ASSESSMENT OF HABITAT CONDITIONS FOR THE RIPARIAN BRUSH RABBIT ON THE SAN JOAQUIN RIVER NATIONAL WILDLIFE REFUGE, CALIFORNIA

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INTRODUCTION

The riparian brush rabbit (*Sylvilagus bachmani riparius*) occupies areas of dense, brushy cover along streamside communities in the San Joaquin Valley, and is California- and federally-listed as endangered (U.S. Fish and Wildlife Service 2000). Currently, only two extant populations of riparian brush rabbits are known. One occurs in Caswell Memorial State Park (CMSP) on the Stanislaus River in southern San Joaquin County and the second population is located along the San Joaquin River and its tributaries near the city of Lathrop (ESRP unpub. data). Both populations are small and are considered at risk of imminent extinction from demographic and/or environmental stochasticity (including or resulting from flooding, wildfire, habitat conversion, disease, predation), and possibly from competition with desert cottontails (*Sylvilagus audubonii*; Williams and Basey 1986, Williams 1988, U. S. Fish and Wildlife Service 1998). Consequently, the establishment of other viable populations within the historical range is crucial to the survival of the riparian brush rabbit.

The recovery plan for the riparian brush rabbit requires the establishment of three additional self-sustaining, wild populations outside of Caswell MSP and within the historical range of the species (U.S. Fish and Wildlife Service 1998). Because the extant populations are isolated from potential habitat at historical sites, reintroductions from existing populations are required, and, since existing populations are too small to serve as sources of wild-born individuals for translocations, controlled propagation is being used to provide animals for reintroduction (Williams et al. 2002). In July 2002, riparian brush rabbits were released on the San Joaquin River National Wildlife Refuge by biologists from the California State University, Stanislaus, Endangered Species Recovery Program. Subsequent releases, dispersal of founders, and successful reproduction by founders have established rabbits throughout the refuge.

The San Joaquin River National Wildlife Refuge (SJRNWR) is located on the San Joaquin River, approximately 11 miles (17 km) west of Modesto in Stanislaus County, California (Figure 1). The refuge, which consists of 6,642 acres (2,688 ha) within an approved refuge boundary of 12,877 acres (5,211 ha), was established in 1987 for the conservation of endangered species and migratory birds, and to provide foraging and roosting habitat for the threatened Aleutian Canada goose (Sacramento River Partners 2002).

Much of the refuge property was previously leveled and cultivated for irrigated agriculture. A levee system separates these portions of the refuge from adjacent areas of brushy and riparian habitat. The habitat between the levee and the San Joaquin River is dominated by blackberry (*Rubus ursinus*), willows (*Salix* spp.), mugwort (*Artemisia douglasiana*), and wild rose (*Rosa* spp.). Prior to the Pelican Fire of July 2004, habitat in the northeastern portion of the property was primarily composed of perennial pepperweed (*Lepidium latifolium*) and other ruderal weeds.

Habitat for riparian brush rabbits generally consists of dense, brushy areas of valley riparian forests, marked by extensive thickets of wild rose (*Rosa* spp.), blackberries (*Rubus* spp.), coyote bush (*Baccharis* sp.), and wild grape (*Vitis californica*). Brush rabbits are closely tied to protective cover and use tunnels under thick growing vegetation for movement and predator avoidance. They rarely venture more than 1 or 2 meters from cover and feed at the edges of shrubs and thickets rather than in large openings. When threatened by predators, they quickly retreat into cover rather than be pursued in open areas. Studies in Oregon revealed that the size and shape of brush rabbit home ranges conformed to the size and shape of clumps of shrubs, and that thickets measuring less than about 460 square meters were uninhabited (Orr 1940, Chapman 1971).

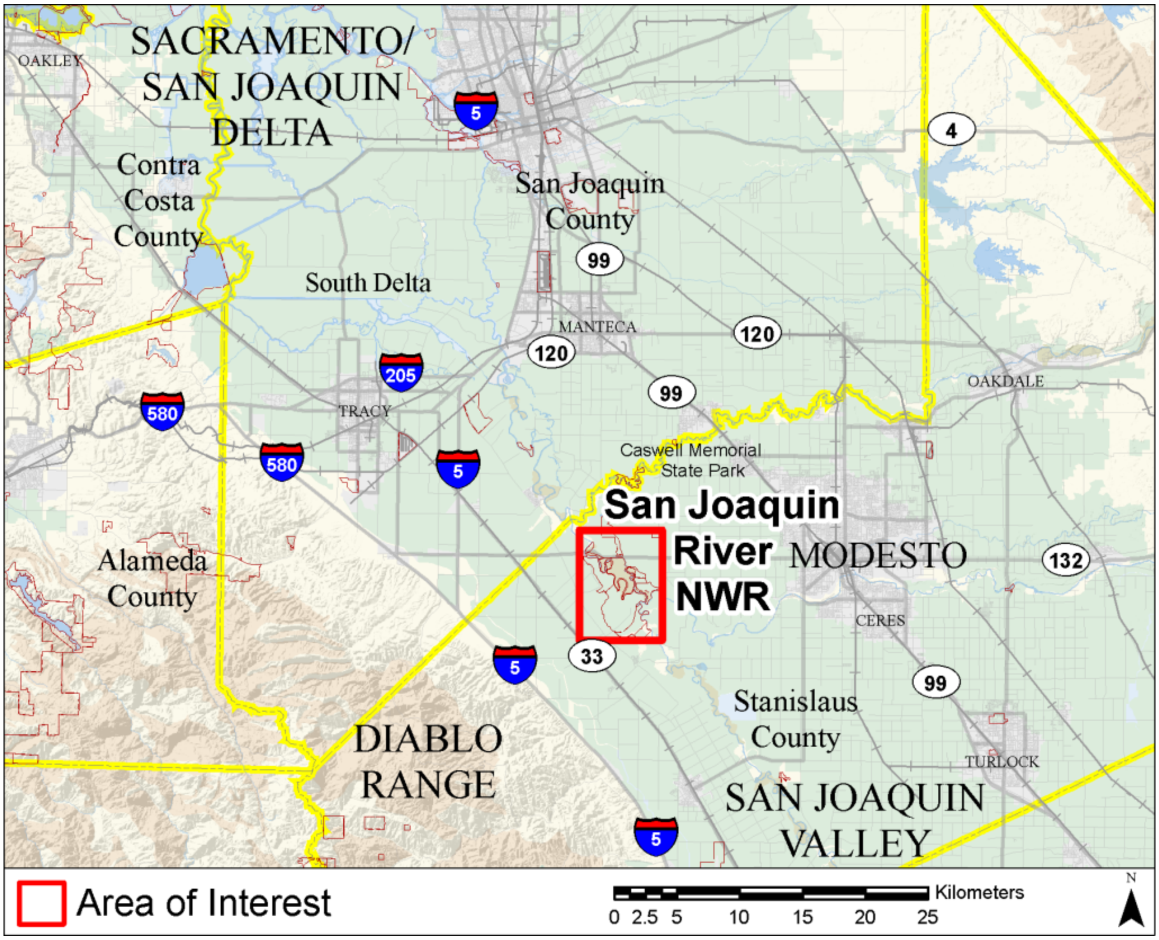

Figure 1. Location of San Joaquin River National Wildlife Refuge.

HABITAT CHARACTERISTICS

Williams and Basey (1986) examined the characteristics of plant communities at sites that were occupied by riparian brush rabbits, in potential habitat that was occupied only by desert cottontails, and at sites with poor habitat. They found few significant relationships between the measured variables and no variables were significantly correlated with riparian brush rabbit occupation. Inhabited sites had fewer willows in the overstory and an absence of seedling and sapling willows in the understory. In addition, ground litter was sparse at areas occupied by desert cottontails. These results led Williams and Basey (1986) to conclude that frequently flooded secondary successional communities were less likely to be inhabited by riparian brush rabbits. They noted also that there were greater areas (measured as length x height along a transect) of roses in the understory of sites occupied by riparian brush rabbits, that inhabited sites generally were composed of a mix of roses, blackberries, coyote bushes and grapes, and that more sites with relatively high quantities (as measured by area) of roses, coyote bushes, and grapes were inhabited than those with only high quantities of blackberries.

