GDE Identification and Monitoring Program Report and Recommendations

Draft Final Report

March 2025

Product of the *Groundwater Dependent Ecosystems (GDE) Identification, Assessment, and Monitoring Program* (hereafter 'the GDE Project')

Prepared by:

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Acknowledgements

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Executive Summary

The 2014 Sustainable Groundwater Management Act (SGMA) mandates that all beneficial users of groundwater, including environmental users such as Groundwater Dependent Ecosystems (GDEs), be considered in Groundwater Sustainability Plans (GSPs) with management strategies to avoid undesirable outcomes given continued groundwater extraction. The GDE Project addressed substantial data gaps which led to the exclusion of the mesquite bosque near the Borrego Sink as a Groundwater Dependent Ecosystem (GDE) in the Borrego Springs Subbasin Groundwater Management Plan (GMP). Through multiple lines of evidence, including field measurements, advanced sensor technologies, and remote sensing datasets, this study confirms that the mesquite bosque is connected to groundwater and functions as a beneficial user of groundwater.

Key Findings

- Groundwater is present within the rooting depth of mesquite trees near the Borrego Sink, with isotope analyses confirming groundwater use.
- Water potential data show that mesquite experience lower water stress compared to nearby non-phreatophytic vegetation.
- Remote sensing analyses show consistent vegetation greenness and productivity during dry periods, further supporting mesquite's dependence on groundwater.
- Evapotranspiration (ET) monitoring and water balance models reveal that mesquite trees use water at rates exceeding annual precipitation, further validating their classification as a GDE.
- There is significant GDE reliant biodiversity associated with the mesquite bosque habitat in the Subbasin.

Using the best available science, the Borrego Springs mesquite bosque represents approximately 1,850 acres of SGMA-relevant GDE. Although in decline from groundwater level decreases, the mesquite bosque remains a highly productive ecosystem that provides valuable ecosystem services and critical habitat for unique flora and fauna. Immediate action is required to ensure its protection, including groundwater allocation in Subbasin water management decision making, hydrological and biological monitoring, and conservation measures. The findings of this study underscore the importance of integrating the mesquite bosque into sustainable groundwater management efforts for long-term ecological and hydrological resilience.

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Acronyms

AOI: Area of Interest
BGS: below ground surface
BS: Borrego Springs
CESA: California Endangered Species Act
CDFW: California Department of Fish and Wildlife
CDL: Clark Dry Lake
CNDDB: California Natural Diversity Database's Special Animals List
DEM: Digital Elevation Model
ET: Evapotranspiration
ETgw: Groundwater transpiration
GDE: Groundwater Dependent Ecosystem
GMP: Groundwater Management Plan
GPP: Gross Primary Productivity
GSA: Groundwater Sustainability Agency
GSP: Groundwater Sustainability Plan
ABDSP: Anza-Borrego Desert State Park
MK Tau: Mann-Kendall's Tau
MW: Monitoring Well
NAIP: National Agriculture Imagery Program
NCCAG: Natural Communities Commonly Associated with Groundwater
NDVI: Normalized Difference Vegetation Index
P: Precipitation
PRISM: Parameter-elevation Regressions on Independent Slopes Model
SDNHM: San Diego Natural History Museum
SGMA: Sustainable Groundwater Management Act
STL: Seasonal and Trend decomposition using Loess method

Vocabulary

Aquifer is defined in Bulletin 118 as "a body of rock or sediment that is sufficiently porous and permeable to store, transmit, and yield significant or economic quantities of groundwater to wells and springs."

Baseline conditions ("Baseline") is a SGMA definition referring "to historic information used to project future conditions for hydrology, water demand, and availability of surface water and to evaluate potential sustainable groundwater management practices of a basin."

Best available science is a SGMA definition that "refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision that is consistent with scientific and engineering professional standards of practice."

Data gap is a SGMA definition that "refers to a lack of information that significantly affects the understanding of the basin setting or evaluation of the efficacy of GSP implementation, and could limit the ability to assess whether a basin is being sustainably managed."

Ecosystem is a biological community of interacting organisms and their physical environment.

Flora are the plants of a region, habitat, or geological period.

Fauna are the animals of a particular region, habitat, or geological period.

Groundwater is defined in Bulletin 118 as "water that occurs beneath the land surface and fills the pore spaces of the alluvium, soil, or rock formation in which it is situated. It excludes soil moisture, which refers to water held by capillary action in the upper unsaturated zones of soil or rock."

Habitat is an ecological or environmental area that is inhabited by a species of animal, plant, or other type of organism.

Honey mesquite the tree, *Neltuma odorata* (formerly *Prosopis glandulosa*); largely referred to as "mesquite".

Mesquite bosque is defined as the community that includes interstitial spaces and associated species.

Minimum threshold is a SGMA definition that "refers to a numeric value for each sustainability indicator used to define undesirable results."

Remote sensing is the scanning of the earth by satellite or high-flying aircraft to obtain information about it.

Subbasin is the Borrego Springs Subbasin, located in eastern San Diego County; the subbasin of interest in this study.

Sustainability indicator is a SGMA definition that "refers to any of the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, cause undesirable results, as described in Water Code Section 10721(x)." The six sustainability indicators include (1) chronic lowering of groundwater levels, (2) reduction of groundwater storage, (3) seawater intrusion, (4) degraded water quality, (5) land subsidence, and (6) depletions of interconnected surface water.

Tagged trees are the mesquite trees selected in this study for repeated measurements at Sites 1 - 5.

Undesirable impact or effect is a term used in SGMA to describe conditions that occur when significant and unreasonable effects for any of the sustainability indicators are caused by groundwater conditions occurring throughout the basin.

Water year is defined as the period from October 1 through the following September 30.

1. Introduction

The 2014 Sustainable Groundwater Management Act (SGMA) stipulates that all beneficial users of groundwater, including environmental users such as groundwater dependent ecosystems (GDE), be considered in Groundwater Sustainability Plans (GSP) (California Water Code, Part 274, Chapter 4, Section 10723.2). Under SGMA, GDEs are defined as "ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface" (California Code Regulations, Title 23, Section 351(m)).

GDEs relying on subsurface groundwater provide a wide range of ecosystem services, including supporting unique vegetation, offering critical wildlife habitat, sequestering carbon, stabilizing soil to prevent erosion, and recreation associated with natural lands. These ecosystems are particularly important during dry periods, as subsurface water helps maintain vegetation function and dependent fauna activity when surface water is unavailable. Unsustainable groundwater extraction poses a significant threat to GDEs, underscoring the need for thorough scientific assessments and ongoing monitoring to provide the best available data to support sustainable groundwater management.

In the Borrego Springs Subbasin, the mesquite bosque near Borrego Sink was historically recognized as a GDE. However, declining groundwater levels, informal reports of deteriorating mesquite health, and uncertainty about the mesquite trees' ability to access groundwater led to its exclusion from the Borrego Groundwater Management Plan (GMP). This decision was based on significant data gaps, including inaccurate mapping of the mesquite bosque, incorrect rooting depths, a lack of field verification, and the absence of data directly assessing mesquite groundwater use.

This project seeks to address these data gaps using the best available scientific methods and data to evaluate whether the mesquite bosque near Borrego Sink is a GDE under SGMA. Through multiple lines of evidence—including direct field measurements, advanced sensor technologies, and remote sensing datasets—we demonstrate that the mesquite bosque is connected to groundwater and qualifies as a GDE, functioning as a beneficial user of groundwater and requiring management action given undesirable outcomes of continued groundwater decline.

Background and Project Approach

The Nature Conservancy's 2018 GDE Guidance Document (Rohde et al., 2018) outlines a systematic approach for the identification, monitoring, and management of GDEs for their inclusion in GSPs under SGMA. This step-by-step methodology ensures that GDEs are accurately identified, assessed for risks, and monitored for potential impacts (see steps outlined in Figure 1.1). The GDE Project focuses on completing Steps 1 and 2, while also providing the best available scientific information to support the critical management actions outlined in Steps 3 through 5. Steps 3 through 5 will require multiple vested stakeholders to collaboratively interact with the best available science provided by Steps 1 and 2 to support long-term Subbasin goals.

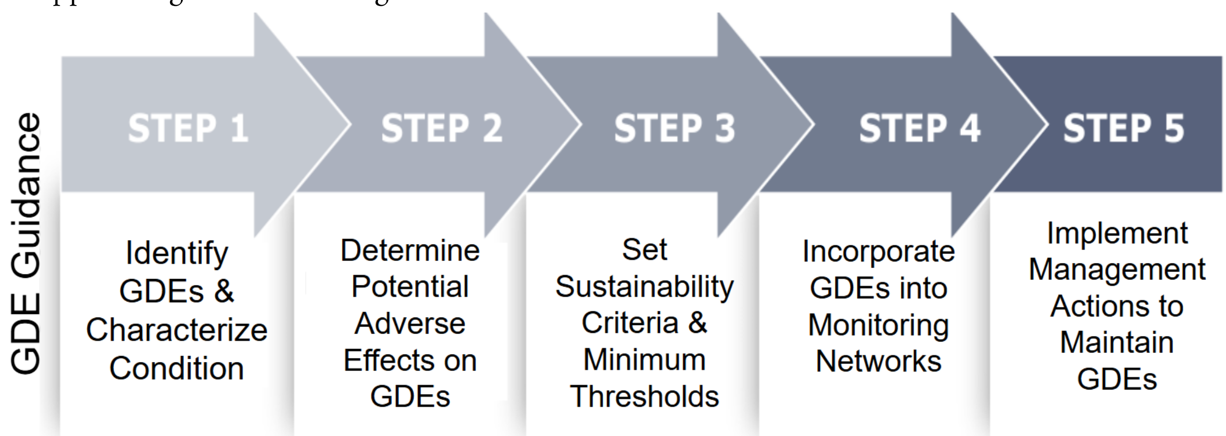

Figure 1.1. Flowchart describing the framework used in the GDE Project to guide GDE identification, monitoring, and management, modified from The Nature Conservancy's 2018 GDE Guidance Document (Rohde et al., 2018). SGMA best practices advise that potential GDEs should be assumed to be GDEs until direct evidence proves otherwise (Rohde et al., 2018).

As emphasized by Eamus et al. (2016), the sustainable management of GDEs must address several key questions:

1. **Where are GDEs located in the landscape?** Without identifying their locations, it is impossible to manage them or allocate groundwater appropriately.
2. **How much groundwater do GDEs use?** Understanding their water requirements and the nature of vegetation coupling to the groundwater system is critical for balancing environmental needs with other groundwater uses.
3. **What threats do GDEs face?** Identifying these risks is essential for implementing measures to ensure their resilience and long-term survival.

4. **What are the responses of GDEs to groundwater over-extraction?** Knowing what indicators to measure can inform the regulation of groundwater extraction to prevent undesirable impacts on GDEs.

Objectives

The primary objectives of this study are to determine whether the mesquite bosque near the Borrego Sink functions as a GDE and to establish a robust baseline for future monitoring of GDEs in the Borrego Springs Subbasin. As described in the literature, GDE status can be accessed through a variety of methods, which are summarized in Table 1.1 (Eamus et al., 2016). We employed each of these methods using field, laboratory, and remote sensing techniques that were catered to the Subbasin. This led us to explicitly: 1) Map the extent of live mesquite near the Borrego Sink; 2) Identify mesquite trees using groundwater; 3) Characterize current variation in mesquite health, water use, and ecological sensitivity; 4) Estimate total groundwater transpired by mesquite; 5) Analyze historical trends in mesquite health; and 6) Establish guidelines for ongoing GDE monitoring in the Subbasin.

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Table 1.1. Methods and results for determination of GDEs**.** Affirmative answers to one or more of the following questions are indicative that the 1,850-acre mesquite bosque habitat in Borrego Springs is a GDE. The mesquite bosque habitat reported here is inclusive of interstitial space between mesquite trees and associated species.

Topic	Method (Report Section)	Result
Groundwater depth and rooting depth		
Is groundwater or the capillary fringe present within the rooting depth of any known phreatophytic vegetation?	Map of mesquite, literature on rooting depth, and groundwater depth (**Mapping the GDE, Depth to Groundwater**)	Yes, 1,850 acres of mesquite bosque habitat are found near the Borrego Sink, where groundwater depths are within 22 - 135 feet bgs.
Ecological field data		
Does isotope source assessment indicate use of groundwater?	Seasonal isotope collection of twigs, soil, rain, and groundwater (**Isotopic Analysis**)	Yes, 48 out of 48 measured mesquite trees near the Borrego Sink showed isotope signatures indicative of groundwater use in 2023 and 2024. All mesquite were located within the 1,850 acre mapped mesquite bosque habitat.
Are plant water relations (predawn and midday water potentials) indicative of less water stress than vegetation located nearby but not accessing the groundwater?	Water potential comparison to creosote, a non-phreatophyte (**Water Potential**)	Yes, mesquite had less negative predawn and midday water potential indicating greater water availability and lower water stress. All mesquite and creosote were located within the 1,850 acre mapped mesquite bosque habitat.
Remote sensing approaches		
Does vegetation maintain or increase live green biomass during extended dry periods of the growing season?	Approach 1 Dry Period NDVI Tau **(Remote Sensing of GDE Behavior)**	Yes, 385 acres of mesquite canopy in the mapped mesquite bosque habitat showed signs of GDE behavior for Approach 1 in 2023 and 397 acres in 2024.
Does vegetation remain green and physiologically active during extended periods of water and temperature stress?	Approach 2 Dry Period NDVI Max **(Remote Sensing of GDE Behavior)**	Yes, 213 acres of mesquite canopy in the mapped mesquite bosque habitat showed signs of GDE behavior for Approach 2 in 2023 and 268 acres in 2024.
Within areas having similar rainfall, do some areas show higher rates of productivity whilst others do not?	Approach 3 Cumulative NDVI of GDE **(Remote Sensing of GDE Behavior)**	Yes, 183 acres of mesquite canopy in the mapped mesquite bosque habitat showed signs of GDE behavior for Approach 3 in 2023 and 73 acres in 2024.
Water balance methods		
Are plant transpiration rates during extended dry periods consistently greater than zero?	ET sensors during dry periods **(Dry Period Evapotranspiration)**	Yes, ET was consistently above zero for the dry period in 2024 at all three measured sites near the Borrego Sink. All sites are located within the mapped mesquite bosque habitat.
Is the annual rate of transpiration by vegetation significantly larger than annual rainfall?	OpenET Ensemble model **(Quantification of Mesquite Groundwater Transpiration)**	Yes, groundwater transpiration was estimated at 130 - 771 acre feet per year from 2015 - 2023 across the 1,850-acre mapped mesquite bosque habitat using OpenET's ensemble model.

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Eamus, D., Fu, B., Springer, A. E., & Stevens, L. E. (2016). Groundwater dependent ecosystems: classification, identification techniques and threats. *Integrated groundwater management: concepts, approaches and challenges*, 313-346.

Rohde, M. M., Matsumoto, S., Howard, J., Liu, S., Riege, L., & Remson, E. J. (2018). *Groundwater dependent ecosystems under the Sustainable Groundwater Management Act: Guidance for preparing groundwater sustainability plans.* The Nature Conservancy.

