The salinity concentration within stands of pickleweed could vary on a microhabitat scale and this variation could be associated with the distribution SMHM within these stands.

Interspecific interactions could also potentially affect the distribution of SMHM within their preferred macrohabitat. The western harvest mouse (*R. megalotis*), California meadow vole (*Microtus californicus*) and house mouse (*Mus musculus)* are sympatric species commonly found within diked and tidal salt marshes (Fisler 1965, Zetterquist 1977, Shellhammer *et al.* 1988, Geissel *et al.* 1988). In their 1988 study conducted on the macrohabitat scale, Geissel *et al.* concluded that competition exists between SMHM and meadow voles. They determined that SMHM are forced into lesser quality habitat in the presence of high densities of meadow voles and can only move into better quality habitat when vole numbers decline.

Previous research on macrohabitat preferences of SMHM however, employed non-random sampling schemes, which reduced the inference of microhabitat preferences to specific areas within the marsh and may have introduced bias in the findings. Geissel *et al.* (1988) restricted their observations to an area covering less than 3 ha within a 142 ha marsh because this area had been sampled in previous censuses. Yet they inferred conclusions and applied them to the entire marsh. Rice (1974) placed three transects along a dike in Triangle Marsh, locating individual traps in proximity to meadow vole runways but did not trap in the marsh proper because of the complications associated with trapping the tidal plain. As in the case of Geissel *et al.*, Rice inferred her conclusions for all of Triangle Marsh even though she had trapped only a peripheral dike area.

Trapping sites have often been selected based on characteristics believed to be important by the investigator but not verified as important. Muench located her traps under "good vegetation cover" (Muench 1985, page 10) and followed Rice's method of situating the traps in close proximity to meadow vole runways, even though the possible significance of rodent runways to SMHM has never been investigated.

Therefore, since microhabitat preferences of SMHM are unknown, researchers may introduce another form of bias, by choosing and identifying their study sites based on perceived optimal or marginal conditions. Zetterquist (1977, page 74) trapping in seven areas between three sites, chose trapping locations to represent a "broad spectrum of marginal conditions." Johnson and Shellhammer (1988, page 2) used a study site based on its "overall vegetation pattern, accessibility and ownership" and then placed traps to "encompass all of the potential SMHM habitats on site." Geissel *et al.* (1988) concluded that SMHM only occupy optimal habitat when meadow vole numbers decline, yet a definition of optimal habitat from a mouse's perspective is not possible since microhabitat preferences are unknown. Hence, most previous studies of SMHM have examined macrohabitat preferences within small areas employing a non-random human perspective, which has made interpretation of results difficult. Restriction of research to such areas may reduce the possibility of identifying actual microhabitat requirements.

In addition to non-random methodology, small sample sizes can also lead to difficulties in data interpretation and misunderstanding of a species' habitat requirements. Studies resulting in small sample sizes greatly reduce the researchers' ability to perform statistical analyses or to reach valid conclusions concerning their research question. A common practice with studies of endangered species (which generate small sample sizes) is the pooling of data across the study period in order to perform statistical analysis (Schroder 1987). Small sample sizes and pooling of data have characterized past SMHM research (Rice 1974, Zetterquist 1977, Geissel *et al.* 1988).

In this study I attempted to circumvent some of the problems associated with previous studies with respect to identifying potential microhabitat requirements or constraints affecting the localized distribution of SMHM. To minimize problems associated with sampling, I employed a randomized design with a large sample size of sites.

In spring 1996 I successfully tested the feasibility of such a design in a pilot study conducted at the New Chicago Marsh, San Francisco Bay National Wildlife Refuge. In addition to testing the feasibility of the random trapping technique, I examined habitat features potentially important to the distribution of the SMHM. Salt marsh harvest mouse captures were evaluated for distributional patterns and possible associations with a particular mean: 1) percent cover of marsh plant species- individually and combined, 2) height of vegetation, or 3) ratio of green to brown vegetation.

I determined that New Chicago Marsh was highly homogeneous with pickleweed dominating the habitat with a relative cover of 66%. Pickleweed was present at 95% of the trap sites. The SMHM population was distributed in a clumped pattern within the pickleweed marsh, but there was no difference in measured habitat variables where the mice were present versus absent. The mice were not associated with any of the habitat variables I tested (Flohr, 1996) and I concluded that within predominantly pickleweed marshes, habitat features as yet unidentified were potentially influencing SMHM distribution.

In the 1997 field season I examined salinity concentrations in pickleweed at randomly chosen trapping sites. Vegetation composition was analyzed for each trap site. Salt marsh harvest mouse captures were evaluated for distributional patterns and possible associations with particular salinity levels in pickleweed. Preferential association with a certain salinity level in the primary component of their diet (pickleweed) could indicate that salinity of pickleweed is a specific microhabitat requirement for SMHM. Since choice of microhabitat can also be related to or influenced by interspecific interactions, I attempted to identify potential interactions between SMHM and the three sympatric species found within the microhabitat: California meadow vole, western harvest mouse and house mouse.

