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SALT MARSH HARVEST MICE AND WIDTH OF SALT MARSHES IN THE SOUTH SAN FRANCISCO BAY

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Most of the once broad and continuous salt marshes of the South San Francisco Bay (South Bay), California have been converted into salt ponds or have been filled. The marshes are much narrower, more fragmented, and increasingly impacted by subsidence and rising sea level than those present at the beginning of the 20th Century. This is especially the case with the nineteen fringing marshes (i.e., long and narrow marshes that extend between the few remaining large salt marshes).

The South Bay salt marshes share several characteristics. They have lost most of their former breadth (i.e., the upper half of their mid-marsh, or pickleweed [*Sarcocornia pacifica*] zones) and most of their high marsh zones that typically support halophytic species such as spearscale (*Atriplex prostrata*), alkali heath (*Frankenia salina*), saltgrass (*Distichlis spicata*), Australian saltbush (*Atriplex semibaccata*), and gumplant (*Grindelia* sp.). Salt marsh harvest mice (*Reithrodontomys raviventris* [SMHM]) live much of their lives in the pickleweed zone and many use the high marsh zone as escape cover during high tides (Fisler 1965; Shellhammer 1982, 1989); hence, marsh alteration and loss have greatly impacted the mouse. Moreover, as Fisler (1965) noted, SMHM formerly moved into grasslands adjacent to marshes during the highest tides of spring and summer, but grasslands now are extremely rare in the South Bay.

Another change has been the spread of brackish plant species, especially alkali bulrush (*Schoenoplectus robustus*) and perennial pepperweed (*Lepidium latifolium*). These brackish habitats were not considered to be used by SMHM until recently, when they were noted in high numbers in Suisun Bay marshes dominated by threesquare bulrush (*Schoenoplectus americanus*) that have substantial thatch layers (Sustaita et al. 2004). H. T. Harvey & Associates (2006) note that SMHM similarly use mature, thatch-filled stands of alkali bulrush, but this is the only study to date of the use of mature bulrush by the mouse in the South Bay. Because of the limited knowledge about the mouse's use of brackish marshes in the South Bay we restrict the scope of this paper to salt marshes.

We visited the tidal salt marshes of the South Bay south of Oakland International and San Francisco International airports during 2002 and characterized and mapped the marshes. We compared our maps with IKONOS infra-red photography from May, 2004 to help determine width (distance from the upper edge of a marsh to the bay) and length (distance measured along the upper edge) of these marshes. We identified seven habitat categories based on width, vegetation, structure, and adjoining habitat (Table 1). We used a database developed by the senior author, combined with ArcView-based maps for all trapping project locations of SMHM throughout their range, to compare capture results with marsh size, connectedness, and character.

Table 1. Linear characterization of the pickleweed (mid-marsh) and high marsh zones in tidal salt marshes of the South San Francisco Bay, California, as of 2002.

Category	Pickleweed[a] marsh width	High marsh width	length/km	% of shoreline
1	100m and >	3-10m	10.6	5.12
2	50-100m	1-3m	17.2	8.30
3	<50m	1-3m	76.3	36.77
4	<50m	0.1-1m	72.1	34.76
5	<50m	Rip-rap	16.7	8.06
6	<50m	Exotics[b]	13.0	6.28
7	none	none	1.5	0.70
All			207.4	99.99

[a] pickleweed (*Sarcocornia pacifica*)
[b] slender iceplant (*Mesenbryantheum nodiflorum*)

The number of SMHM captured on marsh plains of tidal salt marshes showed a highly significant relationship between SMHM capture success and the width of marshes and with width and year (Table 2) when R statistical software (R Development Core Team 2009) was used to run a Generalized Linear Model assuming a binomial probability distribution. The model used was **smhm ~ depth + year + depth:year** where **smhm** is the capture of a mouse, **depth** is the width of the marsh in meters, **year** is the year the trapping was done and **depth:year** is an interaction term. We used 42 SMHM tidal salt marsh projects in the South Bay for this model. Trapping the base of the high marsh gives a good representation of the number of SMHM in the adjacent and broader marsh plain (Duke and Shellhammer 2006). Forty of the trapping projects were also divided into four arbitrary marsh width categories and their average capture efficiencies are presented in Table 3.

Table 2. Coefficients of the Generalized Linear Model of the highly significant relationship between SMHM capture success and the width of marshes and with width and year, South San Francisco Bay, California.

