Florida Salt Marsh Vole
(*Microtus pennsylvanicus dukecampbelli*)
Species Status Assessment

Version 1.1

Florida salt marsh vole (credit: U.S. Fish and Wildlife Service)

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U.S. Fish and Wildlife Service
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Version 1.1 represents an update to the future conditions assessment methodology and results based upon NOAA’s updated sea level rise projections (Sweet et al. 2022). Basic editorial revisions were also made throughout the document to improve clarity, ensure consistency of formatting, and correct grammatical mistakes. This document was prepared by Billy Brooks and Gayle Martin (U.S. Fish and Wildlife Service, Ecological Services) with assistance from Carrie Straight, Sandra Sneckenberger, Tiffany Lane, and Scott Wiggers (U.S. Fish and Wildlife Service, Ecological Services).

Version Updates

Version	Date	Preparers	Rationale
1.0	October 16, 2020	Billy Brooks, Mike Marshal, Stephanie DeMay, and Marcie Mathieu	Informing 5-year review
1.1	January 24, 2025	William Brooks, Gayle Martin	Updating sea level rise projections and method to project future impacts to salt marsh to inform 5-year review; minor editorial and formatting revisions

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EXECUTIVE SUMMARY

The Florida salt marsh vole (FSMV) (*Microtus pennsylvanicus dukecampbelli*) is an endangered subspecies of meadow vole (*Microtus pennsylvanicus*) known initially from a single site near Cedar Key in Levy County, Florida, USA at the time of its listing. The U.S. Fish and Wildlife Service, listed the FSMV as endangered on January 14, 1991, under the Endangered Species Act of 1973, as amended, due to an extremely narrow range, unknown population levels, and threats to the species existence such as high water and stochastic events (oil spills). FSMV inhabit salt marshes along the coast of Florida. Salt marshes are composed of communities of plants which thrive in saline environments that are regularly inundated and drained by tides. FSMV habitat is generally characterized as salt marsh where the vegetation is dominated by saltgrass (*Distichlis spicata*) with smooth cordgrass (*Spartina alterniflora*) and may be near or adjacent to black needle rush (*Juncus roemerianus*).

Separated from the nearest meadow vole population in Georgia by at least 300 miles, the FSMV is endemic to the central Gulf coast of Florida and is only known from the salt marshes of Waccasassa Bay and Suwannee Sound to the east and north of Cedar Key, Levy County, Florida. The full extent of the historical range of the FSMV is unknown. Until 2004, the FSMV was known to occur only from one locality, Island Field Marsh along the shore of Waccasassa Bay. After its listing, further surveying resulted in expansion of the known range to an 8 km (5 mi.) area in the Cedar Key area (Hotaling et al. 2010, p. 797). Currently, the FSMV is known to occur across 32 km (20 mi.) of salt marsh habitat, between the Lower Suwannee River and the Withlacoochee River, Levy County, Florida, USA. Increases in the distribution of the FSMV are highly likely a function of increased survey effort, not actual range expansion. FSMV are potentially at risk due to the species very small range and from the threats of hurricanes and severe storms that cause extreme high water events. The long-term threat to the FSMV is from rising sea levels.

We divided the species range into three units to assess resilience. These units are not meant to represent “populations” in a biological sense; they do not represent groups of demographically linked interbreeding individuals. Data are not available to delineate biological populations of FSMV at this time. Rather, these units were designed to subdivide the species range in a way that facilitates assessing and reporting the variation in current and future resilience across the range. The three units are West, Central, and East, and correspond with the major features in the shape of the coastline. The FSMV has a very limited geographic range, and there is no genetic or ecological evidence to support delineating multiple representative units.

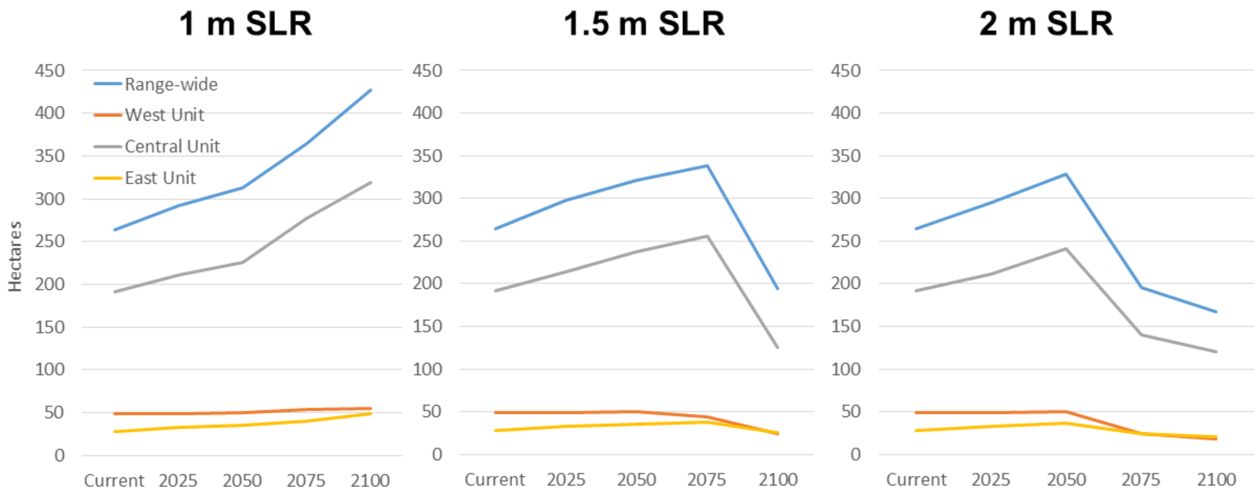
We used habitat information to assess the current condition for FSMV. We assessed resilience range-wide and for each unit by measuring habitat area, habitat connectivity, and the protection status of habitat. We used a predictive habitat model developed by McCleery and Zweig (2016) to measure the current amount of potential habitat within the known range of FSMV. To assess habitat connectivity, we measured patch sizes of both predicted habitat and of salt marsh. Finally, we measured the portion of predicted FSMV habitat and salt marsh extent within the bounds of protected lands. Range-wide, there is currently 264 ha (hectares) of cordgrass/saltgrass salt marsh predicted to be preferred habitat of the FSMV. Habitat is most plentiful in the Central Unit. Habitat is the least plentiful, both in terms of area and the percentage of salt marsh, in the East Unit. Thus, resilience, the ability of populations to withstand stochastic events, is highest is the Central Unit, lower in the West Unit, and is lowest in the East Unit.

The future condition assessment for FSMV was focused on how SLR resulting from climate change will impact habitat. Sea level rise is believed to be the main threat to FSMV resilience, and other described threats to the species (e.g., oil spills, red tides, and extreme high water events) are stochastic events that are difficult to predict. We used spatial data for the current extent of salt marsh to explore the area, connectivity, and protected status of salt marsh between the present and the year 2100, with intermediate time steps at 2025, 2050, and 2075, under different scenarios of SLR: 1-m (meter) by 2100, 1.5-m by 2100, and 2.0-m by 2100, approximately corresponding with the RCP4.5, RCP6.0, and RCP8.5 scenarios.

If baseline greenhouse gas emissions are continued, we are likely to see warming between the RCP6.0 and RCP8.5 emissions scenarios, which correspond to the 1.5- and 2-m sea level rise scenarios in this SSA. Under both of these scenarios, the area of habitat is expected to decline, with range-wide declines in FSMV habitat of at least 26.5-36.7% by 2100. These declines will be preceded by periods of salt marsh expansion, until habitat begins disappearing in earnest after 2075 (1.5-m SLR) or 2050 (2-m SLR). These results indicate an initial increase in resilience range-wide and in the Central and East Resilience Units (the West Unit remains relatively stable initially), followed by rapid decreases in resilience after 2050-2075.

If greenhouse gas emissions are lowered (as a result of policies, technology, societal change, etc.) such that warming occurs in line with the RCP4.5 scenario, we do not expect to see rapid losses of habitat and resilience by 2100. Instead, we expect the area of salt marsh and FSMV habitat (assuming that it remains a constant proportion of the salt marsh in the future) to increase through 2100 range-wide except in the West Unit where it remains fairly stable. However, there likely will be losses of habitat beyond 2100 if sea levels continue to rise, as evidenced by the 1.5- and 2-m SLR sea level rise scenarios. If greenhouse gas emissions are kept to even lower levels such that warming occurs in line with the RCP 2.6 emissions scenario, SLR impacts on habitat will be less than the 1-m scenario.

Sea level rise, the primary threat to FSMV and its habitat, will not only directly impact the salt marsh via habitat loss, fragmentation, and movement. There will also be secondary impacts of increasing vulnerability of FSMV to storm surges and other high water events, and stronger hurricanes, which are likely to become more common with warming temperatures. While FSMV have been resilient to hurricanes in the past (as evidenced by their current persistence), increased frequency and/or magnitude of extreme weather and flooding events could impact the ability of the species to withstand these events. It is plausible, though not certain, that these events that are a natural component of the system might change with warmer sea temperatures and rising sea levels to become more catastrophic and difficult for FSMV to withstand.



Hectares of predicted FSMV habitat range-wide and in each resilience unit under 1-, 1.5-, and 2-m of sea level rise (SLR) from the current condition (2008 data) to 2100.

Updated Future Condition Results (January 24, 2025)

In the Intermediate, Intermediate-High, and High SLR scenarios (Sweet et al. 2022) at both zero and 4 mm/yr (millimeters/year) accretion rates, the area of salt marsh is expected to increase initially from now to the 2070. This increase occurs as the salt marsh extends farther inland but is either not yet submerged on the seaward edge of the marsh, or the loss of the seaward marsh does not outpace the growth of the landward marsh. The 2070 and beyond time frame marks a tipping point and the salt marsh rapidly declines by 2100 (to 8,438 – 8,794 ha) as it is replaced by tidal flats and estuarine open water except under the Intermediate scenario with 4 mm/yr accretion which allows for the salt marsh to remain stable (18,246 ha).

Hectares of Estuarine Wetlands available with 0 and 4 mm/yr marsh accretion rates and sea level projection scenarios (Sweet et al. 2022) in 2050, 2070, 2090, and 2100.

Projection	Accretion (mm/yr)	Scenario	Current 2005-06	2050	2070	2090	2100
2022	0	Intermediate	18,127	22,405	18,246	10,393	8,794
2022	0	Intermediate-High	18,127	22,405	18,246	8,794	8,438
2022	0	High	18,127	18,246	10,393	8,438	8,545
2022	4	Intermediate	18,127	22,405	22,405	18,246	18,246
2022	4	Intermediate-High	18,127	22,405	18,246	10,393	8,794
2022	4	High	18,127	22,405	18,246	8,794	8,438

We note that these predicted habitat areas are based on the assumption that as sea levels rise and the salt marsh shifts, the composition of the salt marsh and its vegetative communities will remain the same as they do currently. Whether this will hold true is uncertain.

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CHAPTER 1 – INTRODUCTION

The Florida salt marsh vole (FSMV) (*Microtus pennsylvanicus dukecampbelli*) is an endangered subspecies of meadow vole (*Microtus pennsylvanicus*) known initially from a single site near Cedar Key in Levy County, Florida, USA, at the time of its listing (Federal Register 1991, p. 1457). The U.S. Fish and Wildlife Service (Service), listed the FSMV as endangered on January 14, 1991, under the Endangered Species Act of 1973, as amended (Act) due to an extremely narrow range, unknown population levels, and threats to the species existence such as high water and stochastic events (oil spills) (Federal Register 1991, p. 1457). After listing, additional surveys concluded an 8 km (5 mi.) range in the Cedar Key area (Hotaling 2010, p. 797). In 2013, through targeted habitat surveying using an innovative camera trapping technique (McCleery et al. 2014, pp. 1-4), the FSMV's known range was extended from 8 km (5 mi.) to 32 km (20 mi.) as they were documented along a 64 km (40 mi.) stretch of suitable salt marsh habitat 11 km (7 mi.) south of the Lower Suwannee River to 8 km (5 mi.) north of the Withlacoochee River, Levy County, Florida, USA (McCleery and Zweig 2016, p. 2).

Every five years after a species is listed under the ESA, the Service is required to conduct a five-year review of its status. The last five-year review of the vole's status was completed in 2024. The Species Status Assessment (SSA) framework (Service 2016, entire; Figure 1-1) is intended to be an in-depth review of the species biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA Report to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from Candidate Assessment to Listing to Consultations to Recovery. As such, the SSA will be a living document that may be used to inform Endangered Species Act decision making, such as listing, recovery, Section 7, Section 10, and reclassification decisions.

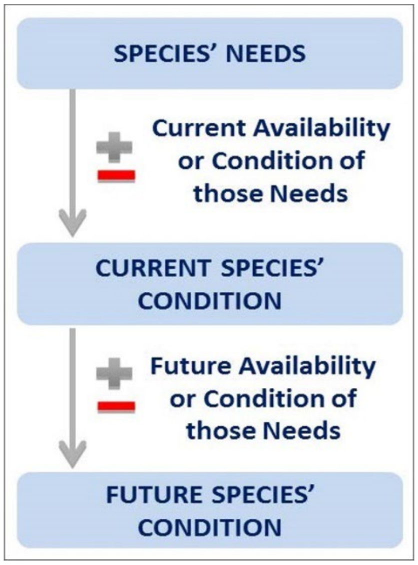


Figure 1-1. Species status assessment framework.

Importantly, the SSA is not a decisional document by the Service, rather it provides a review of available information strictly related to the biological status of the FSMV. Any reclassification decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the Federal Register, with appropriate opportunities for public input.

For the purpose of this assessment, we generally define viability as the ability of the FSMV to sustain resilient populations in natural salt marsh ecosystems over time. Using the SSA framework (Figure 1-1), we consider what the subspecies needs to maintain viability by characterizing the status of the subspecies in terms of its resiliency, redundancy, and representation (Service 2016, entire; Wolf et al. 2015, entire).

Resiliency is assessed at the level of populations and reflects a species ability to withstand stochastic events (events arising from random factors). Demographic measures that reflect population health, such as fecundity, survival, and population size, are the metrics used to evaluate resiliency. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), and the effects of anthropogenic activities.

Representation is assessed at the species (or subspecies) level and characterizes the ability of a species to adapt to changing environmental conditions. Metrics that speak to a species adaptive potential, such as genetic and ecological variability, can be used to assess representation. Representation is directly correlated to a species ability to adapt to changes (natural or human-caused) in its environment.

Redundancy is also assessed at the level of the species and reflects a species ability to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk of such an event across multiple, resilient populations. As such, redundancy can be measured by the number and distribution of resilient populations across the range of the species.

To evaluate the current and future viability of the FSMV, we assessed a range of conditions to characterize the subspecies resiliency, representation, and redundancy (together, the 3Rs) as described above. This SSA provides a thorough account of the known biology and natural history and assesses the risk of threats and limiting factors affecting the future viability of the subspecies.

This SSA includes: (A) a description of FSMV biology (Chapter 2) (B) a description of FSMV ecological needs at the individual, population, and species levels (Chapter 3); (C) a description of influences on the viability of the species (Chapter 4); (D) an assessment of the current condition of the FSMV in terms of resiliency, redundancy, and representation (Chapter 5); and (E) an assessment of the future condition of the FSMV under a variety of scenarios, in terms of resiliency, redundancy, and representation (Chapter 6). This document is a compilation of the best available scientific information (and associated uncertainties regarding that information) used to assess the viability of the FSMV.

CHAPTER 2 – SUBSPECIES ECOLOGY

In this chapter, we provide biological information about the FSMV, including its taxonomic history, morphological description, historical and current distribution and range, and known life history. We then outline the resource needs of individuals.

2.1 Taxonomy

The Florida salt marsh vole (FSMV) (*Microtus pennsylvanicus dukecampbelli*) is a subspecies of meadow vole (*Microtus pennsylvanicus*) in the genus *Microtus* (Woods et al. 1992, p. 131). There are currently 28 subspecies of meadow vole (Jackson 2016, pp. 45-52) which have the largest geographic distribution of any American species in the genus *Microtus* (Reich 1981, p. 2). Meadow voles occur throughout Canada, the United States, and into Mexico in grassy and early successional habitats across their range, including fresh and salt marshes, open-canopied bogs, and agricultural fields (Rowe 2017, unpaginated). From fossil evidence, it was found that the FSMV is a relic of a once widespread population of *Microtus* that occurred throughout the Gulf Coastal Plain of Florida during the Pleistocene when sea levels were low, and fossil records give evidence that the FSMV subspecies has been genetically isolated for over 5,000 years (Woods et al. 1992, p. 131; Austin et al. 2014, p. 637). FSMV are most genetically similar to the dark meadow vole (*M. p. nigrans*) from the salt marshes in tidewater Virginia, the Grand Manan Island meadow vole (*M. p. copelandi*) from Grand Manan Island in New Brunswick, Canada, and the Magdalena Island meadow vole (*M. p. magdalenensis*) from Magdalen Island, Quebec (Woods 1992, p. 131).

Past chromosomal, electrophoretic, and morphometric evidence has confirmed that the FSMV is a subspecies (*Microtus pennsylvanicus dukecampbelli*) (Woods et al. 1982, p. 46). A recent study (Jackson 2016, p. 81) hypothesized 4 major clades within *M. pennsylvanicus* and supports the FSMV as a genetically and ecologically distinct lineage based on molecular analyses and ecological niche models (Figure 2-1). Furthermore, Jackson (2016, p. 28) proposes that the isolated FSMV be elevated to a separate species, *M. dukecampbelli.* For the purposes of this SSA, we rely on the Integrated Taxonomic Information System, which defines FSMV as a subspecies (ITIS 2016, unpaginated).

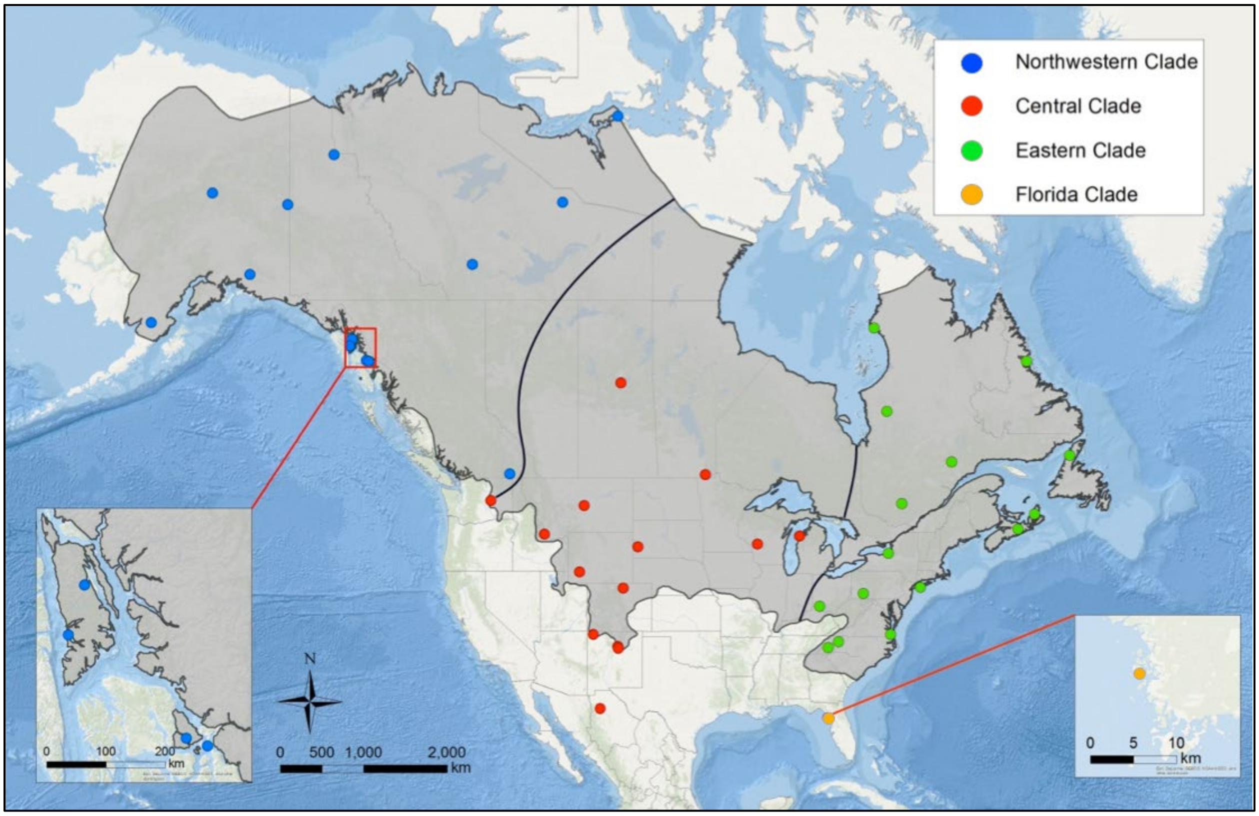


Figure 2-1. Distribution of *M. pennsylvanicus* is shown in gray with dots representing sampling localities. Lines between major clades are hypothesized boundaries (Jackson 2016, p. 44).

Woods et al. (1982, p. 46) found very little genetic variation within the FSMV, which is consistent with the reduction of genetic variability observed in insular populations (Fivush et al. 1975, p. 272; Kilpatrick 1981, pp. 28-59). Austin et al. (2014, entire) developed 21 microsatellite markers for the FSMV from single molecule real time sequencing (Pacific Biosciences). This research suggests genetic separation among subpopulations which might be indicative of a metapopulation. McCleery and Zwieg (2014, p. 11) indicate that marker development was successful in detecting polymorphism within and among the samples and will assist in future research on factors affecting population structure. Further genetic research is needed to determine connectivity between known locations.

2.2 Description

The FSMV is a small (178 – 198 mm (7 – 8 in.) in length) short-tail rodent with a blunt head and short ears. Its fur is dark brown dorsally and dark gray ventrally (Figure 2-2). In contrast to the meadow vole (*Microtus pennsylvanicus*) it is larger in size, darker in coloration, with relatively smaller ears, and differences in skull characteristics (Woods 1992, p. 131).

Figure 2-2. Photographs of the Florida Salt Marsh Vole. Photos courtesy of U.S. Fish and Wildlife Service.

2.3 Distribution

Separated from the nearest meadow vole population in Georgia by at least 300 miles, the FSMV is endemic to the central Gulf coast of Florida and is only known from the salt marshes of Waccasassa Bay and Suwannee Sound to the east and north of Cedar Key, Levy County, Florida. This distribution appears to be a relic from a formerly large range along the Gulf coast during the past 10,000 years when sea levels were lower and suitable habitat extended west of the current coastline of Florida (Woods et al. 1982, p. 43). The range was restricted by rising sea levels and associated changes in vegetation. This population now represents a small remnant of this formerly wide-ranging meadow vole subspecies (Woods et al. 1982, pp. 42-43; Jackson 2016, pp. 80-81).

The full extent of the historical range of the FSMV is unknown. Until 2004, the FSMV was known to occur only from one locality, Island Field Marsh along the shore of Waccasassa Bay. The species was first documented during a small mammal study from 1979 to 1981 where 31 individuals were trapped near Cedar Key, Florida. From 1979 – 2009, nine trapping surveys were conducted at 42 different locations. These surveys included 115 nights trapped and 11,123 trap nights and yielded only 43 individuals from three locations within a 5-mile area in the salt marshes near Cedar Key. At the time of its listing in 1991, the FSMV had only been found in one locality near Cedar Key, Levy County, Florida (Woods 1992, p. 134). After its listing, further surveying resulted in expansion of the known range to 8 km (5 mi.) in the Cedar Key area (Hotaling et al. 2010, p. 797).

In 2004 and 2005, the presence of the Florida salt marsh vole was documented 5 miles northwest of the type locality on the southern section of the Lower Suwanee National Wildlife Refuge (NWR) near Raleigh Islands. In 2009, another location on Lower Suwanee NWR was documented at Long Cabbage Key (Hotaling et al. 2010, p. 797). In 2013, with the development of a method using floating trail cameras (Figure 2-3) to monitor small mammals in marsh environments (McCleery et al. 2014, entire) and the development of a predictive habitat model, 11 additional locations were documented (McCleery and Zweig 2016, p. 4). Ongoing surveys have documented two additional locations (McCleery, pers. comm., 2019). This has expanded the known locations since the last review from two to 15 and the current range from five to 20 miles of coastal salt marsh near Cedar Key (Figure 2-4). This includes locations on the southern section of the Lower Suwannee NWR south along the Levy County coast to the southern section of the Waccasassa Bay Preserve State Park.

Currently, the FSMV is known to occur across 32 km (20 mi.) of salt marsh habitat, between the Lower Suwannee River and the Withlacoochee River, Levy County, Florida (McCleery and Zweig 2016, p. 2). Increases in the distribution of the FSMV are highly likely a function of increased survey effort, not actual range expansion.

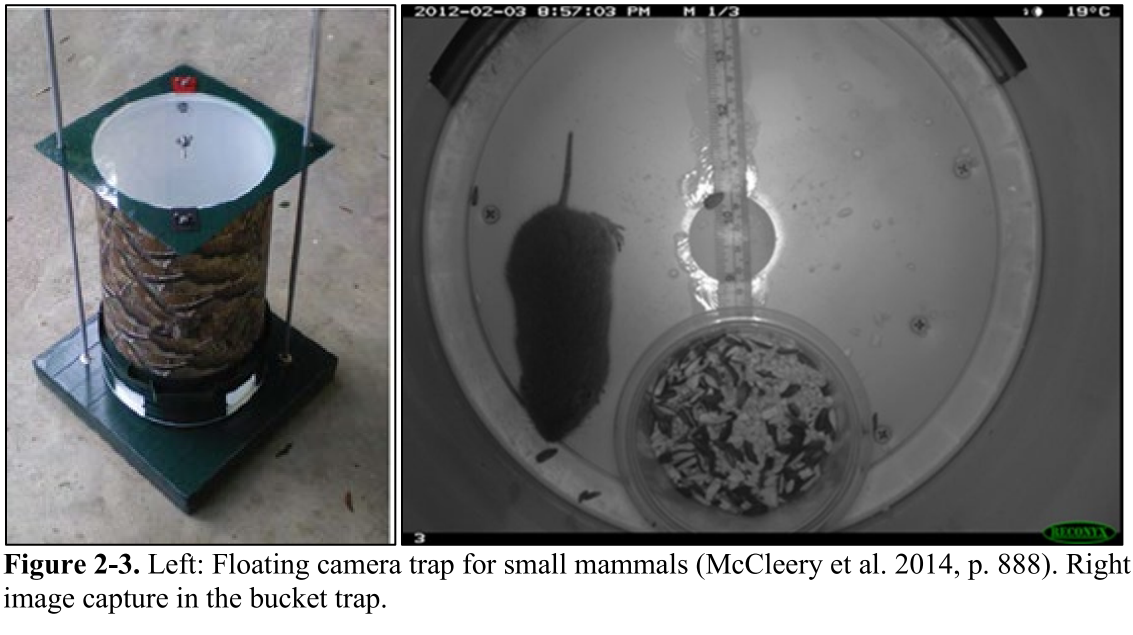


Figure 2-3. Left: Floating camera trap for small mammals (McCleery et al. 2014, p. 888). Right: FSMV image capture in the bucket trap.