MATERIALS AND METHODS

Study site.—New Chicago Marsh (NCM) is a 142 ha (340 acre) diked marsh in the southern end of the San Francisco Bay National Wildlife Refuge (SFBNWR). In the mid-1990's, the marsh was modified to allow tidal water to enter the system. Water levels are maintained using a manually operated tide-gate at the inlet, located 1.5 km north of Triangle Marsh and pumps at the outlet (Hecht and Seel 1990; Fig. 1). Under diked conditions, soil salinities have become higher and the soil pH more basic than nearby tidal marshes (Eicher 1988). The New Chicago Marsh is predominantly pickleweed however the microhabitat reflects the alteration of the site from tidal to diked marsh and consists of a continuum of types ranging from one dominated by grass (introduced annuals and saltgrass, *Distichlis spicata*) with no pickleweed, to one consisting of 100% pickleweed.

Methodology and trapping procedure.—A topographic map of NCM was divided into 207 50 x 50 m blocks and 40 blocks (1 block = 1 trapping site) were randomly chosen and subsequently characterized as being interior or peripheral sites. "Interior sites" were in portions of the marsh that were flooded (or bounded by water on all sides) and were accessible only by kayak. "Peripheral sites" were located around the periphery of the marsh and contiguous with the inland landmass; these were accessible on foot (Fig. 2). Twenty sites were designated as "interior" and twenty designated as "peripheral." Total vegetative species composition was determined for each site using the intercept line transect method. Horizontal coverage of vegetation was measured to the nearest 5 cm

FIG. 1.—New Chicago Marsh (NCM) is a diked marsh within the San Francisco Bay National Wildlife Refuge, Alviso, California. NCM experiences muted tidal flow during high tides as water enters from the inlet 1.5 km north at Triangle Marsh. Water is circulated and excess volume is removed by a pump at the outlet in the southwestern corner of the NCM.