Based on the habitat parameters of recently discovered South Delta population, Williams et al. (2002) suggested that riparian brush rabbits might prefer patchy, secondary successional communities to overgrown climax riparian communities. Appropriate cover is a primary habitat requirement of all cottontail rabbits, and brush rabbits are dependent on cover as a means of escaping predation (Chapman and Litvaitis 2003, Orr 1940). Consequently, it is appropriate to re-evaluate riparian brush rabbit habitat associations. In this assessment, we examine the characteristics of the plant community within and outside of home ranges to better identify specific habitat components that are important to riparian brush rabbits. The results of the habitat analysis could be used to guide restoration efforts and vegetation management practices at newly acquired or occupied sites, in assessing habitat suitability at potential release sites, and in predicting patch occupancy in simulation modeling.

As part of a continuing translocation and monitoring study initiated in 2002, riparian brush rabbit space use data has been collected by the tracking of large numbers of rabbits. The overarching objective of this vegetation analysis is to discern whether there are identifiable differences in habitat characteristics between areas of high use and low use for riparian brush rabbits. To do this, we developed a set of habitat classes, collected field information on the distribution of these classes, and used multi-spectral satellite imagery and GIS to estimate the location and area of each habitat class in the area used by translocated riparian brush rabbits. We also estimated the location and area of habitat classes that were affected by a wildfire that occurred during the translocation and monitoring study in July of 2004 to examine the effect of the fire on riparian brush rabbit space use.

METHODS

HABITAT CLASSES

We developed a set of habitat classes based on specific habitat components that are important to riparian brush rabbits. Habitat classes were developed based on characteristics identified in section Habitat Characteristics of the Introduction including plant communities and vegetation structure for escaping predation.

Dense riparian

Dense riparian areas are dominated by wild roses, blackberries, sandbar and black willows (*Salix exigua* and *Salix goodingii*), box elder (*Acer negundo*), Fremont cottonwoods (*Populus fremontii*), and/or valley oaks (*Quercus lobata*). Dense riparian sites generally have a closed canopy and a very dense understory. Rabbits are likely to use these areas on a regular basis for multiple activities including foraging, breeding, resting, and predator avoidance. Because these areas contain thick overhead cover they might offer greater protection for riparian brush rabbits against aerial predators.

Oak woodland/grass meadow

The oak woodland/grass meadow class is characterized by a closed canopy, fewer understory shrubs (e.g., roses, blackberry), and greater quantities of grass, especially basket sedge (*Carex barbarae*) and creeping wild rye (*Leymus triticoides,)* than is present in dense riparian locations. This vegetation class might be used by rabbits for foraging, but it is unlikely that they would use it very heavily (e.g., breeding, resting, predator avoidance) due to the lack of a thick understory.

Willow/shrub mix

The willow/shrub class is found in areas that are dominated by sandbar willow. Often the willows are mixed with large stands of dense blackberry and/or mugwort and occasionally they are interspersed with patches of roses. Rabbits are likely to use these areas on a regular basis for multiple activities including foraging, breeding, resting, and predator avoidance. Because these areas contain thick overhead cover they might offer greater protection for riparian brush rabbits against aerial predators.

Open non-native grassland

The open non-native grassland habitat class is dominated by tall annual vegetation, measuring from approximately 1 to 3 m in height. Within this class, three sub-groups provide varying levels of habitat value. The vegetation in *Grassland A* seems to form a thick mat and there is less open space at the base of the plants for rabbits to travel. In contrast, the plants in grassland groups B and C seem to be more open at the base, creating runways and space for movement, with some protection from the foliage above.

Grassland A

These are areas that consist of a dense "mat" of vegetation, including plants such as black mustard (*Brassica nigra*); sweet clover (*Melilotus albus*); annual grasses, such as rip-gut brome (*Bromus diandrus*) and creeping wild rye; prickly lettuce (*Lactuca serriola*); and horseweed (*Conyza canadensis*). Based on our field observations, we suspect that riparian brush rabbits are less likely to permanently inhabit these areas. Although this vegetation might be used to travel through, rabbits generally have not been observed using this habitat type for long periods of time (e.g., on a daily or regular basis).

Grassland B

Non-native perennial pepperweed (*Lepidium latifolium*) and Johnson grass (*Sorghum halepense*) form large, continuous patches on the refuge, and were especially common prior to the Pelican fire and subsequent re-planting efforts. Riparian brush rabbits have been observed frequently in pepperweed patches, however their use of sites dominated by Johnson grass appears to have been minimal.

Grassland C

This group is distinguished by tall herbaceous native plants including species such as mugwort, evening primrose (*Oenothera* spp.), and gumweed (*Grindelia squarrosa*). This vegetation is often adjacent to the sandbar willow, blackberry and rose patches. Rabbits seem likely to use these areas on a regular basis; particularly when this group is adjacent to shrub understory and/or dense riparian vegetation. Some rabbits have used the grassland B/C mix exclusively, but there have not been many of these occurrences. These areas might have multiple uses for rabbits including foraging, breeding, and resting. However, they tend to lack a closed canopy and might not be as beneficial to rabbits for predator avoidance.

Bare ground and/or short grasses

Bare ground and/or short grasses (15-30 cm) are not considered suitable for RBR occupation or use. Riparian brush rabbits have not been observed using this habitat class.

Wetlands

Wetlands are marshlands consisting of smartweed, cattail (*Typha* spp.), bullrush (*Scirpus americanus*), etc. Riparian brush rabbits have not been observed using this habitat class and it is not considered suitable for RBR occupation or use.

Water

Water refers to standing water; it is not considered suitable for RBR occupation or use.

MATERIALS

Source Imagery Evaluation

In spring of 2004, we evaluated existing sources of aerial photography and satellite imagery that are suitable for vegetation mapping (see Appendix A). DigitalGlobe QuickBird satellite imagery was chosen for a number of reasons:

- It had the highest ground resolution available from a satellite platform (2.4m color, 0.6 m panchromatic).
- We could custom order imagery to correspond with current ground conditions.
- It included both natural color and infrared bands.
- Data were collected digitally allowing greater quantification possibilities.
- We can order imagery of the same area at a future date and and use it to examine changes to the area over time.
- We can order imagery for other locations—such as potential reintroduction sites—for comparison with the SJRNWR imagery.

Data Acquisition

We originally planned to custom order a scene covering an area including the SJRNWR. Custom orders require a minimum aerial coverage (64 km^2), so we configured the order to cover an area including Caswell State Memorial Park (CSMP) and other lands adjacent to the refuge. Our target date for imagery acquisition was late summer when grasses would be drier and more distinguishable from the darker riparian vegetation. We planned to place an order in mid-July with a 30-day collection window.

Pelican Fire

On 20 July 2004, we were in the process of preparing a data collection order and learned that a major fire (the "Pelican Fire") had taken place at the SJRNWR. During the following week, we contacted staff with the Burned Area Emergency Response (BAER) team tasked with assessing the extent of the fire. The BAER team provided us with initial imagery showing the extent and estimated intensity of the fire (Figure 2).

Based on the extent of the fire, we submitted two orders for imagery: a pre-burn image (5 May, 2004) of the burned area taken and a post-burn image (30 August, 2004) of the original 64 km^2 area (Figure 3-Figure 4).