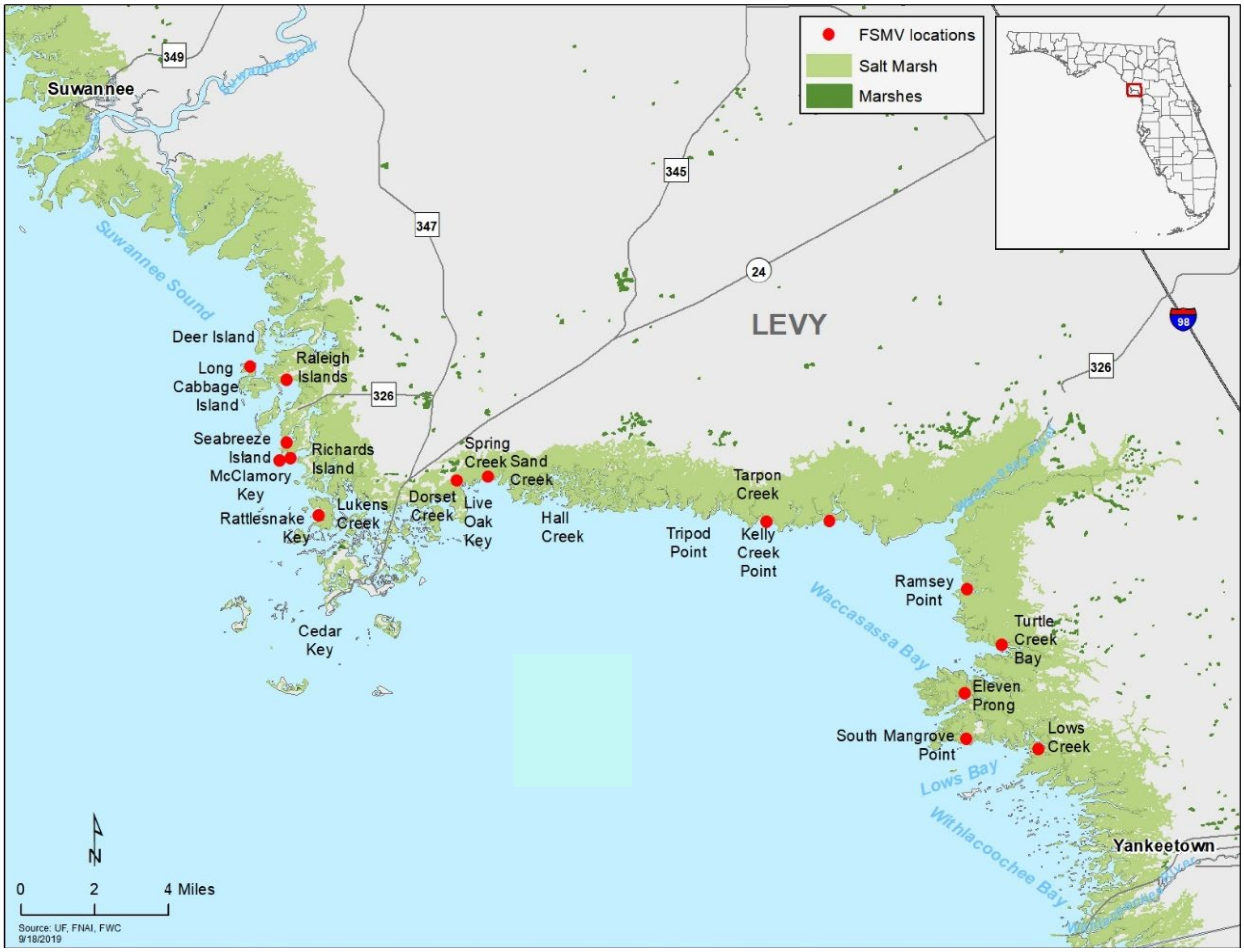


Figure 2-4. Florida Salt Marsh Vole locations 1979-2018.

2.4 Life History

The life history of the FSMV has not been well documented due to their rarity and the difficulty of studying them in salt marsh habitat. Similarly to other *Microtus* populations, it is believed that population densities of FSMV are likely cyclical (Woods 1992, p. 132), meaning that *Microtus* populations can fluctuate dramatically in size through different years or times of year. This is underlined in FSMV studies, when for example, in 1979, no FSMV were captured at Cedar Keys National Wildlife Refuge, while at the same location in March 1980, 9 FSMV were captured in a 6-day trapping period, but in 1988, only 1 FSVM was captured over a 13-day period (Woods 1992, p. 132). During a 30-year period from 1980-2009, 9 surveys with over 11,000 trap nights near Cedar Key, Florida, captured only 43 individuals at 3 locations (Hotaling et al. 2010, p. 796). Because of difficulty in trapping, there is a lack of basic ecological and life history information. With new methods using camera traps and predictive landscape modeling (McCleery et al. 2014, pp. 2-3), FSMV were found at 8 of 36 sites samples yielding a 22% detection accuracy for the model (McCleery and Zweig 2016, p. 4). Methods like these could increase the amount of specific information on the FSMV.

Due to the paucity of life history information for the FSMV, we use meadow voles (*Microtus pennsylvanicus*) as a surrogate for basic life history information of the species, as they are the same species and some live in salt marsh environments.

2.4.1 *Reproduction*

For meadow voles, breeding in general is not constrained to a certain time of year but is generally depressed during summer because high temperatures (34 – 39°C (93 – 102°F)) cause an inability to effectively thermoregulate (Bloch and Rose 2005, p. 296). They have a mating system in which females possess a territory and males display promiscuity where they share domains with multiple females within a mating season (Boonstra et al. 1993, p. 225; Rowe 2017, para. 4). Gestation is approximately 21 days, producing 4 – 6 young in a litter, and neonates are altricial and weigh from 1.6 – 3.0 g, begin vocalizing by day 4, are fully furred by day 7, and are able to open their eyes by day 8 (Reich 1981, p. 3). Like many small mammals, life stages (Figure 2-5) occur quickly for meadow voles as they are able to reach sexual maturity within the year of their birth (as quickly as 25 days for females and 40 days for males), though this fluctuates depending on factors such as time of year recruited and population densities (Boonstra 1989, p. 269). Their mean generation time is 42.33 days and life expectancy in the wild is 2 – 3 months with the potential to live up to 16 months (Golley 1961, p. 157; Rowe 2017, entire).

The meadow vole as a species has a very high reproductive potential (Woods 1992, p. 137). The limited known demographic characteristics of the FSMV and the reproductive potential of voles suggest that the FSMV has great reproductive potential and should be able to recover from population declines that may occur after extreme high water events (Woods 1992, p. 137).

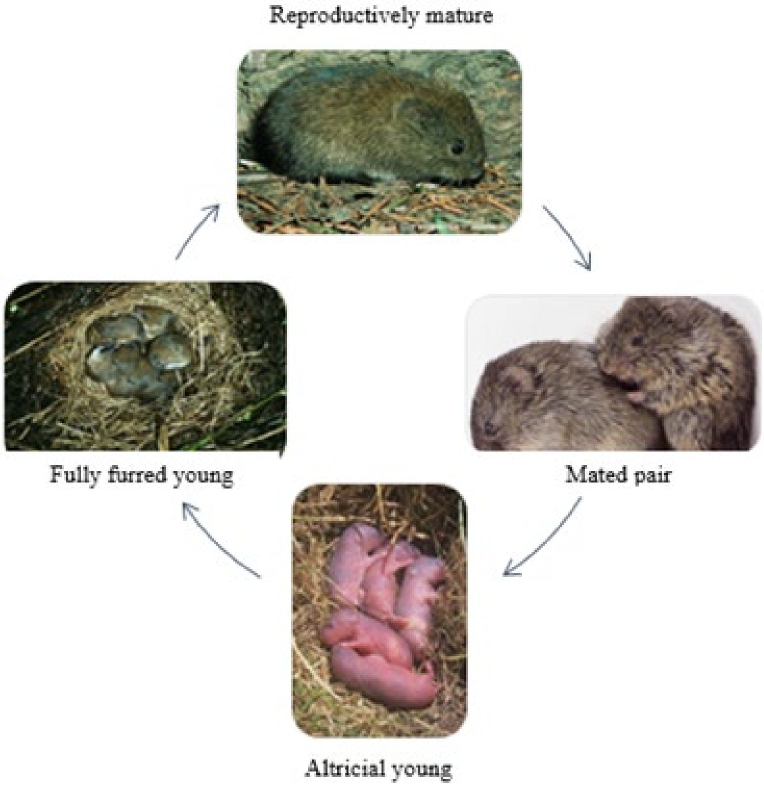


Figure 2-5. Life cycle of *Microtus pennsylvanicus*. Photos: Arkive.

2.4.2 *Behavior*

In order to navigate their habitat, meadow voles create runways in the grass, and are active throughout the day, but most active at crepuscular periods (Harper and Batzli 1996, p. 367). The

FSMV requires the ability to navigate a habitat that floods on average about 0.91 m (3 ft.) twice a day and is susceptible to storm surges.

It has been suggested that survival during high tides and at times of extreme inundation from wind-driven water might be accomplished in several ways: (1) voles might move to high land adjacent to the marshes or onto the occasional islands in the marshes; (2) they might climb up into the tops of vegetation to stay above the water level; (3) they might have an unusual ability to withstand becoming water-soaked and surviving long periods under these conditions while swimming about; and (4) they might have an extensive distribution throughout the salt marsh area and depend on frequent recolonization of marginal habitats most severely affected by tides and storms (Woods et al. 1982, pp. 48-49). Other salt marsh-inhabiting meadow voles have been observed using muskrat houses as rafts during storms in which the habitat is flooded several feet. Meadow voles have also been observed holding onto grasses and branches during high water events and swimming and diving off platforms to move around the marsh (Harris 1953, pp. 482-483). Further research is needed to better understand survival strategies of the FSMV in this dynamic habitat.

2.5 Diet

Meadow voles are herbivorous and appear to be a generalist species. They can consume most available species of grasses, sedges, and herbaceous plant matter (Reich 1981, p. 4). In marsh habitats, the FSMV mostly consumes the plant matter around it such as smooth cordgrass (*Spartina alterniflora*) and saltgrass (*Distichlis spicata*).

How FSMV obtain fresh water in salt marsh environments is an area in need of further study. Getz (1966, entire) conducted tests to see if meadow vole subspecies living in salt marshes had adapted to be able to use saline water sources. He found that salt marsh-inhabiting meadow vole’s need for fresh water was no different than that of an inland-inhabiting meadow vole species. In order to obtain water, other than water gained from consuming vegetation like the freshwater-rich smooth cordgrass, dew is thought to be the most permanent water source for populations of salt marsh inhabiting voles (Getz 1966, p. 206). In order to meet freshwater requirements, subspecies of salt marsh voles in Connecticut had to consume 20 – 25 g of smooth cordgrass every day when they have been known to consume 29 g of vegetation a day (Getz 1966, p. 206). Further research into the FSMV diet and salinity tolerances is needed to know if these dietary needs apply to this subspecies.

2.6 Predators and Competition

Like other subspecies of the widespread meadow vole, the FSMV is likely cyclical in population size (Woods 1992, p. 132). The small mammal community within the FSMV habitat is characterized by shifting densities of species that use different microhabitats at different times (Woods et al. 1982, p. 48; Woods 1992, p. 134). The FSMV is one of four small mammals, including the cotton rat (*Sigmodon hispidus*), marsh rice rat (*Oryzomys palustris*), and cotton mouse (*Peromyscus gossypinus*) that occupy this salt marsh community and the ecotones between the salt marsh and uplands. They compete with each other for limited resources and space in this salt marsh community (Woods et al. 1982, p. 48; Woods 1992, p. 134). The FSMV directly competes with cotton rats as they are both herbivores, and to a lesser extent with marsh rice rats which are omnivorous (will eat bird eggs, insects, and fiddler crabs, in addition to some vegetation) and cotton mice which are primarily granivorous (feed on grain or seeds).

A study comparing population dynamics of meadow voles and house mice (*Mus musculus*) at a dredge disposal site in Virginia found that meadow voles were only able to successfully colonize an area when there was dense enough plant cover, otherwise house mice were the most abundant in a majority of the habitats sampled (Rose and Kratimenos 2006, p. 156). When floating camera traps were deployed in salt marsh habitat in Florida, cameras caught the FSMV in the trap with hispid cotton rats and marsh rice rats (Figure 2-6; McCleery et al. 2014, p. 889).

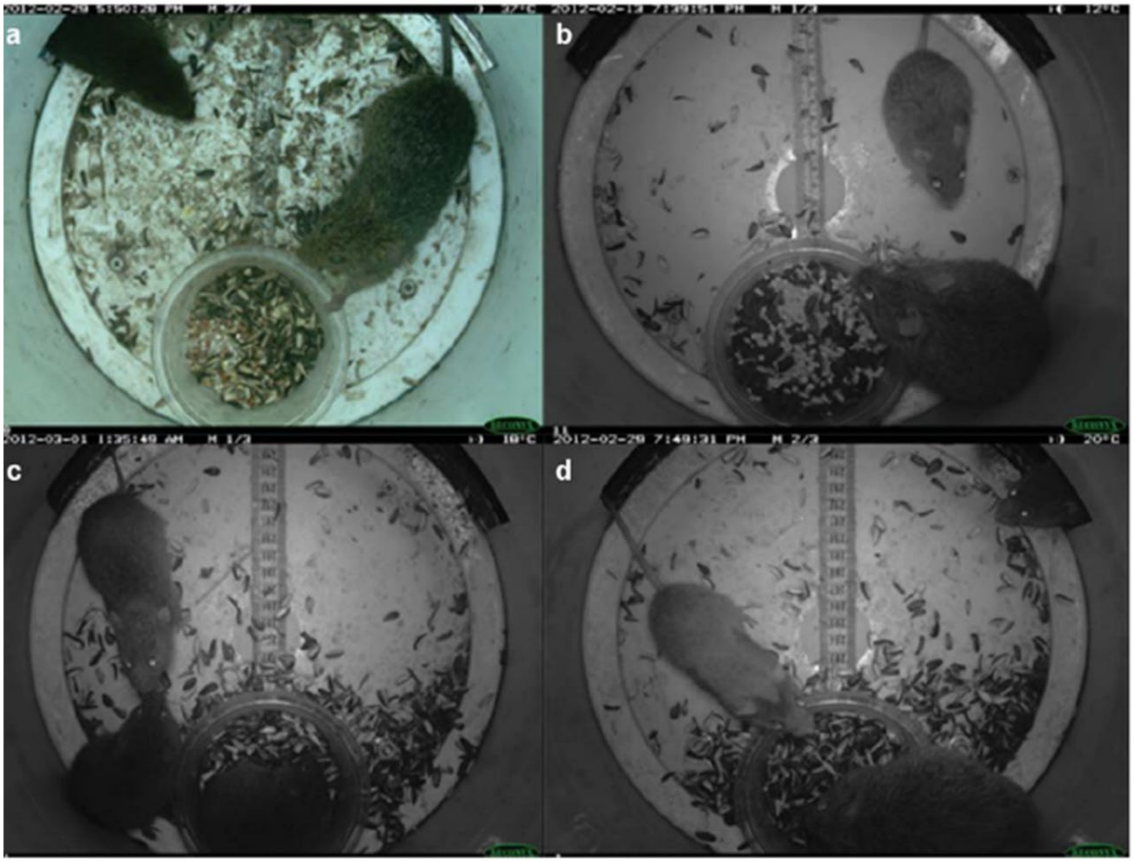


Figure 2-6. Figure from McCleery et al. 2014, showing (a) FSMV and cotton rat (b) rice rat and cotton rat (c) FSMV and rice rat (c), and (d) rice rat, FMSV, and cotton rat.

While there are no data suggesting predation is a significant threat to FSMV, like any other prey species, pressure from predation is likely to influence population trends. The gulf salt marsh mink *(Mustela vison halilimnetes)* is an elusive subspecies of mink that inhabits the coastal marshes from Franklin County, Big Bend region, and Pasco County, Florida (FNAI 2001, entire; http://fwcg.myfwc.com/docs/Salt_Marsh_mink.pdf). This mink is predominantly a carnivore and forages on a variety of small rodents. In McCleery's (2014, p. 4) study using floating camera traps, FSMV, and gulf salt marsh mink, along with raccoons (*Procyon lotor*), hispid cotton rat (*Sigmodon hispidus*) and the marsh rice rat (*Oryzomys palustris)* were found in the same area. While there are no recorded predation events of gulf salt marsh mink on FSMV, they inhabit the same area and are considered potential predators (McCleery et al. 2014, p. 4).

Another source of predation for the FSMV are birds of prey. Species such as the marsh hawk (*Circus cyaneus*), great blue heron (*Ardea herodias*), great egret (*Ardea alba*), and great horned owl (*Bubo virginianus*) have the potential to feed on FSMV even if only opportunistically (FWC 2018a, unpagintaed).

2.7 Individual Needs: Habitat

FSMV inhabit salt marshes along the coast of Florida. Salt marshes are composed of communities of plants which thrive in saline environments that are regularly inundated and drained by tides. They form along shorelines of intertidal areas, most commonly on the eastern coast of the United States. North Florida is home to 70% of the 1.7 million ha (4.1 million ac) of salt marsh in the U.S. (Service 1999, pp. 553-554).

Salt marsh vegetation on the gulf coast is dominated by grasses that have adapted to growing in saline, periodically flooded areas, such as smooth cordgrass, black needlerush, and saltgrass, and the prevalence of different species differs on an elevational gradient (Figure 2-5). Smooth cordgrass occurs at lower elevations and is typically found bordering open water in salt marshes. Generally, as elevation increases, there is a mixing of needlerush and smooth cordgrass, then purely needlerush which is the dominant vegetation type in gulf coast salt marshes. Saltgrass generally proceeds after needlerush, but where FSMV are found, smooth cordgrass and saltgrass are densely intermixed (Figure 2-7; University of Florida 2009, unpaginated). FSMV habitat is generally characterized as salt marsh where the vegetation is dominated by saltgrass with smooth cordgrass and may be near or adjacent to black needlerush (Woods et al. 1982, p. 28; Service 1997, p. 1; McCleery and Zweig 2016, p. 3).

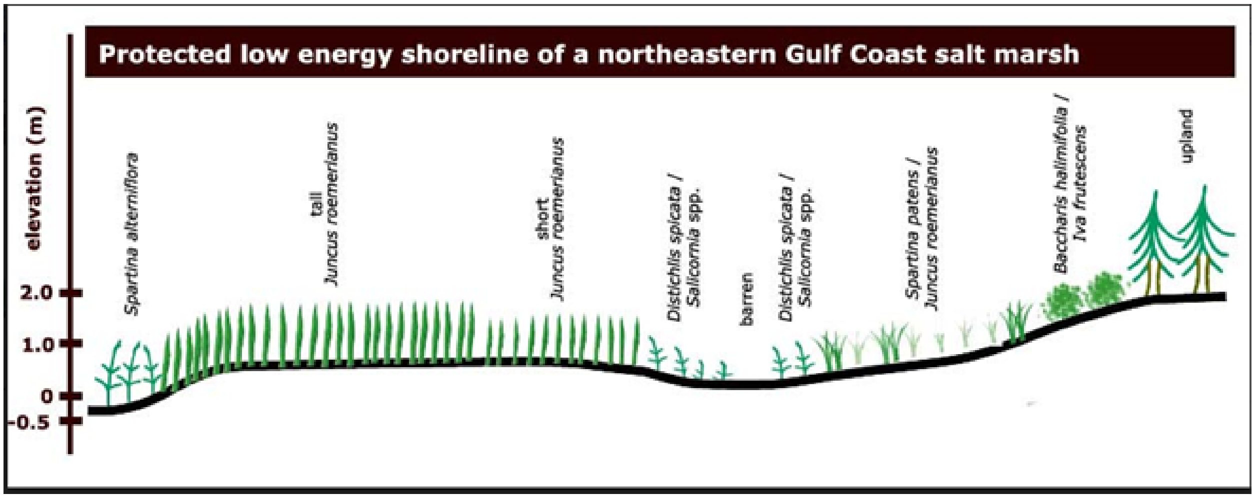


Figure 2-7. Cross section of the general progression of gulf coast salt marsh vegetation. (https://soils.ifas.ufl.edu/florida-wetlands-extension-program/about-wetlands/types-of-wetlands/tidal-salt-marshes).

From the limited number of captures prior to 2010, FSMV distribution within the salt marsh habitat was described as being restricted to saltgrass dominated tidal flats, which generally occur in monotypic stands in the higher salt marsh elevations (Woods et al. 1982, p. 28; Service 1997, p. 1; Raabe and Gauron 2005, p. 3). McCleery and Zwieg (2016, pp. 8-9) conducted exploratory surveys and all vole captures occurred near the Gulf edge of the salt marsh in dwarf (short form) smooth cordgrass intermixed with saltgrass. They developed a predictive landscape model to narrow the area of potential FSMV habitat and documented, through camera trapping, an additional 20 locations (2012 – 2013). McCleery and Zweig (2016, p. 5) suggest FSMV selected larger patches (> 0.49 ha) of habitat that did contain saltgrass but only found voles in patches of habitat intermixed with (16.75 – 43.61%) smooth cordgrass. This habitat is most common in the lower elevations of the salt marsh, which are frequently inundated with tides. They hypothesize that the thicker and taller vegetation at the lower marsh elevations provides shelter and favorable building materials, allowing voles to create their network of tunnels in the vegetation. McCleery and Zwieg (2016, p. 11) also found vole activity decreased outside of smooth cordgrass and saltgrass and that previous description of monotypic stands of saltgrass in the higher elevation in the marsh may represent marginal habitat used during higher population levels.

CHAPTER 3 – SUBSPECIES NEEDS

In order to assess the current and future condition of the subspecies it is necessary to identify the individual, population, and subspecies needs. As defined earlier, resiliency is the ability to withstand disturbances and is associated with population abundance and demography, genetic diversity, growth rate, and habitat quality (Shaffer and Stein 2000, pp. 305-310). In this chapter, we consider the FSMV's ecological needs at the individual, population and subspecies level, and discuss these needs in relation to resiliency, redundancy, and representation (Figure 3-1).

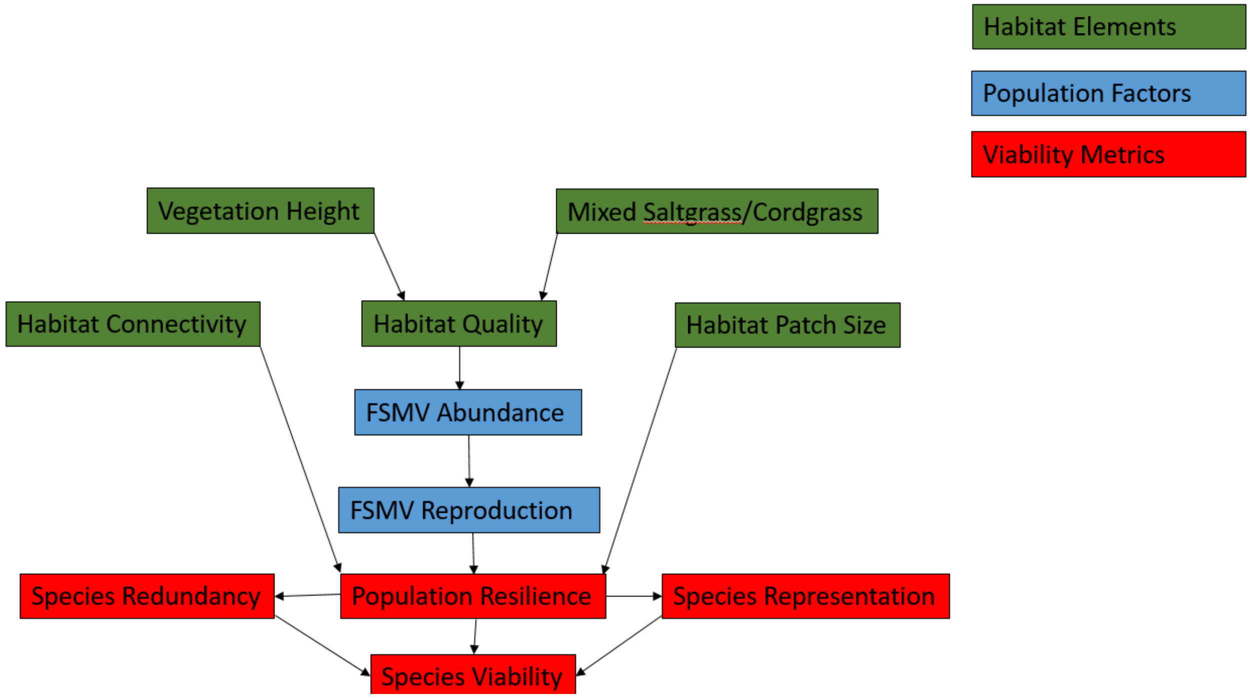


Figure 3-1. Influence diagram depicting the habitat elements and population factors influencing viability of the FSMV.

3.1 Individual Needs

For the FSMV to survive and reproduce, individuals need suitable habitat that supports essential life functions at all life stages. As discussed in Section 2.6, presence of saltgrass vegetation (i.e., saltgrass and smooth cordgrass) of sufficient height (> 73 cm) appears to be essential to the survival and reproductive of individuals, as these habitat elements allow for the construction of networks of tunnels, food and water resource, and nest building (McCleery and Zweig 2016, pp. 4-6). Further research into habitat requirements is needed to increase the knowledge of what suitable habitat is for the FSMV.

3.2 Population Needs

For populations to be resilient, the needs of individuals (e.g., salt marsh vegetation) must be met at a larger scale. Patches of suitable habitat must be large enough (> 0.49 ha; McCleery and Zweig 2016, p. 10) and have sufficient connectivity to support a large enough reservoir of potential mates, while avoiding issues associated with small population sizes, such as inbreeding depression.

3.3 Subspecies Needs

For the subspecies to be viable, there must be adequate redundancy (suitable number, distribution, and connectivity to allow the species to withstand catastrophic events) and representation (genetic and environmental diversity to allow the species to adapt to changing environmental conditions). Redundancy improves with increasing numbers of populations (natural or reintroduced) distributed across the species range, and connectivity (either natural or human-facilitated) allows connected populations to "rescue" each other after catastrophes. Representation improves with the persistence of populations spread across the range of genetic and/or ecological diversity within the species. Long-term viability will require resilient populations to persist into the future; for the FMSV, this will mean maintaining salt marsh habitat to support many redundant populations across the subspecies range.

CHAPTER 4 – INFLUENCES ON VIABILITY

The following discussion provides a summary of the factors that are affecting or could be affecting the current and future condition of the FSMV throughout some or all of its range.

4.1 Development

Urbanization plays both direct and indirect roles in the decline of many species (McKinney 2002, p. 883). Urbanization fragments and replaces natural habitats with artificial structures, impervious concrete and asphalt surfaces, manicured lawns, and gardens full of exotic plant species, and increases levels of air, water, noise, and light pollution, putting the survival of many wildlife in jeopardy (Sutherland 2009, p. 35). Urbanization impacts many wildlife species from direct loss of habitat, fragmentation of habitat, increased road mortality, and to the increase in domestic predators, such as cats and/or dogs.

Levy County is rural with about 40,000 people living in the county's 1,412 square miles (Frank et al. 2014, p. 47); approximately 0.43 people per 0.4 ha (1 ac) (Carr and Zwick 2016, pp. 29, 27). Levy County's coastline is gently sloping landscape which is dominated by small coastal islands, extensive salt marsh, freshwater marshes, and wet forests, thus making it unsuitable for significant urban development (Frank et al. 2014, p. 47). There are minimal impacts to the salt marshes in this area due to development (i.e., the coastal development primarily occurs on Cedar Key and Way Key), though Carr and Zwick (2016, p. 29) estimate a "medium" growth in population with a 32% population increase in Levy County by 2070.

Ninety-two percent of the coastal uplands and marshes within 20 miles of the type location are publicly owned and managed for conservation (Root and Barnes 2006, pp. 78-80) and thus allowing for natural process to operate freely within these areas; and 70% of potential habitat in the coastal marshes within 125 miles of the known range are publicly owned and managed for conservation. There are only 7 locations of FSMV found outside of areas that are not conservation lands.

4.2 Stochastic Disturbances

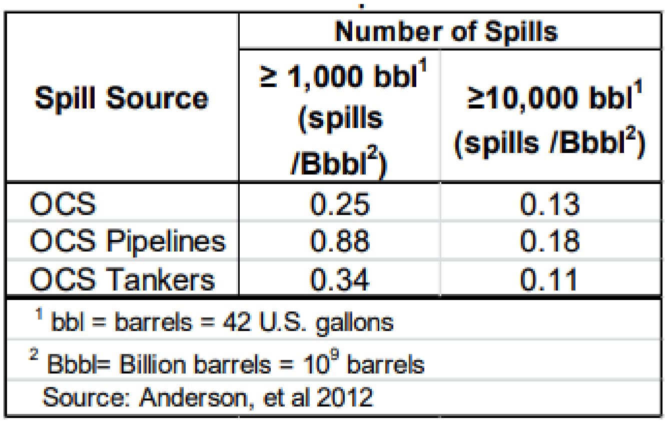
4.2.1 Oil Spills

Thousands of oil spills occur in the United States every year but most involve the spilling of less than one barrel of oil (NOAA Office of Response and Restoration [ORR] 2017, unpaginated). Since 1969, there have been at least 44 oil spills greater than 10,000 barrels in U.S. waters including the largest to date, the 2010 Deepwater Horizon spill in the Gulf of Mexico (NOAA ORR 2017). There have been 16 oil spills recorded in the Gulf of Mexico responsible for the spilling of at least 0.05 million gallons (NOAA ORR 2017). There have been eight spills in the Caribbean Sea with at least 0.05 million gallons spilled (NOAA ORR 2017).

Offshore oil tanker spills pose the same threat. A study of contaminants in diamondback terrapins (*Malaclemys terrapin*) in Louisiana after the Deepwater Horizon spill showed that turtles in areas with higher exposure to crude oil had higher levels of contaminants in their systems. Drabeck et al. (2014, pp. 132-133) found higher levels of toxic contaminants (2-ring aromatic hydrocarbon biphenyl, alkylated PAH dimethylnapthalene, and biphenyl) in the reptiles' tissues sampled. These substances are most commonly associated with crude oil and gasoline (Drabeck et al. 2014, pp. 132-33). Depending on the location and severity of the incident, oil spills could affect all life stages of the FSMV.

Large spills have the potential to reach salt marshes and negatively impact FSMV habitat. Grasses that line the coast of salt marsh habitats die when they come in contact with oil from an oil spill. This die-off of vegetation not only would immediately affect FSMV through a lack of food, water, and shelter source, but the loss of salt marsh vegetation would also cause erosion that would contribute to general land loss (Silliman et al. 2012, p. 11237).

