UPDATED HABITAT SUITABILITY MAPPING FOR RIPARIAN BRUSH RABBITS IN THE NORTHERN SAN JOAQUIN VALLEY AND SACRAMENTO/SAN JOAQUIN RIVER DELTA

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ABSTRACT

The federally endangered riparian brush rabbit (*Sylvilagus bachmani riparius*, RBR) occupies areas of dense, brushy cover along streams in the northern San Joaquin Valley and Sacramento-San Joaquin River Delta in Central California. Populations in both regions are small and at risk from demographic and/or environmental stochasticity (including or resulting from flooding, wildfire, habitat conversion, disease, and predation). Proposed conservation actions for riparian brush rabbit include the establishment of populations in remnant suitable habitat. In 2012 we (Phillips et al. 2013) used GIS to identify remnant suitable habitat and estimate habitat quality based on vegetation type and structure. We estimated habitat quality using existing map-based sources of vegetation class and structure combined with vegetation cover estimates derived from LiDAR. Our current project uses more-recently available data to expand the geographic scope (Figure 1) and improve the detail of the previous (2012) habitat suitability work. The models are critical datasets for the assessment of RBR habitat suitability and the potential for expanding the RBR population to other appropriate habitat within the study area. The habitat modeling results will also support the evaluation of San Luis National Wildlife Refuge Complex (San Luis NWR, Merced NWR, and San Joaquin River NWR) management objectives for riparian ecosystems -- one of their priority resources of concern. This is an initial report intended to provide U.S. Fish and Wildlife Service an assessment of habitat suitability on and near the San Luis National Wildlife Refuge Complex in Merced and Stanislaus Counties to support their RBR conservation efforts. This initial report will be expanded on in future reports that will include additional analyses for habitat connectivity and flood risk.

INTRODUCTION

The riparian brush rabbit (*Sylvilagus bachmani riparius*; RBR) 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). They were first described by Orr (1940) based on individuals collected in riparian habitat west of the confluence of the San Joaquin and Stanislaus Rivers near Vernalis. Riparian brush rabbit populations are currently only known from Caswell Memorial State Park (CMSP) on the Stanislaus River in southern San Joaquin County, in the Southern Sacramento and San Joaquin River Delta in San Joaquin County, and a population established at the San Joaquin River National Wildlife area in Stanislaus County (Figure 1). Populations in both regions are small and are considered at risk 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, 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.

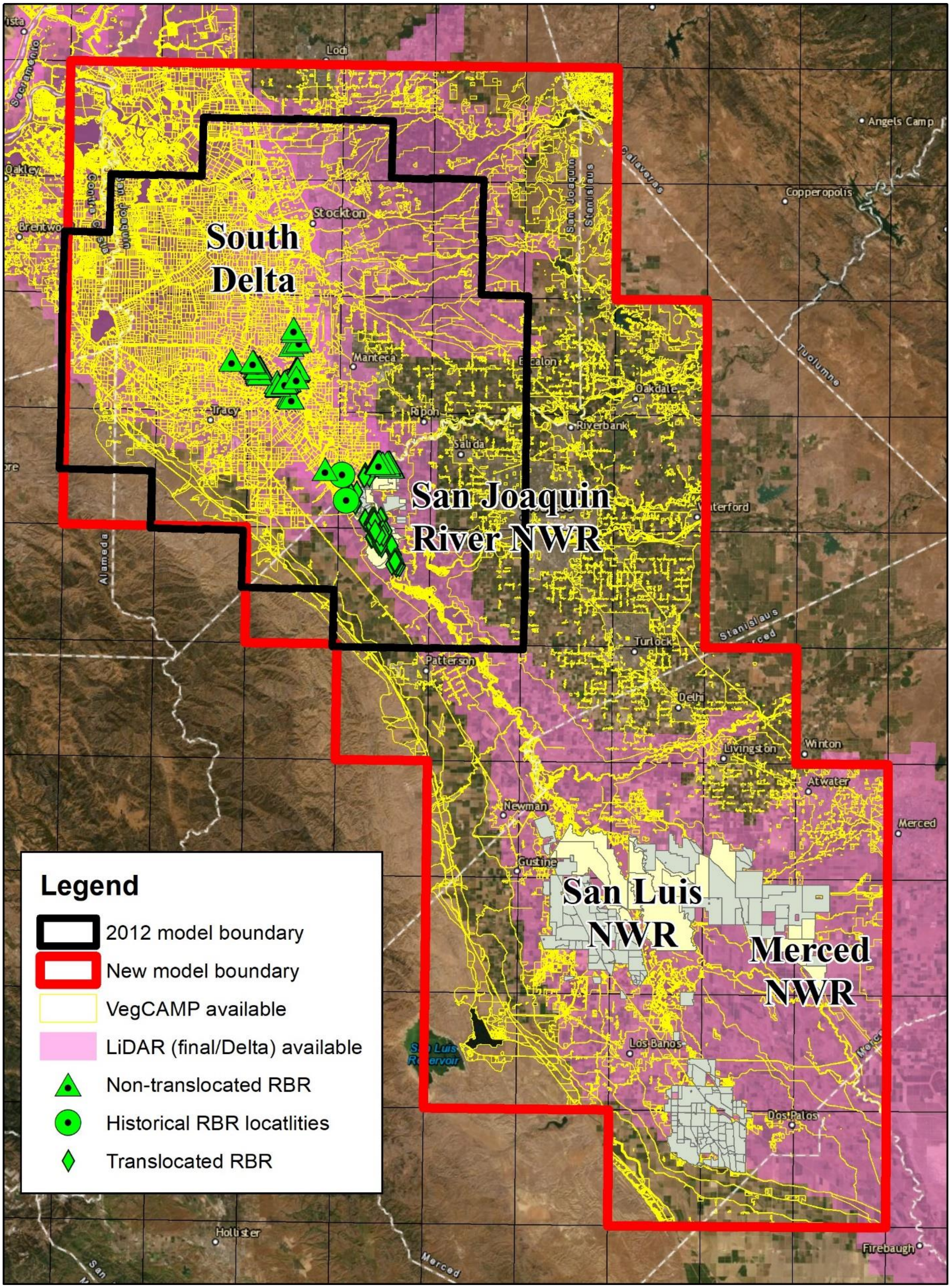

Figure 1. Analysis area for the current habitat suitability modelling for riparian brush rabbit.