Parameter	Estimate	SE	*Z*-value	*P*
Intercept	-3.9124e+1	2.200e+01	-1.779	0.07521
Depth	-2.518e-01	8.468e-02	-2.973	0.00295
Year	1.731e-02	1.110e-02	1.560	0.11869
Depth:year	1.289e-04	4.277e-05	3.014	0.00258

Salt marshes line approximately 60.0% of the vegetated edge of the South Bay, and in most of these marshes the high marsh zone is narrow; 5.1% have high marsh zones 3 to 10 m wide, 45.0% have zones 1 – 3 m wide, and 34.8% have high marsh zones of 1 m or less in width (Table 1). The high marsh zone typically is confined to the bay side of outboard dikes, but these marshes are absent in 15.0% (31.2 km) of the 207.4 km edge of the South Bay that supports tidal salt marshes (Categories 5 – 7; Table 1). Most of the Category 1 marshes (pickleweed marshes more than 100 m wide and a high marsh 3 – 10 m wide) are along Coyote Hill Slough, a waterway modified for flood control in the Newark area (Figure 1). This same area had the broadest high marsh zone and is one of the few areas in the South Bay where there is adjacent grassland.

Table 3. Marsh width and capture efficiencies in forty fringing tidal salt marshes in the South San Francisco Bay, California.

Width (m)	Width ($\bar{x}$)	C. E.[a]	Projects (N)	Marshes with no SMHM (N)
18 – 49	32.7 m	0.33	12	9 (75%)
51 – 91	72.3 m	0.68	12	3 (25%)
104 – 134	117.7 m	1.39	10	3 (30%)
152 – 610	344.1 m	3.82	8	1 (12.5%)

[a] C. E., or capture efficiency, is a measure of mouse numbers and is the number of SMHM captured divided by the number of trap nights times 100.

We categorized ten tidal salt marshes averaging 327 (range = 135 to 774) hectares as being "wide" marshes and at least nineteen fringing marshes as being "narrow" marshes. Seventeen of the fringing marshes had pickleweed or marsh plains that averaged 43 m (12-120m) in width while two marshes had portions that were wider than 120m. Eighteen of the fringing marshes average 4.5 km in length (range = 0.9 to 10.6 km), while the 19th is extremely long (34 km; Figure 1). The marshes in the Alviso area are among the shortest and narrowest in the South Bay, where the shoreline is interrupted by barren or nearly barren stretches of levees. There are very narrow segments in almost all of the fringing marshes with the exception of the two wider marshes previously noted. Only six of the 19 fringing marshes have been live-trapped for SMHM, and four of those six have been trapped only once. All the trapping projects referred to in this paper were projects carried out according to guidelines stipulated in a memorandum of understanding between the H. T. Harvey and Associates and the California Department of Fish and Game and those in Federal Fish and Wildlife Endangered Species Permit TE667512-4 (held by H. Shellhammer).

Salt marsh harvest mice that live in the marsh plain of salt marshes climb to the top of the highest vegetation during the highest high tides (Fisler 1965). Those that live near levees escape to levee vegetation during such tides (H. T. Harvey & Associates 1990). That more mice are likely to live in wide marshes than narrow marshes is intuitive and is reinforced by the relationship between marsh width and capture efficiency reported herein.

Wide marshes with complex channel systems and stands of *Grindelia* within them are very rare today (Goals Project 1999, Fisler 1965). They have been replaced around much of the South San Francisco Bay by narrow marshes with reduced pickleweed zones and extremely narrow high marsh zones. Just how narrow those marshes can become before they act as filters, or possibly even barriers, to mouse movement through them is the question we raise in this paper.