2. Identification of GDEs

Mapping the GDE

Introduction

An important first step in identifying GDEs (Groundwater Dependent Ecosystems) is mapping their extent. There have been a number of different reports of mesquite bosque spatial extent in the region over the last several decades from different environmental reports relevant to groundwater management. For instance, the Natural Communities Commonly Associated with Groundwater (NCCAG) dataset was created by the Department of Water Resources and The Nature Conservancy to serve as a starting point and initial reference dataset for Groundwater Sustainability Agencies (GSA) to identify potential GDEs within California's groundwater basins. The statewide dataset compiles 48 publicly available state and federal agency datasets that map phreatophytic vegetation, perennial streams, naturally flooded wetlands, and springs and seeps to identify locations that likely contain and depend on groundwater. In the Borrego Springs Subbasin, the NCCAG dataset utilizes the Anza-Borrego Desert State Park (ABDSP) and Environs vegetation map (Klausmeyer et al., 2018). However, as this mapping effort was prepared for applications specific to ABDSP, the mapping only covers the area within and immediately adjacent to ABDSP boundaries at the time of mapping, and does not cover the area designated as the Borrego Springs Community Planning Area in the Borrego Springs Community Plan and the San Diego General Plan, and thus fails to capture mesquite found west of the ABDSP boundary. The NCCAG dataset creators request that users review, validate, and supplement the dataset with the best available local knowledge and resources such as higher resolution vegetation mapping and hydrologic and groundwater conditions to better identify potential GDEs (Klausmeyer et al., 2018). There was a more recent and more complete mapping effort of the mesquite bosque conducted in 1995 by the City and County of San Diego as well as the San Diego Association of Governments, which characterized vegetation communities according to the Holland system (Holland 1986, SanGIS 2022). This effort mapped the area of mesquite bosque near the Borrego Sink as 2,800 acres. However, there was a need for a contemporary map reflecting mesquite bosque distribution, given the best available map was completed 30 years ago.

To develop more accurate and contemporary mapping of potential GDE we first conducted image classification of aerial images from 2016 to identify live mesquite trees (*Neltuma odorata* [formerly *Prosopis glandulosa*]) in the Borrego Springs Subbasin near the Borrego Sink (see Appendix A.1 for theory and methods). We then used the classification product to produce a baseline map of mesquite bosque habitat. A "habitat" is an ecological or environmental area that is inhabited by a species of plant, animal, or other type of organism. This habitat map includes the mesquite plant community, inclusive of interstitial spaces and associated species.

Results

The classification of aerial images from 2016 detected 350.1 acres of live mesquite tree canopy near the Borrego Sink (Figure 2.1) which resulted in 1,850 acres of mesquite bosque habitat near the Borrego Sink (Figure 2.2). At our Clark Dry Lake comparison, image classification detected 86.2 acres (Figure 3) of live mesquite tree canopy and 227 acres of mesquite bosque habitat (Figure 2.3 & 2.4).

Conclusions

Our mapping effort identified a large swath of potential mesquite bosque GDE near the Borrego Sink, allowing us to then assess the ecological value of the identified area. We mapped the depth to groundwater, conducted isotopic analysis, measured water potential, analyzed remote sensing data, and collected evapotranspiration data to assess GDE behavior across the extent of identified potential GDE area (see sections **Isotopic Analysis**, **Water Potential**, **Remote Sensing of GDE Behavior**, and **Dry Period Evapotranspiration in the GDE** below).

Compared to the 1995 mapping effort, our Borrego Springs Mesquite Bosque Habitat Map indicates a reduction in mesquite area in the Borrego Springs Subbasin near the Borrego Sink. While the reduction in mesquite bosque area is likely attributed in part to mesquite mortality, it is important to consider differences in data quality, methodology, and the timing of data acquisition when comparing the 1995 map to our map. In 1995, available satellite imagery was of a lower resolution and this habitat map was created by hand-drawing outlines where vegetation appeared to change, which resulted in a coarse assessment. The value in our mapping approach is that it provides for a more quantitatively reliable estimate of change detection moving forward, utilizing reliable, high-quality images.

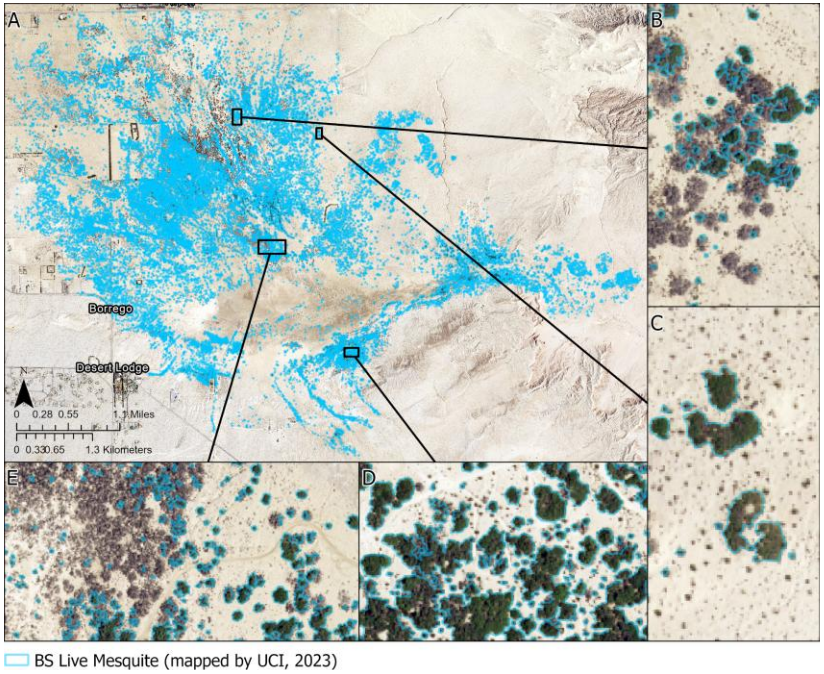

Figure 2.1. Image classification of mesquite in the Borrego Springs Subbasin near the Borrego Sink**.** The analysis discriminates between live and dead mesquite to effectively estimate individual, functional plants. Live mesquite identified through image classification are outlined in turquoise. Insets B and E highlight how dead mesquite (the brown areas in the map) are not included by the image classification. Insets D and C demonstrate the high performance of the classification in designating individual trees in dense and sparse settings, respectively. Base imagery from the National Agriculture Imagery Program (NAIP) taken 22 - 23 April 2016.

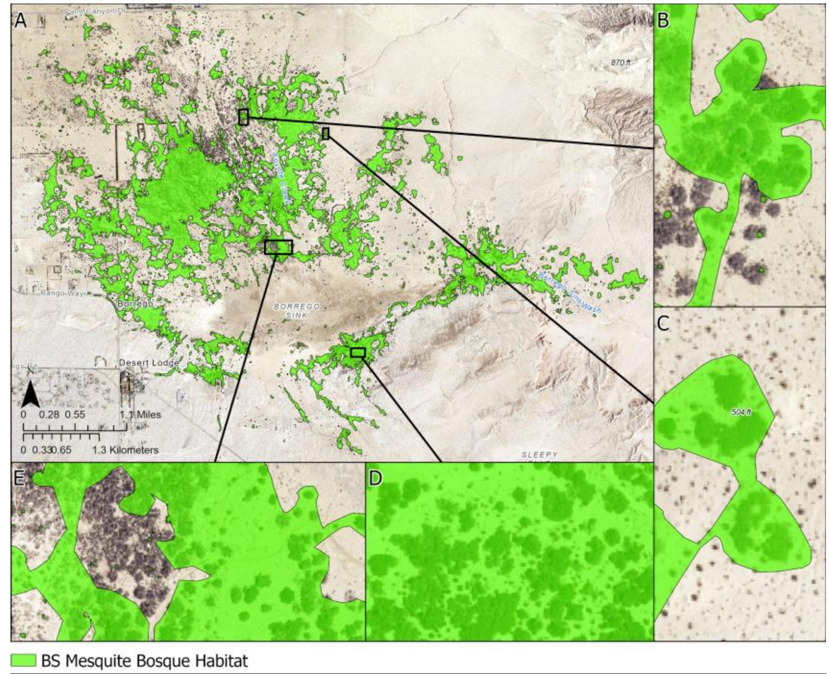

Figure 2.2. Mesquite bosque mapping in the Borrego Springs Subbasin near the Borrego Sink using image classification on 2016 aerial imagery illustrated in Figure 2.1. Blue shaded portions of the map identify inclusive habitat (live canopy-covered ground area, inter-canopy ground area, and associated other plant species). The insets represent the same areas as Figure 1 and demonstrate how habitat is delineated in clustered (B), sparse (C), dense (D), and live-dead mosaic (E), examples of mesquite distribution. Base imagery from the National Agriculture Imagery Program (NAIP) taken 22 - 23 April 2016.

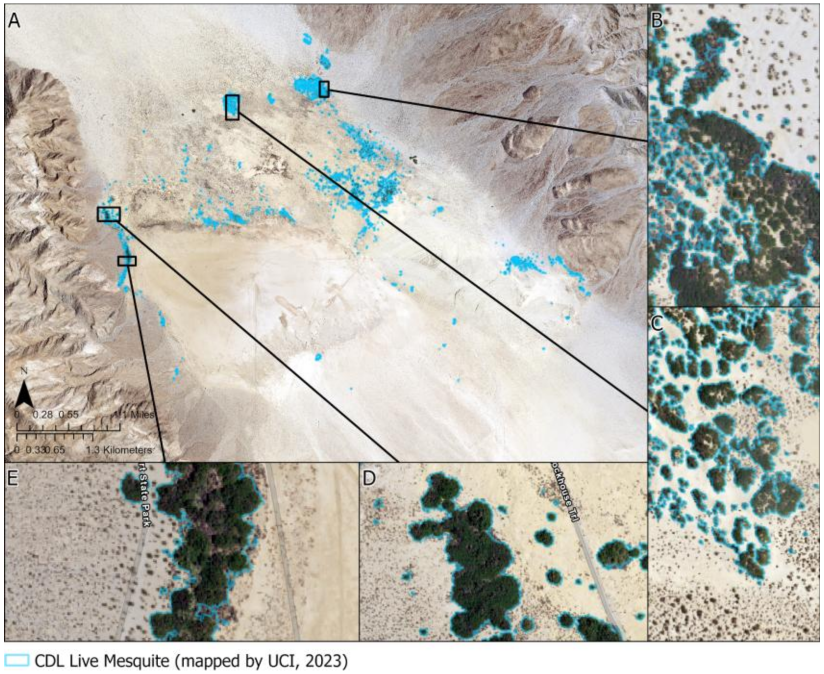

Figure 2.3. Image classification of mesquite at the Clark Dry Lake comparison site**.** The analysis discriminates between live and dead mesquite to more effectively estimate individual, functional plants. Insets highlight the high performance of the classification in designating individual trees in dense (B and C) and clustered (E and D) arrangements. Live mesquite identified through image classification are outlined in turquoise. Base imagery from the National Agriculture Imagery Program (NAIP) taken 22 - 23 April 2016.

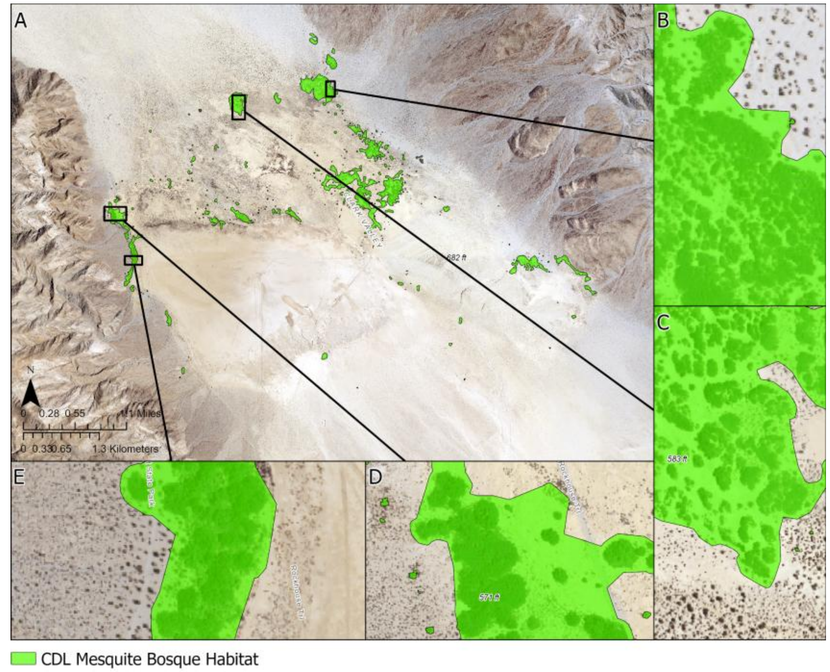

Figure 2.4. Mesquite bosque mapping for the Clark Dry Lake comparison site using image classification on 2016 aerial imagery. Blue shaded portions of the map identify inclusive habitat (live canopy-covered ground area, inter-canopy ground area, and associated other plant species). The insets cover the same area as Figure 2.3 and demonstrate how habitat is delineated in dense (B and C) and clustered (E and D) mesquite distribution. Base imagery from the National Agriculture Imagery Program (NAIP) taken 22 - 23 April 2016.

Study Site and Tree Selection for Ecological Data Collection

To assess the behavior of the mapped mesquite bosque habitat, we selected five study sites based on the location of the mapped mesquite bosque habitat, parcel ownership, and accessibility. All sites are located on land owned by Anza- Borrego Desert State Park or Anza Borrego Foundation. Four sites are located in mesquite bosque habitat within the Borrego Springs Subbasin (Subbasin) and feature variation in mesquite health and live mesquite cover (Sites 1 - 4) and one comparison site is located in Clark Dry lake, outside of the Subbasin (Site 5; Figure 2.5). The Clark Dry Lake site (Site 5) serves as a comparison because it is in a groundwater basin that has not been subjected to overpumping (Ocotillo-Clark Groundwater Basin). The depth to groundwater at Site 5 was last measured as 23.3 ft bgs (2024-06-11; Borrego Rock and Sand) and 21.4 ft bgs (2009-03-09; State Well ID 09S06E36A001S) at the two wells closest to the selected study site, indicating a higher groundwater table on average than the Borrego Springs sites (depth to groundwater was 58.7 ft bgs at MW-5A on 2023-11-13). We refer to Sites 1 and 5 as primary sites due to additional data collection that occurred at these two sites.

We selected 12 live trees at Site 1 - 5 for isotopic analysis and these same trees were used to measure water potential at the primary sites. To ensure live trees were selected, we placed 12 random points in areas of consistently high Normalized Difference Vegetation Index (NDVI) calculated from National Agriculture Imagery Program (NAIP) imagery (0.7 m resolution) taken on 23 April 2016, 4 August 2018, and 15 April 2020. NDVI is a widely used metric for assessing vegetation health or “greenness,” as it correlates with key biophysical properties such as leaf area, chlorophyll content, vegetation cover, structure, and overall productivity (Tucker, 1979). In March 2023, we visited each tree to confirm that the point was marking the location of a live mesquite and we then tagged these trees for repeated measurements.