An analysis for the probability of an oil spill greater than or equal to 1,000 barrels produced and transported during a 15-year period (1996 – 2010) in the outer continental shelf (OCS) of the Gulf of Mexico. Spill rates were expressed in terms of spills per Bbbl (billion barrels) of oil handled (Table 4-1). These calculations determined that platforms on the OCS had a spill rate of 0.25 spills/Bbbl, pipelines had a spill rate of 0.88 spills/Bbbl, and tankers had a spill rate of 0.34 spills/Bbbl. For more than 10,000 barrels of oil spilled in the 15-year period, platforms had a spill rate of 0.13 spills/Bbbl, pipelines had a spill rate of 0.18 spills/Bbbl, and tankers 0.11 spills/Bbbl (Anderson et al. 2012, pp. 25-29). Due to these rates and the many measures put in place to protect salt marsh habitats in the case of an oil spill such as Area Contingency Plans, Environmental Sensitivity Index Maps, Florida Marine Spill Analysis System (FMSAS), and the Wildlife Contingency Plan (WCP) it is "unlikely" a stochastic event such as an oil spill will happen at such a magnitude that would negatively affect FSMV.



Spill Source	Number of Spills	
	≥ 1,000 bbl[1] (spills /Bbbl[2])	≥10,000 bbl[1] (spills /Bbbl[2])
OCS	0.25	0.13
OCS Pipelines	0.88	0.18
OCS Tankers	0.34	0.11

[1] bbl = barrels = 42 U.S. gallons

[2] Bbbl= Billion barrels = 10^9 barrels

Source: Anderson, et al 2012

Table 4-1. Oil spill rates based on a 15-year period (1996 – 2010) for OCS platforms and pipelines and a 20-year period (1989 – 2008) for tankers, as found in Anderson et al. 2012 (p. 41).

4.2.2 Florida Red Tide

A red tide is an abnormally high concentration of microscopic algae that can produce toxic chemicals. Florida red tide (*Karenia brevis*) that is found exclusively in the Gulf of Mexico, can kill mass amounts of fish as well larger marine mammals and can cause illness or death in humans when swimming in a red tide or ingesting contaminated seafood (Anderson 1994, p. 52). Although we do not know the probability that a large red tide event would occur within FSMV habitat, the event has the potential to cause direct mortality to individuals if they were to swim in the waters or ingest it (FWC 2018, http://myfwc.com/research/redtide/faq/).

Florida red tide expert Leanne Flewelling confirmed with the use of her historical data base that since 1990, there have only been 3 recorded Florida red tide blooms along shore between the Suwannee and Withlacoochie rivers (2003, 2005). Although red tides may have the potential to cause fatalities of FSMV, from the time of their placement on the endangered species list to present day, there have been no large algal blooms in the salt marshes of their current range (Figure 4-1).

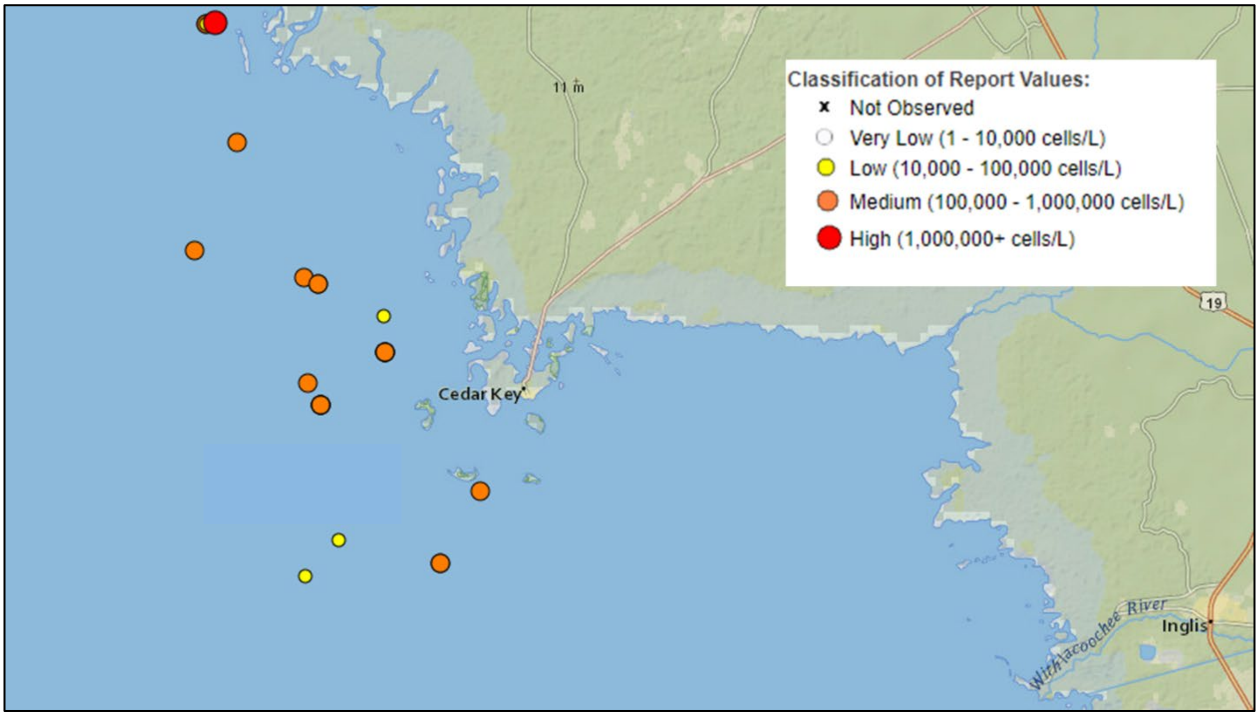


Figure 4-1. Map of red tide events of *Karenia brevis* algae near FSMV range from the date of its listing as endangered to present day (1991 – 2018). Conditions >100,000 cells can result in possible fish kills (NOAA 2016, https://service.ncddc.noaa.gov/website/AGSViewers/HABSOS/maps.htm).

4.3 High Water Events

One of the primary stressors to the FSMV is catastrophic weather, hurricanes, or other strong storm systems that cause extreme high water events. Storm surges can partially or completely inundate the salt marsh habitats. Florida's Gulf coast salt marshes are very vulnerable to flooding because they are low lying and the adjacent Gulf waters are very shallow. Westerly winds from tropical storms and severe frontal boundaries increase the amplitude of the normal high tides, which can elevate water levels above the normal mean high water levels.

Although a large amount of potential habitat has been identified, FSMVs have only been documented within a 20-mile section of coast. Consequently, this subspecies is at risk from catastrophic storm events and may not maintain densities necessary to persist through storm events and seasonal fluctuations of resources. It is noted that FSMV's have shown some resiliency to such events. They were originally documented in 1979 and most recently documented in 2013 at the type location and there are 30 high water events that have been documented for the Cedar Key area during this time period. FSMV has been able to survive in its natural habitat and apparently maintain populations within the tidal marshes near Cedar Key under the extreme conditions from the many tropical and other storm systems that have impacted this area since discovery. However, the FSMV continues to be at risk due to its limited distribution and the potential for catastrophic and repetitive high water events.

4.3.1 Hurricanes

There has been a substantial increase in most measures of Atlantic hurricane activity since the early 1980s, the period during which high-quality satellite data are available. These include measures of intensity, frequency, and duration as well as the number of strongest (Category 4 and 5) storms (Walsh et.al. 2015, entire). The increases in storm strength are linked, in part, to higher sea surface temperatures occurring in the equatorial regions of the Atlantic Ocean where hurricanes form and move (Service 2017, p. 7).

Hurricane activity has been above normal since the Atlantic Multi-Decadal Oscillation (AMO) (the natural variability of the sea surface temperature in the Atlantic Ocean) went into its warm phase around 1992. The increased intensity of tropical storms and hurricanes result in higher storm surge and coastal flooding events and greater impacts to coastal habitats than historically documented. Ecosystem resiliency is reduced when impacts by extreme and repetitive events occur (Service 2017, p. 7). The last direct strike of a hurricane near Cedar Key was Hurricane Gladys (Category 2) in 1968, Hurricane Easy (Category 3) in 1950 and there have been no records of a Category 3-5 landfalls since 1880 (NOAA at http://www.aoml.noaa.gov/hrd/tcfaq/E24.html). During this same time period southeast Florida has had 15 major hurricanes, southwest Florida 10, and northwest Florida 12.

Storm surge and coastal flooding has the potential to result in displacement of FSMV landward to higher elevations and potentially less suitable habitat, as well as direct mortality of individual FSMV. Woods (1988) attempted to determine if FMSVs at the type locality were impacted by heavy storm activity. Two years after the 1985 Hurricane Elena, 49 traps for FSMV were set every day for a month and resulted in no FSMV. Number of traps were then doubled and resulted in locating one FSMV (Woods 1988, pp. 2-6). Number of captures and effort in different studies varied throughout the years, but because their life history is not well studied, we cannot conclude that storm events are influencing population levels more than other factors in studies that have resulted in very few captures (Hotaling et al. 2010, p. 796).

4.3.2 King Tides and Storm Surges

King tides are naturally occurring tides that become exceptionally high during spring tides and atmospheric disturbances, such as a storm passing, or an El Niño event. They can happen anywhere from 2 – 4 times a year and have the potential to cause coastal erosion (Roman-Rivera and Ellis 2018, p. 771). If a winter storm coincides with a King tide, water levels may increase and impacts become greater (NOAA 2016, entire). King tides could potentially cause direct mortality to individual FSMV if they have insufficient places to retreat to. Although studies of FSMV during high water events have not been conducted, other species of salt marsh dwelling meadow vole have been documented using structures in the marshes to survive high water events, but we cannot determine FSMV specific rate of survival rate during stochastic high water events such as king tides. Tide charts of Cedar Key, Florida predicted tides of up to 140 cm (4.6 ft) (NOAA 2018, unpaginated).

A storm surge is an abnormal rise in sea water levels during a storm event (NOAA 2018, entire). These surges can inundate habitat that could cause direct mortality of FSMV.

4.4 Climate Change

In the southeast United States climate change is expected to result in more frequent drought, more extreme heat (resulting in increases in air and water temperatures), increased heavy precipitation events (e.g., flooding), more intense storms (e.g., frequency of major hurricanes increases), and rising sea level and accompanying storm surge (IPCC 2013, entire). Warming in the southeast is expected to be greatest in the summer, which is predicted to increase drought frequency, while annual mean precipitation is expected to increase slightly, leading to increased flooding events (IPCC 2013, entire). Changes in climate may affect ecosystem processes and communities by altering the abiotic conditions experienced by biotic assemblages resulting in potential effects on community composition and individual species interactions (DeWan et al. 2010, p. 7). These changes have the potential to impact FSMV and/or their habitat.

Climate change could intensify or increase the frequency of drought events, such as the one that occurred in the southeastern USA in 2007. Thomas et al. (2004, pp. 145-147) report that the frequency, duration, and intensity of droughts are likely to increase in the southeastern U.S. as a result of global climate change. Increases in frequency and duration of drought conditions could have significant negative impacts to the wetlands that FSMV depend on.

Despite the recognition of climate effects on ecosystem processes, there is uncertainty about what the exact climate future for the southeastern United States will be and how the ecosystems and species in this region will respond. It should be recognized that the greatest threat to many species from climate change may come from synergistic effects. That is, factors associated with a changing climate may act as risk multipliers by increasing the risk and severity of more imminent threats.

4.4.1 Sea Level Rise

Global climate change is what led to the remnant FSMV population (Woods et al. 1982, p. 42-43). Long-term sea level rise will continue to affect the extent of salt marsh available to the FSMV along the central Gulf coast of Florida. Meehl et al. (2005) predicted a future sea level rise due to global climate change by the end of the century, which would significantly change the coastal marshes and adjacent uplands of Florida. According to the Third National Climate Assessment, sea level rise and increasing storm surge events are occurring and are impacting coastal species and ecosystems (Carter et al. 2014, p. 400). It is expected that low-lying coastal habitat will be affected most severely by sea level rise. The varying and dynamic elements of climate science are inherently long term, complex, and interrelated. At present, the science is not exact enough to precisely predict when and where climate impacts will occur. Although we may know the direction of change, it may not be possible to predict its precise timing or magnitude.

Since 1880, global sea level has increased by 0.20 to 0.23 m (8 to 9 in), and the rate of increase over the past twenty years has doubled (Service 2017, p. 5). The long-term trend in sea level rise at the National Oceanic and Atmospheric Association (NOAA) Cedar Key Station shows a 2 millimeter (mm) (0.08 in) increase of the mean high water line (MHWL) per year from 1914 to 2016. As mentioned above, Levy County's coastline is gently sloping and is dominated by small coastal islands, extensive salt marsh, freshwater marshes, and wet forests. The long-term stressor and future habitat changes will be directly related to rising sea levels. Geselbracht et al. (2011, p. 53) using the Sea Level Affecting Marshes Model (SLAMM) to study Waccasassa Bay, indicates that salt marsh dependent species will probably persist due to the projected increases in the overall extent of the salt marsh habitat in response to sea level rise. Florida salt marsh vole's habitat appears to have much better opportunities for potential inland retreat (Frank et al. 2014, p. 67) due to the low lying uplands and sparse coastal development that would impede retreat.

4.4.2 Projected Changes in Temperature and Precipitation

The projected increases in average annual temperature by the late 21st century (compared to the late 20th century) vary from 1.67 to 3.89°C (3 to 7°F) (statewide depending on location and the emissions scenario used). Extreme heat events in Florida are projected to increase relative to 1986 – 2005. By the late 21st century the average temperatures on the hottest days will be 1.67 to 3.89°C (3ºF to 8°F) hotter. Due to the already released, human-induced emissions of greenhouse gases present in the environment, another 0.28°C (0.5°F) increase in surface air temperature would be expected, even if there was a sudden end to all human-induced greenhouse gas emissions (Carter et al. 2014, p. 399). The Florida coastal area is projected between 2041 to 2070 to experience approximately thirty to forty more days a year temperatures above 35°C (95°F) compared to recent historic levels (1971 – 2000) (Figure 4-2).

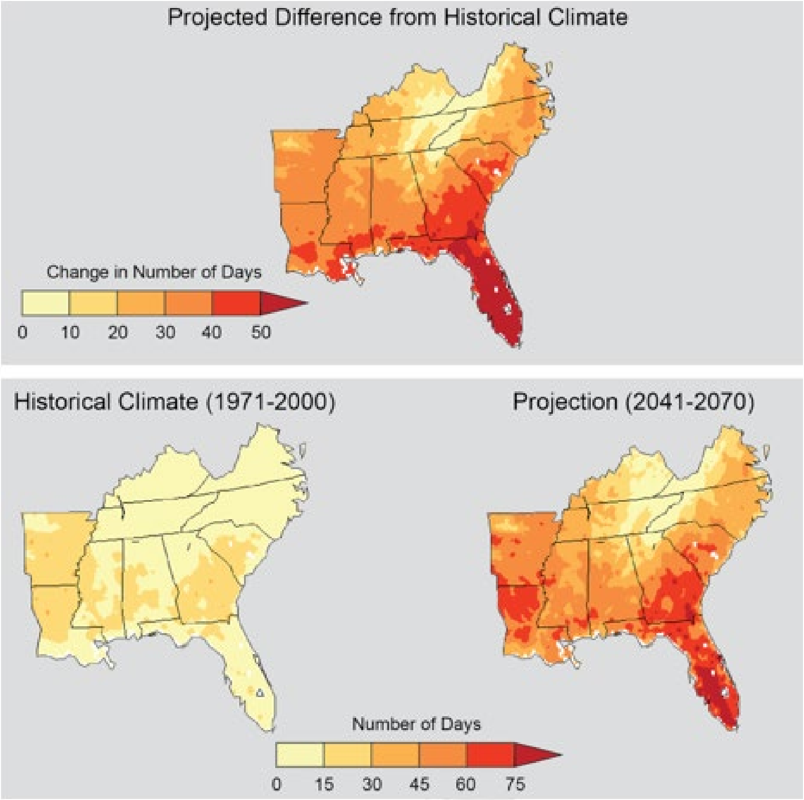


Figure 4-2. Historical and projected changes in temperature in the Southeastern United States (Carter et al. 2014, p. 399).

Precipitation projections are less certain but many models project increases in precipitation during fall and winter across central Florida (Service 2017, pp. 2-5). Projections of future changes in precipitation show substantial shifts in where and how precipitation will fall. Models agree regarding changes in tropical storm and hurricane rainfall events. Greater rainfall rates are expected with about a 20% increase near the center of storms. Scientists continue to research the expectation of precipitation changes in other severe storms (Service 2017, pp. 4-5). Dry consecutive days are expected to increase up to 20% in central Florida by 2100. Extreme conditions (lack of rainfall and increased temperatures) across a coastal ecosystem create losses in vegetative cover that the FSMV relies on for habitat.

Changes in precipitation and temperature have the potential to change the dominant vegetation For example, an increasing number of studies have shown that mangroves continue to encroach northward on both coasts of Florida as the climate warms and cold winter temperatures become less severe (Stevens et al. 2006, entire; Saintilan et al. 2014, entire; Osland et al. 2018, entire). Recent sampling efforts suggest mangrove encroachment could have a negative impact on FSMV, as a preliminary analysis revealed that FSMV were not detected at the 4 southernmost sites where FSMV were detected in 2014, an area where mangroves have substantially encroached (McCleery and Taillie, pers. comm., 2019). In light of these observations, McCleery and Taillie have proposed additional sampling to address multiple related aspects of this potential range contraction of FSMV, particularly identifying areas with varying degrees of mangrove encroachment adjacent to areas where voles occur to use a gradient study approach to quantify the effect of this encroachment on FSMV habitat quality. This study will help to better understand the impacts of the potential threat of mangrove encroachment.

Finally, because breeding for meadow voles is generally depressed during summer due to high temperatures (34 – 39°C (93 – 102°F)) causing an inability to effectively thermoregulate (Bloch and Rose 2005, p. 296), it is possible that an increase in average temperature resulting from climate change may at some point negatively affect reproductive activity of this species.

4.5 Conservation Measures

The Clean Water Act regulates dredge and fill activities that would adversely affect wetlands. Such activities are commonly associated with projects to create dry land for development sites, water-control projects, and land clearing and for water dependent projects such as docks/marinas and maintenance of navigational channels. The U.S. Army Corps of Engineers and the Environmental Protection Agency share the responsibility for implementing the permitting program under Section 404 of the Clean Water Act. Permit review and issuance follows a process that encourages avoidance, minimizing and requiring mitigation for unavoidable impacts to the aquatic environment and habitats. This includes protecting the salt marsh habitat and wildlife like the FSMV that depends upon salt marsh for survival.

The National Wildlife Refuge System Administration Act (NWRAA) represents organic legislation that set up the administration of a national network of lands and water for the conservation, management, and restoration of fish, wildlife, and plant resources and their habitats for the benefit of the American people. Amendment of the NWRAA in 1997 required the refuge system to ensure that the biological integrity, diversity, and environmental health of refuges be maintained. The FSMV occurs on Lower Suwanee NWR (MacKenzie 2004, p. 6) and is protected under this Act.

The FSMV is listed by the State of Florida as a species of concern. The FSMV is protected under rule 68A-27.003 as a Federally-designated endangered species. On State wildlife management areas, regulations (Chapter 68A-15.004, Florida Administrative Code) protect individual FSMV, although the species is yet to have been found on a wildlife management area (WMA). Wildlife management area regulations prohibit destruction or modification of habitat, except for management and restoration activities. Because the FSMV is listed by the State of Florida, these protective regulations apply to this subspecies on the above mentioned State Properties and private properties. Florida Administrative Code, Chapter 62D-2.013 prohibits the destruction of habitat or wildlife from Florida Department of Environmental Protection, Division of Recreation and Parks' properties except as authorized under this regulation. The salt marshes that FSMV depend on are also sovereignty submerged lands and receive protections via state regulations enacted to protect salt marsh systems. Specifically, the Warren B. Henderson Wetlands Act of 1984 established clear guidelines for defining wetland areas that come under state jurisdiction. All dredging and filling activities in state waters require permits unless specifically exempted. Currently, the state of Florida's Department of Environmental Protection has measures put in place to protect shorelines and sensitive habitats if events such as an oil spill were to occur. Area Contingency Plans, Environmental Sensitivity Index Maps, the Florida Marine Spill Analysis System (FMSAS), and Wildlife Contingency Plans (WCP) are some of the many plans the state of Florida has in the event of an oil spill to address the potential harm of an oil spill (FDEP 2019, unpaginated).

Root and Barnes (2006, pp. 78-80) estimated that 92% of the potential FSMV habitat between Horseshoe Beach and the Waccasassa River (40 miles of coastline) is located on and adjacent to publicly managed conservation lands (Figure 4-3). Beyond this 40-mile stretch identified as potential FSMV habitat, smooth cordgrass/saltgrass marshes also occurs north through St. Marks NWR and south through Chassahowitzka NWR. Approximately 70% of this 180 mile section of Florida coastline (Florida's Big Bend Region) is in public ownership. Conservation minded management of these public lands allows for: 1) natural processes to operate freely and thus changes to habitat occur due to current and future environmental conditions; 2) managing the use of resources and activities which minimizes impacts; 3) preservation and restoration to maintain habitats; and 4) reduction of the adverse physical impacts from human use.

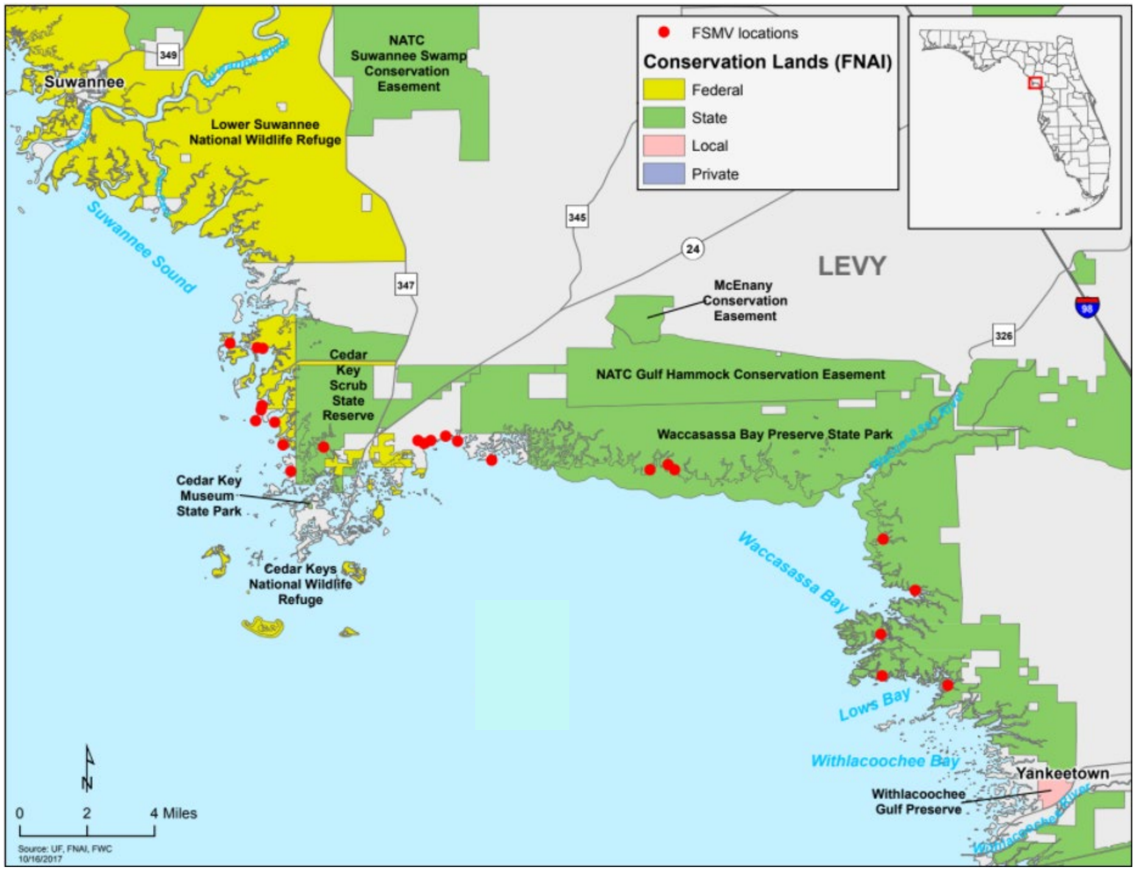


Figure 4-3. Florida salt marsh vole location in relation to publicly managed lands.

The type/original locality, discovered in 1979, is within privately owned salt marsh near the Waccasassa Bay Preserve State Park, and along with the adjacent uplands continues to be a target for acquisition and protection. A proposal to manage and preserve the uplands and adjacent salt marsh vole habitat within the Florida Gulf Coast Mitigation Bank is under review by the U.S. Army Corps of Engineers.

4.6 Summary of Influences on Viability

There are many potential influences on the viability of FSMV (Figure 4-4), although a general lack of data on the specific impacts of both positive and negative influences makes predictions difficult at best. The FSMV is a subspecies with a very limited range and is at risk from any natural or environmental catastrophe. Extreme high water events and oil spills can completely impact the range of 20 miles of coastal marsh habitat known to be occupied. Long-term, these coastal marsh habitats will likely be impacted by sea-level rise, however the adjacent undeveloped conservation lands adjacent to most of the FSMV habitat will accommodate up slope migration of the coastal habitat communities.

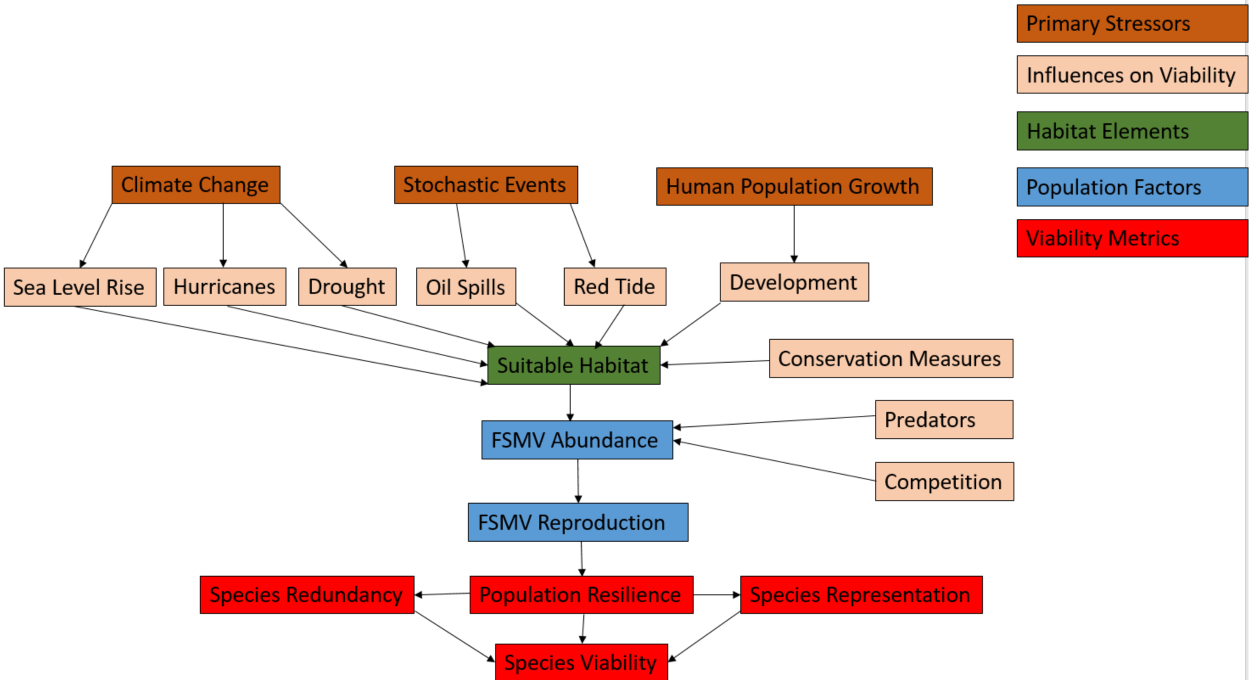


Figure 4-4. Influence diagram depicting the various potential influences on viability for FSMV.

A significant portion, over 90%, of the coastal marshes where the FSMV is known to occur is publicly owned: Lower Suwannee NWR, Cedar Keys NWR, Cedar Key Scrub State Preserve and Waccasassa Bay State Preserve.

Disease, predation, or overutilization for commercial, recreational, scientific, or educational purposes are not known to be a threat to recovery. Regulatory mechanisms are in place to aid in minimizing impacts from development on both privately owned lands and publicly managed lands. Levy County's coastline is rural due to its gently sloping landscape which is dominated by small coastal islands, extensive salt marsh, freshwater marshes, and wet forests, thus making it unsuitable for significant urban development. Hurricanes and other severe storm events that cause extreme high water events are a natural factor affecting the FSMV's continued existence as well as large oil spill events. Given a very limited range and only a few known locations within 20 miles of each other, a hurricane or strong storm event or oil spill could cause a catastrophic decline or possibly the extinction.

