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MOVEMENTS AND HOME RANGE OF SALT MARSH HARVEST MICE

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ABSTRACT—We radio-tagged 44 endangered salt marsh harvest mice (*Reithrodontomys raviventris*) during 1991 and 1992 at Mare Island Naval Shipyard, Solano Co., California, to document movements and home range size of this species. Mean distance moved between 2-hour observation periods was 11.9 m, and mean home range area was 2,133 m^2. There was no significant difference for mean distance moved or size of home range between sexes; between males that had abdominal testes or those that had scrotal testes; or among females that were nonreproductive, developing mammaries, had developed mammaries, or were pregnant. For all salt marsh harvest mice, greatest mean distances moved and largest areas of home range occurred during June, whereas smallest mean distances moved and smallest home ranges occurred during November. There were no significant differences among months for either mean distance moved or home range area. Movement patterns of salt marsh harvest mice revealed that mice crossed roads, levees, and canals.

RESUMEN—Marcamos con radios 44 ratones salt marsh harvest (*Reithrodontomys raviventris*) en peligro de extinción durante 1991 y 1992 en Mare Island Naval Shipyard, Condado Solano, California, para documentar movimientos y tamaño de rango de hogar de esta especie. El promedio de la distancia recorrida en periodos de observación de 2 horas fue de 11.9 m y el promedio de rango de hogar fue de 2,133 m^2. No hubo una diferencia significativa para el promedio de la distancia recorrida ni para el tamaño del rango de hogar entre sexos; entre machos que tenían testículos abdominales o escrotales; ni entre hembras que no estaban reproduciendo, que estaban desarrollando mamas, que tenían mamas ya desarrolladas, o que estaban embarazadas. Para todos los ratones salt marsh harvest, el promedio mayor de distancia recorrida y el más grande rango de hogar ocurrieron en junio, mientras que el promedio menor de distancia recorrida y el menor rango de hogar ocurrieron durante noviembre. Sin embargo, no hubo diferencias significativas entre los meses ni en el promedio de la distancia recorrida ni en el área del rango de hogar. Los patrones de movimiento del ratón salt marsh harvest revelaron que los ratones atravezaron caminos, riberas y canales.

The salt marsh harvest mouse (*Reithrodontomys raviventris*) is endemic to the salt-marsh areas surrounding San Francisco Bay and its tributaries (Shellhammer, 1982, 1989). This mouse was listed as endangered in 1970 by the United States Department of the Interior and in 1971 by the California Department of Fish and Game. Two subspecies are recognized: *R. r. raviventris* occurs in the southern San Francisco Bay region and *R. r. halicoetes,* the subject of our study, occurs in the northern region of the bay (Shellhammer, 1982).

The principal reason for listing the salt marsh harvest mouse as endangered was loss of habitat (United States Fish and Wildlife Service, 1984). Shellhammer (1982) described primary habitat for salt marsh harvest mice as areas dominated by pickleweed (*Salicornia virginica*) with escape cover from inundation during high tides. However, about 80% of the originally estimated 474 km^2 of historic tidal marshes in the San Francisco Bay area have been filled or otherwise highly modified (Jones and Stokes et al., 1979).

Fisler (1965) suggested that individual salt marsh harvest mice will not leave thick cover and that barren areas may be effective barriers to movements between populations. Further, Shellhammer (1977) studied intermarsh movements of salt marsh harvest mice and detected no movements between marshes separated by a dike road as little as 3 m wide. However, Geissel et al. (1988) reported that salt marsh harvest mice traveled considerable distances (85 m or more) and swam or ran across open areas 2 m or more wide.

With the increasing threat of loss of remaining tidal wetlands in the San Francisco Bay area, understanding movement patterns and home range of the salt marsh harvest mouse is needed for its successful management and recovery. Quantifying movements of rodents provides information on home ranges, response to barriers, habitat use, and other aspects of their ecology (e.g., Douglass, 1989; La Polla and Barrett, 1993; Hall and Morrison, 1997). We used radio telemetry to estimate movement patterns and home range of salt marsh harvest mice at Mare Island Naval Shipyard (MINSY), where the United States Navy developed a Memorandum of Understanding with the United States Fish and Wildlife Service to promote conservation of the salt marsh harvest mouse.

