

Technical Memo, Groundwater Dependent Ecosystems survey in Antelope, Corning, and Red Bluff subbasins of Tehama County

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1. Introduction

Groundwater dependent ecosystems (GDEs) rely on groundwater for some or all of their water requirements and include many wetland and riparian zones. These are important sites across the landscape known for many ecosystem services such as high biodiversity, carbon sequestration, climate regulation, and positive impacts for water quality (Howard et al., 2023). As tradeoffs are considered for diverse users of groundwater resources, decisions on groundwater management can have an impact on the ecosystems and their subsequent services. In California, the Sustainable Groundwater Management Act (SGMA) of 2014 states that groundwater sustainability agencies manage groundwater resources for social, economic and environmental benefits and must identify and consider impacts to GDEs in the planning.

GDEs are dominated by phreatophytic vegetation, deep rooted plants that tap into shallow groundwater for some or all of their water needs. As the climate changes these communities become susceptible during periods of drought and lower precipitation (Kibler et al., 2021; Williams et al., 2022). Short-term changes in groundwater can lead to decline of riparian phreatophytes (Scott et al., 1999). In addition, pumping of groundwater can impact these sites and can lead to widespread ecological consequences, including changes in vegetation community (Cooper et al., 2003).

1.1 Purpose

Our work identified GDEs for future monitoring within the Corning, Antelope and Red Bluff subbasins (as initially mapped by Klausmeyer et al., 2018) and assessed the current conditions of GDEs within the Corning and Antelope subbasins with field work – limited to areas we had access to. In the field we assessed the current health and vigor of sites through documenting both the woody and herbaceous plant species to gain a better understanding of the overall plant communities. These field data were then linked with interpolated shallow groundwater levels for longer temporal assessment to determine the likelihood of presence of a GDE and to extrapolate to unsampled communities. Remote sensing data (NDVI) were then used to help inform future monitoring efforts.

This report focuses on the vegetation communities but acknowledges that plants are only one component of an ecosystem. Healthy, diverse vegetation communities are the foundational habitat for a healthy wildlife community. Our overall recommendations for future monitoring efforts are focused on maintaining and improving health and vigor of native GDE communities. However, we additionally support and recommend the eradication and restoration of invasive species dominated sites, specifically *Arundo donax*. These sites have been separately identified and are included in a separate GIS layer (not included in the GDE database).

We used the best available data, however inaccuracies may exist due to the coarse spatial resolution of the groundwater data.

1.2 Previous Investigations

A technical memorandum written in 2021 (Appendix 2-I Part 1 in the GSP for Antelope) outlined the process for identifying and prioritizing GDEs within the Antelope, Bowman and Red Bluff subbasins. Using the TNC guidance, mapped iGDEs from the Natural Communities Commonly Associated with Groundwater (NCCAG) polygons were referenced with 2018 Land IQ imagery to ensure the current conditions of each site. Next the connection to shallow groundwater was evaluated, using a maximum threshold of 30 feet. The GDEs that met both the threshold of 30 feet for groundwater levels and were in the same land use condition were then evaluated using the TNC developed GDE pulse data tool, which incorporates normalized difference vegetation index (NDVI) changes to assess overall health of the ecosystem. The NDVI trends were divided into three categories: No decline, Minimal decline – low priority, and Significant Decline – high priority.

The majority of the GDEs were assessed as No decline. Within Antelope, there were some GDEs that were assessed as low priority and high priority, with the high priority sites located along Salt Creek near and upstream from the confluence with the Sacramento River and along the Sacramento River near the city of Red Bluff.

1.3 Report Organization

This report consists of the following sections:

Section 1 Introduction

Section 2 Desktop Analyses, Outreach and Fieldwork Performed details the GIS work completed prior to field investigations, outreach activities and field sampling carried out

Section 3 GDE GIS analyses reports on methodology for updating of iGDE data layer for the study region

Section 4 GDE Field Survey reports methodology from field sampling in 2024 and 2025.

Section 5 Results combines the results from both the GIS and field surveys for each subbasin

Section 6 Challenges documents challenges we encountered during the study.

Section 7 Future Steps suggests some methodology for continuation of monitoring of health and status of GDEs.

Section 8 References lists references cited throughout the document.

Section 9 Appendices gives more in depth summaries and information on the field sampling data and maps of each sampled site.

2. Desktop Analyses and outreach for field sampling preparation

2.1 Desktop Analyses

Following guidelines of the TNC GDE guidance (Rohde et al., 2018), GDEs within both Corning and Antelope subbasins were prioritized for sampling based on presence of federally listed and California state listed threatened and endangered species and critical habitat, special status species habitat areas, and areas of conservation emphasis (ACE). In both subbasins, many of these sites were along the Sacramento River. Additionally, GDEs were categorized based on their status in the California protected lands database. This database identifies properties that are held in a conservation easement or are protected areas (state, federal or privately managed).

Within the Antelope subbasin, protected lands included Butler Slough (California Dept of Fish and Wildlife), Red Bluff Recreation Area (US Forest Service) and Sacramento River Wildlife Refuge sites (US Fish and Wildlife Service). Within the Corning subbasin, the largest protected lands included Kopta Slough (TNC), Woodson Bridge Preserve (California State Parks), Sacramento River National Wildlife Refuge sites (US Fish and Wildlife), an easement along Stony Creek (NRCS managed), Black Butte Reservoir (US Bureau of Reclamation), Pine Creek (California State Parks and US Fish and Wildlife).

2.2 Outreach to landowners for access

The process for outreach to different agencies, land managers, and private landowners took place between late March and June, 2024 and early 2025. Each land holding entity had different protocols to allow access for sampling and many required a research permit application. In addition, outreach to private landowners was through contacts and connections with people working with LSCE on various components of this overall Tehama County GSP project. However, no private landowners allowed access on their property.

3. GIS analyses

3.1 Methodology

We utilized the iGDE database as mapped by Klausmeyer et al., 2018 as our starting point for each subbasin. We performed an aerial image analysis to verify that GDEs were broadly mapped correctly. This was done in conjunction with an informal general field verification through

driving accessible roads and verifying the identification of iGDEs as well as through our detailed field surveys. Then we created interpolated surfaces for depth to groundwater for each year between 2013 and 2024 and assessed NDVI for each mapped polygon. The specific steps are outlined below and we used all these components to refine the iGDE database for each subbasin, identifying sites that were 'likely GDE' and 'not likely GDE'. In all, one layer was created for each of the subbasins. Polygons that we determined were likely not GDEs were removed from the dataset if they did not meet the criteria for GDE.

3.1.1 Aerial Imagery analysis

We performed our aerial imagery analysis using recent Google Earth satellite imagery (2024). Each iGDE polygon was visually assessed to determine if it should be ground truthed. The evaluation criteria for a ground truthing or further investigation included that the polygon:

- appeared to have structures/homes/roads in unit,
- appeared to now be agriculture land/other land use change,
- has no clear vegetation pattern/no vegetation present,
- was randomly placed or didn't make sense,
- vegetation appeared to not match determined type, or it contains almost all or only sand/gravel or water.

Not all polygons identified as needing ground truthing could be ground truthed, so further aerial photograph investigation was completed on these polygons.

3.1.2 NDVI analysis

Our remote sensing analysis included NDVI (Normalized differenced vegetation index) data downloaded from the Nature Conservancy GDE pulse website (The Nature Conservancy, 2025). NDVI measures plant "greenness" and is a metric of plant health. This is done by using remote sensing/satellite data and analyzing the difference between red (light which is absorbed by the plant) and infrared (light that is reflected by plant). NDVI values range from -1 to +1, where higher values indicate dense, healthy vegetation and lower values (closer to and below 0) show stressed and/or sparse vegetation. We utilized summer months data when plants will be most stressed due to lack of water. Data ranged from June 1-Sept 30 over the years of 1985 to 2024. We used R (version 4.4) to create a long-term average using all years of data. Raw data were then joined to the iGDE dataset using a common attribute. Five vigor classes were created based on Brown (2018): Low (less than or equal to 0.2); Medium-Low (0.2 to 0.3); Medium (0.3 to 0.4); Medium-High (0.4 to 0.5); and High (greater than 0.5). This metric helped us determine the long-term health and condition of each GDE, specifically for the majority of each subbasin where we were not granted access to sample. Additionally, this guided us on our future monitoring recommendations.

3.1.3 Depth to Groundwater analysis

We created interpolated surfaces of depth to groundwater from Fall contours for each year between 2013-2024 ('i08 GroundwaterDepthSeasonal Contours' data from Department of Water Resources downloaded from California Open Data portal – CDEC). We used QGIS to create a triangulated irregular network (TIN) to create a continuous surface based on the contours (pixel size 250m based on the coarse resolution of the input data) for each year. We then used zonal statistics to extract an average depth to water value for each year for each polygon.

3.1.4 Refinement of iGDE layers for each subbasin

We used a step-wise process to refine the GDE database for each subbasin, removing the polygons that were likely not a GDE. We quantified the number of polygons and acreage removed from each step. First, we removed GDE polygons that were identified through the aerial image analysis to no longer be a GDE. Some of these sites were currently planted as orchard or had no vegetation in them. We then summed the 12 years of groundwater data across each polygon and removed ones that had a sum greater than 1000, meaning that they averaged greater than 83 feet over that time period. Next, we removed polygons which were dominated by an invasive species: Giant Reed, Tamarisk, Tree of Heaven, and Himalayan blackberry, as our informal general field verification indicated these communities were generally mapped correctly (see Appendix 1 for example photos of two of these communities). Because the surface contours did not extend to every location within the subbasins each year, some yearly values were NULL. This resulted in a NULL value for the sum total across all years. For each of these polygons, depth to water was examined for the years in which there were values and polygons were kept if any year had a depth to water less than 50 feet. We used 50 feet as our threshold based on our field surveys, which indicated that GDEs were found at sites with interpolated Fall depth to water of 50 feet.

While most GDEs have depth to water levels of 30 feet or less, Valley oak is known to have deeper roots, up to 80 feet (The Nature Conservancy, 2021). This was taken into consideration when removing the final polygons. Finally, we used our field sampling locations as known sites where GDEs exist and the deepest depth to water average one of the sampling locations had was about a 50 foot average for Fall levels over the 12 years. We removed sites that averaged greater than this unless they were Valley Oak sites, which we kept if the average was 80 feet or less.

Finally, we adjusted the extent of some polygons if they included areas that were not consistent with the majority of the polygon (see Appendix 1 for example). For instance, some large polygons had narrow slivers that followed roads, with no identifying GDE characteristics within the slivers. These slivers were removed to create a more homogenous polygon. In addition, some large polygons had houses or other improvements or had portions that were currently in fruit tree production and these features were excluded from the polygon, keeping the remaining, more natural, vegetation as the GDE.

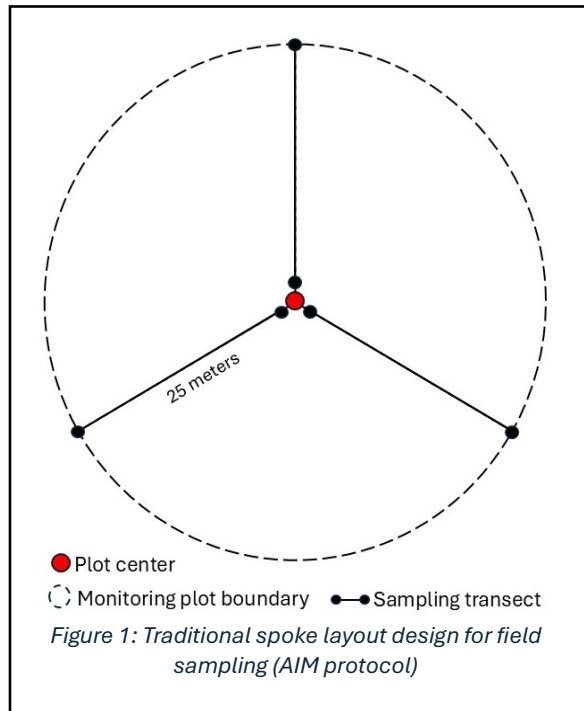
We modified our methods slightly for Red Bluff as there were only informal vegetation community verification, no on the ground field sampling. We were more conservative with our removals and identification of sites that were likely not GDEs. In our informal verification, the iGDE communities identified as 'Riparian Mixed Hardwood' had Valley Oak components, therefore we assumed an 80 foot groundwater depth for these sites. We also did adjust the extents of polygons based on their current land uses.

4. Field Sampling

4.1 Field sampling methodology

The AIM (Assessment, Inventory and Monitoring) field protocol for lentic riparian and wetland systems was selected as the methodology for field sampling (Bureau of Land Management 2024). This protocol has been used across the western US to assess the ecological integrity of wetland communities. It is a robust, standardized, quantitative approach that enables long-term monitoring of trends to help guide land management decisions. We worked with ecologists within the AIM office in Denver, CO to obtain field protocols and sampling tools.

The initial survey that we completed is thorough, and depending on the vegetation type, can take a few hours to complete. The survey entails establishing non-permanent circular plots based on a spoke design, with three 25m transects extending out from the center (Figure 1). If the vegetation community is linear or does not allow for this set up, guidance is provided on additional layouts for plot set up (Chapter 4, Bureau of Land Management, 2024).



Plot sampling locations were randomly generated using QGIS prior to the field visit and navigated to for plot establishment. We navigated to each plot center using an SxBlue II+ sub-meter accuracy GPS unit. Within each plot we collected data on overall site characteristics, vegetation community structure and composition, including determination of if the GDE is correctly mapped, and general soils assessment (if our sampling permit allowed). Photographs were taken at the start and end of each transect (see Appendix 2 for representative plot photos). A species list was created for each plot, using the monitoring plot boundary as the extent. Unknown species were photographed and collected for later identification in the lab using the Jepson Manual:

Vascular Plants of California (Baldwin et al., 2012) and dissecting scope. Vegetation and ground surface cover was recorded using line-point intercept at 1m increments along each of the three transects. Additionally, plant heights were recorded at 2.5m increments along the transects. Woody species were quantified in 2m x 1m quadrats every 2.5m along the transects. DBH (diameter at breast height) and height class were recorded for trees and saplings and canopy cover was assessed for each. For soils data collection, one hole was hand augered near the center of the plot and soils were described and examined for hydric soil indicators and properties, noting the depths at which they occur. The hole was filled back in prior to leaving the plot. Soil sampling did not occur at all plots as some research permits did not allow it.