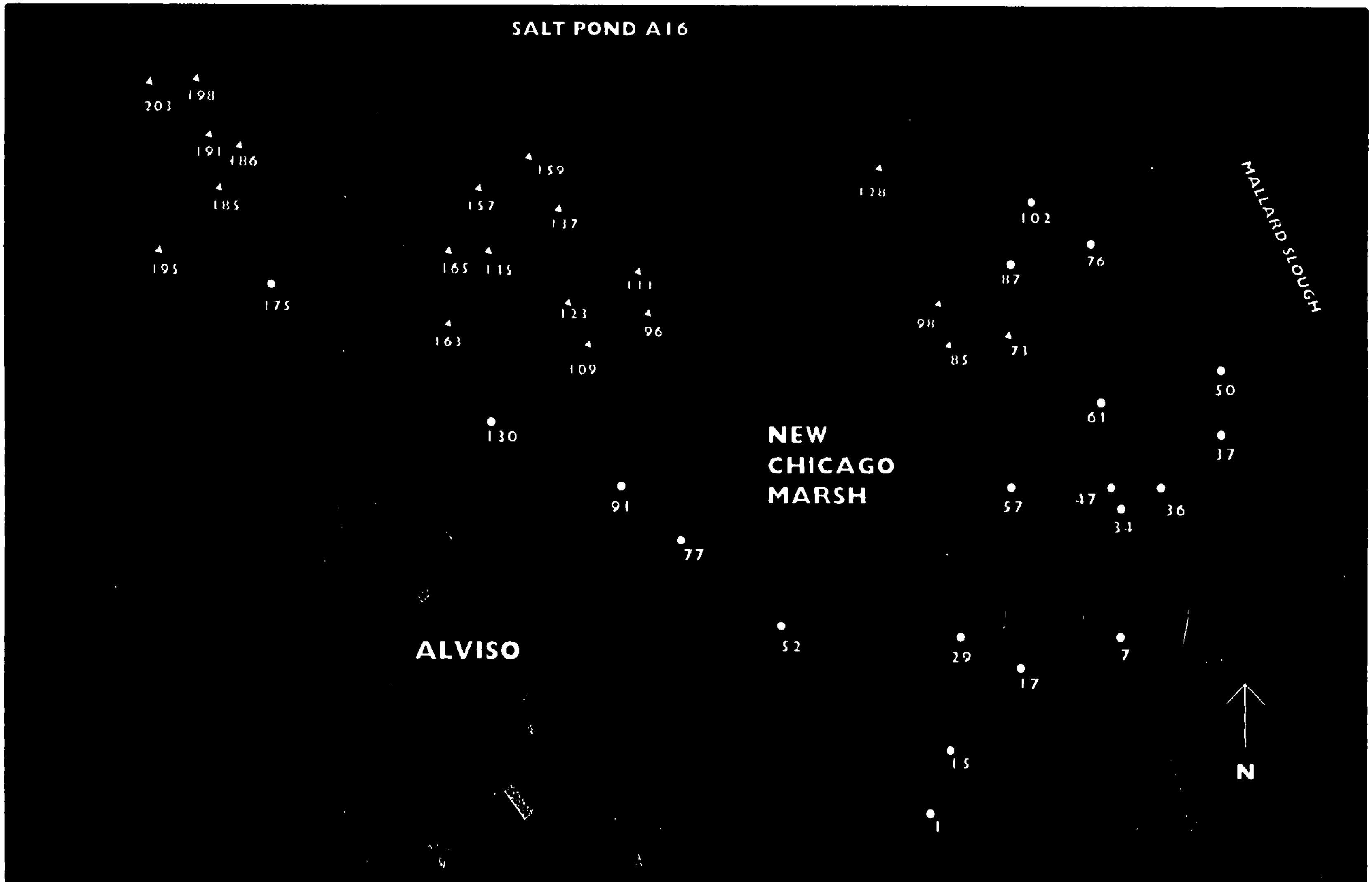

Fig. 2.— Random trapping locations; New Chicago Marsh, Alviso, California. Spring 1997. Twenty sites characterized as "interior", were accessed by boat (◁). Twenty sites characterized as "peripheral" were accessed on foot (○).

(Brower *et al.* 1989). At each of the forty sites, for each sampling period, pickleweed was collected and analyzed for mean salinity content (expressed as mmol/kg of Cl^-).

Trapping was conducted for six months from April 1997 to September 1997. At each site, three Sherman live traps were placed 5 m apart in a triangle for a total of 120 traps. Traps were baited with bird seed and crushed walnuts and supplied with cotton bedding. They were operated for four nights each month for a total of 2,880 trap nights. Traps were set at dusk and all animals were released within one hour of sunrise as per Federal Permits held by H. S. Shellhammer.

Rodents were ear-tagged with unique numbered tags, sexed, measured and weighed. All rodents were identified to species. Salt marsh harvest mice were differentiated from western harvest mice using criteria developed by Fisler (1965) and refined by Shellhammer (1984).

Distribution of salt marsh harvest mice.—The study period was divided into three phases: pre-breeding (April-May), breeding (June-July) and post-breeding (August-September). A Goodness of Fit test to a Poisson (Tabachnick and Fidell 1989, Zar 1984) was performed on the capture data from each phase to determine whether the population distribution of SMHM was random or patterned. For those phases in which a pattern was exhibited, the coefficient of dispersion was used to determine if the distribution of SMHM was clumped or uniform.

Vegetation Composition.—Descriptive statistics were calculated to describe the vegetative composition of the marsh. Relative cover of the three most prevalent species was determined. Presence and relative cover of pickleweed was determined for all sites.

Salinity.—To determine if salinity of pickleweed was related to the presence or absence of SMHM, sites were classified as to whether or not SMHM was present. An independent two-sample *t*-test (Tabachnik and Fidell 1989, Zar 1984) was performed to determine if mean pickleweed salinity differed between sites in which SMHM was present and absent.

Associations between salt marsh harvest mice and microhabitat variables.—A five-way hierarchical loglinear analysis (Tabachnick and Fidell 1989, Zar 1984) was used to test for associations between the presence/absence of SMHM, pickleweed salinity and the presence/absence of other rodent species. For this analysis, data were restricted to the time periods that illustrated a significant clumped or uniform distribution. Salinity data were ordinated into levels 0-5, with (L)5 being the highest salinity concentration. The six levels designated for salinity were as follows: <399 mmol/kg CL^{-}= level (L)0; 400-499 mmol/kg CL^{-}= (L)1; 500-599 mmol/kg CL^{-}= (L)2; 600-699 mmol/kg CL^{-}= (L)3; 700-799 mmol/kg CL^{-}= (L)4; 800-899 mmol/kg CL^{-}= (L)5. Sites were characterized for presence/absence of SMHM, western harvest mouse, meadow vole and house mouse.

An additional analysis was performed to determine whether site location (peripheral or interior) affected associations between SMHM, pickleweed salinity and the presence/absence of other rodent species. A six-way hierarchical loglinear analysis was performed; it included all variables from the previous loglinear analysis plus site location.

RESULTS

Rodent Species.—During the study period, April to September 1997, 184 rodents were captured 440 times. Among captures were 54 SMHM (115 captures), 23 western harvest mice (63 captures), and 4 harvest mice that could not be identified to species (9 captures). Other rodents caught included 78 meadow voles (201 captures) and 29 house mice (61 captures) (Fig. 3, Appendix A). Three shrews (*Sorex* spp.) were also caught.