MATERIALS AND METHODS—MINSY (closed in 1994) is located at the eastern end of San Pablo Bay west of the city of Vallejo, Solano Co., California. It occupies ca. 2,270 ha. The rectangular island is bordered by the San Pablo Unit of the San Francisco Bay National Wildlife Refuge to the north, San Pablo Bay to the west and south, and the Napa River to the east. The island is flat with elevations typically less than 6 m above sea level. Land use was largely industrial and residential along the northern and eastern portions of the island and there was little salt marsh. The least disturbed area of tidal salt marsh (about 160 ha) occupies the western portion of the island. Dominant vegetation within this area was pickleweed with scattered patches of dodder (*Cuscuta salina*). Most of the flat land on the island was composed of diked salt marshes used as dredge disposal ponds. The predominant plant species within ponds was pickleweed. Other plant species within ponds were fat hen (*Atriplex patula*), Australian saltbush (*Atriplex semibaccata*), thistles (*Cirsium* sp.), prickly lettuce (*Lactuca serriola*), curly dock (*Rumex crispus*), sweet fennel (*Foeniculum vulgare*), and coyote bush (*Baccharis pilularis*).

Mice were livetrapped using Sherman small-mammal traps (7.7 by 9.0 by 23.0 cm) among eight permanent trap grids established on the island as part of a long-term study of communities of small mammals in salt marshes (Bias, 1994). Two grids occurred in natural, tidal marshes (grids TM1 and TM3), two grids occurred in newly restored tidal marshes (grids 22 and 23), and four grids occurred in diked marshes (grids 8, 15, 17, and 26). Grids in tidal marsh were 8 by 8 with 15-m trap spacing, grids in restored tidal marsh were 5 by 15 with 10-m trap spacing, grids 8 and 26 were 10 by 10 with 10-m trap spacing, and grids 15 and 17 were 8 by 8 with 10-m trap spacing. Because grids differed in size and shape, different trap spacings were used to fit an approximately equal number of traps in each grid.

Mass to the nearest 0.5 g, length of body, length of tail, length of hind foot, length of ear, age, sex, and reproductive condition were recorded for all salt marsh harvest mice captured. Reproductive condition was estimated for males based on presence or position of testes: nonreproductive (no testicular development); testes abdominal (present but small); or testes scrotal. Reproductive condition was estimated for females based on whether or not the animal was pregnant, presence or development of mammaries (mammaries developing or mammaries developed), or nonreproductive (no mammary development).

Individuals selected from among those captured near the centers of each grid were fitted with radio transmitters. We attempted to tag two adult male and two adult female mice that were 10 g or heavier during each radio telemetry session. An individual animal was used only once during our study. Animals were anesthetized using methoxyflurane (Metofane®, Pitman-Moore, Inc., Washington Crossing, New Jersey) prior to attaching radios. We used scissors to clip a small patch of hair between the scapulae slightly posterior to the head, and then attached a radio transmitter (0.9–1.2 g, SM1 Style, AVM Instrument Company, Ltd., Livermore, California) to this area using gel cyanoacrylate glue (Extra Strength Krazy Glue Gel, Borden Inc., Columbus, Ohio).

Locations (fixes) for each radio-tagged animal were obtained every 2 hours from about 2 hours before sunset to noon the next day (10 fixes per animal per period). We tracked all tagged animals for 8 nights or until radios fell off, whichever occurred first. Animals with radios still attached after 8 nights were located once per day until the radio fell off, or they were livetrapped and the radio was removed.

During 1991, we conducted telemetry sessions in January (grid TM1), March (grids 22 and 23), June (grid TM3), August (grid 26), and December (grid 8). During 1992, telemetry sessions occurred every quarter in the tidal marshes (TM1 and TM3), restored areas (grids 22 and 23), and diked marshes (grids 15, 17, and 26). We determined locations of radio-tagged mice by taking bearings from at least three different trap stations within permanent trap grids. Bearings usually took 5 to 10 min to obtain and were taken from a distance (>30 m) that we thought would minimize disturbance to a mouse. Locations of animals that traveled outside the grid were determined by extending existing grid lines to the areas these animals frequented. Error triangles (Nams and Boutin, 1991) were used to assess location error.