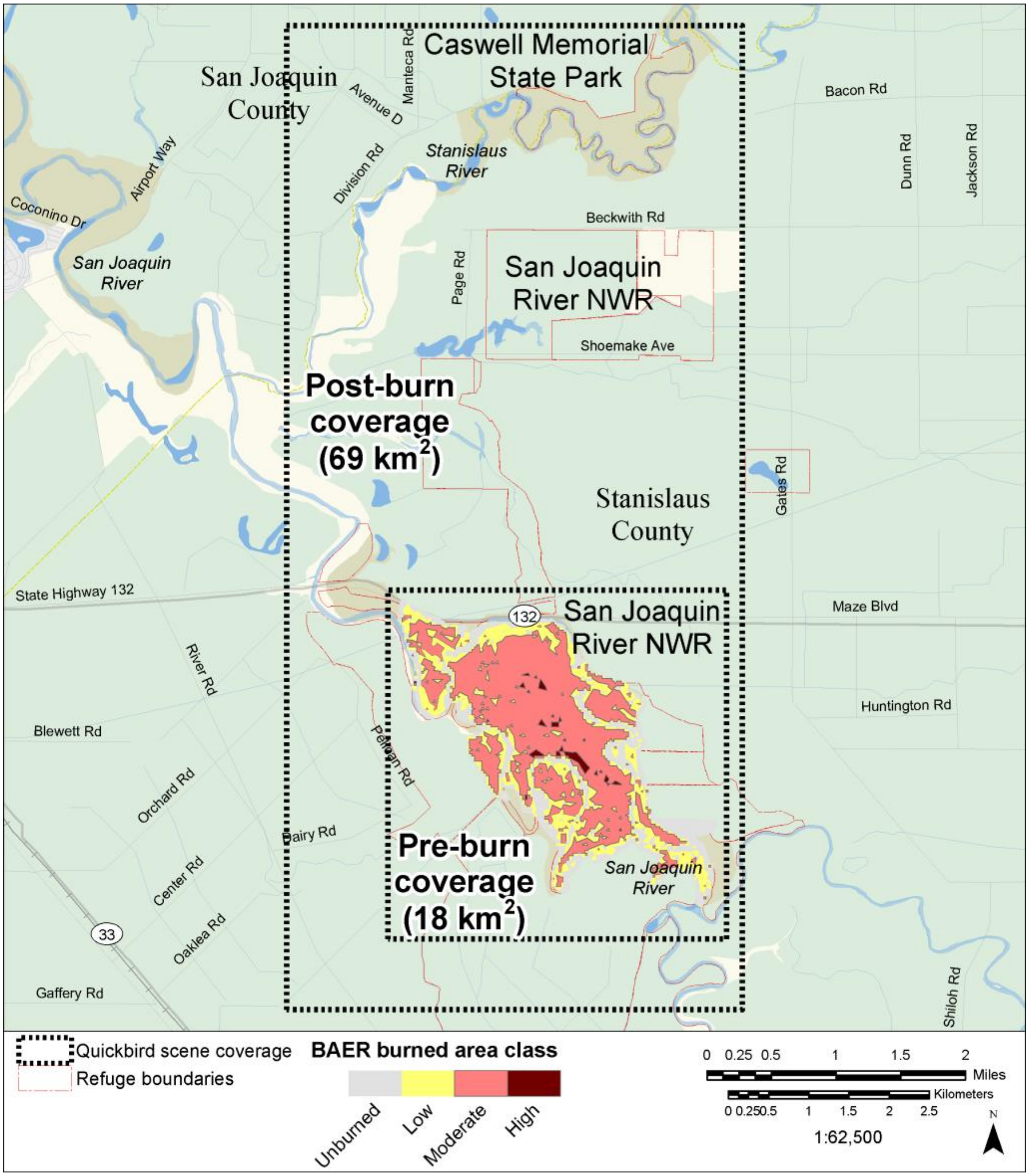

Figure 2. Area covered by pre-fire (5 May, 2004) and post-fire (30 August, 2004) images obtained for vegetation mapping.

DATA PREPARATION

Software and Materials

We used a combination of Erdas Imagine (Leica Geosystems) and ArcGIS (Environmental Systems Research Institute, ESRI) for image processing and analysis. Within ArcGIS, we used Spatial Analysis (ESRI) and Image Analysis (Leica

Geosystems) for raster data manipulation and analysis. We used Workstation Arc/Info (ESRI) for overlay analysis and for the building and maintenance of polygon topology.

SJRNWR Study Area

We defined an area of analysis within the SJRNWR that was limited to the area of existing riparian, grassland, and oak woodlands generally around the area of the Christman Island Refuge Management Unit and including parts of the Gardners Cove, Vierra, Hagerman, and Christman and Colwell Fields Refuge Management Units. A polygon area dividing the undeveloped riparian area from adjacent farmland and other land uses was defined for use as an analysis mask during image classification and other analysis.

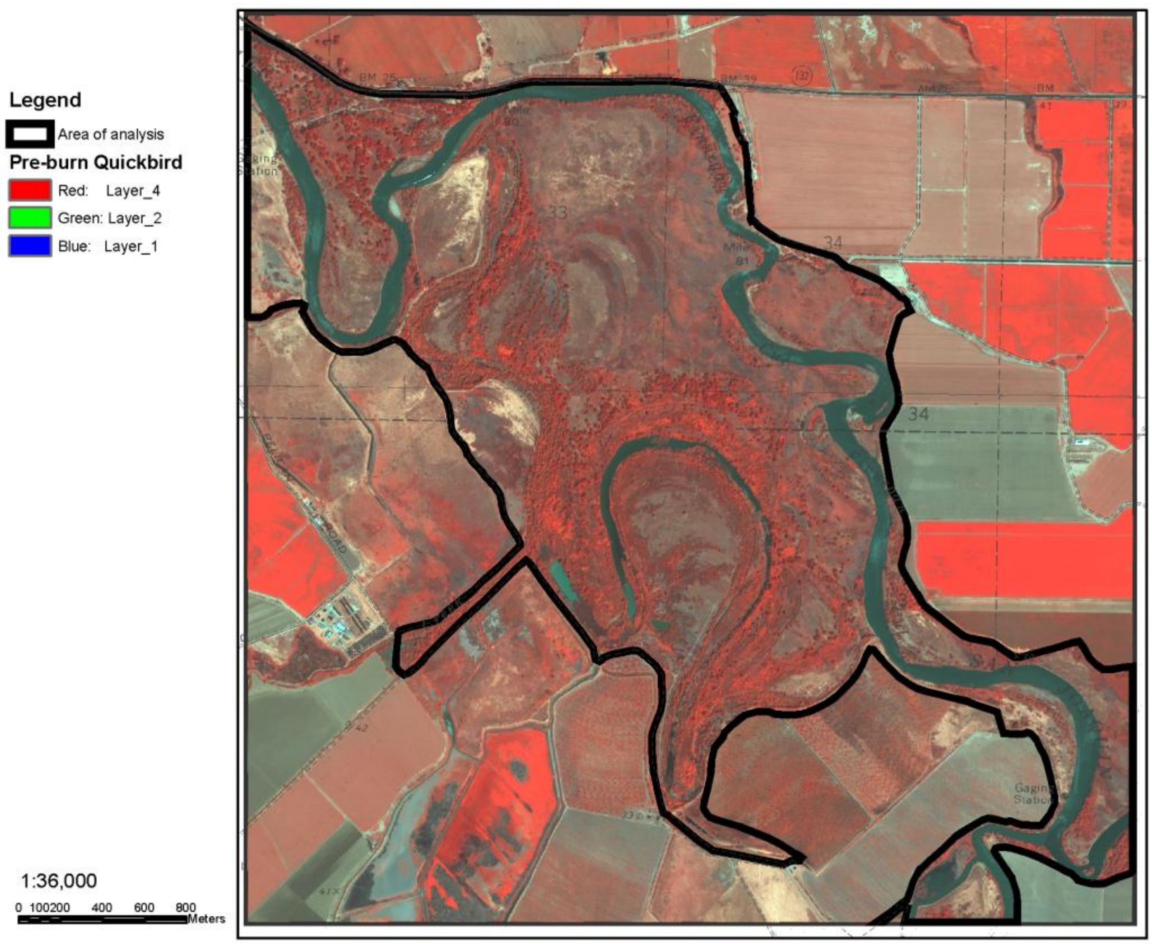

Figure 3. Pre-burn false color infrared image of San Joaquin River National Wildlife Refuge taken 5 May, 2004.