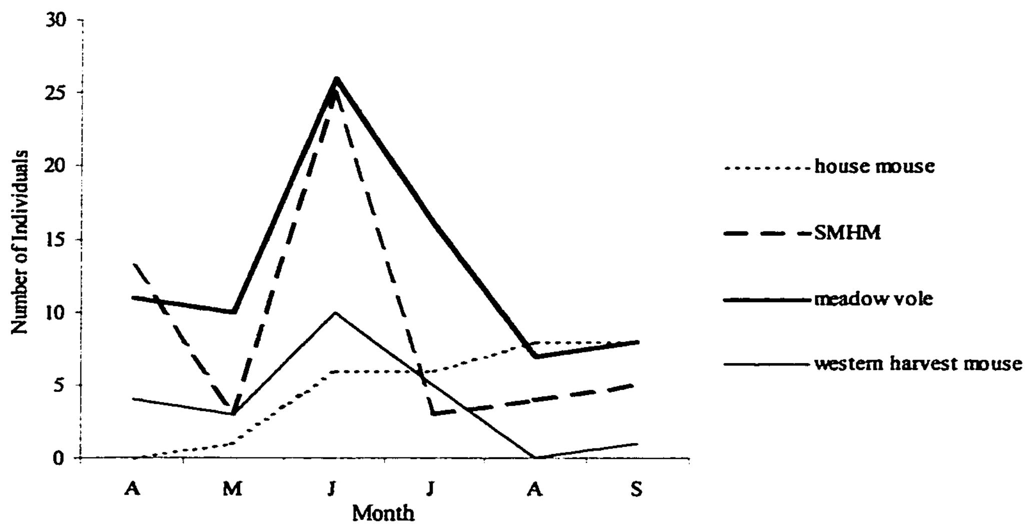

Fig. 3.—Number of rodents captured in New Chicago Marsh, April 1997 through September 1997.

The sex ratio for SMHM was slightly skewed toward males with 33 males and 21 females (1.5:1). Sex ratios for meadow voles and western harvest mice were also skewed toward males (1.8:1), whereas for house mice it was nearly equal (1.2:1). Except for house mice, captures for all species rose through April and May with highest numbers captured in June (Fig. 3). Captures of SMHM declined in July but rose again slightly through August and September. Meadow vole and western harvest mouse captures declined through July and August but slightly rebounded in September. In the case of house mice, captures increased gradually from 0 in April to 8 in September.

Distribution of salt marsh harvest mice.—Two of the three phases of the study period showed a pattern to the population distribution of SMHM. Goodness of Fit tests for the three phases, pre-breeding (April-May), breeding (June-July) and post-breeding (August-September), indicated that the distribution of SMHM during the pre-breeding phase was not different from random. On the other hand, the breeding (CD = 1.407) and post-breeding periods (CD = 1.369) were characterized by a clumped distribution.

Vegetation Composition.—The New Chicago Marsh was predominantly pickleweed (63%) and alkali heath (20%) (Appendix B). Bare ground was also prevalent with 11% relative cover across the marsh. Native saltgrass, *Distichlis spicata* was sparse representing only .02% of all relative cover. The remaining 6% vegetative cover was a mix of mostly non-native invasive species: rabbit's foot grass, *Polypogon monspelliensis*, brass buttons, *Cotula coronopifolia*, seaside heliotrope, *Heliotropium curassavicum*, soft brome, *Bromus hordeaceus*, slender-leaved ice plant, *Mesembryantheum nodiflorum*, sand spurrey, *Spergularia marina*, spiny sowthistle, *Sonchus asper*, and Australian saltbush, *Atriplex semibaccata*.

Pickleweed was present at 100% of the trap sites. For all trap sites, relative cover of pickleweed ranged between 2-100% with an average relative cover of 63%. Seventy percent of all trap sites had $\geq$ 50% relative cover of pickleweed. Relative cover of pickleweed at SMHM capture sites ranged between 19-100% with an average relative cover of 60%. Sixty-seven percent of all SMHM capture sites had ≥ 50% relative cover of pickleweed (Appendix B).

Pickleweed Salinity.—When the study results were treated as a single trapping effort pickleweed salinity levels did not appear to differ between sites where SMHM were present and where they were absent. A two-sample independent *t*-test indicated there was no significant difference ($p = 0.515$) between mean pickleweed salinity values in sites where SMHM were present and where they were absent.

Table 1.—*Significant two-way associations identified by the five-way log-linear analysis.*

Association	p-value
Salinity · SMHM	0.022
Salinity · meadow vole	0.009

The five-way loglinear analysis of data for the breeding and post-breeding phases (those phases showing a clumped distribution of SMHM), indicated that mid-range pickleweed salinity was significantly related to the presence of both SMHM and meadow voles (Table 1). The majority of SMHM and meadow voles were captured at mid-salinity range sites (levels 2 and 3; Fig. 4). Salt marsh harvest mice and meadow voles were absent at sites with the lowest salinity ranges (levels 0 and 1; Fig. 4). Distribution of SMHM was not related to pickleweed salinity values during the pre-breeding (random) phase ($p = 0.340$). There were no statistically significant associations detected between the presence/absence of house mice or western harvest mice and pickleweed salinity values.

Table 2.—*Significant associations identified by the six-way log-linear analysis.*

Association	p-value
Salinity · meadow vole · site	0.024
SMHM · meadow vole	0.973
Salinity · SMHM	0.022
Site location · western harvest	0.002
Site location · meadow vole	0.021

When site location (peripheral versus interior) was included in the loglinear analysis, the results differed (Table 2). The six-way analysis showed a significant three-way association between mid-range level pickleweed salinity, interior sites and the presence of meadow voles. There were no statistically significant relationships between house mice, western harvest mice or pickleweed salinity values. House mice were caught at sites of low salinity ranging from levels 0 through 3. Western harvest mice were captured at sites with salinity levels 2 through 4 (Fig. 4).

