

Species Status Assessment for the Riparian Brush Rabbit (*Sylvilagus bachmani riparius*)

February 2020, Version 3.2



Photograph by Patrick Kelly, California State University, Stanislaus

I) EXECUTIVE SUMMARY

This report summarizes the results of the Species Status Assessment (SSA) for the riparian brush rabbit. To assess the species' viability, we used the three conservation biology principles of resiliency, representation, and redundancy (together, the 3 Rs). These principles rely on assessing the species at an individual, population, and species level in order to determine whether the species can maintain its persistence into the future and avoid extinction by having multiple resilient populations distributed widely across its range. In order to evaluate the 3 Rs and assess riparian brush rabbit viability, we divided the current range of the species into four populations – Caswell Memorial State Park (“Caswell”), Oxbow Preserve (“Oxbow”), the San Joaquin River National Wildlife Refuge (“Refuge”), and the South Delta. The current distribution of the riparian brush rabbit is limited to southern San Joaquin County and northern Stanislaus County. The historical distribution of the species is uncertain but it presumably is many times larger than the current distribution, based on historical habitat availability.

The first part of this SSA report (Chapters 2 through 5) focuses on riparian brush rabbit ecology. The species' ecology is a compilation of the best available biological information on the species (e.g. taxonomy, life history, and habitat) and the species' ecological needs at the individual, population, and species levels. The most important ecological needs for riparian brush rabbit individuals are dense, brushy vegetation; grasses and herbs; ecotonal edges; diversity of plants for food and shelter during the dry season; accessible flood refugia; nest sites and nesting materials; scaffolding shrubs and trees; and connectivity around open areas. The most important needs for riparian brush rabbit populations are abundance, reproduction and recruitment, survival, distribution, and large-scale connectivity. As defined by the SSA Framework, the species-level needs are resiliency, representation, and redundancy. These needs were used to assess the current and future condition of riparian brush rabbit viability.

The second part of this SSA report (Chapters 6 and 7) evaluates the current condition of the species, including the significant past, current, and future influences that are affecting riparian brush rabbit resiliency, representation, and redundancy. The most important influences on the current condition of riparian brush rabbit viability include habitat loss and degradation, flooding, wildfire, drought, predation, and various conservation efforts. We then determined the current condition of the riparian brush rabbit (in terms of the 3 Rs) by assessing the past and ongoing changes associated with each individual, population, and species need. Of the four populations of riparian brush rabbit, one population has high resiliency and three populations have low resiliency. The species' representation and redundancy are both low.

The third part of this SSA (Chapter 8) forecasts the changes in species' viability that might occur in three probable future scenarios. The scenarios were developed based on the expected shifts in environmental conditions and the potential conservation efforts that might occur over the next 40 years. Scenario 1 assumed that the current influences of stressors and conservation efforts would continue at their current rates and/or trajectories into the future. Scenario 2 assumed that stressors and conservation efforts would both increase sharply (more than current rates and/or trajectories). Scenario 3 assumed that stressors would continue at their current rates and/or trajectories and that conservation efforts would increase moderately compared to their current

rates. Under Scenario 1, one population would have high resiliency, two populations would have low resiliency, and one population either would have low resiliency or be extirpated. Under Scenario 2, two populations would have moderate resiliency, one population would have low resiliency, and one population either would have low resiliency or be extirpated. Under Scenario 3, one population would have high resiliency, two populations would have moderate resiliency, and one population would have low resiliency. In all future scenarios, the riparian brush rabbit would have low representation because the species occupies only a small portion of its former range. Population redundancy is low under Scenario 1 and Scenario 2 but redundancy would increase to three resilient populations under Scenario 3.

Based on the results of this SSA, the levels of stressors and of conservation efforts play important roles in determining the future viability of the riparian brush rabbit. Currently, the viability of the riparian brush rabbit is very low. However, with increased conservation efforts, the viability of this species has the potential to improve, even in the face of stressors that are intensifying in response to climate change.

II) TABLE OF CONTENTS

Table of Contents

i)	Executive Summary	2
ii)	Table of Contents	4
CHAPTER 1 Introduction		8
1.1	The Species Status Assessment Framework	8
	Species Ecology.....	8
	Current Species Condition.....	8
	Future Species Condition	9
1.2	Resiliency, redundancy, and representation.....	9
1.3	Viability.....	9
CHAPTER 2 Species Ecology		10
2.1	Physical description.....	10
2.2	Historical distribution.....	11
2.3	Current distribution	11
2.4	Taxonomy.....	13
2.5	Habitat	14
2.6	Life cycle.....	14
2.7	Breeding	15
	Mating System.....	15
	Seasonal cycle	15
	Nesting and rearing young.....	18
	Female reproductive rates.....	18
2.8	Survival and mortality.....	20
2.9	Home Range.....	21
CHAPTER 3 Individual Needs		21
3.1	Dense, brushy vegetation	23
3.2	Grasses and herbs	23
3.3	Ecotonal edges.....	24
3.4	Diversity of plants for dry season needs	25
3.5	Flood refugia	25

3.6	Nest sites and nesting materials	26
3.7	Scaffolding shrubs and trees	26
3.8	Connectivity around open areas (small-scale)	27
CHAPTER 4 Population Needs.....		27
4.1	Population definition.....	28
4.2	Abundance.....	30
4.3	Reproduction and recruitment.....	30
4.4	Survival	31
4.5	Distribution.....	31
4.6	Connectivity for dispersal and migration (large-scale)	31
CHAPTER 5 Species Needs.....		31
5.1	Resiliency	31
5.2	Representation.....	32
5.3	Redundancy	33
CHAPTER 6 Influences to Species Viability.....		35
6.1	Habitat loss and degradation	35
	Development and land use change	35
	Hydrologic changes.....	36
6.2	Flooding	36
6.3	Wildfire	37
6.4	Drought.....	42
6.5	Predation.....	43
6.6	Vegetation management (brush and vegetation removal).....	44
6.7	Forest succession.....	45
6.8	Disease	45
6.9	Nonnative plants.....	46
6.10	Competition.....	46
6.11	Hunting.....	46
6.12	Other stressors	47
6.13	Climate change.....	47
6.14	Beneficial influences (Endangered Species Act)	47

Permittee-responsible mitigation.....	48
HCPs.....	48
Recovery Permits.....	49
6.15 Beneficial influences (conservation efforts)	49
Reintroduction	49
Land acquisition	50
Habitat restoration (including flood refugia).....	50
Flood mortality mitigation.....	51
Nonnative predator management.....	51
CHAPTER 7 Current Condition.....	51
7.1 Summary of methodology.....	51
7.2 Uncertainties and assumptions	54
7.3 Habitat quantity	55
7.4 Habitat quality	57
Habitat suitability model	57
Habitat descriptions from scientific literature and/or species experts	58
7.5 Flood refugia	61
7.6 Abundance and growth rate.....	62
Caswell	62
Oxbow	64
Refuge	65
South Delta	67
7.7 Distribution.....	68
7.8 Connectivity (large-scale)	69
7.9 Population resiliency	72
7.10 Species representation	72
7.11 Species redundancy	73
CHAPTER 8 Future Condition	75
8.1 Methodology	76
8.2 Uncertainties and assumptions	76
8.3 Scenario 1	78
Caswell resiliency.....	78
Oxbow resiliency.....	78

Refuge resiliency	79
South Delta resiliency.....	79
Species representation	79
Species redundancy	79
8.4 Scenario 2	81
Caswell resiliency.....	81
Oxbow resiliency.....	81
Refuge resiliency	82
South Delta resiliency.....	82
Species representation	83
Species redundancy	83
8.5 Scenario 3	85
Caswell resiliency.....	85
Oxbow resiliency.....	85
Refuge resiliency	86
South Delta resiliency.....	86
Species representation	86
Species redundancy	86
8.6 Status Assessment Summary.....	88
References	89
Appendix	97

CHAPTER 1 INTRODUCTION

The Species Status Assessment (SSA) framework (Service 2016, entire) and the SSA Report are intended to support an in-depth review of the species' biology and threats. It includes 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. As such, the SSA Report will be a living document upon which other documents, such as listing rules, recovery plans, and 5-year reviews, would be based if the species warrants listing under the Act.

1.1 The Species Status Assessment Framework

This Report is a summary of the SSA analysis, which entails three iterative assessment stages (Figure 1):

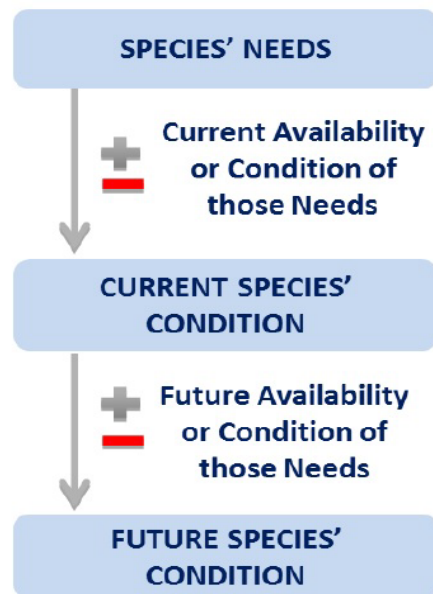


Figure 1. Species Status Assessment Framework. (Service 2016, p. 6)

Species Ecology

An SSA begins with a compilation of the best available biological information on the species (taxonomy, life history, and habitat) and its ecological needs at the individual, population, and species levels. It is based on how environmental factors are understood to act on the species and its habitat.

Current Species Condition

An SSA describes the current condition of the species habitat and demographics and the probable explanations for past and ongoing changes in the abundance and distribution within the species

ecological settings. The ecological settings are the areas representative of the geographic, genetic, or life history variation across the species range.

Future Species Condition

An SSA forecasts the species response to probable future scenarios of environmental conditions and conservation efforts. As a result, the SSA characterizes the ability of the species to sustain populations in the wild over time (i.e. viability). It is based on the best scientific understanding of current and future abundance and distribution within the species ecological settings.

1.2 Resiliency, redundancy, and representation

Throughout the assessment, the SSA uses the conservation biology principles of resiliency, redundancy, and representation (Wolf *et al.* 2015, entire), as a lens to evaluate the current and future condition of the species. Together, the 3Rs—and their core autecological parameters of abundance, distribution, and diversity—comprise the key characteristics that contribute to a species' ability to sustain populations over time. When combined across populations, they measure the health of the species as a whole.

Resiliency is having sufficiently robust populations for the species to withstand stochastic events (i.e. events arising from random factors). We measure resiliency based on metrics of habitat and population health (e.g. birth versus death rates and population size). Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (i.e. demographic stochasticity), variations in rainfall (i.e. environmental stochasticity), or the effects of anthropogenic activities. For riparian brush rabbit, resiliency was measured by assessing the condition of the species' individual and population needs.

Redundancy describes the ability of a species to withstand catastrophic events. Adequate redundancy spreads risk among multiple populations to minimize the potential loss of the species from catastrophic events. Redundancy is characterized by having multiple, resilient populations distributed within the ecological settings and range of the species. For the riparian brush rabbit, redundancy was measured by assessing the number of resilient populations across the range of the species.

Representation describes the ability of a species to adapt to changing environmental conditions. It is characterized by the breadth of genetic and environmental diversity within and among populations. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics within the geographical range. For the riparian brush rabbit, representation was measured by assessing the genetic diversity and unique ecological settings across the range of species.

1.3 Viability

Viability is the ability of a species to sustain populations in the wild over time. Viability is not a static state, and thus we do not attempt to define the species as viable or not viable. In general, species with higher resiliency, redundancy, and representation, are better protected from stochastic and catastrophic impacts to the environment, can better tolerate threats and adapt to changing conditions, and are thus more viable than those with lower levels of the 3 Rs. We

assessed species viability using the best available science to analyze the species' ecology, current condition, and potential future condition under a number of future scenarios, all in the context of the 3Rs.

In summary, the SSA is a scientific review of the best available information, including scientific literature and discussions with experts, related to the biology and conservation status of the riparian brush rabbit.

CHAPTER 2 SPECIES ECOLOGY

2.1 Physical description

The riparian brush rabbit (*Sylvilagus bachmani riparius*) is a small, brown rabbit, differentiated from other brush rabbit subspecies by a combination of moderately pale color, gray sides, and slightly darker back. The riparian brush rabbit is best distinguished from other brush rabbit subspecies by its skull; the rostrum, or snout, of the riparian brush rabbit differs by being convex (protruding outward), rather than straight or concave (Orr 1935, p. 29).

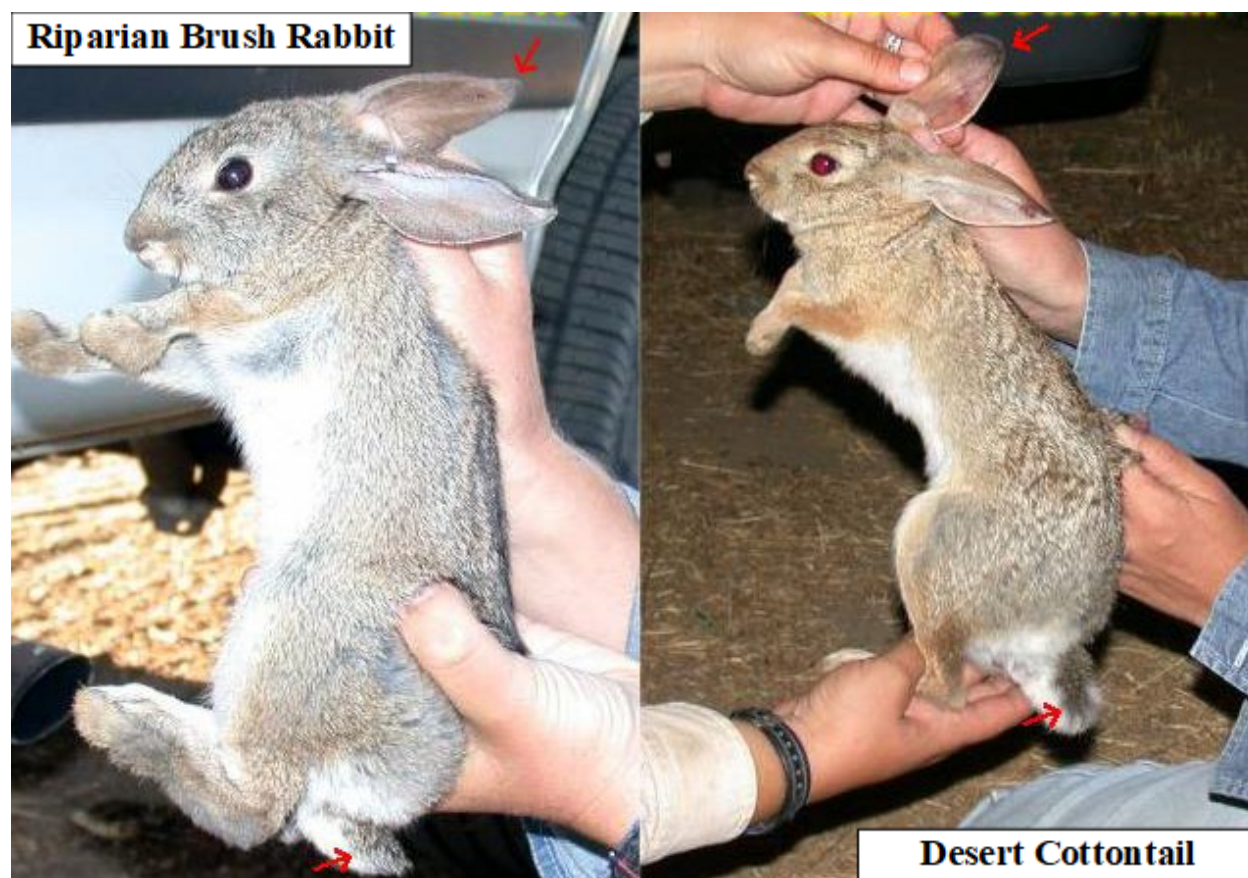


Figure 2. Photographic comparison of riparian brush rabbit (left) and desert cottontail (right) (courtesy of Laurissa Hamilton). Riparian brush rabbits are slightly smaller and have proportionally smaller tails than desert cottontails. Desert cottontails also have black on the tips of their ears.

The riparian brush rabbit is difficult to distinguish both from other brush rabbit subspecies and from the co-occurring desert cottontail (*S. audubonii*). Distinguishing riparian brush rabbit from other brush rabbit subspecies is rarely necessary because its range does not overlap with those of other subspecies. The closest neighboring subspecies of brush rabbit is found in chaparral ecosystems either in the Diablo mountain range (*S. bachmani macrorhinus*) to the west of the riparian valley inhabited by riparian brush rabbit, or in the Sierra foothills (*S. b. mariposae*) to the east. With training and experience, riparian brush rabbits may be distinguished from desert cottontail by visual observation alone (Figure 2).

2.2 Historical distribution

The historical distribution of the riparian brush rabbit is unknown because the subspecies was described after most of its habitat was converted to other land uses. In the 1940 description of the subspecies, Orr wrote that riparian brush rabbits probably inhabited river bottom areas of the San Joaquin River from the delta region to “some distance” south of where specimens were collected (i.e. approximately two miles northeast of Vernalis, California) (1940, p. 159). By that time, the riparian landscape in California’s Central Valley had largely been converted to agriculture or urban areas (California Department of Fish and Game 2009, aerial imagery from 1937). Thus, the subspecies had probably been extirpated from most of its range before it was first documented. Williams & Basey (1986, p. i) suggested that the riparian brush rabbit historically inhabited riparian communities and floodplains of the Merced, Stanislaus, Tuolumne, and San Joaquin rivers in the counties of Merced, Stanislaus, and San Joaquin. Larsen (1993, figure 1, p. 10) presented a possible historical distribution that extended along the San Joaquin River from the southern border of Stanislaus County to the confluence with the Mokelumne River in Contra Costa and Sacramento counties.

Our estimate of the historical (pre-1900) distribution of the riparian brush rabbit is in Figure 3. With ArcGIS Pro¹ software (Esri 2018), we used pre-1900 land cover data from the Central Valley Historic Mapping Project to isolate areas with historical vegetation characterized as “riparian” or “other floodplain habitat” (California State University Chico 2003, spatial dataset). We then excluded areas that were outside of the San Joaquin Basin Hydrological Unit (U.S. Geological Survey 2016, spatial dataset) and the Central California Valley Ecoregion (U.S. Environmental Protection Agency 2013, spatial dataset). Finally, we excluded outlying patches that were smaller than 12 hectares² (30 acres) and created a *Smooth Polygon* [ArcGIS tool, used with Bezier interpolation (Esri 2018)] that encompassed the isolated historical vegetation areas (Figure 3).

2.3 Current distribution

The current distribution of the riparian brush rabbit is limited to southern San Joaquin County and northern Stanislaus County. The subspecies resides in brushy vegetation associated with riparian areas along the Old, Stanislaus, Tuolumne, and San Joaquin rivers. The current

¹ For all ArcGIS analyses, this SSA used ArcGIS Pro, version 2.3.3, and the NAD 1983 California Teale Albers project coordinate system. (Esri 2018)

² Twelve hectares is the approximate size of the smallest isolated area that is currently known to be occupied by riparian brush rabbits.

distribution also includes brushy vegetation along Paradise Cut, Tom Paine Slough, and a small section of the Union Pacific Railroad right-of-way (Figure 3).

In addition to the aforementioned surveyed areas, two rabbit carcasses were collected along the Middle River (just north of the current range depicted in Figure 3) during March of 2017. On October 16, 2019, the Service received genetic confirmation that the carcasses were riparian brush rabbits (Matocq 2019, *in litt.*). This new information indicates that there may be additional, undocumented occurrences of riparian brush rabbit in San Joaquin County. However, there is no additional information on the historical or current status of riparian brush rabbit presence in this area or on the genetic-relatedness of the carcasses to nearby populations. It is currently unknown whether the area along the Middle River supported or supports a breeding riparian brush rabbit population or if the carcasses were incidental observations of dispersing rabbits.

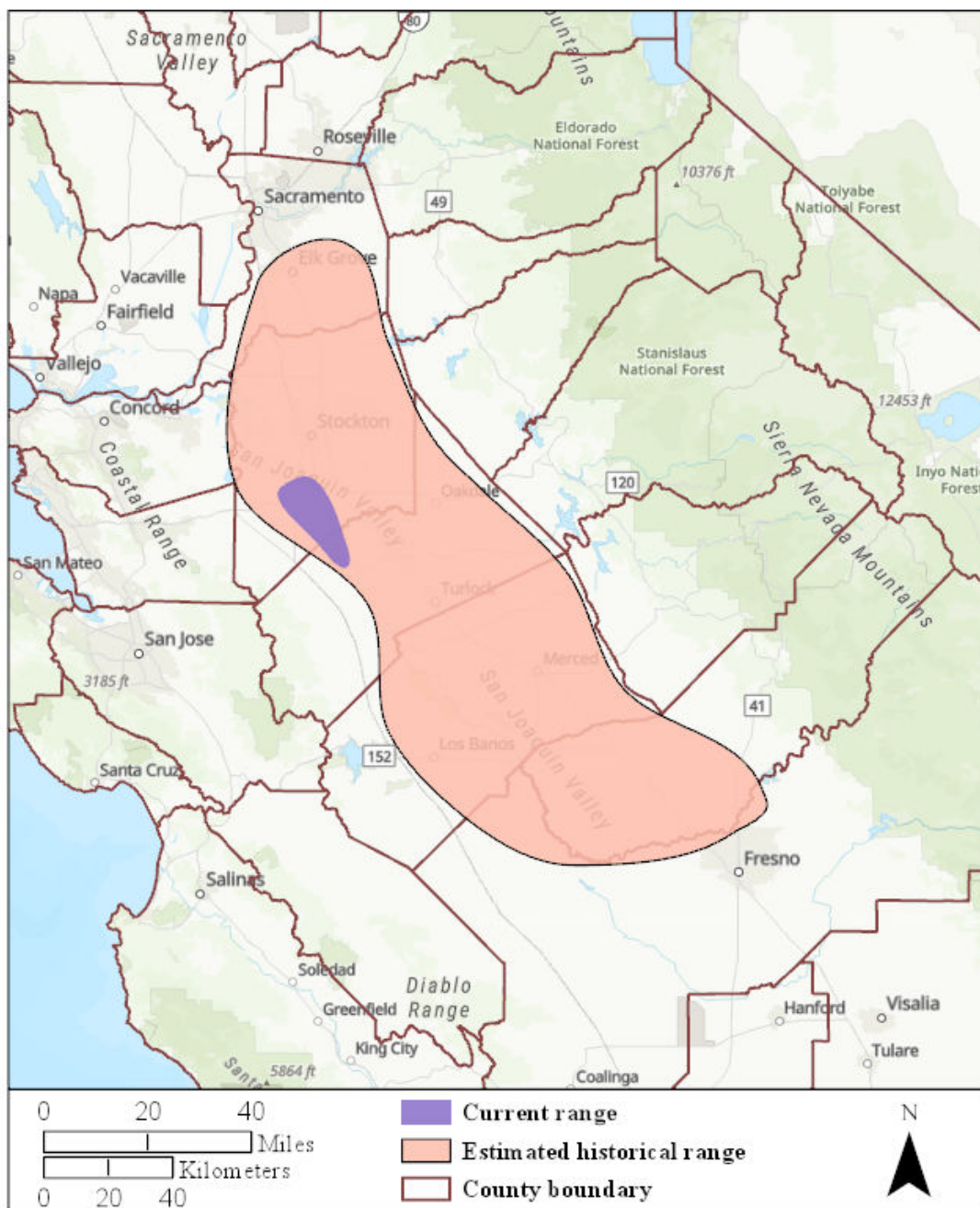


Figure 3. Riparian brush rabbit estimated historical and current range. The estimated historical range is a coarse representation of a potential historical distribution based on pre-1900 land cover (California State University Chico 2003, spatial dataset). The current range is based on occurrence point data that were aggregated into a polygon and smoothed with Bezier interpolation [Smooth Polygon ArcGIS tool (Esri 2018)].

2.4 Taxonomy

The brush rabbit species was first described as *Lepus bachmani* by Waterhouse in 1838, but currently goes by the taxonomic name, *Sylvilagus bachmani*, which was first used by Lyon in

1904 (Chapman 1974, p. 1). The subspecies, riparian brush rabbit (*S. b. riparius*), is recognized as one of 13 [or perhaps 14 (Álvarez-Castañeda & Lorenzo 2016)] subspecies of brush rabbit (*S. bachmani*) (Kelly *et al.* 2019, p. 1). The subspecies was first described by Robert T. Orr in 1935 upon examination of five specimens (Orr 1935, p. 30). The type specimen, from which the description was made, was collected from the west side of the San Joaquin River approximately 3 kilometers (2 miles) northeast of Vernalis, Stanislaus County, California (Orr 1935, p. 29). While there is substantial genetic differentiation between the two remaining natural populations (i.e. Caswell and South Delta) (Constable *et al.* 2011, pp. 16, 24; Matocq *et al.* 2017, p. 22), the taxonomic status of this subspecies is accepted by researchers.

2.5 Habitat

The riparian brush rabbit inhabits riparian vegetation communities that contain large patches of dense, brushy understory that are proximate to open areas dominated by grasses and herbs. Riparian brush rabbit habitat may or may not have a tree overstory; but if present, the tree canopy is open (Kelly *et al.* 2011, p. 4). While the riparian brush rabbit occupies old-growth riparian forest in a portion of its range, it prefers early-successional vegetation systems. Habitat preferences for home ranges in the San Joaquin National Wildlife Refuge (henceforth, Refuge) population were areas dominated by willows (*Salix* spp.) and dense shrubs, followed by open grassland (open spaces at the base of tall grassy vegetation) and dense riparian (closed canopy and very dense understory). Least preferred in home ranges were oak woodlands, dense grasslands (matted vegetation without open spaces for traveling through vegetation), and wetlands (Kelt *et al.* 2014, pp. 519-520). The plant species that are most commonly associated with riparian brush rabbit habitat include California blackberry (*Rubus ursinus*), wild rose (*Rosa californica*), and sandbar willow (*Salix exigua*) (Phillips *et al.* 2005, p. 17; Kelly *et al.* 2011, pp. 1, 4; Kelt *et al.* 2014, p. 519). Other brushy species that are common in riparian brush rabbit habitat include wild grape (*Vitis* spp.), coyote brush (*Baccharis pilularis*), golden currant (*Ribes aureum*), box elder (*Acer negundo*), and elderberry (*Sambucus* spp.) (Williams 1988, p. 15; Kelly *et al.* 2011, p. 3; Kelly 2018b, p. 210). In the open grasslands frequented by rabbits on the Refuge, dominant vegetation included nonnative perennial pepperweed (*Lepidium latifolium*), Johnson grass (*Sorghum halepense*), mugwort (*Artemisia* spp.), evening primrose (*Oenothera elata*), and Great Valley gumweed (*Grindelia camporum*) (Kelt *et al.* 2014, p. 519). More information about specific riparian brush rabbit habitat requirements is presented in CHAPTER 3.

2.6 Life cycle

For the purpose of this SSA, we refer to three life stages for the brush rabbit life cycle, neonate, juvenile, and adult (Figure 4). A brush rabbit neonate is a newborn rabbit that has not yet left its nest and relies entirely upon the milk of its mother. We define a juvenile to be a young rabbit that has left the nest but has not yet achieved adult size (< 500 grams) or reproductive maturity. Rabbits are considered adults when they are ≥ 500 grams and are reproductively mature (Williams *et al.* 2008, p. 353). There are no known cases of riparian brush rabbits achieving sexual maturity while weighing less than 500 grams.

The riparian brush rabbit life cycle is short and the entire cycle, including breeding, can be completed in less than one year (Figure 4).

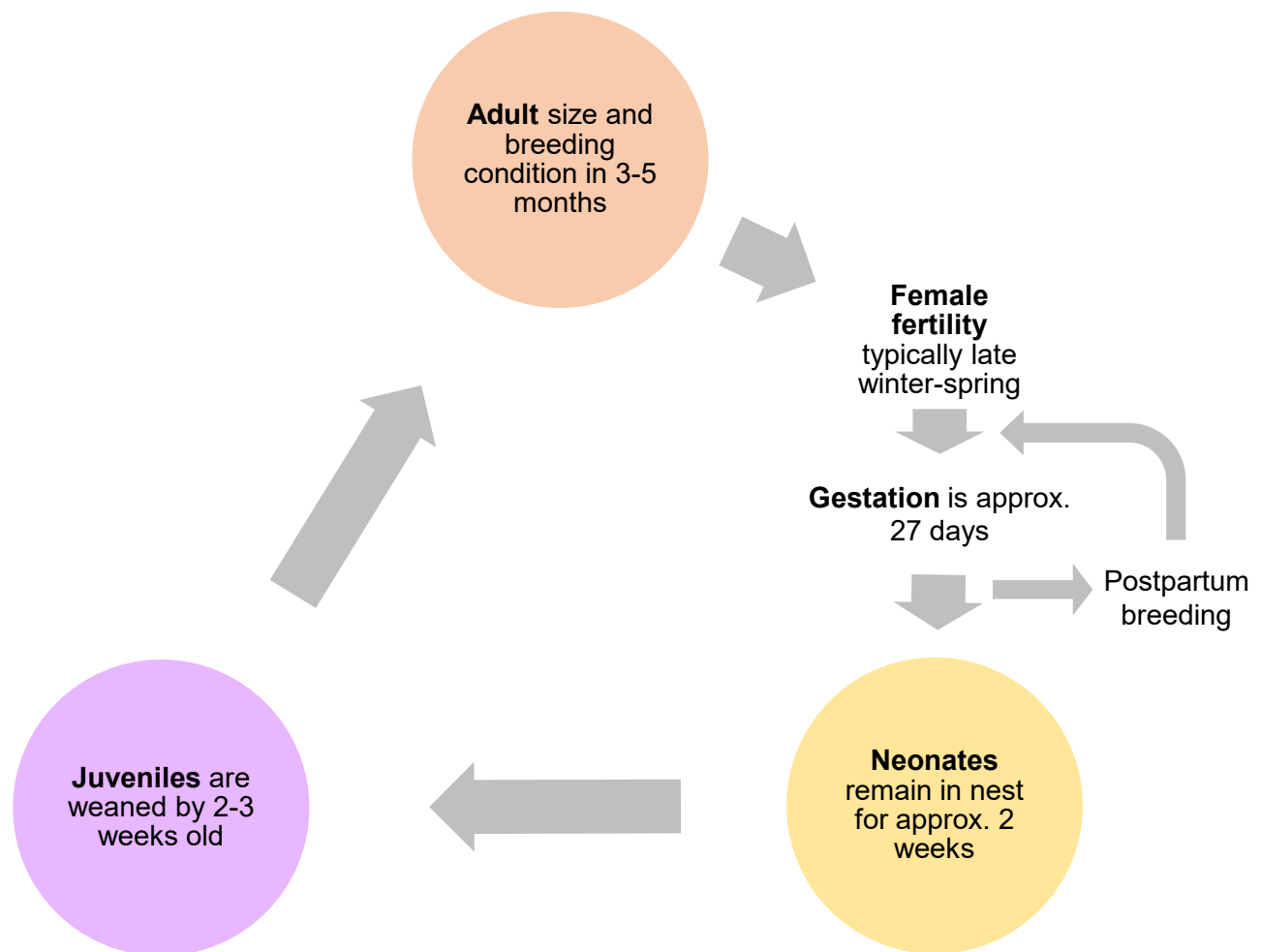


Figure 4. Wild brush rabbit life cycle conceptual diagram.

2.7 Breeding

Mating System

Riparian brush rabbits in captive breeding pens, and presumably in the wild, exhibit a polygynous mating system, with one male dominating the mating of several females. However, dominant males did not prevent non-dominant males from breeding, and some litters were fathered by multiple males (Williams *et al.* 2008, p. 359).

