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Authors
Smith, Katherine R.
Riley, Melissa K.
Barthman–Thompson, Laureen
et al.

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Toward Salt Marsh Harvest Mouse Recovery: Research Priorities

Katherine R. Smith[1,2], Melissa K. Riley[2], Laureen Barthman-Thompson[2], Mark J. Statham[3], Sarah Estrella[2], and Douglas A. Kelt[1]

The state and federally endangered salt marsh harvest mouse (SMHM, *Reithrodontomys raviventris*) is endemic to wetlands within the San Francisco Estuary (the estuary) in California. The biology of SMMH is summarized by Smith et al. (this issue); here, we present the most pressing data gaps and research needs (what we have identified as "Priority Needs"), followed by associated "Recovery Actions" from the 2013 Recovery Plan (USFWS 2013), to facilitate the recovery of SMHM throughout its range. To the degree that resources allow, we strongly urge that all the following research recommendations be implemented throughout the species range, in key habitat types, and with replication.

1. **Potential Effects of Climate Change and Associated Sea Level Rise.** Understanding this threat and how it will affect recovery measures (e.g., tidal restoration) should be, at the least, an ancillary component underlying all research moving forward.

   ### Priority Needs

   a. When possible, research projects should be designed to explicitly investigate how the threat of climate change intersects with other threats, and how it affects SMHM biology. Climate change should be a consideration in all recommendations below.

      i. *Recovery Action 4.4.7* Study the effects of global climate change and resulting sea level rise on tidal marsh ecosystems (page 325).

2. **Range-Wide Population Demographics and Dynamics.** Lack of population and demographic data for SMHM hinder efforts to identify areas of conservation concern or to understand how natural or anthropogenic changes (including habitat loss and restoration) affect population health.

   Additional long-term and comprehensive demographic studies on the SMHM are needed.

Strategically allocating these in key habitats (e.g., managed, tidal, and restored wetlands) would facilitate prioritizing habitat for acquisition and enhancement. Researchers should collaborate to determine densities, carrying capacities, and population viabilities for various habitat types over both short (ca. 5 years) and longer (ca. 50 years) time-periods (USFWS 2010). Such data are essential for population-viability analyses (suggested by USFWS 2013), and crucial for conservation planning in the light of the large shifts in habitat anticipated to be a result of climate change and sea-level rise (Takekawa et al. 2013; Thorne et al. 2018).

Understanding metapopulation dynamics should help to identify characteristics of habitats that serve as demographic sources and sinks, allowing managers to prioritize the former in regional planning. Data on dispersal and colonization are important criteria in site selection for enhancement activities, and in predicting if populations can populate uninhabited patches (e.g., newly created wetlands) or whether assisted colonization will be necessary.

Priority Needs

a. Determine the realized geographic range of the species (and both sub-species) through comprehensive censuses.

b. Obtain population estimates of SMHM.

   i. **Recovery Action 3.1.2.6** Monitor for salt marsh harvest mouse (page 313).

c. Characterize key demographic parameters (survival, reproductive rate, net population growth rate), prioritizing vulnerable populations (e.g., those in the south San Francisco Bay) when resources are limited.

   i. **Recovery Action 4.2.7.1** Conduct a population viability analysis to determine desirable population sizes for long-term persistence of extant south San Francisco Bay SMHM populations (page 321).

d. Characterize demographic relationships among populations (frequency and distance of dispersal, nature of dispersal barriers, and potential for source–sink dynamics).

   i. **Recovery Action 3.2.1** Conduct surveys in suitable habitat for new and relict populations of SMHM (page 316).

3. **Range-Wide Genetics.** Further characterize the genetic structure of SMHM throughout the estuary, but in particular in the south San Francisco Bay where populations are smallest and habitat is most at risk. Losing even very small populations could mean losing unique and rare genetic lineages permanently.

   Understanding SMHM population genetics is critical to both long-term management and prioritization of areas for conservation action (Goals Project 1999; USFWS 2013). Trapping and genetic sampling throughout the potential range of the species would allow validation of species occurrence, especially in isolated and peripheral habitat patches. Such work is essential to delineate the geographic extent of the sub-species, identify distinct populations, and improve understanding of how genetic diversity may influence the effectiveness of conservation measures such as tidal restoration.