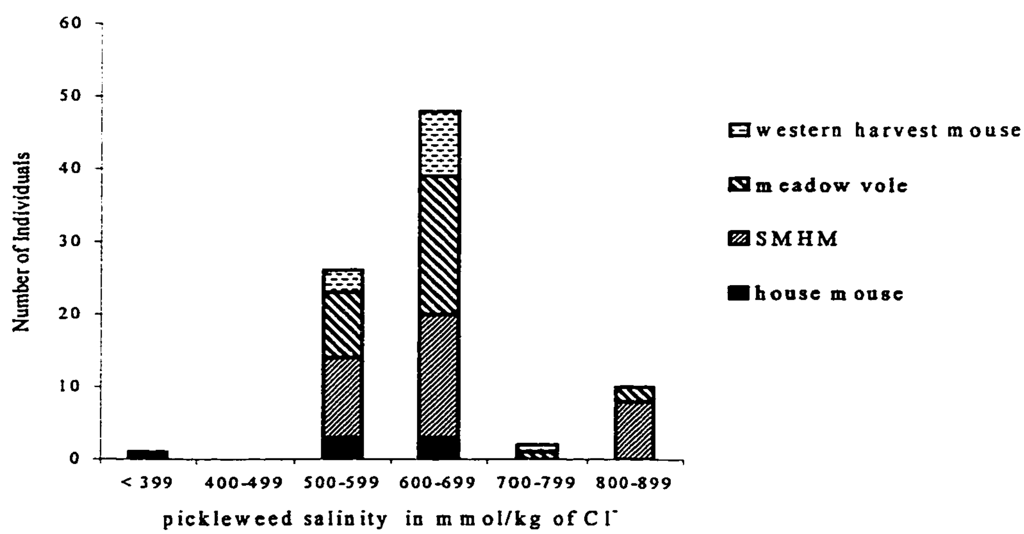

Fig. 4.—Pickleweed salinity categories and total small mammal captures for trapping sites in New Chicago Marsh, June 1997. <399 mmol/kg = level (L)0; 400-499=(L)1; 500-599=(L)2; 600-699=(L)3; 700-799=(L)4; 800-899=(L)5.

Interspecific interactions.—No statistically significant two-way or higher order associations were indicated between meadow voles and SMHM (Table 2). At 14 of 20 sites where SMHM were captured, meadow voles were also present. The three-way interaction between house mice, meadow voles and SMHM ($p= 0.065$) was deemed not significant ($\alpha \leq 0.025$).

Site Location.—Loglinear analysis showed no significant effect of site location on presence or absence of SMHM. Through the six-month course of this investigation, SMHM were captured at 25 of the 40 sites located throughout the marsh (Fig. 5). Of these 25 sites, 58% were flooded interior sites, *i.e.*, isolated islands accessible only by boat. During the peak capture month of June, 65% of the sites where SMHM were caught were interior sites.

A significant effect ($p=0.002$) of site location was detected on the presence or absence of western harvest mice (Table 2). Western harvest mice were conspicuously absent from interior sites. Peripheral sites accounted for 92% of western harvest mouse captures.

The three-way interaction between mid-range pickleweed salinity, interior sites and the presence of meadow voles was found to be statistically significant (Table 2). Sixty percent of meadow vole capture sites were interior sites.