We used the computer program HOME RANGE

TABLE 1—Telemetry summary statistics of mean distance moved between observations and minimum convex polygon (MCP) area by sex and reproductive condition for all *Reithrodontomys raviventris* radio-tagged on Mare Island from 1991 to 1992.

Sex and reproductive condition	n	Mean distance (m)		MCP (m^2)	
		$\bar{x}$	*SE*	$\bar{x}$	*SE*
Males	24	12.51	2.03	3,186.50	2,379.36
Nonreproductive	3	19.13	8.29	2,307.77	1,801.48
Abdominal	7	11.19	4.54	8,528.67	8,167.75
Scrotal	10	10.38	1.90	804.25	255.86
Unknown	4	15.18	6.19	181.96	90.98
Females	20	11.14	1.46	868.62	246.49
Nonreproductive	6	14.55	3.90	1,673.62	696.02
Mammaries developing	5	11.70	2.07	953.20	256.54
Mammaries developed	4	8.00	1.99	263.38	77.82
Pregnant	2	10.65	0.65	461.55	226.06
Unknown	3	7.87	3.67	196.03	115.70

(Ackerman et al., 1989) to calculate mean distance moved between consecutive observations and estimate the minimum convex polygon home range area (Hayne, 1949) of radio-tagged animals. We used the minimum convex polygon primarily for simplicity, flexibility of shape (White and Garrott, 1990: 148), and because of the short duration that animals were tracked. Minimum convex polygon is the most frequently used method and the only method that is strictly comparable between studies (Harris et al., 1990).

We determined the frequency at which mice crossed atypical habitat, or barriers including levees, roads, and canals. Frequency of barrier crossing was the number of sequential fixes that occurred on opposite sides of the barrier relative to the total number of observations (sequential fixes). We also calculated the distance to the nearest barrier from the center of each trapping grid, and for animals that crossed a barrier, distance from the individual's center of activity on the grid to the barrier that it crossed.

We used nonparametric tests because data were not normally distributed. Mann-Whitney U tests (Zar, 1984:138–143) were used to determine if mean distances moved and sizes of home ranges were the same between sexes. We used Kruskal-Wallis tests (Zar, 1984:176–179) to determine if mean distances moved and sizes of home ranges were the same among individuals that varied in reproductive condition within sexes and among months.

RESULTS—We radio-tagged 44 (24 male, 20 female) salt marsh harvest mice during 1991 and 1992 for 334 total days of tracking and 1,500 locations. Mean number of days an individual salt marsh harvest mouse was tracked was 7.6 (SE = 0.5) and mean number of locations per individual was 34 (SE = 2.0). Mean distance moved between consecutive observations was 11.9 m (SE = 1.3) and mean area of home ranges was 2,132 m^2 (SE = 1,301.9).

Mean distance moved and areas of home ranges were not significantly different between sexes of salt marsh harvest mice (mean distance: $U = 238.5$, $W = 448.5$, $P = 0.97$; home range: $U = 217.0$, $W = 427.0$, $P = 0.59$; Table 1). Although mean distances moved and areas of home ranges tended to decrease for males as reproductive condition progressed from nonreproductive to abdominal to scrotal (Table 1), differences among these estimates were not significant (mean distance: $\chi^2 = 2.18$, $P = 0.34$; home range: $\chi^2 = 1.82$, $P = 0.40$). Mean distances moved and areas of home ranges tended to decrease for females as reproductive condition progressed from nonreproductive to mammaries developing to mammaries developed or pregnant (Table 1). However, differences among these estimates were not significant (mean distance: $\chi^2 = 2.60$, $P = 0.46$; home range: $\chi^2 = 5.61$, $P = 0.13$).

As a group, salt marsh harvest mice moved the greatest mean distances and had the largest home range areas during June, whereas they moved the shortest mean distances and had the smallest home ranges during November (Figs. 1 and 2). However, differences among months were not significant for either mean distance moved ($\chi^2 = 12.23$, $P = 0.20$) or area of home ranges ($\chi^2 = 11.28$, $P = 0.26$).