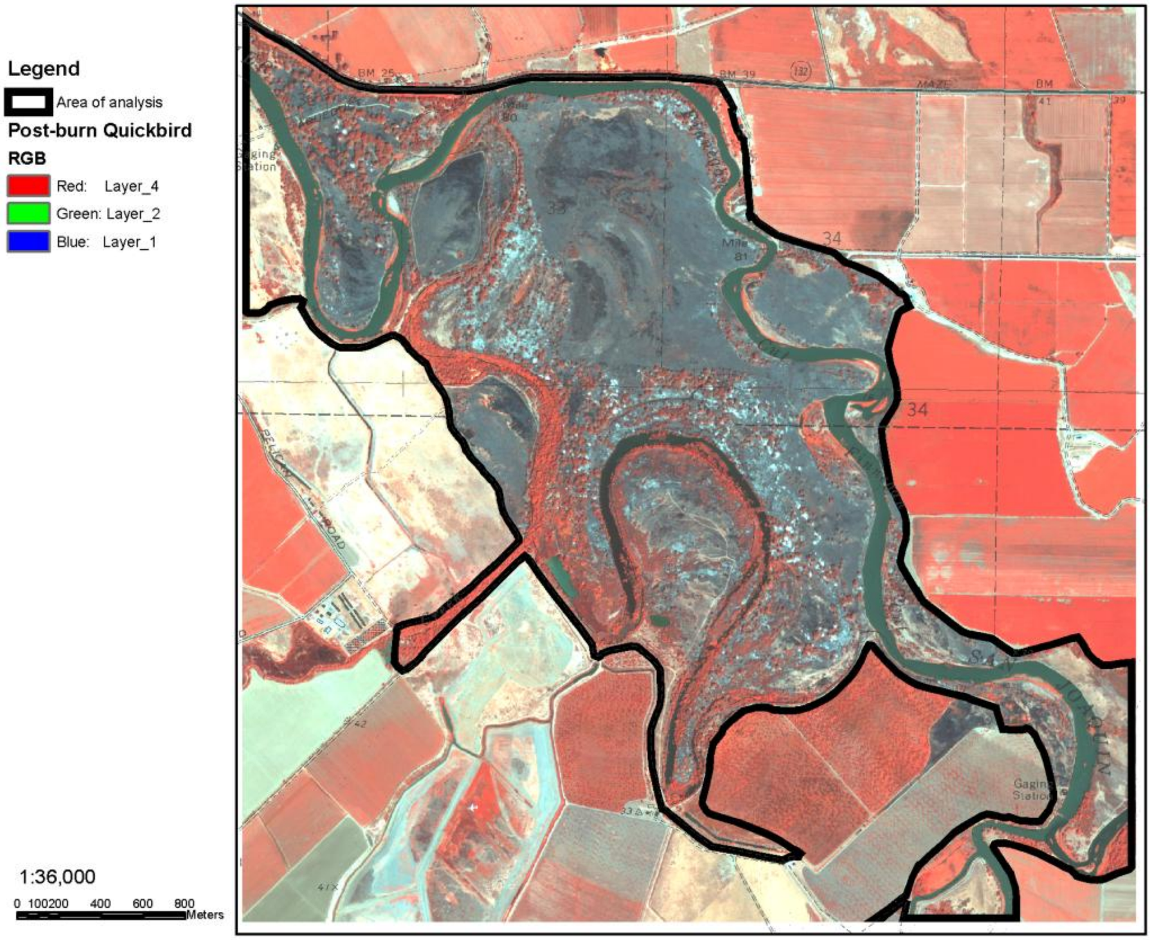

Figure 4. Post-burn false color infrared image of San Joaquin River National Wildlife Refuge taken 30 August, 2004.

ANALYSIS

Sampling of habitat classes and creation of spectral signature file

We delineated areas of known habitat classes onto a project base map. Habitat classifications for these areas were based on:

- Areas manually mapped and classified on a field base map during site visits.
- Areas mapped and classified on a project base map by field biologists based on local knowledge of the refuge during trapping efforts
- Vegetation notes and associated GPS locations taken during RBR surveys.
- Ancillary data such as oblique aerial photography.
- Water features identified by shape and tone in the source imagery.

Sample areas were digitized to a GIS layer by heads-up digitizing. A spectral seed was used to refine the boundaries of target classes. The geographic areas of the habitat classes were used to generate a series of spectral signatures in the blue, green, red, and infrared bands of the pre-burn Quickbird imagery. Signatures for each habitat class were generated using a spectral signature editor in Erdas Imagine by interactively choosing areas of interest based on the GIS layer of sample areas. We did not have adequate field samples of Subgroup C of the Open non-native grassland category for it to be included as a separate class for analysis.

Evaluation of spectral signatures of samples

We used a spectral signature-editing tool in Erdas Imagine to compare spectral signatures of individual samples of the same habitat class to each other and to the mean values of other habitat classes. This process helped identify individual samples that were not consistent with other samples of the same habitat type. In cases where inconsistencies were found, we identified and visually reviewed the sample area. We found that inconsistencies were due to the sampling polygon containing a mixture of classes or to differing amounts of total vegetation between samples. In those cases we edited the boundary of the sample or excluded it from analysis.

We also used the signature-editing tool to compare the mean spectral signatures of samples between classes. This allowed an evaluation of the comparability of spectral signatures between classes. We generated a scatterplot of pixel values in the red and infrared bands with the mean and standard deviation of the sample signatures (Figure 5) and a report of separability (Table 1). Based on the scatterplot and report, bare soil/short grass and water classes were most distinguishable; wetlands were midway between water and other dense vegetation; there was a gradation between dense riparian, oak woodland, and willow shrub mix samples with some overlap between classes; and the non-native grassland classes had overlap between samples of different classes, but the non-native grassland classes as a group were distinguishable from other habitat classes (Figure 5, Table 1).