Seasonal cycle

Onset and duration of brush rabbit breeding varies from year to year. Variation may be associated with rain, forage availability, weather events, and/or temperature (reviewed in

Chapman & Litvaitis 2003, p. 109). The typical period of female fertility for wild riparian brush rabbits is from January to May (Basey 1990, pp. 18-19), which is consistent with observations of other brush rabbit subspecies in California (Orr 1940, p. 185; Mossman 1955, p. 183). However, camera traps documented breeding activity of wild riparian brush rabbits into early August of 2017 (a year with a major flooding event) (Tarcha 2019, *in litt.*). In addition, signs of breeding were observed almost year round in the captive breeding pens (Williams *et al.* 2008, p. 358) (Table 1).

Irregularity in the mammalian breeding season based on environmental factors is well-supported (Conaway 1971, pp. 244-245). For small mammals with short gestation periods, Conaway (1971) suggests that there are one or more environmental factors that depress reproduction, such as photoperiod or quality of nutrition, in the absence of which, breeding would likely occur year-round. Thus, brush rabbits are probably capable of year-round breeding, but environmental conditions confine their breeding activity to a particular time of year, which also varies with interannual environmental conditions. Such conditional fluctuations in breeding cycle are adaptive, and those fluctuations likely extend to other breeding characteristics, such as litter size, number of litters, and age at sexual maturity (Conaway 1971). However, as Conaway (1971, p. 246) points out, these are speculations and could be inaccurate.

Gestation is approximately 27 days (Mossman 1955, p. 183) and female brush rabbits have been observed carrying 2 to 6 embryos with an average of 3.5 to 4 embryos (Orr 1940, p. 186; Mossman 1955, p. 183). Like other cottontail (*Sylvilagus*) species, female brush rabbits are able to conceive immediately postpartum (Chapman & Harman 1972, p. 821). However, available trapping data have not provided evidence of postpartum breeding in populations of riparian brush rabbit. Trapping data suggest that, typically, female riparian brush rabbits are reproductively inactive for portions of the breeding season (Basey 1990, p. 20; Wittmer *et al.* 2016, p. 343).

Table 1. Brush rabbit life stage table. RBR - riparian brush rabbit, BR - brush rabbit species.

Life Stage	Population	J a n	F e b	M a r	A p r	M a y	J u n	J u l	A u g	S e p	O c t	N o v	D e c	Source(s)
Female receptivity	Wild RBR													(Dark green: Basey 1990, pp. 18-19; light green: Tarcha 2019, <i>in litt.</i>)
	Captive RBR													(Williams <i>et al.</i> 2008, p. 355)
Gestation/ birthing	Wild RBR													(Basey 1990, pp. 18-19)
	Captive RBR													(Williams <i>et al.</i> 2008, p. 355)
Lactation	Wild RBR													(Basey 1990, pp. 18-19)
	Captive RBR													(Williams <i>et al.</i> 2008, p. 355)
Juveniles	Wild RBR													Inferred
	Captive RBR													Inferred
Peak of breeding	Wild RBR													(Basey 1990, p. 18)
	Bay area BR													(Mossman 1955, p. 183)
	Oregon BR													(Chapman & Harman 1972, p. 818)
	California BR (general)													(Orr 1940, p. 185)

Nesting and rearing young

Brush rabbits use nests for birthing and raising neonates for approximately two weeks after birth (Orr 1942, p. 302). Riparian brush rabbit nests are rarely observed because nests are typically hidden within large clumps of dense, and often thorny, vegetation (Williams *et al.* 2008, p. 358). Based on the nests of other brush rabbit subspecies, we assume that within the cover of dense brush, riparian brush rabbits build nests with dried grass and rabbit fur in shallow depressions (Orr 1940, p. 187; Orr 1942, pp. 298-299). Riparian brush rabbits have been documented carrying bundles of grass during the breeding season (Tarcha 2019, *in litt.*).

Brush rabbit neonates typically leave the nest at approximately two weeks of age (Orr 1942, p. 302). In a captive breeding pen, a neonate riparian brush rabbit was captured outside of the nest at an estimated ten days of age. However, the age of the young rabbit was estimated with a linear growth model that could have underestimated the age (Williams *et al.* 2008, p. 359). Based on other cottontail species, weaning is assumed complete at 2 to 3 weeks of age (Mossman 1955, p. 179).

In the captive breeding pens, juvenile riparian brush rabbits reached adult size (≥ 500 grams) in approximately 77 to 84 days after birth (Williams *et al.* 2008, p. 359). It is currently unknown if wild riparian brush rabbits also grow at such a rapid rate. Breeding during the same breeding season of birth has not been documented in wild brush rabbit populations. However, female riparian brush rabbits in the captive breeding pens began giving birth at approximately four months of age (Wittmer *et al.* 2016, p. 338). Breeding during the first year after birth is well documented in the eastern cottontail (*Sylvilagus floridanus*) and has been observed in several other cottontail species, including the co-occurring desert cottontail (*S. audubonii*) (reviewed in Chapman & Litvaitis 2003, p. 111).

Female reproductive rates

Prior to the captive breeding program, it was assumed that riparian brush rabbit females had reproductive rates similar to those of other brush rabbit subspecies. Based on the reproductive biology of brush rabbits (i.e. average litter size and postpartum breeding) and a breeding season length of 140 days, Basey (1990, pp. 18, 20) estimated that riparian brush rabbit females produced up to 15 to 20 young per breeding season (5 litters with 3 to 4 young per litter). However, trapping data did not support that female riparian brush rabbits produce successive litters throughout the duration of the breeding season (Basey 1990, p. 20). Thus, Basey (1990, p. 21) suggested a more conservative estimate of 9 to 16 young per female per season (3 to 4 litters with 3 to 4 young per litter). Neither estimate considers non-breeding females, nor females that start breeding during the season of their birth.

The percentage of riparian brush rabbit females reproductively active in each breeding season is not well studied. However, results from trapping females repeatedly throughout a breeding season suggests that wild adult females probably breed during every breeding season but do not remain in breeding status (i.e. estrous, pregnant, lactating) for the entirety of the breeding season (Basey 1990, appendix 1, pp. 58-67). Among the radio-collared females introduced on the Refuge, an estimated 46% were breeding post-release (estimate adjusted for a 30-day period) (Wittmer *et al.* 2016, p. 337). The estimated proportion of adult females breeding within the

captive breeding pens was 89% for a 30-day period (Wittmer *et al.* 2016, p. 343). There are several uncertainties associated with these breeding estimates for captive and wild riparian brush rabbit females. Besides imperfect and incomplete data, the conditions in both populations were unique. In the captive breeding pens, rabbits had protection from predators, ample food, and some veterinary care, but they were also being trapped and examined every two weeks (Wittmer *et al.* 2016, pp. 337, 343). The proportions of wild females breeding may have been affected by the conditions associated with captive-bred introduction. The females studied at the Refuge were captive-bred radio-collared animals that were recently released into, sometimes unoccupied, novel environments.

Riparian brush rabbit females in the captive breeding program had lower reproductive rates than anticipated, in spite of the favorable conditions afforded to the captive rabbit population (i.e. abundant food, shelter, and protection from predation). While the breeding season started earlier and ended later than had been observed in the wild, there was no evidence of females producing more than four litters per season (Williams *et al.* 2008, pp. 354, 358). Between 2002 and 2006, 40 of 45 (89%) female breeders (adults trapped from the South Delta population) were known to have produced young in the captive breeding pens (Williams *et al.* 2007, p. 17). During the same 5-year period, Williams *et al.* (2007, p. 17) conservatively estimated that there were 243 pregnancies among 138 females, producing 639 young that survived to be trapped and marked in the breeding pens. Assuming the numbers of observed pregnancies were approximately equivalent to the numbers of litters, the mean number of young (surviving beyond the first few weeks after birth) per litter was 2.6, the mean number of litters/female/year was 1.7, and the mean number of young/female/year was 4.6 (Table 2). However, these annual rates are biased low, largely because they include females that were born and matured during the same breeding season. Young breeders made a significant contribution to the captive population's productivity (Williams *et al.* 2008, p. 358), but these females were not reproductively active for the entire breeding season. Williams *et al.* (2008, pp. 358-359) measured captive riparian brush rabbit recruitment to trappable age (average age at first capture was 40 days) at 5.3 young per breeding female per season for 2002-2003 in the captive breeding pens. The recruitment rate of 5.3 offspring/female/season probably includes only females that were adults at the start of the breeding season, but this is not explicit in the text. The greatest number of offspring reported to have been produced (raised to a trappable age) by a single rabbit during one breeding season was 13 for a male breeder and 11 for a female breeder (Williams *et al.* 2008, pp. 355-356).³ The numbers of offspring produced by the other breeders (adults trapped from the South Delta population) within the same enclosure were much lower (i.e. 2 to 6 offspring estimated for each of the other two breeding males and 4 to 6 offspring for each of the other two breeding females).

³ Totals were reported by (D. Williams *et al.* 2008, pp. 355-356) based on genotyping of the trapped offspring of riparian brush rabbit breeders (adults trapped from the South Delta population) in the captive breeding pens during 2002 and 2003. Both maximums were from 2003.

Table 2. Female riparian brush rabbit annual reproductive rates in the captive breeding pens, 2002-2006. Numbers of reproductive females, pregnancies, and young produced are from Williams *et al.* (2007, table 4, p. 17).

Year	Number of reproductive females	Number of pregnancies	Number of young produced	Mean young per pregnancy	Mean pregnancies per reproductive female	Mean young per reproductive female per year
2002	15	22	62	2.8	1.5	4.1
2003	53	97	268	2.8	1.8	5.1
2004	11	22	53	2.4	2.0	4.8
2005	28	44	143	3.3	1.6	5.1
2006	31	58	113	1.9	1.9	3.6
Average	28	49	128	2.6	1.7	4.6

2.8 Survival and mortality

Much like other cottontail (*Sylvilagus*) species, the riparian brush rabbit has low survival rates, primarily because of predation mortality (Chapman & Litvaitis 2003, p. 118; Kelly *et al.* 2014, p. 5). The most intensive study of riparian brush rabbit survival and mortality was conducted primarily on radio-collared rabbits that were reared in the captive breeding pens and released onto the Refuge as adults between 2002 and 2005. For captive-bred, released rabbits during 2002-2005, causes of mortality were unknown for the majority of deaths (61.9%), but predation (including presumptive predation) was the greatest known cause of mortality (26.4%) (Hamilton *et al.* 2010, p. 999). Many of the unknown mortalities were also likely from predation.

Captive-bred, released riparian brush rabbits (number of rabbits = 323; years 2002 through 2005) survived for an average of 164 days (Hamilton *et al.* 2010, p. 1002). Post-release survival estimates were significantly lower for the first four weeks after release (71%) than for the subsequent eight weeks (89%) (Hamilton *et al.* 2010, pp. 1002-1003). If excluding the lower survival rate of the first four weeks after release, annual survival rate would be approximately 22%. Survival was positively correlated with body mass (p. 1005) and was affected by the 2005 flood event (p. 1004). The 2005 flooding event at the Refuge reduced survival by approximately 30% during March (Wittmer *et al.* 2016, p. 338). Model results did not support a temporal variation in riparian brush rabbit survival, based either on calendar months or on rainy versus dry seasons (Hamilton *et al.* 2010, p. 1002).

There is evidence that suggests wild-born riparian brush rabbits have higher survival rates than captive-bred, released riparian brush rabbits. During the 2002-2005 survival study, 22 wild-born rabbits at the Refuge were also radio-collared and monitored for survival. The 22 wild-born rabbits survived for an average of 327 days, whereas the translocated rabbits survived for an average of only 164 days (Hamilton *et al.* 2010, p. 1002). Although limited by the low sample size of wild-born rabbits (number of rabbits = 22), the large difference in survival suggests a

large difference in survival rates between wild-born riparian brush rabbits and rabbits translocated into novel environments.

There are limited data on maximum ages of riparian brush rabbits. In captivity, two female riparian brush rabbits lived upwards of six and seven years (Kelly *et al.* 2014, p. 3). Although the large majority of captive-bred released rabbits do not survive their first year (Hamilton *et al.* 2010, pp. 1002-1003), released rabbits can survive for three or more years in the wild (Kelly & Holt 2011, p. 3).

There are no data on neonate or juvenile riparian brush rabbit survival in the wild. Young born in the captive breeding pens during 2002 and 2003 had 79% survival over 298 days or 86% survival over 450 days, respectively (Williams *et al.* 2008, p. 356).

2.9 Home Range

There are limited data on riparian brush rabbit home ranges (i.e. spatial areas used by individuals to fulfill the functions of sheltering, feeding, and reproduction). Brush rabbit home ranges typically are conformed to the size and shape of dense vegetation patches and are generally smaller than home ranges of other cottontail species (Chapman 1971, p. 689; Chapman 1974, p. 2). Of the two studies of riparian brush rabbit home ranges, both observed home range overlap among individual rabbits (Basey 1990, p. 21; Kelt *et al.* 2014, p. 520).

The first of two riparian brush rabbit home range studies occurred in Caswell and was limited by both sample size (six females and three males) and by methodology (baited trapping grid). Home range estimates were very small and females home ranges [0.02 hectare (0.06 acre)] were smaller than male home ranges [0.10 hectare (0.24 acre)] (Basey 1990, p. 21). The smallest home range estimate was 84 square meters (100 square yards; female captured 12 times over a 328-day period) and the largest was 1,781 square meters (2,130 square yards; male captured 13 times over a 68-day period) (Basey 1990, p. 21). A brush rabbit study in Oregon (*Sylvilagus bachmani ubericolor*) also noted that male home ranges were larger than female home ranges (Chapman 1971, p. 689).

The second home range study was conducted using radiotelemetry of 312 riparian brush rabbits that were introduced into restored habitat at the Refuge (Kelt *et al.* 2014, p. 516). Riparian brush rabbit home ranges at the Refuge were much larger than those measured at Caswell. Home ranges were also larger during the breeding season [1.97 hectares (4.87 acres)] than the nonbreeding season [1.60 hectares (3.95 acres)] (Kelt *et al.* 2014, p. 519). In further contrast to the Caswell study, there was no difference in home range size between males and females; and there was considerable overlap (typically, > 85%) in home range areas that was unrelated to sex (Kelt *et al.* 2014, pp. 519-520). While this study was limited neither by sample size, nor by methodology, the results may have been affected by habitat type and factors associated with release of captive-bred rabbits into novel, unoccupied habitat. As noted by the authors, the introduced rabbits dispersed more widely than expected (Kelt *et al.* 2014, p. 518).

CHAPTER 3 INDIVIDUAL NEEDS

We assessed the best available information to identify the physical and biological resource needs to support individual fitness (i.e. survival and ability to produce viable offspring) at all riparian

brush rabbit life stages – neonate, juvenile, and adult. For the purpose of this SSA, the needs that are considered most critical include dense, brushy vegetation; grasses and herbs; ecotonal edges; diversity of plants for food and shelter during the dry season; accessible flood refugia; nest sites and nesting materials; scaffolding shrubs and trees; and connectivity around open areas. These resource needs are summarized by resource function and riparian brush rabbit life stage in Table 3.

Table 3. Riparian brush rabbit individual resource needs and resource function by rabbit life stage.

Individual Resource Need	Resource Function for Neonates	Resource Function for Juveniles	Resource Function for Adults
Dense, brushy vegetation	Sheltering (nest placement)	Sheltering	Sheltering, Reproduction (nest placement)
Grasses and herbs – abundant wet-season forage	Feeding (via lactation), Sheltering (nest material)	Feeding	Feeding, Reproduction
Ecotonal edges – clearings with grasses and herbs along brush thickets	-	Feeding, Sheltering	Feeding, Sheltering
Diversity of plants for needs during the dry season	-	Feeding, Sheltering	Feeding, Sheltering
Accessible flood refugia that provide adequate food and shelter	-	Feeding, Sheltering	Feeding, Sheltering
Nest sites and nesting materials	Sheltering	-	Reproduction
Scaffolding shrubs and trees or structure	-	Feeding, Sheltering	Feeding, Sheltering
Connectivity around open areas	-	Dispersal/ Migration	Dispersal/ Migration, Reproduction

3.1 Dense, brushy vegetation

Thickets of dense, brushy vegetation are critical for the sheltering needs of all brush rabbit subspecies (Orr 1940, p. 169). Unlike some other species of rabbits, brush rabbits do not dig underground burrows for sheltering or nesting. Instead, brush rabbits create and inhabit networks of corridors through dense vegetation (Orr 1940, p. 173). The same dense vegetation that brush rabbits use for sheltering is also used for riparian brush rabbit nesting. Brush rabbits use nests for birthing and raising neonates for approximately two weeks after birth (Orr 1942, p. 302). Thus, all three riparian brush rabbit life stages depend on dense, brushy vegetation for sheltering from predation and exposure to the elements. Adults also need dense vegetation for successful reproduction; vegetation thickets conceal and protect nests from predators and provide safe places to tend to young.

The riparian brush rabbit inhabits vegetation thickets that are composed of a variety of shrubs and early-successional tree species, including nonnative species (Kelly *et al.* 2011, p. 3). To meet riparian brush rabbit needs, the vegetation type and structure must be adequate to protect rabbits from predation and exposure to the elements throughout both the wet and dry seasons. The brushy plants that are most commonly associated with riparian brush rabbit occupancy include blackberry (*Rubus* spp.), wild rose (*Rosa* spp.), and willow (*Salix* spp.) (Phillips *et al.* 2005, p. 17; Kelly *et al.* 2011, pp. 1, 4). Other brushy species that are common in riparian brush rabbit habitat include wild grape, coyote brush (*Baccharis pilularis*), golden currant (*Ribes aureum*), box elder, elderberry (Williams 1988, p. 15; Kelly *et al.* 2011, p. 3; Kelly 2018b, p. 210). Some older studies that took place at Caswell suggested that willow thickets were not favored by riparian brush rabbit (Williams & Basey 1986, p. i; Basey 1990, p. 34); however, subsequent observations have shown that this assumption was inaccurate (Williams *et al.* 2002, p. 6).

The minimum size of brushy vegetation patches required to fulfill riparian brush rabbit needs is unknown. However, we may infer that at least some patches of brush should be approximately 0.05 hectare (0.12 acre) or larger. A radiotelemetry study of brush rabbits in Oregon (*S. b. ubericolor*) concluded that the rabbits selected habitat with brush thickets that were equal to or larger than approximately 5000 square feet (0.11 acre, 0.05 hectare). The Oregon brush rabbits used smaller thicket patches only if in proximity to larger patches (Chapman 1971, p. 689).

3.2 Grasses and herbs

Juvenile and adult riparian brush rabbits feed on a variety of plants, but annual grasses and herbaceous plants are preferred when available (Orr 1940, p. 183; Basey 1990, p. 30). Riparian brush rabbits are known to use areas and/or feed upon native and nonnative grasses and herbs including creeping wild rye (*Leymus triticoides*), peppergrass (*Lepidium* spp.; nonnative), mugwort (*Artemisia douglasiana*), Santa Barbara sedge (*Carex barbarae*), stinging nettle (*Urtica dioica*), and gumplant (*Grindelia camporum*) (Williams *et al.* 2002, pp. 3, 5; Kelly *et al.* 2011, p. 3).

Grasses and herbs become abundantly available during the wet growing season (typically mid-winter to spring), which coincides with the peak of the riparian brush rabbit breeding season (Table 1). The juvenile life stage benefits from the seasonal abundance of grasses and herbs because juveniles require abundant food resources to support their rapid growth rate.

Furthermore, juveniles would have much lower survival rates without abundant food because they would be at a disadvantage if forced to compete for those resources.

Grasses and herbs also appear to be needed for adult riparian brush rabbit reproduction because they supply both abundant food resources⁴ and nesting material. Adult female rabbits require this seasonal food abundance to support the additional energy requirements associated with reproduction (e.g. embryo development and lactation). Adult males might also require this food resource to support the extra energy requirements associated with breeding behaviors (e.g. mate searching, mate defense).

The neonate life stage requires grasses and herbs as a food resource indirectly. Neonates survive and enter the subsequent life stage by feeding from a lactating female, which assumedly maintains milk production with these seasonally abundant food resources. Neonates also use grasses for sheltering because grasses are used as nesting materials (Orr 1940, p. 187; Orr 1942, pp. 298-299; Tarcha 2019, *in litt.*).

Patches of tall grasses and herbs are also used as temporary cover (for sheltering) while riparian brush rabbits forage and travel across the landscape (including migration and dispersal, but also short-distance movement within individual home ranges) (Williams *et al.* 2002, p. 5; Kelly *et al.* 2011, p. 3). While riparian brush rabbit adults and juveniles require grasses and herbs for feeding, we have not concluded that grasses and herbs are a critical need for sheltering because dense, brushy vegetation is more effective for sheltering needs.

3.3 Ecotonal edges

As described above, the riparian brush rabbit requires both dense brush as well as grasses and herbs. Grasses and herbs, however, do not grow abundantly within dense, brushy vegetation; these plants grow best in clearings where the ground is exposed to sunlight (minimal brush cover and an open tree canopy). Because brush rabbits rarely venture far from the protection of brushy cover, they favor areas where clumps or strips of dense, brushy vegetation are bordered by patches of grasses and herbs (Orr 1940, pp. 175, 182). A feature where two different classes of vegetation border each other is considered an ecotonal edge, which is a typical component of early-successional vegetation systems that are maintained by regular disturbances, such as fire or floods. Observations of riparian brush rabbits usually occur in these ecotonal edges between brushy cover and clearings with abundant grasses and herbs (Kelly *et al.* 2011, pp. 3-4).

Ecotonal edges are considered a feeding and sheltering need for the juvenile and adult life stages of riparian brush rabbits because the proximity of food patches to sheltering patches allows the rabbits to forage while remaining close to protective cover. If the rabbits were to travel across extensive open areas to forage for food, they would not be able to escape to safety if threatened with predation. While the resources that make up these ecotonal edges (i.e. dense, brushy

⁴ We assume that the abundance of these preferred food resources during the wet season plays a role in breeding onset, duration, and/or success. This assumption is based on the ecological principle of an interrelationship between annual resource availability and breeding cycle (i.e. a predictable pattern of a wet, growing season, leading to resource abundance that coincides with wildlife breeding seasons).

vegetation and grasses and herbs) are also considered needs for the neonate life stage, we do not consider the spatial configuration of these resources to be a need for neonates.

3.4 Diversity of plants for dry season needs

The general climate pattern within the range of the riparian brush rabbit can be characterized as an annual cycle of a wet season (generally associated with mid-winter and spring) followed by a dry season (generally associated with summer, autumn, and early winter). While grasses and herbs are the preferred food resource of the riparian brush rabbit (Orr 1940, p. 183; Basey 1990, p. 30), these plants do not provide adequate forage during the dry season. The dry season is typically a period during which feeding and sheltering resources are scarce. Thus, riparian brush rabbits, as food generalists, rely on a variety of woody species for feeding throughout much of the year (Kelly 2018a, p. 124). Riparian brush rabbits have been observed eating a variety of plant material from woody species including, wild rose, blackberry, elderberry, wild grape, and dried oak leaves. Rabbits access taller vegetation by standing on their hind legs or climbing, especially for fresh shoots of wild rose and blackberry (Basey 1990, p. 30). Plant species that survive prolonged dry periods are also extremely important for riparian brush rabbit feeding and sheltering during multi-year droughts. Because the neonate life stage generally coincides with the wet season, we consider this dry-season resource to be a need only for the juvenile and adult life stages.

3.5 Flood refugia

Flood refugia that are above, or are protected from, high flood waters are a critical need for many juvenile and adult riparian brush rabbits (Kelly *et al.* 2011, p. 4). Flood refugia can take different forms but they need to be easily accessible from regularly occupied habitat while floodwaters are rising and contain adequate feeding and sheltering resources for dense populations of rabbits. The feeding and sheltering resources needed on the flood refugia are synonymous to the aforementioned individual needs (i.e. dense, brushy vegetation; grasses and herbs; ecotonal edges; and diversity of plants for food and shelter during the dry season). Dense cover and ecotonal edges are especially important on refugia because predation pressure typically increases as rabbits and predators are crowded (Figure 5) into small areas. Food resources must be adequate to support dense populations of herbivores for long periods (often months). Diversity of vegetation for dry-season forage is also important because flooding can begin at the end of the dry-season, before wet-season grasses and herbs become plentiful. Although some nesting occurs on flood refugia (Tarcha 2019, *in litt.*), the refugia are not considered a resource need for neonates because neonates would not be able to travel to and take refuge during flooding events.



Figure 5. Photo of riparian brush rabbits and desert cottontails on a vegetated levee (flood refugium) at the San Joaquin River National Wildlife Refuge during the 2017 flood event. Photo credit: U.S. Fish and Wildlife Service.

3.6 Nest sites and nesting materials

Adult brush rabbits use nests for birthing and for raising neonates for approximately two weeks after birth (Orr 1942, p. 302). Although few riparian brush rabbit nests have been directly observed, we infer that this subspecies constructs nests with dried grass and rabbit fur under the cover of dense, brushy vegetation (Orr 1940, p. 187; Orr 1942, pp. 298-299; Williams *et al.* 2008, p. 358; Tarcha 2019, *in litt.*). Thus, adult riparian brush rabbits require nest sites in dense, brushy vegetation and require grasses as nesting materials (we assume that breeding adults already have fur) to fulfill their reproductive needs. Neonates require these resources for sheltering.

Nest sites and nesting materials are expected to be available where there is dense, brushy vegetation in proximity to grasses and herbs (ecotonal edges). Therefore, this need is accounted for by the above resource needs, and will not be carried forward for analysis.

3.7 Scaffolding shrubs and trees

Woody shrub and tree species with vertical structure appear to have considerable value in riparian brush rabbit habitat. The vertical structure of live or dead woody species, such as arroyo

willow (*Salix lasiolepis*) and coyote brush, provide a scaffold for blackberry and wild rose to climb and maintain some foliage above water during long-duration flood events. Maintaining some growth above water during flood events enhances survival and re-sprouting of blackberry and wild rose (River Partners 2008, pp. 19, 22; Kelly *et al.* 2011, pp. 3-4). Because scaffolding shrubs and trees enhance the survival of blackberry and wild rose, two species that are strongly associated with riparian brush rabbit sheltering and feeding, we consider this resource to be a need for all three life stages of rabbit.

3.8 Connectivity around open areas (small-scale)

Brush rabbits rarely cross even small clearings. They prefer to remain within approximately five meters (five yards) of cover and not venture farther than 13 meters (14 yards) from cover (Orr 1940, pp. 176, 182). Brush rabbits limit their short- and long-distance movements to routes with patches of dense, brushy vegetation, invariably choosing the shortest routes between patches (Chapman 1971, p. 694). Brush rabbits will also travel through tunnels within seasonably available tall grasses and herbs (Orr 1940, p. 174; Kelly *et al.* 2011, p. 3). Tall grasses and herbs do not provide as much cover from predators as dense brush but they do protect rabbits from complete exposure. Clearing areas of dense vegetation has caused riparian brush rabbits to cease use of such areas, and potentially resulted in habitat fragmentation (Williams 1988, p. 20).

While a single, large patch of dense brush, surrounded by grasses and herbs, could fulfill the feeding, sheltering, and nesting needs of individual riparian brush rabbits, an isolated patch of brush would not fulfill all of the individual needs of juvenile and adult rabbits. A connected network of brush patches (i.e. patches connected by corridors with continuous cover or with only short gaps between cover) is required for juveniles and adults to disperse (permanent relocation, typically long distance) and/or migrate (temporary or seasonal movement, typically a short distance in search of nearby resources). Migration is especially important when habitat is inundated with floodwaters. Connectivity among habitat patches is also required for reproduction because it provides access to mates.

In the past, it was suspected that waterways, in addition to open areas, were barriers to brush rabbit movement, but brush rabbits have dispersed across the Stanislaus and San Joaquin rivers (Kelly *et al.* 2014, p. 13; Bureau of Reclamation 2016, p. 12). Genetic research suggests that flowing rivers restrict, but do not block, gene flow (Constable *et al.* 2011, p. 24).

CHAPTER 4 POPULATION NEEDS

At the population level, we used the best available information to assess the resources, circumstances, and demographics that most influence the resiliency of riparian brush rabbit populations. Resiliency determines the ability of a population to withstand stochastic events. Stochastic events that may be experienced by riparian brush rabbit populations include, but are not limited to, floods, wildfires, droughts, and predation. The population needs being considered in this SSA are abundance, reproduction and recruitment, survival, distribution, and large-scale connectivity.

4.1 Population definition

For the purpose of this SSA, we defined riparian brush rabbit populations as spatially congruent groups of individuals (or groups of patches of individuals) that are distinct from each other because of genetic differentiation, spatial isolation, and/or separation by barrier(s) over which genetic exchange is infrequent. Biologically and spatially, the current riparian brush rabbit distribution is best divided into three populations, Caswell, South Delta, and the Refuge. However, for the purpose of this SSA, we split the South Delta group into two populations, the South Delta and the Oxbow Preserve (henceforth, Oxbow). Although the Oxbow population of riparian brush rabbits is within the range of and genetically similar to the South Delta population, Oxbow is best analyzed as its own population for the following four reasons. First, Oxbow has recently become genetically isolated from the rest of the South Delta because it is surrounded by development. Second, Bayesian genetic analyses distinguished Oxbow as a different genetic group from the remainder of the South Delta population (Matocq *et al.* 2017, p. 22). Third, the Oxbow population of riparian brush rabbit is protected and managed, unlike the rest of the South Delta population, which exists primarily on private land. Fourth, there is information about the Oxbow population history and status that is unique to this population and would not apply to the rest of the South Delta. For these reasons, it is best that Oxbow be considered separately from the South Delta, especially when the current and future conditions of populations are analyzed. Thus, the four riparian brush rabbit populations considered in this SSA are Caswell, South Delta, Oxbow, and the Refuge (Figure 6).

To be noted, the four population ranges depicted in Figure 6 encompass all of the non-historical, point occurrence data available except for the following two observations. In 2012, 1 to 2 riparian brush rabbits were observed along the San Joaquin River, 3 to 4 kilometers northwest of the Refuge population range (Kelly *et al.* 2014, pp. 14-15). In 2017, two riparian brush rabbit carcasses were collected along the Middle River, approximately 2.5 to 6.5 kilometers north of the South Delta population range (Emery 2019, pers. comm.). These observations were excluded from population analysis in this SSA because too little is known about these occurrences to add value to the assessment. At this time, it is unknown whether these observations are transitory occurrences, extensions of adjacent populations, subpopulations, or isolated populations. Furthermore, there is no information that would allow a reasonably confident assessment of past, current, or future condition of riparian brush rabbits at these two locations.