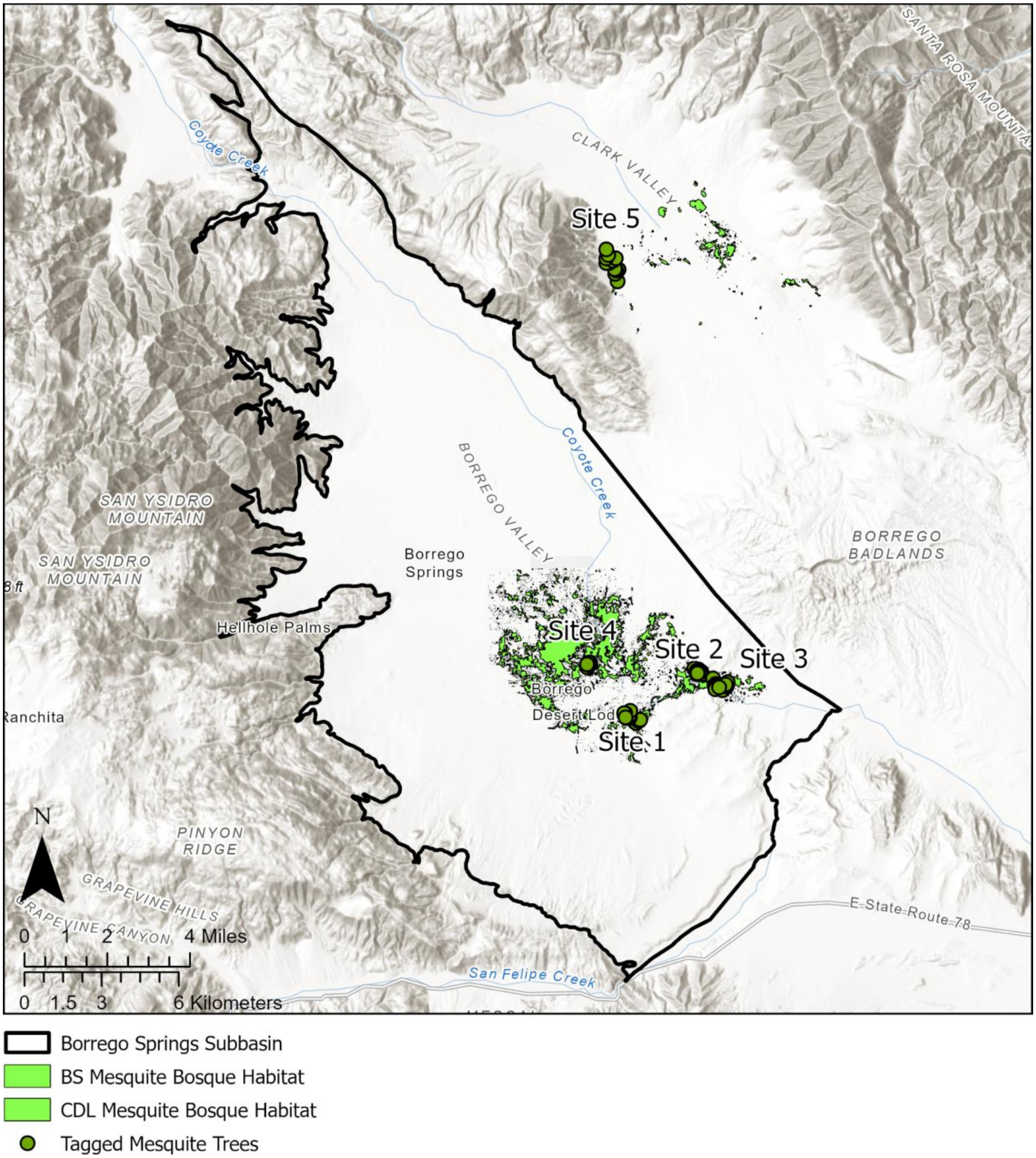

Figure 2.5. Map of the five study sites**, each** containing 12 tagged mesquite trees for repeated measurements.

Mapping Depth to Groundwater

Introduction

Assessing the connection between groundwater and potential GDEs is a critical component of sustainable groundwater management under California's Sustainable Groundwater Management Act (SGMA). The Nature Conservancy's *Identifying GDEs Under SGMA: Best Practices* document (2019) recommends using a depth-to-groundwater raster to evaluate whether vegetation is accessing groundwater. A raster is a type of digital map composed of a grid of cells (i.e., pixels), where each cell represents a specific location and stores a data value for that location, such as elevation, or depth to groundwater. This method provides a spatially explicit estimate of groundwater availability relative to land surface elevation, making it one of the most effective tools for assessing mesquite connectivity to groundwater.

Methods

To determine depth to groundwater across the mesquite bosque habitat, we followed The Nature Conservancy's recommended approach, calculating depth to groundwater as the difference between land surface elevation and groundwater elevation, defined by Equation 2.1:

$$\text{Depth to Groundwater} = \text{Land Surface Elevation} - \text{Groundwater Elevation} \qquad (2.1)$$

We obtained a high-resolution 1 m Digital Elevation Model (DEM) for the Borrego Springs Subbasin from the United States Geological Survey (USGS) 3D Elevation Program, which provides high-accuracy land surface elevation data using LiDAR (Light Detection and Ranging) and other remote sensing techniques. This DEM provides a fine-scale representation of land surface elevation and topography across the Subbasin. To estimate groundwater levels, we acquired a Fall 2024 Groundwater Elevation raster from West Yost, developed through the interpolation of well measurements from the groundwater monitoring program. This raster represents the water table as a continuous surface. Due to a lack of monitoring wells near the Subbasin's edges, groundwater elevation data is unavailable in those areas.

We then calculated depth to groundwater by subtracting the groundwater elevation raster from the DEM at each 1 m grid cell using the *Raster Calculator* function in ArcGIS Pro (v. 3.1.0), resulting in a high-resolution, spatially continuous depth-to-groundwater raster. This dataset provides an estimate of groundwater availability for all locations where groundwater elevation data is present.

Results

The depth-to-groundwater raster predicts that groundwater is closest to the surface near the Borrego Sink, with depths as shallow as 18 feet below ground surface (bgs) in Fall 2024 (Figure 2.6).

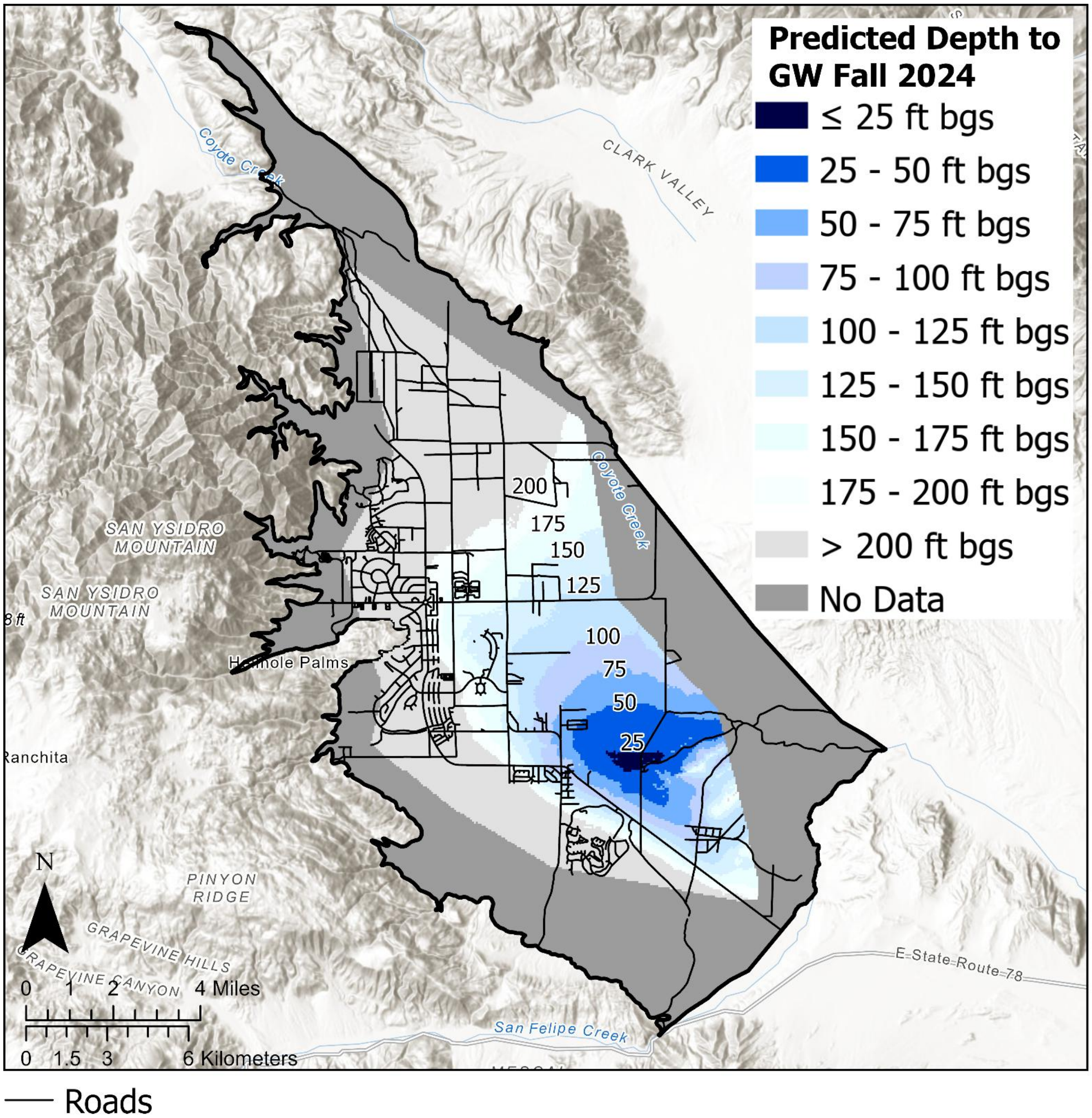

Figure 2.6. Predicted depth to groundwater for Fall 2024, based on the depth-to-groundwater raster. Groundwater is closest to the surface near the Borrego Sink (dark blue), where depths reach as shallow as 18 feet below ground surface (bgs). Areas shown in dark gray indicate "No Data" due to a lack of available well measurements.

Depth to Groundwater in the Borrego Springs Mesquite Bosque

We then overlaid the mesquite bosque habitat polygons and the GPS points for each tagged mesquite tree onto the depth-to-groundwater raster and used the *Zonal Statistics as Table* tool in ArcGIS Pro to extract the minimum, maximum, and mean depth to groundwater for both the entire mesquite bosque habitat distribution and the locations of individual tagged mesquite trees that were measured for isotopes and water potential.

Within the mapped mesquite bosque habitat, predicted groundwater depths range from 22 to 134 ft bgs (Table 2.1; Figure 2.7). The tagged mesquite trees selected for repeated isotope measurements are in areas where predicted groundwater depths range from 23.5 to 51.5 ft bgs.

Table 2.1. Predicted depth to groundwater **for** the mesquite bosque and the tagged mesquite trees in Borrego Springs (Fall 2024).

Area of Interest	Predicted Depth to Groundwater (Fall 2024)		
	Minimum Depth (ft bgs)	**Maximum Depth (ft bgs)**	**Mean Depth (ft bgs)**
Mesquite bosque habitat	22.1	134.0	69.2
Tagged mesquite trees	23.5	51.5	39.8

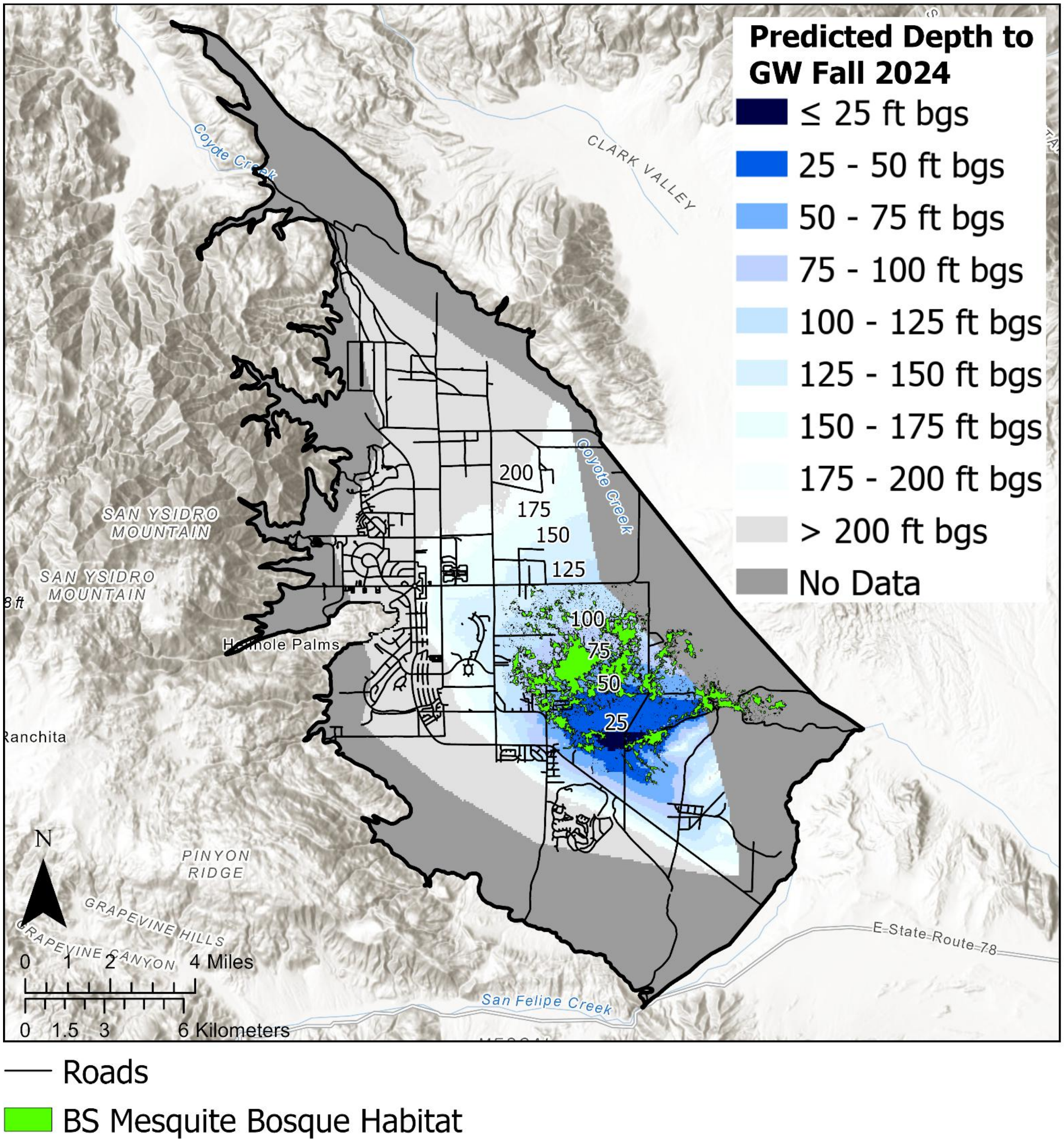

Figure 2.7. Mesquite bosque habitat polygons (green) overlaid on the depth-to-groundwater raster. Mesquite trees near the Borrego Sink are found at groundwater depths ranging from 22.1 - 134.0 ft bgs in Fall 2024.

To assess whether mesquite trees can access groundwater at depths of 22 to 134 ft bgs presented in the depth-to-groundwater raster, we reviewed documented rooting depths of mesquite species. While Appendix D4 (2020) acknowledges a lack of site-specific data for honey mesquite (*Neltuma odorata*) in Borrego Springs, multiple studies confirm the species' ability to develop deep roots, with documented rooting depths for mesquite species ranging from approximately 39 to 175 feet bgs. In the Borrego Sink, Jenkins et al. (1988) recorded mesquite roots extending at least 39.4 feet. Similarly, Phillips (1963) observed *Prosopis juliflora* roots reaching depths of 175 feet near Tucson, Arizona. These findings demonstrate the potential for mesquite species to access groundwater at depths comparable to or exceeding those in the mesquite bosque of Borrego Springs. However, mesquite roots typically do not extend below the water table due to anoxic conditions. Instead, they rely on water from the capillary fringe—the zone immediately above the water table where groundwater rises through capillary action (Jarrell & Virginia, 1990). The thickness of this capillary fringe varies with soil properties. In sandy soils, the capillary fringe may extend approximately 6.5 feet above the water table (Todd & Mays, 2005), while in silt loam— a soil type commonly found in mesquite bosque ecosystems (Soil Survey Staff, 2022)—it can reach up to 11.3 feet (Shen et al., 2013). Based on these findings, the mesquite trees in the Borrego Springs mesquite bosque are well within the documented rooting range for accessing groundwater at depths between 22 and 134 feet bgs.