5. Results

5.1 Summary of field plot verification

We sampled 30 plots across the Antelope and Corning subbasins; 20 plots in Corning and 10 in Antelope. The accuracy of the iGDEs varied for this small sample size across the basins. For the dominant vegetation communities, Valley Oak had a user's accuracy of 82% and Fremont Cottonwood 56% (see Appendix 3 for a confusion matrix and plot level accuracy assessment). Despite potentially lower user accuracy's, polygons not mapped to the correct dominant community were still a GDE community on the ground (ie. there were no 'non-GDE' community types that were sampled). Informal vegetation community verification, accomplished through

driving on accessible roads and verifying dominant plants as they were mapped, resulted in high confidence in the non-native species dominant communities (Giant reed, Himalayan blackberry as examples – see Appendix 4 for additional photos). We do not have quantitative data to support these communities as they were not present in high quantities on the sites we were granted access to sample and we did not want to spend time describing the plant community composition of sites dominated by invasive species.

5.2 Summary of Corning subbasin

Within the Corning subbasin, there were initially 6472.12 acres (1203 polygons) of mapped iGDEs, with the majority of these identified as Fremont Cottonwood and Valley Oak. GIS refinement resulted in 1996.83 acres (586 polygons) that were classified as ‘not likely GDE’ due to the depth to groundwater being too deep over the study period and/or their dominance by invasive species (Figure 2). Many of the polygons in the western portion of the subbasin were designated as such, due to deep groundwater inaccessible by plant roots. Many of the streams that flow east to the Sacramento River, on the western side of I-5, are intermittent or ephemeral, and have been modeled as losing streams, lacking the ability to support widespread GDEs. Notable exclusions were 272.37 acres identified as Giant reed, with the majority of these polygons occurring along the Stony Creek corridor.

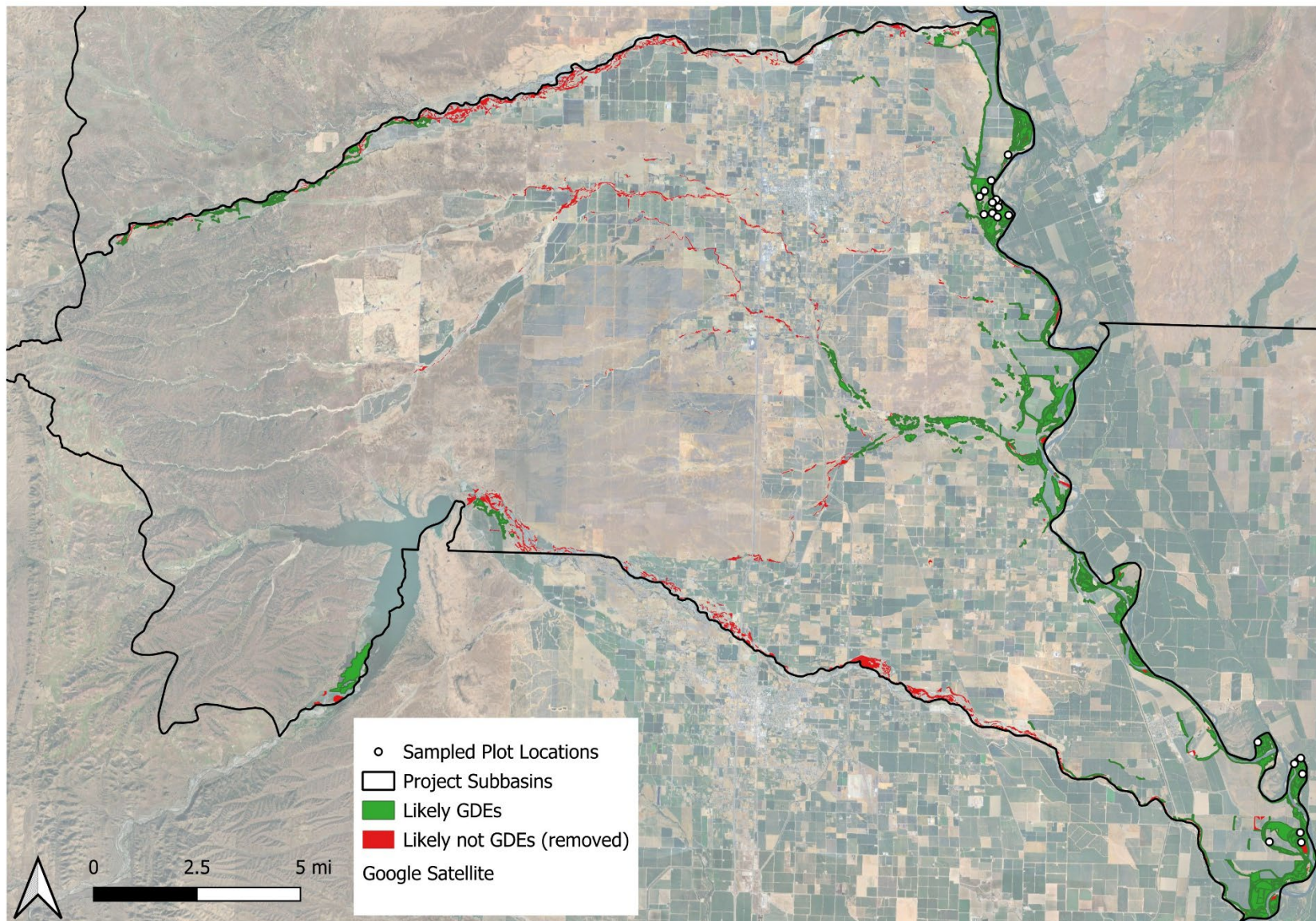


Figure 2: Polygons identified as likely GDE and not likely GDE in the Corning subbasin

The resulting likely GDEs include a total of 4475.29 acres (617 polygons). The dominant vegetation communities were Valley Oak (1391.64 acres, 207 polygons) and Fremont Cottonwood (1231.97 acres, 110 polygons). Less dominant communities include California black walnut (345.60 acres), narrow leaf willow (270.25 acres) and Boxelder (194.08 acres). The majority of these polygons are located east of I-5 and along the Sacramento River, as groundwater levels were more shallow through the study period and are able to support GDEs. While much of Thomas Creek does not appear to support GDEs, the section just west of Simpson Road likely has GDEs present as the creek switches from a predominantly losing stream to a gaining stream moving west.

The majority of the GDEs where data was available on long-term NDVI were classified as medium, medium-high and high, indicating that over the study period these sites were not generally under stress (Figure 3). However, there were a high number of polygons (320) spread across the Corning subbasin where we could not get a long-term average of NDVI because data were missing. There were 809.25 acres of GDEs that were classified as low or medium low on the NDVI scale, indicating that plants on these sites are stressed by the end of the summer months (Table 1). Of the dominant communities, Fremont cottonwood and California black walnut had high acreage that was classified as low (Table 2). However, many communities had high percentages of acres that were missing data.

Table 1: Long-term Normalized Difference Vegetation Index values and acreage across the Corning subbasin. NDVI classes as defined by Brown 2018.

Long-term average NDVI value	Acres	# GDE polygons
Low (<0.2)	625.56	114
Medium - Low (0.2 – 0.3)	183.69	35
Medium (0.3 – 0.4)	511.82	41
Medium - High (0.4 – 0.5)	274.12	59
High (> 0.5)	224.73	48
Missing data	2655.37	320

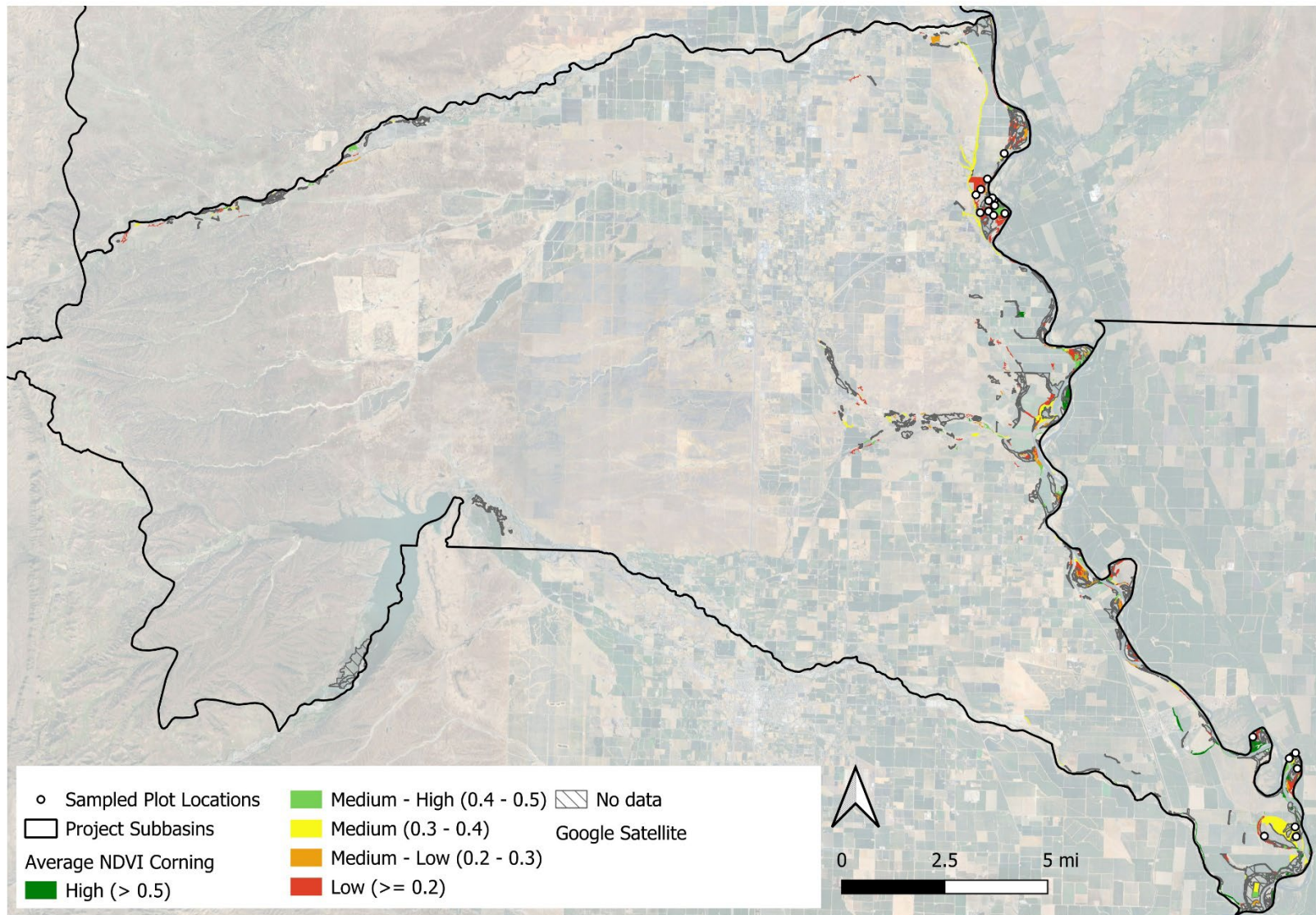


Figure 3: Average long-term average NDVI value for polygons identified as likely GDE.

Table 2: Long-term NDVI values, acreage by GDE community. NDVI categories defined by Brown 2018, where Low = <0.2; Medium-Low is between 0.2 and 0.3; Medium is between 0.3 and 0.4 and Medium-High and High are above 0.4. Medium-high and High are shown as one category.

Plant Community	Low	Medium-Low	Medium	Med-High and High	Missing data
Fremont Cottonwood	156.54 acres	40.08 acres	16.66 acres	150.41 acres	868.29 acres
Valley Oak	92.66 acres	32.45 acres	191.92 acres	92.48 acres	982.13 acres
Boxelder	49.28 acres	12.61 acres	37.01 acres	65.19 acres	29.93 acres
Narrow-leaf willow	48.32 acres	8.54 acres	3.82 acres	76.11 acres	133.46 acres
California black walnut	112.03 acres	--	23.12 acres	45.65 acres	164.80 acres

5.2 Summary of Antelope subbasin

Within the Antelope subbasin, there were initially 1451.41 acres of mapped iGDEs (254 polygons). Refinement of the GDE layer resulted in 1378.83 acres of GDEs (222 polygons), leaving 72.58 acres (32 polygons) that were classified as 'likely not GDEs' due to their dominance by invasive species and the depth to the groundwater being too deep over the study period (Figure 3). Across the subbasin, shallow groundwater levels were higher than in other subbasins, resulting in greater access for the groundwater dependent ecosystems. The dominant communities were 587.9 acres of Valley Oak (96 polygons) and 339.8 acres of Fremont Cottonwood (41 polygons), with less dominant communities of Sycamore (75.68 acres), Narrow-leaf willow (73.67 acres) and California buckeye (76.90 acres).