In summary, FSMV are potentially at risk due to the species very small range and from the threat from hurricanes and severe storms that cause extreme high water events. The long-term threat to the FSMV is from rising sea levels.

CHAPTER 5 – CURRENT CONDITION

In this chapter, we first describe how we delineated representative units and resilience units within the range of FSMV. Then we describe how we used habitat information to assess the current resilience, redundancy, and representation for the species.

5.1 Representative Units

The FSMV has a very limited geographic range, and there is no genetic or ecological evidence to support delineating multiple representative units.

5.2 Resilience Units

We divided the species range into three units to assess resilience (Figure 5-1). These units are not meant to represent "populations" in a biological sense; they do not represent groups of demographically linked interbreeding individuals. Data are not available to delineate biological populations of FSMV at this time. Rather, these units were designed to subdivide the species range in a way that facilitates assessing and reporting the variation in current and future resilience across the range.

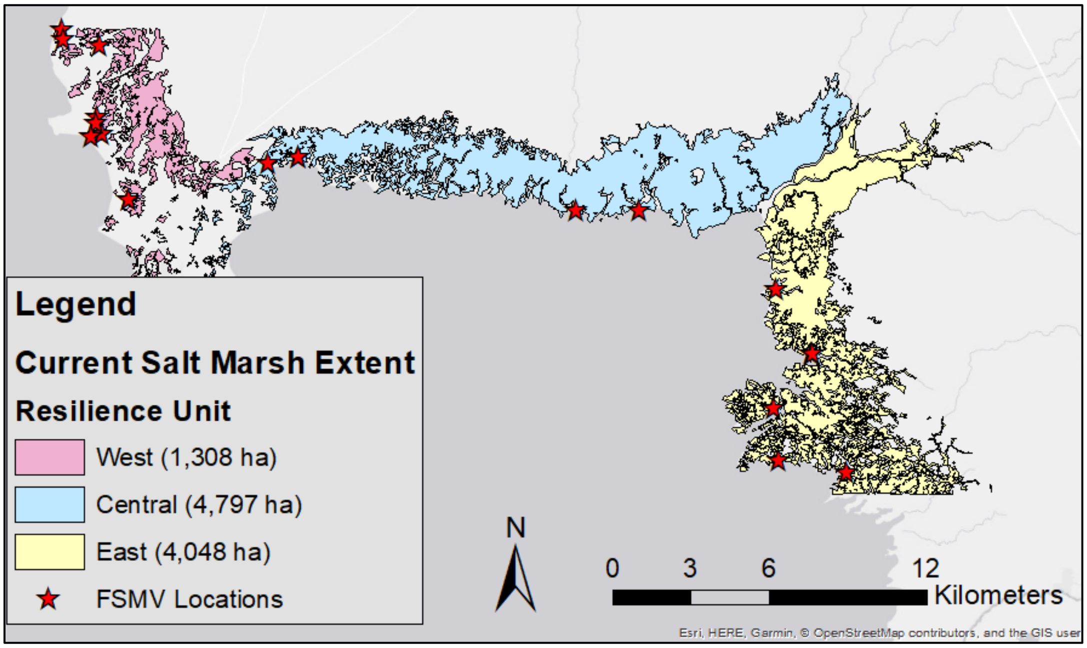


Figure 5-1. Florida salt marsh vole resilience units. Note that a lobe of salt marsh habitat within the bounds of the Central Unit [east of State Road 24] is grouped instead with the West Unit because it is a continuous patch of salt marsh that primarily occurs in the West Unit.

The three units are West, Central, and East, and correspond with the major features in the shape of the coastline. The West Unit and the East Unit fall along coastline that is oriented from north to south, while the Central Unit in the middle falls along coastline that is oriented from west to east. The boundary between the West and Central units is State Road 24, which leads from Cedar Key on the coast north to the mainland, for approximately 5 km north from the coast, at which point the boundary between units follows County Road 347 farther north. The boundary between the Central and East units is the Waccasassa River.

5.3 Current Condition Methods

Population data for FSMV (e.g., occupancy, abundance, demographic rates) are lacking or extremely limited. Consequently, we used habitat information to assess the current condition for FSMV. We assessed resilience range-wide and for each unit by measuring habitat area, habitat connectivity, and the protection status of habitat.

5.3.1 Habitat Area

We used a predictive habitat model developed by McCleery and Zweig (2016, entire) to measure the current amount of potential habitat within the known range of FSMV (Figure 5-2).

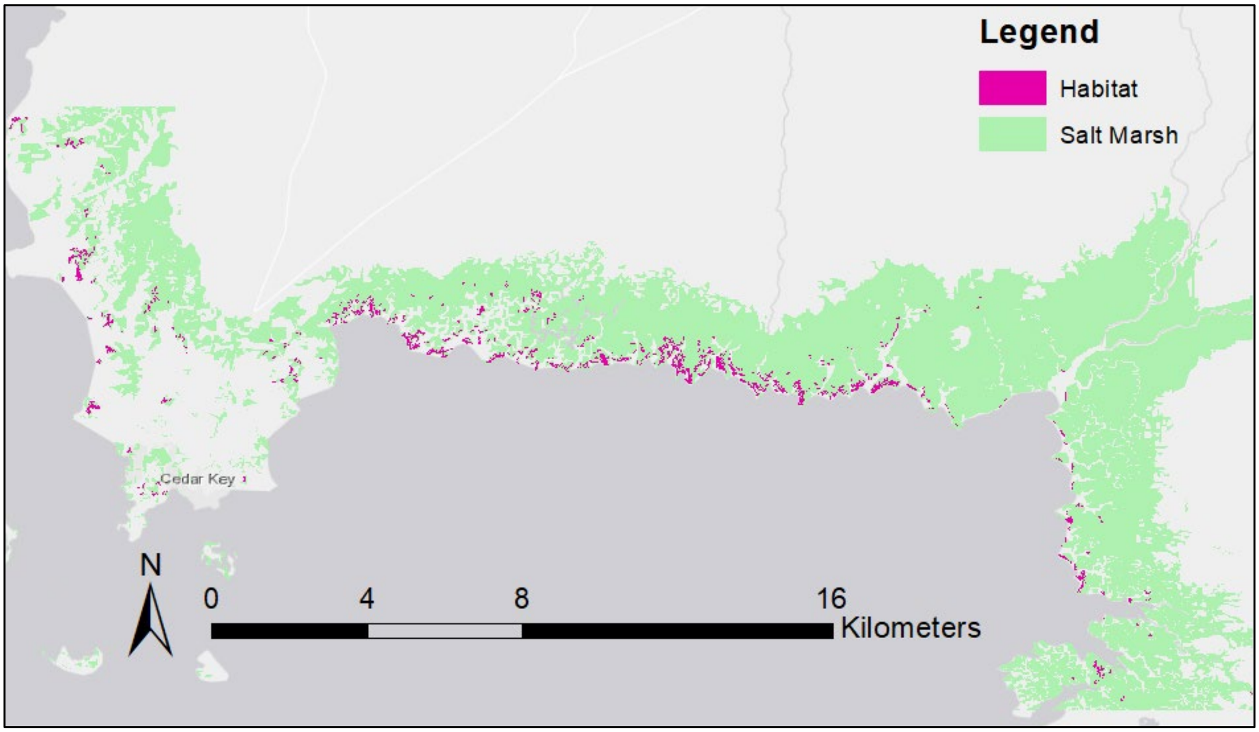


Figure 5-2. Area predicted to be FSMV habitat by the McCleery and Zweig (2016) model, which makes up only 2.6% of salt marsh along the same region of coastline.

To develop this habitat model, FSMV were trapped along transects, and ultimately had 30 captures (McCleery and Zweig 2016, p. 1250). All of the captures occurred in the dwarf smooth cordgrass and saltgrass vegetative community on the seaward edge of the salt marsh. The patches of habitat around captures were delineated and overlaid on digital imagery, and these "training" patches were then used to classify other patches of potential habitat based on shared spectral and textural characteristics (McCleery and Zweig 2016, p. 1250). Of 13,000 ha of salt marsh assessed, 264 ha were identified as potential habitat, mostly located on the seaward side of the salt marsh, and with an average patch size of 0.68 ha (McCleery and Zweig 2016, p. 1252). Thirty-six identified habitat patches were sampled with camera traps to validate the model, and FSMV were found at eight of those (22% model accuracy; McCleery and Zweig 2016, p. 1252). Within identified habitat patches, FSMV were found more specifically in patches > 0.49 ha and with average smooth cordgrass cover between 16.75% and 43.61% (McCleery and Zweig 2016, p. 1252).

Prior to the work of McCleery and Zweig (2016, entire), the species was only known from 3 locations (two in the West Unit and one in the western portion of the Central Unit. Now, FSMV have been recorded 20 times across 15 different locations, representing an expansion of the known range of the species farther east and south than previously known into the middle portion of the Central Unit and into the East Unit. Given how little is known about the species and until recently, where it occurs, it is plausible that the species range still extends farther than currently known limits. However, if FSMV do occur farther north or south than the currently known range, they likely are using habitat differently. McCleery and Zweig (2016, pp. 1252-1253) observed that the dwarf smooth cordgrass and saltgrass communities where FSMV are found are rare outside of the currently known range of the species. North of the currently known range, salt marsh up to the Suwannee River was included in the extent of the habitat model, but habitat was not identified, possibly due to changes in water salinity or tidal energy; south of the currently known range, mangrove is more common on the seaward edge of the salt marsh (McCleery and Zweig 2016, p. 1253). For the purposes of characterizing the current condition of the species, we consider only habitat within the current known extent of the species range. Extending surveys and habitat models to a wider area of salt marsh north and south of the known range is an area ripe for future investigation.

To assess the current condition, we focused on the amount of potential habitat from the above-described model. As we transition into the assessment of the future condition, however, the McCleery and Zweig model cannot be applied (it models only current habitat, with no forecasts of future condition) and our assessment will focus more on patches of salt marsh as a proxy for habitat. In order to provide a measure of potential habitat consistent with methods for the future condition assessment, we also report the current condition of the broader salt marsh within the species range. Current salt marsh spatial data came from the Gulf Coast Prairie Landscape Conservation Cooperative (GCPLCC) Sea-Level Affecting Marshes Model (SLAMM) Gap Analysis Project (available at: http://www.warrenpinnacle.com/prof/SLAMM/GCPLCC/, Geselbracht et al. 2015, entire), and the current condition from this data set corresponds to the year 2008.

5.3.2 Habitat Connectivity

To assess habitat connectivity, we measured patch sizes of both predicted habitat and of salt marsh. Although not all salt marsh is preferred habitat, we assume based on observations from McCleery and Zweig (2016, p. 1252) that FSMV still do use and move through salt marsh that is not of the dwarf smooth cordgrass and saltgrass vegetative community. This measure will serve as a baseline to examine how habitat becomes more or less connected in the future with rising sea levels. We calculated both the average patch size, and the area of patches larger than 1 ha. No FSMV have yet been observed on patches of salt marsh smaller than 1 ha (Figure 5-3; smallest patch is 2.4 ha).

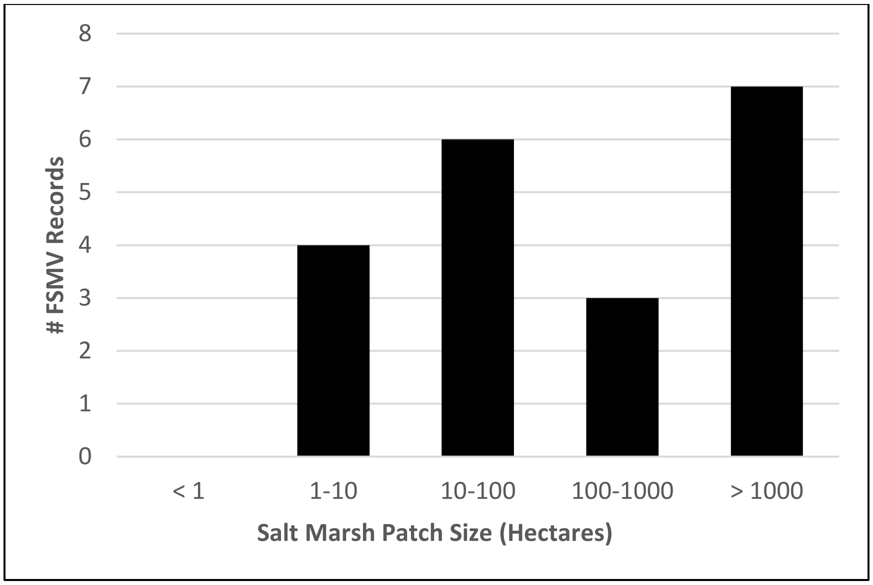


Figure 5-3. Size of salt marsh patches where FSMV have been recorded.

5.3.3 Protection Status

The coastal habitat surrounding the FSMV range is relatively well protected (Figure 5-4). Protected lands include Cedar Key Museum State Park, Waccasassa Bay Preserve State Park, and Cedar Key Scrub State Reserve managed by the Florida Department of Environmental Protection, Cedar Keys and Lower Suwannee National Wildlife Refuges managed by the US Fish and Wildlife Service, and two conservation easements owned by private individuals and managed by the Suwannee River Water Management District. We measured the portion of predicted FSMV habitat and salt marsh extent within the bounds of these protected lands.

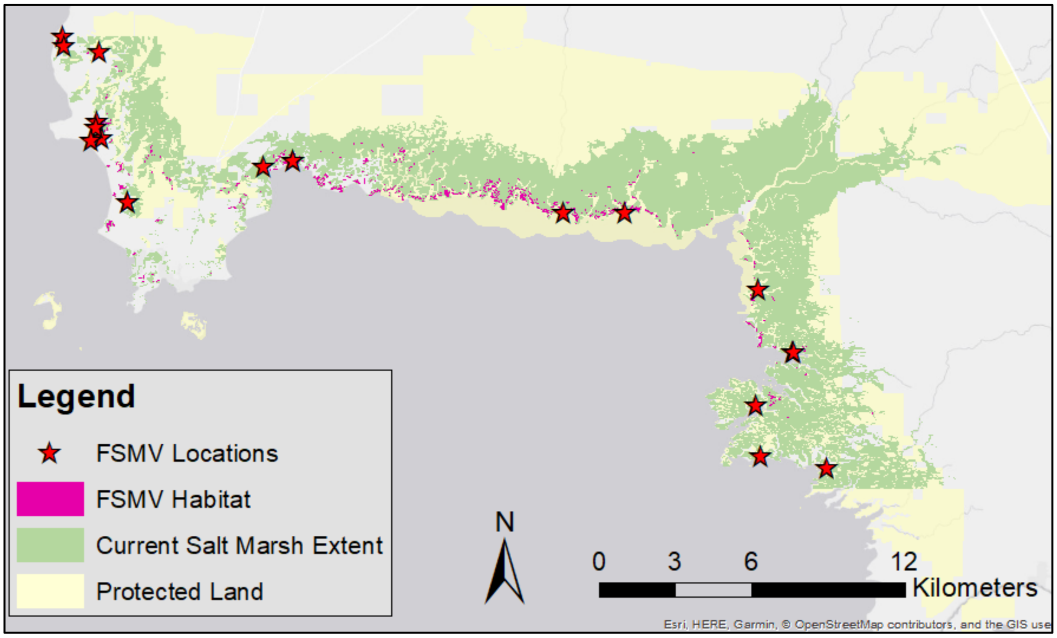


Figure 5-4. Florida salt marsh vole locations, predicted habitat, and current salt marsh extent in relation to protected lands.

In Florida, lands including tidal lands waterward of the mean high water line are considered Sovereign Submerged Lands and are owned by the state (Florida Administrative Code 18-21.003). This means that all FSMV habitat is currently state-owned, giving it a measure of protection even where it is not associated with one of the above parks, preserves, or refuges. Regardless, the amount of habitat or salt marsh within the above-listed protected lands will still provide a useful baseline to compare with future conditions. As sea levels rise, perhaps dramatically, there is uncertainty in whether all lands that become submerged will pass into state ownership.

5.4 Current Condition Results

5.4.1 Habitat Area

Within the known range of FSMV, there are 264 ha of predicted FSMV habitat and 10,153 ha of salt marsh (Table 5-1). Potential habitat thus presently makes up 2.6% of the total salt marsh area within our assessed spatial extent (3.7%, 4.0%, and 0.7% respectively for the West, Central, and East Units). Habitat is most abundant, both in terms of area and percentage of the salt marsh in the Central Unit. Habitat is most sparse, in terms of area and percentage of the salt marsh in the East Unit.

Table 5-1. Area, average patch size, area of patches > 1 ha, and area within protected lands for both FSMV habitat (top) and salt marsh (bottom) within the known range of FSMV.

FSMV Habitat	**Metric**	**Range-wide**	**West Unit**	**Central Unit**	**East Unit**
	Area	264 ha	48 ha	191 ha	26 ha
	Average Patch Size	0.9 ha	0.9 ha	0.9 ha	0.8 ha
	Area Patches > 1 ha (% of total)	160 ha (60.7%)	24 ha (49.4%)	126 ha (66.0%)	11 ha (42.4%)
	Area Protected (% of total)	195 ha (73.8%)	27 ha (56.7%)	142 ha (74.5%)	26 ha (100%)
Salt Marsh	**Metric**	**Range-wide**	**West Unit**	**Central Unit**	**East Unit**
	Area	10,153 ha	1,308 ha	4,797 ha	4,048 ha
	Average Patch Size	12.2 ha	5.4 ha	20.7 ha	11.4 ha
	Area Patches > 1 ha (% of total)	10,025 ha (98.7%)	1,269 ha (97.0%)	4,760 ha (99.2%)	3,996 ha (98.7%)
	Area Protected (% of total)	9,018 ha (88.8%)	1,039 ha (79.5%)	4,268 ha (89.0%)	3,711 ha (91.7%)

5.4.2 Habitat Connectivity

Of the 264 ha of potential preferred FSMV habitat, only 160 ha (61%) occurs in patches larger than 1 ha (Table 5-1). This means that 39% of potential habitat occurs in small highly fragmented patches. There is more habitat in larger patches, both in terms of area (126 ha) and percentage of habitat (66%) in the Central Unit compared to the East and West Units (East Unit: 24 ha, 49% habitat in patches > 1 ha; West Unit: 11 ha, 42% of habitat in patches > 1 ha). The fragmented nature of cordgrass/saltgrass patches is not necessarily cause for concern, as salt marshes are composed of a mosaic of vegetative communities, and FSMV can move through other plant communities, as evidenced by observations of McCleery and Zweig (2016, p. 1252) and the ability of FSMV to persist despite regular flooding of their habitat, perhaps by moving through other vegetative communities to higher ground (Woods et al. 1982, pp. 48-49).

We also measured the connectivity of the broader salt marsh. The salt marsh is currently highly connected, with ≥ 97% of salt marsh in each unit occurring in patches > 1 ha. The average patch size of salt marsh range-wide is 12.2 ha (5.4, 20.7, and 11.4 ha respectively for the West, Central, and East Units).

5.4.3 Protection Status

Currently, not counting Sovereign Submerged Lands, 74% of potential FSMV habitat and 89% of the salt marsh in the assessed area occurs within protected lands, including 100% of predicted FSMV habitat in the East Unit (Table 5-1). The Central Unit contains the largest area of protected FSMV habitat (142 ha; 75% of habitat in that unit). In the West Unit, only 57% of predicted FSMV habitat (27 ha) occurs on protected lands. Considering the broader salt marsh, 89% of salt marsh within the assessed area occurs within protected lands (80%, 89%, and 92%, respectively for the West, Central, and East Units).

5.4.4 Current Resilience

As indicated previously, population information (e.g., abundance, density, occupancy, demographic rates, etc.) for FSMV are not available. The known range of the species only very recently expanded from three known sites clustered within 9 km (kilometers) of each other to 24 sites spanning 34 km. Because of this scarcity of population information, there is a great deal of uncertainty in the status of populations, and our characterization of resilience is based solely on habitat information. Resilience was based primarily on the amount of habitat and salt marsh available, with connectivity and protection status providing auxiliary information and a baseline with which to compare future trends.

Range-wide, there are 264 ha of cordgrass/saltgrass salt marsh predicted to be preferred habitat of the FSMV. Habitat is most plentiful in the Central Unit. Habitat is the least plentiful, both in terms of area and the percentage of salt marsh, in the East Unit. Thus, resilience, the ability of populations to withstand stochastic events, is highest is the Central Unit, lower in the West Unit, and is lowest in the East Unit.

5.4.5 Current Representation and Redundancy

In the SSA framework, resilience of populations is then scaled up to describe redundancy and representation at the species scale. Representation refers to the breadth of genetic and environmental diversity within and among populations, which influences the ability of the species to adapt to changing future conditions. Because of the extremely limited range of FSMV and no evidence at this time of diversity in genetics or ecology within the limited range, we determined that there is only a single representative group within the species.

Redundancy refers to the ability of a species to withstand catastrophic events by spreading risk across multiple populations. Potential catastrophes that threaten FSMV include: oil spills, red tides, and extreme high water events like hurricane storm surges (described in detail in Chapter 4 – Influences on Viability). The FSMV currently has low redundancy. The entire known range of the species spans just over 34 km (straight-line distance between most distant occurrence records) in a single county in Florida. Catastrophes that impact one unit are likely to impact the others. While the current known range is small, there is not currently evidence that the species historically had a larger range. It is also possible that the range could extend farther than currently known, though if it does, FSMV in other areas are likely using habitat differently (McCleery and Zweig 2016, pp. 1252-1253).

CHAPTER 6 – FUTURE CONDITION

In this chapter, we describe how we projected the current condition of FSMV forward in time to assess future resilience, redundancy, and representation.

6.1 Future Assessment Methods

Note to reader: Updated 2022 Sea Level Rise projections and future habitat condition methodology of measuring habitat changes and results are presented here in Section 6.1 and Appendix B2 in blue text.

6.1.1 General Approach

The future condition assessment for FSMV was focused on how SLR resulting from climate change will impact habitat. Sea level rise is believed to be the main threat to FSMV resilience, and other described threats to the species (e.g., oil spills, red tides, and extreme high water events) are stochastic events that are difficult to predict. These stochastic but potentially catastrophic threats are events that the distribution of the species must be redundant against, and are considered in the discussion of future redundancy rather than resilience.

As sea levels rise, salt marsh habitat will not simply be lost to the sea; it will move inland with rising sea levels where not impeded (Figure 6-1). There is little development in the uplands adjacent to FSMV habitat, but we will discuss how current or future urbanization might be expected to impede the ability of the salt marsh to migrate. We used spatial data from the same data set that supplied the current extent of salt marsh (Geselbracht et al. 2015, entire) to explore the area, connectivity, and protected status of salt marsh between the present and the year 2100, with intermediate time steps at 2025, 2050, and 2075, under different scenarios of SLR.

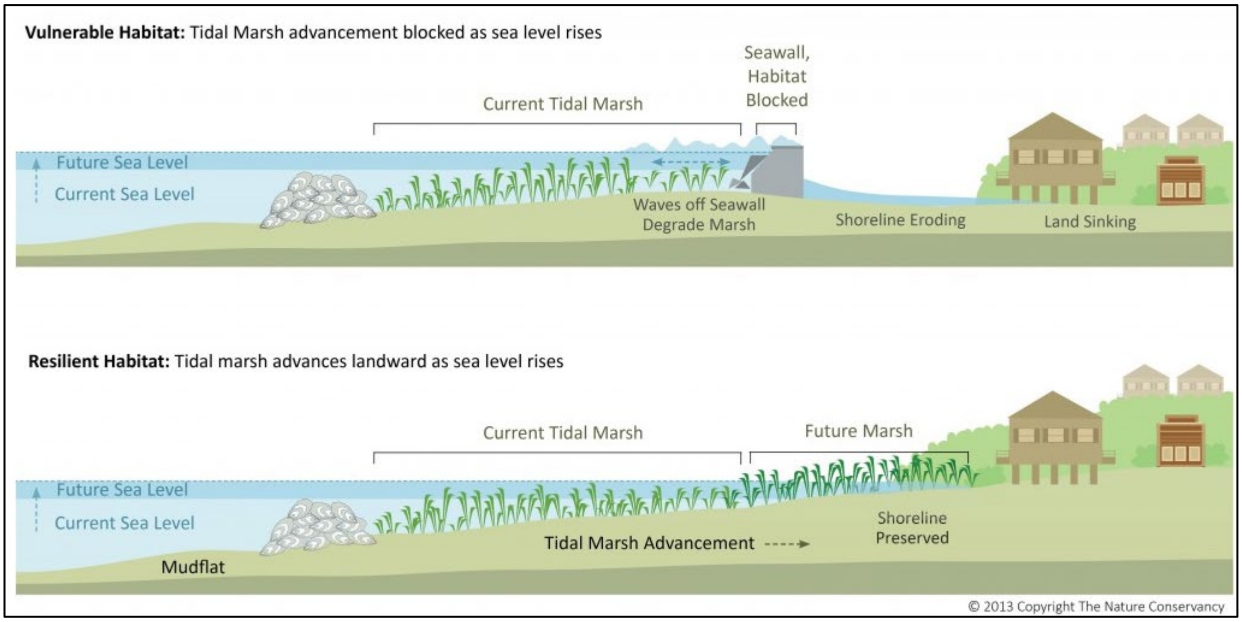


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Figure 6-1. Illustration of how tidal marshes might migrate landward at sea levels rise.

For the current condition assessment, we assessed the status of both FSMV habitat (predicted by McCleery and Zweig, 2016) and the broader salt marsh habitat. For the current condition, our interpretation of results and characterization of resilience focused more heavily on the status of

FSMV habitat, because that is the small portion (~1-4% of the salt marsh, depending on location) of the salt marsh that is being heavily used by FSMV. As we transition into the future condition however, we do not have predictions of future FSMV habitat, and our assessment instead is focused on changes in the broader salt marsh as a proxy for FSMV habitat. We make the assumption here that as the salt marsh responds to changing sea levels, the percentage of the salt marsh that is preferred FSMV habitat (dwarf smooth cordgrass and saltgrass) will remain constant over time.

We also examined the potential influence of development on coastal habitat using the SLEUTH model (Slope, Land use, Excluded, Urban, Transportation and Hillshade; Belyea and Terrando, 2013, entire; Jantz et al. 2010, entire) to visualize and predict the impact of lands that are currently urbanized, and those expected with at least 80% probability to be urbanized by 2050 and 2100. Because of high amounts of uncertainty, we describe the potential effects of urbanization in a narrative, rather than quantitative fashion.

6.1.2 Sea Level Rise Scenarios

For this report we have used an analysis of the 2017 sea-level-rise projections (Sweet et al. 2017) when evaluating potential habitat loss for the Florida salt marsh vole. The updated projections from Sweet et al. (2022) present a broadly similar range of outcomes for the Eastern Gulf areas including the range of Florida salt marsh vole. The 2022 scenarios show a median rise of approximately 0.6 to 2.2 meters by 2100 for this region, which aligns with the magnitude of rise evaluated in the SSA's 2017 analysis. Given that Florida salt marsh voles occupy low-elevation coastal salt-marsh habitats that are highly sensitive to inundation, habitat loss trajectories under the 2022 projections would be expected to mirror those used in the 2017 assessment (1-2 m sea level rise). Consequently, the use of the 2017 sea-level-rise numbers remains reasonable and consistent with the best available information for projecting future habitat conditions for the species. We provide both the 2017 analysis and some updates related to the Sweet et al. (2022) in the narratives below.

As global temperatures increase, sea levels are expected to rise as a result of thermal expansion of ocean water and melting of ice sheets and glaciers, and already have risen about 0.19 m between 1901 and 2010 (IPCC 2014, p. 42). The amount of SLR that will occur in the future will depend largely on the rate of anthropogenic greenhouse gas emissions and associated warming. The IPCC uses Representative Concentration Pathways (RCPs), each associated with a different level of greenhouse gas emissions (themselves associated with different levels of population size, economic activity, lifestyle, energy use, land use patterns, technology, and climate policy) to make future projections about possible future states (IPCC 2014, p. 57). These include a stringent mitigation scenario that aims to keep global warming below 2°C (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one high-emission scenario (RCP8.5; IPCC 2014, p. 57). Without additional efforts to constrain anthropogenic greenhouse gas emissions, continuing baseline levels of emissions is expected to lead to outcomes between the RCP6.0 and RCP8.5 scenarios (IPCC 2014, p. 57). Relative to 1986 – 2005, likely increases in global temperatures under the RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios are, respectively, 0.3-1.7°C, 1.1-2.6°C, 1.4-3.1°C, and 2.6-4.8°C (IPCC 2014, p. 60).