HABITAT COMPONENTS

Habitat components for riparian brush rabbit are described in Phillips et al. 2013 and briefly summarized here:

> Habitat components generally consists of dense, brushy areas of valley riparian forests, marked by extensive thickets of shrubs (e.g., wild rose, blackberries, coyote bush, wild grape) (Hamilton et al. 2010, Kelly et al. 2011). Protective cover is an important habitat feature for brush rabbits for predator avoidance. They forage close to cover, and occasionally can be seen at the edges of shrubs and thickets, but not in open herbaceous areas. When threatened by predators, they quickly retreat into cover (US Fish and Wildlife 1998, Williams and Basey 1986). Brush rabbits do not venture far from dense cover, usually brushy habitat, but open fields of tall grasses and forbs adjacent to dense brush provide foraging opportunities.
>
> Dense shrub understory is important to RBR providing cover and protection from aerial predators and medium to large-sized predators (Kelly et al. 2011). While a dense tree canopy is present at rabbit capture sites at Caswell Memorial State Park, a more open tree canopy is found at capture sites in the South Delta and at most recorded locations of RBR on the San Joaquin River National Wildlife Refuge. In all locations, live-trapping records suggest that RBR primarily utilize areas dominated by dense understory thickets (Kelly et al. 2011). A dense tree canopy does not appear essential for RBR, and it can negatively impact habitat quality by inhibiting understory growth (too much shade under a closed canopy). Tall trees can also provide roosting and perching sites for raptors that prey on RBR (Kelly et al. 2011; ESRP field observations). While a dense shrub understory is necessary, adjacent areas of dense herbaceous understory appear to be important to RBR for foraging where enough cover is present to minimize/reduce the risk of detection by predators.
>
> Kelly et al. (2011) summarize what appear to be the most important vegetation components of RBR habitat:
>
> - Large patches of dense brush composed of riparian vegetation – blackberry, wild rose, willow – or other dense shrub species (**Error! Reference source not found.**, REF _Ref347576742 \h * MERGEFORMAT **Error! Reference source not found.**)
> - Ecotonal edges of brushy species to grasses and herbaceous forbs (**Error! Reference source not found.**, **Error! Reference source not found.**).
> - Scaffolding plants (dead or alive) for blackberry and rose to grow tall enough to withstand flood events.
> - A tree overstory, if present, that is not closed.

METHODS

Data Sources

We used a combination of detailed GIS-based vegetation maps (California Dept. of Fish and Wildlife, California Vegetation Classification and Mapping Program [VegCAMP] 2020, 2018, 2015), LiDAR point cloud data provided by the California Dept. of Water Resources (Woolpert 2016, Photo Science 2009), and digital color infrared (CIR) aerial imagery (National Agriculture Imagery Program [NAIP] 2020) to identify areas best meeting vegetation components of RBR habitat requirements and identify areas of brush and tree cover.

Study Area

Figure 1 shows the current study area (new model boundary) compared to a previous effort in 2012 (Phillips et al. 2013). The current model boundary is intended to capture a wider range of areas that could potentially be used in future species conservation efforts such as establishing additional populations as a hedge against threats such as disease, floods, or fire.

Methodology

Here we present an overview of the methods. We used ESRI ArcGIS Pro with the *Spatial Analyst* (raster/grid analysis) extension and *ModelBuilder* for pre-processing and modelling. Our model used raster-based (a grid of cells) analysis with a raster cell-size of 3m (i.e., our study area is divided into 3m X 3m cells). Raster/grid cells are assigned numbers that we used to encode categorical information from our source data, add the numbers together to get combinations of categorical values, and then classify these combinations into suitability categories ranked 0-9, with 9 being highest quality, 8 being moderate quality, and 7 being marginal quality.

VegCAMP

For the VegCAMP GIS-based (vector/geometry) vegetation maps, we classified the data into four categories:

- Riparian vegetation
- Riparian edge (categories such as Oak Woodlands that frequently occur near riparian vegetation.
- Other natural lands (other non-developed lands that could potentially serve as ecotonal edges if suitable cover is present)
- Unsuitable categories (Urban, Agricultural, Water, and Barren)

We converted the vector data to a raster/gird with the following numerical values for each category (Table 1):

Table 1. Vegetation category model values.

Vegetation category	Value
Unsuitable	100
Other natural lands	200
Riparian edge	300
Riparian	400

Areas classified as *Unsuitable* were screened out from further analysis using LiDAR and/or color-infrared imagery.

LiDAR Point Clouds

LiDAR point clouds are a set of 3-dimentional (X,Y, Z) points collected by aircraft that record where a laser scanner came in contact with the ground, or objects above the ground (vegetation, other structures). The three-dimensional points can be classified by their height above ground level. For available LiDAR point clouds, we classified points by their height above the ground into the following categories:

- Low vegetation (below 1-foot)
- Medium vegetation (1-15 feet)
- High vegetation (above 15 feet)

We used a GIS tool (*LAS Point Statistics as Raster*) to create a raster/grid with numerical values for the most frequent LiDAR class code (e.g., low vegetation, high vegetation). We smoothed/generalized the vegetation boundaries by expanding regions of *Medium* and *High* vegetation by 2 cells (6m) and using the *Majority Filter* tool to replace isolated pixels with the value of their neighbors. We then reclassified these values into the numerical values in Table 2:

Table 2. LiDAR height category model values.

LiDAR height category	Value
Missing data	0
Not medium or high vegetation	10
Medium or high vegetation	20

NDVI derived from Color-infrared NAIP aerial imagery

Color-infrared (CIR) imagery from NAIP was used to help identify the amount of vegetation in areas where we were missing LiDAR data, and as a check for cases where our LiDAR may be mis-classified (e.g., a small structure classified as tree cover), or out of date (areas at San Joaquin River NWR with newly restored vegetation not captured in the older [2007] LiDAR data). The CIR imagery includes a red *(RED)* band and a near-Infrared *(NIR)* band (similar satellite imagery platforms) that allows for the creation of a vegetation index based on the ratio of *RED* (vegetation doesn’t reflect this much) to *NIR* (vegetation reflects much more of this relative to RED). We used some basic raster math functions to calculate the commonly-used Normalized Difference Vegetation Index (NDVI). NDVI = (NIR – RED) / (NIR + RED). NDVI values range from -1 (no vegetation or water) to 1 (highest vegetation). We rescaled the NDVI values to integers from 1-254 and divided them into the following classes:

- 1 – 110: Water, barren, or very sparse vegetation
- 111-140: Sparse to moderate vegetation (e.g., grassland)
- 141-254: Moderate to high vegetation (e.g., dense grass, shrubs, trees).

We should note that one disadvantage of the NDVI values versus LiDAR is that while we can estimate the *presence* of green vegetation, it doesn’t provide information on the *structure* of vegetation (e.g., height). We can guess that more green vegetation provides more cover for RBR but we have less certainty about the height of the cover.

We reclassified these ranges of NDVI values into the numerical values in Table 3:

Table 3. Color-infrared NDVI category model values.

Color-infrared NDVI category	Value
Water, barren, or very sparse vegetation (1-110)	1
Sparse to moderate vegetation (111-140)	2
Moderate to high vegetation (141-254)	3

Combining values from VegCAMP, LiDAR, and NDVI

For each raster/grid cell in the model, we added the numerical category for vegetation class, LiDAR class, and NDVI class (Table 1, Table 2, and Table 3) to create a new raster/grid with combinations of class values from each of the three source layers. For each combination, we manually assigned a habitat quality score of 0-9 based on the combination of values (Table 4).

Table 4. Combined model values with assigned habitat scores (0-9, 9 being highest).