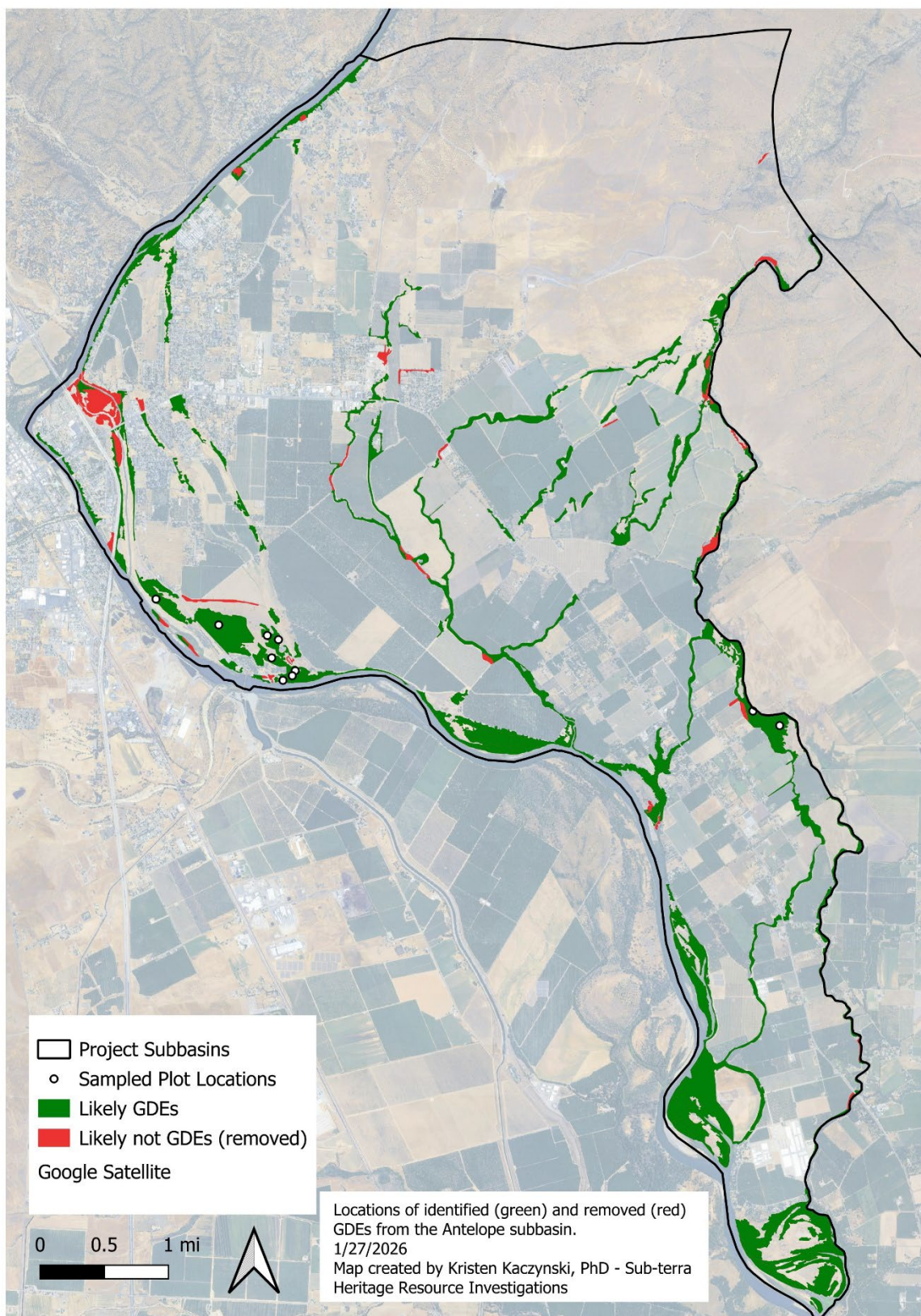


Figure 4: Polygons identified as likely GDE and not likely GDE in the Antelope subbasin

Long-term average NDVI values across the subbasin tended to be low (Table 3), however there was a substantial number of polygons where no NDVI value could be computed due to missing data (Figure 5). The majority of the low NDVI values are found in GDEs identified as Fremont Cottonwood (243.91 acres) (Table 4). There were many polygons with missing data including all GDEs identified as California buckeye and 64% of all narrow leaf willow, however 26.74 acres of this community had low or medium low long-term NDVI averages (Table 4).

Table 3: Long-term Normalized Difference Vegetation Index values and acreage across the Antelope subbasin. NDVI classes as defined by Brown 2018.

Long-term average NDVI value	Acres	# GDE polygons
Low (<0.2)	375.86	67
Medium - Low (0.2 – 0.3)	89.44	21
Medium (0.3 – 0.4)	74.70	11
Medium - High (0.4 – 0.5)	22.81	7
High (> 0.5)	71.86	4
Not enough data to determine	697.73	112

Table 4: Long-term NDVI values, acreage by GDE community. NDVI categories defined by Brown 2018, where Low = <0.2; Medium-Low is between 0.2 and 0.3; Medium is between 0.3 and 0.4 and Medium-High and High are above 0.4. Medium-high and High are shown as one category.

Plant Community	Low	Medium-Low	Medium	Medium-High and High	Missing data
Fremont Cottonwood	243.91 acres	5.34 acres	--	--	90.57 acres
Valley Oak	53.77 acres	53.77 acres	46.86 acres	82.08 acres	363.07 acres
Sycamore	9.64 acres	25.45 acres	9.27 acres	0.14 acres	31.18 acres
Narrow-leaf willow	23.17 acres	3.57 acres	--	--	46.93 acres
California buckeye	--	--	--	--	76.90 acres

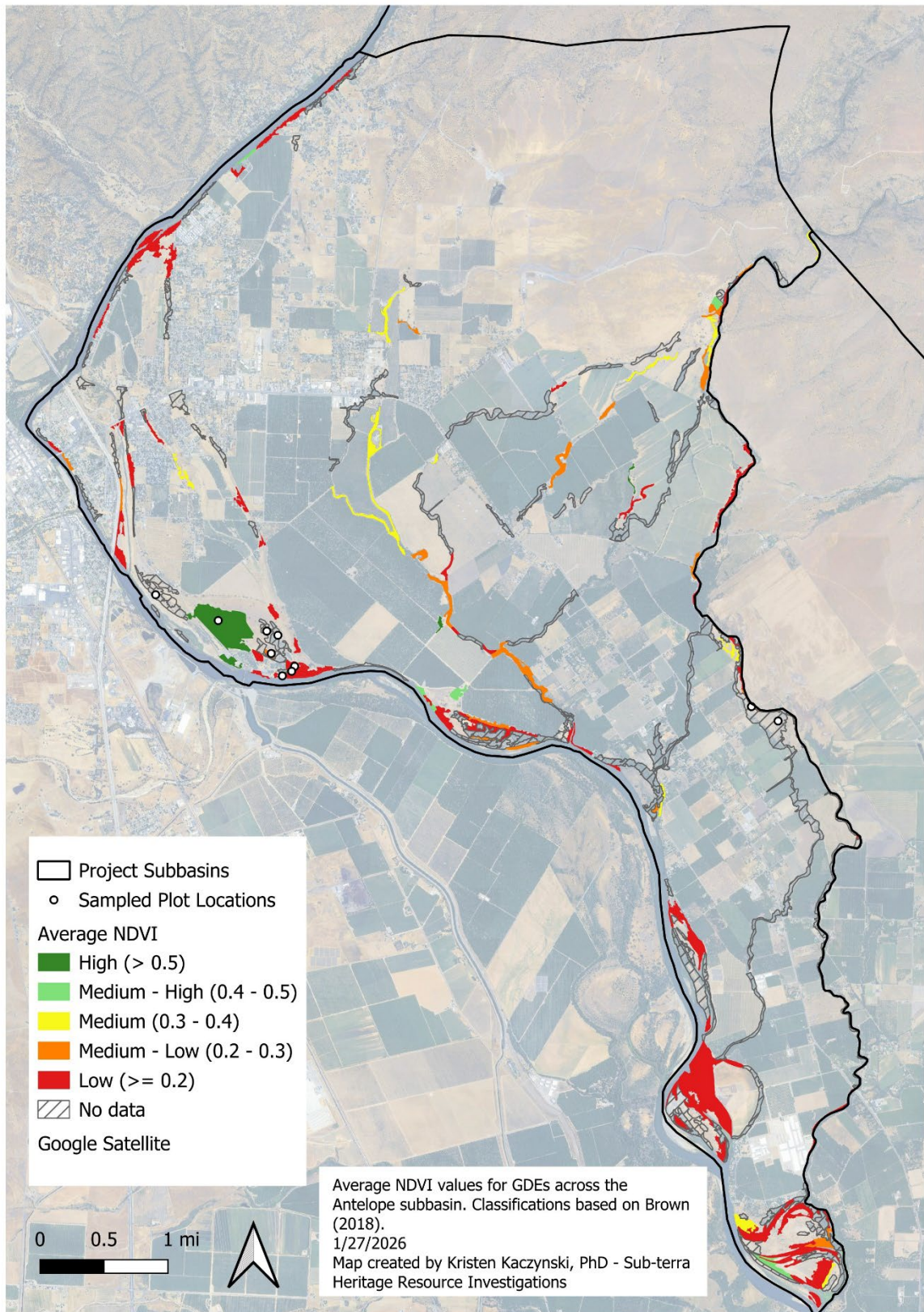


Figure 5: Long-term NDVI averages for polygons identified as likely GDEs in the Antelope subbasin

5.3 Summary of Red Bluff subbasin

Within the Red Bluff subbasin, there were initially 4799.73 acres of mapped iGDEs (980 polygons). Refinement of the database resulted in a total of 3849.02 acres of GDEs (605 polygons) and 950.87 acres identified as 'not likely GDE (Figure 6)'. We did not collect field plot data on any GDEs within the Red Bluff subbasin, however we drove roads to verify vegetation communities within the iGDE database. Many of the 'riparian mixed hardwood' classification had more Valley Oaks than in other subbasins and were therefore all treated as needing a depth to groundwater of 80 feet, rather than 50 feet as assumed for the other GDEs. The dominant communities included Valley Oak (1372.85 acres) and Fremont Cottonwood (1326.09 acres). Many of the likely GDEs occur along and within a short distance from the Sacramento River. Notable likely GDEs also occur along Liza Creek, Red Bank Creek (adjacent to the Tamarisk communities), Coyote Creek, Oat Creek and the North Fork of Dibble Creek. Similar to what we found in the Corning subbasin, the western extent of Stony Creek also has more shallow groundwater and likely GDEs.

Polygons which were dominated by invasive species throughout the Red Bluff subbasin: Tamarisk (103 acres), and 84 acres of Arundo, were removed – and classified as 'not likely GDE' however these sites should be considered for restoration.

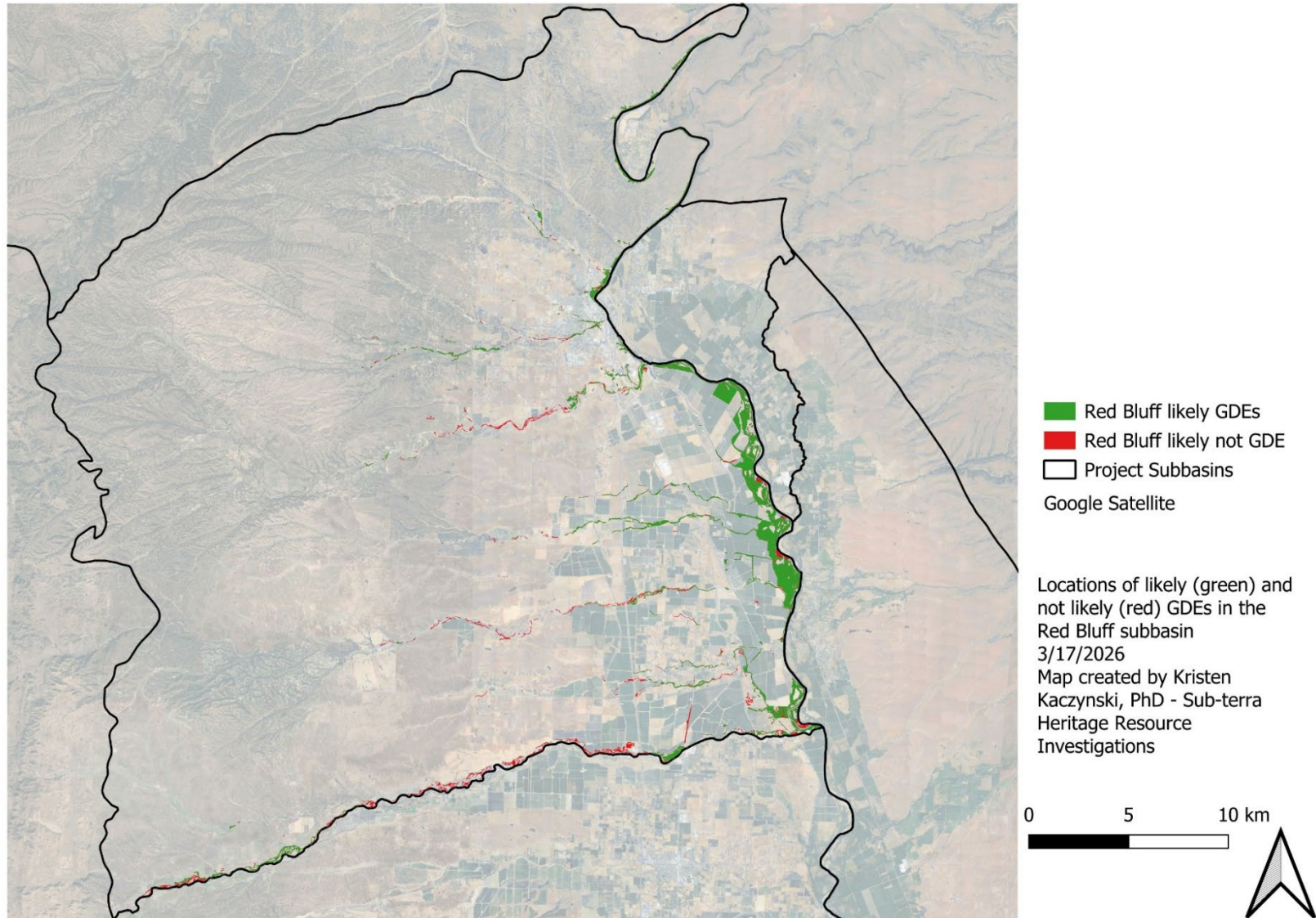


Figure 6: Polygons identified as likely GDE and not likely GDE in the Red Bluff subbasin

Long-term average NDVI values across the subbasin tended to be medium to high (Table 5; Figure 7), with only 13% of the polygons, or 5% of the overall total acreage classified as low or medium-low. The majority of the low NDVI values 78% of the total, are found in GDEs identified as Oregon Goldenaster, an herbaceous plant dominated community. Additional investigation should be done to verify the Oregon Goldenaster plant community as it was not sampled in the field across any subbasin.