Conclusion

By calculating depth to groundwater using high-resolution DEM data and groundwater elevation models, we provide a spatially continuous assessment of groundwater availability in the Subbasin. Our results show that the mesquite bosque habitat in Borrego Springs occurs where groundwater depths range from 22 to 134 feet below ground surface, which is well within the documented rooting depths for mesquite species (39 to 175 feet bgs). These findings demonstrate that mesquite trees in Borrego Springs occur where the regional aquifer is accessible, supporting their classification as a groundwater-dependent ecosystem under SGMA. We then employed field, remote sensing, and advanced sensor technologies to investigate mesquite connection to groundwater throughout the mesquite bosque habitat.

GDE Behavior within the Mapped Area

Sampling Conditions

We used nearby weather stations, soil moisture sensors, and field collected soil moisture to ensure the surface soil conditions were dry at the time of sampling. Sampling during dry conditions increases the likelihood that groundwater use will be captured. Rainfall levels prior to sampling suggest dry conditions, particularly deeper into the dry season (Table 2.2). We confirmed this through assessments of soil moisture, which show that the top 150 cm (59.1 in) of the soil profile was dry at the time of sampling events and throughout the dry season. Average soil moisture was less than 10%, in many cases far less than 10%, during the sampling events, apart from the field collected soil moisture at the primary Clark Dry Lake site at 150 cm (59.1 in) in August 2024, indicative of hydraulic lift. See Appendix A.2 for an in-depth assessment of rain events and soil moisture.

Table 2.2. Rainfall prior to sampling. The date of last rainfall greater than 1 mm (0.04 in) before each sampling campaign. Data for Borrego Springs comes from the Elementary School Weather Station while data for Clark Dry Lake come from the Clark Dry Lake Weather Station. https://anzaborrego.ucnrs.org/weather/

2023			
Campaign	**Rainfall in mm (Rainfall in in)**	**Rainfall Date**	**Days prior to sampling**
Borrego Springs			
April	13.97 (0.55)	2023-03-22	19
May	13.97 (0.55)	2023-03-22	68
August	1.016 (0.04)	2023-08-01	14
November	41.91 (1.65)	2023-08-21	72
Clark Dry Lake			
April	15.75 (0.62)	2023-03-22	19
May	15.75 (0.62)	2023-03-22	69
August	15.75 (0.62)	2023-03-22	146
November	57.66 (2.27)	2023-08-21	72
2024			
Borrego Springs			
April	1.27 (0.05)	2024-04-01	21
May	1.27 (0.05)	2024-04-01	49
August	1.27 (0.05)	2024-04-01	134
Clark Dry Lake			
April	3.048 (0.12)	2024-03-19	34
May	3.048 (0.12)	2024-03-19	62
August	3.048 (0.12)	2024-03-19	147

Isotopic Analysis

Introduction

Part of the process of identifying a Groundwater Dependent Ecosystem (GDE) includes evaluating the behavior of said potential GDE. One method used for identifying GDE is isotopic analysis. Isotopic analysis, a scientific technique used to study the types of atoms (isotopes) present in a substance, can be used to assess the contribution of different water sources to a plant. Stable isotopes are naturally occurring versions of an element that have the same number of protons but different numbers of neutrons. Scientists measure the ratio of different isotopes of the same element in a sample and this ratio provides information on the origins of the sample because different processes (such as evaporation) leave distinct isotopic "signatures." For instance, lighter isotopes (e.g., ^{16}O) evaporate more readily than heavier isotopes (e.g., ^{18}O) and diffuse through similar media at higher rates. Therefore, different levels of exposure to evaporation will result in a different isotopic signature (Barnes & Allison 1988). For this reason, groundwater and surface soil water have different isotopic signatures because of their different paths through the environment, residence times, and exposure to evaporation.

Surface soil water is strongly affected by the evaporative demand of the atmosphere and receives localized rainfall, so the light-versus-heavy oxygen isotope differs as compared to values from aquifer water. This means that surface soil water, which is exposed to evaporation, loses its “light” isotopes frequently, and retains more of the “heavy” isotopes (higher neutron number, e.g., ^{18}O). The results of isotopic analysis are represented as a delta value relative to the heavier isotope (e.g., $\boldsymbol{\delta}^{18}O$) where larger values indicate enrichment in heavy isotopes, demonstrating the signature of evaporation. This isotopic composition data can be used to calculate deuterium-excess, a useful indicator of the effects of evaporation (Craig & Gordon, 1965; Gat, 1996). Plants absorb water through their roots, which can come from sources at various depths. Thus, the composition of water at any given time in plant tissues is a function of these differential uptake patterns from the various depths. We use these values - surface soil water sampled over the depth of rainwater influence, water from the aquifer, and water extracted from plant tissues - to test our hypotheses regarding the presence of GDEs (Figure 2.8).

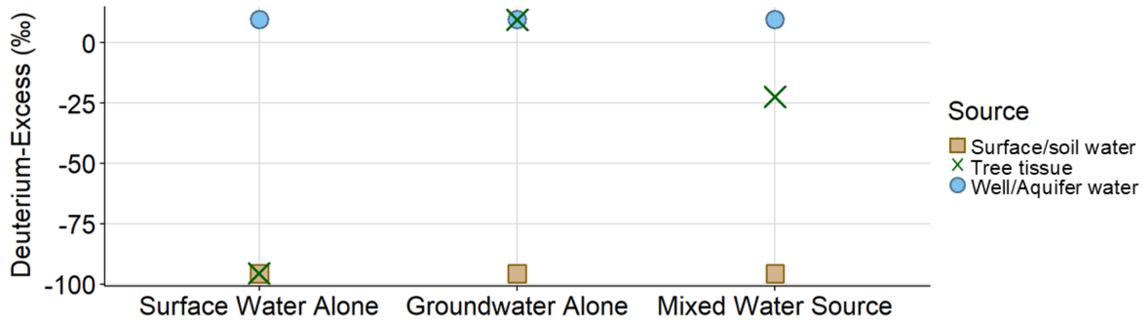

Figure 2.8. Expected behavior of deuterium-excess, a useful indicator of evaporative effects calculated using both $\delta^{18}O$ and $\delta^{2}H$, found under different water-use contexts by trees (see Methods for greater detail). For *Surface Water Alone* there is an overlap of the deuterium-excess of the soil water and tree tissue water. Any variance in the tree tissue water data should be explained by the variance in the soil water signal. In the *Groundwater Alone* scenario (not expected but included as a hypothetical comparison), there is no overlap between the soil water deuterium-excess data and the tree deuterium-excess data; all variance in tissue deuterium-excess is explained by the groundwater isotope signal. In the *Mixed Water Source* scenario, the tree tissue deuterium-excess is intermediate between the soil water and groundwater deuterium-excess. This can be conceptualized by the notion that the surface water signal is diluted by the groundwater signal in the tree tissue.

There are some limitations associated with isotopic analysis that merit consideration. Isotopic analysis indicates the amount of groundwater use for a specific location and time. For that reason, we repeatedly sampled the same 60 trees across Sites 1 through 5 and also added an additional 66 trees during the May 2024 sampling campaign to better assess spatial variability. Additionally, this method does not quantify how much water a plant requires. For an estimate of mesquite groundwater use see the **Quantification of Mesquite Groundwater Transpiration** section.

Methods

To assess the source of water present in plant leaves, we collected twigs, soil, and groundwater samples in 2023 and 2024. In 2023, we collected twigs from 12 mesquite trees across Sites 1 through 5 for a total of 60 trees (Figure 2.9). In 2024 we sampled the same 60 mesquite trees plus three co-located creosote shrubs (*Larrea tridentata*) from Sites 1, 2, 3, and 5, and three co-located saltbush shrubs (*Atriplex lentiformis*) at Site 4. There was not sufficient creosote present at Site 4 for sampling. The creosote and saltbush are comparatively shallow-rooted species that are not expected to directly access groundwater, and these species serve as a comparison to the mesquite trees. In 2024 we also collected an additional six trees at Site 1 and five trees at Site 3, and established Sites 6 through 15 across which sampled an additional 55 mesquite trees for a total of 66 new trees to increase our spatial representation (Figure 2.10, Table 2.3). Twigs were collected in 2023 on 10 through 12 April, 31 May and 1 June, 15 and 16 August, 1 through 3 November and in 2024 on 24 and 25 April, 20 and 21 May, and 14 and 15 August. See Appendix A.3 for more information on collection procedures.

To assess surface soil water as a water source for sampled plants, we sampled soils at one location at each of the five sites at the following depth ranges: 0-10 cm, 10-40 cm, 40-70 cm, 70-100 cm, 100-150 cm. In 2023, soil samples were collected from Sites 1 through 5 on 10 through 12 April 2023 and at the primary sites on 31 May and 1 June 2023. In 2024, soil samples were collected at Sites 1 through 5 on 24 and 25 April, 20 and 21 May, and 14 and 15 August.

To assess groundwater as a water source for sampled plants, we collected samples from a well on State Parks land near Clarks Dry Lake (State Well ID: 10S07E07C001S) and had samples collected by West Yost throughout Borrego Springs (Figure 2.11). The well in Anza-Borrego State Park near Clark Dry Lake (State Well ID: 10S07E07C001S) was sampled in 2023 on 11 April and 31 May and in 2024 on 24 and 25 April, 20 and 21 May, and 14 and 15 August while West Yost sampled seven wells between 12 and 16 November 2023. During the May 2024 sampling campaign, we also sampled five wells at the Wastewater Treatment Plant, one well on private property near the Borrego Sink, and took three water samples from Coyote Creek. We sampled rainfall from storms on 22 December 2023, 24 January 2024, and 14 February 2025. Perched groundwater was not sampled because there was no evidence to suggest it existed within the mesquite bosque habitat; see Appendix D for a discussion on perched groundwater. Water isotopes were analyzed by the University of Wyoming Stable Isotope Facility (Appendix A.3).

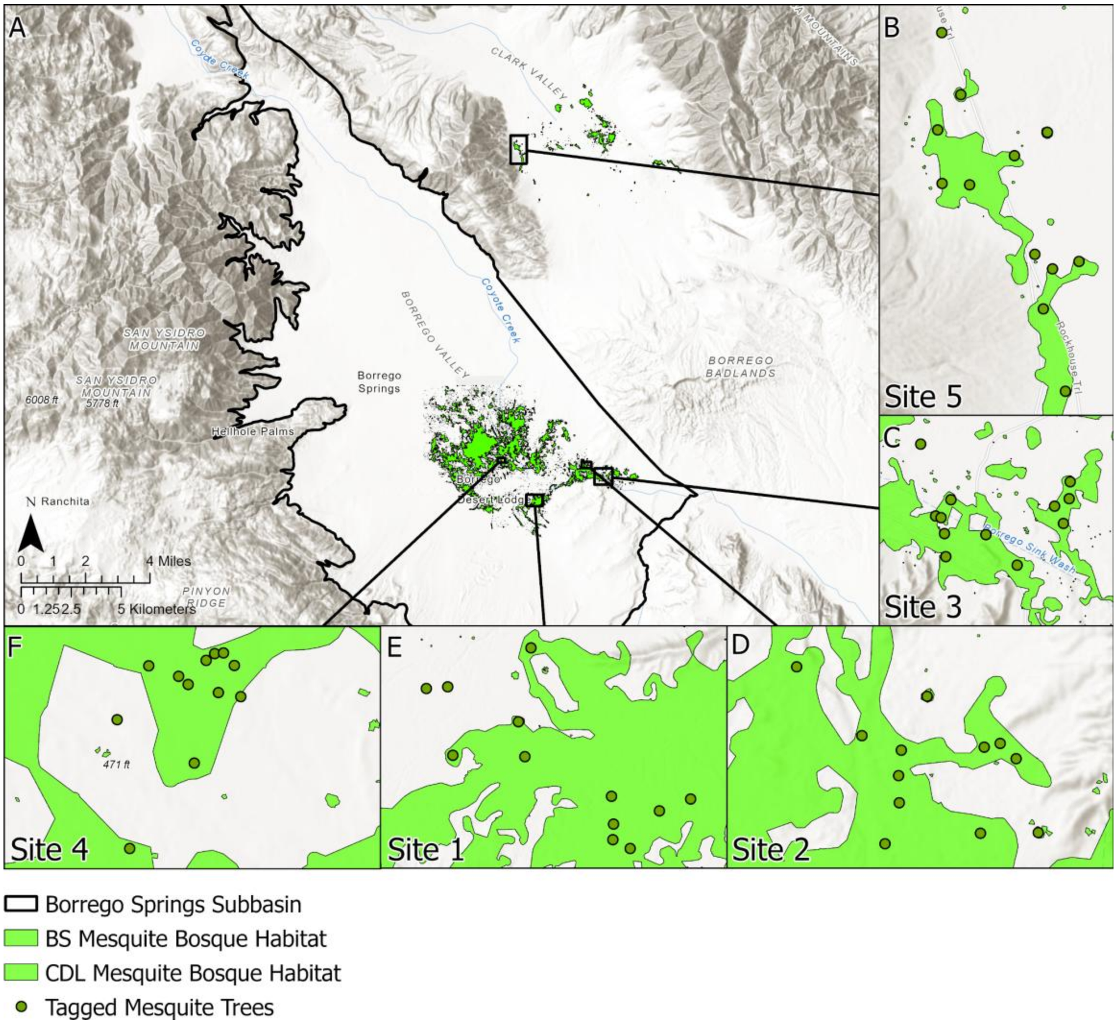

Figure 2.9. Map of the 60 trees sampled for stable isotope analysis. Base imagery for insets B - F from the National Agriculture Imagery Program (NAIP) taken 22 - 23 April 2016.