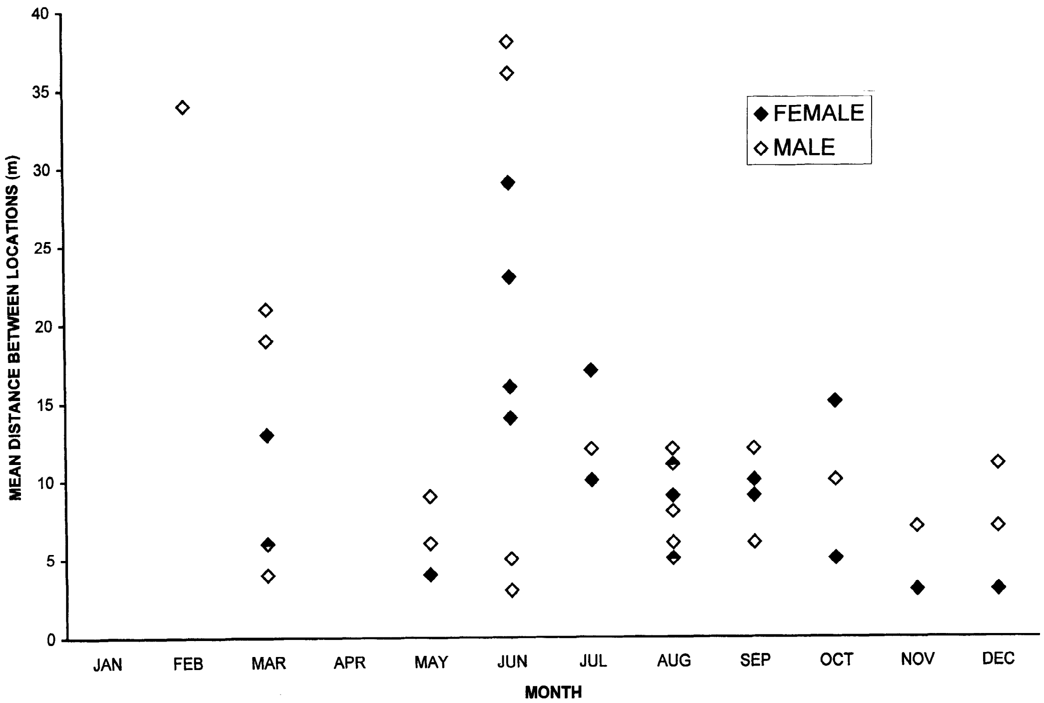

FIG. 1—Mean distance (m) moved between observations of male (open diamond) and female (closed diamond) salt marsh harvest mice (*Reithrodontomys raviventris*) by month radio-tagged on Mare Island during 1991 and 1992.

Of the radio-tagged salt marsh harvest mice, 16 of 44 (36%) moved outside the effective trap grid during telemetry sessions. Of these 16 animals, a mean of 48% (range: 11 to 96%) of the locations were outside the effective trap grid. We defined the effective trap grid as the area of the actual grid plus half the trap spacing around the grid.

Six (3 male, 3 female) of the 44 animals (13.6%) crossed barriers. Of these six animals, frequency of crossing barriers averaged 16.6% (*SD* = 9.51%, range = 4.2 to 29.6%) of observations, and average distance to the barrier crossed was 92.5 m (*SD* = 105.2 m, range = 15 to 300 m). Barriers crossed were: 1) narrow (1 to 2 m) canal (permanent water; 3 animals); 2) roads (3 to 4 m wide) on levees (2 animals); and 3) narrow (1 to 2 m wide) levees (1 animal). Animals thus made both short-distance movements across barriers adjacent to their primary activity areas, and longer-distance movements that were relatively well separated from their activity centers. The average distance from all grids to the nearest barrier was 65.0 m (*SD* = 27.52 m, range = 35 to 110 m).