Priority Needs

a. Genetic delineation of sub-species boundaries.

   i. **Recovery Action 4.3.4** Conduct research to resolve taxonomic uncertainties regarding SMHM (page 323).

b. Genetic characterization of relationships among populations, effectively using genetic markers to document demographic parameters such as extent of dispersal, barriers to dispersal, source–sink dynamics, and metapopulation structure (Peery et al. 2008).

   i. **Recovery Action 4.3.1** Conduct a SMHM population genetic analysis (page 323).

4. **Response to Habitat Restoration.** Virtually no data exist on the effects of restoration activities (e.g., levee removal and subsequent flooding) or the secondary effects of habitat alteration (e.g., development of tidal wetlands). A better understanding of SMMH habitat requirements and dispersal dynamics is vital to acquiring and enhancing suitable habitat in the future.

We suggest managers thoroughly investigate SMHM habitat preference and use in restored wetlands, even if pre-restoration data are lacking.

Priority Needs

a. Characterize the direct effects (e.g., altered survival or reproductive success) of restoration activities such as use of heavy equipment in currently occupied habitat, to minimize negative effects on SMHM during active restoration.

b. Characterize the secondary effects of large-scale shifts in habitat after restoration activities (e.g., changes in SMHM population densities).

   i. *Recovery Action 4.4.1* Conduct studies on the efficacy of various habitat restoration techniques for SMHM (page 324).

c. Determine factors that may influence the colonization of newly-created, potentially-isolated, habitat patches (e.g., typical dispersal distance, minimum viable patch size).

   i. *Recovery Action 4.4.5* Study the time lag between habitat restoration and recolonization by SMHM (page 325).

5. **Environmental Contamination.** The risk of SMHM population failure from chemical contamination—either chronic (e.g., methylmercury) or acute (e.g., oil spill)—calls for a comprehensive assessment (USFWS 2013).

Clark et al. (1992) recommended laboratory feeding trials to assess toxicity of common toxic agents, and regular monitoring of common small mammals to assess contaminant concentrations (and whether SMHM disappear where concentrations increase). At a minimum,

we suggest that researchers collect hair samples during routine monitoring for contaminant testing, even if funds for performing the tests are not yet available.

Priority Needs

a. Characterize the population-level effects of chronic contamination on SMHM and their habitat.

   i. *Recovery Action 4.5.2.5* Establish a list of "biosentinal" species to use as surrogates for SMHM, and establish "acceptable" and "not acceptable" contaminant levels in these species... (page 326).

b. Assess the risk of acute catastrophes; develop contingency plans for SMHM populations potentially threatened by such catastrophes.

   i. *Recovery Action 2.1.5.3* Develop and implement site-specific oil spill prevention and response plans for lands supporting known populations of SMHM (page 293).

6. **Community Context in Current and Future Management.** SMHM surveys generally consider the species in relative isolation, thereby failing to understand how SMHM vary with community composition. We encourage a systems approach to SMHM surveys, documenting co-occurring species, parasites, and predators, to monitor changes in potentially harmful inter-specific interactions in the future.

The importance of broader community dynamics (e.g., predation, competition, parasitism, etc.) should be prioritized in future efforts. Whereas the Recovery Plan (USFWS 2013, page 254) recommends understanding conditions where competition has "significant adverse effects" on SMHM populations, most SMHM researchers do not individually mark most other rodent species (e.g., voles, house mice). We contend that the need to understand the role of competitive dynamics on SMHM comprises a call for data on other rodents captured during routine monitoring activities.

Lacking baseline knowledge of predation pressure on SMHM, it will be difficult to interpret and respond to changes in predation through processes such as sea-level rise and tidal restoration (e.g., altering the availability and configuration of habitat) or urban encroachment (influencing the composition of predator fauna). The application of "molecular scatology" (see Symondson and Harwood 2014) would be optimal, but this assumes molecular barcodes are available for the forage species of interest. As an alternative, we suggest that researchers who perform routine monitoring include standardized observations of predators and predator sign in relation to habitat type and configuration. These data may be most useful to managers designing tidal restorations, especially near urban environments where human-associated predators, such as cats (*Felis catus*), are common.

We recommend that researchers be vigilant for indications of harmful disease outbreak, and identify and implement research needs should they arise, especially near urban areas where SMHM are more exposed to sources of disease, such as domestic pets and sewage.