We assessed the future condition of the salt marsh under three SLR scenarios: 1-m by 2100, 1.5-m by 2100, and 2.0-m by 2100, approximately corresponding with the RCP4.5, RCP6.0, and

RCP8.5 scenarios. We arrived at these SLR amounts using SLR scenarios established by NOAA; Table 6-1a displays the probability that SLR will exceed a given scenario under the RCP4.5 and RCP8.5 carbon emission scenarios (RCP6.0 not assessed in the NOAA report; Sweet et al. 2014, p. 22). For each of these emissions scenarios, we started at the lowest SLR scenario (Low), and if the probability of exceeding that scenario was greater than 5%, we moved down to the next most extreme SLR scenario. We continued this until there was a < 5% chance of exceeding that level of SLR. Under the RCP 4.5 emissions scenario, there was a 73% probability of exceeding the Intermediate-Low scenario, and only a 3% probability of exceeding the Intermediate scenario, the next most extreme. Under the RCP 8.5 emissions scenario, there was a 96% chance of exceeding the Intermediate-Low scenario, a 17% chance of exceeding the Intermediate scenario, and then only a 1.3% chance of exceeding the Intermediate-High scenario. Thus, we chose the Intermediate and Intermediate-High scenarios to bound the plausible range of SLR by 2100.

Table 6-1a. Probability that sea level rise will exceed a given scenario by 2100 under two carbon emissions scenarios, RCP 4.5 and RCP 8.5 (Sweet et al. 2017, p. 22). Each scenario is associated with a global mean sea level rise (GMSLR).

Sea Level Rise Scenario (GMSLR)	RCP 4.5		RCP 8.5	
Low (0.3 m)	98%	↓	100%	↓
Intermediate-Low (0.5 m)	73%	↓	96%	↓
Intermediate (1.0 m)	3%	×	17%	↓
Intermediate-High (1.5 m)	0.5%		1.3%	×
High (2.0 m)	0.1%		0.3%	
Extreme (2.5 m)	0.05%		0.1%	

The Intermediate and Intermediate-High scenarios correspond to 1- m- and 1.5-m of global SLR, respectively. However, actual levels of SLR at finer scales will vary based on local conditions related to tectonic topography, sediment compaction, the elastic response of the Earth to the redistribution of mass, ocean-atmosphere dynamics, and others (Kopp et al. 2015, p. 192-196). We used the NOAA Sea Level Rise Viewer to determine locally-adjusted predictions of SLR for Cedar Key (within the range of FSMV). Under these local scenarios, the Intermediate scenario is expected to produce 1.1 m of SLR, while the Intermediate-High scenario is expected to produce 1.8 m of SLR.

The spatial data we used to project changes in coastal habitat were available in half-meter increments, so we rounded the local SLR scenarios to 1- and 2-m of SLR by 2100, which approximately corresponded to the RCP4.5 and RCP8.5 emissions scenarios, respectively. We also assessed the future condition under 1.5-m SLR, an intermediate value between the low and high bounds to correspond approximately with the RCP6.0 emissions scenario. The current condition for sea levels in this data set was 2008, and subsequent available time steps were at 2025, 2050, 2075, and 2100. At each time step and for each of the three SLR scenarios (1-, 1.5-, and 2-m by 2100), we recalculated the area of salt marsh, average patch size, area in patches of different sizes, and amount of salt marsh within protected lands to compare with the current condition. We also measured the distance from each current FSMV location to the nearest patch of salt marsh ≥ 1 ha to describe how far inland potential habitat might move compared to current locations, and assessed how urbanization might impact the ability of the salt marsh to migrate.

Updated Future Condition Methodology (January 24, 2025)

In this updated future condition analysis, NOAA marsh migration datasets were used to estimate the amount of estuarine wetland change due to sea level rise based upon updated projections from (Sweet et al. (2022). The original analysis methods, presented above, results from the Sea Level Affecting Marshes Model (SLAMM) were used to predict the future habitat conditions based upon Sweet et. al. 2017 sea level projections. These two models and resultant datasets differ in several aspects, with the most prominent being the land cover inputs. SLAMM incorporates National Wetland Inventory (NWI) land cover (Warren Pinnacle Consulting, Inc. 2016), whereas the NOAA Marsh Migration model uses the NOAA Coastal Change Analysis Program (C-CAP) land cover (NOAA 2017).

C-CAP produces a nationally standardized database of land cover and land change for the coastal regions of the U.S. These products provide inventories of coastal intertidal areas, wetlands, and adjacent uplands with the goal of monitoring these habitats by updating the land cover maps every five years. Data used in the marsh migration analysis reflect conditions as they existed when mapped in 2005 to 2006. The model is based on a modified bathtub approach of targeting a specific elevation of flooding that also attempts to account for local and regional tidal variability.

For this updated future condition analysis, the amount of estuarine wetland (EW) available for each foot of SLR was estimated. EW may contain emergent or forested saline wetlands. We note that not all EW is suitable habitat for the FSMV, so an estimate of percent suitable habitat based on current conditions should be conducted to further define the FSMV's suitable habitat and range.

Due to the differences in model design and input parameters (SLR projections, land cover datasets, community change thresholds, etc.), direct comparisons to SLAMM are not recommended. However, these results also provide an estimate of wetland loss over time due to SLR.

Sea level rise projections for the marsh migration data differ by accretion rates. Within the NOAA SLR Viewer Marsh Migration tool, the user can select between 0, 2, 4, and 6 mm/yr. Assuming no accretion would be the worst-case scenario resulting in higher estimates of sea level rise inundating the marsh. Previous SLAMM runs used accretion estimates of 3.9 to 4.7 mm/yr for regularly and irregularly flooded marshes, respectively (Warren Pinnacle Consulting, Inc. 2011). Table 6-1b below provides sea level rise estimates for no accretion and 4 mm/yr accretion for the Sweet et al. 2017 and 2022 projections. The 2022 SLR values were rounded to the nearest foot increment to correspond with the available data layers. Although both the 2017 and 2022 projections are provided for comparison, the actual values used to model marsh transition using SLAMM may be different. SLAMM used the eustatic sea level rise projections adjusted for differences between global SLR and local SLR. Eustatic trends were converted to estimates of relative SLR using the difference between the historic trend and the historic eustatic trend for a particular geographic area (J. Clough, pers. comm, 2022).

Table 6-1b. 2022 SLR values with no accretion rounded to the nearest foot.

Scenario	2030	2050	2070	2090	2100
Intermediate	1	1	2	3	4
Intermediate-High	1	1	2	4	5
High	1	2	3	6	7

6.2 Future Condition Results

In the following section, we summarize the results of our assessment of the future condition under three SLR scenarios. Salt marsh spatial data came from the Gulf Coast Prairie Landscape Conservation Cooperative (GCPLCC) Sea-Level Affecting Marshes Model (SLAMM) Gap Analysis Project (available at: http://www.warrenpinnacle.com/prof/SLAMM/GCPLCC/, Geselbracht et al. 2015, entire). Maps of scenarios at each time step can be found in Appendix A, and tables of values summarized in the following graphs can be found in Appendix B1.

Updated Future Condition Results (January 24, 2025)

The results from the updated future condition analysis also differ as the updated sea level rise projections, are less in the near term (Sweet et al. 2022, p. 9). The timing for different rates of rise for the different scenarios was updated based on new modeling and more realistic assumptions of Greenland and Antarctic ice sheet behavior. A result is that there is less acceleration in the higher scenarios until about 2050 and greater acceleration toward the end of this century, yet all the scenarios maintain the same 2100 targets under both projections. Updated methodologies and results are presented below at the end of Section 6.1 and the entire update, methodology and results, is available in Appendix B2.

6.2.1 Future Habitat Area

In all three SLR scenarios, the area of salt marsh is expected to increase initially (Figure 6-2). This increase occurs as the salt marsh extends farther inland but is either not yet submerged on the seaward edge of the marsh, or the loss of the seaward marsh does not outpace the growth of the landward marsh. In the 1-m SLR scenario, this pattern continues all the way to 2100, the end of our future projections. As the rate of SLR increases however, the growth of salt marsh inland will eventually be outpaced by the loss of seaward salt marsh. In the 1.5-m SLR scenario, the area of salt marsh peaks in 2075 (13,011 ha), and then declines rapidly by 2100 (7,458 ha, a 43% decline). In the 2-m SLR scenario, this peak happens sooner in 2050 (12,645 ha), before declining rapidly through 2075 and 2100 (6,429 ha in 2100, a 49% decline from the peak) as it is replaced by tidal flats and estuarine open water.

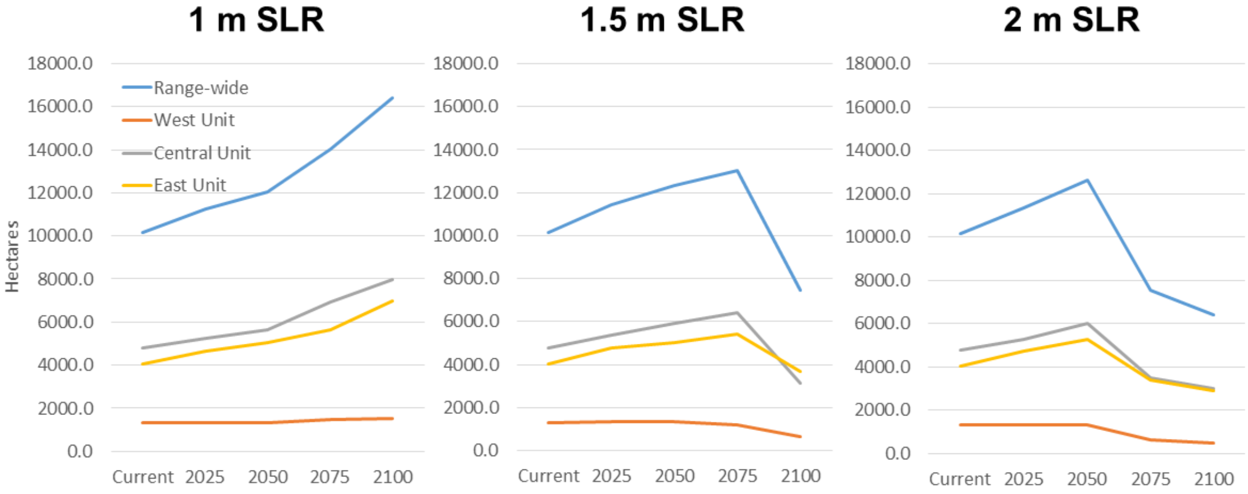

Figure 6-2. Hectares of salt marsh range-wide and in each resilience unit under 1-, 1.5-, and 2-m of SLR (SLR) from the current condition (2008 data) to 2100.

Currently, only 2.6% of the current salt marsh within the FSMV range is predicted to be preferred FSMV habitat (264 ha). If the resilience-unit specific percentages (3.7%, 4.0%, and 0.7%, respectively, for the West, Central, and East Units) are assumed to remain constant in the future, the area of FSMV habitat is expected to peak at 427 ha in 2100 under the 1-m SLR scenario, 338 ha in 2075 under the 1.5-m SLR scenario, and 329 ha in 2100 under the 2-m SLR scenario (Figure 6-3). In the latter two scenarios, after the peak in 2075 and 2100, respectively, FSMV habitat is expected to decline sharply to values lower than the current condition (194 ha in 2100 under the 1.5-m SLR scenario, 196 ha in 2075 and 167 ha in 2100 under the 2-m SLR scenario). As in the current condition, the Central Unit is expected to continue to have the highest resilience (habitat area) compared to the other two units in the future under all scenarios. While the West Unit currently has higher resilience (more habitat) than the East Unit, these two units are predicted to become more similar to each other in terms of habitat area as time goes on under all scenarios.

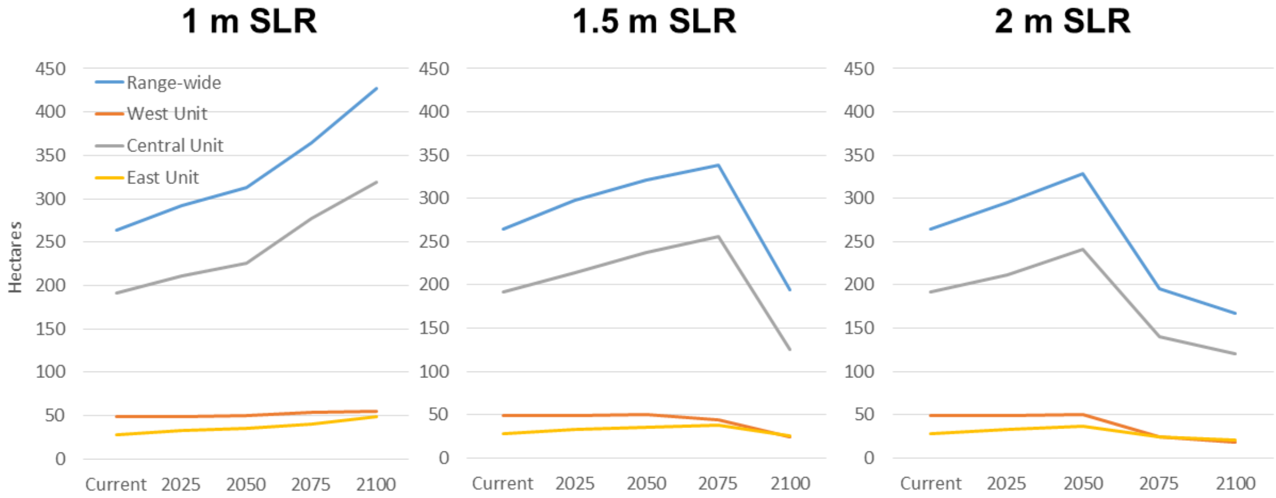

Figure 6-3. Hectares of predicted FSMV habitat range-wide and in each resilience unit under 1-, 1.5-, and 2-m of sea level rise (SLR) from the current condition (2008 data) to 2100.

Again, we note that these predicted habitat areas are based on the assumption that as sea levels rise and the salt marsh shifts, the composition of the salt marsh and its vegetative communities will remain the same as they do currently. Whether this will hold true is uncertain.

Updated Future Condition Results (January 24, 2025)

In Intermediate, Intermediate-High, and High SLR scenarios (Sweet et al. 2022) at both zero and 4 mm/yr accretion rates, the area of salt marsh is expected to increase initially from now to 2050. This increase occurs as the salt marsh extends farther inland but is either not yet submerged on the seaward edge of the marsh, or the loss of the seaward marsh does not outpace the growth of the landward marsh. This pattern continues all the way to 2100, the end of our future projections. However, as the rate of SLR increases, the growth of salt marsh inland will eventually be outpaced by the loss of seaward salt marsh. The area of salt marsh grows and/or stabilizes by 2070 (18,246 – 22405 ha) except under the High projection with no accretion which exhibits a significant decrease by 2070 (10,393 ha). The 2070 and beyond time frame marks a tipping point and the salt marsh rapidly declines by 2100 (8,438 ha – 8,794 ha) as it is replaced by tidal flats and estuarine open water except under the Intermediate scenario with 4 mm/yr accretion which allows for the salt marsh to remain stable (18,246 ha).

We note that these predicted habitat areas are based on the assumption that as sea levels rise and the salt marsh shifts, the composition of the salt marsh and its vegetative communities will remain the same as they do currently. Whether this will hold true is uncertain.

Table 6-3. Hectares of Estuarine Wetlands available with 0 and 4 mm/yr marsh accretion rates and sea level projection scenarios (Sweet et al. 2022) in 2050, 2070, 2090, and 2100.

Projection	Accretion (mm/yr)	Scenario	Current 2005-06	2050	2070	2090	2100
2022	0	Intermediate	18,127	22,405	18,246	10,393	8,794
2022	0	Intermediate-High	18,127	22,405	18,246	8,794	8,438
2022	0	High	18,127	18,246	10,393	8,438	8,545
2022	4	Intermediate	18,127	22,405	22,405	18,246	18,246
2022	4	Intermediate-High	18,127	22,405	18,246	10,393	8,794
2022	4	High	18,127	22,405	18,246	8,794	8,438

6.2.2 *Future Connectivity*

Range-wide, as salt marsh area initially increases with SLR, so too will the area of salt marsh in very large patches. However, after 2050 in the 1.5-m SLR scenario and 2075 in the 2-m SLR scenario, as the overall salt marsh area decreases, the composition changes such that large patches make up less of the remaining salt marsh (Figure 6-4; see also maps in Appendix A and tables in Appendix B1). Even in the 1-m SLR scenario, the amount of salt marsh in patches smaller than 100 ha is expected to grow, as both the landward edge of the salt marsh advances in a highly fragmented way, and the seaward edge becomes fragmented as it retreats (Figure 6-5).

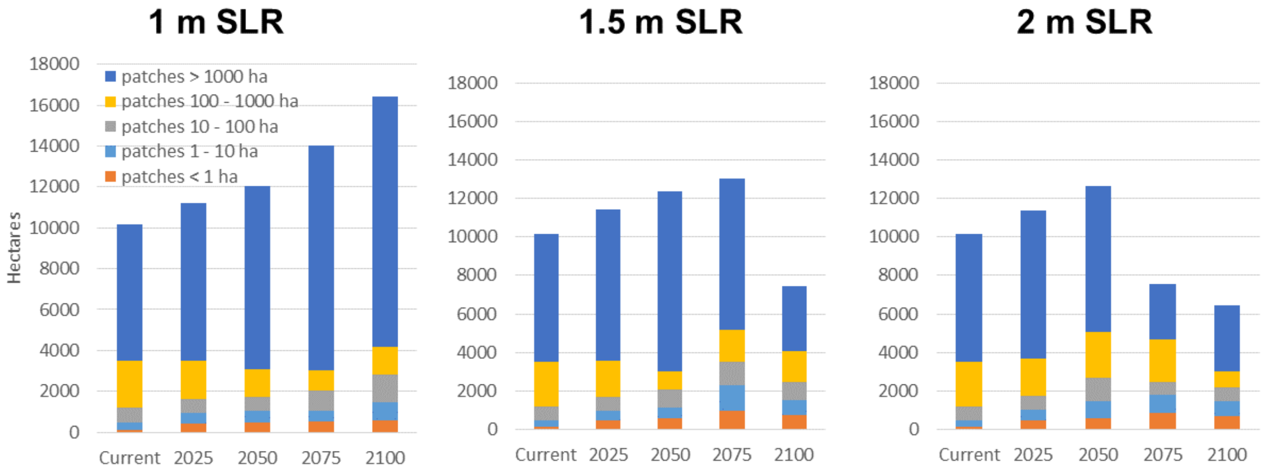

Figure 6-4. Hectares of salt marsh patches of different sizes range-wide under 1-, 1.5-, and 2-m of sea level rise (SLR) from the current condition (2008 data) to 2100.

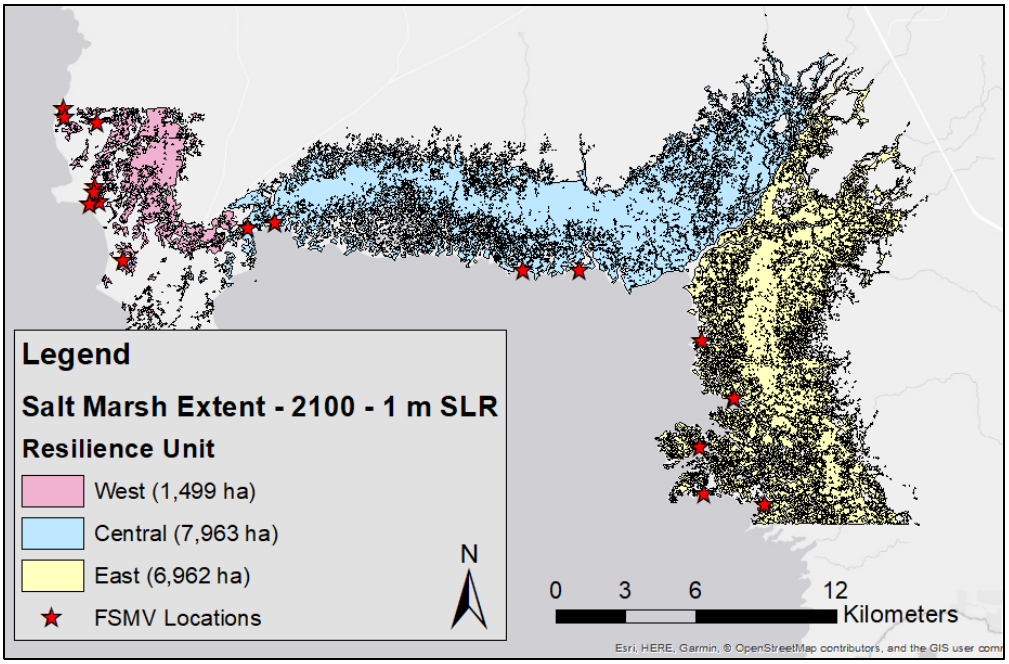

Figure 6-5. Example map (1-m SLR scenario in the year 2100) illustrating how fragmentation occurs at the landward edge of the salt marsh as it advances, and at the seaward edge of the salt marsh as it retreats, while staying relatively more intact in the center.

This increase in fragmentation could have two primary effects on FSMV. First, as patches become smaller they are less likely to support FSMV. Within potential habitat, FSMVs select patches > 0.49 ha (McCleery and Zweig 2016, p. 1252). Currently, the five smallest patches of salt marsh where FSMV have been recorded are 2.4, 3.0, 3.0, 4.5, and 9.2 hectares large. Second, increased fragmentation could limit the ability of FSMV to move between patches of salt marsh as they disperse, forage, or move to escape high water events. This second impact is speculative and not well understood. It is suspected that FSMV have the ability to swim (marsh-inhabiting meadow voles have been observed swimming by Harris (1953, p. 482), and swimming might be a way that FSMV are currently able to persist through high water events. However, the time and distance that individuals might be able to swim to fulfill their life history needs without incurring fitness consequences is unknown. Thus, the effect of increased isolation of salt marsh patches on FSMV resilience is also largely unknown.

6.2.3 Future Protection Status

As discussed in the Section 5.3.3, all FSMV habitat currently is state-owned Sovereign Submerged Land, providing some measure of protection. As sea levels rise, there is uncertainty about whether lands that become submerged will automatically pass into state ownership as Sovereign Submerged Lands. Here we assess the future protection status of salt marsh considering current protected land boundaries and not considering Sovereign Submerged Lands. We also note that FSMV and its habitat likely gain some measure of protection by virtue of the inaccessibility of the habitat, regardless of regulatory protection status.

As the salt marsh moves inland, less of it will occur within the boundaries of currently protected areas (Figure 6-6). With only 1-m of SLR by 2100, the change will be minimal, as the range-wide percentage of salt marsh on protected lands declines from 89% currently to 73% by 2100.

With 1.5- or 2-m of SLR, the percent of salt marsh on protected lands initially declines gradually but begins rapidly retreating away from protected lands after 2050. Range-wide, the percent of salt marsh on protect land declines to 71% in 2075 and 47% in 2100 in the 1.5-m SLR scenario, and 55% in 2075 and 44% in 2100 in the 2-m SLR scenario.

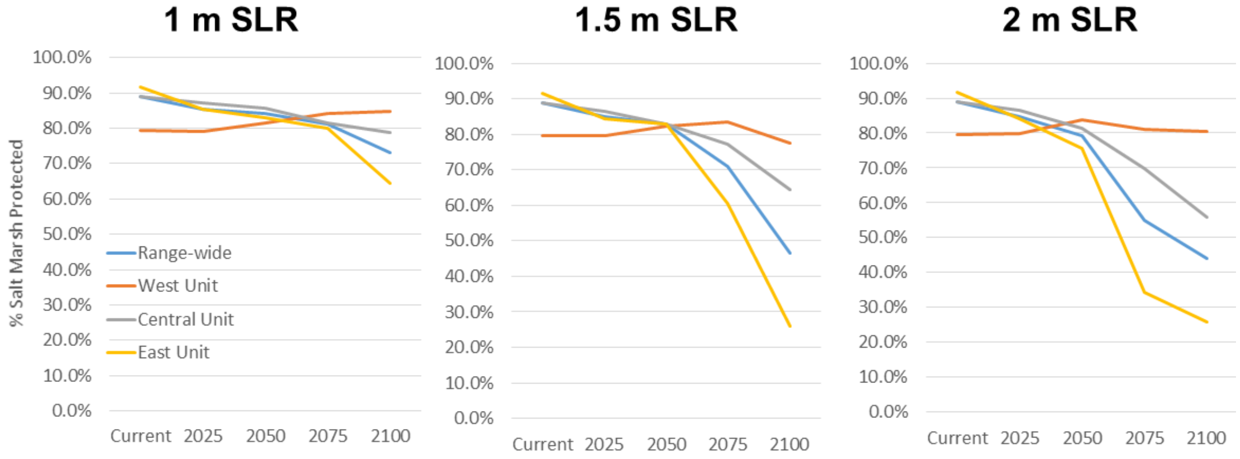

Figure 6-6. Percent of salt marsh that falls within protected areas range-wide and in each resilience unit under 1-, 1.5-, and 2-m of sea level rise (SLR) from the current condition (2008 data) to 2100.

These changes are not consistent across resilience units; in the West Unit, around 80-85% of salt marsh will be within protected lands regardless of the scenario and future year. The biggest declines in protection status will occur in the East Unit, where currently 92% of the salt marsh lies within protected lands. By 2100, that portion is expected to decline to 26% with 1.5- to 2-m of SLR (Figure 6-7).

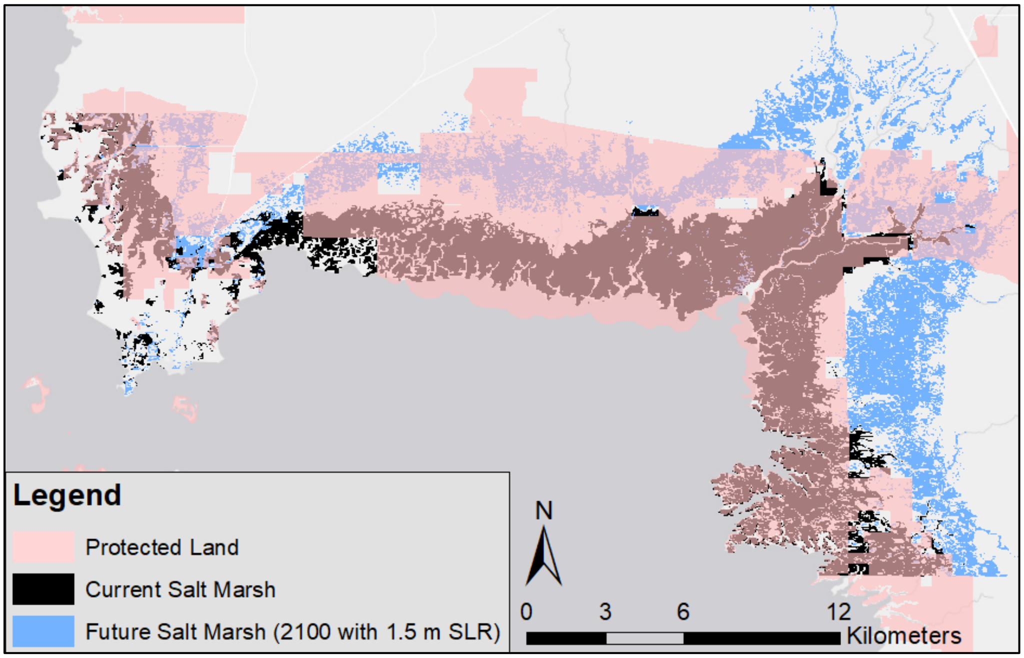

Figure 6-7. Example map illustrating the amount of salt marsh within protected lands currently and by 2100 under the 1.5-m SLR scenario.

6.2.4 *Distance Moved*

We measured the distance the salt marsh is predicted to move inland under each SLR scenario as it is replaced by tidal flats and estuarine open water (Figure 6-8). As FSMV and their habitat are typically found at the seaward edges of the greater salt marsh, we measured the linear distance between each current FSMV location and the nearest salt marsh patch larger than 1 ha for each scenario and time point, which effectively measured the distance between current locations and the seaward edge of the retreating salt marsh.

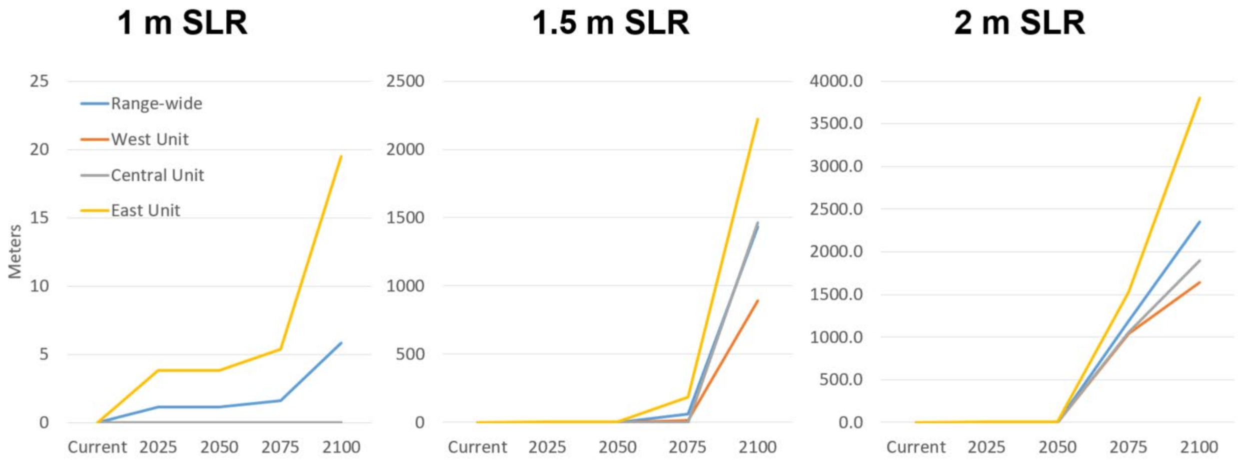

Figure 6-8. Distance between current FSMV locations and the nearest future salt marsh patch larger than 1 ha range-wide and in each resilience unit under 1-, 1.5-, and 2-m of sea level rise (SLR) from the current condition (2008 data) to 2100. *Note the different y-axes.*

Under the 1-m SLR scenario, while salt marsh will be expanding landward, it will also largely remain in its current locations, though in a more fragmented state than at present. Only in the 1.5- and 2-m SLR scenarios does the salt marsh retreat dramatically and no longer exist in its present locations.