Total Value	Vegetation Class	LiDAR Class	NDVI Class	Habitat Score
100	100 - Not suitable	N/A (screened out)	NA (screened out)	0
201	200 - Other Natural	00 - No Data	1 - Barren/Water	4
202	200 - Other Natural	00 - No Data	2 - Low vegetation	5
203	200 - Other Natural	00 - No Data	3 - High vegetation	6
211	200 - Other Natural	10 - Low/Ground	1 - Barren/Water	4
212	200 - Other Natural	10 - Low/Ground	2 - Low vegetation	5
213	200 - Other Natural	10 - Low/Ground	3 - High vegetation	6
221	200 - Other Natural	20 - Shrub/Tree	1 - Barren/Water	5
222	200 - Other Natural	20 - Shrub/Tree	2 - Low vegetation	7
223	200 - Other Natural	20 - Shrub/Tree	3 - High vegetation	8
301	300 - Riparian Edge	00 - No Data	1 - Barren/Water	5
302	300 - Riparian Edge	00 - No Data	2 - Low vegetation	6
303	300 - Riparian Edge	00 - No Data	3 - High vegetation	7
311	300 - Riparian Edge	10 - Low/Ground	1 - Barren/Water	5
312	300 - Riparian Edge	10 - Low/Ground	2 - Low vegetation	6
313	300 - Riparian Edge	10 - Low/Ground	3 - High vegetation	7
321	300 - Riparian Edge	20 - Shrub/Tree	1 - Barren/Water	6
322	300 - Riparian Edge	20 - Shrub/Tree	2 - Low vegetation	7
323	300 - Riparian Edge	20 - Shrub/Tree	3 - High vegetation	8
401	400 - Riparian	00 - No Data	1 - Barren/Water	6
402	400 - Riparian	00 - No Data	2 - Low vegetation	7
403	400 - Riparian	00 - No Data	3 - High vegetation	8
411	400 - Riparian	10 - Low/Ground	1 - Barren/Water	6
412	400 - Riparian	10 - Low/Ground	2 - Low vegetation	7
413	400 - Riparian	10 - Low/Ground	3 - High vegetation	8
421	400 - Riparian	20 - Shrub/Tree	1 - Barren/Water	7
422	400 - Riparian	20 - Shrub/Tree	2 - Low vegetation	8
423	400 - Riparian	20 - Shrub/Tree	3 - High vegetation	9

Screening for small, isolated patches

Particularly with the relatively fine scale of the model (3m X 3m cells), the results will include isolated, small patches that are classified as marginal to high quality habitat but have less real value due to their size and isolation. When including these small, isolated patches in the calculation of total area of habitat, the results reflect a higher area estimate than reality. So in addition to results (with no screening), we combined cells with a score of 7-9 (marginal to high quality) used the Region Group tool to locate and screen out smaller patches. This allowed us to present results with no screening, with patches smaller than 1 acre screened out, and with patches with less than 10 acres screened out. The patch sizes are somewhat arbitrary but present the effect of screening on the area totals. We calculated the results both or the study area as a whole and for smaller sub-regions such as San Luis NWR and San Joaquin NWR.

RESULTS AND DISCUSSION

RESULTS

Table 5 and Figure 2 present the model results across the study area. We should note that the study area is intentionally large so some areas considered habitat may be well beyond the historical range of the species. We added an additional figure (Figure 3) with a dark background to better highlight the results, particularly where the data is very thin along riparian corridors.

Table 5. Summary of results by potential habitat quality class for the whole study area including the results of screening patches smaller than 1ac or 10ac.

	No screening		Screen < 1ac		Screen < 10ac	
Habitat quality class	Acres	Km^2	Acres	Km^2	Acres	Km^2
Unsuitable	1,873,732	7,583				
Screened out	-	-	8,287	34	19,043	77
7 (Marginal)	20,843	84	12,789	52	7,546	31
8 (Moderate quality)	9,984	40	9,871	40	7,504	30
9 (High quality)	13,065	53	12,945	52	9,799	40

Figure 4 and Figure 5 illustrate the effect of screening for different patch sizes (eliminating isolated patches smaller than 1 acre or 10 acres) using a closer view of the data near San Luis NWR in Merced County

Table 6 presents the model results by organizational unit of the San Luis National Wildlife Refuge Complex.

Table 6. Summary of results by potential habitat quality class for organizational units of the San Luis National Wildlife Refuge Complex (SLNWRC).

	Area (Acres)			
SLNWRC Organizational Unit	**Less than 1 acre**	**7 - Marginal**	**8 - Moderate**	**9 - High**
Grasslands Wildlife Management Area	2,756	2,566	270	467
Merced NWR	123	88	44	51
San Luis NWR	617	648	178	463
San Joaquin River NWR	144	1,032	1,141	1,000

DISCUSSION

One thing we should emphasize is that this work only considers some mappable elements that are consistent with areas of known habitat for RBR and is intended to help highlight areas with greater potential to be habitat. There may be other factors (e.g., predators or other threats) that may cause any particular site to not be able to sustain RBR populations. We recommend that any model results be field verified for sites being considered for use as RBR habitat.