Priority Needs

a. Characterize small mammal assemblages thoroughly, individually marking all captured animals; and record comprehensive data about community composition during survey activities.

 i. *Recovery Action 4.5.1.1* Determine the effects of non-native species on tidal marsh ecosystems. Conduct studies to determine the direct and indirect effects of invasive species... (page 326).

b. Characterize key inter-specific interactions; we recommend field efforts be structured to quantify how predation, competition, and parasites affect SMHM population size and health.

 i. *Recovery Action 4.2.7.4* Study the nature and strength of predation on SMHM (page 322).

 ii. *Recovery Action 4.5.4.3* Conduct other research on SMHM predator/prey and parasite/host relationships (page 328).

c. Quantify how SMHM habitat use changes in response to changes in the community (e.g., in likely competitors or predators).

 i. *Recovery Action 4.2.7.2* Investigate the use of sub-optimal habitats by SMHM to cope with inter-specific competition (page 322).

d. Integrate habitat-based observations of community structure into projected habitat shifts, to help managers incorporate predicted assemblage structure in long-term planning.

 i. *Recovery Action 4.2.7.2* The role of bulrush (*Schoenoplectus spp.*) and cattail (*Typha spp.*) in SMHM biology needs to be more thoroughly examined in the south San Francisco Bay, especially when such areas are lightly flooded by tides (page 322).

 ii. *Recovery Action 4.2.7.3* Study the impact of *Spartina alterniflora* and its hybrids, and *Lepidium latifolium* on SMHM (page 322).

7. **Improved Collaboration and Meta-Analyses.** Collaboration and integration of parallel data sets across multiple sites—with the ultimate objective of strengthening quantitative estimates of key parameters while better understanding how local context influences SMHM biology—is essential.

The pursuit of meta-analyses across replicate sites is a critical need (e.g., Beston 2011; Koricheva et al. 2013). Current regulations mandate similar sampling efforts at a number of sites throughout the estuary, and the 2013 Recovery Plan recommends a research coordinator position to maximize the effect of potential collaborations (USFWS 2013). Non-standardized field methods have limited earlier efforts by members of the ad-hoc inter-agency SMHM Working Group to pursue integrative analyses, so standardized field methods are needed. Such coordinated efforts would support all the recovery actions listed above, as well as the following:

i. ***Recovery Action 2.1.1*** Coordinate with existing agencies to develop and implement mechanisms for coordinated, long-term management of SMHM and their habitat (page 290).

ii. ***Recovery Action 2.1.3.2*** Develop and implement standardized SMHM monitoring techniques to evaluate ecosystem function and response, species response, and threat response to interim management activities (page 291).

iii. ***Recovery Action 3.3*** Periodically review and improve methods of SMHM monitoring (page 316).

iv. ***Recovery Action 3.5*** Periodically review progress toward SMHM recovery and long-term conservation of species of concern, and identify warranted changes in status (delisting, uplisting, or downlisting) (page 317).

v. ***Recovery Action 4.1*** Designate a research coordinator to coordinate all tidal marsh research sponsored or overseen by U.S. Fish and Wildlife Service (page 317).

The SMHM continues to need protection from both historic and contemporary threats. Management and conservation of SMHM in the face of emerging threats (e.g., climate change and associated sea-level rise, which "likely imperils [SMHM] and the resources necessary for its survival," USFWS 2010:27), will require continued investment in basic and applied research to help managers detect responses to large-scale restoration and climate change—and implement necessary management actions. We encourage researchers to consider climate change when they design field efforts, thereby providing further insight on how SMHM may be affected.

Though coordination has been improved recently through the SMHM Working Group, we believe the greatest impediments to conservation of the SMHM are the lack of dedicated personnel and funding. To this end, we propose creation of an independent program coordinator position to prioritize and facilitate centralized and sustained research funding

toward commonly agreed-upon objectives among researchers and management agencies. This position would support complementary and management-driven research, standardization of methods, and integration of collaborative efforts. This position, likely funded jointly by key regulatory agencies, would require programmatic autonomy and should interface closely with the SMHM Working Group. The research needs highlighted in Smith et al. (this issue) and the recommendations herein provide a foundation from which such efforts can be developed.

Our intent has been to identify key threats and associated research and management needs that will improve the chances of SMHM recovery throughout its range. We encourage researchers and managers to revisit such an effort regularly, with 5- to 10-year updates to ensure applied research remains appropriately targeted at priority research needs.

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