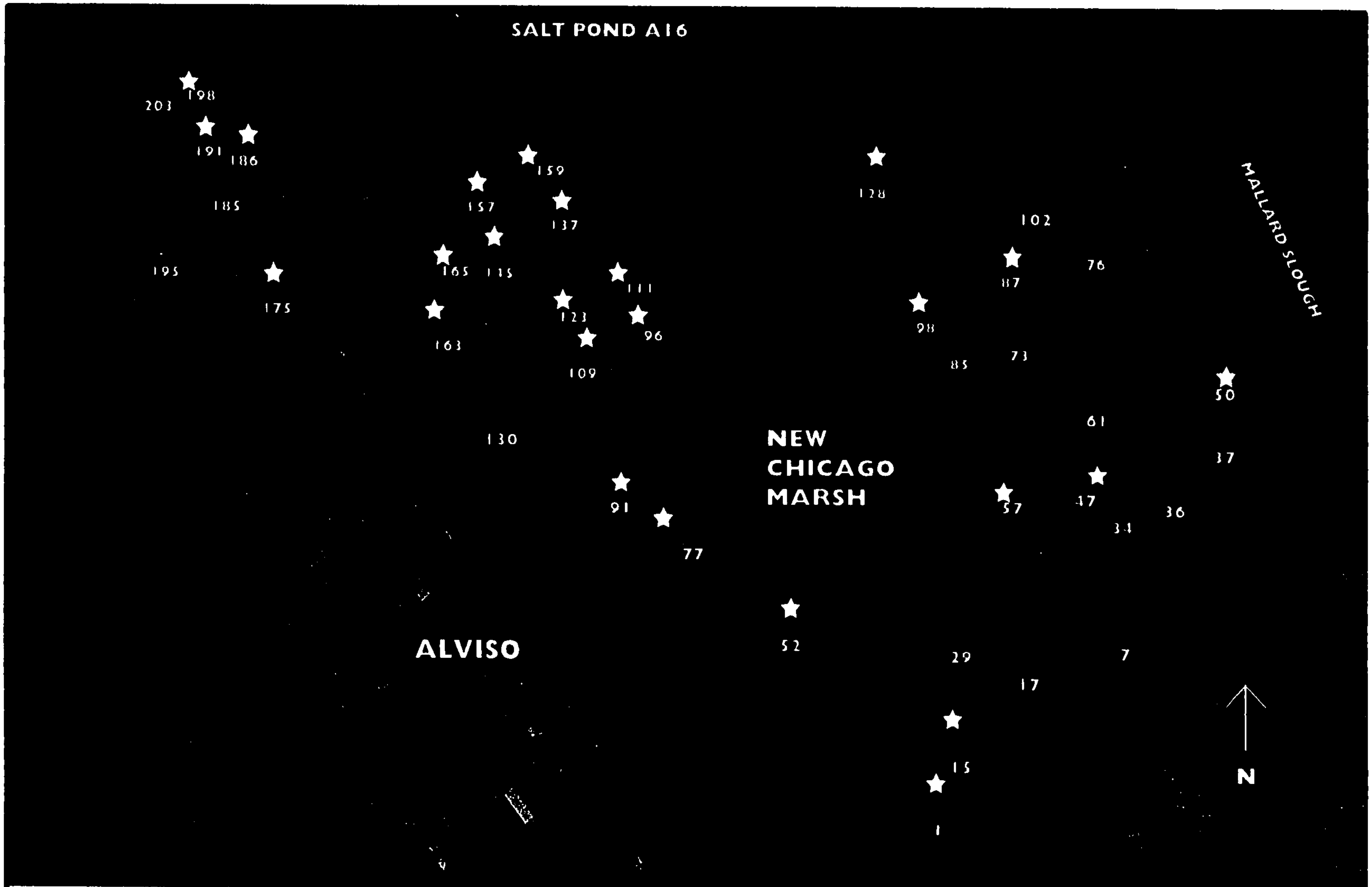

Fig. 5.—Salt marsh harvest mouse (*Reithrodontomys raviventris*) capture locations (denoted ☆); New Chicago Marsh, Alviso, California. Spring 1997.

DISCUSSION

In this study the distribution of SMHM displayed a clumped pattern during the breeding and post-breeding seasons. Not only did this distributional pattern become discernable but the pattern was maintained even as individual capture locations changed over time. Schaub (1971) and Wondollek *et al.* (1976) also found the dispersion of SMHM to be uneven within salt marshes, although no statistical tests were conducted on their data. Wondollek *et al.* (1976) concluded that the majority of their SMHM population preferred particular parts of the marsh.

The presence or absence of pickleweed and the effect of salinity of surrounding water on pickleweed appear to be important characteristics for the distribution of SMHM. Wondollek *et al.* (1976) captured SMHM most often in pickleweed which ranged between 45-75 cm in height and which was intermixed with other halophytic vegetation. Shellhammer *et al.* (1982) found that SMHM used pickleweed as their primary habitat and that the value of pickleweed increased with depth, density and the degree of intermixing with other halophytic marsh vegetation. Johnson and Shellhammer (1988) found that SMHM were most often captured in pickleweed dominated sites within diked marshes, although the mice were occasionally captured in grassland sites. Zetterquist (1977) found that pickleweed salinity is positively associated with water salinity but there was no relationship between water salinity and trap success of SMHM. Geissel *et al.* (1988) also found that salinity of nearby standing water was positively associated with salinity of pickleweed. They reported that the salinity of pickleweed was inversely correlated to the height of the plant. In their first sampling period, Geissel *et al.* found that SMHM tended to be found more often in shorter (more saline) pickleweed, but in a second sampling effort, there was no apparent association with the mice and height of pickleweed. They concluded that competition from meadow voles forced SMHM into less optimal habitat (shorter, hypersaline pickleweed) but that as the salinity of the diked marsh increased, the ability of SMHM to utilize hypersaline food increased their competitive advantage, allowing them to colonize areas previously dominated by voles.

I found that SMHM and meadow voles were more common in habitats with mid-range salinity levels in pickleweed. All trap sites had pickleweed present and although some SMHM were captured at sites with high pickleweed salinity, SMHM were absent from those sites in which pickleweed was low in salinity. Geissel *et al.* (1988) found a relationship between the height of pickleweed and salinity of pickleweed and that at certain times the mice are found within one height category. Wondollek *et al.* (1976) captured SMHM most often in pickleweed, which ranged between 45-75 cm in height. Zetterquist (1977) observed no relationship between the presence of SMHM and the salinity of the site. In this current study, the mice were associated with a particular range of salinity in pickleweed during a part of their life cycle. It is possible that the mice in the studies of Wondollek *et al.* and Geissel *et al.* were keying in on a particular salinity level within the pickleweed, rather than just the height of the plant for cover purposes since Geissel *et al.* (1988) demonstrated that salinity of the plant is related to its height.