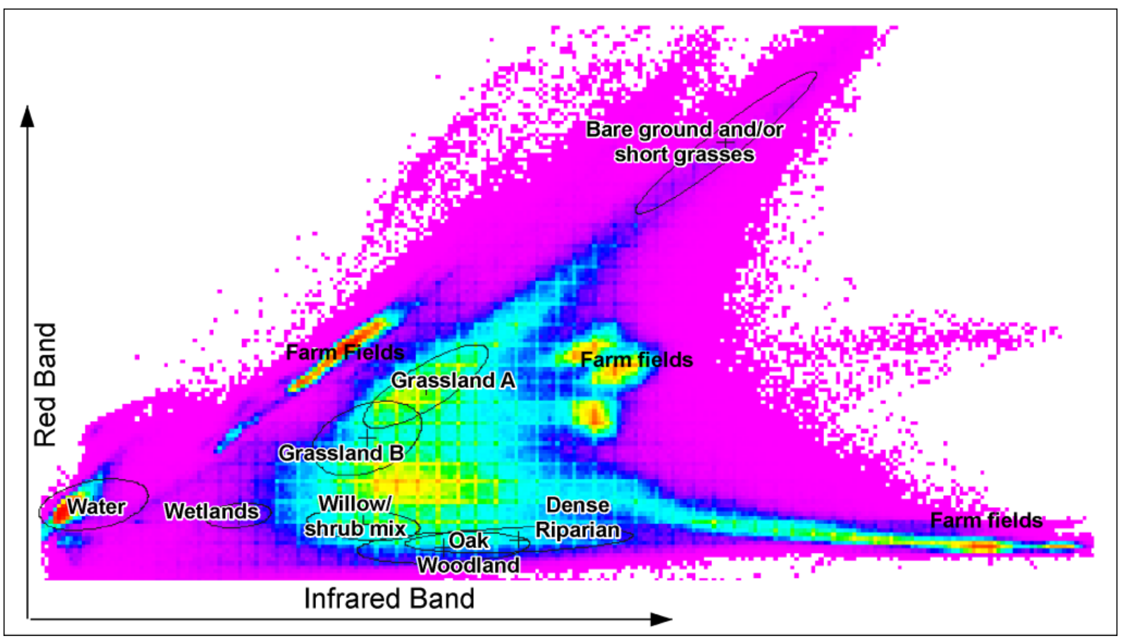

Figure 5. Scatterplot of red and infrared bands of the pre-fire image identifying mean (cross symbol) and one standard deviation (ellipse area) of habitat class samples.

Table 1. Euclidean distance of mean spectral signatures of habitat class samples in the blue, green, red and infrared bands of the pre-fire image. Units are 11 bit (1-2048) pixel values of the image bands.

	Riparian Forest	Oak Woodland	Willow/ Shrub	Grassland A	Grassland B	Barren/ short grass	Wetlands	Water
Riparian Forest	0	81	160	209	203	554	288	438
Oak Woodland	81	0	91	207	170	606	213	365
Willow/Shrub	160	91	0	180	112	618	203	278
Grassland A	209	207	180	0	84	448	255	366
Grassland B	203	170	112	84	0	530	174	290
Barren/short grass	554	606	618	448	530	0	702	793
Wetlands	288	213	203	255	174	702	0	154
Water	438	365	278	366	290	793	154	0
Total	**1933**	**1733**	**1642**	**1749**	**1563**	**4251**	**1989**	**2684**

Supervised classification and classification assessment

We classified the pre-fire multispectral image in Erdas Imagine using a maximum likelihood classification within the SJRNWR Study Area. The classification was supervised based on the spectral signatures taken from the GIS layer of our habitat samples and was saved to a thematic raster layer. During the classification we generated a distance image indicating how far off (Euclidean spectral distance) each pixel of the classified image was from the mean value of the class it was assigned to. We used the distance image to evaluate how well areas were classified based on spectral distance, with a low distance indicating a closer match from sample to classified area. We also used a fuzzy classification to generate layers indicating the second, third, and fourth best classification per pixel. We used the fuzzy classification to estimate “next best” classifications and to explore how misclassification could potentially affect habitat suitability values.

Data generalization and conversion to GIS

We used a majority filter function with a 9x9 window and “half of cells” replacement threshold to generalize the classified thematic raster layer. We did this to eliminate single or small groups of pixels of one class within larger areas of another class. We generalized and smoothed boundaries of the resulting areas using a boundary clean function to expand and shrink boundaries between classes. We converted the generalized thematic raster to a vector polygon file (ESRI Shapefile) with a mimum mapping unit of 100 m^2.

Identification of areas burned in the Pelican Fire

We estimated the area burned in the July 2004 Pelican Fire by generating a vegetation index based on the post-fire imagery in the red and infrared bands (Normalized Difference Vegetation Index, NDVI). We visually assessed the areas burned using the post-fire imagery and incrimentally adjusted an image mask based on NDVI values until it appeared to visually best match the areas that were burned (close to 0.25 NDVI on a scale of -1 to 1). We extracted the areas that had an NDVI of less than 0.25 to estimate the areas burned. We generalized the extracted area using a majority filter and boundary clean function and converted the estimated burned area to a vector polygon file (ESRI Shapefile) for comparison with the estimated pre-fire habitat areas.

Overlay analysis and area calculations

We imported the habitat class and burned area ESRI Shapefiles into Arc/Info coverages to build polygon topology (to avoid overlapping areas and gaps in the data) and calculate the area of each polygon. We generated a new set of polygons based on the intersections of the habitat class polygons and the burned area, a frequency table of total area by habitat class in the SJRNWR Study Area, and a second frequency table of total area by habitat class in the burned and unburned areas.

RESULTS

HABITAT CLASS AREA AND DISTRIBUTION

We estimate that approximately half (49%) of the SJRNWR Study Area consists of non-native grassland of varying habitat value depending on plant structure and proximity to more suitable riparian habitat (Table 2). Approximately 38% of the SJRNWR Study Area is riparian vegetation, consisting of dense riparian areas of canopy with understory (11%), oak woodlands with less understory (7%), and willow and shrub areas (19%). The remaining 14% are mostly wetlands and open water, community types most or completely unsuitable for riparian brush rabbits (Table 2, Figure 6).

Table 2. Estimated areas of habitat classes in the SJRNWR Study Area.

Habitat Class		Hectares	Percent	Total Hectares	Total Percent
Riparian	Dense Riparian	85.2	11.4%	282.2	37.8%
	Oak Woodland	54.6	7.3%		
	Willow/Shrub	142.4	19.1%		
Grasses	Grassland A	113.3	15.2%	363.9	48.7%
	Grassland B	221.6	29.7%		
	Barren/Short Grass	29.1	3.9%		
Wetlands/Water	Wetlands	4.9	0.7%	96.2	13.5%
	Water	96.2	12.9%		