Table 5: Long-term Normalized Difference Vegetation Index values and acreage across the Red Bluff subbasin. NDVI classes as defined by Brown 2018.

Long-term average NDVI value	Acres	# GDE polygons
Low (<0.2)	54.76	19
Medium - Low (0.2 – 0.3)	119.82	58
Medium (0.3 – 0.4)	491.15	149
Medium - High (0.4 – 0.5)	701.69	159
High (> 0.5)	2481.59	220

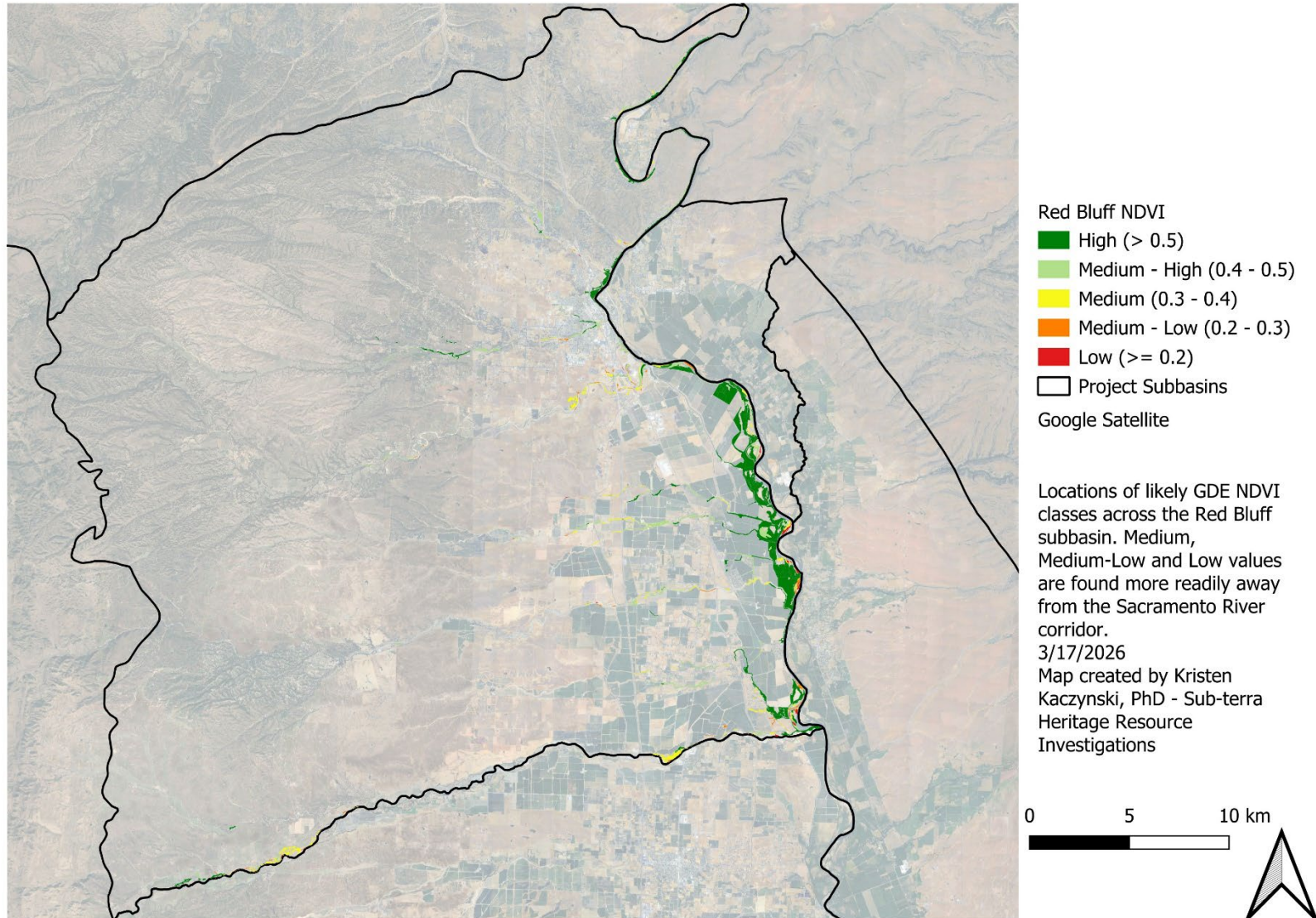


Figure 7: Long-term NDVI averages for polygons identified as likely GDEs in the Red Bluff subbasinA

5.4 Summary of GDE field sampling investigation

We were granted access to and sampled 30 iGDEs within eight locations: Woodson Bridge, Irvine Finch, Capay, Bidwell-Sacramento State Park, Pine Creek, and Kopta Slough within the Corning subbasin and Butler Slough and Red Bluff Recreation Area within the Antelope subbasin. Access to the plots was challenging at some locations due to lack of trails and overgrown vegetation (impenetrable poison oak and grape vines). Detailed maps of field sampled areas can be found in Appendix 5.

All vegetation communities that were sampled were dominated by native woody vegetation, but some had high understory cover of non-native and invasive species. See Appendix 6 for community descriptions of Valley Oak, Fremont Cottonwood, California Black Walnut and Narrow-leaf willow.

The GDE community composition varied depending on the dominant vegetation present. Understory communities were a mix of native and non-native forbs and grasses. Overall current health assessed at each location varied. No sites showed evidence of widespread canopy dieback. Dieback was common on some trees across most sites, likely due to the multi-year drought over the past decade. Some sites were recent restoration sites (Butler Slough, Red Bluff Recreation Area, Pine Creek) and therefore lacked structural diversity and full canopies. Some of the smaller shrubs and saplings at these sites were struggling and showed dieback possibly indicating that the future vegetation community may look different than the one we sampled. Other sites, such as Woodson Bridge, Kopta, and Capay, showed communities that were in good health, with many vigorous trees. See Appendix 7 for site specific photos.

At the sites where we could sample soils through hand augering, none showed indicators of hydric soils within the shallow soil surface (< 12 inches), indicating consistent deeper groundwater levels.

6. Challenges

Our biggest challenge over the course of our study was lack of access to field sampling sites to verify GDEs. We sampled predominantly on public lands (and a Nature Conservancy easement) along the Sacramento River corridor. While this is where a lot of the GDEs were likely to occur, and where the majority of the high priority identified GDEs, it would have been very beneficial to sample away from the Sacramento River and along some of the other tributaries flowing into it. One area in particular that we would have liked to sample was along the western portion of Thomes Creek where likely GDEs were identified.

Additionally, the shallow groundwater contours we had access to were coarse scale and interpolated based on few shallow groundwater monitoring wells. This resulted in some iGDE

polygons in some years not having a depth to groundwater. Additional groundwater monitoring wells that are instrumented or read a few times a year – both spring and fall readings are ideal - will be helpful to create a more robust shallow groundwater dataset.

7. Next steps for future monitoring

Our field data collection provided a snapshot of the current health (in 2024 and 2025) of the groundwater dependent ecosystems by collecting data on the vegetation. The data collection technique can be time consuming for the complete dataset (a few hours), but the repeatability of the methods allow for comparison over time. Repeating the surveys in a few years at these 30 field sites, as well as identification and sampling of additional sites is recommended.

If time is limited, we suggest that future plot-based measurements focus on collecting a subset of the data. As a priority, we recommend repeat photography along the transects to be able to compare and perform qualitative visual assessment of potential changes. In addition, line point intercept along the transects to assess and quantify potential changes in the woody vegetation. There are fewer woody species and identification and measurement can be less challenging for non-botanists. In addition, many of the herbaceous species we encountered were annuals, which are driven more by precipitation and soil moisture rather than groundwater. Woody plants will be more likely to have deeper roots and the ability to access groundwater, therefore changes in their condition would be more indicative of potential changes in shallow groundwater.

In addition, we would recommend remote sensing techniques to monitor the sites identified as having a low NDVI average over the study years as well as subset of the ones that did not have data. While there are additional factors that could be driving the decline in vegetation, a large factor could be that they are experiencing groundwater decline. NDVI monitoring allows more landscape level assessment of the health of the GDEs and the GDE pulse database through the Nature Conservancy is a quick way to assess. The database relies on satellite imagery with a 30m pixel resolution. Therefore it is worth noting that just because a polygon has a low NDVI value does not mean it is an indicator of the overall health of the community. For instance, if a Valley Oak polygon has a low average NDVI value, it could be that the satellite imagery is picking up on the dead annual herbaceous layer of grasses, which would be expected to be low. The trees, however, may still be healthy and green. Therefore, incorporating some field verification would be beneficial.

Invasive species dominated polygons were removed from the database as these sites in their current state are not worth monitoring. We do want to bring attention to Giant Reed (*Arundo donax*), a tall (6-26 ft), perennial grass which occurs most commonly along Stony Creek. This invasive species is widely recognized to both deplete groundwater resources and has been

shown to alter fire regimes. It's been estimated to use 6x the amount of water per year than native riparian vegetation – where one acre of the plant has been estimated to consume 24 acre-feet of water compared to 4 acre-feet of water by native plants (California Invasive Plant Council, 2011). In addition, the tall reeds have high flammability and their growth patterns lead to increased fuel loading and fuel continuity, posing a danger for wildfire spread (Fusco et al., 2019). The plant is also fire adapted and resprouts vigorously after fire. In stands that are heavily dominated with giant reed, we recommend removal and restoration, acknowledging that this process can be challenging. There are many different techniques for eradication and the choice will depend on the size of the infestation and resources available (Waterworth, 2015).

7. References

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Appendix 1: Example of iGDE polygon adjustment.



0 100 200 ft

Example of iGDE from NCCAG dataset that has been modified due to changes in land use in the Red Bluff subbasin. The red area has been removed from the original polygon due to the presence of more structures than trees.



Red Bluff likely GDE
Red Bluff likely not GDE
Google Satellite

Map created by Kristen Kaczynski, PhD
Sub-Terra Heritage Resource Investigations

March 10, 2026

Appendix 2: Representative Field Photos



Figure A2.1: Valley Oak woodland transect at Butler Slough, Antelope subbasin (photo taken 5/24/2024)



Figure 8: Box elder transect in Woodson Bridge Preserve (State Parks), Corning subbasin. Photo taken 6/10/2024



Figure A2.3: Sandbar willow transect at Woodson Bridge Preserve (State Parks), Corning subbasin. Photo taken 6/7/2024

Appendix 3: Accuracy Assessment for field sampled plots

Table A3.1: Confusion Matrix for field verification of iGDE sampled plots

	Field verified											
classified as	Valley Oak	Fremont Cottonwood	Creeping Wildrye	California Black Walnut	Narrowleaf willow	Sycamore	Arroyo willow	Boxelder		Total	User Accuracy	Commission Error
Valley Oak	9	0	0	2	0	0	0	0		11	82%	18%
Fremont Cottonwood	2	5	0	2	0	0	0	0		9	56%	44%
Creeping Wildrye	0	0	1	0	0	0	0	0		1	100%	0%
California Black Walnut	1	0	0	2	0	0	0	0		3	67%	33%
Narrowleaf willow	0	0	0	0	2	0	0	0		2	100%	0%
Sycamore	0	0	0	0	0	1	0	0		1	100%	0%
Arroyo willow	0	0	0	0	0	0	1	0		1	100%	0%
Boxelder	1	0	0	0	0	0	0	1		2	50%	50%
TOTAL	13	5	1	6	2	1	1	1		30		
Producer's Accuracy	69%	100%	100%	33%	100%	100%	100%	100%				
Omission Error	31%	0%	0%	67%	0%	0%	0%	0%				

Table A3.2: Accuracy of sampled plot sites across Corning and Antelope subbasins

Plot	Mapped iGDE community	Actual GDE community	General Location
WB 1	Fremont Cottonwood	Fremont Cottonwood	Corning
WB 2	Valley Oak	California Black Walnut	Corning
WB 3	Narrow leaf willow	Narrow leaf willow	Corning
WB 4	Box elder	Box elder	Corning
WB 5	Valley Oak	California Black Walnut	Corning
CAP 1	Creeping Wildrye	Creeping Wildrye	Corning
CAP 2	Valley Oak	Valley Oak	Corning
CAP 3	SALA	SALA	Corning
KOP 1	Narrow leaf willow	Narrow leaf willow	Corning
KOP 2	Fremont Cottonwood	Fremont Cottonwood	Corning
KOP 3	Valley Oak	Mixed Valley Oak	Corning
KOP 4	Valley Oak	Valley Oak	Corning
KOP 5	Valley Oak	Valley Oak	Corning
KOP 6	Fremont Cottonwood	Fremont Cottonwood	Corning
KOP 7	Fremont Cottonwood	Fremont Cottonwood	Corning
BS 1	Valley Oak	Valley Oak/AECA	Antelope
BS 2	California Black Walnut	Valley Oak	Antelope
IF 1	Sycamore	Sycamore	Corning
BID 1	Fremont Cottonwood	California Black Walnut/Cottonwood	Corning
RB 1	Fremont Cottonwood	Valley Oak/Fremont Cottonwood	Antelope
RB 2	Box elder	Valley Oak	Antelope
RB 3	California Black Walnut	California Black Walnut	Antelope
RB 4	Fremont Cottonwood	Fremont Cottonwood	Antelope
RB 5	Valley Oak	Valley Oak	Antelope
RB 6	Valley Oak	Valley Oak	Antelope
RB 7	Fremont Cottonwood	Valley Oak	Antelope
RB 8	Fremont Cottonwood	California Black Walnut	Antelope
PCU 1	Valley Oak	Valley Oak	Corning
PCL 1	Valley Oak	Valley Oak	Corning
PCL 2	California Black Walnut	California Black Walnut	Corning

Appendix 4: Examples of sites not likely groundwater dependent ecosystems removed from the GDE database in initial aerial imagery GIS survey and informal field verification