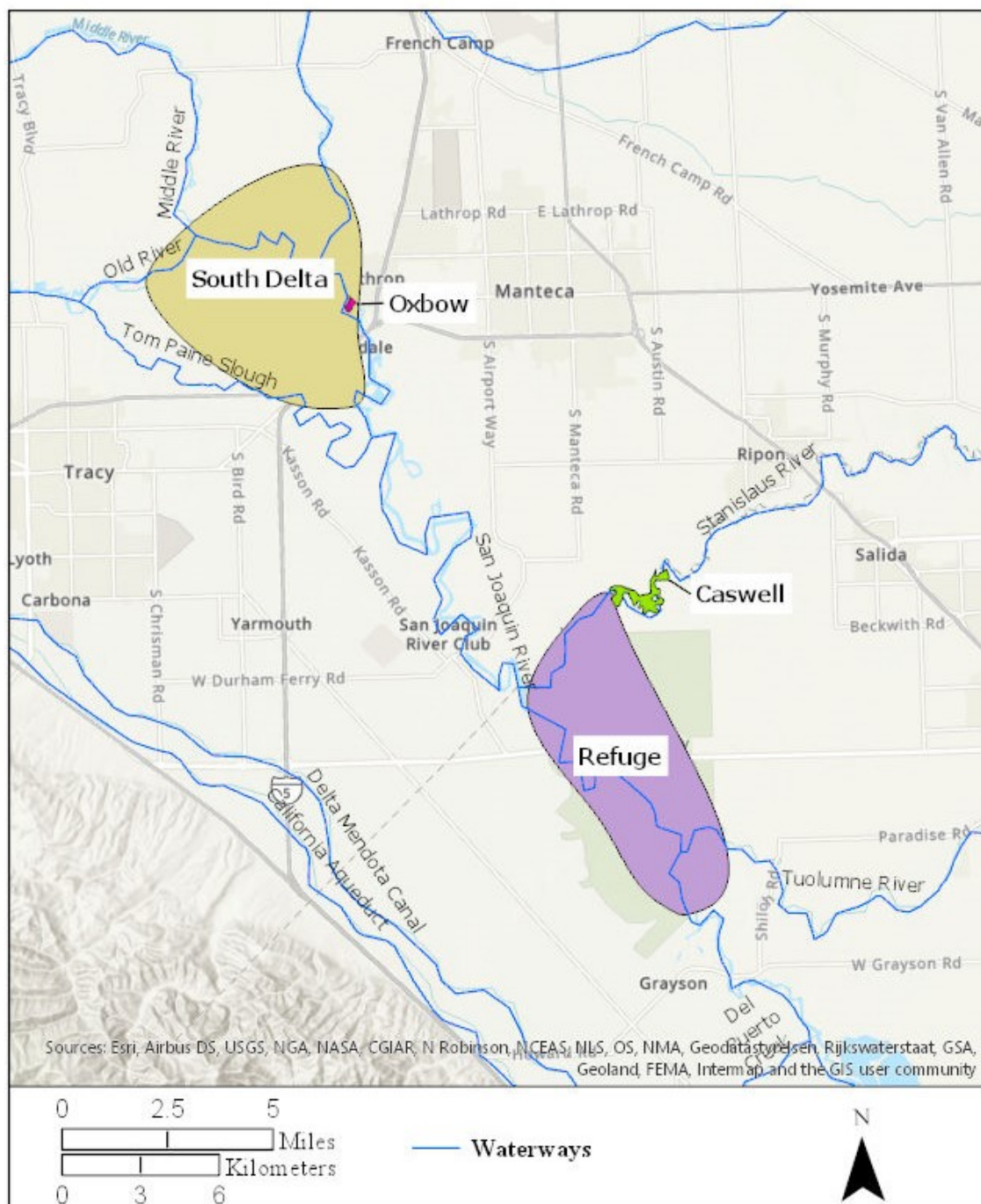


Figure 6. Current distribution of four riparian brush rabbit populations, southern San Joaquin County and northern Stanislaus County, California. The population ranges depicted above are Caswell Memorial State Park, Oxbow Preserve, San Joaquin River National Wildlife Refuge, and South Delta.

4.2 Abundance

Riparian brush rabbit abundance, or population size, is positively correlated with resiliency. Larger populations are better able to withstand stochastic influences that cause mortalities (e.g. floods, wildfires, and increases in predation pressure). Typically, large populations will have more surviving individuals after stochastic mortality events than small populations. The more individuals that survive, the quicker the population will be able to recover via reproduction and recruitment. Smaller surviving populations require more breeding cycles and time to achieve a healthy population size. The additional time increases the chances that additional stochastic mortality events will occur before the population recovers. Thus, a series of natural stochastic events may have little effect on the viability of large populations, but cause extirpations of small populations.

It is also important to note that the relationship between population abundance and resiliency is not linear. Depending on the availability of resources and habitat, an area can only support a maximum number of individuals (i.e. carrying capacity), beyond which the population will decrease because of inadequate amounts of food, shelter, or reproductive resources. Populations with high densities (individuals per unit area) may be subject to increased mortality from disease (from overcrowding and increased risk of transmission) and/or predation (from predator attraction to density of prey). Populations with high densities may also be affected by stochastic events that do not affect small populations. For example, a drought may limit food availability that would lead to starvation in dense populations, but no food shortage in low-density populations. While populations with low abundances may be able to withstand some stochastic events without negative effects, they are much more vulnerable to fragmentation and extirpation from a single event.

4.3 Reproduction and recruitment

Reproduction and recruitment are required to maintain and increase population abundance. As such, they are required for population resiliency. To persist into the future, populations must reproduce and have young become part of the adult breeding population (i.e. recruitment) at rates equal or greater than adult mortality. For successful reproduction, female rabbits must be fertile, have access to mates, and have adequate habitat resources for reproduction (see resource needs in Table 3). Early season breeding may be critical for riparian brush rabbit populations because early litters produce females that are able to breed later during the same season (Williams *et al.* 2008, p. 358). Recruitment is integrally tied to juvenile survival/mortality. For recruitment to occur, at least some juveniles must survive to become active members of the adult breeding population. To maintain population size (i.e. growth rate = 0), recruitment (measured by reproductive and survival rates) must be equal to adult mortality.⁵

As a short-lived prey species, riparian brush rabbits need to reproduce prolifically each year, because substantial adult and juvenile mortality is typical (see Section 2.8). Stochastic events, such as seasonal flooding and predation, increase rabbit mortality. Thus, prolific breeding is vital

⁵ This statement assumes that the population is not experiencing immigration or emigration.

for population resiliency, such that enough young are recruited into the population to continue breeding.

4.4 Survival

Survival, like reproduction, is positively related to population abundance and resiliency. The riparian brush rabbit has low survival rates, primarily because of predation mortality (Chapman & Litvaitis 2003, p. 118; Kelly *et al.* 2014, p. 5). Survival rates are also drastically affected by flood events (M. Lloyd *et al.* 2006, entire). Low survival rates are extremely limiting for population growth and abundance; they may prevent populations from being able to withstand stochastic events. Thus, adequate survival is a need for population resiliency.

4.5 Distribution

Assuming that densities of individuals are adequate, the distribution of individuals across a spatial area is positively related to population resiliency and negatively related to extirpation risk. In the presence of stressors (e.g. flood events and fires), populations with limited distributions are at greater risk of extirpation. Distribution is most commonly regulated by habitat availability and connectivity. The distribution of individuals generally increases with the availability of habitat across a population range. Because riparian brush rabbit habitat is frequently exposed to environmental stressors (details in CHAPTER 6), distribution is an especially important population need for this species.

4.6 Connectivity for dispersal and migration (large-scale)

Connectivity across a population range and between different populations is a need for population resiliency. Connectivity between populations also facilitates species redundancy and representation. Connectivity not only allows individuals to migrate out of an area in response to stressors, it also allows individuals to repopulate areas after extirpations.

CHAPTER 5 SPECIES NEEDS

Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Figure 7). Resiliency is assessed at the population level (CHAPTER 4) and representation and redundancy are assessed across the entire range of the species. Viability is defined as the ability of the riparian brush rabbit to sustain populations in natural ecosystems and/or human-modified ecosystems over time.

5.1 Resiliency

Resiliency gauges the probability that the populations comprising a species are able to withstand or bounce back from environmental or demographic stochastic events. Resiliency is assessed in terms of riparian brush rabbit individual and population needs, as described in CHAPTER 3 and CHAPTER 4. See the conceptual model in Figure 7 to review how individual and population needs relate to resiliency and species viability.

5.2 Representation

Species representation gauges the probability that a species is capable of adapting to environmental changes. It is measured by the breadth of genetic and environmental diversity within and among populations. Representation enhances the likelihood that the riparian brush rabbit will remain viable while environmental conditions change in response to stressors such as land use change, hydrological changes, drought, and nonnative species. Implications of these stressors are discussed in more detail in CHAPTER 6.

In terms of genetic diversity, the riparian brush rabbit has similar levels of heterozygosity and allelic diversity to that of neighboring brush rabbit subspecies (Matocq *et al.* 2017, p. 21). This is noteworthy considering the riparian brush rabbit has undergone substantial range contraction (Figure 3). However, mitochondrial diversity of the riparian brush rabbit is much lower than that of *S. b. macrorhinus*. This suggests a loss of historical diversity caused by genetic drift working independently within the fragmented riparian brush rabbit populations, shifting the frequencies of alleles without profoundly altering heterozygosity (Matocq *et al.* 2017, p. 21).

It is unknown if local adaptations contribute to the genetic differentiation among riparian brush rabbit populations. The two remaining natural populations of riparian brush rabbit [i.e. South Delta (including Oxbow) and Caswell Memorial State Park] exhibit substantial genetic differentiation from each other. The genetic distance (i.e. measure of genetic difference) between the South Delta and the Caswell Memorial State Park (henceforth, Caswell) populations is only slightly less than the genetic distances between the West Diablo population of *S. b. macrorhinus* and populations of riparian brush rabbit (Matocq *et al.* 2017, pp. 21-22). The substantial genetic differentiation between the South Delta and Caswell populations is likely from the loss of habitat connectivity between the two populations, which prevented gene flow and resulted in genetic drift acting independently on each population. Habitat fragmentation and loss of connectivity has also appeared to affect within-population genetic structure. Bayesian analyses identified two genetic groups within the South Delta population, one group associated with the Oxbow Preserve, and the other group associated with the remainder of the South Delta population (Matocq *et al.* 2017, p. 22). However, the genetics support that gene flow between Oxbow and the South Delta occurred more recently than gene flow between Caswell and the South Delta or Oxbow populations (Matocq *et al.* 2017, p. 22).

The riparian brush rabbit population at the Refuge was introduced, beginning in 2002, with progeny of South Delta rabbits. Several years later, the Refuge population retains a strong affinity toward the South Delta population, yet exhibits less differentiation from the nearby Caswell population than does the South Delta population (Matocq *et al.* 2017, p. 35).

The environmental conditions (in terms of habitat) among the Caswell, South Delta, and Refuge populations vary considerably given the populations' close proximity. Caswell is primarily old-growth riparian forest; the South Delta contains narrow fragmented strips with mostly open canopy, early-successional vegetation, and herbaceous weeds; while the Refuge habitat is largely restored, early-successional riparian vegetation with little or nonexistent canopy. While these variations demonstrate that the riparian brush rabbit can exist under a range of habitat conditions, it does not indicate that this species has adapted to the conditions within which it exists. It is

more likely that the riparian brush rabbit occupies these habitats because they are the only remaining fragments of a formerly expansive riparian landscape in the Central Valley. The transformation of the Central Valley landscape is discussed in further detail in Section 6.1.

Historically, the riparian brush rabbit was likely distributed continuously along rivers and floodplains across a much larger range (Figure 3). If the estimated historical range is reasonably accurate, ecological variation across the range could have resulted in genetic differentiation because of local adaptations. Considering the current size of the species range, most of the species' historical representation has probably been lost.

5.3 Redundancy

Redundancy describes the ability of a species to withstand catastrophic events. Redundancy gauges the probability that the species has a margin of safety to withstand and/or rebound after catastrophic events. It can be measured through the duplication and distribution of populations or meta-populations across the range of the species. The greater the number of populations a species has distributed over a landscape, the better it will be able to recover after catastrophic events.

Catastrophic events that could affect the riparian brush rabbit include large floods (e.g. 100-year floods) or large wildfires. During a catastrophic flood event, all waterways in the given region would typically be affected; however, it is likely that different waterways and hydrological systems (regulated by the same dam network) would be affected to different degrees. Therefore, riparian brush rabbit redundancy would improve with multiple populations distributed across different waterways, hydrological systems, and watersheds.

If a catastrophic flood occurred in the riparian brush rabbit's range, all current populations would be strongly affected because all are clustered near the main stem of the San Joaquin River in the middle of the Central Valley. However, the species retains some redundancy because it occurs along different waterways (San Joaquin, Stanislaus, and Old rivers, as well as Tom Paine Slough and Paradise Cut) and in different watershed sub-basins [currently the Lower San Joaquin River, Upper Tuolumne, Upper Stanislaus, and San Joaquin Delta (hydrological unit code 8 sub-basins)]. Some of these waterways and/or sub-basins might be affected less than others in a catastrophic flood. This being considered, the riparian brush rabbit would have much better redundancy in the face of catastrophic floods if the species occupied more of its historical range (Figure 3), especially along upper river reaches that are farther from the San Joaquin River.

The riparian brush rabbit species currently has some redundancy to withstand catastrophic wildfire because there is limited fire-fuel connectivity between the northern (South Delta and Oxbow) and southern (Caswell and the Refuge) populations. However, if a catastrophic wildfire occurred, it could destroy most, if not all, riparian brush rabbit habitat in the Caswell and Refuge populations. Redundancy would be improved with more populations that are spread out beyond the species' current distribution.

Implications of flooding and fire are discussed in more detail in CHAPTER 6.

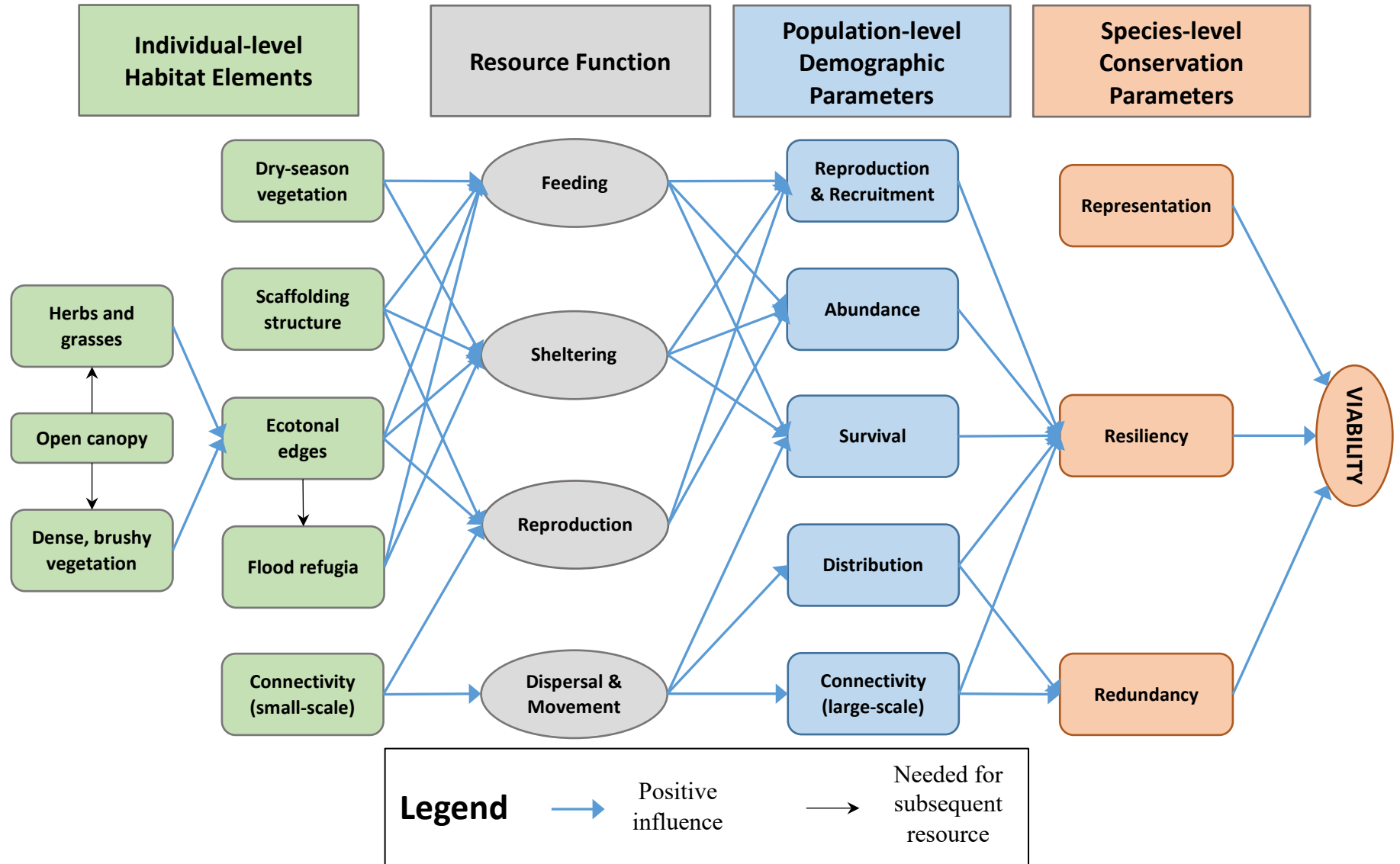


Figure 7. Conceptual model of riparian brush rabbit viability. Model includes the relationships among habitat elements, resource functions, demographic parameters, and conservation parameters.

CHAPTER 6 INFLUENCES TO SPECIES VIABILITY

In this section, we evaluate the significant past, current, and future influences that are affecting riparian brush rabbit resiliency, representation, and redundancy. These influences affect individual, population, or species needs, ultimately affecting the viability of the species. The majority of these influences are considered “stressors” to the riparian brush rabbit, in that they negatively influence viability. Positive influences on riparian brush rabbit viability, such as conservation efforts, are also covered in this chapter.

6.1 Habitat loss and degradation

Habitat loss and habitat degradation are likely the strongest influences on the riparian brush rabbit’s current condition. Although the greatest changes to habitat quantity and quality occurred in the past, the effects of these stressors still play a major role in the viability of the riparian brush rabbit. Habitat loss and degradation affect all individual and population needs. In addition to loss of resiliency, these stressors also reduce the species’ redundancy and representation. Habitat loss and degradation are still occurring at present and the effects of past hydrological changes are intensifying as other stressors increase.

Development and land use change

In the Central Valley, the start of rapid land use change, development, and riparian forest destruction coincided with the 1849 Gold Rush (Thompson 1961, p. 301; Katibah 1984, p. 27). The influx of population associated with the Gold Rush led to rapid development and the establishment of agriculture. Woody riparian vegetation was extensively harvested to fuel steamships that were navigating the Central Valley rivers (Thompson 1961, p. 311). As early as 1868, the drastic extent of riparian forest destruction across the Central Valley was reported by multiple sources (reviewed in Thompson 1961, pp. 311-313). The clearing of these forests also allowed agricultural expansion into the formerly wooded areas (Thompson 1961, p. 313). CALFED (2014, p. 120) estimates that less than 2% of the historical extent of riparian areas remains in the San Joaquin Valley.

At present, riparian habitat loss is continuing to occur in the South Delta population range. Habitat is being cleared for residential development, highway widening, and other relatively small-scale projects. Urban flood protection projects, are also affecting much of the remaining habitat in the South Delta at multiple scales (Larsen Wurzel and Associates 2019, p. 9; Reclamation District 2062 2017, p. 3, attachment h; Service 2019, p. 22). In 2007, California legislation (Senate Bill 5) went into effect, which proposed a 200-year level of flood protection for urbanized or urbanizing areas. Urban flood protection activities that are planned [and ongoing (Larsen Wurzel and Associates 2019, p. 9)] in the South Delta include creating and/or improving levees, weirs, bypasses, and facilities to meet standards for 200-year flood events in the Central Valley (San Joaquin Area Flood Control Agency 2014, pp. 6, 39, 47, 71-74). In addition to planned projects, unplanned emergency response actions also affect habitat. During 2017, approximately 0.65 hectare (1.61 acres) of riparian brush rabbit habitat was lost as a result of emergency levee seepage repair (Service 2019, p. 22). These stressors are expected to continue into the future for the South Delta population, especially as the Central Valley’s population increases.

Hydrologic changes

Since 1850, the San Joaquin Valley hydrologic system has changed dramatically. Numerous dams and levee systems have been constructed to support agriculture and industry, and to protect communities/development from flooding. These alterations changed the natural streamflow pattern of the San Joaquin River and its tributaries (CALFED 2014, pp. 119-120). Dams and levees enabled the conversion of former riparian brush rabbit habitat into agriculture and other development. While the dams and levees provide flood control and consistent water supply for agriculture, they have also increased the severity and duration of flooding in the remaining strips of riparian habitat situated between the rivers and levees (Basey 1990, p. 35; Close & Williams 1998, p. 20).

Another result of land use change and water use in the San Joaquin Valley and Delta is land subsidence (i.e. the sinking of an area of land). Land subsidence has likely contributed to the increase in duration of seasonal floods. In some areas of the Valley, land surface elevation has decreased by more than 8.5 meters (28 feet) (Galloway & Riley 1999, p. 23). Although subsidence rates have slowed since the 20th century, Deverel & Leighton (2010, pp. 1, 21) predict that land surface elevations in the Delta will decrease from a few centimeters to over 1.3 meters (4.3 feet) by 2050.

Prior to the dam and levee construction during the 1960s and 1970s, some areas along the San Joaquin River and its tributaries were used as pasture because they periodically flooded (Williams & Basey 1986, p. 13). The pastures contained numerous patches of shrubs and trees and had uneven topography, which provided high-ground refugia for riparian brush rabbits during floods (Williams & Basey 1986, p. 13; Basey 1990, p. 38). These pastures have since been cleared, leveled, and converted to row crops, vineyards, or orchards (Williams & Basey 1986, p. 13). The loss of the flood refugia provided by pastures probably contributed to extirpations of the riparian brush rabbit, even where habitat was still available (Williams & Basey 1986, p. 13; Basey 1990, p. 38).

At present, the manmade hydrological systems that are in place (current dams and levee systems) continue to negatively affect the resiliency of riparian brush rabbit populations. As these systems age and as the effects of climate change (Section 6.13) continue to manifest in the Central Valley, dams and levees will continue to need to be replaced with new infrastructure. As flooding becomes more severe (Westerling *et al.* 2018, p. 6) and more land area is needed to contain floodwaters, we expect the new hydrological infrastructure to be larger (Delta Stewardship Council 2018, p. 1) and potentially more damaging to riparian brush rabbit population resiliency. Therefore, we expect this stressor to increase in the future.

6.2 Flooding

Seasonal flooding is a natural feature of riparian brush rabbit habitat. However, land conversion and hydrologic changes to the Central Valley's riverine systems have affected the riparian brush rabbit's ability to withstand floods (see Section 6.1). Floods affect the remaining populations of riparian brush rabbit and their habitat every few years. Flood events are caused by heavy precipitation, rapid snowmelt, and/or reservoir releases (Hamilton *et al.* 2010, p. 1000; Kelly *et*

al. 2013, p. 4; Kelt *et al.* 2014, p. 522). Dams and levee systems exacerbate the effects of floods in the areas occupied by riparian brush rabbit.

Floods affect all life stages of riparian brush rabbits and have a considerable influence on survival (Hamilton *et al.* 2010, p. 1005). Floods cause direct mortality through drowning and indirect mortality through increased starvation and exposure to predation (Kelly *et al.* 2013, p. 5; Service 2017a, *in litt.*; Service 2017, p. 4). Mortality from flood events is estimated at 50-95% of population abundance (Williams 1993, p. 1; Service 2017b, *in litt.*). Flood mortality rates increase with flood duration and decrease with availability and quality of flood refugia (with ample food and cover). Flood events decrease population distribution (Williams 1988, p. 11). Although unmeasured, flood events likely decrease reproductive and recruitment rates because of stress, overcrowding and competition on refugia, predation of young, lack of adequate resources, and/or lack of nesting sites. The extent of overcrowding and resulting increase in exposure that occurred during 2017 at the Refuge is evident in Figure 5.

Long-duration flood events may last for as long as six months (Service 2017, no page) and inundate as much as 95% of riparian brush rabbit habitat (Service 2017a, *in litt.*). Inundation for long periods causes both immediate and delayed destruction and degradation of habitat (food, shelter, and space). Native riparian plant-species are adapted to frequent, short flood events. However, many native riparian shrubs, including California blackberry and wild rose, do not survive long periods of inundation (River Partners 2008, p. 8). Other effects of recent flood events on riparian brush rabbit habitat include erosion and scouring (M. R. Lloyd & Kelly 2008, p. 1; Gantenbein *et al.* 2019, p. 28), decreases in shrub cover/density of plants (Gantenbein *et al.* 2019, p. 9), and the introduction of nonnative plants (Forrest 2018, pers. comm.; Gantenbein *et al.* 2019, p. 9).

Floods affect the resiliency of all riparian brush rabbit populations but to different degrees. The magnitude of the effect depends on the frequency/duration of flooding, availability of high-ground refugia, and quality of food and cover on refugia. The response of the South Delta population to floods has not been studied but it is expected to be similar to those of the other populations.

Large population reductions (“bottlenecks”) from flood-related mortality have likely caused losses of genetic diversity (Williams 1993, p. 12). The loss of genetic diversity decreases species representation. Catastrophic flood events, or floods in populations with low resiliency have likely also contributed to riparian brush rabbit extirpations in the past, reducing species redundancy. Flood events are expected to increase in frequency and severity in the future (Dettinger *et al.* 2009, p. 46; Westerling *et al.* 2018, p. 6). This stressor has and will have a strong influence on riparian brush rabbit viability.

6.3 Wildfire

The frequency of historical wildfire in the riparian brush rabbit range is unknown, but Native Americans were known to use fire in riparian areas for a variety of purposes (Fryer 2015, pp. 4-5). Small fires, as a source of disturbance, actually support many of the habitat needs of riparian brush rabbits such as ecotonal edges, brushy early-successional vegetation, and clearings with grasses and herbs. However, modern wildfires have the potential to be larger and more

destructive than in the past because of invasive nonnative vegetation, wildfire suppression, and drought. Hydrological changes that have altered the flooding regimes in riparian areas may also contribute to an increase in fire severity by causing buildups of flood debris (Pettit & Naiman 2007, pp. 676-677). Considering the small quantity of remaining habitat and the few populations, wildfire is a tremendous risk to this species' viability.

Destructive wildfires occur when dry, ignitable fuels are abundant. Fires in the Central Valley could be ignited by lightning but more often, they are ignited by anthropogenic sources (Fryer 2015, pp. 2, 5), such as arson, road sparks, or transmission-line failures. Fires can cause direct mortality to all stages of riparian brush rabbit or indirect mortality through increased exposure to predation, habitat loss, and starvation (Kelly *et al.* 2014, pp. 1, 19-20). Fires may also cause indirect mortality of brush rabbits as they seek refuge in firebreaks and are subsequently run over by fire-fighting vehicles (Quinn 1979, pp. 125-126). Sub-lethal, fire-related trauma in riparian brush rabbits has also been recorded (Hamilton *et al.* 2010, p. 1005). The effects of wildfire on reproductive and recruitment rates have not been studied; however, the effects are expected to occur because of stress, overcrowding and competition in unburned areas, increased predation exposure, diminished resources, and/or lack of nesting sites.

Catastrophic fires might have the potential to do more harm to riparian brush rabbit populations than floods because fires can destroy a population's entire habitat and there are no fire refugia to mitigate effects. In the short term, even small fires may be more destructive to riparian brush rabbit habitat than long-duration floods. The dense, brushy vegetation needed by this species also increases fire risk and can intensify fires when they do occur.

Caswell is especially vulnerable to catastrophic wildfire because of the buildup of decadent vegetation and the three-dimensional vertical structure of the forest. Caswell has periodically experienced small wildfires, the largest recorded being only 0.2 hectare (0.5 acre), but all were quickly contained (Basey 1990, p. 41). While extremely vulnerable to fire, Caswell is not at a particularly high risk of fire occurrence because it is surrounded by low-fuel agricultural land and has low exposure to ignition risk (e.g. roadways and transmission lines). The greatest ignition risks at Caswell are campfires and arson. At present, fire-risk management activities are not taking place at the Park (Reith 2019, pers. comm.). However, as fire risk increases in the future, we anticipate that fire-risk management activities will become a regular part of the Park's management.

In September of 2009, a small wildfire [0.1 hectare (0.25 acre)] burned annual grassland at Oxbow Preserve (Gantenbein *et al.* 2019, p. 20). The Oxbow Preserve receives ongoing vegetation management that both decreases fire risk and improves riparian brush rabbit habitat quality (Gantenbein *et al.* 2019, p. 1).

The Refuge population is the only riparian brush rabbit population that has documented exposure to large wildfire. Approximately one large wildfire [> 202 hectares (500 acres)] occurs every five years and several ignitions, usually caused by trespassers, occur each year (Service 2006, p. 45). In July 2004, the Pelican wildfire (arson-caused) burned 588 hectares (1,453 acres) of the Refuge (Figure 8), including 412 hectares (1,018 acres) of the available riparian brush rabbit habitat (Hamilton *et al.* 2010, p. 1000). The habitat primarily burned in small clumps of less than 0.4 hectare (1 acre), but much of the thick brush burned completely, removing all of understory

cover (BAER Team 2004, p. 37). Based on post-fire radio telemetry, the Pelican fire did not appear to have a detrimental effect on the population, probably because the fire bypassed most of the highest-quality habitat along slough channels where most of the radio-collared rabbits resided (Hamilton *et al.* 2010, p. 1005). Among radio-collared individuals, there were three fire-related mortalities and few injuries after the fire (Kelt *et al.* 2014, p. 522). However, Kelt *et al.* (2014, pp. 520, 522) suggested that post-fire mortality may have been greater because there were numerous mortalities that were of unknown causes within seven months after the Pelican fire.

In June of 2008, another arson-caused wildfire, the River fire, burned a couple hundred hectares at the south end of the Refuge (Lloyd and Kelly 2008) (Figure 8). The total burned area was 235 hectares (580 acres) (CAL FIRE *et al.* 2016, spatial dataset). Prior to the River fire, there was evidence suggesting several riparian brush rabbits inhabited the area before it burned. Post-fire trapping near the burned area did not capture riparian brush rabbits but there was a high capture rate (6%) of desert cottontails (M. R. Lloyd & Kelly 2008, pp. 1-2). In 2013, a smaller wildfire burned approximately 7.7 hectares (19 acres) of Faith Ranch, a habitat restoration property held by the Refuge. Much of the burned area was high quality habitat; riparian brush rabbit mortalities likely occurred but fire effects were not studied (Kelly *et al.* 2014, pp. 1, 19).

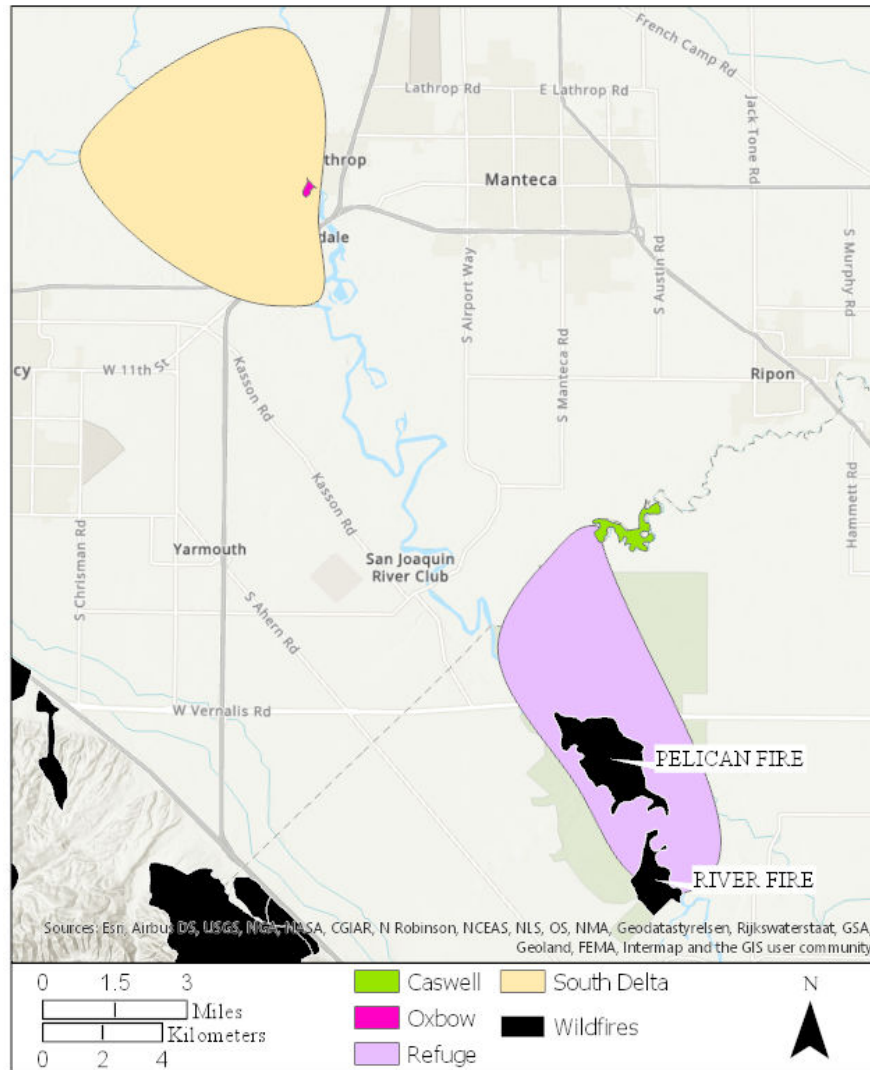


Figure 8. Large wildfires in the riparian brush rabbit range. (CAL FIRE *et al.* 2016, spatial dataset)

The Oxbow and South Delta populations have lower risk of catastrophic wildfire than the Caswell and Refuge populations because habitat occurs in isolated patches that are surrounded by agriculture and development. There are also lower fuel loads in these populations. Therefore, fire, if ignited, would be less severe and/or smaller. The surrounding private landowners and the area's proximity to fire department resources also ensure that fire response would be rapid. However, habitat patches are so small in these populations that localized extirpations and further fragmentation would likely result if the riparian corridor were to burn. While the scattered distribution of the South Delta riparian brush rabbit occurrences reduces the likelihood that one catastrophic fire could eliminate the entire South Delta population, the close proximity of the South Delta habitat to human activity increases the likelihood of a fire ignition. Even small, low-intensity wildfires in the Oxbow and South Delta populations could have considerable negative influence on the population's resiliency

Coarse estimates of fire threat within each of the four population ranges, based on CAL FIRE data of fire frequency and fire hazard, are presented in Figure 9 and Figure 10 (CAL FIRE 2004, spatial dataset).