DISCUSSION—Our estimates for sizes of home ranges were considerably larger (138 to 164%) than those reported by Geissel et al. (1988) in the south San Francisco Bay. However, Geissel et al. (1988) used live-trapping data to estimate home ranges; telemetry data have been shown to produce larger and more accurate estimates of home ranges than trapping data (e.g., Bergstrom, 1988; Douglass, 1989; Hall and Morrison, 1997).

Both male and female mice crossed levees, roads, and canals. Because of the short (2 h) time between telemetry fixes and extent of the barriers, animals could not have moved around the barriers. The majority of animals did not make such movements, which could be a reflection of the short duration (8 days) the radios were attached. These results concur with observations of Geissel et al. (1988) that barren areas are not effective barriers to move-

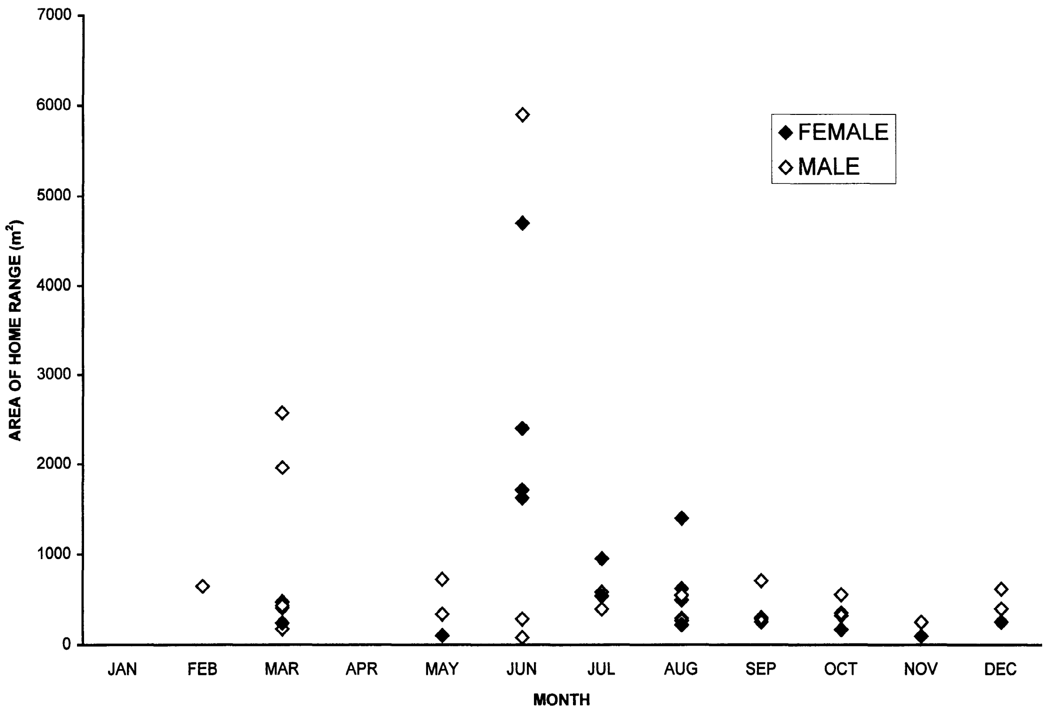

FIG. 2—Home range area (m^2) estimated by minimum convex polygon of male (open diamond) and female (closed diamond) salt marsh harvest mice (*Reithrodontomys raviventris*) by month radio-tagged on Mare Island during 1991 and 1992. One male, radio-tagged during June 1991, was not plotted on this figure as the home range estimate for this mouse of 57,613 m^2 would increase the scale of the Y axis and distort the variation among the other estimates.

ment between populations of salt marsh harvest mice as was suggested by Fisler (1965) and Shellhammer (1977).

Our results could assist in management and recovery of the salt marsh harvest mouse. Knowing year-round distances traveled and areas of home ranges of salt marsh harvest mice will assist land and wildlife managers in determining spacing needed between areas of suitable habitat. For example, isolated habitat patches should be no further from other habitat patches than the greatest observed dispersal distance traveled. Further, our observations that salt marsh harvest mice cross atypical or barren habitat indicates that these features are not absolute barriers to dispersal.

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