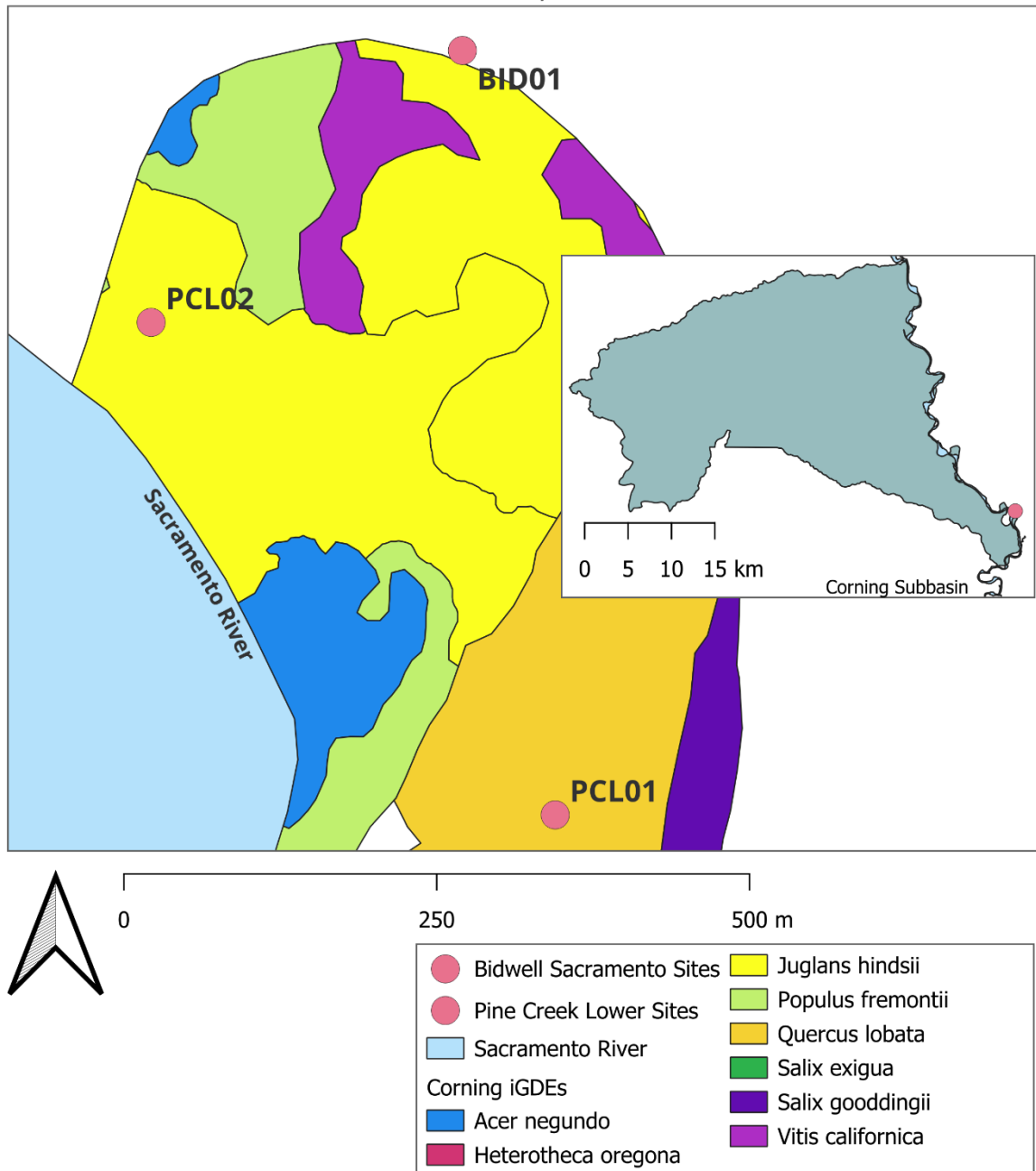
Figure A4.1: Arundo & Eucalyptus site along Bannin Creek in Corning subbasin. Example of a site removed from iGDE database



Figure A4.2: Pink flowering trees are Tamarisk, along Red Bank Creek in Red Bluff subbasin

Appendix 5: maps of field sampling locations

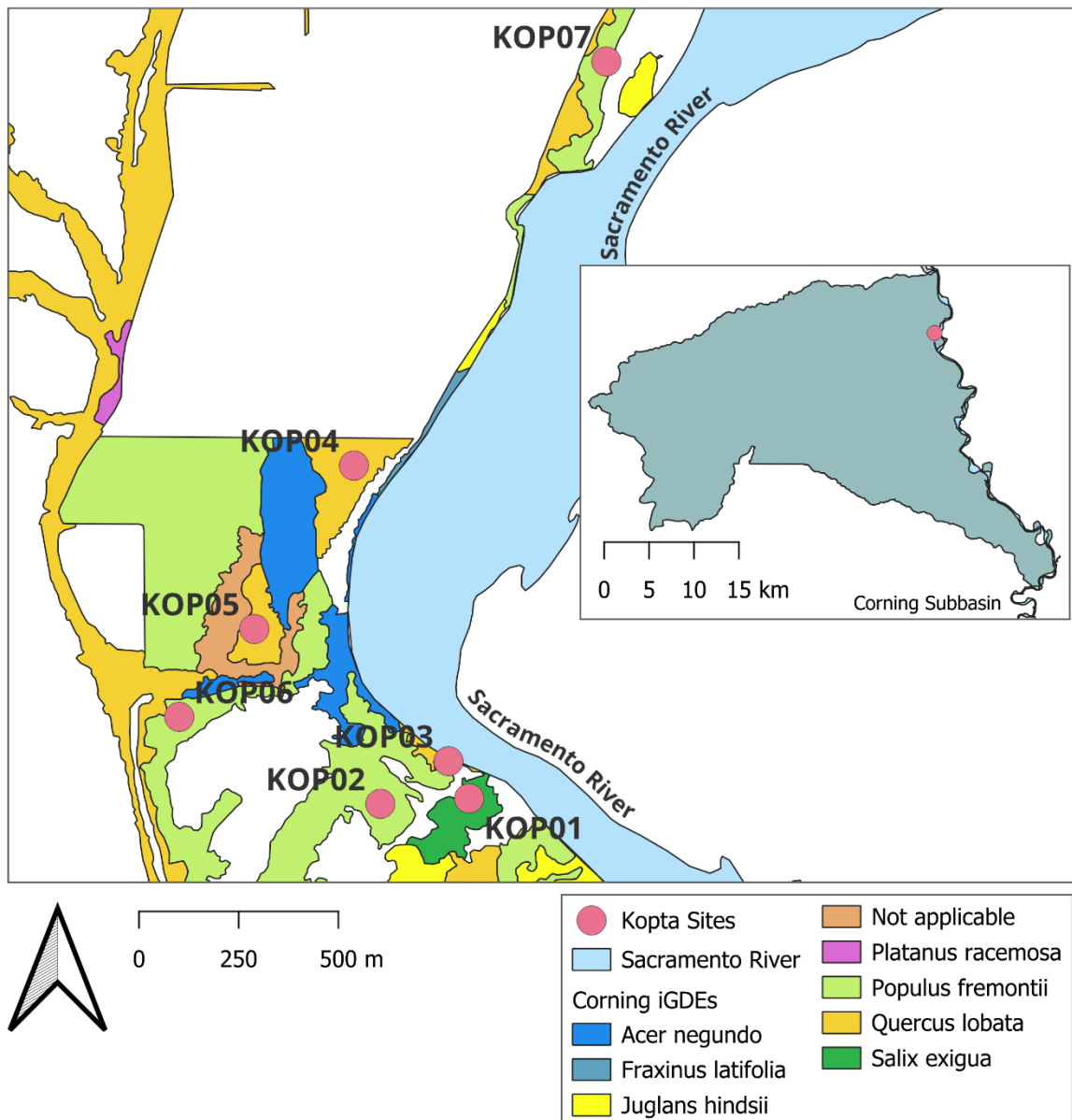
Pine Creek Unit Lower Sites 01, 02 and
Bidwell Sacramento River State Park Site 01
Chico, CA



Pine Creek Unit Lower Sites and the Bidwell Sacramento Site located in the Corning Subbasin were identified as ground water dependent ecosystems (iGDEs) dominated by *Quercus lobata* (PCL01), *Juglans hindsii* (PCL02), and *Populus fremontii* (BID01) respectively. After ground truthing these were confirmed except for BID01 which was a mixed canopy of *Juglans hindsii*, *Populus fremontii*, and various other species.

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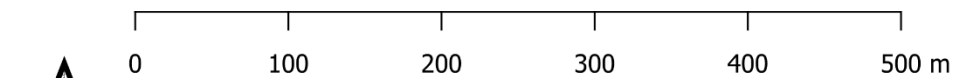
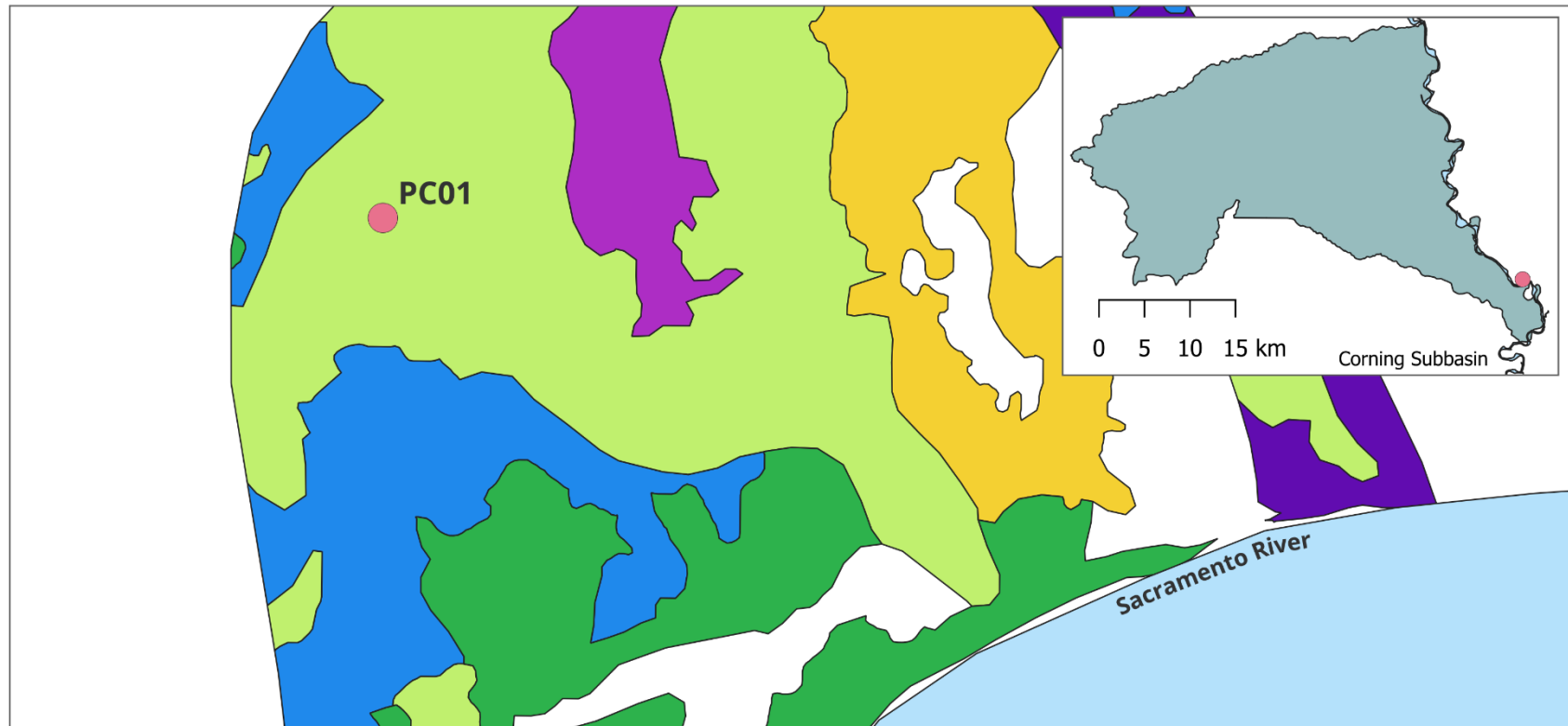
Kopta Slough Sites 01, 02, 03, 04, 05, 06, and 07 Corning, CA



Kopta Slough sites located in the Corning Subbasin were identified as groundwater dependant ecosystems (iGDEs) dominated by *Salix exigua* (KOP01), *Populus fremontii* (KOP02, KOP06, & KOP07), and *Quercus lobata* (KOP03, KOP04, & KOP05) respectively. After ground truthing these were all confirmed except KOP03 where it was difficult to confirm *Quercus lobata* as the dominant species with large patches of *Vinca major* and *Rubus armeniacus* blocking the north end of the sampling site.