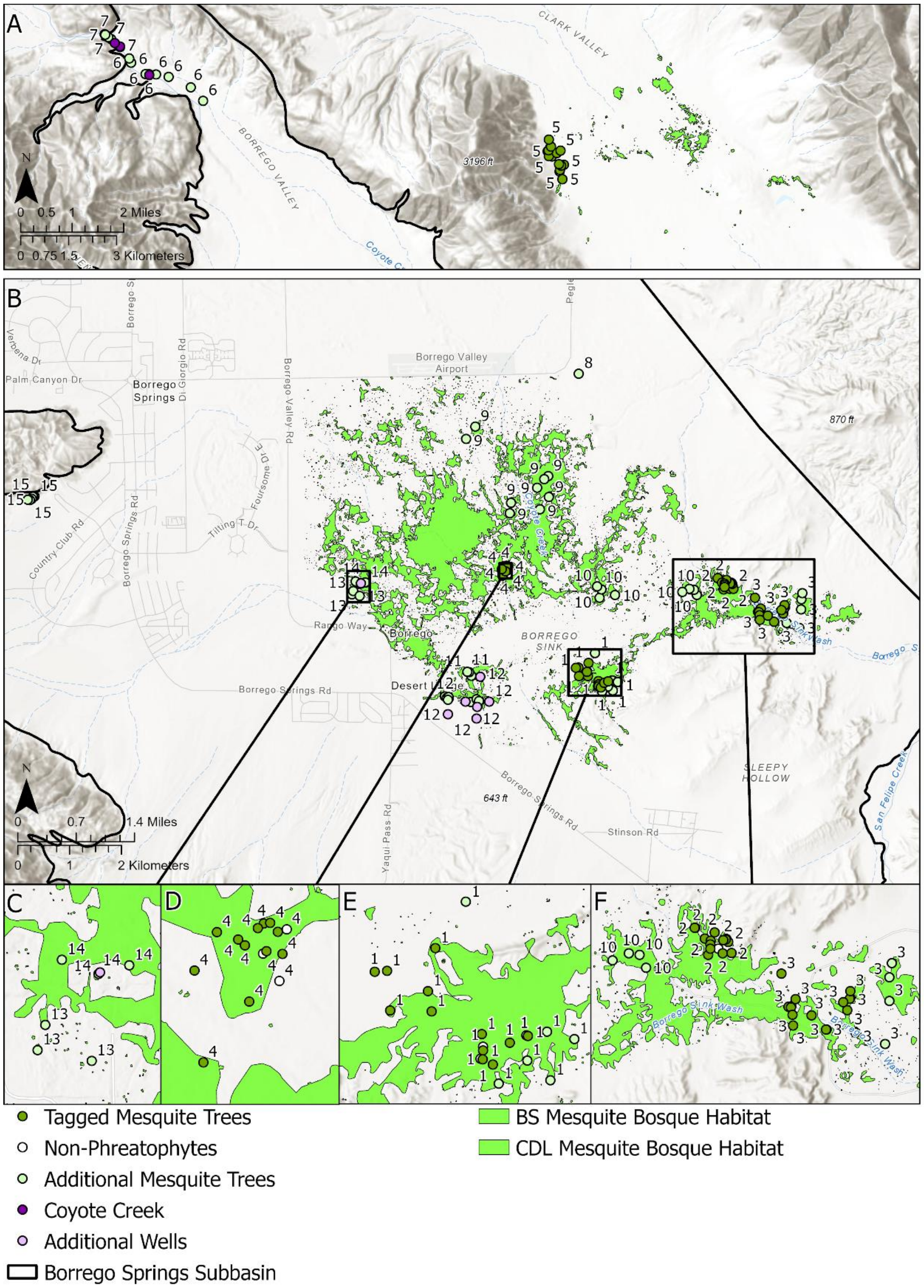

Figure 2.10. Map of isotopic sampling. Map of the 60 tagged mesquite trees sampled for isotopic analysis at every campaign and the 66 additional mesquite trees, three Coyote Creek water samples, and six wells sampled for isotopic analysis in May 2024. Map A indicates the samples collected at Site 5 near Clark Dry Lake and Sites 6 and 7 near Lower Willows. Map B indicates the samples collected near the Borrego Sink and insets C through F zoom in on high density areas. See Table 1 for site descriptions.

Table 2.3. Description of sites sampled for isotopic analysis.

Site	Description
1	Central portion of the mesquite bosque south of the Borrego Sink
2	Southeastern portion of the mesquite bosque
3	Southeastern portion of the mesquite bosque
4	Central portion of the mesquite bosque north of the Borrego Sink
5	Comparison mesquite bosque near Clark Dry Lake located in a different basin (Ocotillo-Clark Groundwater Basin)
6	Coyote Canyon in the far northern part of the Subbasin near Lower Willows
7	Coyote Canyon in the far northern part of the Subbasin near Lower Willows
8	Mesquite tree near Palm Canyon Dr and Old Springs Rd; outside of the mapped mesquite bosque GDE
9	Central portion of the mesquite bosque north of the Borrego Sink
10	Southeastern portion of the mesquite bosque
11	Southwestern portion of the mesquite bosque near the Wastewater Treatment Plant
12	Southwestern portion of the mesquite bosque near the Wastewater Treatment Plant
13	Western portion of the mesquite bosque near Yaqui Pass Rd and Rango Way
14	Western portion of the mesquite bosque near Yaqui Pass Rd and Rango Way
15	Small section of mesquite trees near the Steele/Burnand Anza-Borrego Desert Research Center; outside of the mapped mesquite bosque GDE

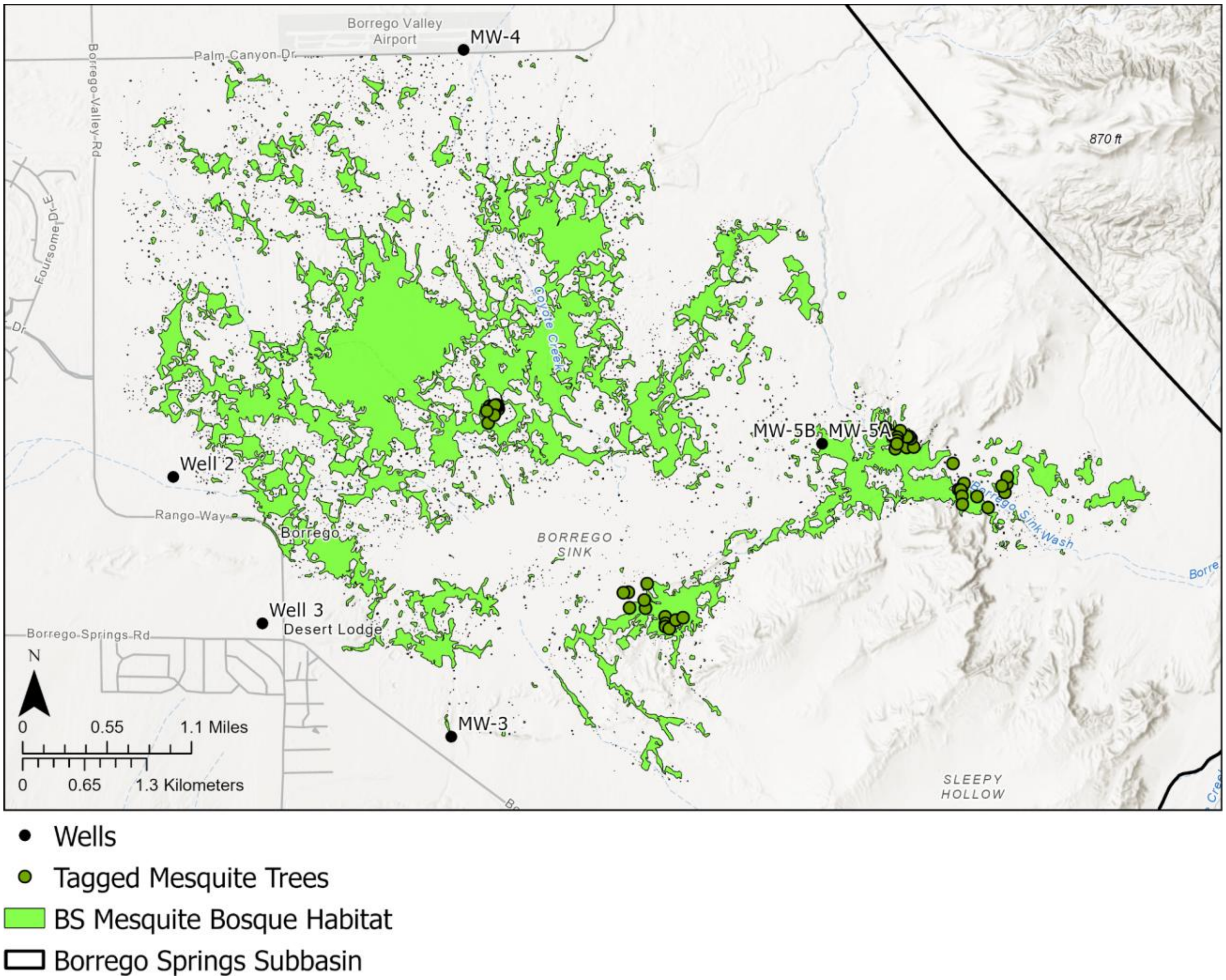

Figure 2.11. Map of the wells sampled for stable isotope analysis. Wells 1 - 4 are anonymized for privacy reasons, so the coordinates presented here have been altered.

Isotopic composition

Hydrogen (δ^2H) and oxygen ($\delta^{18}O$) isotopic composition are represented as ‰ (parts per thousand) notation relative to the standard, Vienna standard Mean Ocean Water, and defined by Equation 2.2:

$$\delta^2H \text{ or } \delta^{18}O = 1{,}000\times(R_{sample}/R_{standard}) - 1, \qquad (2.2)$$

where R_{sample} and $R_{standard}$ are the ratio of the heavy to light isotope ($^2H/H$ or $^{18}O/^{16}O$) of the sample and the standard, respectively (Dawson et al., 2002). We used δ^2H and $\delta^{18}O$ to we calculate water deuterium-excess (Dansgaard, 1964) using Equation 2.3:

$$\text{Deuterium-excess} = \delta^2H - 8 \times \delta^{18}O. \qquad (2.3)$$

Deuterium-excess is a good indicator of the effects of evaporation (Craig & Gordon, 1965; Gat, 1996). This makes deuterium-excess a useful indicator for comparing groundwater and surface water sources for mesquite trees since surface waters are subjected to intense evaporation while groundwater is a less evaporated water source.

Percent groundwater use

We can use deuterium-excess in a simple, two end-member mixing model to estimate the percentage of groundwater in mesquite tree tissue. In these models, groundwater is one end-member and the average soil profile value as the other end member (Post 2002). This approach assumes that soil moisture contributes uniformly as a source across 0 to 150 cm (59.1 in) soil depth to patterns of root uptake, which is a conservative estimate for determining the end-member. To determine the optimal source of groundwater to use in our mixing models for trees located in Borrego Springs, we sampled broadly in the vicinity of the mesquite bosque (Figure 2.11). Due to the similarity in isotopic values and their being the two wells closest to the sampled mesquite trees, we selected MW-3 and MW-5A as the wells to be averaged and used in the mixing models (see Appendix A.3 for further details on well selection for the mixing model and for Table A3 which has deuterium-excess, $\delta^{2}H$, and $\delta^{18}O$ for all seven sampled wells).

Equation 2.4 is an example of how this mixing model calculates the proportion of groundwater in mesquite tissue using average deuterium-excess (d-excess) data from all 12 trees at the primary Clark Dry Lake site (Site 5), the local well water, and the average soil profile values from the primary Clark Dry Lake site (Site 1) in May 2023.

$$\text{Proportion of groundwater in mesquite tissue} = \frac{d\text{-}excess_{Tree} - d\text{-}excess_{Soil}}{d\text{-}excess_{Well} - d\text{-}excess_{Soil}} \quad (2.4)$$

$$\text{Proportion of groundwater in mesquite tissue} = \frac{-15.6 - (-66.4)}{6.2 - (-66.4)}$$

$$\text{Proportion of groundwater in mesquite tissue} = 0.71$$

$$\text{Percentage of groundwater in mesquite tissue} = 71\%$$

Due to sampling constraints, the wells MW-3 and MW-5A were sampled once during the study period (November 2023) and these averages were used for all Borrego Springs models. We do not expect the values of these wells to change dramatically across seasons. The well near Clark Dry Lake serves as an example as it was sampled during five of the six field campaigns. Using the example above, we can conduct a demonstration by inputting the lowest measured deuterium-excess and the highest measured deuterium-excess values of the well near Clark Dry Lake to assess how the percentage of groundwater in mesquite tissue changes. The well near Clark Dry Lake had deuterium-excess values that ranged from 4.0‰ to 10.2‰ which resulted in percentages of groundwater in mesquite tissue of 72% and 66%, respectively. Similarly, in 2023, soils were only sampled at the primary sites in Borrego Springs (Site 1) and Clark Dry Lake (Site 5) in May and August 2023 and so averages for Site 1 were input into the mixing model for Sites 2 - 4 for those campaigns. All analyses were performed in R (R Core Team, 2024; v. 4.3.3).

Results

Isotopic composition

The plant extracted water isotopic signature from Sites 1 through 5 includes an evenly-mixed to majority-contribution of the local groundwater (Figure 2.12, Appendix A.3 Figure A5 & A6). Sites near the Borrego Sink and the site at Clark Dry Lake both demonstrate a dilution of the soil surface oxygen isotope values by the groundwater signature (Figure 2.12). In each case (Sites 1-5), there is no overlap between the distribution of mean soil oxygen isotope values and the plant tissue extracted isotope values. The data exhibit the trend expected from our *Mixed Water Source* scenario explained in **Figure 2.8**. This suggests that mesquite trees draw water from both sources, which is consistent with other research showing that mesquite are facultative phreatophytes that can utilize both surface water and groundwater depending on availability (Brunel 2009).

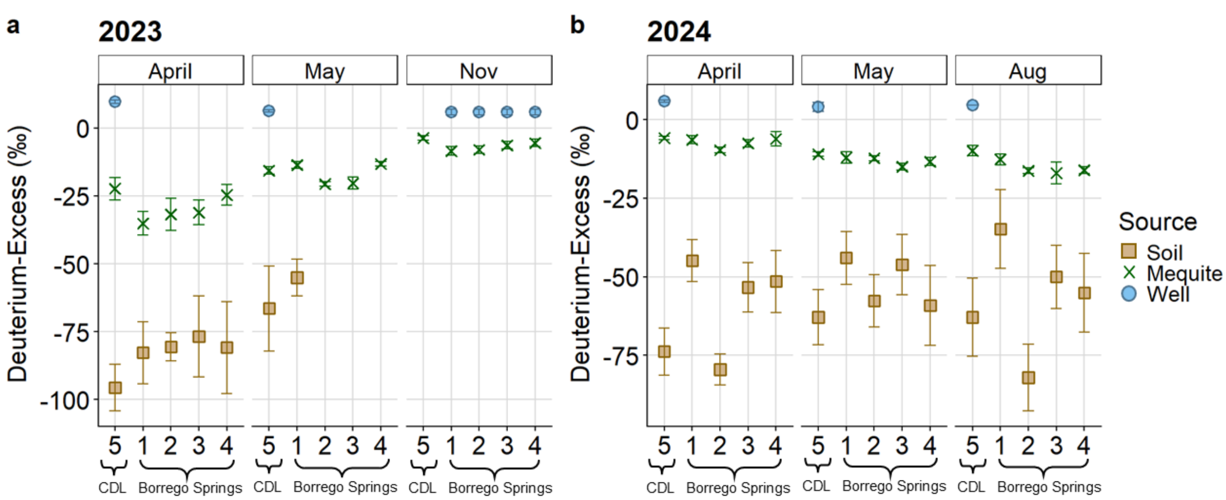

Figure 2.12. Deuterium-excess of the soil water (brown squares), tree tissue water (green crosses), and well water (blue circles) at the four sites in Borrego Springs and the reference site at Clark Dry Lake. Well water is a value derived from the most-adjacent well sample possible (an average of MW-3 and MW-5A for Sites 1 - 4 and 10S07E07C001S for Site 5). These data indicate a mixed water source for mesquite at all locations. The soil, tree, and well water data are represented by the mean (point) and standard error (error bars).

In 2024, we conducted isotopic analysis on three creosote shrubs at all sites, except Site 4 where we collected from saltbush. Due to the low sample size of the creosote and saltbush, which was necessary due to time constraints, we did not conduct statistical tests or run the two-source mixing model. We did, however, compare the deuterium-excess values and we found that the creosote and saltbush had deuterium-excess values closer to the soil profile (-57.2 ± 23.6‰; mean ± SD) than did the mesquite. Creosote and saltbush had an average deuterium-excess of -23.0 ± 9.1‰ across all sites while mesquite had an average deuterium-excess of -11.4 ± 6.4 ‰ across all sites. This indicates that creosote and saltbush, which are considered non-phreatophytic, have deuterium-excess values that differ from mesquite, and which show greater similarity to the signature of surface water and lesser similarity to the signature of groundwater than do mesquite (Table 2.4).

Table 2.4. The average and standard deviation of the deuterium-excess for the non-phreatophytes creosote and saltbush and the phreatophytic mesquite across locations and sampling time periods in 2024.