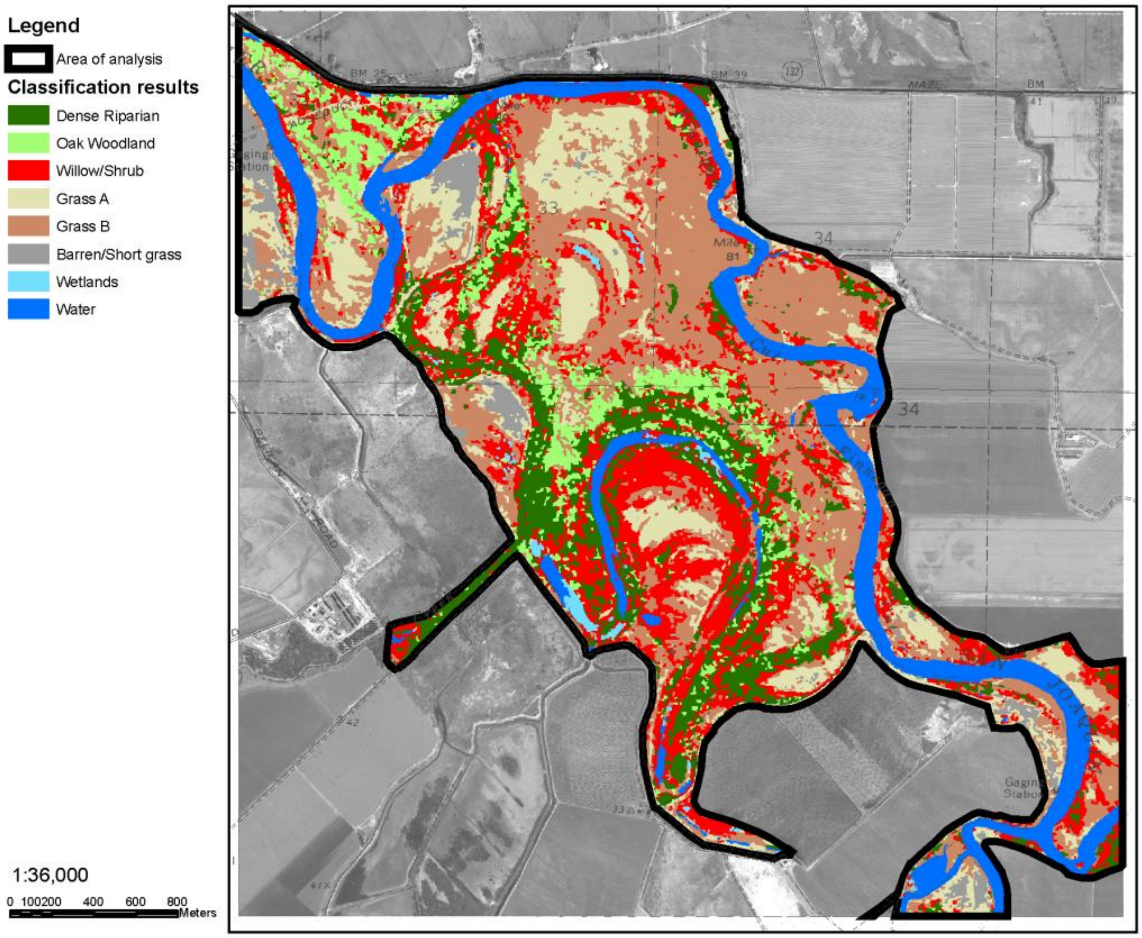

Figure 6. Estimated distribution of habitat classes in area of analysis.

CLASSIFICATION ASSESSMENT

Spectral distance

We computed the sum of distance values within the area of each habitat class to evaluate the relative amount of Euclidean spectral distance by habitat class (Figure 7). Higher distance values indicate relative dissimilarity of the pixels that were assigned to the habitat class and the samples used to define the habitat class. We also visually evaluated the spatial distribution of higher spectral distance values by plotting the spectral distance image (calculated during classification) and highlighting the areas with the highest spectral distance values (Figure 8). This provided us with the ability to visualize the parts of the study area that have a higher potential for misclassification. Grassland areas along the western and eastern edges of the study area contained the largest areas of higher spectral distances.

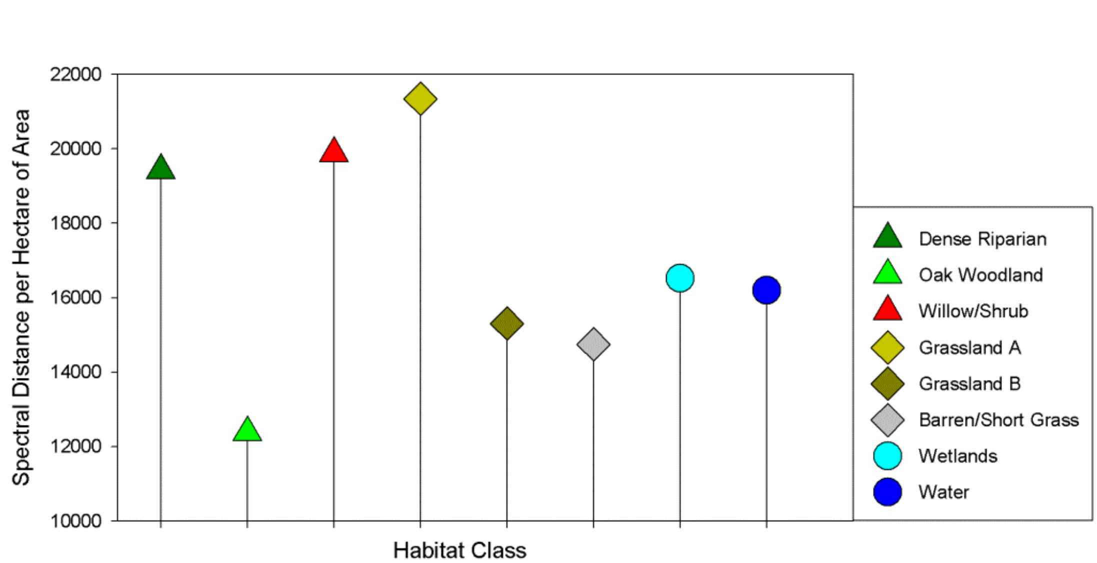

Figure 7. Sum of spectral distance divided by total area of each habitat class.

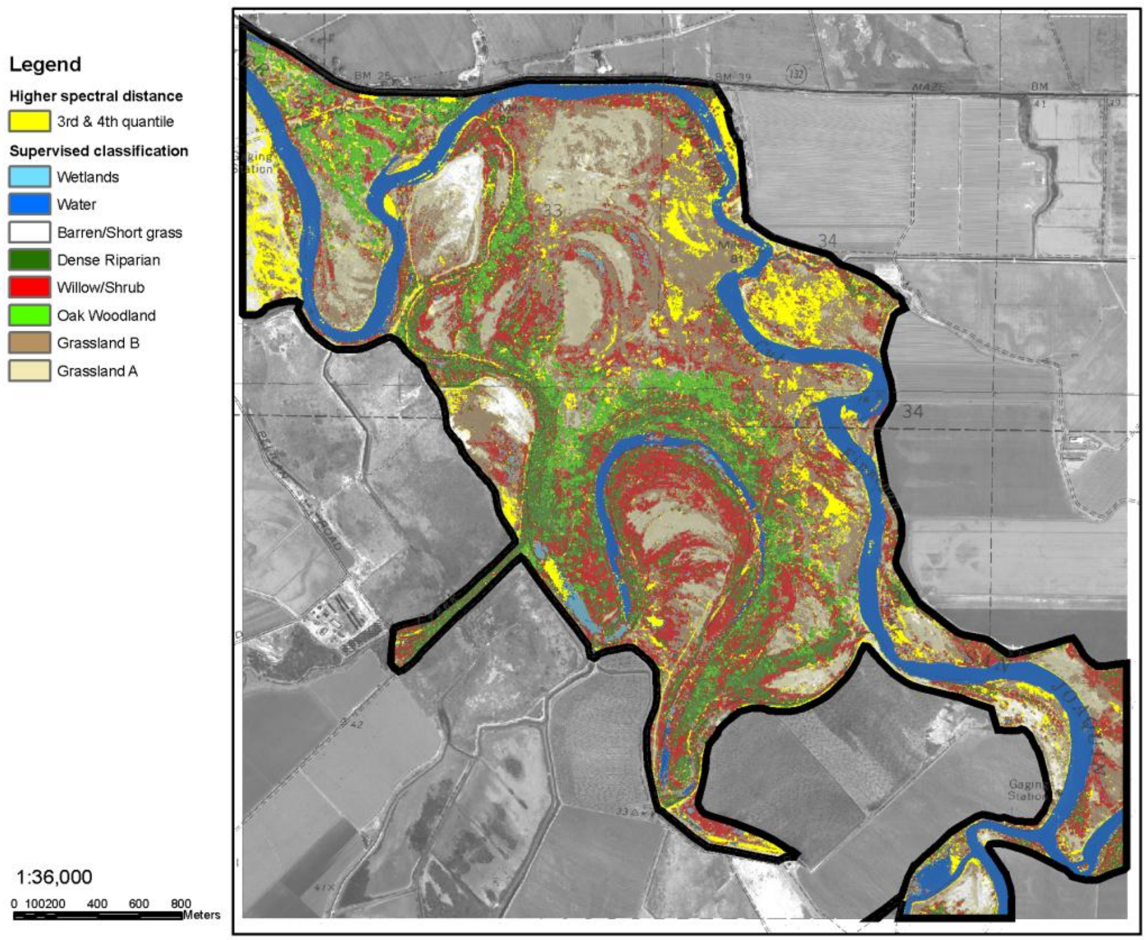

Figure 8. Areas of the highest Euclidean distance (in yellow) between their spectral signature and the mean spectral signature used to define their assigned habitat class.