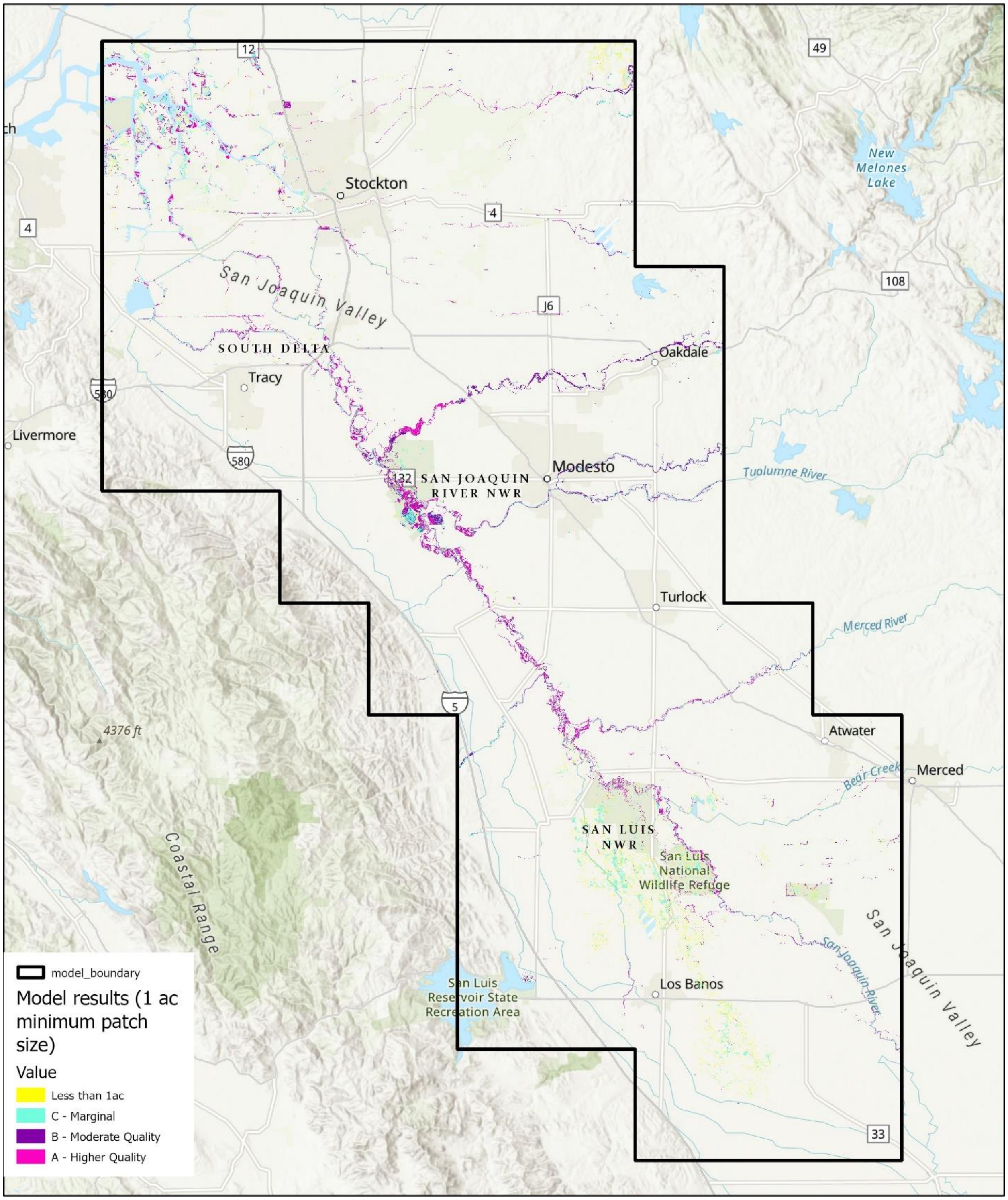

Figure 2. Overview of model results.

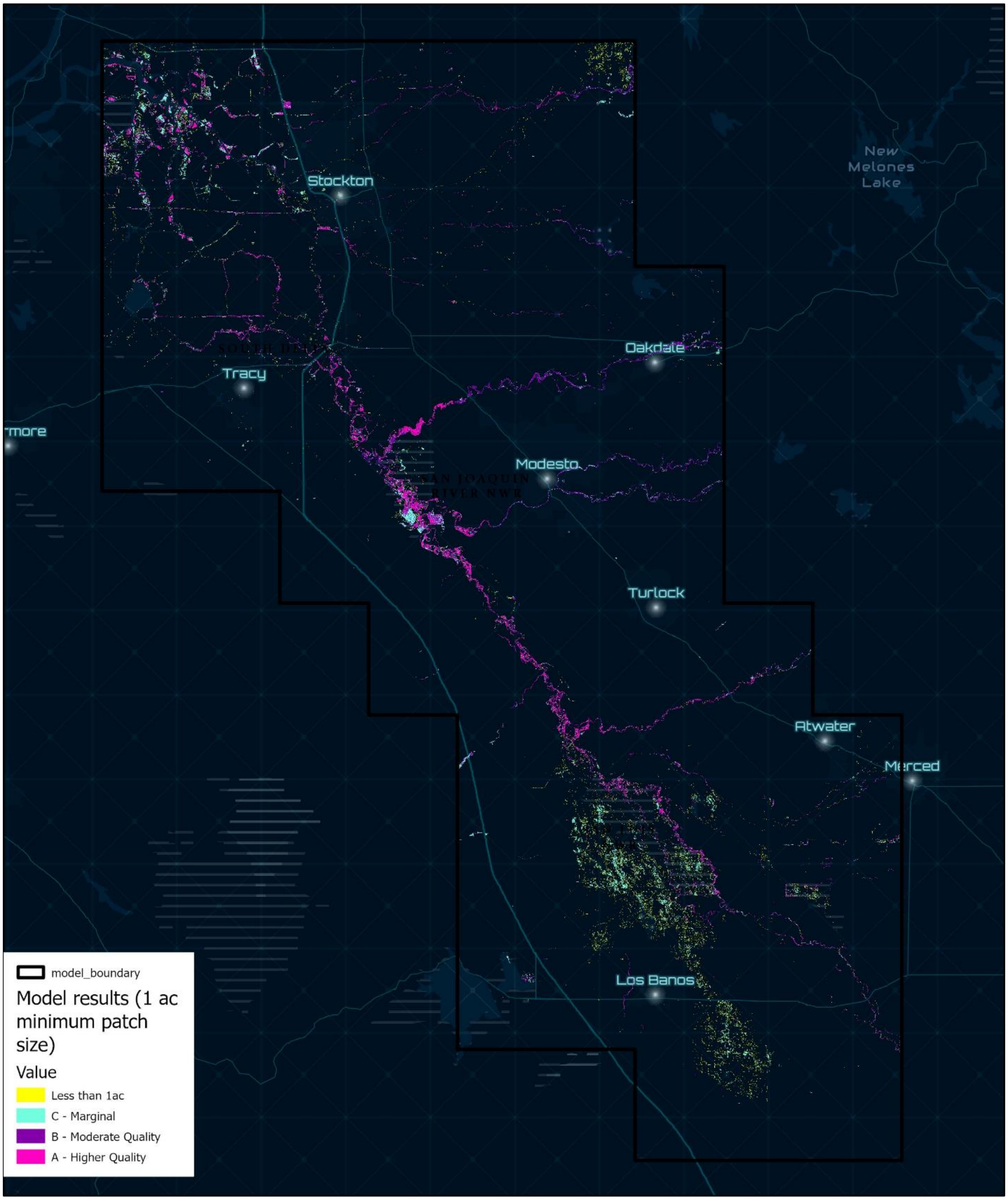

Figure 3. Overview of model results with a darker background to better highlight results.