Species	Avg. Deuterium-Excess (‰)	Std. Dev. Deuterium-Excess (‰)
Borrego Springs		
Non-Phreatophyte	-24.5	8.2
Mesquite	-15.0	11.3
Clark Dry Lake		
Non-Phreatophyte	-16.7	10.1
Mesquite	-10.7	8.2

In 2024 we additionally sampled a larger spatial spread of mesquite trees and wells to better understand spatial variability in deuterium-excess across the Subbasin (Figure 2.13, Figure 2.14). These data demonstrated that trees in the northern and western portion of the mesquite bosque near the Borrego Sink (Sites 9 and 11 through 14) generally had more negative deuterium-excess values, indicating values closer to the d-excess values of surface water. On the other hand, trees in the southeastern portion of the mesquite bosque near the Borrego sink (Sites 1 through 4, and Site 10) and sites near Lower Willows in Coyote Canyon (Sites 6 and 7) had less negative deuterium-excess values, indicating values closer to the value of groundwater. Overall, this expanded sampling highlights the high spatial variability of deuterium-excess across the mesquite bosque habitat near the Borrego Sink as well as mesquite trees in the northern part of the Subbasin (Lower Willows area).

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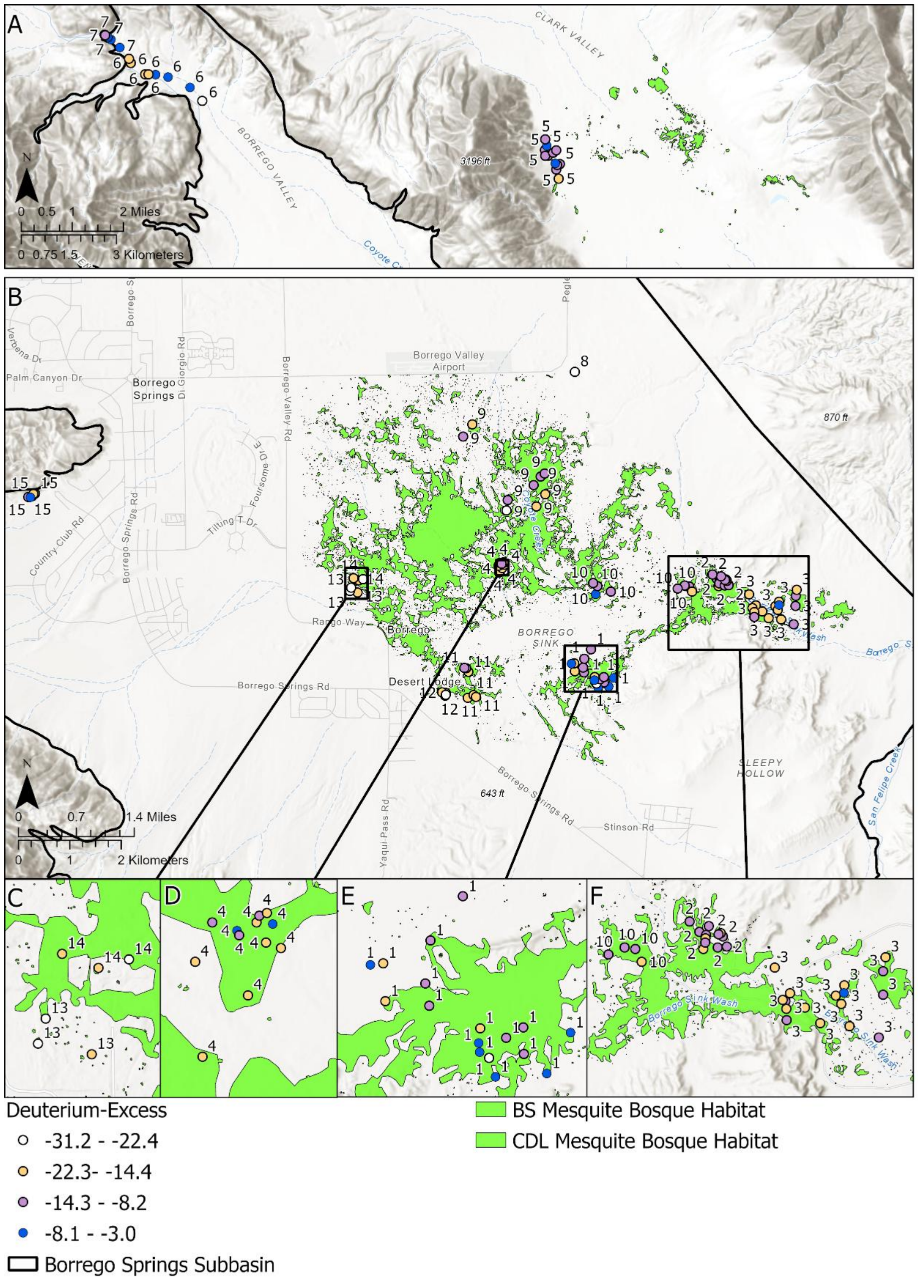

Figure 2.13. Map of the deuterium-excess values across the 60 tagged mesquite trees at Sites 1 through 5 as well as the extra 66 mesquite trees sampled only in May 2024. All data are from the May 2024 sampling campaign.

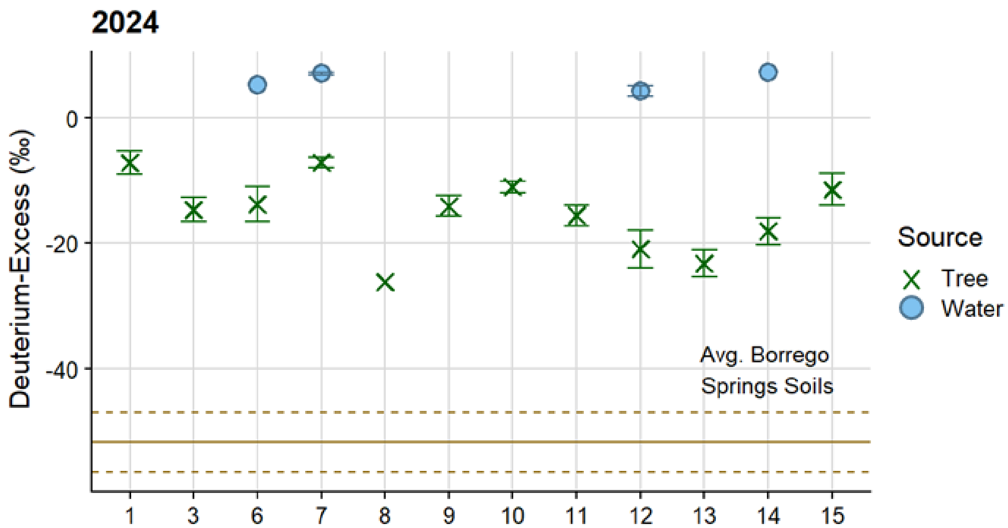

Figure 2.14. Deuterium-excess of tree tissue water (green crosses) and water from a well (Sites 12 and 14) or Coyote Creek (Sites 6 and 7) (blue circles) at the additional sites sampled only in May 2024. The tree and water values are represented by the mean (point) and standard error (error bars). The solid brown line is the average deuterium-excess across all Sites 1 - 4 (all located in the Subbasin) during the May 2024 sampling campaign. The dotted brown lines indicate the standard error of the mean.

Percent groundwater use

Mesquite trees throughout all sampled locations near the Borrego Sink have signatures of groundwater in both 2023 and 2024. In 2023, the average deuterium-excess values suggested that an average of 66.5 ± 15.6% (mean ± standard deviation) of the water in mesquite tissues originating from the groundwater isotopic signature in Borrego Springs, with values that ranged between 54% (Site 1 in April) and 81% (Site 4 in November) (Figure 2.15). At Clark Dry Lake, average deuterium-excess values resulted in an average of 75.8 ± 11.0% of the water in mesquite tissues originating from the groundwater isotopic signature; values ranged from 70% in April 2023 to 86% by November 2023. In 2024, the average percent groundwater in mesquite tissue was 69.3 ± 13.3%, ranging from 54% at Site 1 in August to 82% at Site 2 in April. At Clark Dry Lake, average deuterium-excess values resulted in a groundwater use percentage of 80.5 ± 6.52% with a range from 78% in May 2024 to 85% in April 2024. Hence, across these two years, the percentage of groundwater in mesquite tissue ranged from 54% to 82% across the four Borrego Springs sites (Sites 1 through 4) and between 70% and 86% at the one Clark Dry Lake site (Site 5).

While there is some variation in the mean groundwater fraction between locations, most of the variation comes from differences in a few individual trees (Figure 2.16). This variation can likely be explained by plant age, rooting depth, or access to surface soil moisture. The overall conclusion of these data is that mesquite trees throughout their distribution near the Borrego Sink are accessing groundwater.

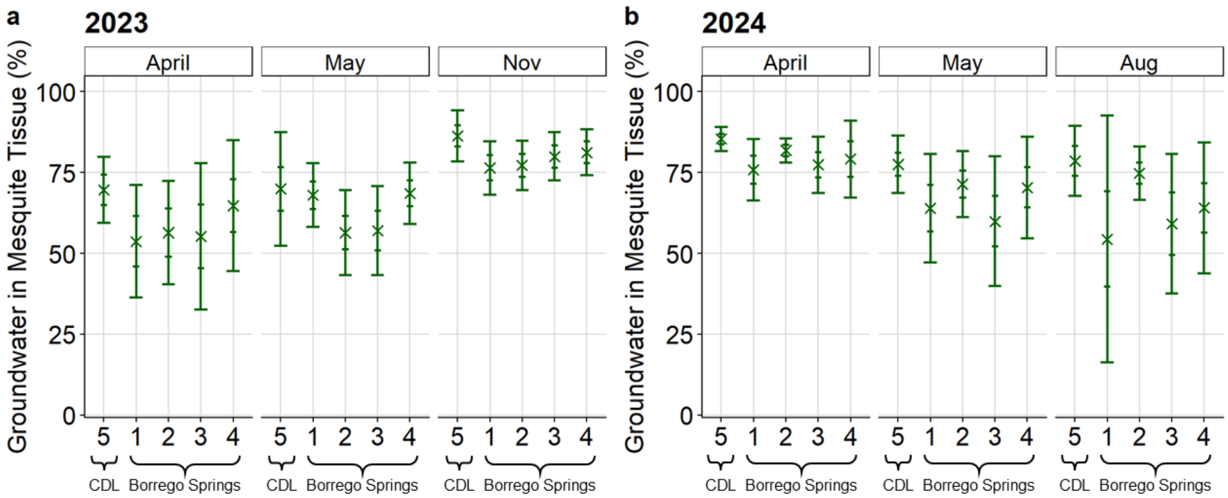

Figure 2.15. Groundwater fraction in plant tissues calculated from deuterium-excess of the soil water, tree tissue water, and well water for each of the five sentinel sites in Borrego Springs and the reference site at Clark Dry Lake using a two-end mixing model as in Equation 3. Well water is a value derived from the most-adjacent well sample possible (an average of MW-3 and MW-5A for Sites 1 - 4 and 10S07E07C001S for Site 5).

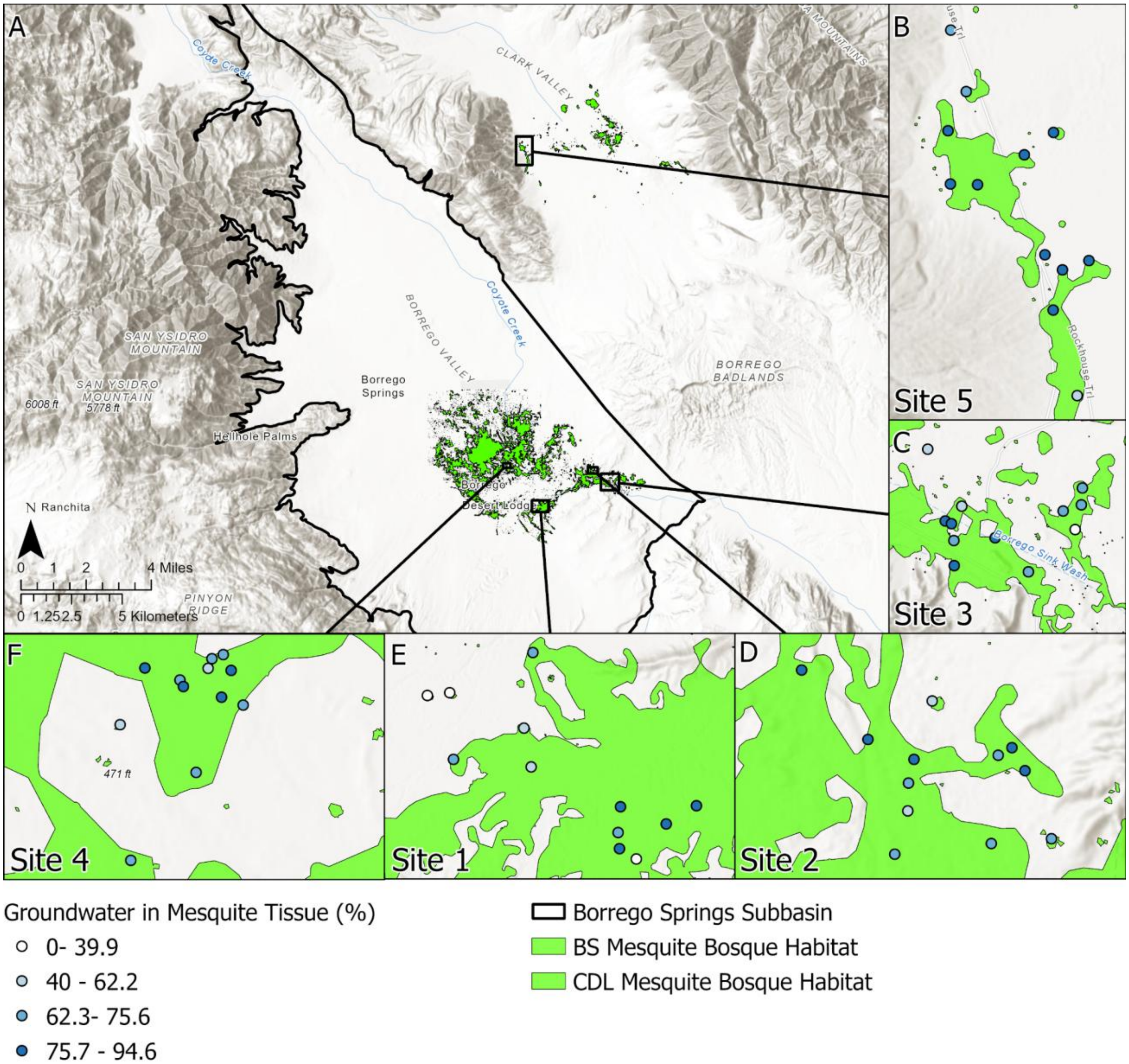

Figure 2.16. Spatial representation of the groundwater fraction in plant tissues calculated from deuterium-excess of the soil water, tree tissue water, and well water for each of the four sites in Borrego Springs and the reference site at Clark Dry Lake using a two-end mixing model as in Equation 3. Well water is a value derived from the most-adjacent well sample possible (an average of MW-3 and MW-5A for Sites 1 - 4 and 10S07E07C001S for Site 5). Base imagery of insets B - F from the National Agriculture Imagery Program (NAIP) taken 22 - 23 April 2016.

Conclusion

Overall, these findings confirm groundwater use by the mesquite in the mesquite bosque GDE near the Borrego Sink in Borrego Springs. The comparison of deuterium-excess between groundwater and soil surface water suggests a mixed water source for the mesquite in Borrego Springs near the Borrego Sink and near Clark Dry Lake. When comparing the average mesquite deuterium-excess to the average non-phreatophytic deuterium-excess, the non-phreatophytes differ from the mesquite and demonstrate values less similar to groundwater than do mesquite. The groundwater fraction data also indicate a mixed water source for the mesquite while highlighting a greater use of groundwater at the Clark Dry Lake site where groundwater is closer to the soil surface compared to the Borrego Springs sites and overall high spatial variability in the fraction of groundwater found in mesquite tissue. Together, these lines of evidence confirm that there are groundwater-dependent mesquite trees within the Mesquite Bosque Habitat map.