The range-wide average distance moved by 2100 is predicted to be 1.4 km with 1.5-m of SLR, and 2.4 km with 2-m of SLR. The distances moved will be largest in the East Unit (2.2 and 3.8 km with 1.5- and 2-m of SLR, respectively), and smallest in the West Unit (0.9 and 1.6 km with 1.5- and 2-m of SLR, respectively).

The consequences of these distances moved for FSMV and their habitat are not well understood. If the movement is gradual and the vegetative communities used by FSMV remain intact as they shift, there may be little to no detrimental effect on FSMV (other than the separate but related effects of habitat loss and fragmentation). If the preferred dwarf smooth cordgrass and saltgrass communities at the seaward edge of the salt marsh are simply lost rather than shifting with the rising sea levels, FSMV likely will be negatively impacted.

6.2.5 *Urbanization*

Urbanization is not expected be in direct competition for space with the majority of FSMV and their habitat in the future. In the most extreme SLR scenario, 2-m, by 2100 only 5.9% of predicted salt marsh is expected to occur on areas predicted to be developed. However, development can place pressure on the salt marsh if seawalls or other infrastructure are installed to protect developments from rising seas. This infrastructure can also prevent coastal habitats from migrating landward (Figure 6-1 in Section 6.1.1). This risk is highest in the western portion of the FSMV range, where expansion is predicted around the communities of Cedar Key, Rosewood, and Sumner. By 2050, even in the most extreme SLR scenario (Figure 6-9, top), migration of the salt marsh is expected to be relatively minimal, with transitional fresh marsh and swamp present in the area between the salt marsh and developed areas. By 2075 and continuing through 2100, however, (Figure 6-9, bottom) salt marsh is predicted to abut right up to predicted developed areas in this western part of the range. There is uncertainty in whether this predicted development will occur, given the risk from SLR which was not incorporated into the SLEUTH model, and uncertainty in whether and how developments might be protected from rising seas. If infrastructure prevents the natural migration of coastal habitats, the West Unit and western portion of the Central Unit may experience losses of resilience after the salt marsh begins accelerating in its migration away from its present location. If tidal habitats cannot migrate, they will just be inundated in place, and the habitat will be lost. Under the 1-m SLR scenario, this is unlikely to happen within the assessed time frame. Under the 1.5-m SLR scenario, this loss of resilience might not happen until after 2075. Under the 2-m SLR scenario, this loss of resilience might happen after 2050.

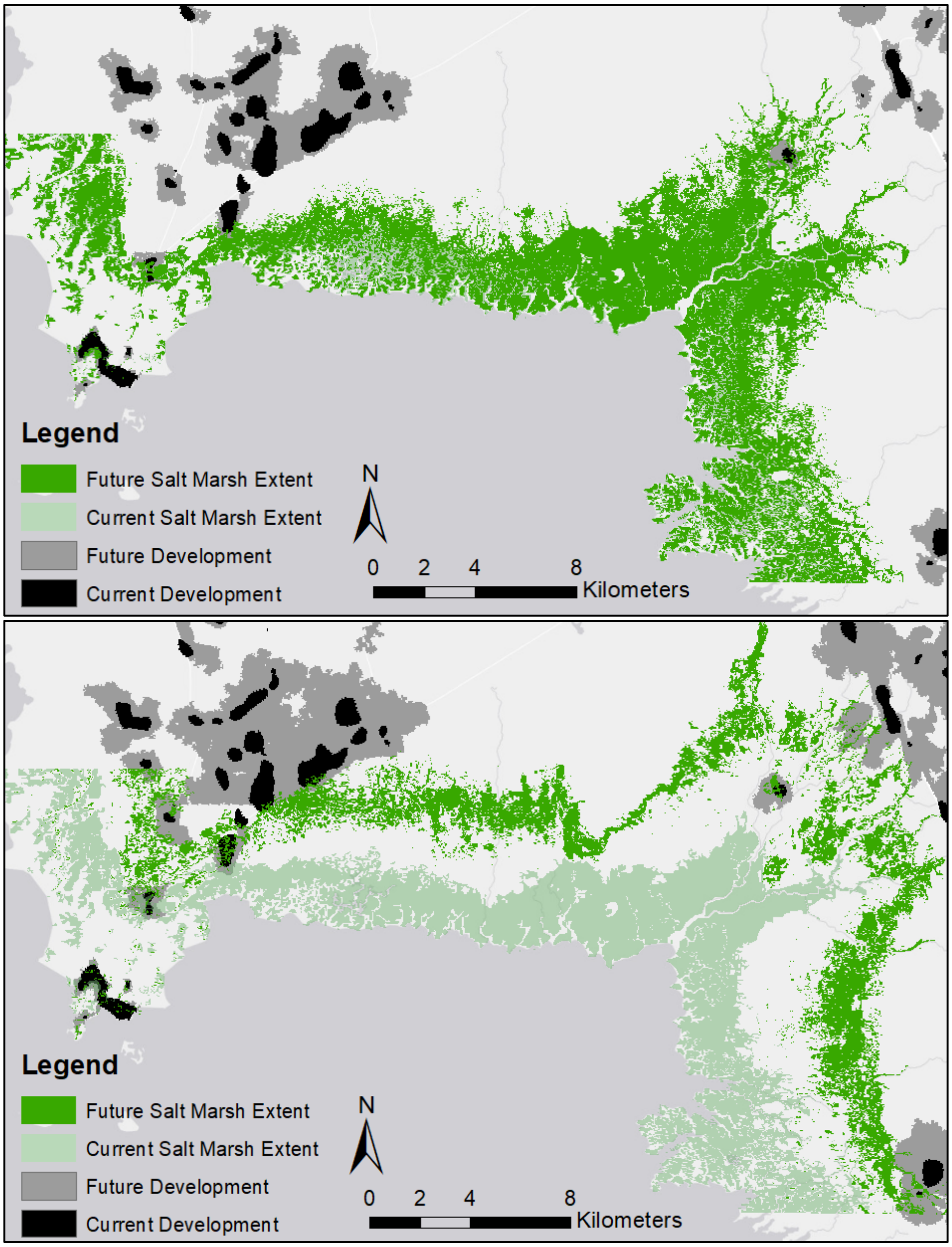

Figure 6-9. Current and future urbanization (at least 80% probability of being urbanized) and salt marsh extent (in accordance with the most extreme, 2-m, sea level rise scenario) in (top) 2050 and (bottom) 2100.

6.2.6 Future Resilience

Our resilience assessment here focuses on direct impacts of SLR on salt marsh habitat. Our scenarios were based on the RCP4.5-8.5 greenhouse gas emissions scenarios. If baseline greenhouse gas emissions are continued, we are likely to see warming between the RCP6.0 and RCP8.5 emissions scenarios, which correspond to the 1.5- and 2-m sea level rise scenarios in this SSA. Under both of these scenarios, the area of habitat is expected to decline, with range-wide declines in FSMV habitat of at least 26.5-36.7% by 2100. These declines will be preceded by periods of salt marsh expansion, until habitat begins disappearing in earnest after 2075 (1.5-m

SLR) or 2050 (2-m SLR). These results indicate an initial increase in resilience range-wide and in the Central and East Resilience Units (the West Unit remains relatively stable initially), followed by rapid decreases in resilience after 2050-2075.

If greenhouse gas emissions are lowered (as a result of policies, technology, societal change, etc.) such that warming occurs in line with the RCP4.5 scenario, we do not expect to see rapid losses of habitat and resilience by 2100. Instead, we expect the area of salt marsh and FSMV habitat (assuming that it remains a constant proportion of the salt marsh in the future) to increase through 2100 range-wide except in the West Unit where it remains fairly stable. However, there likely will be losses of habitat beyond 2100 if sea levels continue to rise, as evidenced by the 1.5 and 2-m SLR sea level rise scenarios. If greenhouse gas emissions are kept to even lower levels such that warming occurs in line with the RCP 2.6 emissions scenario, SLR impacts on habitat will be less than the 1-m scenario.

Resilience is based primarily in this assessment on habitat area, because we can assume that amount of habitat is directly related to the ability of the species to persist in abundances that allow it to withstand stochastic demographic and environmental events. The effects of the other assessed factors, connectivity, protection status, distance moved, and impacts of urbanization, are more uncertain. We presume that increased fragmentation of habitat, apparent under all scenarios, will have negative impacts on resilience by decreasing the amount of habitat in large enough patches to support FSMV, and creating more distance between suitable patches. Without any information about the ability or endurance of FSMV to swim or otherwise disperse, we cannot predict at what point fragmentation begins negatively influencing individual fitness and population resilience. The influence of protection status on the resilience of the species may be minimal, as FSMV habitat occurs in state-owned Sovereign Submerged Lands regardless of the protection status of adjacent uplands (though there is uncertainty in how future submerged lands will be treated as sea levels rise), there is little to no development pressure on FSMV habitat or the adjacent uplands, and FSMV habitat is likely afforded some protection simply by its inaccessibility. The distance the salt marsh moves in the future may or may not influence FSMV resilience, dependent on the rate of the shift in relation to the ability of the plant community to remain intact/able to support FSMV. Finally, urbanization might further reduce resilience after 2050 – 2075, depending on the scenario, in the West Unit and the west portion of the Central Unit if development prevents the salt marsh from migrating naturally. The remainder of the Central Unit and the East Unit are unlikely to have resilience significantly impacted by urbanization.

6.2.7 Future Representation and Redundancy

As for the Current Condition, we have determined that there is only a single representative group within the species, and so do not assess representation for FSMV.

Sea level rise, the primary threat to FSMV and their habitat, will not only directly impact the salt marsh via habitat loss, fragmentation, and movement. There will also be secondary impacts of increasing vulnerability of FSMV to storm surges and other high water events, and stronger hurricanes, which are likely to become more common with warming temperatures (Day et al. 2008, p. 482; Service 2017, p. 7). While FSMV have been resilient to hurricanes in the past (as evidenced by their current persistence), increased frequency and/or magnitude of extreme weather and flooding events could impact the ability of the species to withstand these events. It is not known how the species currently persists in the face of extreme weather and high water events, whether by moving to higher ground, climbing to the tops of vegetation, or swimming (Woods et al. 1982, p. 48), so it is difficult to predict how the increased strength or frequency of extreme events might impact their persistence. It is plausible, though not certain, that these events that are a natural component of the system might change with warmer sea temperatures and rising sea levels to become more catastrophic and difficult for FSMV to withstand.

Faced with the potentially increased risk of stochastic catastrophic climatic events, the redundancy of FSMV is expected to remain low. The range is not expected to increase as a result of natural or human-mediated expansion. No Resilience Units are expected to be extirpated with a high degree of certainty, though the West Unit faces a higher risk of extirpation than the others. The West Unit has the smallest area of salt marsh and predicted FSMV habitat and is expected to experience the lowest percentage loss of habitat, but is also the most likely of the units to have the migration of the salt marsh impeded by urbanization. Farther from the cluster of development in the western portion of the range, FSMV habitat is expected to persist in the future, but the range is still small and catastrophes that impact one unit are likely to impact the entire range of the species. As described in the Current Redundancy discussion, there is no current evidence that the FSMV historically occupied a larger range than it does now, and it is possible that the range of the species could extend farther than presently known in different kinds of habitat.

This concludes our assessment of FSMV needs, current condition, and future condition. It is apparent that resilience will decline in the future as sea levels rise and lead to habitat loss and fragmentation, but the rate of these impacts will depend on the rate of greenhouse gas emissions and associated warming and sea level rise, as reflected in the presented scenarios. This assessment should be updated as new information becomes available, and in particular can be strengthened with further study into FSMV demographics, abundance, distribution, habitat associations, dispersal modes and capabilities, how FSMV react to extreme high water and storm events, and predictions of whether coastal vegetative communities will remain intact as they migrate landward.

LITERATURE CITED

Anderson, D. 1994. Red Tides. Scientific American 271:52-58.

Anderson, C.M., M. Mayes, and R. LaBelle. 2012. Update of Occurrence Rates for Offshore Oil Spills. OCS Report BOEM 2012-069.

Austin, J.D., E.V. Saarinen, A. Arias-Perez, R.A. McCleery, R.H. Lyons. 2014. Twenty-one novel microsatellite loci for the endangered Florida salt marsh vole (*Microtus pennsylvanicus dukecampbelli*). Conservation Genetics Resources 6:637-639.

Belyea, C.M., and A.J. Terrando. 2013. Urban growth modeling for the SAMBI Designing Sustainable Landscapes Project. North Carolina State University. http://www.basic.ncsu.edu/dsl/urb.html. Accessed 10 March 2018.

Bloch, C.P., and R.K. Rose. 2005. Population dynamics of *Oryzomys palustris* and *Microtus pennsylvanicus* in Virginia tidal marshes. Northeastern Naturalist 12:295-306.

Boonstra, R., and F.H. Rodd. 1983. Regulation of breeding density in *Microtus pennsylvanicus*. Journal of Animal Ecology 52:757.

Carr, M.H., and P.D. Zwick. 2016. Florida 2070: Mapping Florida's future—alternative patterns of development in 2070. Technical Report prepared for Florida Department of Agriculture and Consumer Services & Friends of Florida. Prepared by Geoplan Center at the University of Florida.

Carter, L.M., J.W. Jones, L. Berry, V. Burkett, J.F. Murley, J. Obeysekera, P.J. Schramm, and D. Wear, 2014: Ch. 17: Southeast and the Caribbean. Climate Change Impacts in the United States: The Third National Climate Assessment, J.M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, pp. 396-417. doi:10.7930/J0NP22CB.

Clough, J. 2022. E-mail to G. Martin, Fish and Wildlife Biologist, U.S. Fish and Wildlife Service from J. Clough, President, Warren Pinnacle Consulting, Inc. April 14, 2022.

Day, J.W., R.R. Christian, D.M. Boesch, A. Yáñez-Arancibia, J. Morris, R.R. Twilley, L. Naylor, L. Schaffner, and C. Stevenson. 2008. Consequences of climate change on the ecogeomorphology of coastal wetlands. Estuaries and Coasts 31:477-491.

DeWan, A., N. Dubois, K. Theoharides, and J. Boshoven J. 2010. Understanding the impacts of climate change on fish and wildlife in North Carolina. Defenders of Wildlife Report. Washington, D.C.

Drabeck, D.H., M.W.H. Chatfield, and C.L. Richards-Zawacki. 2014. The Status of Louisiana's Diamondback Terrapin (*Malaclemys terrapin*) Populations in the Wake of the Deepwater Horizon Oil Spill: Insights from Population Genetic and Contaminant Analyses. ournal of Herpetology 48:125-136.

Fivush, B., R. Parker, and R.H. Tamarin. 1975. Karyotype of the beach vole, *Microtus breweri*, and endemic island species. Journal of Mammology 56:272-273.

Florida Department of Environmental Protection (FDEP). 2019. Oil Spill Tool Kit. https://floridadep.gov/oer/oer/content/oil-spill-tool-kit.

Florida Fish and Wildlife Commission (FWC). 2018a. http://myfwc.com/wildlifehabitats/profiles/birds/raptors-and-vultures/osprey/.

Florida Fish and Wildlife Commission (FWC). 2018b. Red Tide FAQ. http://myfwc.com/research/redtide/faq/.

Frank, K., D. Jourdan, and M. Volk. 2014. Planning for coastal change in Levy County: opportunities for adaptation. Technical Report, University of Florida. 206 pp.

Geselbracht, L., K. Freeman, E. Kelly, D.R. Gordon, and F.E. Putz. 2011. Retrospective and prospective model simulations of sea level rise impacts on Gulf of Mexico coastal marshes and forests in Waccassa Bay, Florida. Climatic Change 107:35-57.

Geselbracht, L.L., K. Freeman, A.P. Birch, J. Brenner, and D.R. Gordon. 2015. Modeled sea level rise impacts on coastal ecosystems at six major estuaries on Florida's Gulf Coast: Implications for adaptation planning. PLoS ONE 10:e0132079.

Getz, L.L. 1966. Salt tolerances of salt marsh meadow voles. Journal of Mammology 47:201-207.

Golley, F.B. 1961. Energy values of ecological materials. Ecology 42:581-584.

Harper, S.J., and G.O., Batzli. 1996. Monitoring use of runways by voles with passive integrated transponders. Journal of Mammalogy 77:364-369.

Harris, V.T. 1953. Ecological relationships of meadow voles and rice rats in tidal marshes. Journal of Mammology 34:479-487.

Hotaling, A.S., H.F. Percival, W.M. Kitchens, and J.W. Kasbohm. 2010. The Persistence of Endangered Florida Salt Marsh Voles in Salt Marshes of the Central Florida Gulf Coast. Southeastern Naturalist 9:795-802.

Integrated Taxonomic Information System. 2016. http://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=202373.

Intergovernmental Panel on Climate Change (IPCC). 2013. Summary for Policymakers. In: T. F. Stocker, et al. eds. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, pp. 3-29. IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. 151 pp.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. 151 pp.

Jackson, D.J. 2016. The molecular systematics and phylogeography of the widespread North American meadow vole *(Microtus pennsylvanicus*). Thesis, University of New Mexico, Albuquerque, New Mexico, U.S.A. http://digitalrepository.unm.edu/biol_etds/149.

Jantz, C. A., S. J. Goetz, D. Donato, and P. Claggett. 2010. Designing and implementing a regional urban modeling system using the SLEUTH cellular urban model. Computers, Environment, and Urban Systems 34:1-16.

Kilpatrick, C.W. 1981. Genetic structure of insular populations. In M.H. Smith and J. Joule. Mammalian population genetics. University of Georgia Press, Athens. pp. 28-59.

Kopp, R.E., C.C. Hay, C.M. Little, and J.X. Mitrovica. 2015. Geographic variability of sea-level change. Current Climate Change Reports 1:192-204.

MacKenzie, T. 2004. Rare Voles Love Suwannee. Fish and Wildlife News. Summer 2004. p. 6.

McCleery, R.A., C.L. Zweig, M.A. Desa, R. Hunt, W.M. Kitchens, and H.F. Percival. 2014. A novel method for camera-trapping small mammals. Wildlife Society Bulletin 38:887-891.

McCleery, R.A., and C.L. Zweig. 2016. Leveraging limited information to understand ecological relationships of endangered Florida salt marsh vole. Journal of Mammalogy 97:1249-1255.

McKinney, M.L., 2002. Urbanization, biodiversity, and conservation. Bioscience 52:883-890.

Meehl, G.A., W.M. Washington, W.D. Collins, J.M. Arblaster, A. Hu, L.E. Buja, W.G. Strand, and H. Teng. 2005. How much more global warming and sea level rise? Science 307:1769-1772.

National Oceanic and Atmospheric Administration (NOAA). 2016. https://service.ncddc.noaa.gov/website/AGSViewers/HABSOS/maps.htm.

National Oceanic and Atmospheric Administration (NOAA). 2017. http://www.aoml.noaa.gov/hrd/tcfaq/E24.html.

National Oceanic and Atmospheric Administration (NOAA). 2018. https://tidesandcurrents.noaa.gov/noaatidepredictions.html?id=8727520&legacy=1.

National Oceanic and Atmospheric Administration [NOAA] Office for Coastal Management. 2017. Detailed Method for Mapping Sea Level Rise Marsh Migration. 8 pp.

National Oceanic and Atmospheric Administration [NOAA] Office of Response and Restoration (ORR). 2017. https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/largest-oil-spills-affecting-us-waters-1969.html.

Osland, M.J., L.C. Feher, J. López-Portillo, R.H. Day, D.O. Suman, J.M. Guzmán Menéndez, and V.H. Rivera-Monroy. 2018. Mangrove forests in a rapidly changing world: Global change impacts and conservation opportunities along the Gulf of Mexico coast. Estuarine, Coastal and Shelf Science 214:120-140.

Raabe, E.A., and L.C. Gauron. 2005. Florida salt marsh vole habitat: Lower Suwannee National Wildlife Refuge. U.S. Geological Survey, Open-File Report 2005-1417. St. Petersburg, Florida.

Reich, L.M. 1981. *Microtus pennsylvanicus*. Mammalian Species 159:1-8.

Roman-Rivera, A.M., and J.T. Ellis. 2018. The king tide conundrum. Journal of Coastal Research 34:769-771.

Root, K.V., and J. Barnes. 2006. Risk assessment for a focal set of rare and imperiled wildlife in Florida. Draft Final Report for FWC Contract No. 03111, Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida. 248 pp.

Rose, R.K., and G.E. Kratimenos. 2006. Population dynamics of meadow voles and feral house mice on a dredge disposal site. The American Midland Naturalist 156:376-385.

Rowe, S. 2017. Microtus pennsylvanicus: meadow vole. From: Animal Diversity Web. https://animaldiversity.org/accounts/Microtus_pennsylvanicus/.

Saintilan, N., N.C. Wilson, K. Rogers, A. Rajkaran, and K.W. Krauss. 2014. Mangrove expansion and salt marsh decline at mangrove poleward limits. Global Change Biology 20:147-157.

Shaffer, M.L., and M.A. Stein. 2000. Safeguarding our precious heritage. In: B.A. Stein, L.S. Kutner, J.S. Adams, eds. Precious heritage: the status of biodiversity in the United States. Oxford University Press, New York. pp. 301-321.

Silliman, B.R., J. van de Koppel, M.W. McCoy, J. Diller, G.N. Kasozi, K. Earl, P.N. Adams, and A.R. Zimmerman. 2012. Degradation and resilience in Louisiana salt marshes after the BP–Deepwater Horizon oil spill. Proceedings of the National Academy of Sciences 109:11234-11239. DOI: 10.1073/pnas.1204922109.

Stevens, P. W., S. L. Fox, and C. L. Montague. 2006. The interplay between mangroves and saltmarshes at the transition between temperate and subtropical climate in Florida. Wetlands Ecology and Management 14:435-444.

Sutherland, R.W. 2009. The Effects of Urbanization on Reptiles and Amphibians in the Sandhills Region of North Carolina. Dissertation. Durham: Duke University.

Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, and C. Zervas. 2017. Global and regional sea level rise scenarios for the United States. National Oceanic and Atmospheric Administration (NOAA) Technical Report NOS CO-OPS 083. 75 pp.

Sweet, W. V., B. D. Hamlington, R. E. Kopp, C. P. Weaver, P. L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A. S. Genz, J. P. Krasting, E. Larour, D. Marcy, J. J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K. D. White, and C. Zuzak, 2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M.F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips, and S.E. Williams. 2004. Extinction risk from climate change. Nature 427:145-148.

University of Florida. 2009. Gulf Coast Salt Marshes. https://soils.ifas.ufl.edu/florida-wetlands-extension-program/about-wetlands/types-of-wetlands/tidal-salt-marshes

U.S. Fish and Widlife Service (Service). 1997. Recovery plan for the Florida salt marsh vole. U.S. Fish and Wildlife Service, Atlanta, Georgia. 9 pp.

U.S. Fish and Wildlife Service (Service). 1999. Multi-species recovery plan for South Florida. U.S. Fish and Wildlife Service, Vero Beach, Florida. 44 pp.

U.S. Fish and Wildlife Service (Service). 2016. U.S. Fish and Wildlife Service species status assessment framework: an integrated analytical framework for conservation. Version 3.4.8, August 2016.

U.S. Fish and Widlife Service (Service). 2017. Climate Change. Unpublished Report, January 27, 2017. U.S. Fish and Wildlife Service. 8 pp.

Walsh, K.J.E., S. Camargo, G. Vecchi, A.S. Daloz, J. Elsner, K. Emanuel, M. Horn, Y.-K. Lim, M. Roberts, C. Patricola, E. Scoccimarro, A. Sobel, S. Strazzo, G. Villarini, M. Wehner, M. Zhao, J. Kossin, T. LaRow, K. Oouchi, S. Schubert, H. Wang, J. Bacmeister, P. Chang, F. Chauvin, C. Jablonowski, A. Kumar, H. Murakami, T. Ose, K. Reed, R. Saravanan, Y. Yamada, C. Zarzycki, P.-L. Vidale, J. Jonas, and N. Henderson. 2015. Hurricanes and climate: the U.S. CLIVAR working group on hurricanes, B. Am. Meteorol. Soc. 96:997-1017, https://doi.org/10.1175/BAMS-D-13-00242.1.

Warren Pinnacle Consulting, Inc. 2011. Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Cedar Keys NWR. 45 pp.

Warren Pinnacle Consulting, Inc. 2016. Evaluation of Regional SLAMM Results to Establish a Consistent Framework of Data and Models. Prepared for the Gulf Coast Prairie Landscape Conservation Cooperative. 165 pp.

Wolf S., B. Hartl, C. Carroll, M.C. Neel, D.N. Greenwald. 2015. Beyond PVA: Why recovery under the Endangered Species Act is more than population viability. BioScience 65:200-207.

Woods, C.A., W. Post, and C.W. Kilpatrick. 1982. *Microtus pennsylvanicus* (Rodentia: Muridae) in Florida: a Pleistocene relict in a coastal salt marsh. Bulletin of the Florida State Museum, Biological Science 28(2):25-52.

Woods C.A. 1988. Status survey of the Florida Saltmarsh Vole; *Microtus pennsylvanicus dukecampbelli*. Final Report: submitted by The Florida State Museum, University of Florida, Sept. 28, 1988.

Woods, C.A. 1992. Florida Saltmarsh Vole, *Microtis pennsylvanicus dukecampbelli*. In S.R. Humphrey. Rare and Endangered Biota of Florida, Volume 1. Mammals. University Presses of Florida, Tallahassee. pp. 131-139.

APPENDIX A: FUTURE CONDITION MAPS

Future scenario maps of salt marsh extent, scenarios in legend. Salt marsh spatial data came from the Gulf Coast Prairie Landscape Conservation Cooperative (GCPLCC) Sea-Level Affecting Marshes Model (SLAMM) Gap Analysis Project (available at: http://www.warrenpinnacle.com/prof/SLAMM/GCPLCC/, Geselbracht et al. 2015, entire), and the current condition from this data set corresponds to the year 2008.

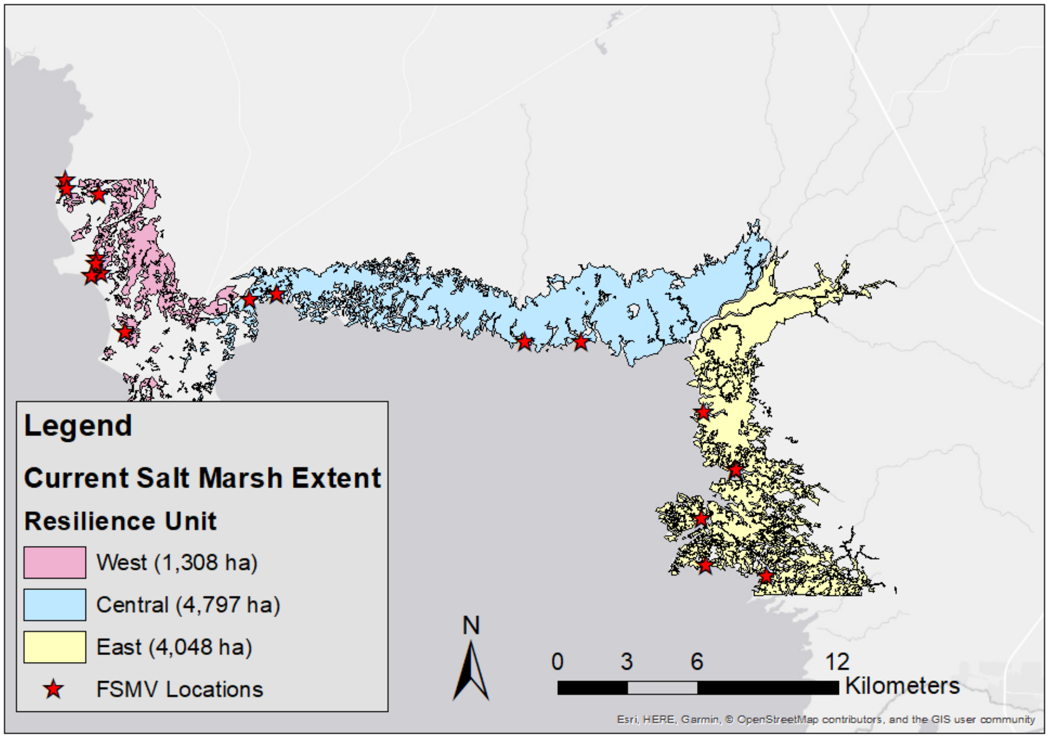

Figure A1. Current (2008) scenario maps of salt marsh extent across the FSMV range.