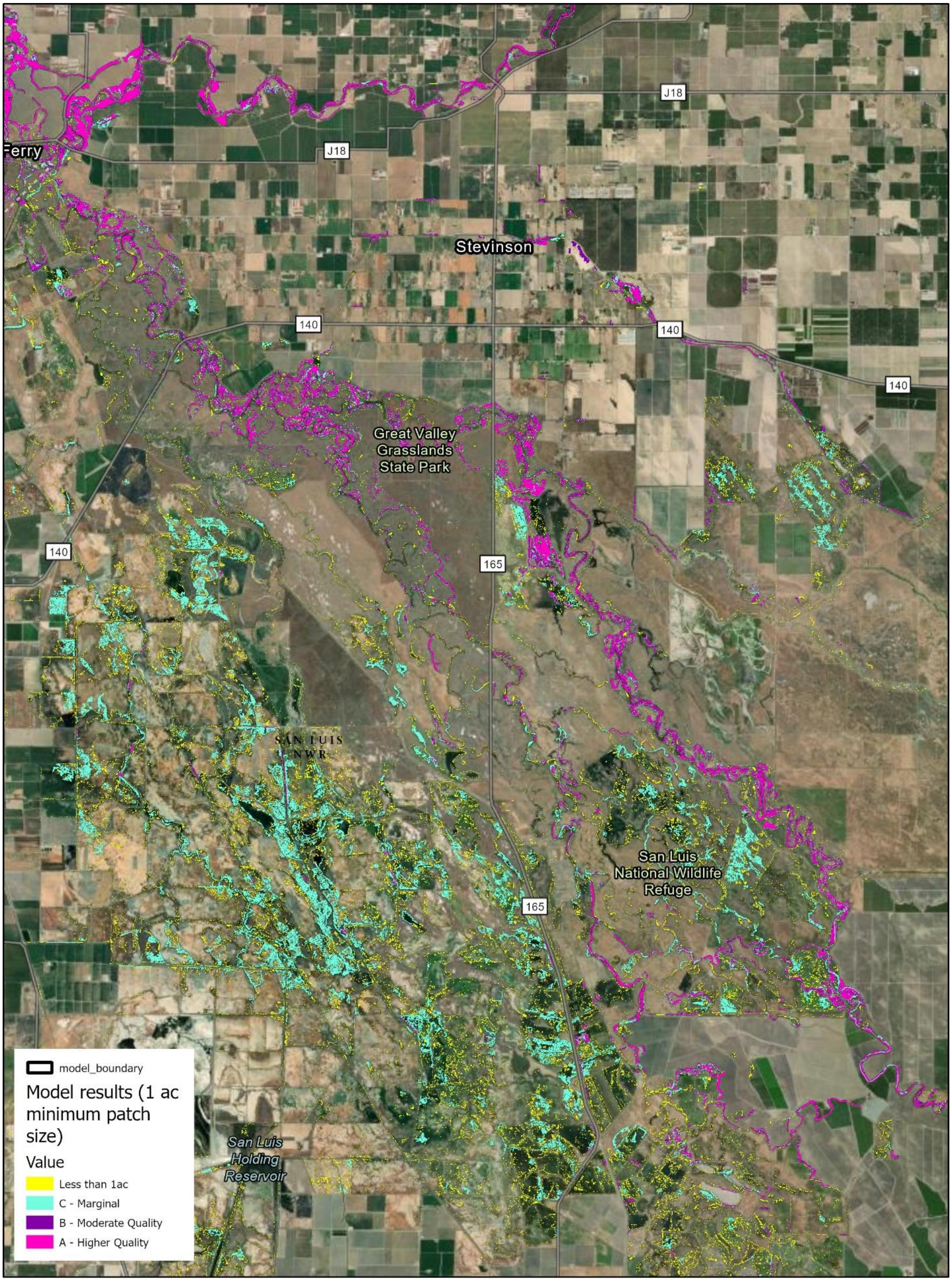

Figure 4. Habitat suitability results near San Luis NWR highlighting isolated patches less than 1 acre (in yellow).

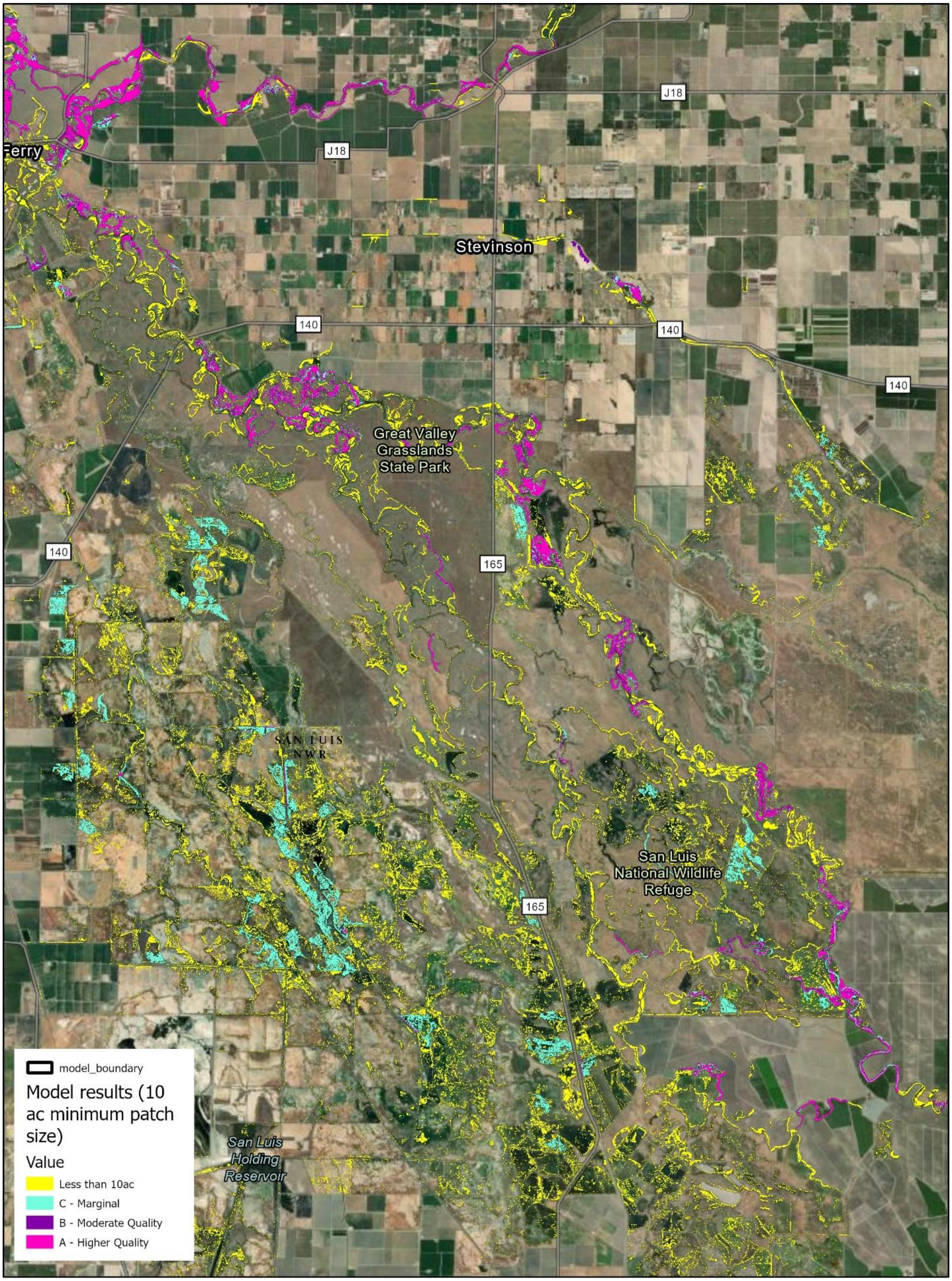

Figure 5. Habitat suitability results near San Luis NWR highlighting isolated patches less than 10 acre (in yellow).

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Appendix A. Analysis of flood risk in the analysis area

Riparian zones of the Central Valley are vulnerable to flooding which has been identified as a threat to riparian brush rabbit populations (Williams et al. 2002). In addition to our analysis of habitat quality, we estimated what areas would be flooded during a significant flooding event. To do so we examined the extent of flooding shortly after a severe flood event in early 2017 (Lund 2017, Vekleroy 2017).