Water Potential

Introduction

Leaf water potential is a reliable indicator of water availability and moisture stress, reflecting the balance between soil moisture supply, atmospheric demand, and plant water uptake (Lambers et al. 2008). As plants transpire (lose water through small leaf openings called stomata) water flows from the soil to the roots. At predawn, when transpiration is minimal and water flow is equilibrated within the plant-soil system, leaf water potential is closely aligned with soil water potential, offering a baseline measure of water availability for plants. Lower, or more negative, predawn leaf water potential values indicate lower water availability. At midday, when transpiration is highest, leaf water potential approximates a measure of water stress. Lower, or more negative, midday leaf water potential values indicate greater water stress. Similar values between conditions, sites, or plants reflect similar water availability in the soil-plant system.

We measured predawn and midday water potential of mesquite across the growing season to assess differences in water availability and water stress between mesquite trees near the Borrego Sink and near Clark Dry Lake, our comparison site with comparatively shallow groundwater levels. We additionally compared a facultative phreatophyte (mesquite) to a species that does not readily utilize groundwater (creosote) to compare water availability and water stress as the dry season progresses.

Methods

To assess water availability and water stress of mesquite we assessed predawn and midday water potential on 24 mesquite trees in 2023 and 24 mesquite trees and six creosote shrubs in 2024. These mesquite and creosote were located at Sites 1 and 5, our primary Borrego Sink and Clark Dry Lake sites, respectively. Plants were sampled in 2023 on 10 through 12 April, 31 May and 1 June, 15 and 16 August and in 2024 on 24 and 25 April, 20 and 21 May, and 14 and 15 August.

We collected three twigs per tree using the protocol described by Rodriguez-Dominguez et al. (2022). Briefly, we collected a twig containing several leaves, placed it into a plastic bag which was nested within a larger plastic bag containing a moist paper towel, and then placed it into a cooler such that the bag did not touch the ice packs. Midday water potential was assessed between 11:15 am and 1:15 pm and predawn water potential was assessed between 3:00 and 5:30 am. In the lab, we used a Scholander-style pressure bomb (PMS Instrument Company, Corvallis, OR, USA) to determine water potential, noting the pressure at the first sign of water. All analyses were performed in R (R Core Team, 2024; v. 4.3.3).

Results

In 2023, leaf water potential varied by time of day, primary site, and month ($X^2 = 6.9$, $P = 0.009$) (Figure 2.17). Between the two sites, predawn leaf water potential did not differ across time and neither did midday leaf water potential, except for August where midday leaf water potential was more negative at the primary Borrego Sink site (Tukey: $P < 0.05$). Overall, this suggests similar water availability to the mesquite at each site but greater water stress in August at the Borrego Sink site.

In 2024, leaf water potential was shaped by an interaction between site and month ($X^2 = 16.0$, $P < 0.001$). Leaf water potential was similar between the primary Borrego Sink and Clark Dry Lake sites in both May and August, the driest times of the year, but leaf water potential was less overall negative at the Clark Dry Lake site compared to the Borrego Sink site in April (Tukey test: $P < 0.05$) suggesting greater water availability and lower water stress in this month. The difference in leaf water potential in April 2024, prior to the onset of the dry season, likely reflects differences in surface water availability between the sites as the Clark Dry Lake site received greater rainfall (Table 2.2 under **Sampling Conditions**).

In 2024 we additionally measured leaf water potential on three creosote shrubs at each of the two primary sites. Due to the low sample size of creosote, which was necessary due to time constraints, we did not conduct statistical tests comparing the mesquite and creosote. However, in comparing the average values between these two species, we found that across both sites and all sampling periods, creosote shrubs had an average predawn leaf water potential and an average midday leaf water potential that were lower, or more negative, than mesquite trees (Table 2.5).

Table 2.5. The average and standard deviation of leaf water potential values across sites and sampling time periods for mesquite and creosote in 2024. MPa: Megapascal

Site	Species	Avg. Water Potential (MPa)	Std. Dev. Water Potential (MPa)
Predawn			
1	Creosote	-4.1	0.5
1	Mesquite	-2.3	0.5
5	Creosote	-3.6	0.8
5	Mesquite	-1.9	0.5
Midday			
1	Creosote	-5.2	0.4
1	Mesquite	-3.4	0.5
5	Creosote	-4.4	0.6
5	Mesquite	-3	0.8

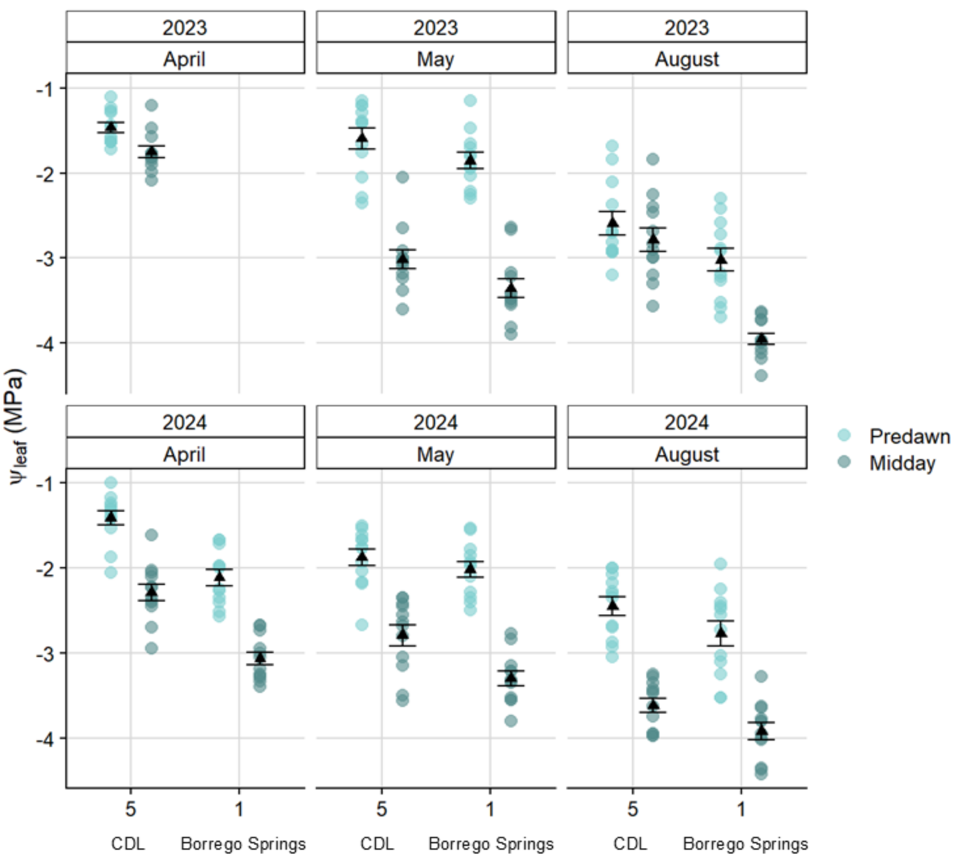

Figure 2.17. Leaf water potential in 2023 (top panel) and 2024 (bottom panel) across the three sampling periods. The points represent raw data, the black triangles indicate the mean, and the black error bars show the standard error. MPa: Megapascal

Conclusion

These findings highlight similarities in water availability and water stress between mesquite near the Borrego Sink and mesquite near Clark Dry Lake and greater water availability and lower water stress of mesquite relative to creosote, suggesting the mesquite near the Borrego Sink are accessing groundwater. Mesquite had a lower midday water potential in August 2023 at the site near the Borrego Sink relative to the site near Clark Dry Lake suggesting greater water stress at this site, likely due to lower groundwater levels. However, the overall similarity in both predawn and midday water potentials across most seasons in both 2023 and 2024 indicate similarities in mesquite plant-water relations between the two sites. As the Clark Dry Lake mesquite bosque is not contested as being a GDE, this suggests that mesquite bosque near the Borrego Sink is also accessing groundwater. The higher, less negative, predawn and midday leaf water potential values of mesquite relative to creosote at both sites throughout the dry season indicates groundwater use by mesquite. In summary, these findings indicate that the mesquite bosque at the primary Borrego Springs site near the Borrego Sink (Site 1) is groundwater dependent.

Remote Sensing of GDE Behavior

Introduction

To identify groundwater dependent vegetation across the entire mesquite bosque habitat, we applied three remote sensing approaches to systematically evaluate the behavior of the vegetation in response to ecosystem water availability (Table 2.6). Each approach captures vegetation dynamics over a different time frame, allowing for a comprehensive assessment of mesquite groundwater use across both space and time. For each remote sensing approach, we compared vegetation behavior across three areas of interest (AOIs): the Borrego Springs mesquite bosque (the potential GDE), the Clark Dry Lake mesquite bosque (a known GDE), and a nearby non-GDE habitat (Appendix Figure A7). By analyzing vegetation behavior in these distinct regions, we aimed to determine whether the Borrego Springs mesquite bosque exhibits patterns consistent with groundwater reliance (i.e., resembling the Clark Dry Lake GDE), or patterns more characteristic of surface water use (i.e., resembling the non-GDE habitat).

Methods

The three approaches are based on the "green island" conceptual framework used in the detection of Groundwater Dependent Ecosystems (GDEs) through remote sensing (Dresel et al. 2010; Eamus et al. 2016). This method compares vegetation characteristics between areas with unknown access to groundwater and those with and without access. These comparisons can be made at a single time point, across seasons, or over annual cycles. For example, during extended dry periods when near-surface soil water is depleted, vegetation accessing groundwater tends to maintain better health and greenness than vegetation relying solely on residual soil moisture. This resilience during drought conditions is a key indicator of groundwater use and is used to identify groundwater dependent vegetation using the Normalized Difference Vegetation Index (NDVI) as a proxy for vegetation health and greenness in Approaches 1 and 2. In Approach 3, we use cumulative NDVI over the entire water year to identify vegetation with persistent groundwater access, as continuous water availability supports sustained biomass accumulation and higher productivity throughout the year.

Table 2.6. Table of remote sensing approaches used to identify GDE behavior.

Approach	Assumption	Dates Used	Simple Description
#1. Change in NDVI across an extended dry period	GDE should maintain or increase NDVI across the dry period due to access to groundwater (tau > 0).	Day 50 - 80 of growing season drought	Pixels with tau > 0 indicate maintained or increased NDVI across the dry period, suggesting access to groundwater that supports survival during the first extended drought of the season.
#2. Comparison of maximum NDVI across extreme dry period with heat stress	GDE should show higher NDVI across dry periods than non-GDE due to access to groundwater.	Day 80 - 120 of growing season drought	Pixels with high NDVI throughout this period with extremely dry conditions and high temperatures suggest access to groundwater, allowing vegetation to persist through extreme summer drought conditions.
#3. Comparison of cumulative NDVI across the water year	GDE should have higher cumulative NDVI than non-GDE due to the potential to accumulate biomass throughout the year due to access to groundwater.	Entire water year (Oct 1 - Sept 30)	Pixels with high cumulative NDVI indicate access to groundwater, enabling above-average growth throughout the year, highlighting persistent water availability and groundwater use.

Data Acquisition

To assess whether vegetation is accessing groundwater, we calculated NDVI, a widely used remote sensing metric for evaluating vegetation health or "greenness." NDVI correlates with key biophysical properties such as leaf area, chlorophyll content, vegetation cover, structure, and overall productivity (Tucker, 1979). We obtained Sentinel-2 satellite imagery using Google Earth Engine at a 10 m resolution (i.e., a pixel size of 10 m × 10 m) for each Area of Interest (AOI) over the designated time frames. Sentinel-2's high spatial resolution and frequent revisit time (every five days) make it well-suited for NDVI calculations and year-round vegetation monitoring. To ensure data accuracy, we removed cloud and shadow pixels before analysis. For each image, we calculated NDVI and applied the remote sensing approaches accordingly. Full details on each approach can be found in Appendix A.4.

Results

Across all three approaches, mesquite trees throughout the Borrego Springs mesquite bosque habitat exhibited GDE behavior, indicating groundwater reliance in both 2023 and 2024 (Table 2.7). When combining results from all approaches, approximately 527 acres of mesquite canopy in Borrego Springs showed signs of groundwater use in 2023 (Figure 2.18), and 558 acres in 2024 (Figure 2.19). These acreage estimates represent the total canopy area of mesquite that show signs of GDE behavior, as if the trees were placed side by side, and do not include bare ground inter-tree spaces that are characteristic of a habitat area designation. In comparison, the CDL mesquite bosque—while also showing strong GDE behavior—covered just over 150 acres, reflecting its smaller overall extent. These findings reinforce the conclusion that mesquite in both locations exhibit similar patterns of groundwater use, while the Non-GDE habitat showed no signs of GDE behavior.

Within the Borrego Springs mesquite bosque, the strongest indicators of GDE behavior in both years were concentrated around the Borrego Sink, where groundwater is closer to the surface. In contrast, the northern portion of the bosque near Palm Canyon Road and the western portion of the bosque near Borrego Valley Road showed fewer signs of GDE behavior, consistent with deeper groundwater levels and higher human disturbance in those areas. These spatial patterns further support our findings that mesquite in Borrego Springs rely on groundwater, particularly in regions where groundwater is more readily available.

Conclusion

Our remote sensing analysis reveals that mesquite trees throughout the Borrego Springs mesquite bosque exhibit clear patterns of groundwater dependence, similar to the known GDE at Clark Dry Lake. Across all three approaches, we observed consistent GDE behavior in both 2023 and 2024, with the strongest indicators of groundwater use concentrated around the Borrego Sink, where groundwater is more accessible. These results confirm that the mesquite bosque habitat in Borrego Springs relies on groundwater for its survival and is thus a SGMA defined GDE.