At present, the riparian brush rabbit population most at risk from wildfire is the Refuge, while the one least at risk is the South Delta. Caswell and the Refuge have the most risk for catastrophic wildfire. On the other hand, small fires would be more detrimental to the resiliency of Oxbow and the South Delta than they would be to Caswell or the Refuge. A catastrophic fire at Caswell or a moderate fire at Oxbow could result in population extirpation, which would decrease species redundancy and representation. According to predictions, wildfire frequency and severity are expected to increase in the riparian brush rabbit range over the next 40 years (Westerling *et al.* 2018, p. 6).

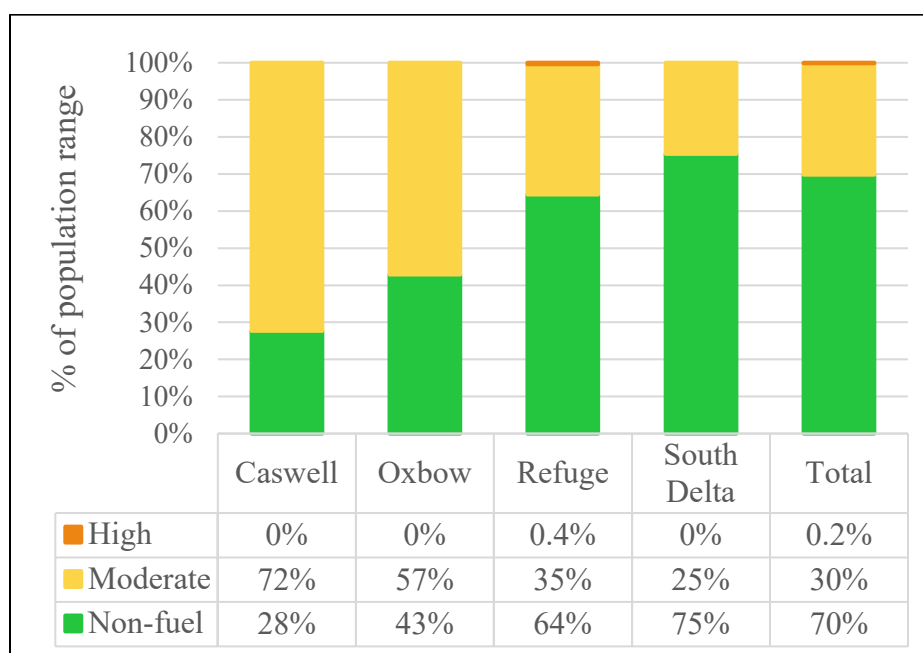


Figure 9. Fire threat as percentage of area for each riparian brush rabbit population range. Note that population ranges include non-habitat areas. (CAL FIRE 2004, spatial dataset)

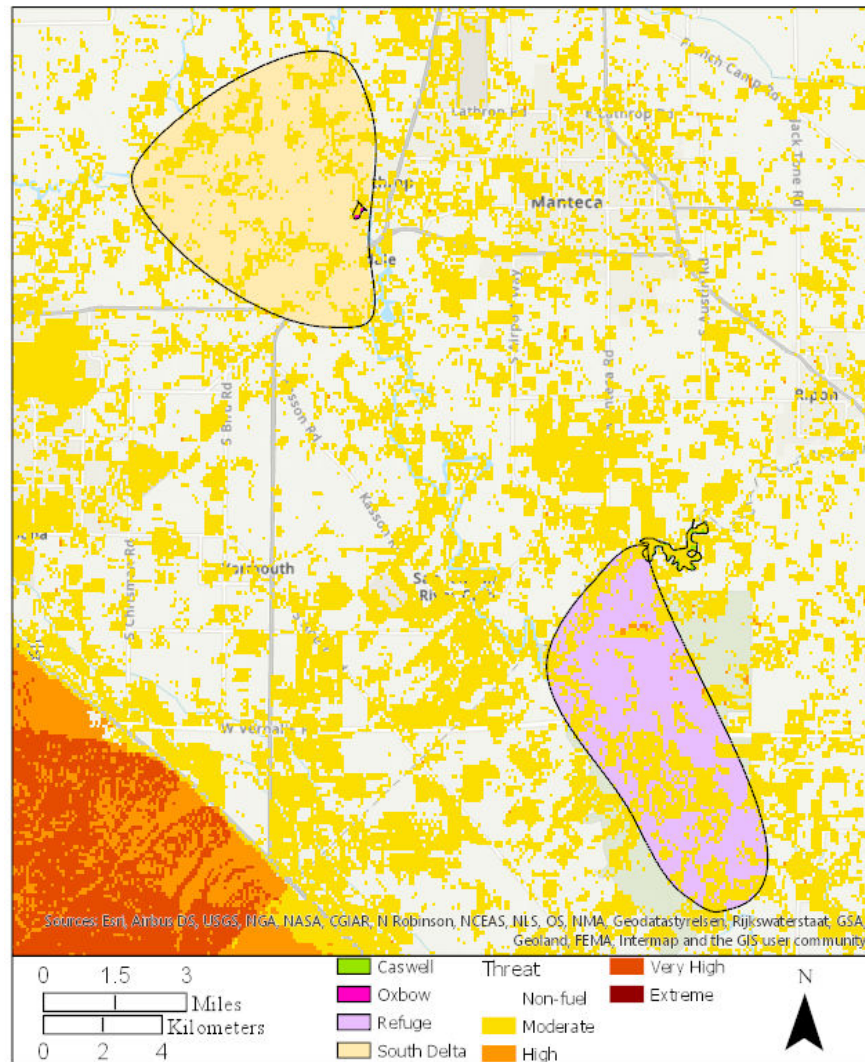


Figure 10. Rating of wildfire threat based on a combination of (1) fire frequency, or the likelihood of a given area burning, and (2) potential fire behavior (hazard). These two factors are combined to create four threat classes ranging from moderate to extreme. (CAL FIRE 2004, spatial dataset)

6.4 Drought

Drought affects the quality and quantity of the vegetation that riparian brush rabbits rely on for food and shelter. Several years of drought can reduce the carrying capacity of riparian brush rabbit habitat (Larsen 1993, p. 11), which decreases population abundance and potentially decreases survival and reproductive rates. During prolonged drought, some food sources may be reduced (Center for Natural Lands Management 2019, *in litt.*). The vegetation on high-ground flood refugia is the most vulnerable to drought conditions because it is farthest from the water table (Forrest 2018, pers. comm.). Drought influences all populations of riparian brush rabbit but populations with higher plant diversity, including drought-tolerant species, are more resilient to this stressor. We expect drought severity and frequency to increase in the future for all populations (Westerling *et al.* 2018, p. 6).

6.5 Predation

Predation is a natural stressor for riparian brush rabbits and often acts as a population regulation mechanism⁶ for small mammals. However, if population abundance is low or if new predators are introduced to a species' range, predation may be detrimental to the species' viability. As discussed in Section 2.8, predation has a strong influence on riparian brush rabbit survival and abundance. Predation is the primary cause of mortality in the absence of floods (Williams *et al.* 2008, p. 357; Hamilton *et al.* 2010, pp. 1002, 1005; Kelly *et al.* 2014, p. 1). While predation is unlikely to be the sole cause of extirpation, it has considerable influence on riparian brush rabbit population demographics and resilience.

The riparian brush rabbit has numerous natural predators including various predatory birds (Accipitridae and Strigidae families), coyote (*Canis latrans*), gray fox (*Vulpes cinereoargenteus*), bobcat (*Lynx rufus*), long-tailed weasel (*Mustela frenata*), mink (*Neovison vison*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), and potentially snakes (Williams 1988, p. 16; Rentner & Lloyd 2010, p. 5; Kelly *et al.* 2011, p. 6; Wittmer *et al.* 2016, p. 343). It has been suggested that increased avian predation could be linked to riparian brush rabbit decline at Caswell because increased tree density provided additional hunting perches (Elsholz 2010, p. 64). Native great-horned owls (*Bubo virginianus*) nesting at Oxbow Preserve have been the largest source of predation stress for Oxbow riparian brush rabbits (Gantenbein 2018, pers. comm.).

Nonnative predators are also present in riparian brush rabbit habitat including feral/free-ranging domestic cats (*Felis catus*), domestic dogs (*Canis familiaris*), red fox (*Vulpes vulpes*), and black rat (*Rattus rattus*). Cats are known to have preyed on riparian brush rabbits at the Refuge (Kelly *et al.* 2011, p. 6) and cats are common at Caswell (Cook & Quinn 1992, pp. 25-26). The black rat, an exotic invasive species that is prolific in riparian areas, is a concern as a predator of rabbit neonates (Kelly *et al.* 2011, p. 6).

Little is known about predation rates throughout most of the South Delta range. The risk of nonnative predation tends to increase for populations that are adjacent to residential properties, along public roads or waterways, and/or are subject to human disturbance. Oxbow management noted repeated predation of riparian brush rabbits by a nonnative red fox on the Preserve (Gantenbein 2018, pers. comm.). However, predation rates could be lower in the rest of the South Delta if native predators are rare or absent. At Oxbow, domestic cats have been observed on the Preserve but managers suggest that neighborhood cats have less of an effect than native avian predators and coyotes (Gantenbein *et al.* 2019, p. 15).

The Caswell and Refuge population ranges have the same species of riparian brush rabbit predators (Table 4) but the magnitude of effects that each predator species causes likely differs between populations. Predator effect varies by habitat, concentrations of individuals, and other factors. There have been fewer predator species documented in the Oxbow and South Delta populations (Table 4). Fewer types of predators does not necessarily signify that there is less

⁶ Population regulation can be important for species that are rapid reproducers. In the absence of stressors, prolific reproducers become overpopulated, which may lead to mass starvation and mortality. Habitat may also sustain damage if resources are overutilized.

predation in these populations. Failure to document several of the predators in the South Delta may only indicate that the population is less studied.

Table 4. Predators known to occur in each riparian brush rabbit population.

Predator	Caswell	Oxbow	Refuge	South Delta
Accipitridae (diurnal raptors)	x	x	x	x
Owls	x	x	x	
Coyote	x	x	x	
Gray fox	x		x	
Bobcat	x		x	
Long-tailed weasel	x		x	
Mink	x		x	
Raccoon	x	X	x	
Striped skunk	x	X	x	
Snakes	x		x	
Cat	x	x	x	x
Dog	x	x	x	x
Black rat	x	x	x	x
Red fox		x		

6.6 Vegetation management (brush and vegetation removal)

Large-scale vegetation clearing, such as that for development and agriculture is addressed in Section 6.1. This section addresses the influences of, typically small-scale, vegetation management practices on riparian brush rabbit viability. Some types of vegetation management practices can positively affect riparian brush rabbit habitat by mimicking natural disturbances that create areas with early-successional vegetation and ecotonal edges. However, even these practices can decrease population resiliency where habitat patches are small and fragmented, such as those in the South Delta population. In the past, the Caswell population was adversely affected by clearing of brush for mosquito and fire control (Williams 1986, p. 23; Williams 1988, p. 17). At present, fuel reduction and/or brush removal is not occurring at Caswell (Reith 2019, pers. comm.). Therefore, the Caswell population is not currently exposed to this stressor. Considering the Park's commitment to species conservation, we do not expect vegetation management practices to be a stressor for the Caswell population in the future.

Some vegetation management practices are detrimental to riparian brush rabbit habitat and flood refugia. In 2009, and again in 2014, the U.S. Army Corps of Engineers (henceforth, Corps) issued strict vegetation guidelines that require all federal project levees be free of vegetation, with the exception of erosion-controlling perennial grasses (U.S. Army Corps of Engineers 2014, pp. 2.1-2.2). These guidelines are important to maintain the structural integrity of the levee systems but they prevent these levees from serving as flood refugia. At the Refuge, much of the land area has or is being restored as natural floodplain. Therefore, only the levees that surround the Refuge floodplain need to adhere to the Corps' vegetation guidelines. The levees in the Refuge interior have been revegetated to serve as riparian brush rabbit flood refugia. Similarly,

the Oxbow population contains vegetated high ground on a berm through the center of the Preserve although it is not sufficient for prolonged periods; riparian brush rabbits at Oxbow cannot rely on the adjacent levee system for flood refugia, which is devoid of vegetation due to USCOE/CVFPB levee maintenance requirements. However, in areas where the only unflooded land available for riparian brush rabbits are levee crowns, these vegetation guidelines influence the abundance, distribution, and habitat connectivity of riparian brush rabbit populations. The actual effects of the Corps' guidelines on the South Delta population have not been studied but they are expected to be significant. Brush removal also occurs to reduce fuel loads and wildfire risk in the South Delta. This has also been recognized as a "severe threat" to the South Delta population (Williams *et al.* 2000, pp. 7-8).

6.7 Forest succession

At present, forest succession is only influencing the resiliency of the Caswell population of riparian brush rabbit. Several decades ago, the old-growth riparian forest at Caswell had more openings in its tree canopy (Elsholz 2010, p. 68). The openings created ecotonal edges and allowed sunlight to reach the forest floor to support growth of shrubs, grasses, and herbs. Habitat research has demonstrated that riparian brush rabbits prefer areas with an open canopy (Williams & Basey 1986, p. 12; Basey 1990, p. 34; Elsholz 2010, p. 64). Historically, the Caswell area was exposed to disturbances including scouring floodwaters (now moderated by the 1978 New Melones Dam), wildfires, and grazing (Williams *et al.* 2002, p. 6). Without these historical disturbance regimes, the existing tree canopy has remained intact and former canopy gaps have been gradually closing. The progression of Caswell habitat into a climax forest community with few canopy openings has reduced the quality and quantity of riparian brush rabbit habitat at the Park (Williams *et al.* 2002, p. 4; Constable *et al.* 2011, p. 3). The undisturbed forest succession at Caswell is considered a stressor that may contribute to reducing the viability of the riparian brush rabbit at Caswell.

6.8 Disease

Diseases known to occur in brush rabbits and related *Sylvilagus* species include, but are not limited to, tularemia, plague, myxomatosis, silverwater, California encephalitis, equine encephalitis, listeriosis, Q-fever, and brucellosis. Brush rabbits are also hosts to a variety of ecto- and endo-parasites, some of which cause fatal diseases (Kelly 2018a, p. 124). In the wild, the rate of disease occurrence or effect on riparian brush rabbit populations is unknown. However, there were 23 mortalities (out of 83 total mortalities that were of known causes) attributed to disease during the first two years of the captive breeding program, 19 in the propagation pens and 4 in translocated Refuge riparian brush rabbits (Williams *et al.* 2008, p. 358). Of the disease mortalities, parasitic encephalitis (presumed *Baylisascaris* roundworms) was most often implicated, but necrotizing typhlitis, bacterial sepsis, and intestinal lymphoma also contributed to mortalities (Gilardi *et al.* 2004, no page; Williams *et al.* 2008, p. 357). During this same period, ocular disease (keratitis, uveitis, and conjunctivitis) was a cause of riparian brush rabbit morbidity (Gilardi *et al.* 2004, no page). Of 30 riparian brush rabbits screened for antibodies to *Encephalitozoon cuniculi* and *Treponema cuniculi*, one rabbit from the South Delta population was weakly seropositive for *Encephalitozoon*. However, no evidence of disease due to either pathogen has been found in riparian brush rabbits (Gilardi *et al.* 2004, no page).

The small population size and restricted distribution of the riparian brush rabbit increase its vulnerability to disease and parasite infestations. If flood frequency and duration increases in the future, overcrowding on flood refugia for long periods would increase the probability of a disease outbreak. The overcrowding on flood refugia is a new circumstance for this species. At present, we do not consider disease to be a serious detriment to viability. However, we note that disease occurrence might increase and has the potential to become a serious stressor in the future.

6.9 Nonnative plants

Nonnative plants, especially exotic grasses and thistles, are ubiquitous across all riparian brush rabbit populations. However, the riparian brush rabbit is a generalist forager and may not be disadvantaged by moderate invasions of nonnative plants. Brush rabbits have frequently been observed foraging on nonnative plants grasses and herbs (Orr 1940, pp. 180-181; Basey 1990, p. 6). Nonnative Himalayan blackberry (*Rubus discolor*) grows in riparian brush rabbit habitat and hybridizes with native California blackberry (Kelly *et al.* 2011, p. 3). However, there is no evidence to indicate that Himalayan blackberry affects habitat quality. Nonnative thistles such as milk thistle (*Silybum marianum*) and bull thistle (*Cirsium vulgare*) provide cover during the growing season, but these species do not provide adequate cover through the dry season (Kelly *et al.* 2011, p. 3). Nonnative plants do not appear to be detrimental to riparian brush rabbit, but they may preclude the benefits of native riparian vegetation, which would provide food and cover during wet and dry seasons. At present, nonnative plants are not considered a stressor for riparian brush rabbits, and will not be carried forward in the analysis. However, nonnative invasive plants could become a significant issue in the future for managing wildfire risk (Fryer 2015, pp. 6-7).

6.10 Competition

Competition with native desert cottontails (*Sylvilagus audubonii*) has frequently been identified as a potential stressor to the riparian brush rabbit (Williams & Basey 1986, p. 14; Basey 1990, p. 44; Cook & Quinn 1992, pp. 20-21; Larsen 1993, p. 12). Under normal conditions (i.e. no flooding or burning), there is no evidence that co-habitation with desert cottontails affects riparian brush rabbits. Desert cottontails are a wide-ranging native species that also occupies riparian areas, but their preferred microhabitat differs from that of the riparian brush rabbit. However, competition with any other herbivores is a stressor when food resources are limited, such as when animals are forced to cluster in small areas to avoid floodwaters or fire. Desert cottontails occur among all known riparian brush rabbit populations except for Oxbow. While competition might be a critical consideration when in combination with other stressors, it is not considered a major stressor and will not be carried forward in the analysis.

6.11 Hunting

Brush rabbits are a game species in California but hunting brush rabbits and cottontails in the known range of the riparian brush rabbit is regulated by the California Fish and Wildlife Department. However, the current hunting regulations (CCR T14-308, California Mammal Hunting Regulations, 2018-2019) ban brush rabbit and cottontail hunting in only a portion of the South Delta population range. The California Department of Fish and Wildlife has begun working on a proposal to update this regulation (Applebee 2019, *in litt.*). Hunting is not known

to be a major stressor to riparian brush rabbit, especially because hunting is not permitted at Caswell, Oxbow, or the Refuge. This stressor will not be carried forward in the analysis.

6.12 Other stressors

Other potential stressors for riparian brush rabbit populations have been identified. Such stressors include the use of rodenticides, herbicides, road traffic, and pipes that act as pitfalls (Williams 1988, p. 16; Basey 1990, pp. 45, 51; Cook & Quinn 1992, p. 26). There is little or no information on the magnitude of influence that these stressors may have had or could have on riparian brush rabbit populations but we do not consider them to have considerable effects on riparian brush rabbit viability. At Oxbow Preserve, trespassers have also been identified as a stressor to the riparian brush rabbit population. Trespassers have cut holes in the predator-exclusion fencing, left garbage that might attract predators, and increased the risk of wildfire at the Preserve (Gantenbein 2018, pers. comm.; Gantenbein *et al.* 2019, appendix E - no page). Steps taken by Preserve managers has reduced trespassers from Oxbow. The stressors discussed in this section will not be carried forward in the analysis.

6.13 Climate change

Climate change influences riparian brush rabbit viability by increasing the magnitude of other stressors, thereby affecting the species' resource and population needs. According to California's Fourth Climate Change Assessment, the San Joaquin Valley region is expected to experience a higher frequency of catastrophic floods, more severe and frequent wildfires, and more intense and frequent drought over the next 40 years (Westerling *et al.* 2018, p. 6). We expect climate change to have considerable and increasing influence on riparian brush rabbit viability in the future.

6.14 Beneficial influences (Endangered Species Act)

The Endangered Species Act of 1973, as amended (Act), is the primary Federal law providing protection for the riparian brush rabbit. The Service has responsibility for administering the Act, including sections 7, 9, and 10 that address take. Section 9 prohibits the taking of any federally listed endangered or threatened species. Take is defined in Section 3 as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. Harass is defined by Service regulations at 50 CFR 17.3 as an intentional or negligent act or omission which creates the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavior patterns which include, but are not limited to, breeding, feeding, or sheltering. Harm is defined by the same regulations as an act that actually kills or injures wildlife. Harm is further defined to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing essential behavior patterns, including breeding, feeding, or sheltering. The Act provides for civil and criminal penalties for the unlawful taking of listed species.

Since listing, the Service has analyzed the potential effects of Federal projects under section 7(a)(2), which requires Federal agencies to consult with the Service prior to authorizing, funding, or carrying out activities that may affect listed species. For projects without a Federal nexus that would likely result in incidental take of listed species, the Service may issue incidental take

permits to non-Federal applicants pursuant to section 10(a)(1)(B). Incidental take is defined as take that is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity (50 CFR 402.02). To qualify for an incidental take permit, applicants must develop, fund, and implement a Service-approved Habitat Conservation Plan that details measures to minimize and mitigate the project's adverse impacts to listed species. Many of these Habitat Conservation Plans are coordinated with the State of California's related Natural Community Conservation Planning program.

The status of the riparian brush rabbit as a species listed under the ESA can reduce the severity of the effects of habitat loss from the main drivers for habitat loss/fragmentation (i.e. development, agriculture, and hydrological changes), which continue to be a threat to the riparian brush rabbit, directly and indirectly, throughout its range (see Section 6.1). Development projects that are subject to section 7 consultation or result in the issuance of an incidental take permit under section 10 typically include habitat compensation, which can reduce the severity of overall habitat loss typically associated with these projects. Habitat compensation can occur via a variety of mechanisms, including the purchase of credits at approved conservation banks, through permittee responsible mitigation, and through the development of habitat conservation plans (HCP's) and Safe Harbor Agreements. However, there are currently no conservation banks, or Safe Harbor Agreements for the riparian brush rabbit. More information about conservation banks within the Sacramento Fish and Wildlife Office's Service area can be found at <https://www.fws.gov/sacramento/es/Conservation-Banking/Banks/In-Area/>.

Permittee-responsible mitigation

Permittee-responsible mitigation includes activities or projects undertaken by a permittee (or authorized agent) to provide compensatory mitigation for which the permittee retains full responsibility. Permittee-responsible mitigation projects are typically not established in advance of the impacts they are offsetting and they do not have credits that can be used at a later time to offset different impacts, like conservation banks. Habitat compensation through permittee responsible mitigation for the riparian brush rabbit has occurred for a number of projects. The primary agencies implementing the permittee responsible mitigation include, but are not limited to, the Central Valley Project, California Department of Transportation, Bureau of Reclamation, Army Corps of Engineers, City of Tracy, and City of Manteca. Additional information regarding many of the projects associated with permittee-responsible mitigation for the riparian brush rabbit are in the Appendix.

HCPs

Habitat Conservation Plans (HCPs) provide a pathway forward to balance wildlife conservation with development. The primary objective of the HCP program is to conserve species and the ecosystems they depend on while streamlining permitting for economic development. Being included as a covered species under an HCP means that habitat will be set aside and managed for the species as compensation for covered activities, such as planned urban development, within the area the HCP covers. In addition, within the permitted area avoidance, minimization, and other conservation measures (e.g. monitoring, seasonal work windows, habitat management, etc.) will be put into place. There are two HCPs that include the riparian brush rabbit as a covered

species. The following are the HCPs that include the riparian brush rabbit as a covered species: the San Joaquin County Multi-Species Habitat Conservation and Open Space Plan (permit issued in 2001) and the PG&E San Joaquin Valley Operations & Maintenance HCP (permit issued in 2007). More information about the HCPs that include the riparian brush rabbit as a covered species can be found at <https://ecos.fws.gov/ecp0/profile/speciesProfile?sId=6189>.

Recovery Permits

Recovery permits, also referred to as 10(a)1(A) permits, allow scientists to take listed species as a means to ultimately contribute to the recovery of the listed species. The data acquired from some actions covered under recovery permits (e.g., occurrence, abundance, distribution, etc.) allow the Service to make informed decisions for the species that will enhance their survival and recovery. Recovery permits can be issued for activities that directly aid the recovery of a species, such as captive breeding, reintroductions, habitat restoration, removal or reduction of threats, and educational programs. The Service's recovery permitting program aids in the conservation of listed species by ensuring permittees have adequate field experience and qualifications for conducting activities with the target listed species and, for most species, ensures that permittees are following standardized protocols while surveying. The recovery permitting application process ensures that scientific proposals are crafted using the recommended actions laid out in the Recovery Plan for the target species. There are minimum qualifications to obtain a recovery permit for the riparian brush rabbit and a draft of protocol survey guidelines for the subspecies is available. Minimum qualifications and species-specific protocols can be found at <https://www.fws.gov/sacramento/es/Permits/>.

A substantial amount of new information about the riparian brush rabbit has been obtained through the recovery permit program. New information included life history and ecological requirements, distribution, vital rates, genetic structure and diversity, phylogenetic relationships, and species' response to fires and floods. Successful captive rearing and the reintroduction of a riparian brush rabbit population has also been permitted through the program. Additional information regarding the research and recovery projects that were permitted through the recovery permit program are in Section 6.15 and in the Appendix.

6.15 Beneficial influences (conservation efforts)

Numerous riparian brush rabbit conservation and research projects have taken place over the years; the most important projects for consideration in this SSA are discussed below. More details for most of the conservation projects funded between 1997 and 2019 are in the Appendix.

Reintroduction

Prior to 1998, the only known population of riparian brush rabbit existed at Caswell. Since that time, another population was discovered in the South Delta agricultural community. Rabbits from the South Delta population were trapped for a captive breeding program run by the Endangered Species Recovery Program at California State University, Stanislaus. Between 2002 and 2013, approximately 1,500 captive-bred riparian brush rabbits were released on the Refuge and Refuge-managed properties (Kelly 2018b, p. 212). This effort has created the most abundant riparian brush rabbit population in existence and has increased the species' redundancy.

Land acquisition

After the 1997 catastrophic flood on the lower San Joaquin River, several landowners in the floodplain west of the San Joaquin River sought to sell their flood-prone land for inclusion in the existing San Joaquin River National Wildlife Refuge. This coincided with federal and state initiatives to seek alternate methods of flood control, including restoration of riparian habitat and hydrologic function of the floodplain. During 1999-2000, the Service acquired 824 hectares (2,037 acres) of floodplain and riparian habitat west of the San Joaquin River, 85 hectares (210 acres) of floodplain habitat immediately south of the Refuge, and 14 hectares (35 acres) of riparian habitat along the Stanislaus River north of the Refuge. The Service also purchased additional ranch lands both in fee title and in easement on lands that could be restored to reestablish riparian habitat connectivity between Caswell and the Refuge (Service 2006, p. 9). In 2011, River Partners (non-profit organization) purchased Dos Rios Ranch (southeast of the Refuge on the east side of the San Joaquin River) for riparian habitat restoration (U.S. Bureau of Reclamation 2018, p. 2).

Habitat restoration (including flood refugia)

In the past, minor habitat enhancement projects were funded at Caswell (Appendix). Since 2002, River Partners has been working with the Service to restore native riparian forests, shrublands, and grasslands in the Refuge population area (River Partners 2002, p. 2; Rentner 2019, *in litt.*). These large-scale restorations [i.e. >1,300 hectares (>3,300 acres)] have incorporated planting designs to accommodate riparian brush rabbit needs.

In addition to riparian vegetation restoration, considerable resources have been used to create high-ground flood refugia for the riparian brush rabbit (Appendix). Since 2001, habitat restoration in the Refuge population area included the construction and vegetation of earthen mounds. After high mortality during the 2006 flood event at the Refuge, focus considerably increased on creating more refugia mounds and paying close attention to functionality of the mound design (Lloyd *et al.* 2011, no page). Earthen mounds created after the 2006 flood were flat-topped, generally rose ≥ 2.0 meters (6.6 feet) above the surrounding topography, and had surface areas (at apex) ranging from 0.06 to 0.11 hectare (0.15 to 0.27 acre) (Lloyd *et al.* 2007, pp. 5, 8). The mounds, and retired levees, were planted with native riparian vegetation to provide food and cover for rabbits during flood events (Lloyd *et al.* 2007, p. 9).

The importance of the creation and vegetation of high-ground flood refugia at the Refuge was demonstrated during the 2011 flood event. Rabbits were abundant on the vegetated levees and post-flood surveys found brush rabbit sign on all of the new refugia mounds (Lloyd *et al.* 2011, no page). River Partners, Refuge personnel, and species experts have worked to revise refugia design to maximize riparian brush rabbit survival during long-duration flood events. The current restoration designs specify that at least 5% land area be made into flood refugia suitable for riparian brush rabbits and oriented to direct riparian brush rabbit movement away from the deepest part of the floodplain. The use of these restoration designs is ongoing at the Refuge and the neighboring conservation properties (Rentner 2019, *in litt.*).

Flood mortality mitigation

Various actions have been taken to lessen the consequences of flood events for riparian brush rabbit populations. Since the 1970s, there have been efforts to rescue riparian brush rabbits that climbed shrubs and trees to escape rising water (Williams & Basey 1986, p. 14). While rabbit rescues, to our knowledge, have not occurred at Caswell in recent years, they have and still occur, as needed, at the Refuge (Service 2017b, *in litt.*) and are planned for, if needed, at Oxbow (Gantenbein *et al.* 2019, pp. 2, 33). During 2006, approximately 15 rabbits were rescued from Paradise Cut levees and held at the captive-breeding facility until floodwaters receded (Aubrey 2006, *in litt.*).

At Oxbow, the Center for Natural Lands Management (non-profit organization) installed artificial cover structures on the flood refugium berm for riparian brush rabbits to use during the 2017 flood events and documented use by RBR with remote camera (Gantenbein *et al.* 2019, pp. 33, appendix D - no page). During the long-duration flood in 2017, the Refuge provided supplemental food for riparian brush rabbits after natural food sources were depleted on the refugia (Service 2017, p. 2).

Nonnative predator management

Actions have been taken to manage the effects of nonnative predators on two riparian brush rabbit populations. In the past, the California Department of Parks and Recreation trapped and removed feral cats from Caswell (Williams *et al.* 2002, p. 12), but the program is not currently in operation. At Oxbow, fences have been built and are still maintained to exclude neighborhood cats and dogs from the Preserve (Gantenbein 2018, pers. comm.).

CHAPTER 7 CURRENT CONDITION

7.1 Summary of methodology

To assess the current condition of the riparian brush rabbit for this SSA, we divided the current range of the species (Figure 3) into four populations, Caswell, Oxbow, South Delta, and the Refuge (Figure 6). As described in the introduction of CHAPTER 4, we defined populations as spatially congruent groups of individuals (or groups of patches of individuals) that are distinct from each other because of genetic differentiation, spatial isolation, and/or separation by barrier(s) over which genetic exchange is infrequent.

We developed the Condition Category Table (Table 5) to evaluate the condition of individual needs (CHAPTER 3) and population needs (CHAPTER 4) of each riparian brush rabbit population. We also evaluated the quantity of habitat in each population. Table 5 defines the criteria used to rank the condition of individual and population needs as low (score = 1), moderate (score = 2), and high (score = 3).