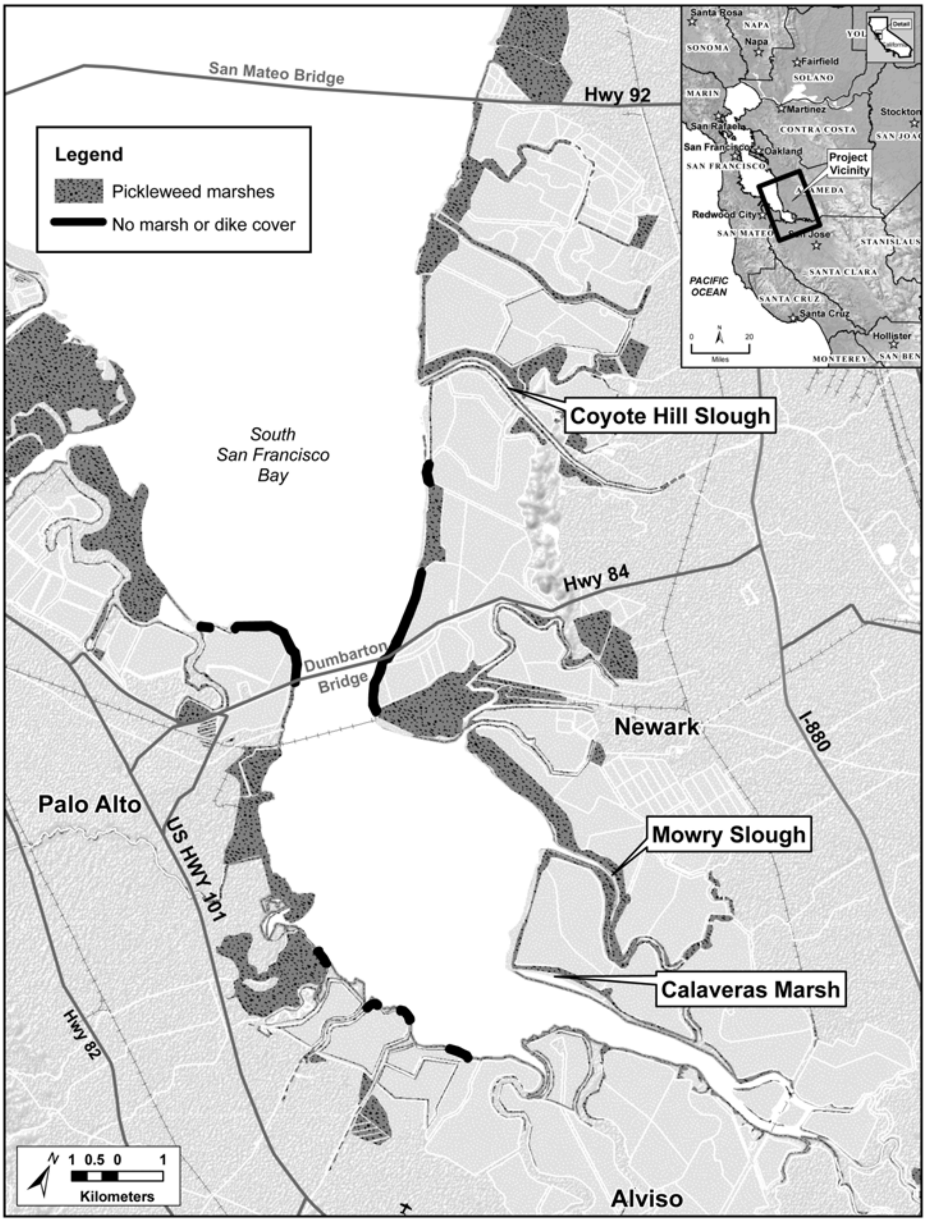

Figure 1. The southern portion of the South San Francisco Bay. The dark bars along the edges of the bay are areas of devoid of both mid or high marsh; the dikes on either side of the Dumbarton Bridge are covered with rip-rap.

Few large marshes have been trapped out on their marsh plains, but they have large populations as indicated by high trapping efficiencies (Table 3). There are in the South Bay, however, few wide connections though which SMHM can move between population centers in these large marshes, in part a result of stretches of rip-rap and barren levees without adjacent marshes of any kind (Figure 1). And, while there is a difference of opinion about distances that SMHM will move across barren areas (Bias 1994; Bias and Morrison 1999, 2006; Fisler 1965; Geissel et al. 1988; Hulst et al. 2001; Shellhammer 1982, 1989; Shellhammer et al. 1988), we contend it is highly unlikely that SMHM move hundreds of meters over such inhospitable environments, and speculate that such areas present absolute barriers to mouse movement.

But what of the narrow marshes with little to no high marsh adjoining them? In the South Bay, 34.8% of marshes are ≤ 50 meters wide, and some have high marsh zones ≤ 1 m wide. Some parts of those marshes are ≤ 20 meters in width, and we suspect those would not support more than the home range of one mouse between dike and bay based on home range size in diked South Bay marshes (Geissel et al. 1988) and in tidal marshes in the San Pablo Bay (Bias 1994). We contend that very narrow marshes are likely to have little mouse movement through them, especially those with little escape cover (e.g., grasses and halophytes) on adjacent levees. Hulst et al. (2001) suggested that "levees and grassy areas should not be dismissed as non-habitat for the salt marsh harvest mouse" and we agree that animals can and do move through such areas, especially where these areas provide more or less continuous cover. However, that is not the case along many of the narrow marshes of the South Bay, where long stretches of levees are bare and lack high marsh zones.

We suspect that narrow marshes, particularly in the absence (or near absence) of adjacent high marshes, are likely to restrict mouse movements between larger marshes. As a result, there may be only occasional movement by SMHM between population centers. If narrow marshes reduce opportunities for movement by mice between large marshes, it is likely that there are more populations of SMHM, but of smaller size, in the South Bay than currently recognized.

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