To identify areas flooded we obtained satellite imagery from the European Space Agency's Sentinel-2 MultiSpectral Instrument (MSI, ESA 2022) on the first cloud-free day shortly after the peak of the flooding (March 1, 2017). We mosaiced imagery from the MSI to cover our model study area (Figure 6). Using the green and infrared bands of the MSI imagery, we applied a normalized difference water index (NDWI, McFeeters 2013) to identify standing surface water in the analysis area (Figure 7).

We combined the NDWI results with our habitat quality analysis (with 1-acre minimum patch size) to separate what was in standing water (*flooded*) or not (*not flooded*, Table 7,

Figure 8, Figure 9, Figure 10).

Table 7. Habitat quality with 2017 flood status.

	Screen < 1ac		Flooded (2017-03-01)		Not flooded (2017-03-01)	
Habitat quality class	**Acres**	**Km^2**	**Acres**	**Km^2 / %**	**Acres**	**Km^2**
7 (Marginal)	12,789	52	3,224	13 (25%)	9,565	39
8 (Moderate quality)	9,871	40	2,838	12 (29%)	7,033	28
9 (High quality)	12,945	52	3,823	15 (30%)	9,122	37

Discussion

From 25%-30% of marginal to high quality habitat had standing surface water shortly after the 2017 flood event (Table 7). In areas to be managed as riparian brush rabbit habitat in the San Luis NNWRC (Figure 9, Figure 10), Williams et al. (2002) recommend the establishment of flood refugia (e.g. higher elevation areas that rabbits can escape to) with appropriate vegetation. The creating or adaptation of flood refugia should be a key consideration for restoring, or managing areas to support riparian brush rabbit populations.

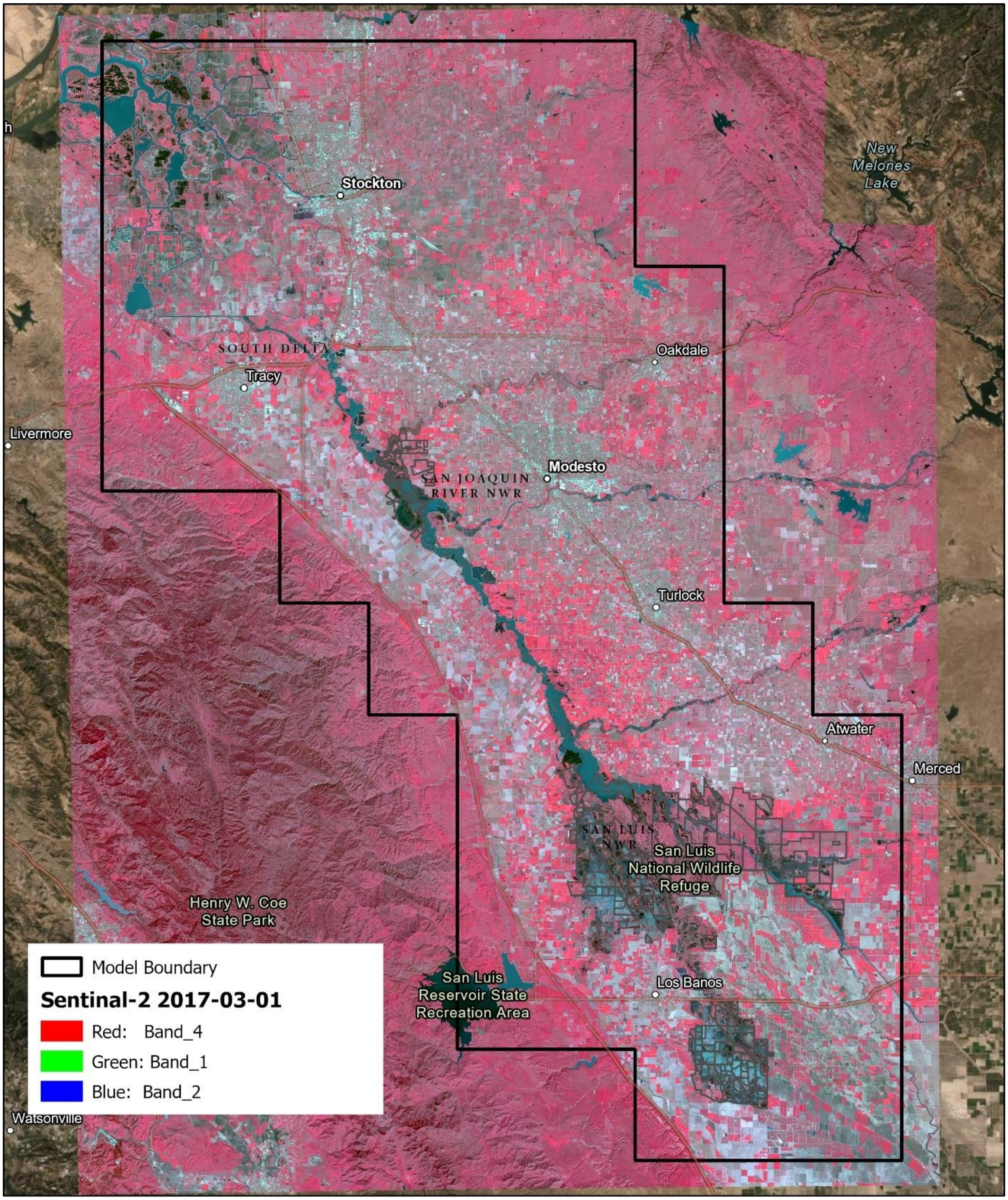

Figure 6. Sentinal-2 Imagery Mosaic showing flooded areas (dark colors).