I detected no association between meadow voles and SMHM throughout the year, whereas Geissel *et al.* (1988) concluded there was a competitive interaction between the two species. Despite capture rates similar to the present study, Geissel *et al.* found a negative association between the presence of meadow voles and SMHM in their first trapping effort but not in their second. The findings in the present study appear to contradict those of Geissel *et al.* However, in the present study the randomized sampling technique incorporated sites within the entire marsh whereas Geissel *et al.*'s study was restricted to the periphery of the marsh. It may be that the edges of the marsh are the only places where competition may occur. Although the location of the site was not statistically significant for SMHM, it was statistically significant for western harvest mice and meadow voles. Salt marsh harvest mice were found throughout the habitat, whereas western harvest mice were found preferentially at peripheral sites and meadow voles were found preferentially at interior sites. It was only through random sampling that these results could be obtained as few researchers have trapped the interior of salt marshes before.

Site location could reflect a number of factors acting on population dynamics. Interior sites are often characterized by extensive waterways and flooding and by floristic micropatterns and predation pressures, which may differ from those associated with peripheral sites. Further investigation is needed to address the possibilities of the influence of the various factors associated with site location on rodent populations.

This study incorporated design elements that made it possible to examine temporal-spatial shifts in SMHM distribution. By randomly trapping across the habitat over a six-month period and analyzing the data pooled and un-pooled, I found that populations of SMHM do not appear to exhibit spatial stasis through time.

There can be many reasons for the pattern (or lack of pattern) to the distribution of a population. This study took place during El Niño conditions when the area was much wetter than in the recent past and this may have affected the SMHM population distribution. The lack of a pattern in the first phase of the study may be due to the small sample size (n=16) of SMHM which were captured at that time. However, it is also possible that the change in distribution of SMHM in time and space is indicative of a response to a: 1) change in the mouse's environment, 2) change in microhabitat requirements, or 3) change in both 1 and 2. A statistically-detectable pattern of population distribution, as well as associations between mid-range salinity levels in pickleweed and the presence of specific rodent species, indicates it is likely that microhabitat choices for SMHM are influenced by different parameters at different times in the life cycle (*i.e.*, what is optimal for one life phase may not be optimal for another life phase). It appears that this rodent has a more complex life history than has been previously described.

The threat to continued preservation of SMHM is not likely to be from sympatric rodent species. The threat to SMHM continues to be habitat degradation (*e.g.*: desalinization) as former tidal marshes become diked and diked marshes become dying marshes from lack of saline water flowing through them. Managed, diked marshes (particularly in the South Bay) appear to be the key to survival of SMHM. Managers and biologists attempting to preserve SMHM need to be concerned with monitoring and maintaining water salinity and levels, as well as tidal marsh vegetation (*e.g.*: pickleweed), within diked marshes. Various researchers have found that salinity of pickleweed is related to the salinity of water (Zetterquist 1977, Rice 1974, Geissel *et al.* 1988). In this study, I found the distribution of SMHM in the breeding and post-breeding phases to be related to the mid-range salinity level in pickleweed, whereas the mice were absent from those sites in which pickleweed was low in salinity. The potential role for SMHM of a specific salinity range in their main food source is a question for future investigation, however the detection of this association during part of their life cycle indicates that muted tidal flows are necessary to properly manage diked salt marshes. Mid-range salinity of pickleweed is important to the presence of SMHM. The more de-salinized a site becomes, the less saline the pickleweed and the less likely that marsh will support SMHM populations.

It remains a challenge to emulate tidal marsh salinities and vegetation in a diked marsh. Additional research is needed to provide a better understanding of the ecology of the mouse and to identify other microhabitat parameters which could be important in guiding conservation efforts for SMHM in highly altered environments.

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Appendix A: Rodent Capture/Recapture Data, NCM, 1997

	SMHM: new male	SMHM: new female	SMHM: total new	SMHM: recap male	SMHM: recap	SMHM: total recaps	SMHM: total	WHM: new male	WHM: new female	WHM: total new	WHM: recap male	WHM: recap female	WHM: total recaps	WHM: total captures	VOLE: new male	VOLE: new female	VOLE: total new	VOLE: recap male	VOLE: recap	VOLE: total recaps	VOLE: total captures	MUS: new male	MUS: new female	MUS: total new	MUS: recap male	MUS: recap female	MUS: total recaps	MUS: total
April	8	5	13	1	3	4	17	1	3	4	0	0	0	4	5	6	11	0	1	1	12	0	0	0	0	0	0	0
May	1	2	3	2	2	4	7	2	1	3	0	0	0	3	6	4	10	10	0	10	20	1	0	1	0	0	0	1
June	13	12	26	14	8	22	48	8	2	10	5	1	6	16	15	11	26	12	12	24	50	4	2	6	2	3	5	11
July	2	1	3	10	5	15	18	4	1	5	18	0	18	23	8	8	16	15	10	25	41	2	4	6	2	3	5	11
August	3	1	4	3	2	5	9	0	0	0	11	0	11	11	2	5	7	12	12	24	31	4	4	8	3	5	8	16
Sept.	4	1	5	6	5	11	16	0	1	1	5	0	5	6	6	2	8	25	14	39	47	5	3	8	7	7	14	22
Totals			54			61	115			23			40	63			78			123	201			29			32	61

Appendix B: Vegetation Composition at NCM Trap Sites, 1997.