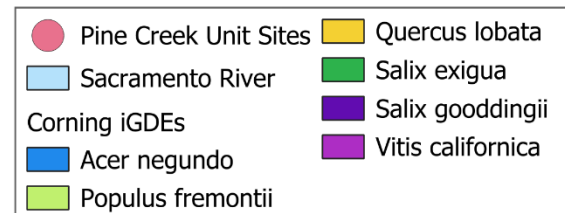
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Pine Creek Unit Site 01 Chico, CA

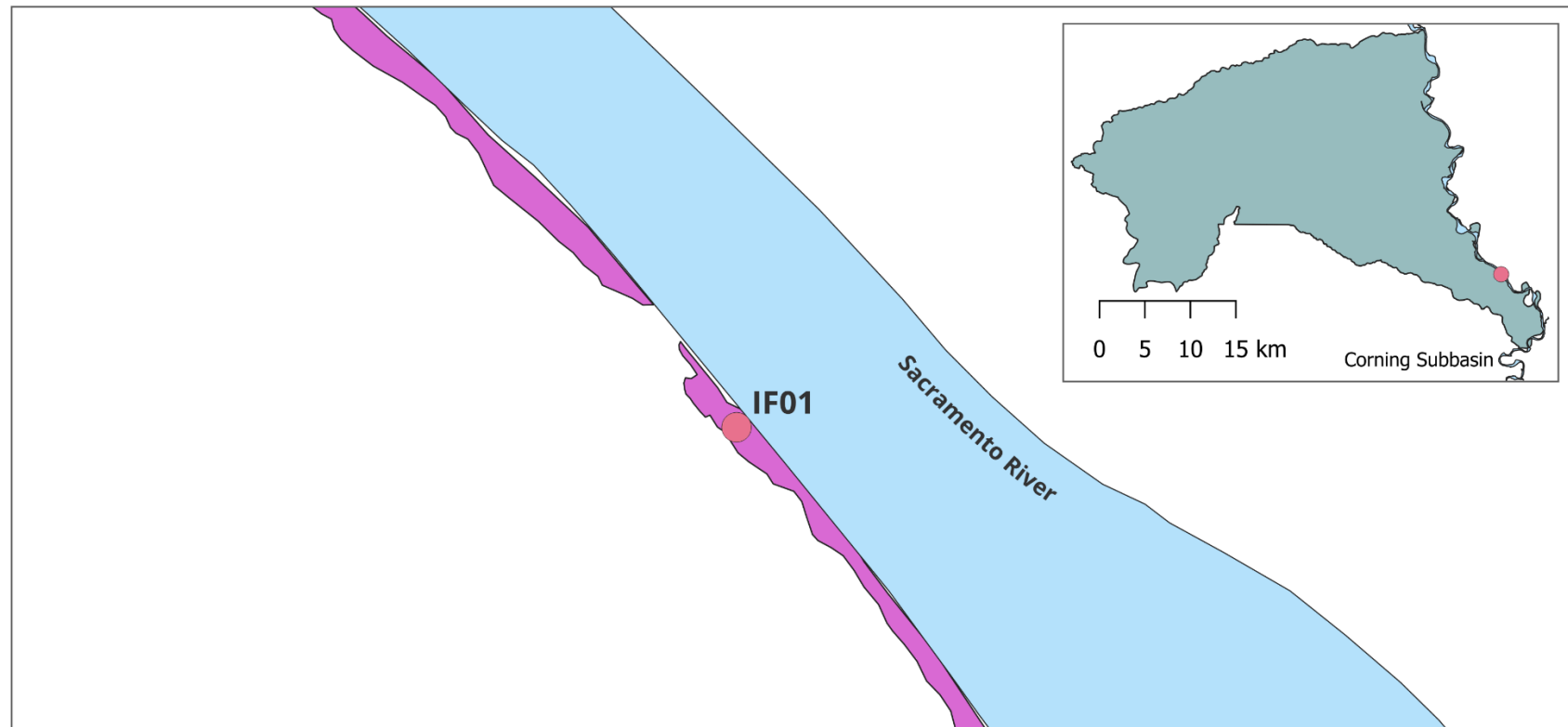


Pine Creek Unit sites located in the Corning Subbasin were identified as ground water dependent ecosystems (iGDEs) dominated by *Populus fremontii* (PC01). Groundtruthing confirmed the identification.

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Irvine Finch Boat Ramp Site 01 Chico, CA



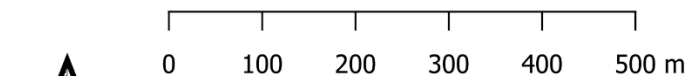
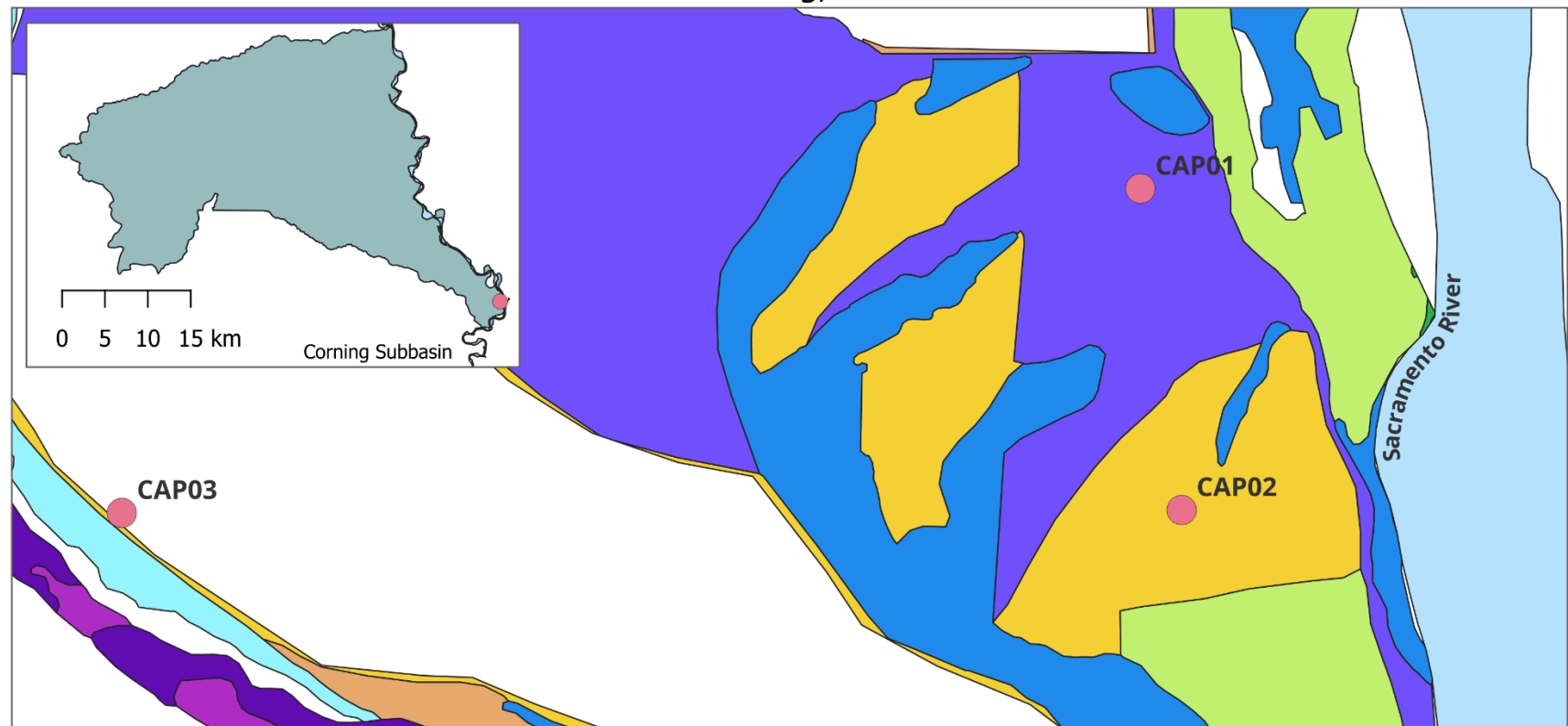
0 100 200 300 400 500 m

Irvine Finch site located in the Corning Subbasin was identified as a ground water dependent ecosystem (iGDEs) dominated by *Platanus racemosa* (IF01). After ground truthing this was confirmed, *Quercus lobata* was also found to be a large composition of the canopy.

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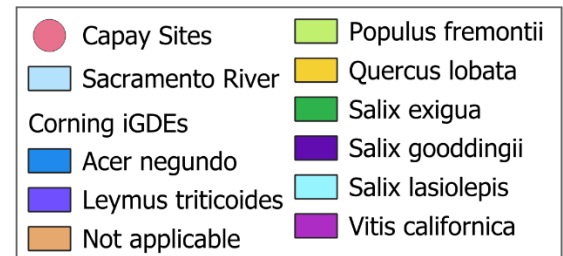
- Irvine Finch Boat Ramp Sites
- Sacramento River
- Corning iGDEs
- *Platanus racemosa*

Capay Unit Sites 01, 02, and 03, Corning, CA

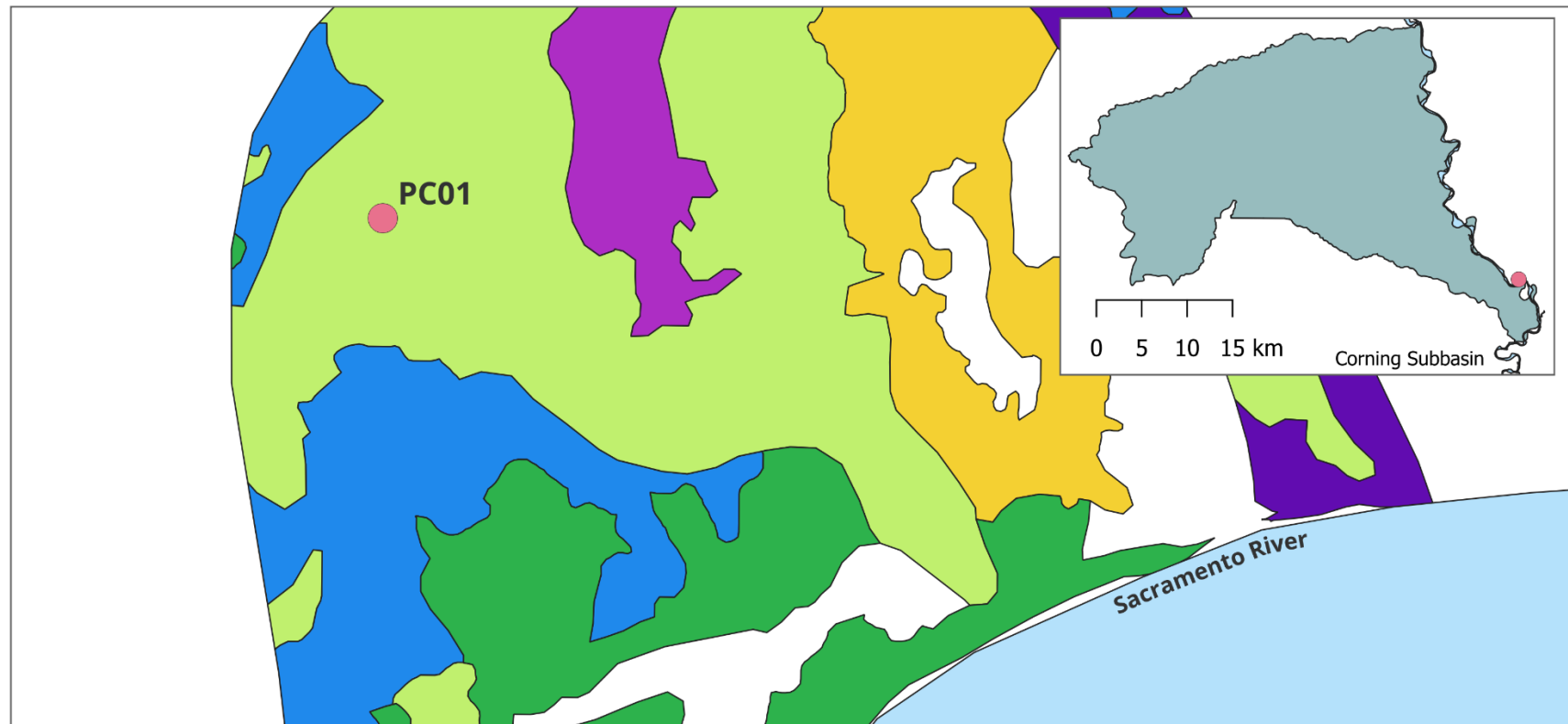


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Capay Unit Sites located in the Corning Subbasin were identified as ground water dependent ecosystems (iGDEs) dominated by *Leymus triticoides* (CAP01), *Quercus lobata* (CAP02), and *Salix lasiolepis* (CAP03) respectively and each confirmed as such with ground truthing.



Pine Creek Unit Site 01 Chico, CA



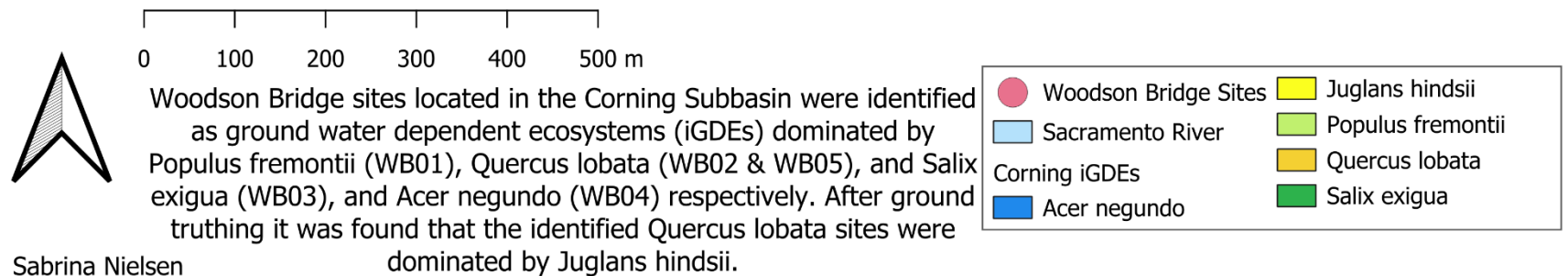
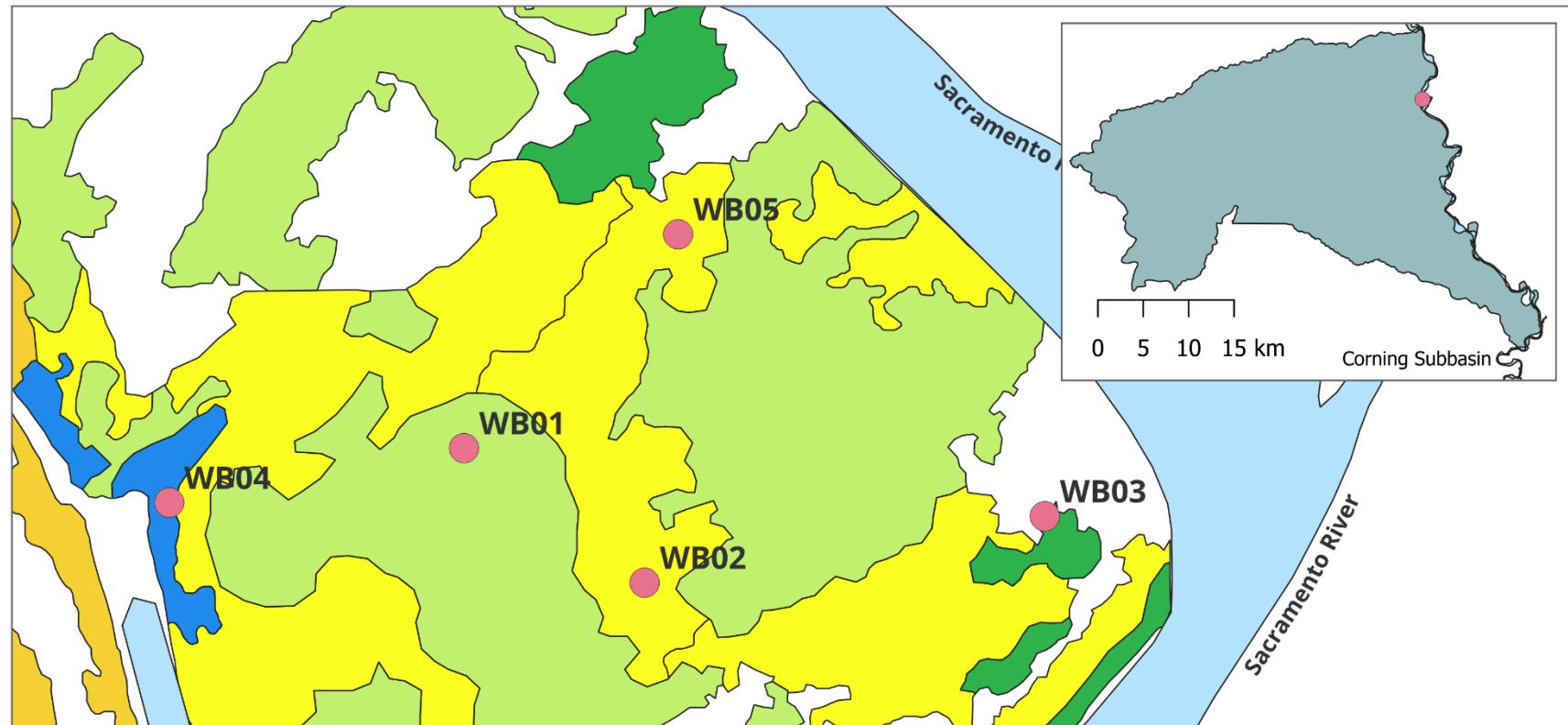
0 100 200 300 400 500 m