Fuzzy secondary and tertiary classifications

We ran a second and third set of zonal statistics on our classified areas to calculate the majority of "second best" and "third best" classes within each habitat class (Table 3). This provides some indication of likely alternate classifications for potentially misclassified areas and of the implications of the misclassification for habitat suitability. Within the riparian vegetation and grassland categories, second best sub-classes were members of the same categories, but not necessarily the same category of habitat suitability.

Table 3. Majority of "second best" and "third best" classification by habitat class.

Classification	Majorty of "Second best" class	Majority of "Thrid best" class
Dense Riparian	Oak Woodland	Willow/Shrub
Oak Woodland	Dense Riparian	Willow/Shrub
Willow/Shrub	Dense Riparian	Oak Woodland
Grassland A	Grassland B	Barren/Short Grass
Grassland B	Grassland A	Willow/Shrub
Barren/Short Grass	Grassland A	Grassland B
Wetlands	Willow/Shrub	Grassland A
Water	Dense Riparian	Wetlands

HABITAT SUITABILITY

We assessed habitat quality by assigning a category of *High*, *Moderate*, and *Unsuitable* to each habitat class (Table 4, Figure 9). We categorized non-native grassland as *Mixed* suitability due to the likelihood of some misclassifications (based on spectral distance) and the implications of the misclassifications for habitat quality (based on fuzzy classification). We did so to avoid overestimating the area of the moderately suitable habitats (groups *B* and *C* of the non-native grasses) relative to area ofthe unsuitable habitat of *Grassland A*. Additional field surveys are recommended to classify habitat suitability for non-native grassland areas.

Table 4. Area and percentage of habitat suitability classes in the area of analysis.

Habitat Classes	Habitat Suitability	Hectares	Percent
Dense Riparian, Willow Shrub	High suitability	227.56	30.46%
Oak Woodland	Moderate suitability	54.61	7.31%
Non-native Grassland	Mixed suitability	334.85	44.82%
Barren/Short Grass, Wetlands, Water	Unsuitable	130.15	17.42%

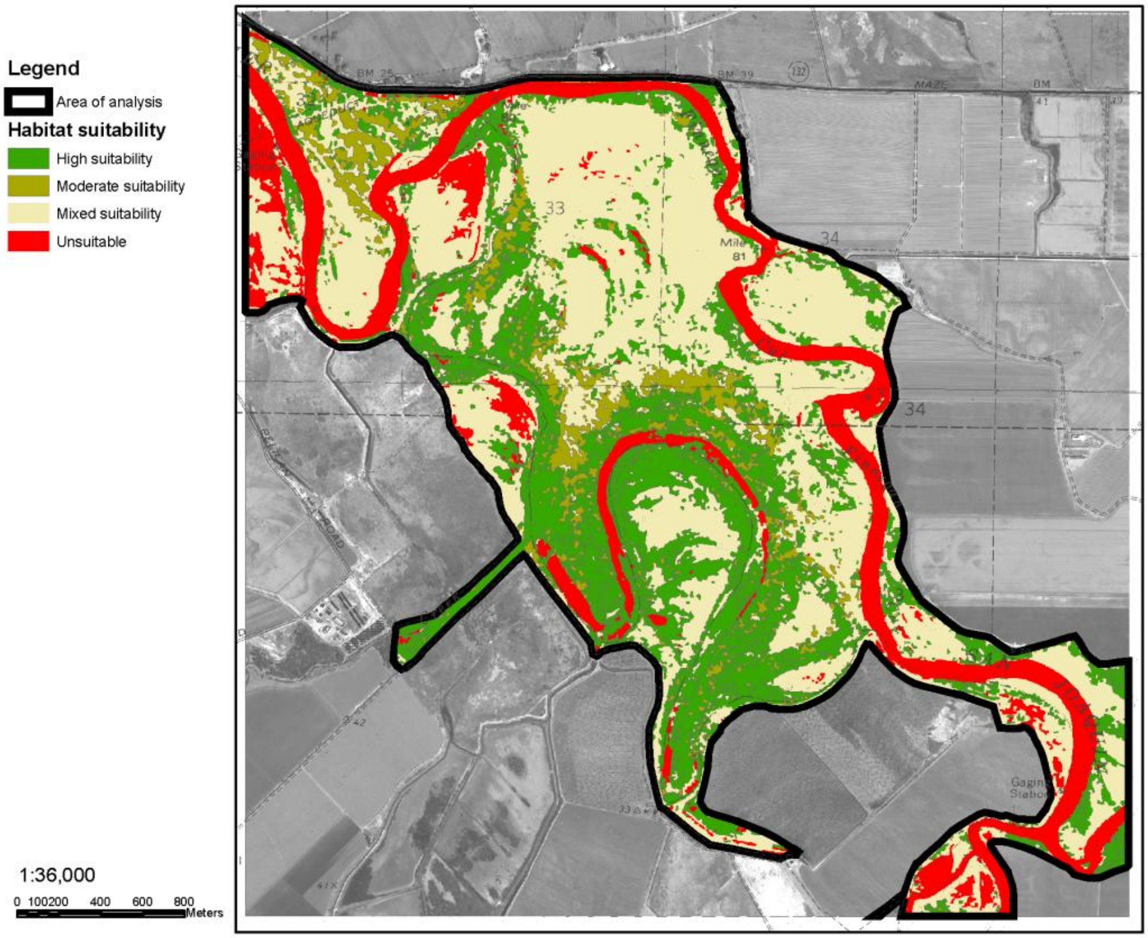

Figure 9. Distribution of habitat suitability classes in the area of analysis.

AREAS AFFECTED BY THE PELICAN FIRE

We estimate that during the Pelican Fire of July 2004, approximately 58% of the area of analysis burned (432 ha; Table 5, Figure 10); approximately 80% of grassland areas and 50% of riparian areas burned (Table 5).

Table 5. Areas of habitat classes estimated to occur in and outside areas burned during the Pelican Fire of July, 2004.

HabitatSuitability	Habitat Class	Hectares		Percent burned	Total Percent burned
		Unburned	Burned		
High	Dense Riparian	47.59	37.57	44.12%	52.55%
	Willow/Shrub	60.39	82.01	57.59%	
Moderate	Oak Woodland	30.37	24.24	44.39%	44.39
Mixed	Grassland A	25.48	87.81	77.51%	80.86%
	Grassland B	38.62	182.93	82.57%	
Unsuitable[1]	Barren/Short Grass	15.24	13.84	47.59%	47.59