Site	PW	RC-PW	Bare	RC-Bare	Water	RC-Water	Alk	RC-Alk	Dist	RC-Dist	Rabbit	RC-Rabbit	Other	RC-Other	Cot	RC-Cot
1**	4.6	51	0.8	9	0	0	0	0	0	0	0.1	1.1	0	0	4	38.9
7	3.1	34	0.8	9	0	0	4.4	49	0	0	0	0	0.7	8	0	0
15	5.2	58	0	0	0	0	2.2	24	0	0	0	0	1.6	18	0	0
17	8.3	92	0.4	4	0	0	0.3	3	0	0	0	0	0	0	0	0
29	6.8	76	0.9	10	0	0	1.3	14	0	0	0	0	0	0	0	0
34	7.7	86	0.6	7	0	0	0.7	8	0	0	0	0	0	0	0	0
36	3.6	43	0	0	0	0	5	56	0	0	0.4	4	0	0	0	0
37	8.6	96	0	0	0	0	0	0	0.4	4	0	0	0	0	0	0
47	8.1	90	0.9	10	0	0	0	0	0	0	0	0	0	0	0	0
50	0.7	8	0	0	0	0	8	89	0.3	3	0	0	0	0	0	0
52	7.8	87	1.2	13	0	0	0	0	0	0	0	0	0	0	0	0
57	7.7	86	0.8	9	0	0	0	0	0	0	0	0	0.5	6	0	0
61	2.3	26	2.7	30	0	0	3.3	37	0	0	0.7	8	0	0	0	0
73	7.8	78	0.3	3	0	0	1.5	15	0	0	0.4	4	0	0	0	0
76	10	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	6.7	74	1.5	17	0.8	9	0	0	0	0	0	0	0	0	0	0
85	3.2	32	1.9	19	1.5	15	2.9	29	0	0	0	0	0.1	1	0	2
87	6.1	61	0.2	2	0	0	3.7	37	0	0	0	0	0	0	0	0
91	2.9	32	1.7	19	0	0	2.6	29	0	0	0	0	1.8	20	0	0
96	2.1	21	2.3	23	0.5	5	4.3	43	0	0	0.2	2	0.6	6	0	0
98	7.8	78	0.8	8	0	0	1.4	14	0	0	0	0	0	0	0	0
102	8.4	84	0.8	8	0.5	5	0.3	3	0	0	0	0	0	0	0	0
109	2.6	26	1.5	15	1.6	16	3.8	38	0	0	0	0	0.3	3	0	3
111	3.9	39	5.2	52	0.3	3	0.6	6	0	0	0	0	0	0	0	0
123	10	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
128	1.9	19	0.2	2	1.5	15	6.4	64	0	0	0	0	0	0	0	0
130	6.4	71	0.7	8	0	0	1.9	21	0	0	0	0	0	0	0	0
137	5.2	52	1.1	11	0	0	2.2	22	0	0	0.1	1	1.4	14	0	0
145	6.9	69	0.9	9	0	0	1.1	11	0	0	0	0	0	0	1	73

Appendix B: cont'd

Site	PW	RC-PW	Bare	RC-Bare	Water	RC-Water	Alk	RC-Alk	Dist	RC-Dist	Rabbit	RC-Rabbit	Other	RC-Other	Cot	RC-Cot
157	10	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
159	6.5	65	2.1	21	0	0	0	0	0	0	0	0	0	0	1	14
163	10	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
165	7.6	76	0.9	9	0	0	1.5	15	0	0	0	0	0	0	0	0
175	4.5	50	1.3	14	0	0	2.1	23	0	0	0	0	1.1	12	0	0
185	5.4	54	1.4	14	1.8	18	1.4	14	0	0	0	0	0	0	0	0
186	3.8	38	0.3	3	0	0	5.8	58	0	0	0	0	0	0	0	0
191	7.6	76	0.5	5	1.1	11	0.8	8	0	0	0	0	0	0	0	0
195	8.5	85	1.5	15	0	0	0	0	0	0	0	0	0	0	0	0
198	6.6	66	2.9	29	0	0	0.5	5	0	0	0	0	0	0	0	0
203	4.4	44	1.3	13	0	0	4.3	43	0	0	0	0	0	0	0	0

****bold font denotes SMHM capture site**

Legend
RC- relative cover
PW- pickleweed, *Salicornia virginica*
Bare- bare ground
Alk- alkali heath, *Frankenia grandifolia*
Dist- saltgrass, *Distichlis spicata*
Rabbit- rabbit's foot grass, *Polypogon monspelliensis*
Cot- brass buttons, *Cotula coronopifolia*
Other- non-native invasives*

*** Includes:**
seaside heliotrope, *Heliotropium curassavicum*
soft brome, *Bromus hordeaceus*
slender-leaved ice plant, *Mesembryanthemum nodiflorum*
sand spurrey, *Spergularia marina*
spiny sowthistle, *Sonchus asper*
Australian saltbush, *Atriplex semibaccata*