Pine Creek Unit sites located in the Corning Subbasin were identified as ground water dependent ecosystems (iGDEs) dominated by *Populus fremontii* (PC01). Groundtruthing confirmed the identification.

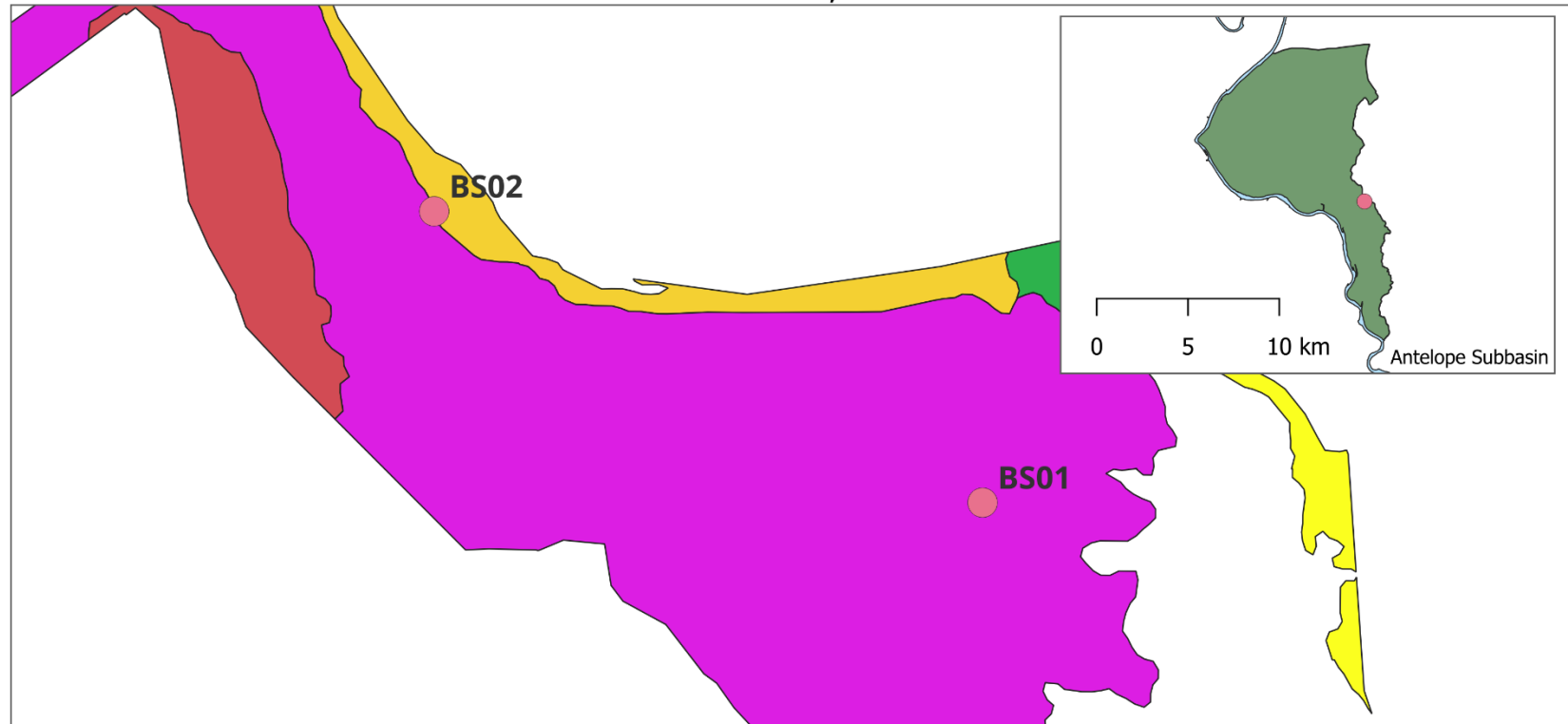
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- Pine Creek Unit Sites
- Sacramento River
- Corning iGDEs
- Acer negundo*
- Populus fremontii*
- Quercus lobata*
- Salix exigua*
- Salix gooddingii*
- Vitis californica*

Woodson Bridge State Recreation Area Sites 01, 02, 03, 04, and 05, Corning, CA



Butler Slough Sites 01, and 02 Red Bluff, CA

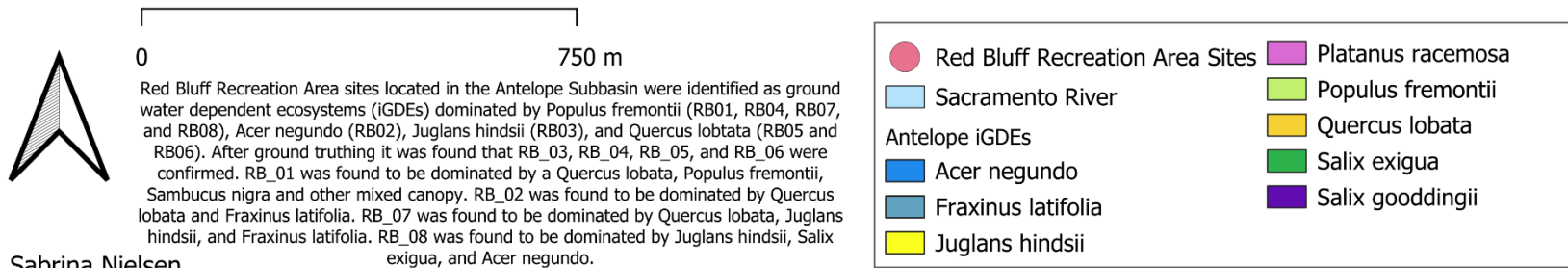
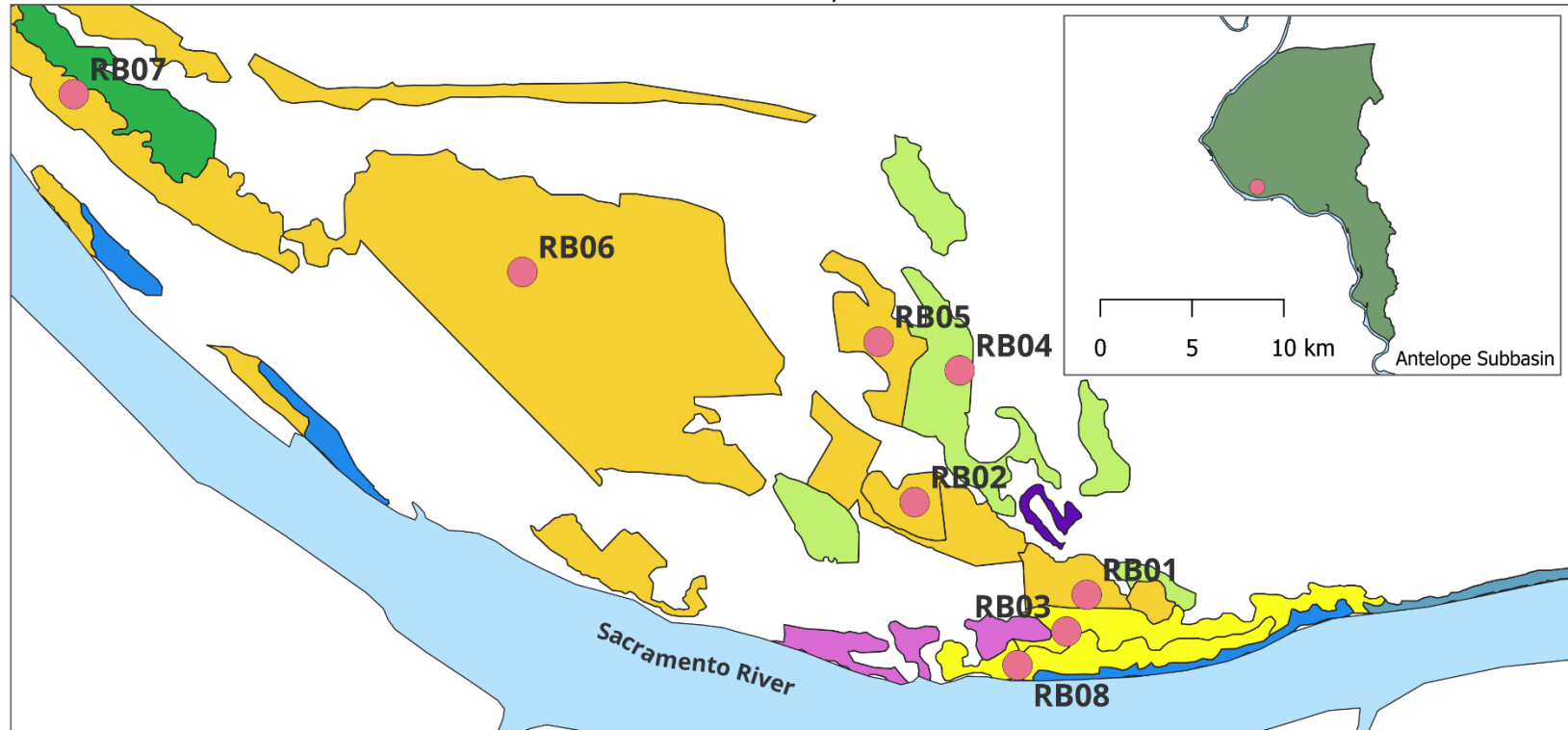


Butler Slough sites located in the Antelope Subbasin were identified as ground water dependent ecosystems (iGDEs) dominated by *Quercus lobata* (BS01) and *Juglans hindsii* (BS02) respectively. After ground truthing it was found that BS01 was dominated by *Aesculus californica*.

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- Butler Slough Sites
- Antelope iGDEs
- *Juglans hindsii*
- *Quercus lobata*
- *Rubus armeniacus*
- *Salix exigua*
- *Aesculus californica*

Red Bluff Recreation Area Sites 01, 02, 03, 04, 05, 06, 07, and 08 Red Bluff, CA



Red Bluff Recreation Area sites located in the Antelope Subbasin were identified as ground water dependent ecosystems (iGDEs) dominated by *Populus fremontii* (RB01, RB04, RB07, and RB08), *Acer negundo* (RB02), *Juglans hindsii* (RB03), and *Quercus lobata* (RB05 and RB06). After ground truthing it was found that RB_03, RB_04, RB_05, and RB_06 were confirmed. RB_01 was found to be dominated by a *Quercus lobata*, *Populus fremontii*, *Sambucus nigra* and other mixed canopy. RB_02 was found to be dominated by *Quercus lobata* and *Fraxinus latifolia*. RB_07 was found to be dominated by *Quercus lobata*, *Juglans hindsii*, and *Fraxinus latifolia*. RB_08 was found to be dominated by *Juglans hindsii*, *Salix exigua*, and *Acer negundo*.

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Appendix 6: Summaries of Groundwater Dependent Ecosystem Vegetation community composition

Community Overview

Name: *Quercus lobata* / Valley Oak (QULO)

Plots Sampled: 14 plots (CAP02, BS01, IF01, KOP03, KOP04, KOP05, BS02, RB01, RB02, RB05, RB06, RB07, PCU01, PCL01)

Total Sample Points: 1,042 LPI points analyzed

Habitat Description

Valley Oak are the dominant tree in floodplains, and riparian areas with reliable groundwater access. These stands represent California's most iconic riparian oak woodland, with QULO being the oldest and longest living species in the area that supports countless others.