For several of the individual and population needs, there was not enough information available to determine the condition of the need for three or more of the populations. However, other information was available that served as an indicator for two or more riparian brush rabbit needs. The individual needs of dense, brushy vegetation; grasses and herbs; ecotonal edges (patch heterogeneity); diversity of plants for the dry-season; nest sites and nesting materials; and small-

scale connectivity, are all represented by “habitat quality” in the Condition Category Table (Table 5). The population needs of reproduction, recruitment, and survival are reflected by the long-term “growth rate” in Table 5. The need of scaffolding shrubs and trees was not included in the analysis because the condition of this need is unknown for all populations. In instances where not enough information was available to assign a condition category for a population, the condition was labeled as unknown. More details about the analysis of each need in Table 5 are in sections 7.3 through 7.8.

Table 5. Condition Category Table for ranking riparian brush rabbit population resiliency.

Condition category	Habitat quantity ⁷	Habitat quality ⁸	Flood refugia	Abundance ⁹	Growth rate (long-term)	Distribution	Connectivity (large-scale)
HIGH (healthy)	> 350 hectares (> 865 acres)	Habitat suitability/quality score ≥ 2.5	$\geq 10\%$ of habitat area is high ground that has ample food and cover	≥ 500	Population is increasing ($\lambda > 1$)	Habitat quantity is \geq than 50 hectares; individuals are spread widely across the population range and habitat is interconnected across range.	Population has connectivity to ≥ 2 other populations OR to 1 other population and has potential to expand into unoccupied habitat
MODERATE (moderately healthy)	25 to 350 hectares (62 to 865 acres)	Habitat suitability/quality score $\geq 1.5 < 2.5$	$\geq 5\%$ of habitat area is high ground that has ample food and cover	≥ 200 < 500	Population is stable ($\lambda \approx 1$)	Habitat quantity is \geq than 50 hectares; individuals are spread widely across the population range but some of the range is fragmented.	Population has connectivity to one other population OR has potential to expand into unoccupied habitat
LOW (unhealthy)	< 25 hectares (< 62 acres)	Habitat suitability/quality score < 1.5	$< 5\%$ of habitat area is high ground that has ample food and cover	< 200	Population is decreasing ($\lambda < 1$)	Habitat quantity is $<$ 50 hectares and/or habitat is highly fragmented	Population is isolated

⁷ Among various levels of habitat quality, Basey (1990, pp. 74-75) estimated riparian brush rabbit densities that ranged from 1 to 14 rabbits per hectare. If abundance were moderate at 350 rabbits, a moderate quantity of habitat might range from 25 hectares ($350 \div 14$) to 350 hectares ($350 \div 1$).

⁸ See Section 7.4 for details.

⁹ Categories were derived upon consideration of the historical abundance estimates (Caswell during 1980s and 1990s) and the stressors acting on the Caswell population during the time of the abundance estimates.

7.2 Uncertainties and assumptions

In addition to the limitations and uncertainties associated with the various models and datasets used for the current condition analyses, we have identified the following uncertainties and assumptions.

In many cases, the most recent information available for many of the species' needs was several years old. Our assessment of current conditions might not reflect the actual conditions at the time this SSA is published.

The minimum area required to support the needs of an individual riparian brush rabbit or of a population is unknown. We assumed that small areas (< 25 hectares) would have low resiliency because of the dynamics of riparian brush rabbit habitat and the frequent reoccurrence of stressful conditions (e.g. flood events and drought). There is considerable uncertainty in the estimated quantity and quality of habitat at Caswell based on the results of the habitat suitability model by Phillips *et al.* (2013a, entire; 2013b, spatial dataset). The quantity of habitat at Caswell is likely an overestimation. The accuracy of the habitat suitability model could also be out of date for any or all of the populations.

The estimates of high ground as a proportion of total habitat were based on the best available information and should not be considered comprehensive or precise. For example, we know that Caswell contained some small high-ground areas that are not levees (Williams 1988, p. 11) but the quantity of available high ground is unknown. Thus, it was not included in our assessment. The available levee data within the riparian brush rabbit population ranges were line data, which did not include levee width or crown area. The levees likely vary in width; however, a standard of 6 meters (20 feet) was used to calculate area for all levee crowns and the berm refugium at Oxbow. A crown width of 20 feet is standard for "major streams" according to the California Code of Regulations (23 CCR § 120, Register 2010, No. 16, p. 4.18).

The abundance and growth rate for the Oxbow and South Delta populations were unknown. We made the assumption that the size of the Oxbow Preserve (11 hectares) would preclude its ability to support a moderate abundance of riparian brush rabbits (200 to 499 individuals) and rated Oxbow abundance as low. The conditions of growth rate for Oxbow and of abundance and growth rate for the South Delta were not used to calculate current condition for those populations. However, if growth rate is high for Oxbow, the resiliency of the Oxbow population would be moderate. Likewise, the resiliency of the South Delta population would be moderate if the conditions of abundance and growth rate are both moderate or if at least one condition is high.

For Caswell and the Refuge, we assumed that long-term growth rate reflects riparian brush rabbit rates of reproduction, recruitment, and survival. We also assumed that, in some cases, long-term trends in capture rates may be used as proxies for long-term growth rates. Considering the uncertainties of these assumptions, we also used other sources of information to support our determinations of condition.

Our assessment of current conditions was limited to the extent of our knowledge of riparian brush rabbit occurrences. Extensive surveys have been conducted to locate new occurrences of

riparian brush rabbits in areas with suitable habitat (Basey 1990, pp. 34-35; Williams *et al.* 2000, p. 4). However, many areas, especially in the South Delta, could not be surveyed because of a lack of access. Furthermore, two observations (one from 2012 on the San Joaquin River and the other from 2017 along the Middle River) needed to be excluded from the population assessment because of inadequate information (see Section 4.1).

7.3 Habitat quantity

Habitat quantity was measured by the total habitat area within each population range. We used the habitat suitability model by Phillips *et al.* (2013a, entire; 2013b, spatial dataset) to measure the quantity of riparian brush rabbit habitat within each of the four population ranges (Figure 6; Figure 12). According to the model, the total quantity of habitat (of varying quality) within the four population ranges is approximately 1,965 hectares (4,856 acres). Individual habitat quantities for each population are in Figure 11.

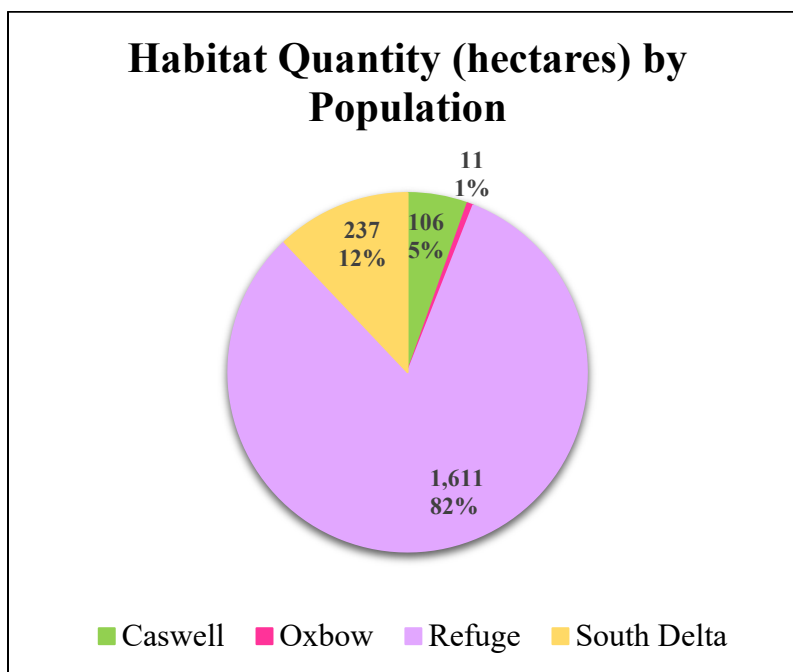


Figure 11. Hectares of habitat area within each population range (Figure 6) based on the habitat suitability model by Phillips *et al.* (2013b, spatial dataset). Percentages are for the total habitat area within the four population ranges.

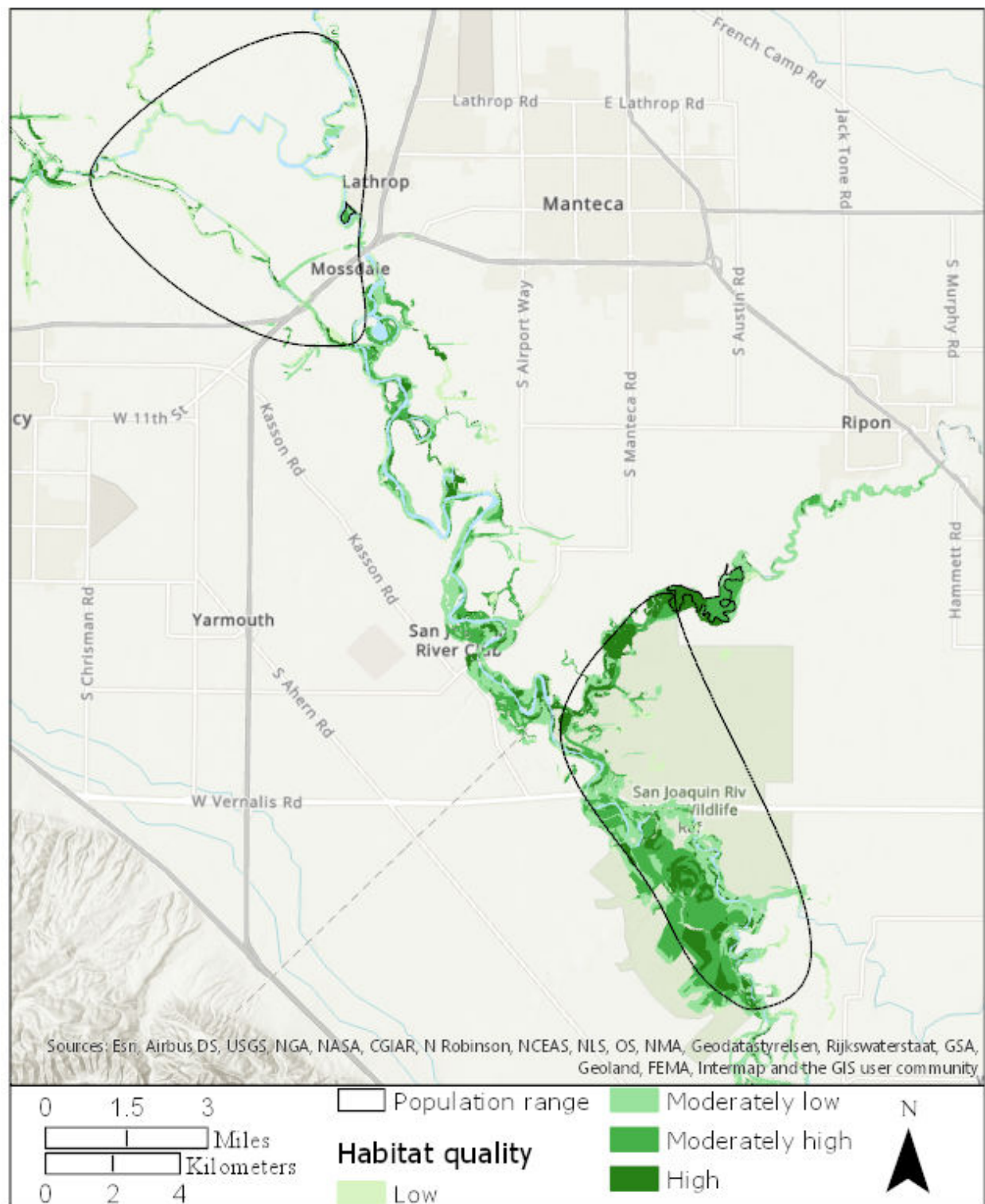


Figure 12. Occupied and potential riparian brush rabbit habitat in and around the four populations, Caswell, Oxbow, South Delta, and Refuge (Phillips *et al.* 2013b, spatial dataset). Habitat quality is classified as low, moderately low, moderately high, or high based on the habitat suitability model by Phillips *et al.* (2013a, entire; 2013b, spatial dataset).

7.4 Habitat quality

To measure habitat quality for each of the four populations, we used the habitat suitability model by Phillips *et al.* (2013a, entire; 2013b, spatial dataset). We also used qualitative and/or quantitative habitat descriptions from scientific literature and species experts to validate the model results, and/or to adjust condition categories based on the limitations of the model.

Habitat suitability model

The habitat suitability model used four datasets, including a Light Detection and Ranging (LiDAR) dataset, to describe vegetation class, structure, and cover (Phillips *et al.* 2013a, p. iii). Habitat suitability was classified as high, moderately high, moderately low, low, or not habitat. The percentages of each habitat class within each population range is in Figure 13. Note that the data in Figure 13 include only the areas within each population range that are characterized as habitat by Phillips *et al.* (2013b, spatial dataset) (Figure 12). Approximately 90% of the Caswell and Oxbow population ranges are classified as habitat by the model, while only 33% of the Refuge and 4% of the South Delta population ranges are classified as habitat by the model (Figure 12).

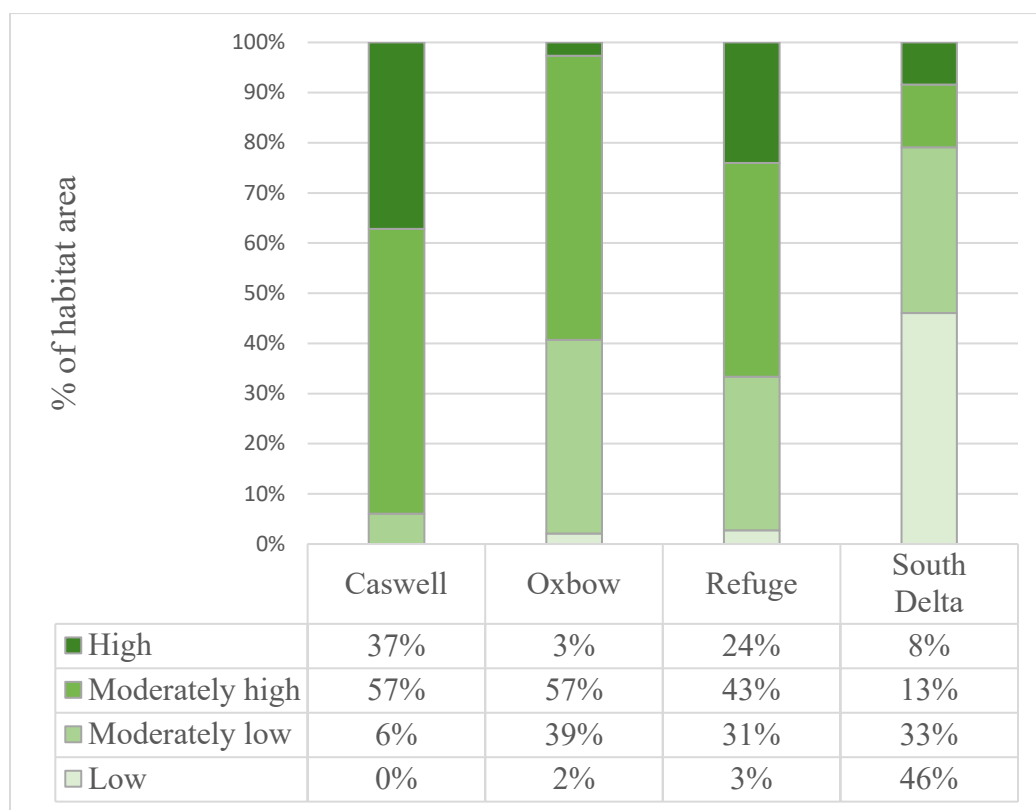


Figure 13. Percentages of population habitat area based on the habitat quality classes of high, moderately high, moderately low, and low from Phillips *et al.* (2013a, entire; 2013b, spatial dataset). The analysis area used for these data includes only the areas within each population range that are characterized as habitat by Phillips *et al.* (2013b, spatial dataset) (Figure 12).

Considering the habitat area classified by Phillips *et al.* (2013b, spatial dataset), the current conditions of habitat quality would be moderate to high for Caswell, moderate for Oxbow, moderate for the Refuge, and low for South Delta (Table 6).

Table 6. Columns 2 and 3 are rankings from the habitat suitability model by Phillips *et al.* (2013b, spatial dataset). As displayed in Column 2, the habitat suitability model classified habitat quality into four ranks, high (4), moderately high (3), moderately low (2), and low (1). We reclassified the 1 to 4 rankings to fit into the SSA condition categories of high (3), moderate (2), and low (3) (Column 3). Column 4 presents the qualitative (and quantitative) rankings of habitat quality from scientific literature and/or species experts.

Population	Habitat suitability model rating (score from 1 to 4)	Condition category for habitat suitability model (score from 1 to 3)	Condition category from other source(s) (score from 1 to 3)
Caswell	Moderately high (3.3)	Moderate-High (2.5)	Low ¹⁰ (1.4)
Oxbow	Moderately high (2.6)	Moderate (1.9)	High ¹¹ , Low ¹²
Refuge	Moderately high (2.9)	Moderate (2.2)	Moderate ¹³
South Delta	Moderately low (1.8)	Low (1.4)	Low ¹⁴

Habitat descriptions from scientific literature and/or species experts

Caswell

The vegetative community at Caswell is characterized as old growth, riparian oak forest with decadent vegetation and extensive tree canopy. According to the Phillips *et al.* (2013b, spatial dataset) habitat suitability model, there are approximately 106 hectares (262 acres) of riparian brush rabbit habitat within Caswell. This estimate is remarkably similar to the habitat area reported by Basey (1990, p. 39) for 1987, approximately 104.5 hectares (258 acres). However, in contrast to the suitability model rankings (Figure 13), Basey (1990, p. 39) rated 6% of the habitat as high quality, 31% at moderate quality, and 63% as low quality. Based on these ratings, and the status of conditions suggested by Williams *et al.* (2002, p. 4) and Constable *et al.* (2011, p. 3), the current condition of the habitat at Caswell would be low (Table 6).

There are several reasons why there could be a discrepancy between the model and other characterizations of the habitat quality. For example, Basey's observations took place during the 1980s while the datasets used by Phillips *et al.* (2013a, pp. 8-9, 24) were more recent (2003-2011). However, the datasets used for the habitat suitability model were limited for Caswell, compared to the South Delta region (Phillips *et al.* 2013a, p. 24) and they might not have been

¹⁰ Basey 1990, p. 39

¹¹ Gantenbein *et al.* 2019, p. 27

¹² California Department of Fish and Wildlife 2019, no page

¹³ Phillips *et al.* 2005, pp. 17-18; Service 2006, pp. 20-21; Rentner 2019, *in litt.*

¹⁴ Williams *et al.* 2002, pp. 1-3, 5-6; Phillips *et al.* 2013b, pp. 17-18

adequately able to delineate among fine-scale habitat attributes. Furthermore, it is likely that the model ranking parameters did not rate riparian brush rabbit habitat needs adequately for the conditions at Caswell. According to the ranking parameters, canopy density only affected habitat quality rankings if the density was greater than or equal to 90% (Phillips *et al.* 2013a, p. 12).

Historically, the Caswell area was exposed to disturbances including scouring floodwaters (now moderated by the 1978 New Melones Dam), wildfires, and grazing (Williams *et al.* 2002, p. 6). Since the abatement of these disturbances, the tree canopy has expanded and become denser. The tree canopy shades the understory, which suppresses the growth of shrubs, grasses, and herbs. As a result, the early-successional vegetation that is preferred by riparian brush rabbits has become rarer. The progression of Caswell habitat into a climax forest community with few canopy openings has reduced the quantity and quality of riparian brush rabbit habitat at the Park (Williams *et al.* 2002, p. 4; Constable *et al.* 2011, p. 3).

Based on the information described above and the decrease in riparian brush rabbit abundance at Caswell (Section 7.6), we consider the current condition of habitat quality at Caswell to be low (Table 6).

Oxbow

The Oxbow Preserve is currently owned and managed by the Center for Natural Lands Management. The property is within the city of Lathrop, California and is bordered by the San Joaquin River on all but the northeast side of the Preserve. Historically (i.e. mid-20th century), the Oxbow area was used for agriculture, and possibly grazing (Gantenbein *et al.* 2019, p. 7 and aerial imagery in figure 4). In 2004, the Oxbow Preserve was established as partial mitigation for adverse effects to the riparian brush rabbit associated with the Mossdale Landing housing development (Gantenbein *et al.* 2019, p. 1). Since the Preserve's establishment, the Center for Natural Lands Management has managed and enhanced the habitat for riparian brush rabbit at Oxbow (Gantenbein *et al.* 2019, pp. 20-23). The current habitat is characterized as a patchy matrix of vegetation types including second-growth riparian forest, dense brush (willow thickets, blackberry, wild rose), and open grasslands (Gantenbein *et al.* 2019, p. 8). The patch heterogeneity creates ecotonal edges, a habitat need for riparian brush rabbits. In general, Oxbow is described as "good" quality riparian brush rabbit habitat (Gantenbein *et al.* 2019, p. 27). However, the California Natural Diversity Database ranks the Oxbow habitat quality and population condition as "fair" (California Department of Fish and Wildlife 2019, no page).

Based on our assessment of the available information, we consider the current condition of habitat quality at Oxbow to be moderate, as determined by the habitat suitability model by Phillips *et al.* (2013b, spatial dataset).

Refuge

The riparian brush rabbit population referred to as the Refuge in this SSA, occupies an extensive area that includes much of the San Joaquin River National Wildlife Refuge, as well as neighboring properties (i.e. Faith Ranch, Buffington Tract, and Dos Rios Ranch) that are being managed and restored by the San Luis National Wildlife Refuge Complex and by River Partners. Historically, the area served as a natural floodplain for the meandering San Joaquin River. Although some of the land retained its natural riparian vegetation, much of the area was

converted to livestock pasture, and then to agriculture during the 20th century (Service 2006, pp. 20-21).

Since 2002, River Partners has been working with the Service to restore native riparian forests, shrublands, and grasslands in the Refuge population area (River Partners 2002, p. 2; Rentner 2019, *in litt.*). These large-scale restorations [i.e. >1,300 hectares (>3,300 acres)] have incorporated planting designs specifically for riparian brush rabbit habitat creation and enhancement (Rentner 2019, *in litt.*). Thus, much of the Refuge population range contains, or will contain, habitat that meets the individual and population needs of riparian brush rabbits. However, a large proportion of the Refuge is managed for other wildlife and plant species, many of which have habitat needs that are different from riparian brush rabbit needs (Phillips *et al.* 2005, pp. 17-18; Rentner 2019, *in litt.*).

Based on our assessment of the available information, the habitat descriptions from scientific literature and/or species experts are in agreement with the habitat suitability model (Phillips *et al.* 2013b, spatial dataset). The current condition of habitat quality for the Refuge population is moderate (Table 6).

South Delta

The South Delta population range contains linear patches of habitat that extend along a railroad and water channels, including the San Joaquin River, Old River, Paradise Cut, and Tom Paine Slough (Figure 6). Most of the habitat is on private land that is surrounded by agriculture and urban development (Williams *et al.* 2002, pp. 1-3). The South Delta habitat is characterized by mostly open canopy; numerous patches of dense, early-successional vegetation; and areas of tall, herbaceous weeds. Much of the habitat has remained in the early-successional stage because of a combination of disturbances including periodic floods, levee and channel clearing, and farming practices (Williams *et al.* 2002, p. 6).

Generally, the vegetated areas are very narrow in the South Delta, often only 5 to 20 meters (16 to 66 feet) wide (Williams *et al.* 2002, p. 3). This configuration of habitat suggests that small-scale and large-scale connectivity is poor in the South Delta because narrow habitat restricts movement and narrow transit corridors are at risk of becoming fragmented. The linear nature of the habitat limits most riparian brush rabbit activity to the steep sides of water channels, the bases of levees, and other low-ground areas (Williams *et al.* 2002, p. 5). The linearity of the habitat can also be beneficial for riparian brush rabbits because of the associated ecotonal edges that border the habitat strips; however, some brush edges are bordered by ruderal vegetation (Phillips *et al.* 2013b, pp. 17-18) that is inadequate to meet riparian brush rabbit needs. It is unknown whether the South Delta's high proportion of ecotonal edge to brushy cover is overall beneficial, or detrimental, to the population.

Based on our assessment of the available information, the habitat descriptions from scientific literature and/or species experts are in agreement with the habitat suitability model (Phillips *et al.* 2013b, spatial dataset). The current condition of habitat quality for the South Delta population is low (Table 6).

7.5 Flood refugia

The current condition of flood refugia was measured by the amount (proportion of habitat) and quality (amount of food and cover) of high ground within each population's habitat area. For all populations, we used the Federal Emergency Management Agency levee data (2016, spatial dataset) to determine the total length of all levees within and proximate¹⁵ to riparian brush rabbit habitat for each of the four population ranges using ArcGIS Pro (Esri 2018). For Oxbow, we also used high-resolution imagery (Esri & DigitalGlobe 2018, 30cm imagery from September 2018) to estimate the length of the refugium berm in Oxbow Preserve. To calculate area, we multiplied the total length of all levees/berm for each population habitat range and multiplied by 6 meters (20 feet).

For the Refuge, we used GIS data from our files and high-resolution imagery (Esri & DigitalGlobe 2018, 30cm imagery) to determine the total area of artificial high-ground mounds within the Refuge population range that were above water during the 2017 flood. We also included the natural high-ground riparian brush rabbit habitat [approximately 16 hectares (40 acres)] on the Refuge (Forrest 2018, pers. comm.).

The estimated proportion of total high ground area (including areas without adequate food and cover) to habitat area for each population range are provided in Table 7. Based on the proportion of high ground alone, Caswell, Oxbow, and the Refuge were all ranked low for current condition of flood refugia. Approximately 8% of South Delta habitat is high ground because of its close association with levees. However, flood refugia condition in the South Delta are also in low condition because most of the levees are maintained to be free of vegetation.

Table 7. Estimated areas and percentages of high ground (both with and without adequate food and cover) within or near habitat for the four riparian brush rabbit population ranges. Area units are in hectares followed by acres in parentheses. The high-ground areas are estimated based on the available information and should not be interpreted as precise.

Population	Total habitat area	Levee/ berm area	Mounds area	Natural high ground area	Sum of high ground ÷ habitat area × 100%	Condition based on % high ground
Caswell	106.5 (263.1)	0.4 (0.9)	0.0	-	0.4%	Low
Oxbow	10.7 (26.4)	0.3 (0.7)	0.0	-	2.6%	Low
Refuge	1610.7 (3980.2)	28.5 (70.4)	3.0 (7.5)	16.0 (39.5)	2.9%	Low
South Delta	247.5 (611.7)	20.5 (50.8)	0.0	-	8.3%	Moderate

¹⁵ In the South Delta population range, some of the levees included in the analysis were parallel to, and just outside of, the outer edges of habitat areas.

7.6 Abundance and growth rate

By the time the riparian brush rabbit was federally listed as Endangered in 2000, conservation efforts for the species were focused on creating a captive breeding program from the few rabbits that remained in the wild. During subsequent years, conservation efforts and funds were dedicated to studying riparian brush rabbit ecology, habitat restoration, and monitoring translocated rabbits that were introduced on San Joaquin National Wildlife Refuge. Studies focused on estimating the abundance of the natural riparian brush rabbit populations had lower priority. Furthermore, capture rates in the natural populations were frequently too low to use capture-recapture population estimation (Close & Williams 1998, p. 8), as had been used in the past. Besides anecdotal abundance estimates, the Caswell population has not been estimated since 1993 (Williams 1993, p. 5), and the Oxbow and South Delta populations have never been estimated. Thus, we consider historical and/or anecdotal estimates of abundance and evaluate whether the current condition of abundance can be inferred with moderate confidence.¹⁶ If we are less than moderately confident, we consider abundance as unknown.

To infer abundance from historical and/or anecdotal population estimates, we used capture rate data. Capture rate is equal to the number of rabbits captured divided by the number of trap days; trap days are the number of traps multiplied by the number of 24-hour periods that the traps were set. We also used capture rates over time to infer the condition of population growth rate (i.e. growth rate is $>$, $<$, or ≈ 1.0).

Caswell

The best available information suggests that the Caswell riparian brush rabbit population has low abundance and low growth rate. Drastic population reductions, caused by flood events, have occurred in this population (California Department of Fish and Wildlife 2019, no page)

The largest population estimate for Caswell was 320 to 540 riparian brush rabbits for the winter of 1986 to 1987. The estimate was for 104.5 hectares (258 acres). Average density was 4.1 (range = 1 to 14) rabbits per hectare (Basey 1990, pp. 39, 73-75). However, it should be noted that Basey's estimate was extrapolated across the 104.5 hectares from capture-recapture data for six rabbits, within a small study area.

During January of 1993, there were an estimated 241 (95% confidence interval = 170 to 608) riparian brush rabbits in an estimated 81 hectares (200 acres) of habitat at Caswell (abundance estimate was based on capture-recapture data for 41 rabbits). Riparian brush rabbit density in the surveyed areas was 3.0 (95% confidence interval = 2.1 to 7.5) rabbits per hectare (Williams 1993, p. 5).

Surveys during or following flood years (e.g. 1983, 1986, and 1997) did not elicit enough captures to adequately estimate population size or density. Caswell population reports following flood events were typically anecdotal, with estimates of less than 10 rabbits to a maximum

¹⁶ For this SSA, we define "moderate confidence" as being 70 to 90% sure that a relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.

estimate of 31 rabbits (Williams 1988, p. 17; Basey 1990, p. 45; Close & Williams 1998, p. 8; California Department of Fish and Wildlife 2019, no page).

The riparian brush rabbit population has not rebounded since the 1997 flood, although it had done so after past flood events. Zero riparian brush rabbits were captured during the 1997 trapping efforts, and two to six rabbits were captured during each of the following three years (Williams *et al.* 2000, p. 5). The numbers of trap days per year ranged from 928 in 1999 (two captures) to 2,772 in 1997 (zero captures). In 2007, following the 2006 flood, only one riparian brush rabbit was captured on Caswell (2,520 trap days) (Kelly *et al.* 2007, p. 26). The following two surveys, years 2008 and 2012, elicited only two captures each (2,520 and 1,200 trap days, respectively) (Kelly, Lloyd *et al.* 2008a, p. 19; Kelly *et al.* 2014, p. 13). The Caswell population has not been surveyed since 2012.

Capture rates over time for Caswell are in Figure 14. When there were an estimated 241 riparian brush rabbits at Caswell, the capture rate was 1.86% (Williams 1993, p. 5). Since the 1997 flood, capture rates have ranged from a low of 0% in 1997 to a high of 0.62% in 2002 (Figure 14).

The best available information suggests that the conditions at Caswell have not improved for the riparian brush rabbit since 2012. Thus, we have moderate-to-high confidence¹⁷ that the current condition of abundance at Caswell is low. Based on Figure 14, historical population estimates from the 1980s and 1990s, and failure of the population to rebound during non-flood years, the long-term growth rate of the population is less than one (low condition).

¹⁷ We are more than 70% sure that this assumption accurately reflects the reality in the wild as supported by some available information and/or that it is consistent with accepted conservation biology principles.