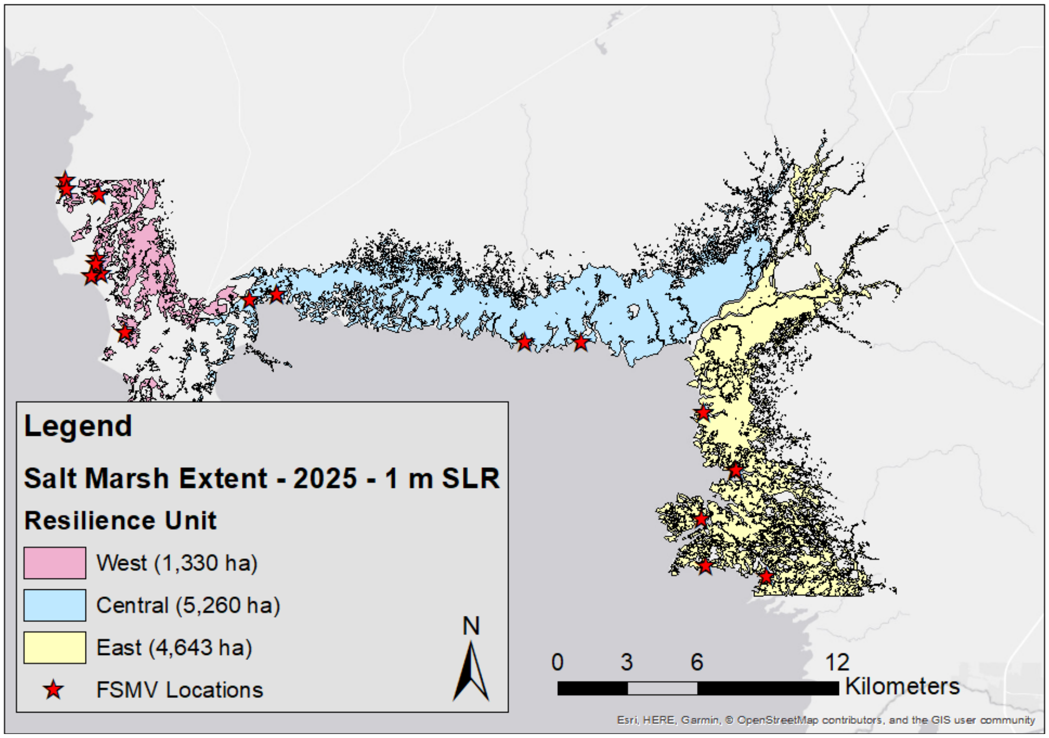

Figure A2. Future (2025) scenario maps of salt marsh extent with 1 meter sea level rise across the FSMV range.

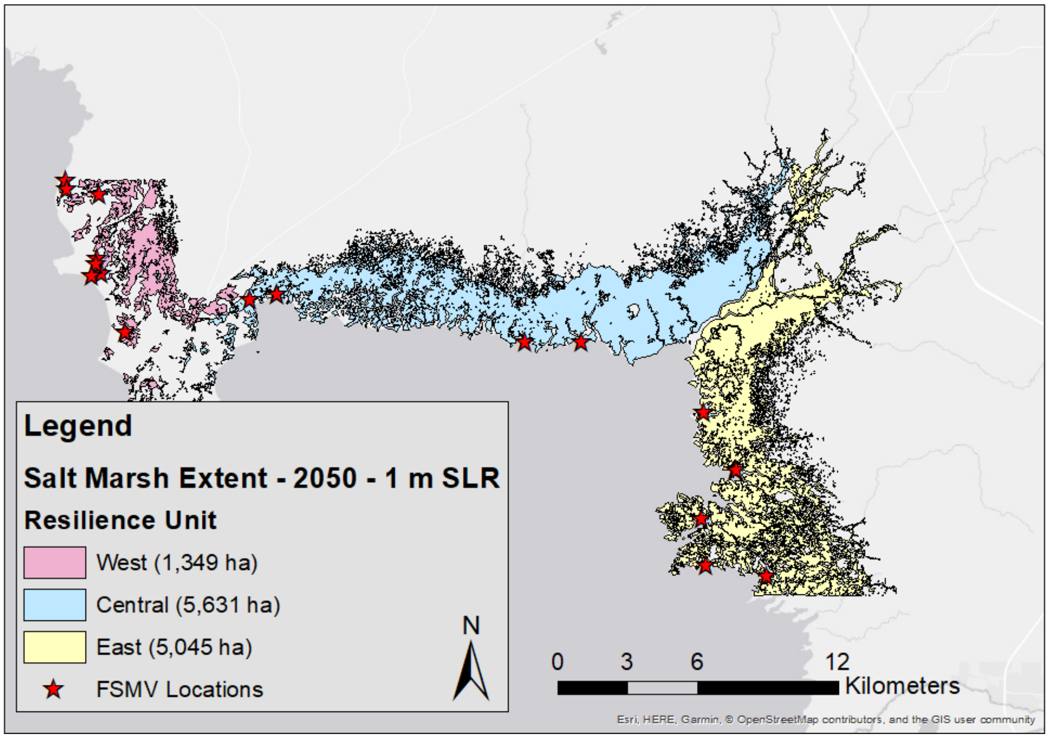

Figure A3. Future (2050) scenario maps of salt marsh extent with 1 meter sea level rise across the FSMV range.

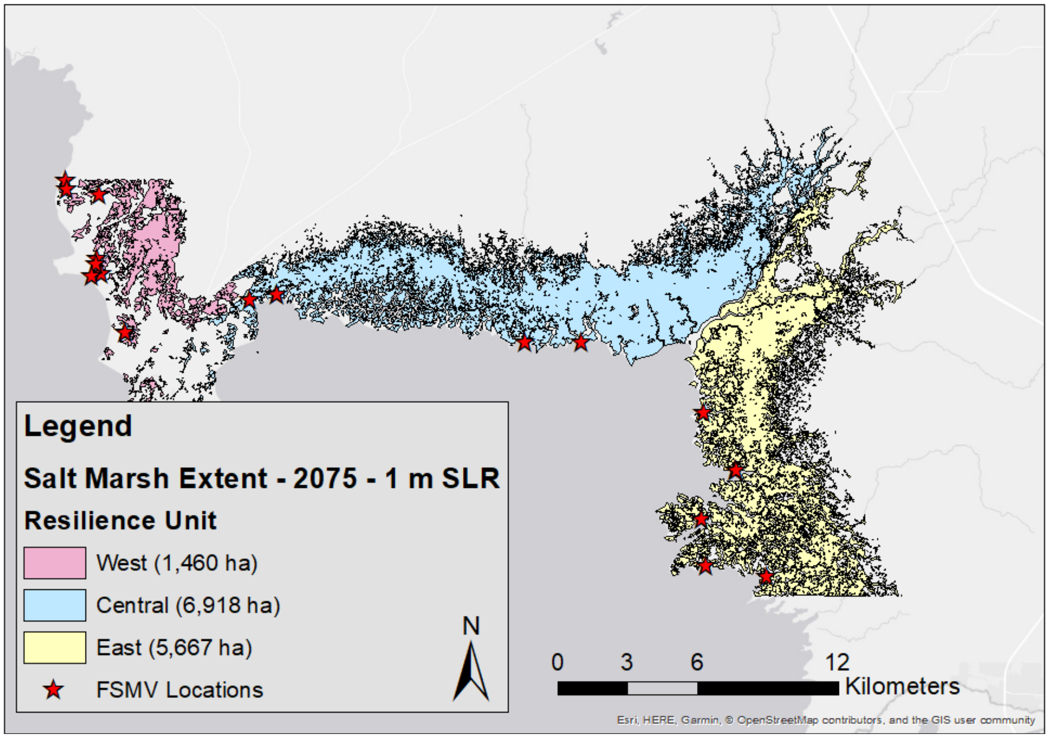

Figure A4. Future (2075) scenario maps of salt marsh extent with 1 meter sea level rise across the FSMV range.

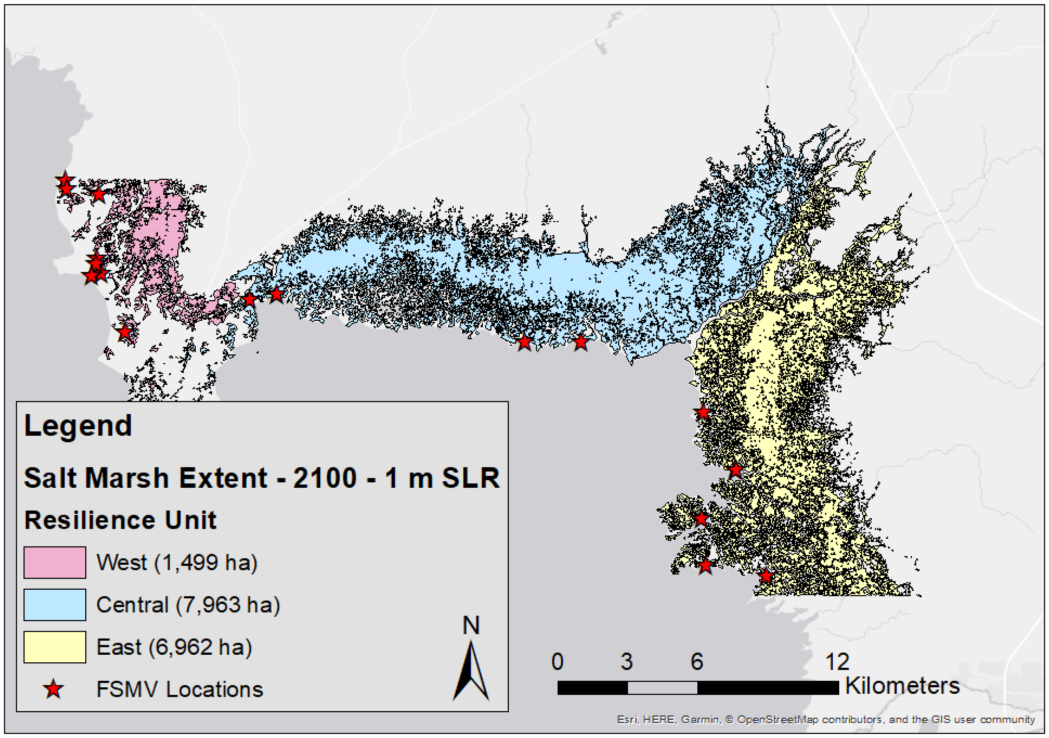

Figure A5. Future (2100) scenario maps of salt marsh extent with 1 meter sea level rise across the FSMV range.

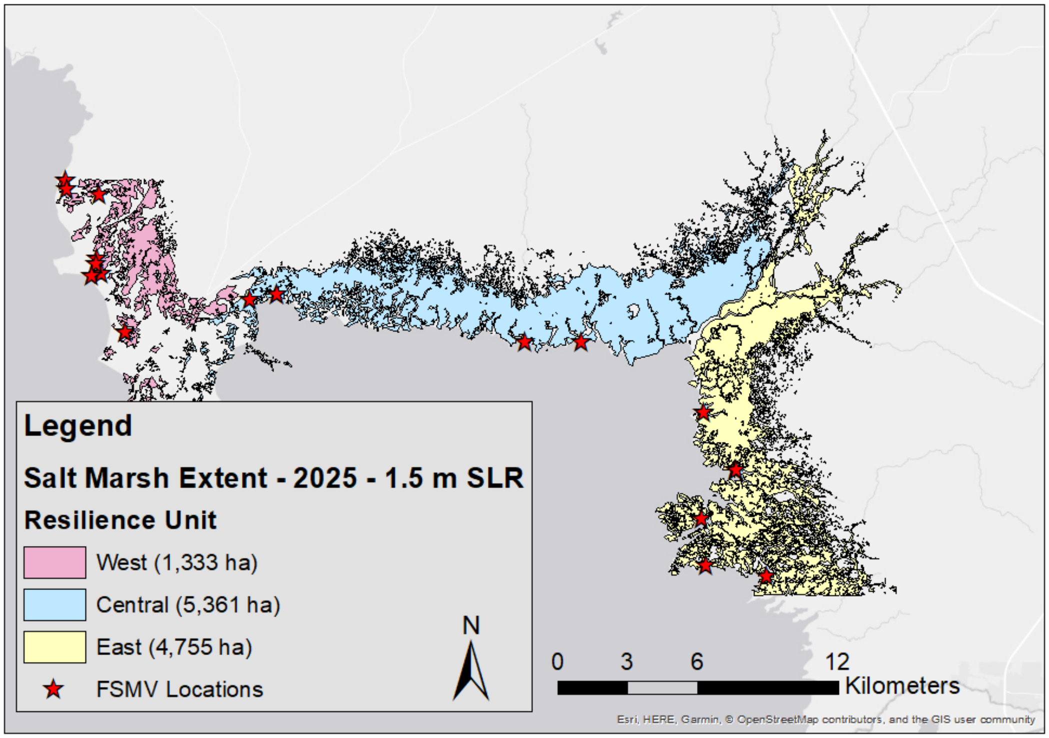

Figure A6. Future (2025) scenario maps of salt marsh extent with 1.5 meter sea level rise across the FSMV range.

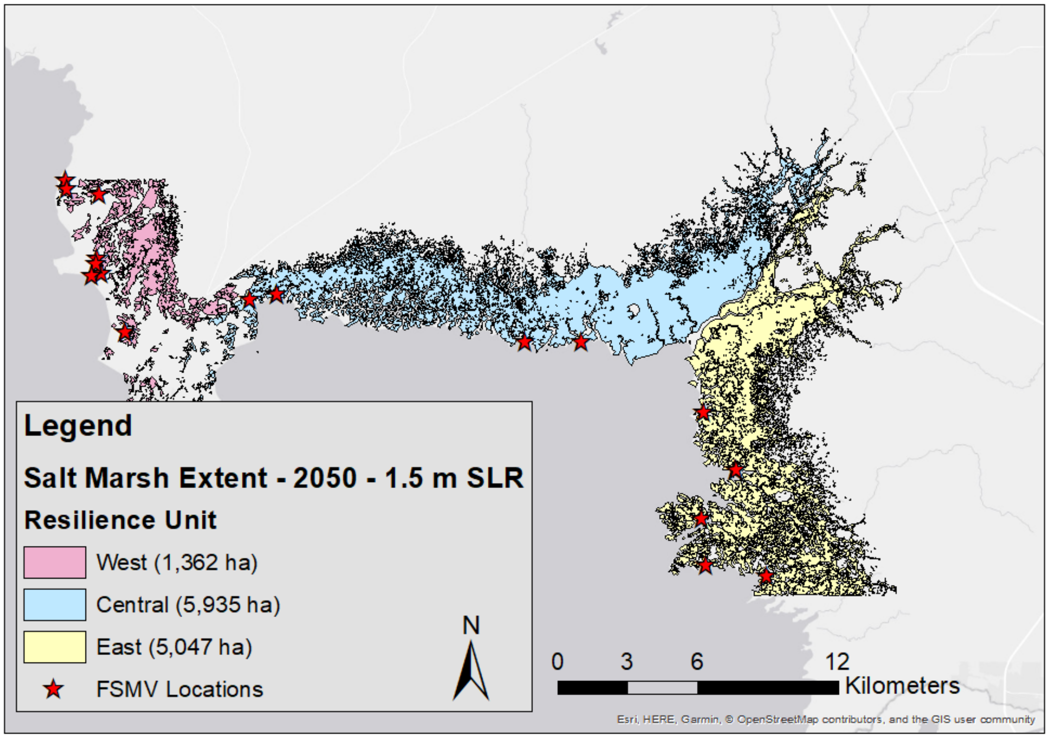

Figure A7. Future (2050) scenario maps of salt marsh extent with 1.5 meter sea level rise across the FSMV range.

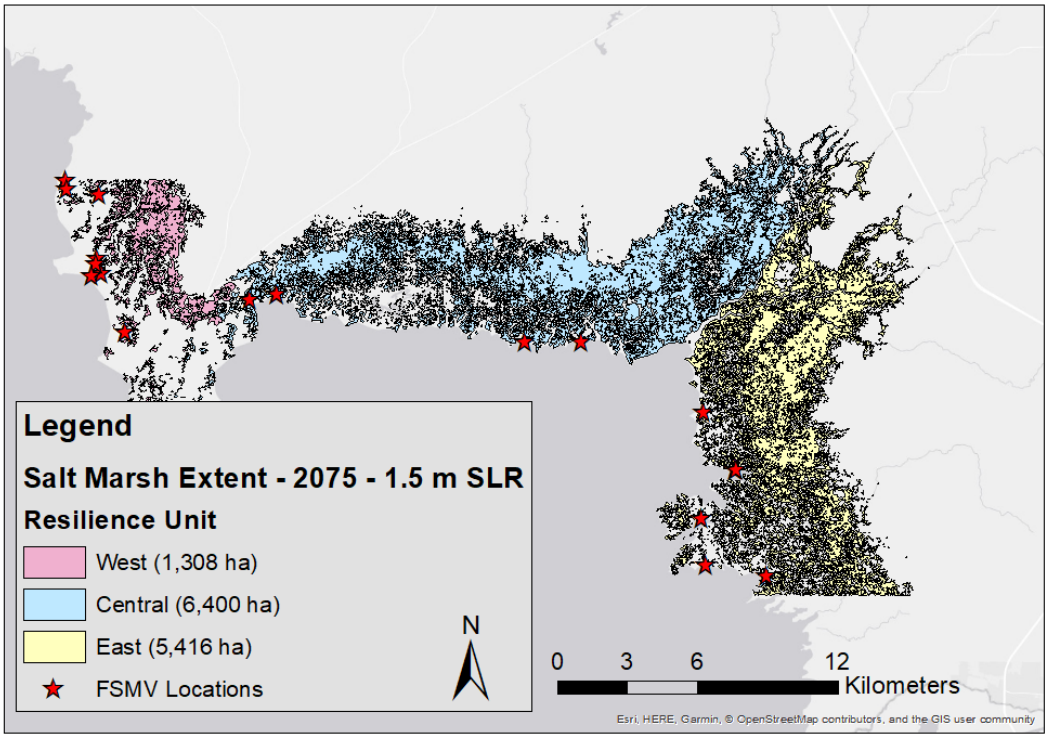

Figure A8. Future (2075) scenario maps of salt marsh extent with 1.5 meter sea level rise across the FSMV range.

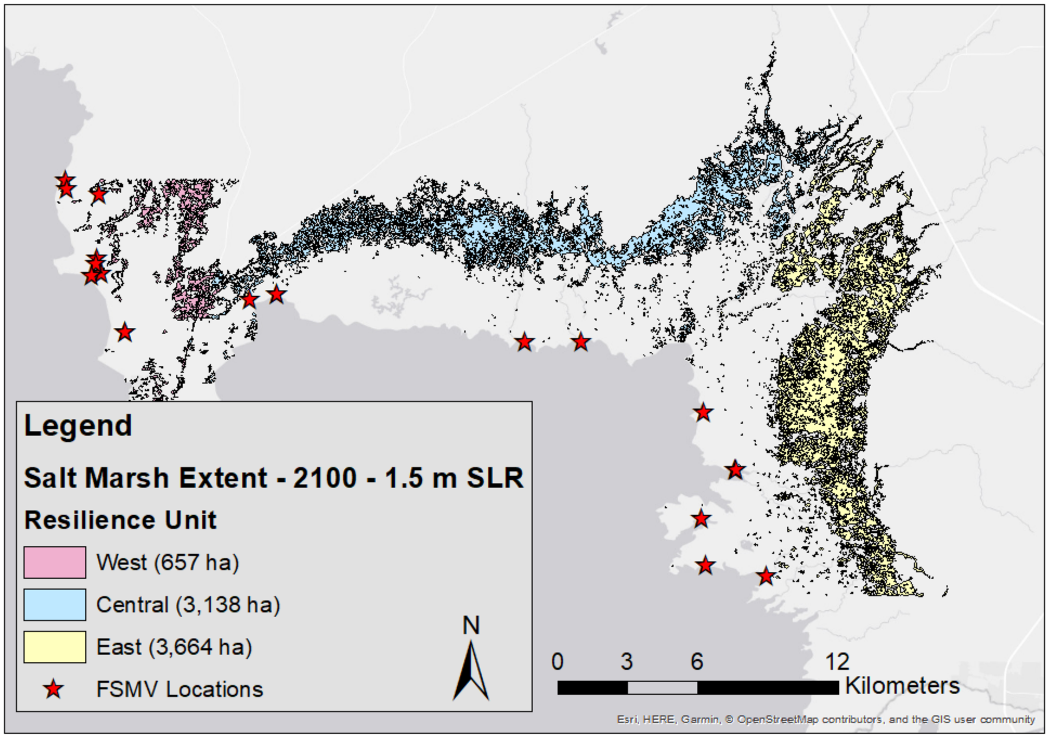

Figure A9. Future (2100) scenario maps of salt marsh extent with 1.5 meter sea level rise across the FSMV range.

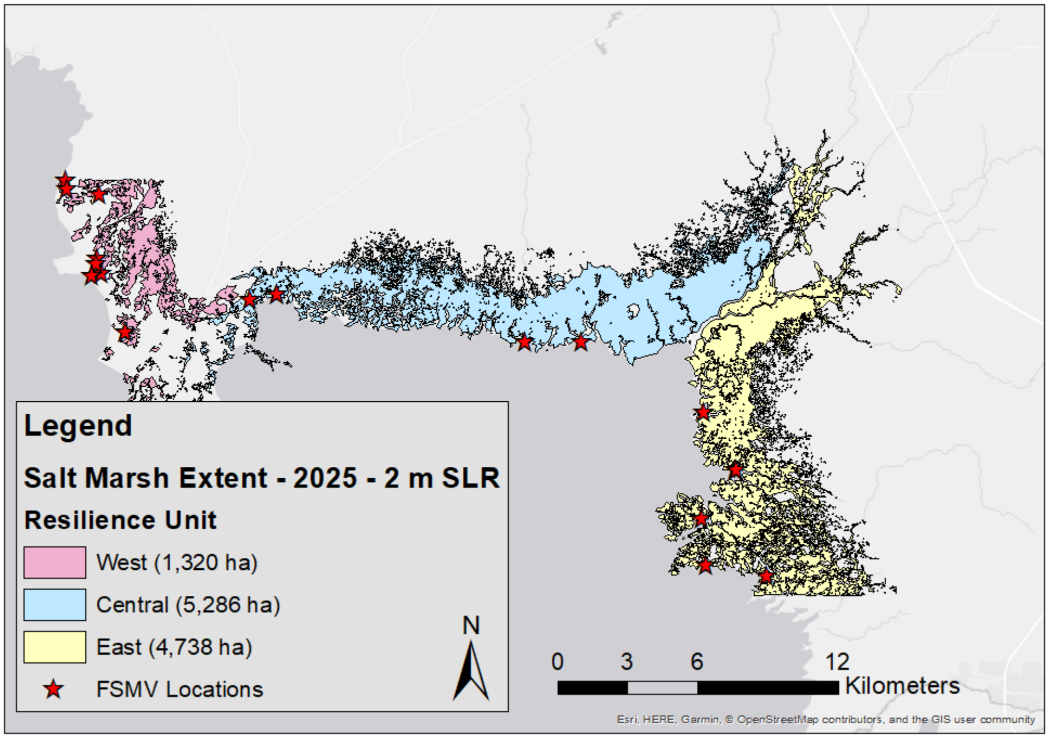

Figure A10. Future (2025) scenario maps of salt marsh extent with 2 meters sea level rise across the FSMV range.

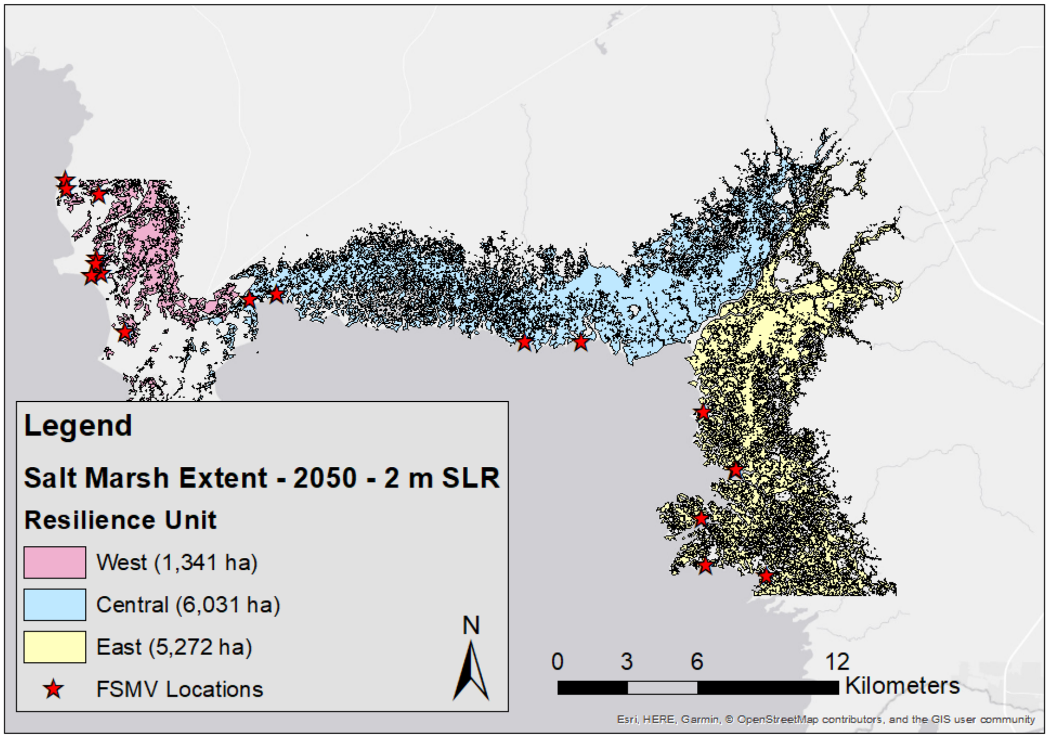

Figure A11. Future (2050) scenario maps of salt marsh extent with 2 meters sea level rise across the FSMV range.

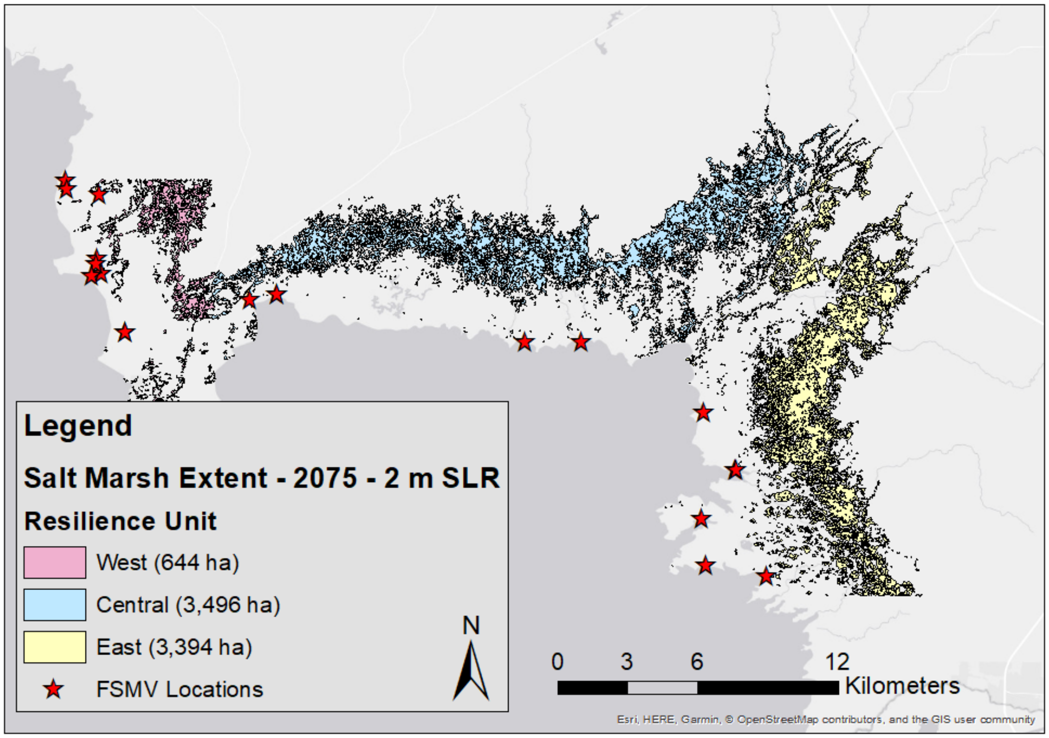

Figure A12. Future (2075) scenario maps of salt marsh extent with 2 meters sea level rise across the FSMV range.