1. Exluding Water and Wetland classes.

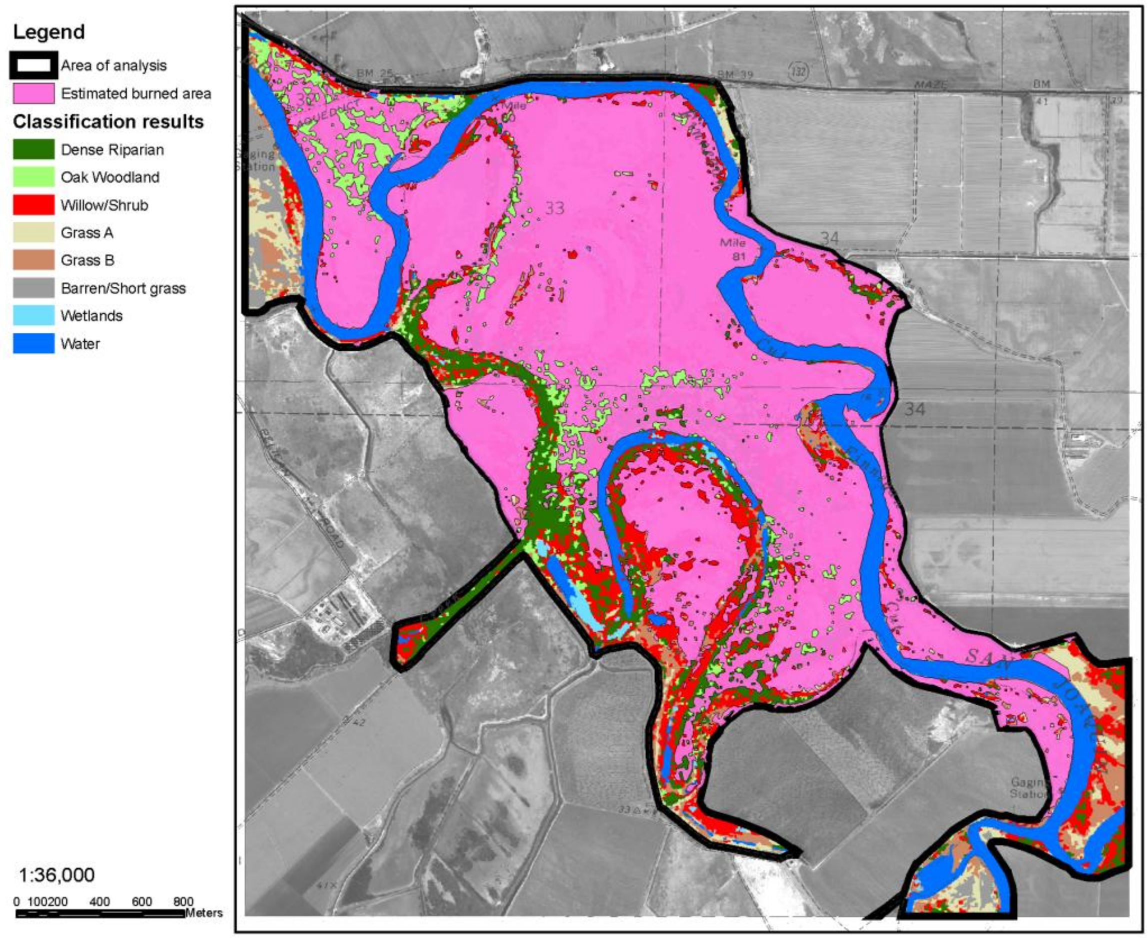

Figure 10. Estimated habitat classes and areas burned during the Pelican Fire of July, 2004.

CONCLUSIONS

Like most other cottontail species, riparian brush rabbits are found in shrub-dominated habitat that provides understory cover and forage (Orr 1940, Chapman and Litvaitis 2003). They frequently use areas with a dense understory composed of thickets of wild rose, blackberries, and willows. These areas provide the greatest protection from aerial predators and are considered to represent high quality habitat for dispersing rabbits.

Within the SJRNWR Study Area, this vegetation can be found primarily in the riparian forest and willow/shrub mix. Approximately, 30% (228 ha) of the SJRNWR Study Area consists of this high quality habitat (Table 4), most of which is located along slough channels and the San Joaquin River.

Oak woodlands with less dense understory are found adjacent to riparian forest and willow/shrub mix areas and can provide areas for foraging but provide less protection from predators. Approximately 7% (55 ha) of the SJRNWR Study Area consists of this moderate quality habitat (Table 4).

Non-native grasses comprise approximately 45% (334 ha) of the SJRNWR Study Area (Table 4), however, 30% (222 ha) of this community type (*Grassland B*) might be of higher value to riparian brush rabbits when it is located in closer proximity to areas with a thick understory (Table 2).

The Pelican Fire burned approximately 58% (432 ha) of the SJRNWR Study Area, affecting a significant amount of habitat for riparian brush rabbits (and riparian woodrats, *Neotoma fuscipes riparia*): 53% (120 ha) of high quality dense riparian and willow/shrub mix habitat and 44% (24 ha) of moderately suitable oak woodland habitat burned (Table 5). Because brush rabbits are dependent on dense vegetation to evade predators, this significant loss of cover might have resulted in surviving brush rabbits congregating in unburned areas where suitable habitat remained. However, water-filled slough channels and open areas with little or no cover may have provided significant movement barriers for rabbits on the refuge. In addition to the impacts related to habitat loss, the fire no doubt injured or killed individuals (of both species) but there is no way to estimate the extent of that impact.

This analysis focused on the classification and quantification of the available habitat for riparian brush rabbits at the San Joaquin River National Wildlife Refuge. Information and techniques derived from this analysis will provide multiple benefits for managing and evaluating habitat for riparian brush rabbits.

Similar analyses can be used to assess the effects of future catastrophic events (e.g., fire or flooding) at occupied sites and to evaluate associated risk factors on riparian brush rabbits. For example, the impacts of a catastrophe on habitat quality can be quantified and specific components of a property can be identified for intensive restoration or recovery (“rescue”) efforts. Information derived from vegetation classification can be used to formulate strategies to mitigate the impacts of a catastrophe and to focus rescue and planning efforts. Threats from crowding in fragmented patches of post-fire habitat can be identified and measures can be taken to minimize potential negative impacts (e.g., to counteract intensified predation pressure).

Additionally, habitat classification methods presented in this report could be used to predict the suitability of potential habitat when considering future land acquisitions (for rabbit reintroductions). High, marginal, and poor habitat value can be estimated and the amounts of each quantified before making other management decisions or performing translocations.

Finally, these analytical methods will be useful in developing predictions and testable hypotheses about patch occupancy at future potential translocation sites. They can also be used in modeling the viability and recovery of riparian brush rabbits.

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APPENDIX A. SOURCES OF SATELLITE IMAGERY OR AERIAL PHOTOGRAPHY FOR SAN JOAQUIN RIVER NWR

SATELLITE PLATFORMS

DigitalGlobe Quickbird

- Samples:
    - http://www.digitalglobe.com/sample_imagery.shtml
    - http://www.npagroup.co.uk/imagery/satimagery/qb.htm
- Cost: Approx. $3000
- Coverage: SJR NWR and CMSP
- Color/IR: Both natural and IR
- Resolution: 0.7m b/w, 3m color, pan-sharpened 70cm
- Dates: Uknown, will be 2004

Space Imaging Ikonos

- Samples:
    - http://www.spaceimaging.com/products/ikonos/reference.htm
    - http://www.npagroup.co.uk/imagery/satimagery/ikonos.htm
- Cost: Approx. $1300
- Coverage: Large area around the SJRNWR
- Color/IR: Both natural and IR
- Resolut: 1m b/w, 4m color, pan-sharpened 1m
- Dates: East half: 2002-08-29, West half: 2002-07-30

AERIAL PHOTOGRAPHY

Existing sources

USGS DOQQ

- Samples
    - http://terraserver.microsoft.com
- Cost: Free
- Coverage: California
- Color/IR: B/W only
- Resolution: 1m
- Dates: 1993-1998

USFWS Vegetation Mapping

- (Pers. Comm. Mark Pelz, FWS Refuge Planning)
- Cost: Unknown
- Coverage: SJRNWR
- Color/IR: IR
- Resolution: Unknown
- Dates: 1999

Commercial products

AirphotoUSA

- Samples: http://www.airphotousa.com/samples/
- Cost: $1,350.00
- Coverage: Unkown, need to determine coverage
- Color/IR: True color only
- Resolution: Depends on avail
- Dates: November, 2002

Custom flights

Aerial Photo Mapping (local company)

- Cost: Uknown, waiting for quote
- Coverage: Custom
- Color/IR: Uknown
- Resolution: Custom
- Dates: Depends on if there is existing photos or need new ones flown
- Update: Company does not provide aerials in this area

WAC (Oregon)

- Cost: $3,000-$12,000
- Coverage: Custom
- Color/IR: Uknown
- Resolution: About 1:12,000 - 1:24,000
- Dates: Probably 2001
- Equal Area Normalization