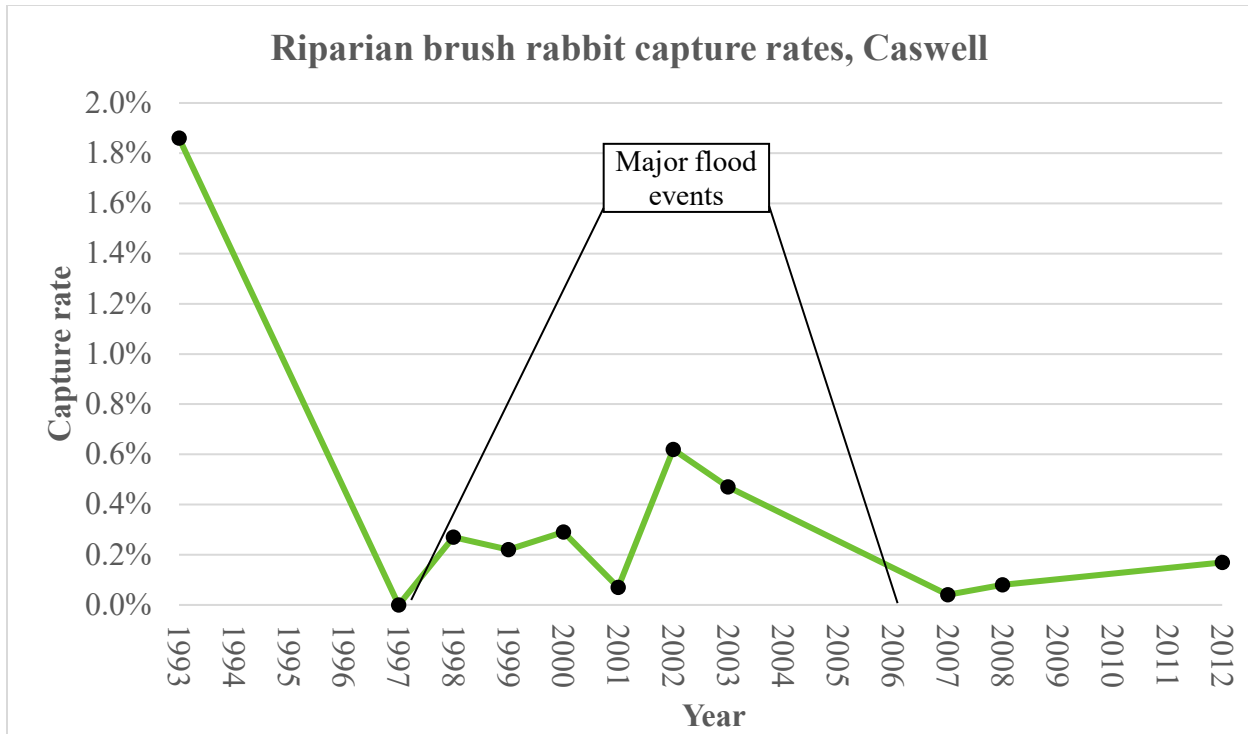


Figure 14. Riparian brush rabbit capture rates at Caswell during annual winter (Jan to Feb) trapping surveys. Capture rate = # of rabbits captured ÷ # of trap days × 100%. Trap days = # of traps set × # days open. There are no survey data for 1994-1996, 2004-2006, and 2009-2010. Flood events, of varying severity, occurred at Caswell in 1997, 1998, and 2006. Flood events may have also occurred in 2011 and/or 2012. (Williams *et al.* 2005, p. 32; Kelly *et al.* 2007, p. 26; Kelly *et al.* 2008a, p. 19; Kelly *et al.* 2014, p. 13)

Oxbow

The Oxbow riparian brush rabbit population has not been surveyed to estimate population size. Therefore, the current condition of abundance is unknown. However, the amount of habitat available at the Preserve (approximately 11 hectares) would indicate that population abundance is less than 200 individuals. The highest density of riparian brush rabbits estimated by Basey (1990, pp. 74-75) was 14 rabbits per hectare. At the high density of 14 rabbits per hectare, the Preserve would support approximately 154 riparian brush rabbits. Therefore, the current condition of abundance for the Oxbow population was ranked as low.

Trapping, primarily to capture rabbits for the captive-breeding program, was conducted during 2003, 2008 to 2010, and 2012. Capture rates have mostly been high for this population but they have fluctuated drastically. The highest capture rate was 14.44% in 2003 and the lowest was 0.42% in 2008 (Figure 15). Beginning in 2008 to 2009, the Center for Natural Lands Management has operated camera traps to document riparian brush rabbit distribution, predator presence, and other wildlife presence on the Preserve (Gantenbein *et al.* 2019, pp. 20, 24, 28). Since the initial 2003 surveys, riparian brush rabbits have been regularly observed both directly and on camera trap photographs (p. 12). However, Gantenbein *et al.* (2019, pp. 27-28) reported

that camera-trap capture rates have notably decreased at Oxbow since the 2017 flood, thereby indicating that a substantial population loss likely occurred from flood-related trauma and predation.

The available information is inadequate to determine the long-term growth rate of the Oxbow population. Therefore, the current condition of growth rate for Oxbow is unknown.

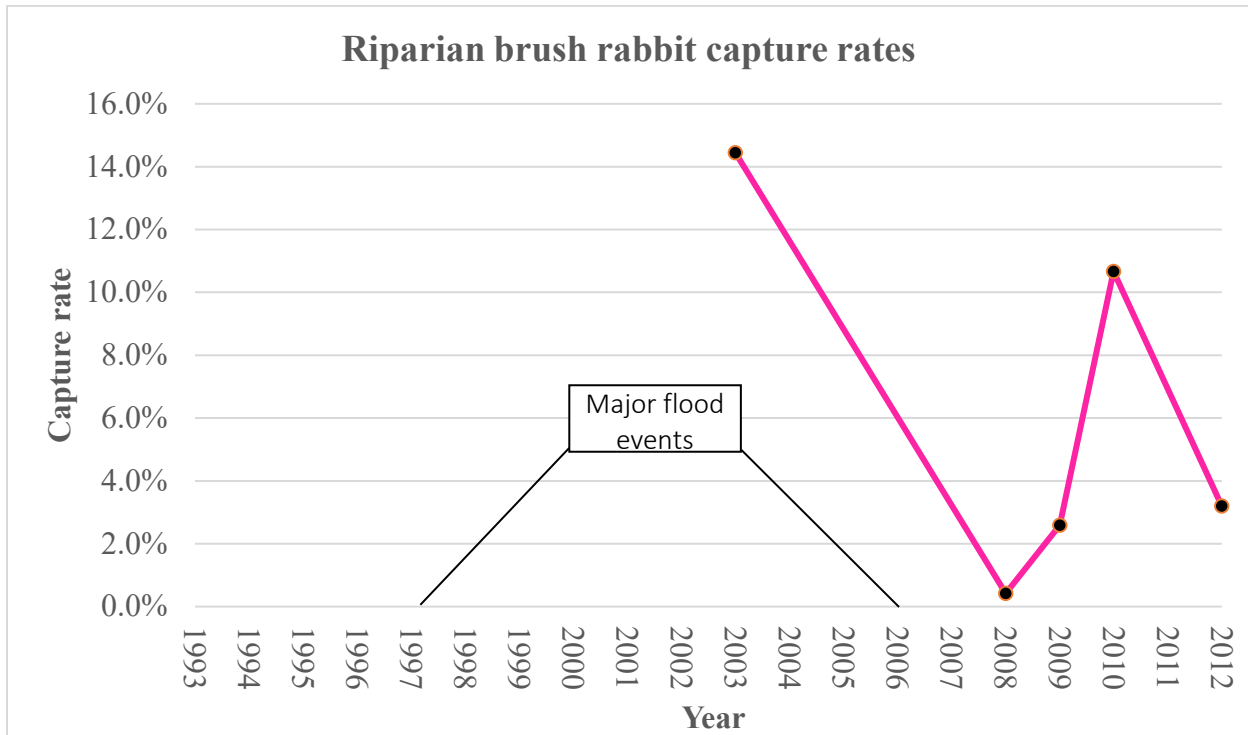


Figure 15. Riparian brush rabbit capture rates in the Oxbow population. Capture rate = # of rabbits captured ÷ # of trap days × 100%. Trap days = # of traps set × # days open. Flood events, of varying severity, occurred in 1997, 2006, and 2011. (M. R. Lloyd & Williams 2003, pp. 2-3; Kelly, Lloyd *et al.* 2008b, p. 11; Kelly & Lloyd 2009a, pp. 16-17; Kelly & Lloyd 2010, p. 9; Kelly *et al.* 2013, p. 18)

Refuge

Based on studies of riparian brush rabbits at Caswell, Wittmer *et al.* (2016, p. 340) calculated a carrying capacity (i.e. maximum sustainable population) of 2,550 rabbits at the Refuge but noted that the estimate is conservative because the Refuge contained more suitable habitat than Caswell. During March and April of the 2017 flood, riparian brush rabbits on the vegetated levee refugia numbered in the hundreds (Service, unpublished data) and the surviving population was estimated at 930 rabbits during April (Service 2017b, *in litt.*). These data and recent observations by Refuge managers (Forrest 2018, *in litt.*; Hopson 2019, *in litt.*) indicate that the current condition of abundance in the Refuge population is high.

During the riparian brush rabbit captive breeding and introduction program, released and wild-born rabbits in the Refuge population were monitored with trapping during the spring and fall of most years (Figure 16). The capture rates in Figure 16 suggest that the Refuge population

gradually rebounds following flood events. By distinguishing between capture rates for translocated and wild rabbits, these data indicate that reproduction and recruitment are positive; however, the data are influenced by the population supplementation (release of captive-bred rabbits) that was ongoing throughout the period. When released captive-bred rabbits reproduced, the capture rate of wild-born rabbits would increase. With artificial population supplementation, the influence of survival rates may not be accurately reflected in Figure 16.

To assess the current condition of long-term growth rate in the Refuge population, we considered other sources of information, in addition to the capture rate data in Figure 16. We know that riparian brush rabbits from the Refuge are naturally dispersing into new areas (U.S. Bureau of Reclamation 2018, p. 11). Refuge managers also consider the Refuge population to be robust and to have significantly improved since the six-month long flood during 2017 (Forrest 2018, *in litt.*; Hopson 2019, *in litt.*) Based on all of the available information, we ranked the current condition of the Refuge population's long-term growth rate as high.

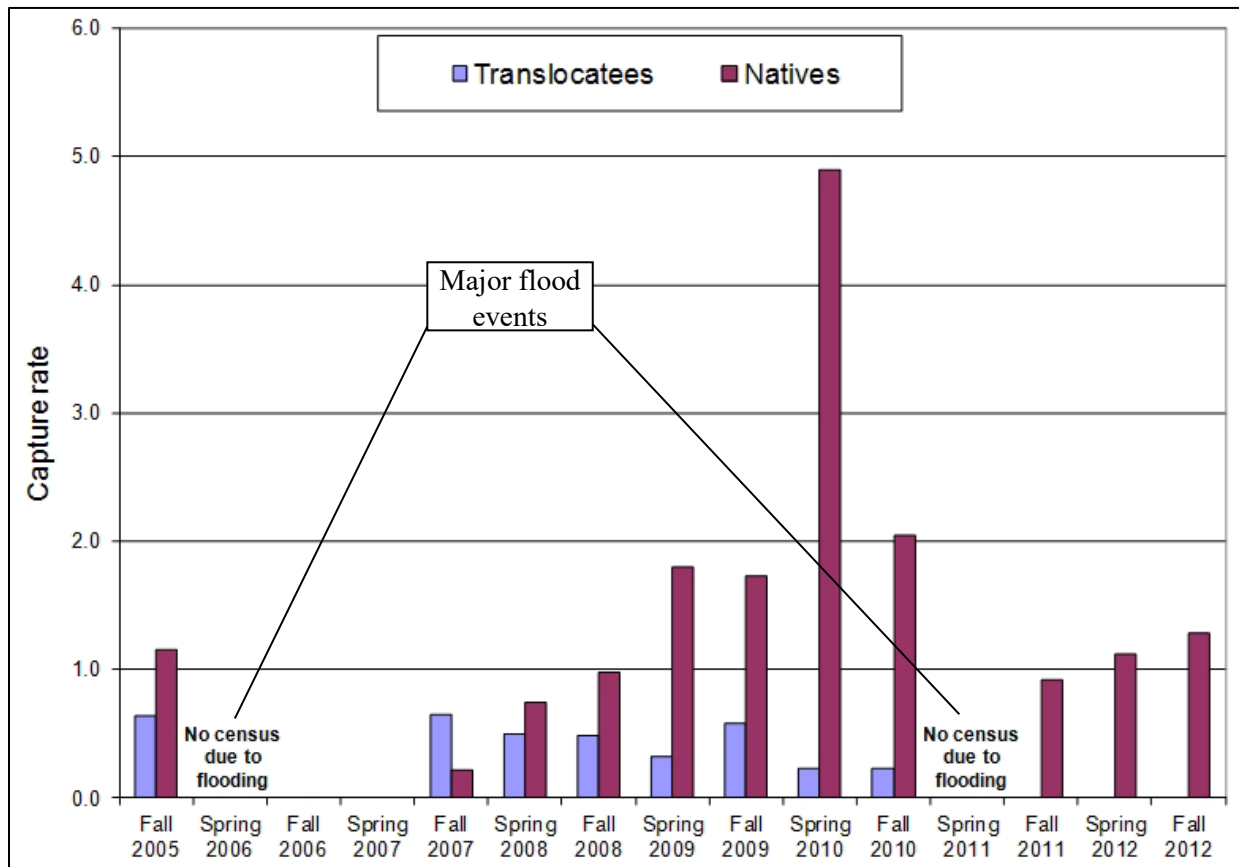


Figure 16. From Kelly *et al.* (2013, p. 12, figure 7), “Overall capture rates of brush rabbits during censuses at the San Joaquin River NWR – West Unit (Fall 2005 – Fall 2012).” Capture rate = # of rabbits captured ÷ # of trap days × 100%. Trap days = # of traps set × # days open. Flood events occurred in 2005, 2006, 2011, and 2012. “Translocatees” are riparian brush rabbits that were born in the captive breeding pens and released onto the Refuge. “Natives” are progeny of captive-bred riparian brush rabbits, but were born in the wild.

South Delta

The South Delta population was first discovered near the Southern Pacific Railroad and Paradise Cut in 1998. Based on 1998 to 1999 captures and habitat assessment, Williams *et al.* (2000, p. 7) estimated (anecdotally) there were approximately 25 to 100 individuals in this segment of the South Delta population. The remainder of the currently known occupied areas in the South Delta were documented in 2001 and 2003 (California Department of Fish and Wildlife 2019, no page). For 2001, Williams *et al.* (2002, p. 1) estimated (anecdotally) there were a few hundred riparian brush rabbits in the South Delta population.

The South Delta population is assumed larger than the Caswell population because more successional vegetation is available in the South Delta habitat (Constable *et al.* 2011, p. 3). In addition to the known occurrences of riparian brush rabbits in the South Delta range, there is potential habitat on private lands along the Middle, Old, and San Joaquin rivers (Figure 18) that has not been surveyed (Phillips *et al.* 2013b, pp. 17-18).

Between 1999 and 2012, various portions of the South Delta range were trapped to capture rabbits for the captive-breeding program. Capture rates for this population are high compared to Caswell and the Refuge (Figure 17). However, capture rates could be biased high because locations varied among years, and because areas with high densities of rabbits were targeted.¹⁸ The capture rate trend appears to be slightly decreasing (Figure 17) but it could also be exhibiting random or natural population fluctuations, while the population growth rate is stable. Without additional information, the current condition of growth rate for the South Delta population is unknown.

¹⁸ Considering the high capture rates for Oxbow and the rest of the South Delta, capture rates may be indicative of habitat structure, food condition/quality (traps were baited), and/or population density. At this time, the reason(s) for capture rates being higher in the northern part of the riparian brush rabbit range cannot be determined.

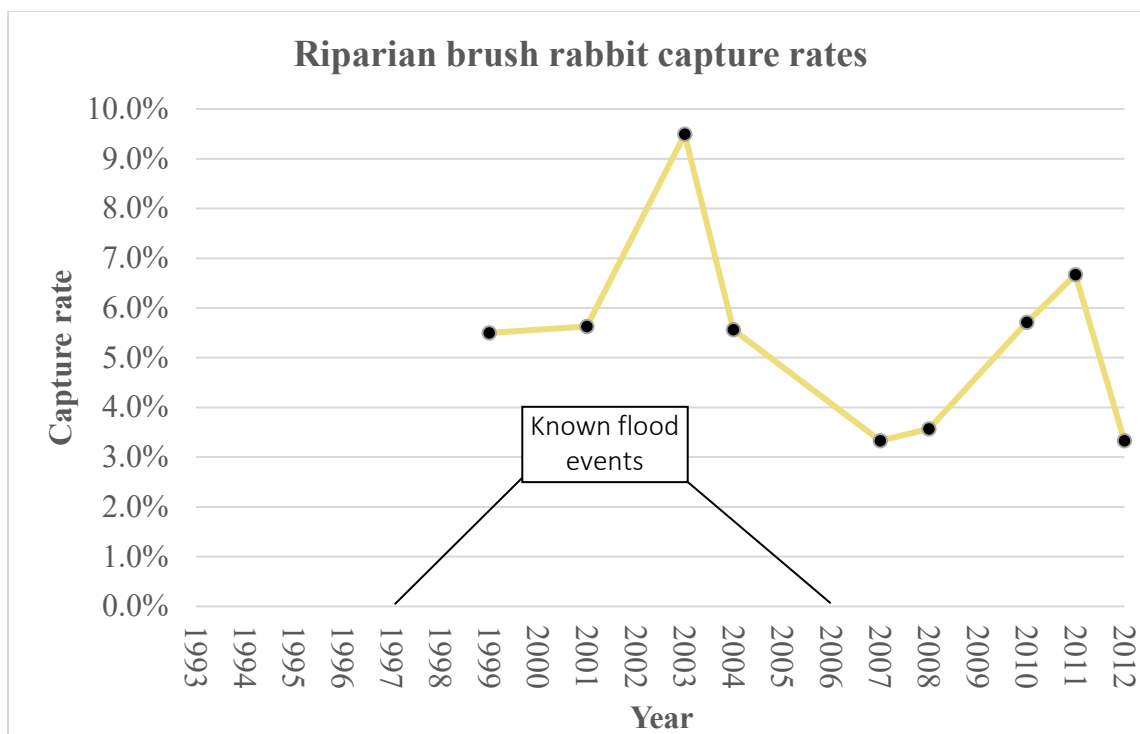


Figure 17. Riparian brush rabbit capture rates in the South Delta population. Capture rate = # of rabbits captured ÷ # of trap days × 100%. Trap days = # of traps set × # days open. Trapping locations and times of year varied for each capture rate. Capture rates reported for 1999, 2003, 2008, and 2010 include trapping data from later month(s) of the preceding years. Flood events occurred in 1997 and 2006. Flood events may have also occurred in 2011 and/or 2012. (Williams *et al.* 2000, p. 7; Williams & Hamilton 2002, pp. 4-5; Vincent-Williams *et al.* 2004, p. 4; Williams *et al.* 2005, p. 5; Kelly *et al.* 2007, p. 25; Kelly *et al.* 2008a, p. 18; Kelly & Lloyd 2009b, p. 12; Kelly & Lloyd 2010, p. 9; Kelly & Holt 2011, p. 7; Kelly *et al.* 2013, pp. 17-18)

7.7 Distribution

In the presence of stressors (e.g. flood events and fires), populations with limited distributions are at greater risk of extirpation. The distribution of individuals across a population is largely determined by habitat availability and connectivity. To determine the current condition of distribution for each population, we assessed the quantity of habitat available across a population range and the interconnectedness of the habitat within each population range.

During the 1980s, riparian brush rabbits at Caswell were widely distributed across the Park (Williams 1988, p. 13; Basey 1990, p. 37). However, approximately 50% of the park area had little evidence of rabbit occupancy because the areas were frequently flooded, did not contain shrubs or had few low shrubs, and/or had a closed tree canopy (Williams 1988, p. 13). Following the 1997 flood, riparian brush rabbit distribution across Caswell decreased and has not recovered since. After 1997, riparian brush rabbits were limited to only three areas of the park (Williams *et al.* 2000, pp. 5-6). Rabbit sign became scarce or absent (Williams *et al.* 2005, p. 31) in areas of Caswell that previously supported medium densities (i.e. 6 to 10 rabbits per hectare) of riparian brush rabbits (Basey 1990, pp. 40, 74). Since 2003, riparian brush rabbits have only been trapped

in the Fenceline Trail area during winter trapping surveys (Kelly *et al.* 2007, p. 26; Kelly *et al.* 2008a, p. 19; Kelly *et al.* 2014, p. 13). Based on the above information, the current condition of the distribution of riparian brush rabbits at Caswell is low.

The amount of habitat and size of the Oxbow population range is small. Therefore, the Oxbow population does not gain resiliency with distribution across its limited range. The current condition of the distribution of riparian brush rabbits at Oxbow is low.

The available habitat area in the Refuge population range is very large (Section 7.3) and is connected across the range (Figure 12). Based on trapping data, Rentner & Lloyd (2010, p. 5) also noted that the long vegetated levees appeared to facilitate rabbit dispersal and movement across the Refuge, even during flood events. The current condition of the distribution of riparian brush rabbits in the Refuge population is high.

Riparian brush rabbits in the South Delta are widely distributed across a geographic area and among different waterways (Figure 12). However, distribution is confined to fragmented and linear habitat strips (Phillips *et al.* 2013a, p. 16). Therefore, the current condition of the distribution of riparian brush rabbits in the South Delta is moderate.

7.8 Connectivity (large-scale)

In this SSA, large-scale habitat connectivity is assessed as the presence of habitat corridors and landscape features that enable riparian brush rabbits to successfully disperse and move long distances. Connectivity among the four populations was also informed by the results of genetic analyses. At this scale, connectivity is typically viewed in terms of inter-population connectivity (i.e. movement from one population to a different population). Inter-population connectivity is important for both population resiliency and species redundancy (Section 7.10). Connectivity, in terms of the ability of individuals to move successfully within a population range, was addressed in Section 7.7.

A habitat connectivity model for the riparian brush rabbit was developed by Phillips *et al.* (2013a, entire) by relating habitat suitability (Figure 12) with a cost-distance analysis in ArcGIS software. According to the connectivity model, capture-recapture data (Endangered Species Recovery Program, unpublished data), and genetic research (Matocq *et al.* 2017, pp. 22, 35), there is ongoing connectivity between the Caswell and Refuge populations. The habitat suitability model by Phillips *et al.* (2013a, p. iii) determined that there are approximately 3,500 hectares (8,645 acres) of riparian brush rabbit habitat (of varying quality) near the existing populations. Most of the modeled habitat (72%) is south of the confluence of the San Joaquin and Stanislaus rivers (Caswell and Refuge populations). Riparian brush rabbits from the Refuge population have been documented dispersing across the San Joaquin River onto newly restored habitat at Dos Rios Ranch (U.S. Bureau of Reclamation 2018, p. 11). Based on the availability of [presumed] unoccupied habitat, ongoing riparian floodplain restoration (Rentner 2019, *in litt.*), and the known connectivity between Caswell and the Refuge, the current conditions of connectivity for Caswell and the Refuge are both high.

The land surrounding Oxbow Preserve (on both sides of the river) is primarily residential housing or is cleared for future development (Figure 18). Oxbow is essentially an isolated fragment of the South Delta population. The current condition of connectivity for Oxbow is low.

Similar to Oxbow, the South Delta population is flanked by development but it is also surrounded by agriculture, which is marginally more conducive to riparian brush rabbit occupancy (Figure 19). While small patches of potential habitat exist outside of the known population range, habitat patches are fragmented. There is no evidence of recent connectivity between the South Delta and Caswell or the Refuge. The current condition of connectivity for the South Delta is low.

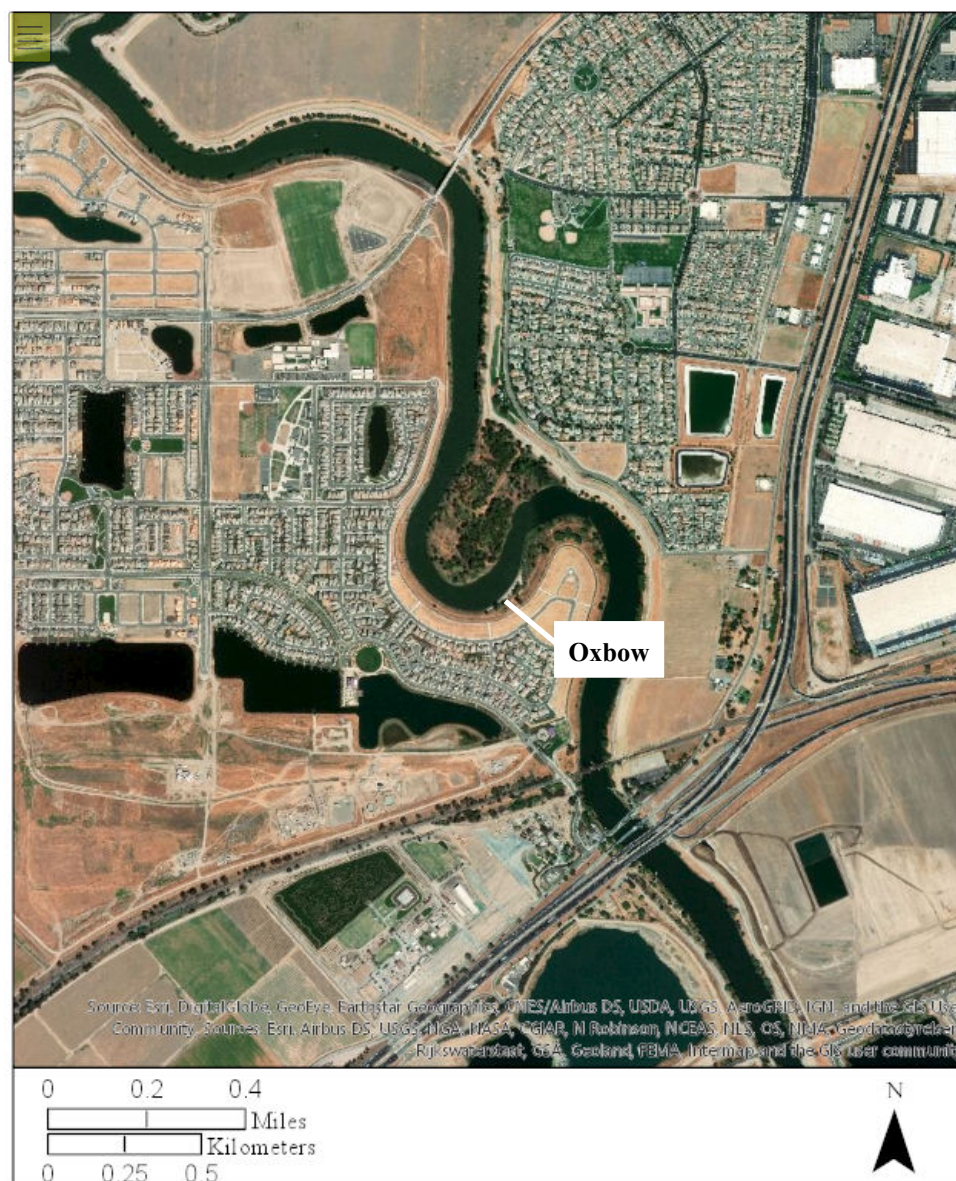


Figure 18. Imagery of Oxbow Preserve in 2018, Lathrop, California. (Esri & DigitalGlobe 2018, imagery)



Figure 19. Imagery of South Delta population range in 2018. (Esri & DigitalGlobe 2018, imagery)

7.9 Population resiliency

To achieve an overall rating of resiliency for each population, we averaged the scores (low = 1, moderate = 2, and high = 3) of individual and population needs across each population (Table 8). For the final score, habitat quality was given twice the weight as the other needs (entered twice in the average) because it reflects several riparian brush rabbit needs. Definitions of condition categories for each need are in Table 5.

Of the four populations of riparian brush rabbit, three populations are currently in low condition and one population is in high condition (Table 8).

7.10 Species representation

To assess the current condition of representation, the species' ability to adapt to change, we consider the current diversity of ecological conditions and genetic material among the four riparian brush rabbit populations. In general, representation is high when a species exists across a wide range ecological conditions and has high genetic diversity. These measures of representation are correlated with (but not dependent upon) the size of the geographic area occupied by the species.

Historically, the riparian brush rabbit was likely distributed continuously along rivers and floodplains across a much larger range. Ecological variation across the larger historical range may have resulted in genetic differentiation through local adaptations and natural selection. Over time, the species' range has been reduced to fragmented remnants within an area approximately 30 kilometers (20 miles) long in California's Central Valley (Figure 3). The extensive range reduction suggests that the riparian brush rabbit has lost most of its historical representation.

As described in Section 5.2, the current populations of riparian brush rabbit occupy habitats that vary in vegetation and structure. There is also substantial genetic differentiation between the two remaining natural populations of riparian brush rabbit [i.e. South Delta (including Oxbow) and Caswell]. However, there is little variation in climate or topography within the currently occupied range; habitat variation is primarily related to human activities or forest succession. This suggests that the variation is in habitat quality, not in ecological conditions that give way to natural selection over many generations. Furthermore, the genetic differentiation likely resulted from genetic drift (Matocq *et al.* 2017, p. 21) that followed habitat fragmentation and/or population reductions. Populations that experience genetic drift undergo a loss of genetic diversity. Therefore, it is likely that the riparian brush rabbit lost much of its historical genetic diversity by range reduction and lost local genetic diversity through genetic drift.

As explained above, the current variations in habitat and in genetic material among riparian brush rabbit populations are not indicative of the species' ability to adapt to change (i.e. representation). Genetic drift is also likely to continue affecting riparian brush rabbit representation when flood events cause mortality of large portions of populations. Therefore, the current condition of representation for this species is low.

7.11 Species redundancy

To assess the current condition of redundancy, the species' ability to withstand catastrophic events, we consider the number of resilient populations throughout the riparian brush rabbit range. Currently, the riparian brush rabbit has one resilient population (Table 8). However, redundancy could be slightly better (i.e. two resilient populations) if the Oxbow population growth rate (currently unknown) is found to be in high condition. Whether there are one or two resilient populations, the current species redundancy is low.

Low redundancy is a serious concern for the conservation of this species because riparian brush rabbit habitat is very prone to flooding. If a catastrophic flood (e.g. 100-year flood) occurred in the species' range, all current populations would be strongly affected because all are clustered near the main stem of the San Joaquin River in the middle of the Central Valley. The riparian brush rabbit would be much more likely to withstand a catastrophic flood event if populations occurred along upper river reaches, far from the San Joaquin River. For redundancy against catastrophic floods, multiple resilient populations should be distributed across different hydrological systems in the species' historical range.

Table 8. Current condition of riparian brush rabbit population resiliency for four populations.

Population	Habitat quantity	Habitat quality (× 2)	Flood refugia	Abundance	Growth rate	Distribution	Connectivity (large-scale)	Current condition
Caswell	Moderate	Low	Low	Low	Low	Low	High	Low
Oxbow	Low	Moderate	Low	Low	Unknown	Low	Low	Low
Refuge	High	Moderate	Low	High	High	High	High	High
South Delta	Moderate	Low	Low	Unknown	Unknown	Moderate	Low	Low

CHAPTER 8 FUTURE CONDITION

This section of the SSA forecasts the species' response to probable future scenarios of environmental conditions and conservation efforts. The future scenarios project the stressors discussed earlier in the SSA into the future and consider the effects those threats would potentially have on riparian brush rabbit viability. The concepts of resiliency, representation, and redundancy are applied to future scenarios to describe the future viability of riparian brush rabbit. Three future scenarios are described and the future resiliency for each riparian brush rabbit population was assessed. By using three scenarios, it allowed us to consider a range of future possibilities for predicting the future viability of the species. For this SSA, the future was assessed at approximately 40 years. This period represents our best understanding of the projected future conditions related to climate change for California (Westerling *et al.* 2018, entire).

Scenario 1 assesses riparian brush rabbit future viability when the influences of stressors and of conservation efforts continue at their current rates and/or trajectories over the next 40 years. Scenario 2 assesses riparian brush rabbit future viability when the influences of stressors and of conservation efforts increase sharply over the next 40 years (increases more than current rates and/or trajectories). Scenario 3 assesses riparian brush rabbit future viability when the influences of stressors continue at their current rates and/or trajectories and conservation efforts increase moderately over the next 40 years. For each population, Table 9 shows the historical and present occurrence of each of the stressors and the conservation efforts that were considered for predicting the future viability of the species.

Table 9. Historical and present influencers of viability (stressors and conservation efforts). X - had or has influence, U - uncertain.