Canopy Dominant

***Quercus lobata* (Valley Oak)** - 279 points (26.8% of total)

- Present in 100% of community plots with >66% relative cover

Co-dominant Trees

***Populus fremontii* (Fremont Cottonwood)** - 76 points (7.3%)

- Co-occurs in 64% of QULO plots (9/14)

***Platanus racemosa* (California Sycamore)** - 63 points (6.0%)

- Found in 50% of QULO plots (7/14)

***Fraxinus latifolia* (Oregon Ash)** - 52 points (5.0%)

- Present in 43% of QULO plots (6/14)

Invasive Grass Layer

***Bromus diandrus* (Ripgut Brome)** - 96 canopy + 265 understory = 361 total points (34.6%)

- Most abundant species overall in QULO communities
- Present in 93% of plots (13/14)

***Bromus japonicus* (Japanese Brome)** - 75 points (7.2%)

- Co-occurs with *B. diandrus* in 71% of plots

***Vicia villosa* (Hairy Vetch)** - 73 points (7.0%)

- Found in 57% of plots (8/14)

Native Understory

***Toxicodendron diversilobum* (Poison Oak)** - 88 points (8.4%)

- Present in 79% of QULO plots (11/14)

***Carex barbarae* (Santa Barbara Sedge)** - 60 points (5.8%)

- Native perennial sedge indicating seasonal moisture
- Present in 43% of plots (6/14)

Community structure

- Canopy coverage: 78% $\pm$ 12% (mean $\pm$ SD)
- Native:Non-native ratio: 0.68 (native species slightly outnumbered)
- Species richness: 15.4 $\pm$ 4.2 species per plot
- Woody species diversity: 3.8 $\pm$ 1.6 woody species per plot

Restoration note?

- 3 plots identified as restored sites (BS01, RB05, PCL01) show 23% lower invasive cover

GDE / Phreatophytes

- 87% of woody biomass from recognized phreatophytes
- Large *Q. lobata* specimens (>1000 cm) present in 71% of plots
- Valley oak seedlings (<2m) present in only 36% of plots
- Dominated by mature individuals
- Multiple invasives in 93% of plots

Community Overview

Name: *Populus fremontii* / Fremont Cottonwood (POFR)

Plots Sampled: 6 plots (WB01, KOP02, KOP06, BID01, RB01, RB04)

Total Sample Points: 487 LPI points analyzed

Habitat Description

Fremont Cottonwood dominate active floodplains, streambanks, and recent alluvial deposits with surface water or shallow groundwater access. These fast-growing, pioneer trees and indicate periodic flooding.

Canopy Dominant

***Populus fremontii* (Fremont Cottonwood)** - 177 points (36.3% of total)

- Clear dominant in 83% of community plots (5/6)

Co-dominant Trees

***Juglans hindsii* (Northern California Black Walnut)** - 39 points (8.0%)

- Present in 67% of POFR plots (4/6)

***Salix nigra* (Black Willow)** - 25 points (5.1%)

- Found in 50% of POFR plots (3/6)

***Acer negundo* (Box Elder)** - 19 points (3.9%)

- Detected in 50% of plots (3/6)

Invasive Grass Layer

***Bromus diandrus* (Ripgut Brome)** - 100 points (20.5%)

- Most abundant understory species
- Present in 100% of POFR plots (6/6)

***Bromus japonicus* (Japanese Brome)** - 38 canopy points (7.8%)

- Always co-occurs with *B. diandrus*

Native Understory

***Rubus ursinus* (California Blackberry)** - 66 points (13.5%)

- Present in 83% of POFR plots (5/6)

***Carex barbarae* (Santa Barbara Sedge)** - 39 points (8.0%)

- Perennial wetland sedge indicating seasonal saturation
- Found in 67% of plots (4/6)

***Galium aparine* (Cleavers)** - 38 points (7.8%)

- Present in 67% of plots (4/6)

***Fraxinus latifolia* (Oregon Ash)** - 31 points (6.4%)

- Co-occurs in 50% of plots (3/6)

Community Structure

- Canopy coverage: 85% $\pm$ 8% (highest among all community types)

GDE / Phreatophytes

- Cottonwood seedlings present in only 33% of plots (2/6)
- Invasive grasses in 100% of plots

Community Overview

Name: *Juglans hindsii* / Northern California Black Walnut (JUHI)

Plots Sampled: 8 plots (WB02, WB05, BID01, RB03, RB04, RB07, RB08, PCL02)

Total Sample Points: 723 LPI points analyzed

Habitat Description

Northern California Black Walnut communities occur on riparian terraces and valley bottoms with reliable groundwater access. These groves represent relict populations of once-extensive Central Valley riparian forests.

Canopy Dominant

***Juglans hindsii* (Northern California Black Walnut)** - 288 points (39.8% of total)

- Present in 100% of community plots as clear dominant

Co-dominant Trees

***Fraxinus latifolia* (Oregon Ash)** - 45 points (6.2%)

- Present in 75% of JUHI plots (6/8)

***Quercus lobata* (Valley Oak)** - 9 woody points

- Co-occurs in 50% of plots (4/8) but usually subdominant

***Populus fremontii* (Fremont Cottonwood)** - 8 woody points

- Found in 38% of plots (3/8)

Invasive Grass Layer

***Bromus diandrus* (Ripgut Brome)** - 54 canopy + 202 understory = 256 total points (35.4%)

- Most abundant species in JUHI understory
- Present in 100% of plots (8/8)

***Bromus japonicus* (Japanese Brome)** - 38 canopy points (5.3%)

- Co-occurs with *B. diandrus* in 88% of plots (7/8)

Native Understory

***Galium aparine* (Cleavers)** - 117 points (16.2%)

- Present in 88% of JUHI plots (7/8)

***Carex barbarae* (Santa Barbara Sedge)** - 95 points (13.1%)

- Perennial wetland sedge indicating seasonal soil saturation
- Found in 75% of plots (6/8)

***Rubus ursinus* (California Blackberry)** - 58 points (8.0%)

- Present in 63% of plots (5/8)

***Vicia cracca* (Bird Vetch)** - 44 points (6.1%)

- Found in 50% of plots (4/8)

Non-native

***Conium maculatum* (Poison Hemlock)** - 67 points (9.3%)

- Invasive biennial herb, highly toxic
- Present in 63% of plots (5/8)

Community Structure

- Canopy coverage: 72% $\pm$ 15%

GDE / Phreatophytes

- Cultural significance: Traditional Native American food and craft materials
- Walnut seedlings present in 63% of plots (5/8)
- Invasive grasses in 100% of plots

Community Overview

Name: *Salix exigua* / Sandbar Willow (SAEX)

Plots Sampled: 2 plots (KOP01, WB03)

Total Sample Points: 150 LPI points analyzed

Habitat Description

Sandbar Willow forms dense riparian shrublands along active floodplains and seasonal waterways. This pioneering species represents early successional riparian habitat with high water table access.

Canopy Dominant

***Salix exigua* (Sandbar Willow)** - 62 points (41.1% of total)

- Target species present in both plots
- Heights: 64-600 cm, average: 321 cm (n=19)
- Dominant shrub layer forming dense thickets

Co-Dominant Natives

***Aristolochia californica* (California Pipevine)** - 49 points (32.5%)

- Native vine, present in both plots
- Heights: 10-300 cm, average: 93 cm (n=4)
- Important butterfly host plant

***Quercus lobata* (Valley Oak)** - 31 points (20.5%)

- Large native oak, present in 1 plot only
- Heights: 500-1000 cm, average: 938 cm (n=8)

***Juglans hindsii* (Northern California Black Walnut)** - 22 points (14.6%)

- Native riparian tree, present in 1 plot only
- Heights: 1000 cm (consistent height, n=4)

***Elymus glaucus* (Blue Wildrye)** - 21 points (13.9%)

- Native perennial bunchgrass, present in both plots
- Heights: 32-90 cm, average: 59 cm (n=7)

***Artemisia douglasiana* (California Mugwort)** - 8 points (5.3%)

- Native perennial herb, present in both plots

Native Understory

***Carex barbarae* (Santa Barbara Sedge)** - 10 points (6.6%)

- Native perennial sedge, present in both plots
- Wetland indicator species

***Vitis californica* (California Grape)** - 4 points (2.6%)

- Native vine, present in both plots
- wildlife food source

***Acer negundo* (Box Elder)** - 1 point (0.7%)

- Native riparian tree, present in 1 plot only

Galium aparine - 5 points (3.3%)

- Annual herbaceous vine, present in both plots

Invasive Grass and Forb Layer

***Avena barbata* (Wild Oat)** - 51 points (33.8%)

- Non-native annual grass
- Present in 1 plot only, but high abundance

***Torilis arvensis* (Hedge Parsley)** - 45 points (29.8%)

- European annual herb, present in both plots

- Major invasive across both sites

POA2 (Non-identified Poaceae) - 24 points (15.9%)

- Non-native grass species, present in 1 plot only

Vicia species (VIC1) - 19 points (12.6%)

- Non-native herb, present in 1 plot only

Bromus diandrus (Ripgut Brome) - 15 points (9.9%)

- Non-native annual grass, present in 1 plot only

Centaurea spp. (CECA) - 10 points (6.6%)

- Non-native thistle

Conium spp (COMA4) - 4 points (2.6%)

- Non-native toxic herb, present in 1 plot only

Community Structure

- **Canopy coverage:** Dense willow shrubland with emergent trees
- **Cross-plot species:** 9 species occurring in both plots

Groundwater Dependent Ecosystem (GDE) Characteristics

- **Sandbar Willow:** Pioneer riparian shrubland
- **Valley Oak:** Likely indicates deep groundwater access
- **CABA4:** seasonally wet soils

Habitat

- **California Pipevine:** Host for California Pipevine Swallowtail butterfly

Appendix 7: Plot specific examples of GDE communities



Figure A7.1: Kopta plot 7, showing healthy, vigorous individuals and some dead overstory of Fremont Cottonwoods (Corning subbasin)



Figure A7.2: Butler Slough plot 2, showing healthy Valley Oaks in the foreground and some dead overstory in the background (Antelope subbasin)



Figure A7.3: Red Bluff Recreation Area, plot 2, showing canopy dieback on Box Elder along transect and dead shrubs in the understory.

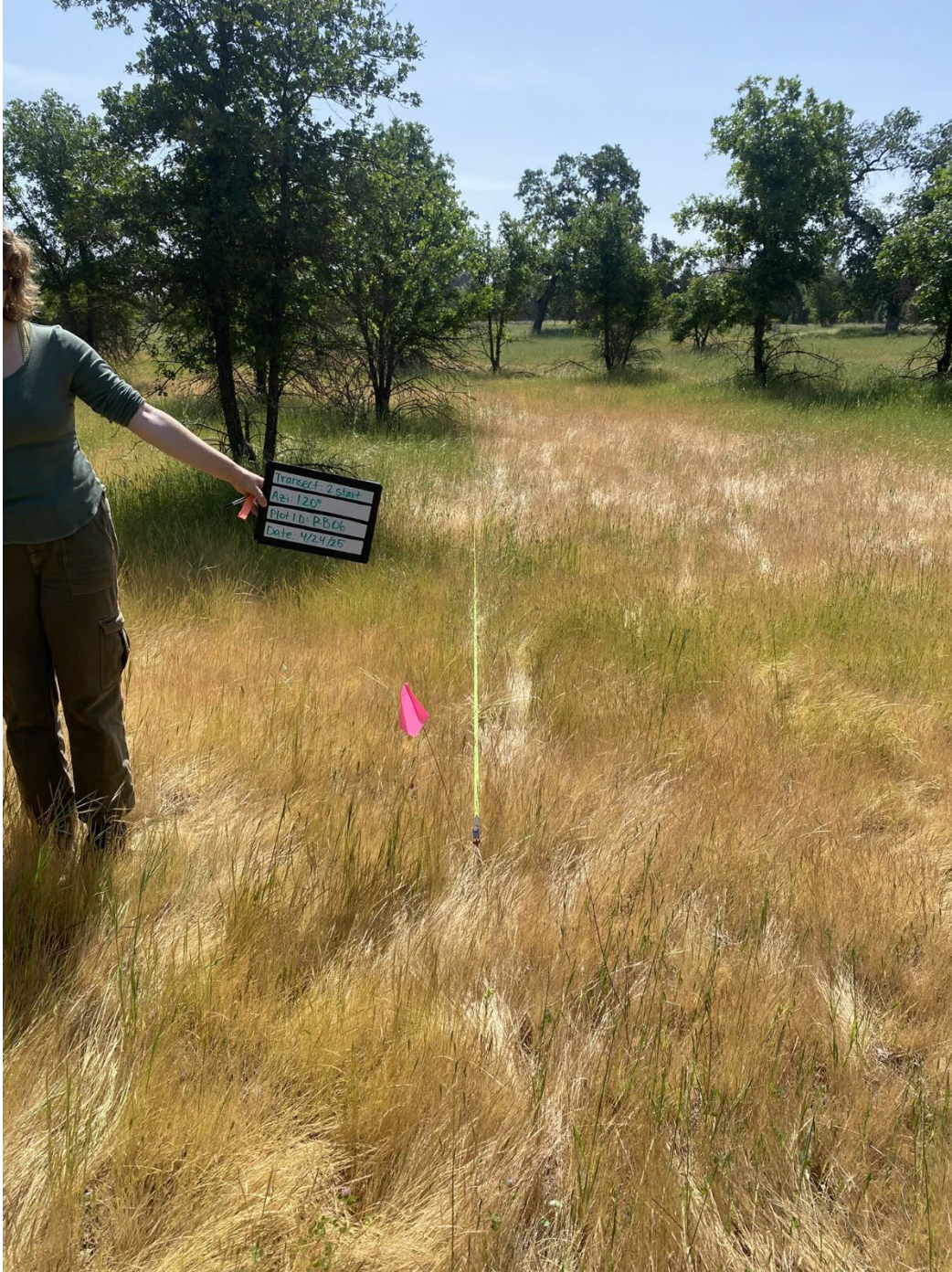


Figure A7.4: Red Bluff Recreation Site, plot 6 showing healthy, young Valley Oak trees and an understory of non-native annual grasses.



Figure A7.5: Pine Creek Lower Unit, plot 1, showing healthy, vigorous Valley Oak overstory community



Figure A7.6: Kopta Slough, plot 4, showing healthy overstory canopy species in background with dead younger Valley Oak individual along the transect.