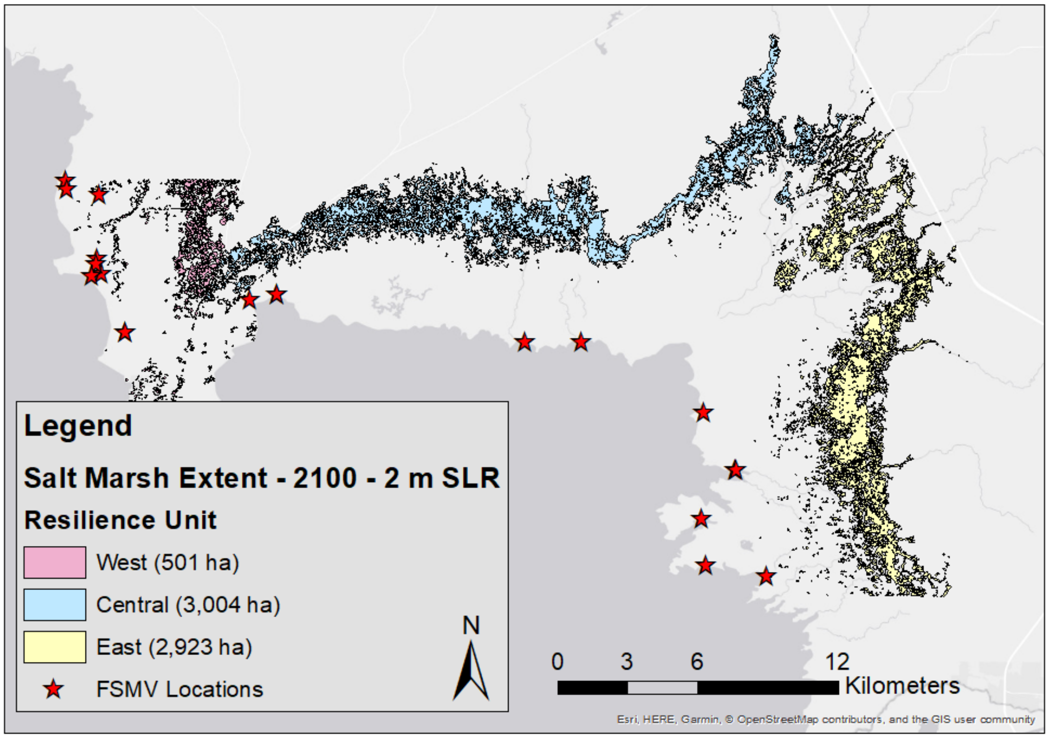

Figure A13. Future (2100) scenario maps of salt marsh extent with 2 meters sea level rise across the FSMV range.

APPENDIX B1: FUTURE CONDITION TABLES

Table B1-1. Future habitat metrics from the current condition (2008 data) to 2100 with 1-m of sea level rise by 2100. Units are hectares (ha) for area and meters (m) for distance (Sea-Level Affecting Marshes Model Gap Analysis Project Geselbracht et al. 2015, entire).

Future 1 m SLR by 2100	**Current**				**2025**				**2050**			
Metric	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**
Area salt marsh	10,152.5	1,307.6	4,796.7	4,048.3	11,233.1	1,330.3	5,260.2	4,642.6	12,024.8	1,349.3	5,631.0	5,044.5
Area potential FSMV habitat	264.0	48.4	191.9	28.3	292.1	49.2	210.4	32.5	312.6	49.9	225.2	35.3
Mean salt marsh patch size	12.2	5.4	20.7	11.4	3.6	3.7	3.4	3.7	3.5	3.3	3.5	3.5575
Median salt marsh patch size	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0616
Minimum salt marsh patch size	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0576
Maximum salt marsh patch size	4,423.5	740.2	4,423.5	2,216.5	4,632.0	749.3	4,632.0	3,112.3	4,897.1	785.1	4,897.1	4,067.3
Area patches < 1 ha	127.5	38.6	36.2	52.7	412.1	50.7	206.9	154.6	474. 5	59.1	230.4	185
Area patches 1-10 ha	344.9	92.4	114.6	137. 9	511.1	92.9	187.2	231.0	545. 4	91.2	226.4	227.9
Area patches 10-100 ha	708.7	264.4	222.3	222.0	685.1	264.8	234.2	186.2	720.5	244.8	277.2	198.5
Area patches 100-1000 ha	2331.4	912.2	0	1419.2	1,880.4	921.9	-	958.5	1,320.1	954.2	-	365.9
Area patches > 1000 ha	6640.0	0	4423.5	2216.5	7,744.3	-	4,632.0	3,112.3	8,964.3	-	4,897.1	4067.3
% salt marsh in patches < 1 ha	1.3	3.0	0.8	1.3	3.7	3.8	3.9	3.3	3.9	4.4	4.1	3.7
% salt marsh in patches 1-10 ha	3.4	7.1	2.4	3.4	4.6	7.0	3.6	5.0	4.5	6.8	4.0	4.5
% salt marsh in patches 10-100 ha	7.0	20.2	4.6	5.5	6.1	19.9	4.5	4.0	6.0	18.1	4.9	3.9
% salt marsh in patches 100-1000 ha	23.0	69.8	0.0	35.1	16.7	69.3	0.0	20.6	11.0	70.7	0.0	7.3
% salt marsh in patches > 1000 ha	65.4	0.0	92.2	54.8	68.9	0.0	88.1	67.0	74.5	0.0	87.0	80.6
Area of salt marsh in protected lands	9,018.2	1,039.0	4,268.5	3,710.7	9603.4	1054	4582.1	3967.8	10,107.7	1101	4,826.3	4,180.7
% area of salt marsh in protected lands	88.8	79.5	89.0	91.7	85.5	79.2	87.1	85.5	84.1	81.6	85.7	82.9
Average distance to nearest ≥ 1 ha patch	-	-	-	-	1.1	0	0	3.8	1.1	0	0	3.8

Table B1-1. Continued.

Future 1 m SLR by 2100	Current				2075				2100			
Metric	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**
Area salt marsh	10,152.5	1,307.6	4,796.7	4,048.3	14,045.2	1,460.0	6,918.4	5,666.7	16,423.9	1,498.7	7,963.0	6,962.2
Area potential FSMV habitat	264.0	48.4	191.9	28.3	365.2	54.0	276.7	39.7	427.0	55.5	318.5	48.7
Mean salt marsh patch size	12.2	5.4	20.7	11.4	3.8	4.1	4.4	3.1	4.1	2.6	4.9	3.8
Median salt marsh patch size	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Minimum salt marsh patch size	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Maximum salt marsh patch size	4,423.5	740.2	4,423.5	2,216.5	6,117.1	974.6	6,117.1	4,925.5	7,105.1	780.2	7,105.1	4,073.3
Area patches < 1 ha	127.5	38.6	36.2	52.7	508.8	48.7	223.9	236.3	579.5	86.2	235.0	258.4
Area patches 1-10 ha	344.9	92.4	114.6	137. 9	517.4	77.8	253.1	186.5	860.4	134.5	351.5	374.4
Area patches 10-100 ha	708.7	264.4	222.3	222.0	1,001.7	358.9	324.4	318.4	1,387.0	287.6	271.5	827.9
Area patches 100-1000 ha	2331.4	912.2	-	1419.2	974.6	974.6	-	-	1,321.5	990.4	-	331.1
Area patches > 1000 ha	6640.0	-	4423.5	2216.5	11,042.6	-	6,117.1	4,925.5	12,275.4	-	7,105.1	5,170.3
% salt marsh in patches < 1 ha	1.3	3.0	0.8	1.3	3.6	3.3	3.2	4.2	3.5	5.7	3.0	3.7
% salt marsh in patches 1-10 ha	3.4	7.1	2.4	3.4	3.7	5.3	3.7	3.3	5.2	9.0	4.4	5.4
% salt marsh in patches 10-100 ha	7.0	20.2	4.6	5.5	7.1	24.6	4.7	5.6	8.4	19.2	3.4	11.9
% salt marsh in patches 100-1000 ha	23.0	69.8	0.0	35.1	6.9	66.8	0.0	0.0	8.0	66.1	0.0	4.8
% salt marsh in patches > 1000 ha	65.4	0.0	92.2	54.8	78.6	0.0	88.4	86.9	74.7	0.0	89.2	74.3
Area of salt marsh in protected lands	9,018.2	1,039.0	4,268.5	3,710.7	11,406.6	1,228.9	5,642.8	4,535.0	12,018.4	1,269.0	6,262.4	4,487.0
% area of salt marsh in protected lands	88.8	79.5	89.0	91.7	81.2	84.2	81.6	80.0	73.2	84.7	78.6	64.4
Average distance to nearest ≥ 1 ha patch	-	-	-	-	1.6	0	0	5.4	5.8	0	0	19.5

Table B1-2. Future habitat metrics from the current condition (2008 data) to 2100 with 1.5-m of sea level rise by 2100. Units are hectares (ha) area and meters (m) for units of distance (Sea-Level Affecting Marshes Model Gap Analysis Project Geselbracht et al. 2015, entire).

Future 1.5 m SLR by 2100	Current				2025				2050			
Metric	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**
Area salt marsh	10,152.5	1,307.6	4,796.7	4,048.3	11,448.0	1,332.9	5,360.6	4,754.5	12,343.89	1,361.5	5,935.4	5,047.0
Area potential FSMV habitat	264.0	48.4	191.9	28.3	297.6	49.3	214.4	33.3	320.94	50.4	237.4	35.3
Mean salt marsh patch size	12.2	5.4	20.7	11.4	3.4	3.4	3.3	3.6	3.23	3.3	3.3	3.1
Median salt marsh patch size	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.09	0.1	0.1	0.1
Minimum salt marsh patch size	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.06	0.1	0.1	0.1
Maximum salt marsh patch size	4,423.5	740.2	4,423.5	2,216.5	4,676.6	751.7	4,676.6	3,177.6	5,140.25	814.3	5,140.3	4,167.7
Area patches < 1 ha	127.5	38.6	36.2	52.7	448.7	54.2	228.4	166.1	557.81	59.1	261.1	237.6
Area patches 1-10 ha	344.9	92.4	114.6	137.9	498.9	93.1	184.1	221.7	561.69	92.2	239.7	229.8
Area patches 10-100 ha	708.7	264.4	222.3	222.0	730.5	261.4	271.5	197.6	974.37	395.9	294.3	284.2
Area patches 100-1000 ha	2,331.4	912.2	-	1,419.2	1,915.9	924.2	-	991.7	942.12	814.3	-	127.8
Area patches > 1000 ha	6,640.0	-	4,423.5	2,216.5	7,854.2	-	4,676.6	3,177.6	9,307.91	-	5,140.3	4,167.7
% salt marsh in patches < 1 ha	1.3	3.0	0.8	1.3	3.9	4.1	4.3	3.5	4.5	4.3	4.4	4.7
% salt marsh in patches 1-10 ha	3.4	7.1	2.4	3.4	4.4	7.0	3.4	4.7	4.6	6.8	4.0	4.6
% salt marsh in patches 10-100 ha	7.0	20.2	4.6	5.5	6.4	19.6	5.1	4.2	7.9	29.1	5.0	5.6
% salt marsh in patches 100-1000 ha	23.0	69.8	0.0	35.1	16.7	69.3	0.0	20.9	7.6	59.8	0.0	2.5
% salt marsh in patches > 1000 ha	65.4	0.0	92.2	54.8	68.6	0.0	87.2	66.8	75.4	0.0	86.6	82.6
Area of salt marsh in protected lands	9,018.2	1,039.0	4,268.5	3,710.7	9,721.5	1,061.2	4,642.0	4,018.3	10,219.50	1,121.6	4,916.8	4,181.1
% area of salt marsh in protected lands	88.8	79.5	89.0	91.7	84.9	79.6	86.6	84.5	82.8	82.4	82.8	82.8
Average distance to nearest ≥ 1 ha patch	-	-	-	-	1.1	0	0	3.8	1.6	0	0	5.4

Table B1-2. Continued.

Future 1.5 m SLR by 2100	Current				2075				2100			
Metric	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**
Area salt marsh	10,152.5	1,307.6	4,796.7	4,048.3	13,011.2	1,194.6	6,400.4	5,416.3	7,458.3	656.6	3,137.7	3,663.9
Area potential FSMV habitat	264.0	48.4	191.9	28.3	338.3	44.2	256.0	37.9	193.9	24.3	125.5	25.6
Mean salt marsh patch size	12.2	5.4	20.7	11.4	2.0	1.3	2.5	1.7	1.4	0.9	1.2	1.8
Median salt marsh patch size	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Minimum salt marsh patch size	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Maximum salt marsh patch size	4,423.5	740.2	4,423.5	2,216.5	5,093.9	496.6	5,093.9	2,736.9	1,936.3	190.8	1,936.3	1,430.0
Area patches < 1 ha	127.5	38.6	36.2	52.7	991.5	126.9	386.0	478.6	772.5	128.8	364.8	278.9
Area patches 1-10 ha	344.9	92.4	114.6	137.9	1,319.6	231.8	470.2	617.6	758.8	103.8	353.6	301.4
Area patches 10-100 ha	708.7	264.4	222.3	222.0	1,213.6	156.6	450.2	606.8	918.4	67.1	483.1	368.3
Area patches 100-1000 ha	2,331.4	912.2	-	1,419.2	1,655.7	679.3	-	976.4	1,642.3	357.0	-	1,285.3
Area patches > 1000 ha	6,640.0	-	4,423.5	2,216.5	7,830.9	-	5,093.9	2,736.9	3,366.3	-	1,936.3	1,430.0
% salt marsh in patches < 1 ha	1.3	3.0	0.8	1.3	7.6	10.6	6.0	8.8	10.4	19.6	11.6	7.6
% salt marsh in patches 1-10 ha	3.4	7.1	2.4	3.4	10.1	19.4	7.3	11.4	10.2	15.8	11.3	8.2
% salt marsh in patches 10-100 ha	7.0	20.2	4.6	5.5	9.3	13.1	7.0	11.2	12.3	10.2	15.4	10.1
% salt marsh in patches 100-1000 ha	23.0	69.8	0.0	35.1	12.7	56.9	0.0	18.0	22.0	54.4	0.0	35.1
% salt marsh in patches > 1000 ha	65.4	0.0	92.2	54.8	60.2	0.0	79.6	50.5	45.1	0.0	61.7	39.0
Area of salt marsh in protected lands	9,018.2	1,039.0	4,268.5	3,710.7	9,215.0	998.8	4,944.6	3,271.6	3,480.7	509.2	2,024.7	946.7
% area of salt marsh in protected lands	88.8	79.5	89.0	91.7	70.8	83.6	77.3	60.4	46.7	77.6	64.5	25.8
Average distance to nearest ≥ 1 ha patch	-	-	-	-	62.1	14.1	0	185.8	1,432.6	890.5	1,463.1	2,220.4

Table B1-3. Future habitat metrics from the current condition (2008 data) to 2100 with 2-m of sea level rise by 2100. Units are hectares (ha) for area and meters (m) for units of distance (Sea-Level Affecting Marshes Model Gap Analysis Project Geselbracht et al. 2015, entire).

Future 2 m SLR by 2100	**Current**				**2025**				**2050**			
Metric	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**
Area salt marsh	10,152.5	1,307.6	4,796.7	4,048.3	11,344.2	1,320.4	5,286.3	4,737.5	12,644.6	1,341.4	6,031.4	5,271.7
Area potential FSMV habitat	264.0	48.4	191.9	28.3	295.0	48.9	211.5	33.2	328.8	49.6	241.3	36.9
Mean salt marsh patch size	12.2	5.4	20.7	11.4	3.3	3.4	3.1	3.5	3.0	3.1	3.1	2.9
Median salt marsh patch size	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Minimum salt marsh patch size	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Maximum salt marsh patch size	4,423.5	740.2	4,423.5	2,216.5	4,510.4	746.4	45,10.4	3,167.6	5,058.7	840.4	5,058.7	2,506.9
Area patches < 1 ha	127.5	38.6	36.2	52.7	464.2	53.3	241.3	169.7	595.2	62.0	267.3	265.8
Area patches 1-10 ha	344.9	92.4	114.6	137.9	533.0	91.6	201.5	239.9	862.0	104.8	414.8	342.3
Area patches 10-100 ha	708.7	264.4	222.3	222.0	770.2	258.1	333.2	178.9	1,200.3	334.2	290.7	575.5
Area patches 100-1000 ha	2,331.4	912.2	-	1,419.2	1,898.9	917.5	-	981.4	2,421.5	840.4	-	1,581.1
Area patches > 1000 ha	6,640.0	-	4,423.5	2,216.5	7,678.0	-	4,510.4	3,167.6	7,565.6	-	5,058.7	2,506.9
% salt marsh in patches < 1 ha	1.3	3.0	0.8	1.3	4.1	4.0	4.6	3.6	4.7	4.6	4.4	5.0
% salt marsh in patches 1-10 ha	3.4	7.1	2.4	3.4	4.7	6.9	3.8	5.1	6.8	7.8	6.9	6.5
% salt marsh in patches 10-100 ha	7.0	20.2	4.6	5.5	6.8	19.5	6.3	3.8	9.5	24.9	4.8	10.9
% salt marsh in patches 100-1000 ha	23.0	69.8	0.0	35.1	16.7	69.5	0.0	20.7	19.2	62.6	0.0	30.0
% salt marsh in patches > 1000 ha	65.4	0.0	92.2	54.8	67.7	0.0	85.3	66.9	59.8	0.0	83.9	47.6
Area of salt marsh in protected lands	9018.2	1039.0	4268.5	3710.7	9614.6	1054.2	4570.9	3989.5	10024.8	1125.9	4907.6	3991.3
% area of salt marsh in protected lands	88.8	79.5	89.0	91.7	84.8	79.8	86.5	84.2	79.3	83.9	81.4	75.7
Average distance to nearest ≥ 1 ha patch	-	-	-	-	1.1	0	0	3.8	2.3	0	0	7.6

Table B1-3. Continued.

Future 2 m SLR by 2100	**Current**				**2075**				**2100**			
Metric	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**	**Total**	**West**	**Central**	**East**
Area salt marsh	10,152.5	1,307.6	4,796.7	4,048.3	7,534.8	644.3	3,496.3	3,394.2	6,429.1	501.4	3,004.4	2,923.3
Area potential FSMV habitat	264.0	48.4	191.9	28.3	195.9	23.8	139.9	23.8	167.2	18.6	120.2	20.5
Mean salt marsh patch size	12.2	5.4	20.7	11.4	1.2	0.8	1.2	1.4	1.3	0.6	1.5	1.5
Median salt marsh patch size	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Minimum salt marsh patch size	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Maximum salt marsh patch size	4,423.5	740.2	4,423.5	2,216.5	1,495.1	274.5	1,382.9	1,495.1	1,730.7	54.9	1,704.1	1,730.7
Area patches < 1 ha	127.5	38.6	36.2	52.7	884.5	130.3	403.8	350.4	720.6	131.2	294.3	295.0
Area patches 1-10 ha	344.9	92.4	114.6	137.9	896.8	97.1	397.4	402.3	750.1	137.0	297.6	315.5
Area patches 10-100 ha	708.7	264.4	222.3	222.0	704.0	14.5	337.6	351.9	724.7	233.1	269.7	221.9
Area patches 100-1000 ha	2,331.4	912.2	-	1,419.2	2,171.4	402.4	974.5	794.5	798.8	-	438.7	360.1
Area patches > 1000 ha	6,640.0	-	4,423.5	2,216.5	2,878.0	-	1,382.9	1,495.1	3,434.8	-	1,704.1	1,730.7
% salt marsh in patches < 1 ha	1.3	3.0	0.8	1.3	11.7	20.2	11.5	10.3	11.2	26.2	9.8	10.1
% salt marsh in patches 1-10 ha	3.4	7.1	2.4	3.4	11.9	15.1	11.4	11.9	11.7	27.3	9.9	10.8
% salt marsh in patches 10-100 ha	7.0	20.2	4.6	5.5	9.3	2.3	9.7	10.4	11.3	46.5	9.0	7.6
% salt marsh in patches 100-1000 ha	23.0	69.8	0.0	35.1	28.8	62.5	27.9	23.4	12.4	0.0	14.6	12.3
% salt marsh in patches > 1000 ha	65.4	0.0	92.2	54.8	38.2	0.0	39.6	44.0	53.4	0.0	56.7	59.2
Area of salt marsh in protected lands	9018.2	1039.0	4268.5	3710.7	4133.6	522.8	2444.7	1166.2	2837.8	403.1	1682.0	752.7
% area of salt marsh in protected lands	88.8	79.5	89.0	91.7	54.9	81.1	69.9	34.4	44.1	80.4	56.0	25.7
Average distance to nearest ≥ 1 ha patch	-	-	-	-	1,189.1	1,035.9	1,057.3	1,528.7	2,352.5	1,642.0	1,893.9	3,800.2

APPENDIX B2: UPDATED FUTURE CONDITION

Updated Sea Level Rise Methodology for Calculating Future Habitat Condition

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In this updated future condition analysis, NOAA marsh migration datasets were used to estimate the amount of estuarine wetland change due to sea level rise based upon projections from Sweet et al. (2022) for the range of the Florida salt marsh vole in Levy County, Florida. In SSA Version 1.0 (Service 2022), results from the Sea Level Affecting Marshes Model (SLAMM) were used to predict the future habitat conditions based upon Sweet et. al. 2017 sea level projections. These two models and resultant datasets differ in several aspects with the most prominent being the land cover inputs. SLAMM incorporates National Wetland Inventory (NWI) land cover (Warren Pinnacle Consulting, Inc. 2016), whereas the NOAA Marsh Migration model uses the NOAA Coastal Change Analysis Program (C-CAP) land cover (NOAA 2017). The resultants differ as the updated sea level rise projections are less in the near term (Sweet et al. 2022) as the timing for different rates of rise for the different scenarios was updated based on new modeling and more realistic assumptions of Greenland and Antarctic ice sheet behavior. A result is that there is less acceleration in the higher scenarios until about 2050 and greater acceleration toward the end of this century (Sweet et al. 2022).

C-CAP produces a nationally standardized database of land cover and land change for the coastal regions of the U.S. These products provide inventories of coastal intertidal areas, wetlands, and adjacent uplands with the goal of monitoring these habitats by updating the land cover maps every five years. Data used in the marsh migration analysis reflect conditions as they existed when mapped in 2005 to 2006. The model is based on a modified bathtub approach of targeting a specific elevation of flooding also accounts for local and regional tidal variability. Data are provided in 30-m resolution (NOAA 2017).

For this updated future condition analysis, the amount of estuarine wetland (EW) available for each foot of SLR was estimated. EW may contain emergent or forested saline wetlands. We note that not all EW is suitable habitat for the FSMV, so an estimate of percent suitable habitat based on current conditions should be conducted to further define the FSMV's habitat and range.

Due to the differences in model design and input parameters (SLR projections, land cover datasets, community change thresholds, etc.), direct comparisons to SLAMM are not recommended. However, these results should provide an estimate of wetland loss over time due to SLR.

Sea level rise projections for the marsh migration differ by accretion rates. Within the NOAA SLR Viewer Marsh Migration tool, the user can select between 0, 2, 4, and 6 mm/yr. Assuming no accretion would be the worst-case scenario resulting in higher estimates of sea level rise inundating the marsh. Previous SLAMM runs used accretion estimates of 3.9 to 4.7 mm/yr for regularly and irregularly flooded marshes, respectively (Warren Pinnacle Consulting, Inc. 2011). Table 1 provides sea level rise estimates for no accretion and 4 mm/yr accretion for the Sweet et al. 2017 and 2022 projections. The 2022 SLR values were rounded to the nearest foot increment to correspond with the available data layers (Tables 2 and 3). Although both the 2017 and 2022 projections are provided for comparison, the actual values used to model marsh transition using SLAMM may be different. SLAMM used the eustatic sea level rise projections adjusted for differences between global SLR and local SLR. Eustatic trends were converted to estimates of relative SLR using the difference between the historic trend and the historic eustatic trend for a particular geographic area (J. Clough, pers. comm, 2022).

Table B2-1. SLR projections by scenario with 0 and 4 mm/yr marsh accretion rates based on Sweet et al. (2017 and 2022)

Projection	Accretion (mm/yr)	Scenario	2030	2050	2070	2090	2100
2022	0	Intermediate	0.56	1.08	1.8	2.85	3.54
2022	0	Intermediate-High	0.59	1.28	2.49	4.13	5.12
2022	0	High	0.62	1.51	3.18	5.51	6.76
2017	0	Intermediate	0.69	1.31	2.13	3.12	3.61
2017	0	Intermediate-High	0.92	1.84	3.18	4.86	5.84
2017	0	High	1.15	2.43	4.33	6.73	8.2
2017	0	Extreme	1.28	2.82	5.22	8.33	10.17
2022	4	Intermediate		0.56	1.02	1.8	2.36
2022	4	Intermediate-High		0.75	1.71	3.08	3.94
2022	4	High		0.98	2.4	4.46	5.58
2017	4	Intermediate	0.43	0.79	1.35	2.07	2.43
2017	4	Intermediate-High	0.66	1.31	2.4	3.81	4.66
2017	4	High	0.89	1.9	3.54	5.68	7.02
2017	4	Extreme	1.02	2.3	4.43	7.28	8.99

Table B2-2. 2022 SLR values with no accretion rounded to the nearest foot.

Scenario	2030	2050	2070	2090	2100
Intermediate	1	1	2	3	4
Intermediate-High	1	1	2	4	5
High	1	2	3	6	7

Table B2-3. 2022 SLR values with 4 mm/yr accretion round to the nearest foot.

Scenario	2030	2050	2070	2090	2100
Intermediate		1	1	2	2
Intermediate-High		1	2	3	4
High		1	2	5	6

Table B2-4. Amount of Estuarine Wetland available per foot of SLR and percent change from current.

SLR Value (ft)	Hectares of Estuarine Wetland	Percent Change from Current
Current ~2005-06	18,127.22	
1	22,404.70	24%
2	18,246.35	1%
3	10,392.91	-43%
4	8,793.93	-51%
5	8,358.08	-54%
6	8,438.08	-53%
7	8,545.18	-53%

In all three SLR scenarios (Sweet et al. 2022) at both zero and 4 mm/yr accretion rates, the area of salt marsh is expected to increase initially from now to the 2070. This increase occurs as the salt marsh extends farther inland but is either not yet submerged on the seaward edge of the marsh, or the loss of the seaward marsh does not outpace the growth of the landward marsh.

This pattern continues all the way to 2100, the end of our future projections. However, as the rate of SLR increases, the growth of salt marsh inland will eventually be outpaced by the loss of seaward salt marsh. The area of salt marsh grows and/or stabilizes by 2070 (18,246 – 22405 ha) except under the High projection with no accretion which exhibits a significant decrease by 2070 (10,393 ha). The 2070 and beyond time frame marks a tipping point and the salt marsh rapidly declines by 2100 (8,438 ha – 8,794 ha) as it is replaced by tidal flats and estuarine open water except under the Intermediate scenario with 4 mm/yr accretion which allows for the salt marsh to remain stable (18,246 ha).

Again, we note that these predicted habitat areas are based on the assumption that as sea levels rise and the salt marsh shifts, the composition of the salt marsh and its vegetative communities will remain the same as they do currently. Whether this will hold true is uncertain.

Table 6-3. Hectares of Estuarine Wetlands available with 0 and 4 mm/yr marsh accretion rates and sea level projection scenarios (Sweet et al. 2022) in 2050, 2070, 2090, and 2100.

Projection	Accretion (mm/yr)	Scenario	Current 2005-06	2050	2070	2090	2100
2022	0	Intermediate	18,127	22,405	18,246	10,393	8,794
2022	0	Intermediate-High	18,127	22,405	18,246	8,794	8,438
2022	0	High	18,127	18,246	10,393	8,438	8,545
2022	4	Intermediate	18,127	22,405	22,405	18,246	18,246
2022	4	Intermediate-High	18,127	22,405	18,246	10,393	8,794
2022	4	High	18,127	22,405	18,246	8,794	8,438

Literature Cited

Clough, J. 2022. E-mail to G. Martin, Fish and Wildlife Biologist, U.S. Fish and Wildlife Service from J. Clough, President, Warren Pinnacle Consulting, Inc. April 14, 2022.

NOAA Office for Coastal Management. 2017. Detailed Method for Mapping Sea Level Rise Marsh Migration. 8 pp.

Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy, J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak. 2022. Global and regional sea level rise scenarios for the United States: Updated mean projections and extreme water level probabilities along U.S. coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf

Warren Pinnacle Consulting, Inc. 2011. Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Cedar Keys NWR. 45 pp.

Warren Pinnacle Consulting, Inc. 2016. Evaluation of Regional SLAMM Results to Establish a Consistent Framework of Data and Models. Prepared for the Gulf Coast Prairie Landscape Conservation Cooperative. 165 pp.