Stressor or conservation effort	Caswell		Oxbow		Refuge		South Delta	
	Hist.	Pres.	Hist.	Pres.	Hist.	Pres.	Hist.	Pres.
Development and land use change	X		X		X		X	X
Hydrologic changes	X	X	X	X	X	X	X	X
Flooding	X	X	X	X	X	X	X	X
Wildfire			X			X		
Drought	X	X	U	X	U	X	U	X
Predation	X	X	X	X	X	X	X	X
Vegetation/brush removal	X						X	X
Forest succession	X	X						

Stressor or conservation effort	Caswell		Oxbow		Refuge		South Delta	
	Hist.	Pres.	Hist.	Pres.	Hist.	Pres.	Hist.	Pres.
Disease	U	U	U	U	X	U	X	U
Reintroduction					X			
Restoration including refugia	X		X	X	X	X		
Land acquisition	X		X		X	X		
Flood mortality mitigation	X			X	X	X	X	
Nonnative predator management	X		X	X				

8.1 Methodology

Three potential future scenarios were considered and the future viability of riparian brush rabbit was assessed under each scenario. For each scenario, a description is given of the scenario assumptions, and the effects of each scenario on resiliency is described for each riparian brush rabbit population. Resiliency for each population was assessed using the Condition Category Table (Table 5) and the methods described in the current condition section (Section 7.1) of this SSA. The effects of each scenario on overall species representation and redundancy are also summarized.

8.2 Uncertainties and assumptions

Similar to the assessment of current condition, there are some population needs where conditions are unknown. The assessments of resiliency with and without the unknown information might result in different determinations of population condition.

Future scenarios are based on our understanding of the current climate change models. These models have considerable uncertainty and may not accurately reflect the future condition in the range of the species. Furthermore, each future scenario is only one possibility out of an infinite number of possible scenarios.

The assumed influences that each stressor and conservation effort will have on the riparian brush rabbit under each of the three future scenarios are in Table 10.

Table 10. Status of the stressors and conservation efforts in each of the three future scenarios.

Stressor or conservation effort	Scenario 1	Scenario 2	Scenario 3
	Influences of stressors and conservation efforts continue at their current rates/trajectories.	Influences of stressors and conservation efforts increase sharply (increases more than current rates/trajectories).	Influences of stressors continue at their current rates/trajectories and conservation efforts increase moderately.
Development/land use change	Remain stable	Remain stable	Remain stable
Hydrologic changes	Remain stable/increase at current trajectory	Large increase	Remain stable/increase at current trajectory
Flooding	Increase at current trajectory	Large increase	Increase at current trajectory
Wildfire	Increase at current trajectory	Large increase	Increase at current trajectory
Drought	Increase at current trajectory	Large increase	Increase at current trajectory
Predation	Remain stable	Increase	Remain stable
Vegetation/brush removal	Remain stable	Increase	Remain stable
Forest succession	Remain stable	Decrease	Decrease
Disease	Remain stable	Increase	Remain stable
Reintroduction	Not occurring	Increase	Might occur
Restoration including refugia	Remain stable but eventually decrease	Increase	Increase
Land acquisition	Remain stable but eventually decrease	Increase	Remain stable
Flood mortality mitigation	Remain stable	Increase	Increase
Nonnative predator management	Remain stable	Remain stable	Remain stable

8.3 Scenario 1

Under Scenario 1, climate change would bring noticeable, but not catastrophic, increases in the frequency and severity of flooding, wildfire, and drought. The hydrological changes that have altered disturbance regimes in riparian brush rabbit habitat and affected flood durations would continue. The increased need to accommodate higher severity flood events would require larger hydrological infrastructure.¹ Residential development, vegetation/brush removal, and forest succession would remain stable with continued effects on the quantity and quality of riparian brush rabbit habitat in the currently affected populations. Predation and disease would continue at current levels. The conservation efforts currently benefitting riparian brush rabbit populations would continue at their current rates but restoration and land acquisition would eventually be expected to decrease during the next 40 years as the acquisitions and restorations of available lands are completed. The future conditions of individual needs, population needs, and overall resiliency for each population under Scenario 1 are in Table 11.

Caswell resiliency

Under Scenario 1, the frequency and severity of flooding and drought would increase at Caswell. The likelihood of catastrophic wildfire at Caswell would also increase, but would not necessarily occur. Under these uncertain circumstances, the condition of habitat quantity might decrease from moderate to low, but would likely remain in moderate condition (25 to 350 hectares). The levees that separate the Park from agriculture lands might need to be modified or rebuilt, or might remain as they are in the current condition. Forest succession would continue to affect the quantity and quality of riparian brush rabbit habitat. Conservation measures, which are not currently occurring at Caswell, would not be expected to increase under Scenario 1. However, ongoing conservation measures for the neighboring Refuge population would continue to support large-scale population connectivity for this population. Under Scenario 1, the resiliency of the Caswell population would remain in low condition or the population might be extirpated. The likelihood of extirpation of this population is unknown under this scenario because precise information about its current abundance and growth rate are unavailable.

Oxbow resiliency

Under Scenario 1, the frequency and severity of flooding and drought would increase at Oxbow. The levee that currently separates the Preserve from the adjacent residential community would remain as it is in its current condition. Conservation measures, including restoration of the refugium berm, flood mortality mitigation, and predator exclusion, would be expected to continue at current rates under Scenario 1. Although the quality of the flood refugium would improve in Scenario 1, the proportion of high ground to habitat area would remain the same. Therefore, the condition of flood refugia would remain low. The known conditions of the other riparian brush rabbit needs at Oxbow would not be expected to change in Scenario 1. The current growth rate of the Oxbow population is unknown. If future research determines that the growth rate of the Oxbow population is greater than one, then the condition of Oxbow resiliency under

¹ For Scenario 1, we assumed that taller levees requiring more land area would be built over the next 40 years. Some of the occupied South Delta habitat would also be affected by the expansion of Paradise Cut (San Joaquin County Resource Conservation District 2019, pp. 2-3).

Scenario 1 would be moderate. Otherwise, the resiliency of the Oxbow population would remain in low condition. Given that the current condition of growth rate is unknown, we also consider it unknown under Scenario 1 in the future. The resiliency of the Oxbow population under Scenario 1 is low.

Refuge resiliency

Under Scenario 1, the frequency and severity of flooding, wildfire, and drought would increase at the Refuge. The likelihood of catastrophic wildfire at the Refuge would increase, but would not necessarily occur. Flood events, wildfires, and droughts would decrease the condition of habitat and population needs but the continuation of land acquisition and habitat restoration would mitigate most of these effects. The levees that separate the Refuge from neighboring properties might need to be modified or rebuilt, but these changes would not be likely to affect population resiliency. Under Scenario 1, the resiliency of the Refuge population would remain in high condition.

South Delta resiliency

Under Scenario 1, the frequency and severity of flooding and drought would increase in the South Delta. The increased need to accommodate higher severity flood events would require larger levee systems and a portion of the South Delta habitat would also be negatively affected by the expansion of Paradise Cut (San Joaquin County Resource Conservation District 2019, pp. 2-3). Residential development and vegetation/brush removal would remain stable and continue to have negative effects in the South Delta population. Conservation measures, which are not currently occurring at in the South Delta population, would not be expected to increase. Under Scenario 1, the quantity and quality of riparian brush rabbit habitat and flood refugia would decrease but the condition categories would not change. The increase in stressors would likely cause further fragmentation of the South Delta population, which would decrease the population distribution from moderate to low. The abundance and growth rate of the South Delta population would remain unknown. Under scenario 1, the resiliency of the South Delta population would remain in low condition.

Species representation

As described in Section 7.10, the current condition of representation for the riparian brush rabbit is low because it only occupies a small portion of its former range. Under Scenario 1, the future condition of species representation would remain low.

Species redundancy

As described in Section 7.11, the current condition of redundancy for the riparian brush rabbit is low because there is only one resilient population in the range of the species. Under Scenario 1, the future condition of species redundancy would remain low with one resilient population. However, redundancy could improve if the Oxbow population growth rate is found to be in high condition. If so, there would be two resilient populations within the species' range.

Table 11. Scenario 1 future condition of riparian brush rabbit population resiliency for four populations. Under Scenario 1, the influences of stressors and conservation efforts continue at their current rates/trajectories. Changes from current conditions are underlined.

Population	Habitat quantity	Habitat quality (× 2)	Flood refugia	Abundance	Growth rate	Distribution	Connectivity (large-scale)	Scenario 1 condition
Caswell	Moderate <u>or decrease to low</u>	Low	Low	Low	Low	Low	High	Low <u>or</u> Extirpated
Oxbow	Low	Moderate	Low	Low	Unknown	Low	Low	Low
Refuge	High	Moderate	Low	High	High	High	High	High
South Delta	Moderate	Low	Low	Unknown	Unknown	<u>Decrease to low</u>	Low	Low

8.4 Scenario 2

Under Scenario 2, climate change would result in large, and sometimes catastrophic, increases in the frequency and severity of flooding, wildfire, and drought. The hydrological changes that have altered disturbance regimes in riparian brush rabbit habitat and affected flood durations would increase and conflicts would intensify between the protection of human needs versus the protection of wildlife needs. The increased necessity to accommodate higher severity flood events would require larger hydrological infrastructure (negative influence to resiliency) and/or innovative solutions (e.g. floodplain restoration) that might benefit the riparian brush rabbit. Residential development would remain stable but vegetation/brush removal would increase (to decrease wildfire risk), especially along roads, transmissions lines, and near private property. The influence of predation would increase under Scenario 2 because increases in flooding, wildfire, drought, and vegetation/brush removal would expose rabbits to predation more frequently and for longer durations. Where overcrowding occurs during flood events, the rate of disease would slightly increase under Scenario 2. The influence of forest succession at Caswell would actually decrease in this scenario because of wildfire disturbance, vegetation/brush removal, and habitat restoration. All of the conservation efforts identified in Table 9 (i.e. reintroduction, restoration, land acquisition, flood mortality mitigation, and predator management) would increase during the next 40 years. The future conditions of individual needs, population needs, and overall resiliency for each population under Scenario 2 are in Table 12.

Caswell resiliency

Under Scenario 2, the frequency and severity of flooding and drought would increase at Caswell. Larger wildfires would also occur at Caswell but increases in measures to reduce fire risk (including vegetation/brush removal, but also tree thinning and similar measures that mimic forest disturbance) by the California Department of Parks and Recreation would reduce the probability of a catastrophic wildfire. Wildfire, drought, and vegetation management would temporarily reduce riparian brush rabbit habitat quantity and quality at Caswell and would lower population resiliency if affected areas were occupied. However, these stressors would also be expected to improve the quantity and quality of riparian brush rabbit habitat after several years. The new disturbances would remove forest succession as a stressor for this population. Increases in conservation efforts such as land acquisition adjacent to the Park and habitat restoration would increase the availability and quality of both habitat and flood refugia in this population. If necessary, reintroduction and/or population supplementation might occur. The reestablishment of flood mortality mitigation and predator management efforts at the Park would prevent the Caswell population from becoming extirpated before the effects of other conservation efforts are realized. Under Scenario 2, riparian brush rabbit habitat quality, abundance, growth rate, and distribution would all be expected to increase to moderate or higher for the Caswell population. Over the course of 40 years, the resiliency of the Caswell population would increase to moderate under Scenario 2.

Oxbow resiliency

Under Scenario 2, the frequency and severity of flooding and drought would increase at Oxbow. With an increased likelihood of catastrophic flood events in this scenario, Oxbow Preserve could

become completely inundated, including the berm flood refugium. Complete inundation would expose the entire Oxbow population to near-certain predation and starvation as it forces rabbits onto unvegetated levees and into the residential neighborhood outside of the Preserve. Under these circumstances, flood mortality mitigation and extensive restoration efforts would be necessary to prevent the extirpation of riparian brush rabbits from Oxbow. If floods increase only in frequency and duration, but not severity, the restored flood refugium berm would protect the population from flood-related extirpation. However, the additive effects of frequent flood events and increases in drought, predation, and disease, would negatively influence population abundance and growth rate (i.e. reproduction, recruitment, and survival). Under Scenario 2, wildfire risk would also increase. If fuels are not managed under this scenario, a wildfire could lead to extirpation of the Oxbow population. Furthermore, fuels management might also decrease the habitat quality at Oxbow by decreasing the amount of vegetation. Restoration efforts would improve the quality of the flood refugium in Scenario 2, but the condition of flood refugia would remain low because the proportion of high ground to habitat area would remain the same. Habitat quality would be expected to decrease from moderate to low because of increased exposure to flooding and drought and the intensification of vegetation/brush management to mitigate fire risk. Given the additive effects of stressors on this population, growth rate would be in low condition. Under Scenario 2, the Oxbow population would remain in low condition or be extirpated.

Refuge resiliency

Under Scenario 2, the frequency and severity of flooding, wildfire, and drought would increase. Catastrophic flood events and/or wildfires would be likely to occur in the Refuge population range. Under Scenario 2, flood severity would affect Refuge population resiliency in both negative and positive ways. The increased need of the region to accommodate higher severity flood events would drive innovative solutions, such as natural floodplain restoration. This driver would enable increases in land acquisition and restoration conservation efforts, which would also lead to additional riparian brush rabbit introductions under this scenario. Floodplain restoration might also decrease the risk of catastrophic wildfires for this population. Under this scenario, habitat quality would be expected to increase (from restoration) in some areas but decrease (from intensity of stressors) in other areas. Therefore, overall habitat quality would remain moderate for the Refuge population. Restoration efforts would be expected to increase the condition of flood refugia from low to high. The severity, frequency, and additive effects of stressors under Scenario 2 would decrease both the growth rate and the distribution of the Refuge population from high to moderate. Overall population resiliency for the Refuge would decrease from high to moderate condition.

South Delta resiliency

Under Scenario 2, the frequency and severity of flooding and drought would increase in the South Delta. Wildfire risk would still be low for this population because of increases in measures taken by private landowners to reduce fire risk (including vegetation/brush removal). In contrast to the effects of vegetation management in the Caswell population, the fuel reductions in the South Delta that would occur under Scenario 2 could result in considerable habitat loss, especially when coupled with the effects of drought. With the increased likelihood of

catastrophic flood events in this scenario, sections of habitat in the South Delta could become completely inundated, forcing rabbits into neighboring agricultural fields and developed areas where predation and starvation would be likely. The increased need for South Delta waterways to accommodate more water during flood events may contribute to localized riparian brush rabbit extirpations near developed areas. Alternatively, opportunities to mitigate flood severity with floodplain restoration might encourage South Delta conservation efforts if private landowners want to sell agricultural lands that are affected by flooding. Without land acquisitions in the South Delta, increased conservation efforts would have only minor influence at most.¹ Under Scenario 2, habitat quantity will decrease but it could either remain in moderate condition (25 to 350 hectares) or decrease to low condition. Population growth rate (currently unknown) would be in low condition after 40 years and population distribution would decrease from moderate to low. South Delta population resiliency would remain in low condition under Scenario 2. Extirpation of this population is also possible under Scenario 2 but might not occur within 40 years.

Species representation

As described in Section 7.10, the current condition of representation for the riparian brush rabbit is low because it only occupies a small portion of its former range. Under Scenario 2, the future condition of species representation would remain low.

Species redundancy

As described in Section 7.11, the current condition of redundancy for the riparian brush rabbit is low because there is only one resilient population in the range of the species. Under Scenario 2, the future condition of species redundancy would remain low but it would improve from the current condition because there would be two resilient populations within the range of the species. Under Scenario 2, there is also potential for redundancy to increase to three or more resilient populations if land acquisitions for floodplain restoration occur in the South Delta. Given the uncertainty of both South Delta land acquisition and the likelihood that the riparian brush rabbit population on the acquired land would be resilient within 40 years, we consider that species redundancy would continue to be low (two resilient populations) under Scenario 2.

¹ The potential for land acquisitions in the South Delta will be assessed under Scenario 2 in the Species redundancy section. Land acquisition will not be considered in the assessment of South Delta population resiliency.

Table 12. Scenario 2 future condition of riparian brush rabbit population resiliency for four populations. Under Scenario 2, influences of both stressors and conservation efforts increase sharply (greater increases than current rates/trajectories). Changes from current conditions are underlined.

Population	Habitat quantity	Habitat quality (× 2)	Flood refugia	Abundance	Growth rate	Distribution	Connectivity (large-scale)	Scenario 2 condition
Caswell	Moderate	<u>Increase to Moderate</u>	Low	<u>Increase to Moderate</u>	<u>Increase to Moderate or High</u>	<u>Increase to Moderate</u>	High	<u>Increase to Moderate</u>
Oxbow	Low	<u>Decrease to Low</u>	Low	Low	<u>Unknown to Low</u>	Low	Low	Low or Extirpated
Refuge	High	Moderate	<u>Increase to Moderate</u>	High	<u>Decrease to Moderate</u>	<u>Decrease to Moderate</u>	High	<u>Decrease to Moderate</u>
South Delta	<u>Moderate or decrease to low</u>	Low	Low	Unknown	<u>Unknown to Low</u>	<u>Decrease to Low</u>	Low	Low

8.5 Scenario 3

Under Scenario 3, climate change would bring noticeable, but not catastrophic, increases in the frequency and severity of flooding, wildfire, and drought. The hydrological changes that have altered disturbance regimes in riparian brush rabbit habitat and affected flood durations would continue. The increased need to accommodate higher severity flood events would require larger hydrological infrastructure.¹ Residential development, vegetation/brush removal, and forest succession would remain stable with continued effects on the quantity and quality of riparian brush rabbit habitat in the currently affected populations. Predation and disease would continue at current levels. The conservation efforts that currently benefitting riparian brush rabbit populations would continue and some of the conservation efforts would increase and/or benefit populations that are not currently affected by conservation. The future conditions of individual needs, population needs, and overall resiliency for each population under Scenario 3 are in Table 13.

Caswell resiliency

Under Scenario 3, the frequency and severity of flooding and drought would increase at Caswell. The likelihood of catastrophic wildfire at Caswell would also increase, but would not necessarily occur. The levees that separate the Park from agriculture lands might need to be modified or rebuilt, or might remain as they are in the current condition. Forest succession would have less influence on the quantity and quality of riparian brush rabbit habitat because restoration efforts, which are not currently occurring at Caswell, would increase under Scenario 3. Under Scenario 3, restoration efforts would increase the conditions of habitat quality and flood refugia from low to moderate but distribution would remain low. Abundance and growth rate would be expected to increase over the next 40 years; however, these increases would be tampered by increases in the frequency and severity of stressors related to climate change. Therefore, Caswell abundance and growth rate would only increase from low to low-to-moderate condition. Under Scenario 3, the resiliency of the Caswell population would increase from low to moderate condition.

Oxbow resiliency

Under Scenario 3, the frequency and severity of flooding and drought would increase at Oxbow. The levee that currently separates the Preserve from the adjacent residential community would remain as it is in the current condition. Conservation efforts at Oxbow would increase under Scenario 3. Restoration to increase the carrying capacity for riparian brush rabbits at the Oxbow Preserve would increase the condition of habitat quality from moderate to high. Restoration would also improve the quality of the flood refugium, but the proportion of high ground to habitat area would remain the same. Therefore, the condition of flood refugia would remain low. The current growth rate of the Oxbow population is unknown, but conservation efforts under Scenario 3 would support a moderate growth rate (rate ≈ 1.0), in spite of the influences of stressors. The resiliency of the Oxbow population under Scenario 3 would be moderate.

¹ For Scenario 3, we assumed that taller levees requiring more land area would be built over the next 40 years. Some of the occupied South Delta habitat would also be affected by the expansion of Paradise Cut (San Joaquin County Resource Conservation District 2019, pp. 2-3).

Refuge resiliency

Under Scenario 3, the frequency and severity of flooding, wildfire, and drought would increase at the Refuge. The likelihood of catastrophic wildfire at the Refuge would also increase, but would not necessarily occur. Flood events, wildfires, and droughts would decrease the condition of habitat and population needs but the continuation and increase of land acquisition and habitat restoration would mitigate most of these effects. The levees that separate the Refuge from neighboring properties might need to be modified or rebuilt, but these changes would not be likely to affect population resiliency. Under Scenario 3, the resiliency of the Refuge population would remain in high condition.

South Delta resiliency

Under Scenario 3, the frequency and severity of flooding and drought would increase in the South Delta. Accommodating higher severity flood events would require larger levee systems and a portion of the South Delta habitat would also be negatively affected by the expansion of Paradise Cut (San Joaquin County Resource Conservation District 2019, pp. 2-3). Residential development and vegetation/brush removal would remain stable and continue to have negative effects in the South Delta population. Increases in conservation efforts in the South Delta would be limited because most of the riparian brush rabbit habitat is on private land. Under Scenario 3, the quantity and quality of riparian brush rabbit habitat and flood refugia would decrease but the condition categories would not change. The increase in stressors would likely cause further fragmentation of the South Delta population, which would decrease the population distribution from moderate to low. The abundance and growth rate of the South Delta population would remain unknown. Under scenario 3, the resiliency of the South Delta population would remain in low condition.

Species representation

As described in Section 7.10, the current condition of representation for the riparian brush rabbit is low because it only occupies a small portion of its former range. Under Scenario 3, the future condition of species representation would remain low.

Species redundancy

As described in Section 7.11, the current condition of redundancy for the riparian brush rabbit is low because there is only one resilient population in the range of the species. Under Scenario 3, the future condition of species redundancy would improve from a low condition to a low-to-moderate condition of three resilient populations.

Table 13. Scenario 3 future condition of riparian brush rabbit population resiliency for four populations. Under Scenario 3, the influences of stressors continue at their current rates/ trajectories and conservation efforts increase moderately. Changes from current conditions are underlined.

Population	Habitat quantity	Habitat quality (× 2)	Flood refugia	Abundance	Growth rate	Distribution	Connectivity (large-scale)	Scenario 3 condition
Caswell	Moderate	<u>Increase to Moderate</u>	<u>Increase to Moderate</u>	<u>Increase to Low-Moderate</u>	<u>Increase to Low-Moderate</u>	Low	High	<u>Increase to Moderate</u>
Oxbow	Low	<u>Increase to High</u>	Low	Low	<u>Unknown to Moderate</u>	Low	Low	<u>Increase to Moderate</u>
Refuge	High	Moderate	Low	High	High	High	High	High
South Delta	Moderate	Low	Low	Unknown	Unknown	<u>Decrease to low</u>	Low	Low

8.6 Status Assessment Summary

We used the best available information to forecast the likely future condition of the riparian brush rabbit. The goal of this SSA was to describe the viability of the species in a manner that will address the needs of the species in terms of resiliency, representation, and redundancy. We considered the possible future condition of the species for each of three plausible scenarios. Our results describe a range of possible future viabilities that vary in terms of population resiliency and species redundancy (Table 14).

The riparian brush rabbit faces a variety of stressors including habitat loss and degradation, flooding, wildfire, drought, climate change, predation, vegetation management (brush and vegetation removal), forest succession, and disease. These stressors, and the levels upon which they act on the various populations, play a large role in the future viability of the riparian brush rabbit. Based on our results, riparian brush rabbit conservation efforts also play an equally important role in determining the future viability of the species. Currently, and in all future scenarios, the riparian brush rabbit has low representation because the species occupies only a small portion of its former range. The species' viability is also impaired by low redundancy, with only one population that currently exhibits resiliency. In two of the three future scenarios, species redundancy has the potential to increase. Our assessment indicates that riparian brush rabbit viability would possibly improve only if conservation efforts are expanded.

Table 14. Summary of riparian brush rabbit population resiliency under current conditions and under three future scenarios.

Population	Current condition	Scenario 1 condition	Scenario 2 condition	Scenario 3 condition
Caswell	Low	Low or Extirpated	Moderate	Moderate
Oxbow	Low	Low	Low or Extirpated	Moderate
Refuge	High	High	Moderate	High
South Delta	Low	Low	Low	Low

REFERENCES

- Álvarez-Castañeda, S. T. & Lorenzo, C. 2016. Genetic evidence supports *Sylvilagus mansuetus* (Lagomorpha: Leporidae) as a subspecies of *S. bachmani*. *Zootaxa* 4196:289–295.
- BAER Team. 2004. Pelican fire burned area emergency stabilization plan. US Official News.
- Basey, G. E. 1990. Distribution, ecology, and population status of the riparian brush rabbit (*Sylvilagus bachmani riparius*). California State University, Stanislaus.
- Bureau of Reclamation. 2016. Dos Rios Ranch riparian brush rabbit recovery project, environmental assessment. U.S. Department of Interior.
- CAL FIRE. 2004. Fire Threat. Fire and Resource Assessment Program, California Department of Forestry and Fire Protection.
- CAL FIRE, U.S. Forest Service, Bureau of Land Management, National Park Service & U.S. Fish and Wildlife Service. 2016. Fire perimeters, 1878-2015. Fire and Resource Assessment Program, California Department of Forestry and Fire Protection.
- CALFED. 2014. Ecosystem Restoration Program conservation strategy for restoration of the Sacramento-San Joaquin Delta, Sacramento Valley and San Joaquin Valley regions.
- California Department of Fish and Wildlife. 2019. Occurrence report and map for riparian brush rabbit (*Sylvilagus bachmani riparius*).
- California Department of Fish and Game. 2009. Sacramento Delta 1937, mosaic_4.img. Agricultural Adjustment Administration (AAA), U.S. Department of Agriculture, Western Division Laboratory, 1937. 1:20,000.
- California State University Chico. 2003. Historic vegetation base map (pre-1900).
- Chapman, J. A. 1974. *Sylvilagus bachmani*. *Mammalian Species* 34:1-4.
- Chapman, J. A. & Litvaitis, J. A. 2003. Eastern cottontail: *Sylvilagus floridanus* and allies. In: *Wild Mammals of North America* (Ed. by G. A. Feldhammer, B. C. Thompson & J. A. Chapman), pp. 101-125. Johns Hopkins University Press, Baltimore, Maryland.
- Chapman, J. A. 1971. Orientation and homing of the brush rabbit (*Sylvilagus bachmani*). *Journal of Mammalogy* 52:686-699.
- Chapman, J. A. & Harman, A. L. 1972. The breeding biology of a brush rabbit population. *The Journal of Wildlife Management* 36:816-823.

Close, C. L. & Williams, D. F. 1998. Habitat management for riparian brush rabbits and woodrats with special attention to fire and flood. California State University, Stanislaus.

Conaway, C. H. 1971. Ecological adaptation and mammalian reproduction. *Biology of reproduction* 4:239-247.

Constable, J., Phillips, S., Williams, D., Youngblom, J. & Kelly, P. 2011. Characterization of genetic structure and phylogenetic relationships of riparian brush rabbit populations, final report. California State University, Stanislaus.

Cook, R. R. & Quinn, J. F. 1992. An inventory of the mammals of Caswell Memorial State Park with special attention to the riparian brush rabbit (*Sylvilagus bachmani riparius*) & riparian woodrat (*Neotoma fuscipes riparia*).

Delta Stewardship Council. 2018. Agenda item 10: Paradise Cut implementation challenges.

Dettinger, M. D., Hidalgo León, H. G., Das, T., Cayan, D. R. & Knowles, N. 2009. Projections of potential flood regime changes in California. California Climate Change Center.

Deverel, S. J. & Leighton, D. A. 2010. Historic, recent, and future subsidence, Sacramento-San Joaquin Delta, California, USA. *San Francisco Estuary and Watershed Science* 8.

Elsholz, C. R. 2010. Riparian brush rabbit habitat requirements in Caswell Memorial State Park. Thesis. San José University.

Esri. 2018. ArcGIS Pro. Desktop Version 2.3.3.

Esri & DigitalGlobe. 2018. High resolution 30cm imagery.

Federal Emergency Management Agency. 2016. FEMA Levees. ArcGIS Pro, Esri.

Fryer, J. L. 2015. Fire regimes of woody riparian communities of the central valley, California. https://www.fs.fed.us/database/feis/fire_regimes/CA_valley_riparian/all.html. Retrieved July 16, 2019.

Galloway, D. & Riley, F. S. 1999. San Joaquin Valley, California. Land subsidence in the United States: US Geological Survey Circular 1182:23-34.

Gantenbein, E., Labbé, M. & Rogers, D. L. 2019. Draft management plan (2019-2029) for the Oxbow Preserve (N022) _redacted.

Gilardi, K. V., Terio, K. A., Hamilton, L. P., Williams, E. V. & Williams, D. F. 2004. Disease monitoring in captively propagated and reintroduced riparian brush rabbits (*Sylvilagus bachmani riparius*) in California. *Heath and conservation of captive and free-ranging wildlife*, 297-298.

Hamilton, L. P., Kelly, P. A., Williams, D. F., Kelt, D. A. & Wittmer, H. U. 2010. Factors associated with survival of reintroduced riparian brush rabbits in California. *Biological Conservation* 143:999-1007.

Katibah, E. F. 1984. A brief history of riparian forests in the central valley of California. In: *California Riparian Systems: Ecology, Conservation, and Productive Management* (Ed. by R. E. Warner & K. M. Hendrix), pp. 23-29. University of California Press.

Kelly, P. A. 2018a. *Sylvilagus bachmani* (Waterhouse, 1839) brush rabbit. In: *Lagomorphs: Pikas, Rabbits, and Hares of the World* (Ed. by A. T. Smith, C. H. Johnston, P. C. Alves & K. Hacklander), pp. 122-125. Johns Hopkins University Press, Baltimore, Maryland.

Kelly, P. A. & Holt, J. L. 2011. Quarterly report: controlled propagation and release of riparian brush rabbits in the northern San Joaquin Valley, California (1 January - 31 March 2011). California State University, Stanislaus.

Kelly, P. A. & Lloyd, M. R. 2010. Quarterly report: controlled propagation and release of riparian brush rabbits in the northern San Joaquin Valley, California (1 January - 31 March 2010). California State University, Stanislaus.

Kelly, P. A. & Lloyd, M. R. 2009a. Draft annual report: controlled propagation and release of riparian brush rabbits in the northern San Joaquin Valley, California (1 July 2008 - 30 June 2009).

Kelly, P. A. & Lloyd, M. R. 2009b. Quarterly report: controlled propagation and release of riparian brush rabbits in the northern San Joaquin Valley, California (1 October - 31 December 2009). California State University, Stanislaus.

Kelly, P. A., Edgarian, T. K. & Banbury, J. L. 2014. Controlled propagation, reintroduction and monitoring of riparian brush rabbits on the San Joaquin River wildlife refuge and adjacent lands (1 October 2011 - 31 December 2013), final report. California State University, Stanislaus.

Kelly, P. A., Edgarian, T. & Cannizzo, F. 2013. Controlled propagation and release of riparian brush rabbits in the northern San Joaquin Valley, California (8 June 2011 - 31 December 2012), final report. California State University, Stanislaus.

Kelly, P. A., Lloyd, M. R. & Hamilton, L. P. 2008a. Draft annual report: riparian brush rabbit project (1 July 2007 - 30 June 2008).

Kelly, P. A., Lloyd, M. R. & Hamilton, L. P. 2008b. Quarterly report: riparian brush rabbit project (1 January– 31 March 2008).

Kelly, P. A., Lloyd, M. R. & Hamilton, L. P. 2007. Annual report: riparian brush rabbit project (1 June 2006 – 30 June 2007). California State University, Stanislaus.