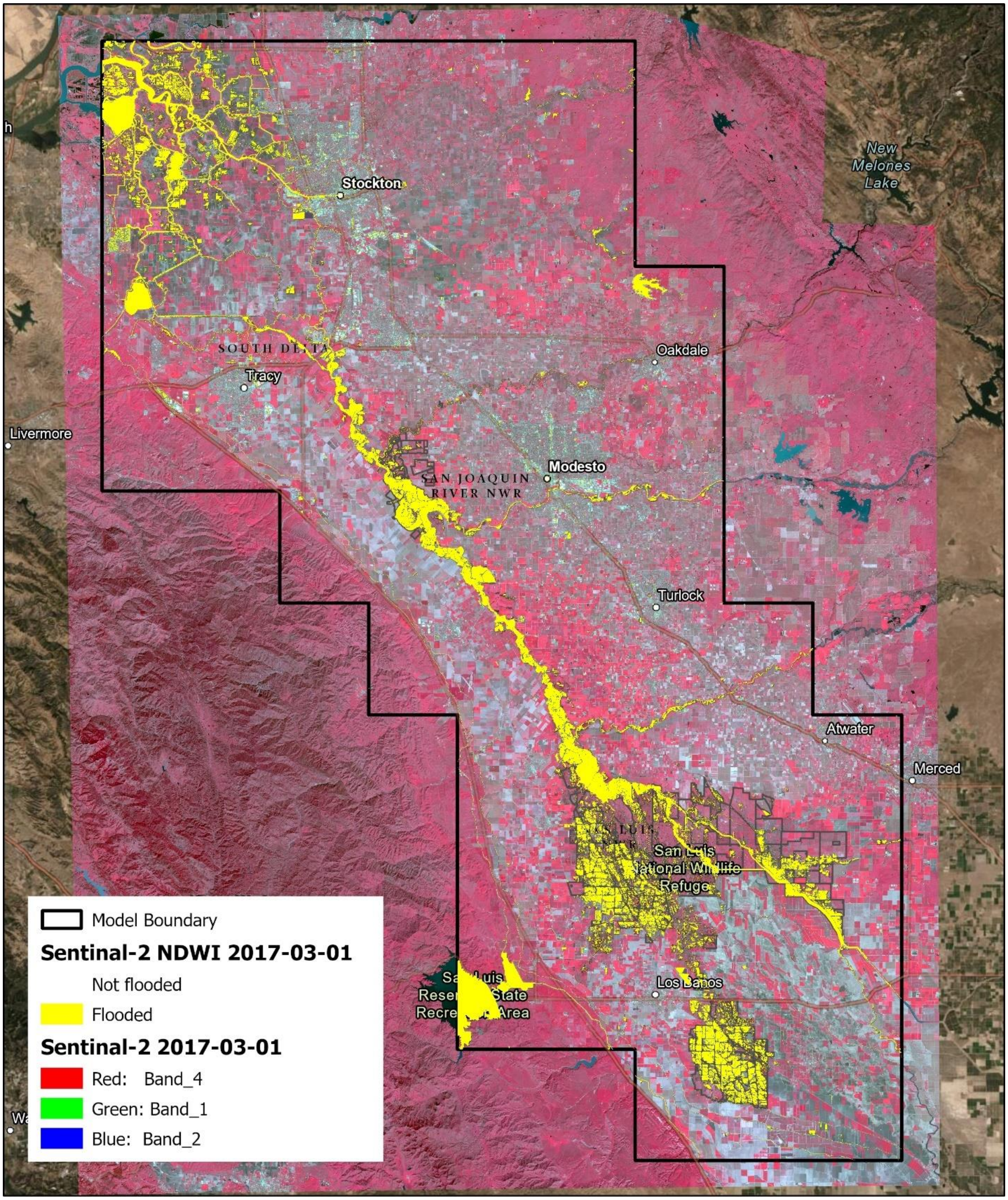

Figure 7. Normalized difference water index (NDWI) based on Sentinal-2 multispectral imagery.

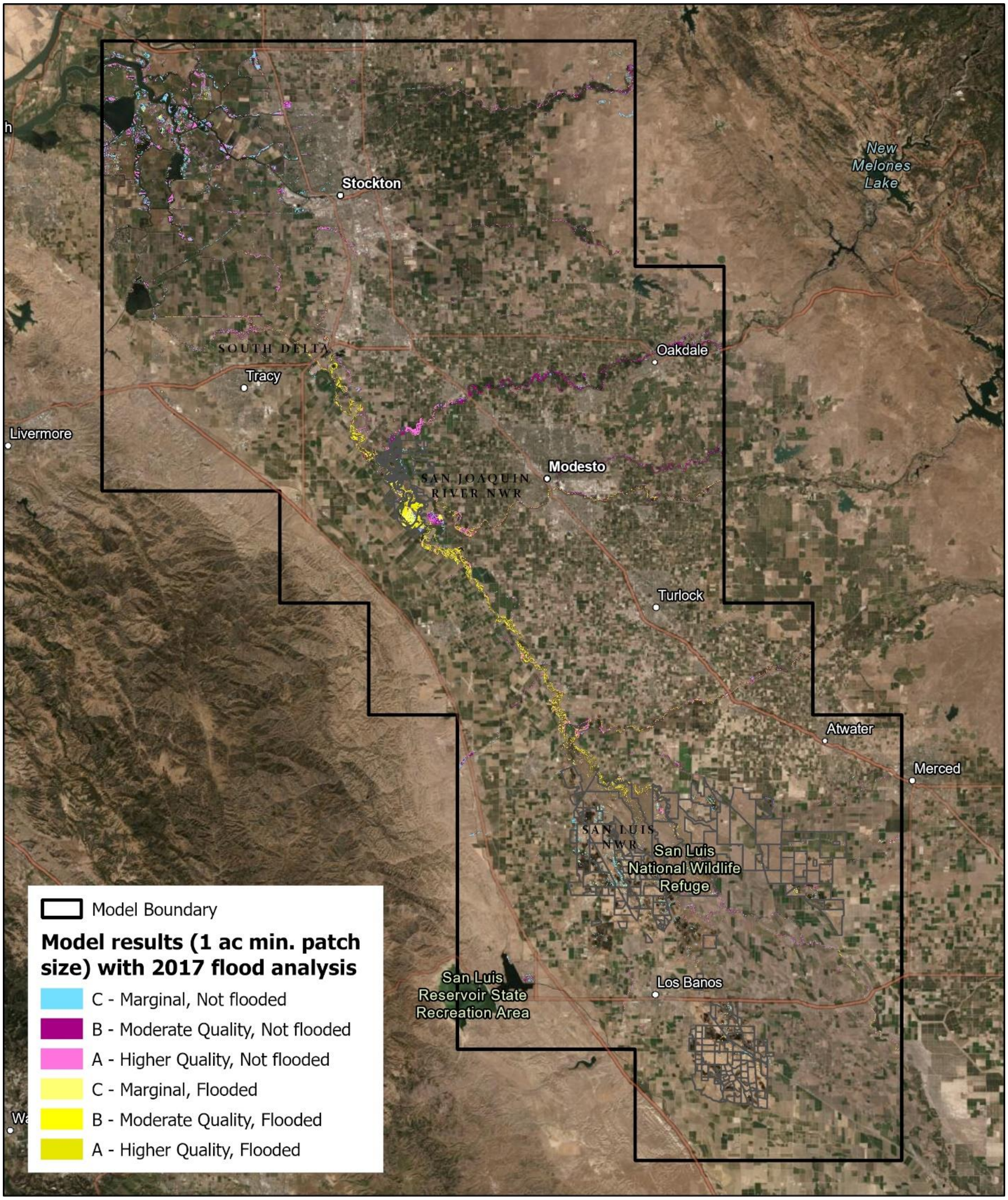

Figure 8. Habitat quality with flooded/not flooded areas identified.

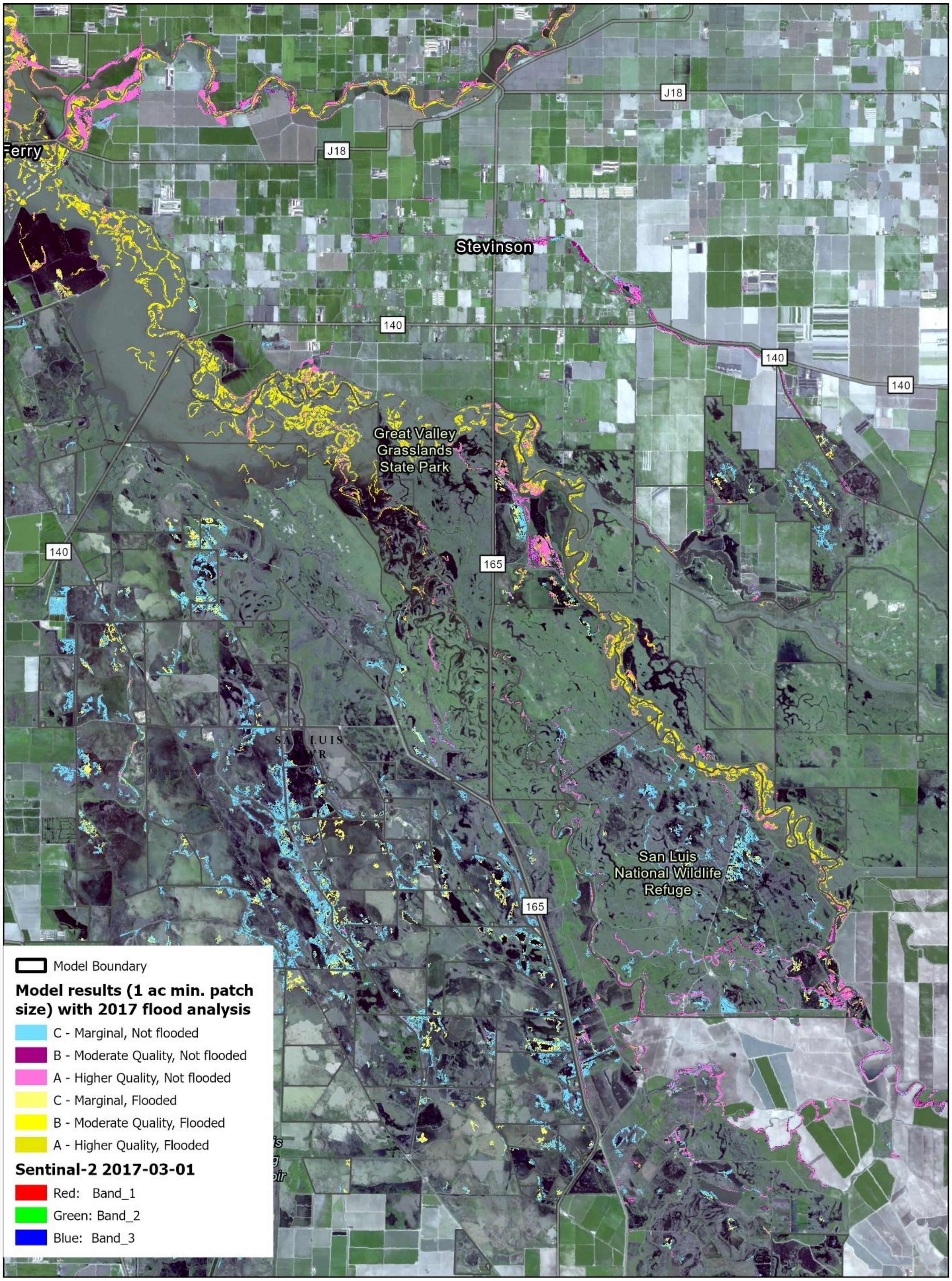

Figure 9. Habitat quality with flooded/not flooded areas identified in area of San Luis NWR in Merced County.

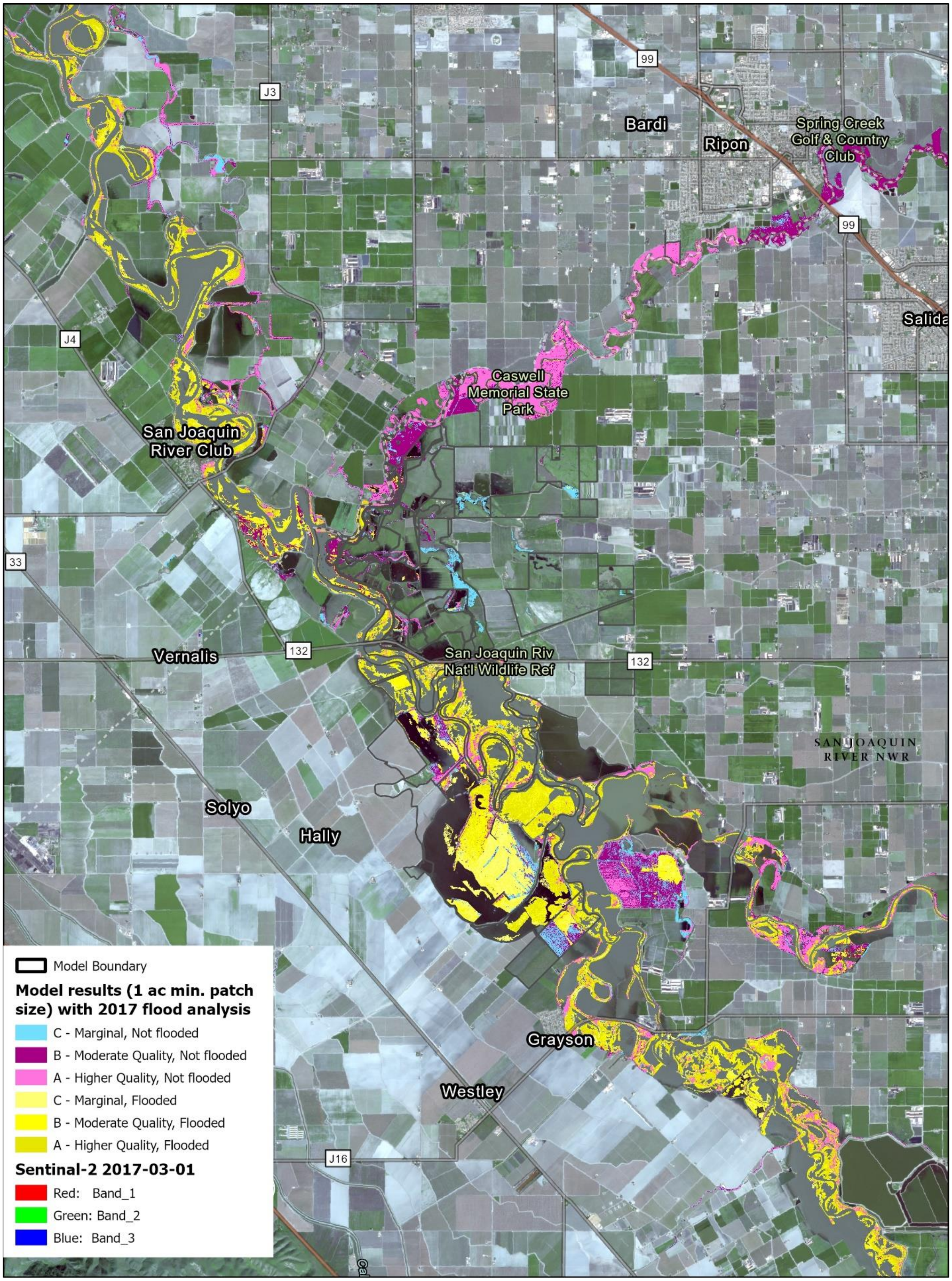

Figure 10. Habitat quality with flooded/not flooded areas identified in area of San Joaquin NWR in Stanislaus County.

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