- Kelly, P. A. 2018b. Reintroduction of the riparian brush rabbit in the San Joaquin Valley, California, USA. In: *Global Reintroduction Perspectives: 2018* (Ed. by P. S. Soorae), pp. 210-215. IUCN/SSC Reintroduction Specialist Group & Environment Agency, Abu Dhabi.
- Kelly, P. A., Lorenzo, C. & Alvarez-Castaneda, S. T. 2019. *Sylvilagus bachmani*, brush rabbit. The IUCN RedList of Threatened Species 2019.
- Kelly, P. A., Edgarian, T. K., Lloyd, M. R. & Phillips, S. E. 2011. Conservation principles for the riparian brush rabbit and riparian woodrat. California State University, Stanislaus.
- Kelt, D. A., Kelly, P. A., Phillips, S. E. & Williams, D. F. 2014. Home range size and habitat selection of reintroduced *Sylvilagus bachmani riparius*. *Journal of Mammalogy* 95:516-524.
- Larsen, C. J. 1993. Status review of the riparian brush rabbit (*Sylvilagus bachmani Riparius*) in California.
- Larsen Wurzel and Associates. 2019. Mossdale tract program: 2019 annual adequate progress report update for urban level of protection. http://cvfpb.ca.gov/wp-content/uploads/2019/08/2019_SJAFCFA-_Adequate-Progress.pdf. Retrieved October 9, 2019.
- Lloyd, M. R., Forrest, K., Kelly, P. A., Holt, J. L., Edgarian, T. K. & Rentner, J. R. 2011. Utilizing adaptive management in the recovery of the endangered riparian brush rabbit at the San Joaquin River National Wildlife Refuge, California. Poster session presented at Fish and Wildlife Service conference, Conserving the Future: Wildlife Refuges and the Next Generation. Madison, Wisconsin, July 2011.
- Lloyd, M., Hamilton, L., Kelly, P., Williams, D. & Williams, E. 2006. Survivorship of endangered *Sylvilagus bachmani riparius* (riparian brush rabbits) following wildfire and flooding.
- Lloyd, M. R. & Kelly, P. A. 2008. Post-fire riparian brush rabbit survey at the San Joaquin River NWR (July 14-25, 2008).
- Lloyd, M. R., Smith, M. & Kelly, P. A. 2008. Christman Island & Vierra Unit rabbit mounds, San Joaquin River NWR. California State University, Stanislaus.
- Lloyd, M. R. & Williams, D. F. 2003. Riparian brush rabbit survey: Mossdale Landing, San Joaquin County, California, February 2003. California State University, Stanislaus.
- Matocq, M., Kelly, P., Rippert, J. & Phillips, S. 2017. Population genetic structure of the riparian brush rabbit (*Sylvilagus bachmani riparius*): using multiple marker systems to gain insight into historic and ongoing genetic connectivity. University of Nevada, Reno and California State University, Stanislaus.

Mossman, A. S. 1955. Reproduction of the brush rabbit in California. *The Journal of Wildlife Management* 19:177-184.

Orr, R. T. 1942. Observations on the growth of young brush rabbits. *Journal of Mammalogy* 23:298-302.

Orr, R. T. 1940. The Rabbits of California. In: *Occasional Papers of the California Academy of Sciences, no. 19*. (Ed. by F. M. MacFarland), pp. 227. California Academy of Sciences, San Francisco, California.

Orr, R. T. 1935. Descriptions of three new races of brush rabbit from California. *Proceedings of the Biological Society of Washington* 48:27-30.

Pettit, N. E. & Naiman, R. J. 2007. Fire in the riparian zone: characteristics and ecological consequences. *Ecosystems* 10:673-687.

Phillips, S. E., Hamilton, L. P. & Kelly, P. A. 2005. Assessment of habitat conditions for the riparian brush rabbit at the San Joaquin River National Wildlife Refuge, Stanislaus County, California. California State University, Stanislaus.

Phillips, S. E., Edgarian, T. K., Lloyd, M. R. & Kelly, P. A. 2013a. Habitat suitability and connectivity for riparian brush rabbits in the northern San Joaquin Valley and Sacramento/San Joaquin River Delta. California State University, Stanislaus.

Phillips, S. E., Edgarian, T. K., Lloyd, M. R. & Kelly, P. A. 2013b. Dataset: Habitat suitability and connectivity for riparian brush rabbits in the northern San Joaquin Valley and Sacramento/San Joaquin River Delta. Endangered Species Recovery Program, California State University, Stanislaus.

Quinn, R. D. 1979. Effects of fire on small mammals in the chaparral. *Cal-Neva Wildlife Transactions* 125-133.

Reclamation District 2062. 2017. Report of adequate progress towards an urban level of flood protection, River Islands at Lathrop, phase 1 area.
https://www.ci.lathrop.ca.us/sites/default/files/fileattachments/public_works/page/1931/1_12_pm_public_works_1_12_pm.pdf. Retrieved October 8, 2019.

Rentner, J. & Lloyd, M. 2010. Results are in: endangered rabbits are living in our planted habitats! *River Partners Journal*.

River Partners. 2008. Effects of long duration flooding on riparian plant species in restoration plantings. San Joaquin River National Wildlife Refuge, Stanislaus County, California.

River Partners. 2002. San Joaquin River National Wildlife Refuge riparian restoration plan for spring 2002 (Project A: Fields H8, H9, and H20), San Joaquin River National Wildlife Refuge, Stanislaus County, California.

San Joaquin Area Flood Control Agency. 2014. Lower San Joaquin River and Delta South regional flood management plan. November 2014.
<https://www.sjafca.com/ljsrdsrfmp.php#hide1>. Retrieved October 9, 2019.

San Joaquin County Resource Conservation District. 2019. Paradise Cut expansion project brochure.

Service. 2006. San Joaquin River National Wildlife Refuge final comprehensive conservation plan.

Service. 2017. Riparian Brush Rabbit Survey during a Flood Event at the San Joaquin River National Wildlife Refuge, FY17. 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.

Service. 2019. Biological Opinion on Phase 3 of the Reclamation District 17 Levee Seepage Repair Project, 2015-F-0303. San Francisco Bay-Delta Fish and Wildlife Office, Sacramento, California.

Thompson, K. 1961. Riparian forests of the Sacramento Valley, California. *Annals of the Association of American Geographers* 51:294-315.

U.S. Army Corps of Engineers. 2014. Guidelines for landscape planting and vegetation management at levees, floodwalls, embankment dams, and appurtenant structures. ETL 1110-2-583. Engineering Technical Letters.

U.S. Bureau of Reclamation. 2018. Riparian habitat restoration at Dos Rios Ranch, Environmental Assessment No. 18-05-MP.

U.S. Environmental Protection Agency. 2013. Omernik's Level III ecoregions of the conterminous United States. National Health and Environmental Effects Research Laboratory, Office of Research and Development, US Environmental Protection Agency. 1:3,000,000.

U.S. Geological Survey. 2016. Watershed boundary dataset: HUC 6s. Esri. USGS 1:24,000.

Vincent-Williams, E., Lloyd, M. R., Williams, D. F. & Kelly, P. A. 2004. Riparian brush rabbit: central Lathrop specific plan, San Joaquin County, California, February 2004. California State University, Stanislaus.

- Westerling, L., Medellin-Azuara, J. & Viers, J. 2018. San Joaquin Valley summary report. California's fourth climate change assessment. University of California, Merced.
- Williams, D., Kelly, P., Hamilton, L., Lloyd, M., Williams, E. & Youngblom, J. 2008. Recovering the endangered riparian brush rabbit (*Sylvilagus bachmani riparius*): Reproduction and growth in confinement and survival after translocation. In: *Lagomorph Biology*, pp. 349-361. Springer Berlin Heidelberg, Berlin, Heidelberg.
- Williams, D. F. 1993. Population censuses of riparian brush rabbits and riparian woodrats at Caswell Memorial State Park during January 1993. California State University, Stanislaus.
- Williams, D. F. 1988. Ecology and management of the riparian brush rabbit in Caswell Memorial State Park. California State University, Stanislaus.
- Williams, D. F. 1986. Mammalian species of special concern in California. California State University, Stanislaus.
- Williams, D. F. & Hamilton, L. P. 2002. Riparian brush rabbit survey: Paradise Cut along Stewart Tract, San Joaquin County, California, August 2001.
- Williams, D. F. & Basey, G. E. 1986. Population status of the riparian brush rabbit (*Sylvilagus bachmani riparius*). California State University, Stanislaus.
- Williams, D. F., Kelly, P. A. & Hamilton, L. P. 2002. Controlled propagation and reintroduction plan for the riparian brush rabbit (*Sylvilagus bachmani riparius*). California State University, Stanislaus.
- Williams, D. F., Hamilton, L. P., Lloyd, M. R., Kelly, P. A., Youngblom, J. J. & Larsen, S. 2007. Controlled propagation and translocation of riparian brush rabbits: summary report for 2001-2006. California State University, Stanislaus.
- Williams, D. F., Lloyd, M. R., Hamilton, L. P., Vincent-Williams, E., Youngblom, J. J., Gilardi, K. & Kelly, P. A. 2005. Controlled propagation and translocation of riparian brush rabbits: annual report for 2003.
- Williams, D. F., Hamilton, L. P., Youngblom, J. J., Lee, C. & Kelly, P. A. 2000. Riparian brush rabbit studies, 1997-2000. California State University, Stanislaus.
- Wittmer, H. U., Kelt, D. A., Kelly, P. A. & Williams, D. F. 2016. Use of simulation modeling to evaluate management strategies for reintroduced riparian brush rabbits in California. *Journal of Fish and Wildlife Management* 7:334-346.
- Wolf, S., Hartl, B., Carroll, C., Neel, M. C. & Greenwald, D. N. 2015. Beyond PVA: why recovery under the Endangered Species Act is more than population viability. *BioScience* 65:200-207.

In litteris

Applebee, D. 2019. California Department of Fish and Wildlife. Riparian brush rabbit. Email to Stephanie Prevost of the U.S. Fish and Wildlife Service.

Aubrey, C. 2006. Riparian brush rabbit site visit. Email to Riparian Mammal Group.

Center for Natural Lands Management. 2019. Comments to riparian brush rabbit rapid data assessment. Email to Stephanie Prevost of the U.S. Fish and Wildlife Service.

Forrest, K. 2018. U.S. Fish and Wildlife Service, San Luis National Wildlife Refuge Complex. Riparian woodrat and brush rabbit. Email to Stephanie Prevost of the U.S. Fish and Wildlife Service.

Hopson, E. 2019. U.S. Fish and Wildlife Service, San Joaquin River National Wildlife Refuge. 2017 estimated riparian brush rabbit population and flood mortality. Email to Stephanie Prevost of the U.S. Fish and Wildlife Service.

Matocq, M. 2019. University of Nevada Reno. Riparian brush rabbit. Email to Joshua Emery of the U.S. Fish and Wildlife Service.

Rentner, J. 2019. River Partners. Riparian Brush Rabbit recovery – habitat restoration and flooding memo. Email to Stephanie Prevost of the U.S. Fish and Wildlife Service.

Service. 2017a. 2017 Riparian brush rabbit flooding mortality report. Memo.

Service. 2017b. Riparian brush rabbit flood issues fact sheet, January-April. Memo.

Tarcha, C. 2019. California State University, Stanislaus graduate student. Email to Stephanie Prevost of the U.S. Fish and Wildlife Service.

Personal communications

Emery, J. 2019. U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office. Conversation with Stephanie Prevost of the U.S. Fish and Wildlife Service.

Forrest, K. 2018. U.S. Fish and Wildlife Service, San Luis National Wildlife Refuge Complex. Meeting notes recorded by Stephanie Prevost of the U.S. Fish and Wildlife Service.

Gantenbein, E. 2018. Center for Natural Lands Management. Oxbow Preserve site visit meeting notes recorded by Stephanie Prevost of the U.S. Fish and Wildlife Service.

Reith, H. 2019. California Department of Parks and Recreation. Phone call notes recorded by Stephanie Prevost of the U.S. Fish and Wildlife Service.

APPENDIX

Funding contributions for riparian brush rabbit projects, 1997-2019 (not comprehensive).

Year Initiated	Funding Source	Grant Amount	Project/Activity Title	Summary of Project/Activity	Dates
1997	California Department of Parks and Recreation	\$100,000	Caswell Memorial State Park	Park staff implement habitat improvements for the riparian brush rabbit.	1997-2000
1997	CVPIA Habitat Restoration Program (HRP) “(b) (1) other.”	\$85,000	Riparian Brush Rabbit/Riparian Woodrat	“Survey, restoration (258 acres riparian hardwood). CDPR, CDFG, ESRP, Ripon Fire Dept. partners.” Source: CVPCP online database	1997-2001
1998	Central Valley Project Conservation Program (CVPCP)	\$30,000	Riparian Brush Rabbit and Riparian Woodrat Surveys at Caswell Memorial State Park		1998-1999
1999	ESA Section 6 Cooperative Endangered Species Conservation Fund	\$50,000	Section 6 Grant	ESRP riparian brush rabbit surveys, research, controlled propagation pen construction.	1998-1999
2000	ESA Section 6 Cooperative Endangered Species Conservation Fund	\$28,350	Section 6 Grant	ESRP riparian brush rabbit surveys at Caswell MSP, research, controlled propagation pen construction.	2000-2001
1999	Central Valley Project Conservation Program (CVPCP), and CVPIA Habitat Restoration Program (HRP) “(b) (1) other.”	\$276,000 \$82,000	Riparian Brush Rabbit	Species survey, habitat management, and construction of controlled propagation pens.	1999-2001
2000	CVPIA Habitat Restoration Program (HRP) “(b) (1) other.”	\$93,257	Genetic structure and phylogenetic relationships of riparian brush rabbit populations”	Studies and surveys.	2000 - 2006

Draft SSA for the riparian brush rabbit, Version 3.2 February 2020

Year Initiated	Funding Source	Grant Amount	Project/Activity Title	Summary of Project/Activity	Dates
2000	Central Valley Project Conservation Program (CVPCP), and CVPIA Habitat Restoration Program (HRP) “(b) (1) other.”	\$126,000 \$41,500	Riparian brush rabbit breeding pen construction	Development and design.	2000 - 2002
2000	Central Valley Project Conservation Program (CVPCP)	\$101,000	Christman Island Refugia (habitat enhancement)	Move fill, habitat restoration on Christman Island Tract, West Unit, and SJRNWR.	unknown
2001	Bureau of Reclamation, Friant Division	\$375,000	Riparian Brush Rabbit, authority numbers: A30 1785 8943 332 20 B O A30 1787 8943 332 20 B O A30 1785 8921 342 93 0 0 A30 1785 8943 332 20 B O	Brush rabbit surveys and monitoring, relocation preparations, construction of two breeding pens.	2001-2002
2001	Central Valley Project Conservation Program (CVPCP)	USBR Fresno Office \$140,000 CVPCP \$23,000	Riparian brush rabbit captive breeding program	Research and management.	2001-2002
2001	CALFED grant ERP-01-N08	\$7,968,112	San Joaquin River NWR Riparian Habitat Protection & Floodplain Restoration Project - Phase II	Land acquisition, restoration, and reintroduction of riparian brush rabbits	2001-2006

Draft SSA for the riparian brush rabbit, Version 3.2 February 2020

Year Initiated	Funding Source	Grant Amount	Project/Activity Title	Summary of Project/Activity	Dates
2002	CALFED grant ERP-01-N11	\$2,720,085	Habitat Acquisition for Riparian Brush Rabbit and Riparian Woodrat	Land acquisition, restoration, and reintroduction of riparian brush rabbits	2002-2008
2002	Central Valley Project Conservation Program (CVPCP), and CVPIA Habitat Restoration Program (HRP) “(b) (1) other.”	\$53,000 \$218,000	Riparian Brush Rabbit	Riparian habitat restoration. Riparian brush rabbit propagation.	2002
2002	Central Valley Project Conservation Program (CVPCP)	\$133,126	Implementation of Specific Actions to Benefit Riparian Woodrat and Riparian Brush Rabbit at Caswell Memorial State Park , San Joaquin County, California. Grant # 02FG200124”	Habitat Restoration. 1. Recreation management fencing at campground to protect riparian brush rabbit habitat. 2. Remove dead non-native vegetation from previous invasive species control actions at Caswell. 3. Remove 7-10 acres of invasive, non-native trees and giant cane throughout the park. 4. Conduct monitoring of Caswell MSP populations 5. Acquire 90 acres for creating flood refugia. (Original grant was for \$155,320, with \$22,193 later de-obligated)	2003-2006
2003	CVPIA Habitat Restoration Program (HRP) “(b) (1) other.”	\$230,000	Riparian Brush Rabbit Captive Breeding Program	Studies and surveys. Continued recovery actions for the riparian brush rabbit (<i>FY03 funding may be reduced based on prior year funding already committed</i>).	2003-2006
2003	Central Valley Project Conservation Program (CVPCP)	\$400,000	Riparian Brush Rabbit Captive Breeding and Reintroduction in 2004.	Contribute funding for staff, materials, supplies, surveys, captive reproduction, propagation, genetics, and release of captive raised rabbits for FY 2004.	2003-2006
2004	Central Valley Project Conservation Program (CVPCP)	\$253,022	Riparian brush rabbit reintroduction and translocation monitoring	Endangered Species Restoration Program monitoring of riparian brush rabbits released at the Refuge.	2004-2007

Draft SSA for the riparian brush rabbit, Version 3.2 February 2020

Year Initiated	Funding Source	Grant Amount	Project/Activity Title	Summary of Project/Activity	Dates
2004	BAER	\$570,000	Fire restoration activities	Fire-related restoration activities at the Refuge. Approximately \$130,000 was allocated to ESRP to conduct post-fire riparian brush rabbit monitoring, and for the construction of release pen #3.	unknown
2004	Wildlife Conservation Board (WCB) Habitat Conservation Fund (Prop 117), Section 2786(d) IWCP	not known	Miller Lake Wetland Restoration, Stanislaus County	Create a mix of open water, emergent wetlands, and riparian forest: 1. Remove sediments to enhance and deepen a degraded oxbow lake and provide a 32-acre permanent wetland. 2. Create 30 acres of managed seasonal wetlands. 3. Restore a 22-acre fallow-field to riparian habitat and upland grassland habitats. 4. Construct new levees, excavate swales, and create islands and benches within the new wetlands, and 5. Install water control structures. -The improvements to riparian forest at this location will provide wildlife refuge at very high winter floods on land immediately adjacent to the Refuge and Caswell MSP.	2004-2006
2005	DWR Flood Protection Corridor Program	\$1,755,542	Vierra Unit Flood Protection and Ecosystem Restoration at San Joaquin River National Wildlife Refuge – SAP Contract #4600003357	Restore approximately 311 acres of riparian habitat in the Vierra Tract (fields V1 to-V9) in the West Unit of the Refuge, targeting riparian songbirds, riparian brush rabbit, and valley elderberry longhorn beetle; expanding the floodplain of the San Joaquin River promoting transient floodwater storage and ecosystem function.	2005-2011
2005	City of Tracy– Central Valley Regional Water Quality Control Board: Supplemental Environmental Project, Administrative Civil Order R5-2005-0500	\$40,000	Vierra Unit Restoration – Levee Planting	Plant approximately 2,000 linear feet of abandoned Army Corps of Engineers on the Refuge Vierra Tract to provide flood-refugia for riparian brush rabbits.	2005-2008

Draft SSA for the riparian brush rabbit, Version 3.2 February 2020

Year Initiated	Funding Source	Grant Amount	Project/Activity Title	Summary of Project/Activity	Dates
2005	City of Manteca – Central Valley Regional Water Quality Control Board: Supplemental Environmental Project, Administrative Civil Order R5-2004-0028	\$204,000	Vierra Unit Restoration – Levee Planting 2	Plant approximately 11,000 linear feet of abandoned Army Corps of Engineers levees on the Refuge Vierra Tract, to provide flood-refugia for riparian brush rabbits.	2005-2008
2005	CVPIA Habitat Restoration Program (HRP) “(b) (1) other.”	\$144,334	Dos Rios Ranch Working Landscapes	Initial survey/planning activities at the Dos Rios Ranch in Stanislaus County CA, located at the confluence of the Tuolumne and San Joaquin Rivers and adjacent to the San Joaquin River NWR.	2005-2007
2006	CALFED grant ERP-02D-C11. California Bay Delta Authority (CBDA) Agreement F-05-ER-041. California Department of Fish and Game, Project Number P0685579	\$6,427,131 -- --	Recovery Implementation for Riparian Brush Rabbit and Riparian Woodrat on the Lower Stanislaus River	1. Land Acquisition. Acquired 184.34 acres. 2. Data Collection 3. Restoration and Management Plan 4. Flood Refugia Plan 5. Flood Refugia Construction 6. Plant propagation and planting 7. Restoration planting maintenance. Restored riparian habitats along the lower Stanislaus and San Joaquin Rivers adjacent to the Caswell State Park and the San Joaquin River National Wildlife Refuge, to reintroduce riparian brush rabbits near the Caswell MSP population.	2006 - 2011
2006	Wildlife Conservation Board (WCB) Wildlife Conservation Fund. CVPIA Habitat Restoration Program (HRP) “(b) (1) other.” Natural Resources Agency of the State of California’s River Parkways Program (Proposition 50)	\$400,000 \$238,958 \$250,000	Riparian Restoration on Hagemann Unit 1 Riparian Restoration for Endangered Species at the San Joaquin River NWR (Grant #06FG202077)	This project restored and enhanced 173 acres of riparian vegetation on 4 former agricultural fields (H4, H24, H25, and H26: project area) within the Hagemann Unit of the San Joaquin River National Wildlife Refuge. This project also restored elevated floodplain to serve as flood-refuge.	2006-2010

Draft SSA for the riparian brush rabbit, Version 3.2 February 2020

Year Initiated	Funding Source	Grant Amount	Project/Activity Title	Summary of Project/Activity	Dates
2006	USFWS Delisting and Recovery Implementation Funds	\$50,000	Flood Damage Assessment and Amelioration	ESRP will conduct a rabbit census at the Refuge and Faith ranch; assess the condition and suitability of the existing flood-damaged habitat; make recommendations regarding the captive propagation program; and make recommendations regarding amelioration future flooding impacts with well-placed and well-designed flood refugia, and how habitat restoration designs can be improved to minimize the likelihood of rabbit death in future flood events.	2006
2006	USFWS Recovery Funds for Preventing Extinction and Showing Success	\$107,500	High ground refugia construction at Christman Island and Vierra Unit Rabbit Mounds at SJR NWR	River Partners will contract to construct approximately 5 large or 17 small flood-refugia mounds; Alternatively, densely plant approximately ¾ miles of levee to provide riparian brush rabbit habitat.	2006-2010
2006	USFWS Challenge Cost-Share	\$25,000	Flood Refugia Mounds	River Partners will use spoil from adjacent wetland excavation to build 20 flood refugia mounds (40' x 80' x 8' high). Approximately 1,700 woody plants will be planted on the mounds. Approximately \$109,000 of CALFED grant funds will be combined with the \$25,000 Challenge Cost Share to complete these activities.	2006
2006	USBOR South Central California Area Office	\$25,000 \$20,000	Flood Refugia Habitat	Establish woody, shrubby vegetation on newly constructed flood refugia mounds.	2006-2007
2006	CLMA and USFW	\$32,000	Faith Ranch	Establish and monitor riparian brush rabbits on the privately owned Faith Ranch, in the East Unit of the Refuge.	2006
2006	City of Manteca – Central Valley Regional Water Quality Control Board: Supplemental Environmental Project, Administrative Civil Order R5-2006-0131	\$111,000	Hagemann Unit Restoration - Levee Planting	Plant approximately 5,300 linear feet of abandoned Army Corps of Engineers levees on the San Joaquin River National Wildlife Refuge, to provide flood-refugia for riparian brush rabbits.	2006-2009

Year Initiated	Funding Source	Grant Amount	Project/Activity Title	Summary of Project/Activity	Dates
2006	Monier-Lifetile – Central Valley Regional Water Quality Control Board: Supplemental Environmental Project, Administrative Civil Order R5-2006-0508?	not known	Vierra Unit Restoration – Levee Planting.”	Plant approximately 1,000 linear feet of abandoned Army Corps of Engineers levees on the San Joaquin River National Wildlife Refuge (Refuge), to provide flood-refugia for riparian brush rabbits.	2006-2009
2007	Central Valley Project Conservation Program (CVPCP), and CVPIA Habitat Restoration Program (HRP) “(b) (1) other.”	\$115,762	Riparian Brush Rabbit Genetics (Grant number 07FG200082)	Quantify the genetic diversity and phylogenetic relationships of the Caswell State Park population and the South Delta population; this data can be used to refine translocations and in population management.	2007-2011
2007	CVPIA Habitat Restoration Program (HRP) “(b) (1) other.”	\$250,000	Riparian Restoration for Endangered Species, on the West Unit, San Joaquin River NWR, Stanislaus County, CA (Grant #07FG200067 and #R10AP20615).	Riparian restoration on 117 acres of the Hagemann Tract in the West Unit of the Refuge [field H3 (31 acres) and field H23 (86 acres)]. Restoration of 41 acres described will commence in 2008.	2007 - 2010
2007	Central Valley Project Conservation Program (CVPCP), and CVPIA Habitat Restoration Program (HRP) “(b) (1) other.”	\$806,736	Dos Rios Ranch Land Protection and Riparian Restoration Project (Grant number 07FG200056)	Acquisition of the 1,603-acre Dos Rios Ranch in Stanislaus County CA, located at the confluence of the Tuolumne and San Joaquin Rivers, extending along the south side of the Tuolumne River and along the east side of the San Joaquin River. Dos Rios Ranch is adjacent to the San Joaquin River NWR.	2007 - 2012
2008	Central Valley Project Conservation Program (CVPCP) , and CVPIA Habitat Restoration Program (HRP) “(b) (1) other.”	\$467,816	Habitat Restoration for Endangered Species on the SJR NWR - Arambel Unit” (Grant # 08FG200044 and #R10AP20589)	Create 148 acres of high quality riparian habitat on the Refuge Arambel Tract by restoring 75 acres of farmland and enhancing 73 acres of existing riparian habitat. The 148 acres will be planted in 2008. River Partners will ultimately implement full-scale restoration on approximately 223 acres of this unit, upon receipt of supplemental funding.	2008-2012

Draft SSA for the riparian brush rabbit, Version 3.2 February 2020

Year Initiated	Funding Source	Grant Amount	Project/Activity Title	Summary of Project/Activity	Dates
2008	California Resources Agency, River Parkways Program.	\$2,591,000 <i>(land costs)</i> \$124,000 <i>(Escrow).</i>	Dos Rios Ranch Land Protection and Riparian Restoration Project”	Contribute to the acquisition of the Dos Rios Ranch in Stanislaus County, CA. (\$2,591,000 for land costs and \$124,000 for escrow fees).	2008-2012
2008	California Department of Water Resources, Flood Protection Corridor Program.	\$2,859,156 <i>(acquisition)</i> \$140,244 <i>(pre-acquisition costs)</i>	Dos Rios Ranch Land Protection and Riparian Restoration Project	Contribute to the acquisition of the Dos Rios Ranch in Stanislaus County, CA.	2008-2012
2008	NRCS Wetland Reserve Program.	\$8,670,000	Dos Rios Ranch Land Protection and Riparian Restoration Project”	Contribute to the acquisition of the Dos Rios Ranch in Stanislaus County, CA.	2008-2012
2008	USFWS North American Wetlands Conservation Act grant program.	\$1,000,000	“Dos Rios Ranch Land Protection and Riparian Restoration Project”	Contribute to the acquisition of the Dos Rios Ranch in Stanislaus County, CA.	2008-2012
2009	Central Valley Project Conservation Program (CVPCP)	\$231,000	Reintroduction/captive breeding	Emergency funding for captive breeding program, due to State budget freeze on grant funding. Pass through of FY2009 EOY funds from CVPCP to Reclamation’s South Central California Office, which had an existing contract with ESRP.	2009 – 2010?
2010 and 2011	CVPIA Habitat Restoration Program (HRP) Central Valley Project Conservation Program (CVPCP).	\$357,036	Riparian Restoration at San Joaquin River National Wildlife Refuge, Riparian Brush Rabbit Refugia (Lara Levee, Lara Field) (Grant # R10AP20062)	1. Plant both sides of a 1.8-mile (2.8-kilometer) existing levee on the Refuge’s Lara Tract, to produce approximately 17.45 acres of dense thickets for riparian brush rabbit flood refugia. 2. Plant 4.5 acres to restore natural high-ground flood refugia for riparian brush rabbits. (\$220,515 of FY2010 funds from HRP and CVPCP for Phase I; \$1366,521 of FY2011 funds from CVPCP for Phase I).	2010-2012

Draft SSA for the riparian brush rabbit, Version 3.2 February 2020

Year Initiated	Funding Source	Grant Amount	Project/Activity Title	Summary of Project/Activity	Dates
2010	DWR Flood Protection Corridor Program	\$3,171,344	“Ecosystem Restoration and Floodwater Attenuation at the San Joaquin River National Wildlife Refuge” SAP Contract #4600009040	Restore approximately 551 acres of riparian habitat on the Refuge’s Hagemann and Arambel tracts, targeting riparian songbirds, riparian brush rabbit, and valley elderberry longhorn beetle; expanding the floodplain of the San Joaquin River promoting transient floodwater storage and ecosystem function.	2010-2014
2011	Central Valley Project Conservation Program (CVPCP).	\$390,673	“Riparian Brush Rabbit captive propagation, reintroduction and monitoring” (Agreement number R11AP20141)	Complete the controlled propagation and reintroduction of riparian brush rabbits onto the Refuge and adjacent lands.	2011-2013
2011	USFWS Southwest Pacific Regional Office	\$60,000	Riparian Brush Rabbit Recovery Plan	Develop a draft and final recovery plan for the riparian brush rabbit.	2011-2013
2012	Wildlife Conservation Board (WCB).	\$5,483,108	“Dos Rios Ranch Land Protection and Riparian Restoration Project”	Contribute to the acquisition of the Dos Rios Ranch in Stanislaus County, CA.	2012
2012	Central Valley Project Conservation Program (CVPCP), and NRCS Wetland Reserve Program, and River Partners	\$1,054,372	Dos Rios Ranch Habitat Restoration – Phase 1	Restore cropland and slough to 150 acres of riparian habitat and 48 acres of wetland habitat, respectively; construct and vegetate a 5-acre bunny mound.	2012-2016
2013	FWS Habitat Restoration Program (HRP)	\$112,852	Riparian Brush Rabbit population genetic structure	Genetic research.	2013-2017
2015	Central Valley Project Conservation Program (CVPCP) Other(s)	\$447,415 \$495,830	Dos Rios Ranch Restoration for Riparian Brush Rabbit Recovery	Restoration at Dos Rios Ranch.	2015-
2018	CVPIA Habitat Restoration Program (HRP) Other(s)	\$500,101 \$252,551	Riparian Habitat Restoration at Dos Rios Ranch	Restoration at Dos Rios Ranch.	2018-

Draft SSA for the riparian brush rabbit, Version 3.2 February 2020

Year Initiated	Funding Source	Grant Amount	Project/Activity Title	Summary of Project/Activity	Dates
2019	Central Valley Project Conservation Program (CVPCP)	\$42,400	San Joaquin River NWR Land Protection Project		2019-
	Other(s)	\$2,151,800			
2019	FWS Habitat Restoration Program (HRP)	\$470,494	Riparian Brush Rabbit Refugia Restoration at San Joaquin River NWR	Restoration of flood refugia at San Joaquin River NWR.	2019-

Reviewer Name	Chapter	Page	Line #	Comment
Erik Gantenbein	2.3	12	12	comment regarding dispersal during flood event
Erik Gantenbein	3.1	23	23	comment regarding RBR use of willow
Erik Gantenbein	3.3	24	36	comment regarding ecotonal edges/grazing
Erik Gantenbein	3.5	25		comment regarding predator pressure during flood event
Erik Gantenbein	3.5	25		comment regarding reproduction stress/failure during flood event
Erik Gantenbein	3.7	27		question relating to conflicts with other regulatory bodies
Erik Gantenbein	4.1	28		comment regarding genetic comparison and dispersal
				comment regarding reproduction confirmation at Oxbow after flood event. Photo attached.
Erik Gantenbein	4.3	30		
Erik Gantenbein	6.2	37	2	comment regarding effect of flood management
Erik Gantenbein	6.2	37	13	comment regarding documented reproductive stress during flood event
Erik Gantenbein	6.4	42	5	edited text and comment
Erik Gantenbein	6.5	44		edited table 4
Erik Gantenbein	6.6	45	4-Feb	inserted text and comment
Erik Gantenbein	6.12	46	12	edited text
Erik Gantenbein	6.13	46		comment regarding climate change
Erik Gantenbein	6.15	50		comment regarding land acquisition
Erik Gantenbein	6.15	50		comment regarding efforts to enhance high ground refugia
Erik Gantenbein	6.15	51	8	comment regarding monitoring
Erik Gantenbein	6.15	51	11	inserted text
Erik Gantenbein	6.15	51	20	comment regarding predator control
Erik Gantenbein	7.8	69		deleted text due to redundancy
Erik Gantenbein	7.8	70		Figure 18. suggestion to edit figure extending arrow to Preserve