Table 2.7. Table of results for the remote sensing approaches used to identify GDE behavior with predicted acreage of GDE found within the Borrego Springs (BS) and Clark Dry Lake (CDL) mesquite bosque habitat in 2023 and 2024. ***Note that acreage estimates quantify only live mesquite canopy that passes each approach and are calculated as if each mesquite tree stood side by side.*

	BS 2023	**BS 2024**	**CDL 2023**	**CDL 2024**
Approach	**GDE Acreage Predicted**	**GDE Acreage Predicted**	**GDE Acreage Predicted**	**GDE Acreage Predicted**
#1. Change in NDVI across an extended dry period	384.80	397.22	41.80	33.72
#2. Comparison of maximum NDVI across extreme dry period	212.46	267.51	130.23	155.29
#3. Comparison of cumulative NDVI across the water year	182.93	73.14	139.47	116.30
Total unique acreage passing one or more approach: ***Note that acreage estimates quantify only live mesquite canopy that passes each approach and are calculated as if each mesquite tree stood side by side.*	**527.03**	**557.55**	**158.37**	**169.49**

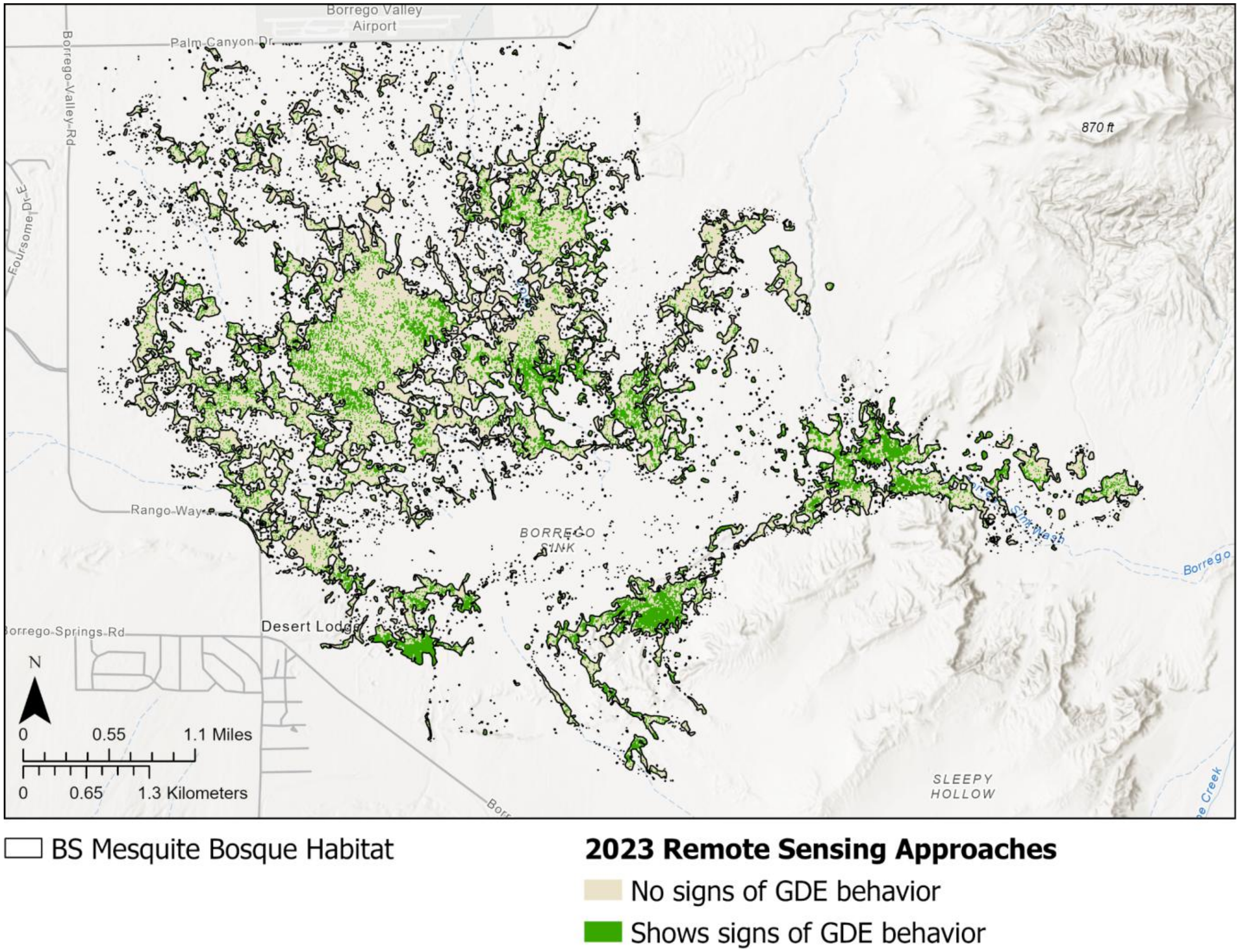

Figure 2.18. Spatial extent of GDE behavior in 2023. Map showing the spatial extent of GDE behavior identified by three different approaches in 2023. Areas in green represent live vegetation exhibiting GDE behavior in at least one approach, highlighting GDE hotspots across most of the Borrego Springs mesquite bosque. In total, 527 acres of mesquite showed signs of groundwater use in 2023.

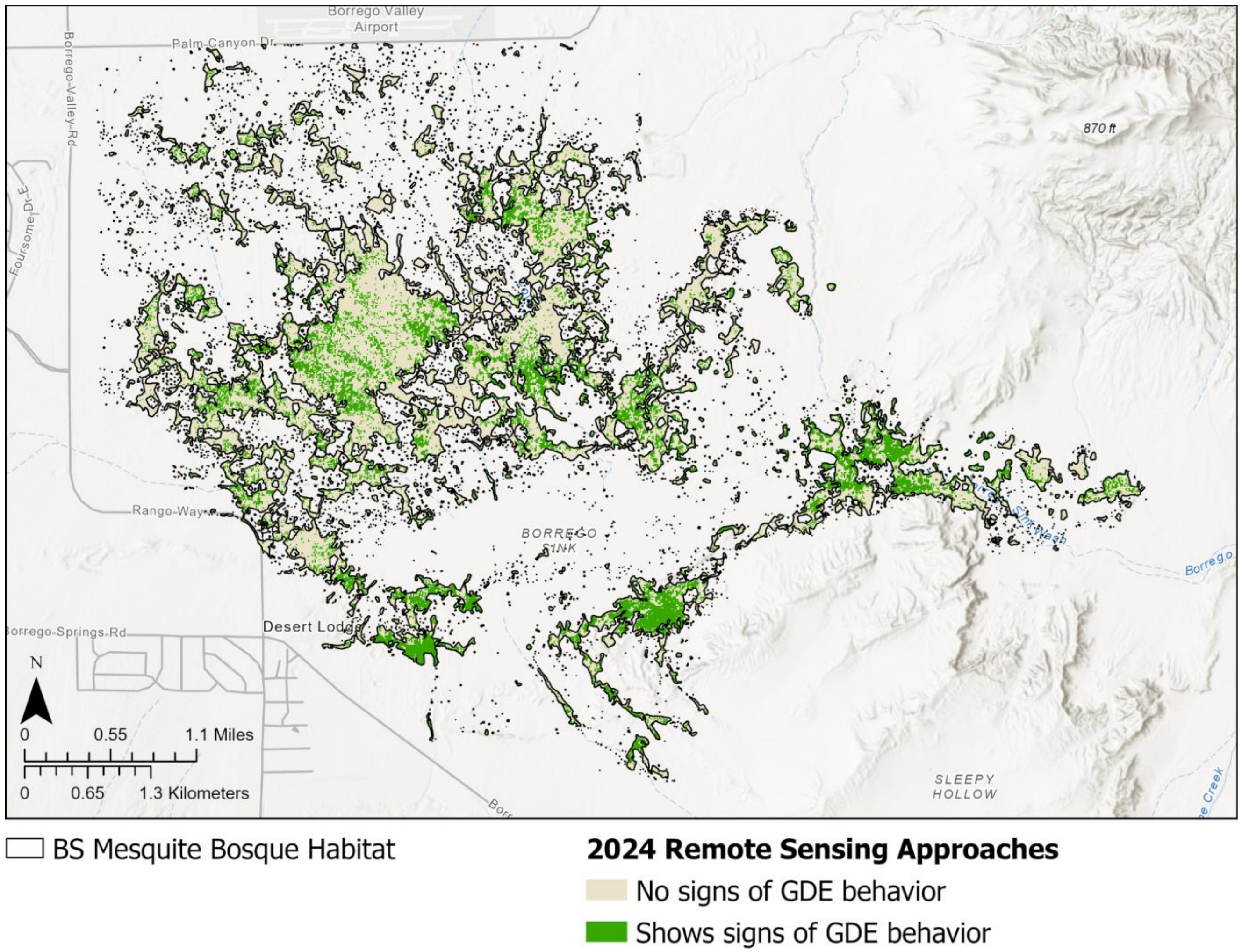

Figure 2.19. Spatial extent of GDE behavior in 2024. Map showing the spatial extent of GDE behavior identified by three different approaches in 2024. Areas in green represent live vegetation exhibiting GDE behavior in at least one approach, highlighting GDE hotspots across most of the Borrego Springs mesquite bosque. In total, 558 acres of mesquite showed signs of groundwater use in 2024.

Dry Period Evapotranspiration in the GDE

Introduction

In Groundwater Dependent Ecosystems (GDEs), vegetation relies on groundwater during dry periods when surface water is scarce (Eamus et al. 2016). As surface water declines, the physics of root water uptake dictates that plants will increasingly draw from deeper sources, causing GDEs to use more groundwater to meet their water demands. This example of groundwater use can be observed through evapotranspiration (ET) patterns—if ET rates exceed precipitation or remain stable or even increase during seasonal drought, it confirms that vegetation is utilizing groundwater. By tracking these patterns over time, we can identify water-use strategies by plant species and quantify groundwater use within the GDE. This data is essential for identifying GDEs, assessing ecosystem health, detecting changes in groundwater availability, and informing conservation efforts to support the sustainable management of these ecosystems.

Methods

ET Sensor Deployment

In mid-May 2024, we installed LI-COR LI-710 evapotranspiration (ET) sensors at four sites, including three mesquite bosque habitat sites near the Borrego Sink (Sites 1, 2, and 4) and one mesquite bosque habitat site at Clark Dry Lake (Site 5) (Figure 2.20). These sensors quantify ET by leveraging the turbulent movement of air above the land surface. They measure vertical fluctuations in water vapor concentration at 30-minute intervals, providing continuous data on water movement within these ecosystems. In simple terms, these sensors act like a "weather station" for ecosystems, measuring how much water they are transporting to the atmosphere through evapotranspiration.

The LI-710 sensors work by measuring the concentration of water vapor in the air above the sensor's footprint, which is the spatial area from which the sensor collects data. The sensor's footprint is typically 10 times the height of the sensor, corresponding to a radius of about 300 meters at the mesquite sites, meaning that each sensor captures the ET of vegetation within this area. A key factor influencing the footprint is the fetch, which refers to the upwind distance over which air travels before reaching the sensor. Wind speed directly impacts fetch, and higher wind speeds increase the effective fetch by bringing in air from farther upwind, potentially expanding the footprint, while lower wind speeds reduce it, making measurements more localized. The dominant wind direction in the Borrego Springs mesquite bosque is from the northwest. In Figure 2.20, we illustrate the location of the ET sensors, highlighting the 300 m radius footprint in purple, which contains dense mesquite cover at all sites, and the wind-biased fetch in blue, which contains a mix of mesquite and bare ground cover. This means that when strong, consistent winds come from the northwest, the ET signal captures a greater contribution from the bare ground. As a result, ET measurements and groundwater use estimates are conservative.

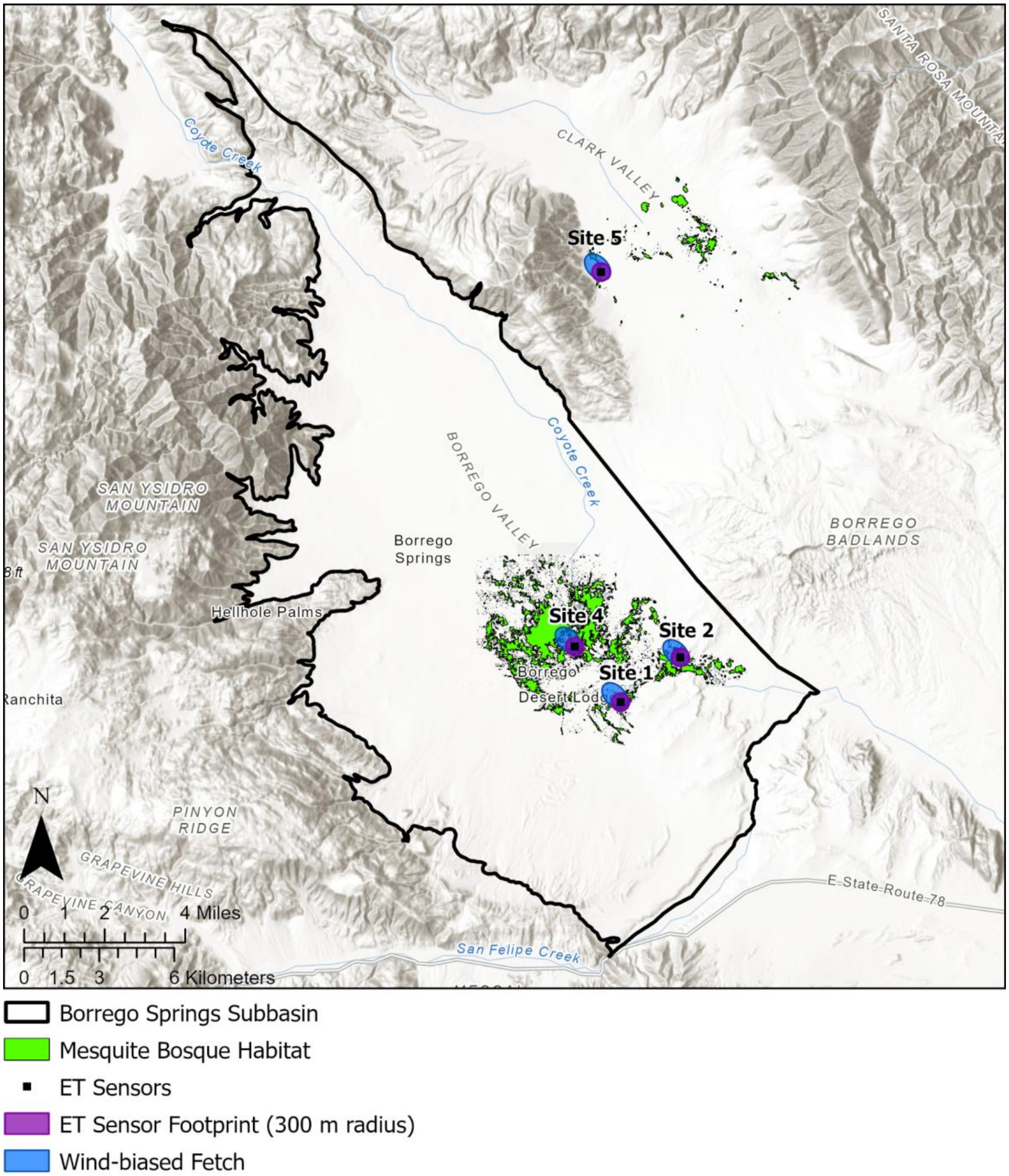

Figure 2.20. Map of evapotranspiration (ET) sensors. ET Sensors (LI-COR LI-710) were installed in three mesquite bosque habitats near the Borrego Sink (Sites 1, 2, and 4) and at one mesquite bosque habitat at Clark Dry Lake (Site 5).

ET and Precipitation Data Analysis

To assess precipitation trends across the ET sensor deployment period, we used PRISM daily precipitation data, a widely recognized dataset with high spatial resolution and accuracy in estimating precipitation (PRISM Climate Group, 2025). PRISM integrates ground-based weather station data with advanced interpolation techniques, making it a reliable source for climate and hydrological studies. We then verified the PRISM data with local weather station data to confirm rainfall events.

To evaluate mesquite water use, we focused on ET measurements recorded during active plant photosynthesis, from 6:00 AM to 7:00 PM daily. We excluded data from non-photosynthetic hours to isolate vegetation-driven transpiration and to avoid stable nighttime atmospheric conditions, which can reduce measurement accuracy due to weak turbulence. We then aggregated the daytime ET values at daily, weekly, monthly, and yearly scales to analyze trends over time. Occasionally, technical difficulties caused missing ET values, particularly for Site 2 for the month of June. To address these missing ET values at Site 2, we applied a gap-filling approach using the average daytime ET value calculated for the growing season (May–October), ensuring a conservative ET estimate for the missing periods.

Results

Precipitation

The 2024 water year (1 October 2023 – 30 September 2024) in the Borrego Springs Subbasin was characterized by low precipitation, totaling 77.32 mm (3.04 in). During the ET sensor deployment period (17 May 2024 – 31 January 2025), only 6.44 mm (0.25 in) of rainfall occurred (Figure 2.21). Given these conditions, direct rainfall contributions to ET were minimal, allowing us to identify the groundwater contributions to mesquite ET.

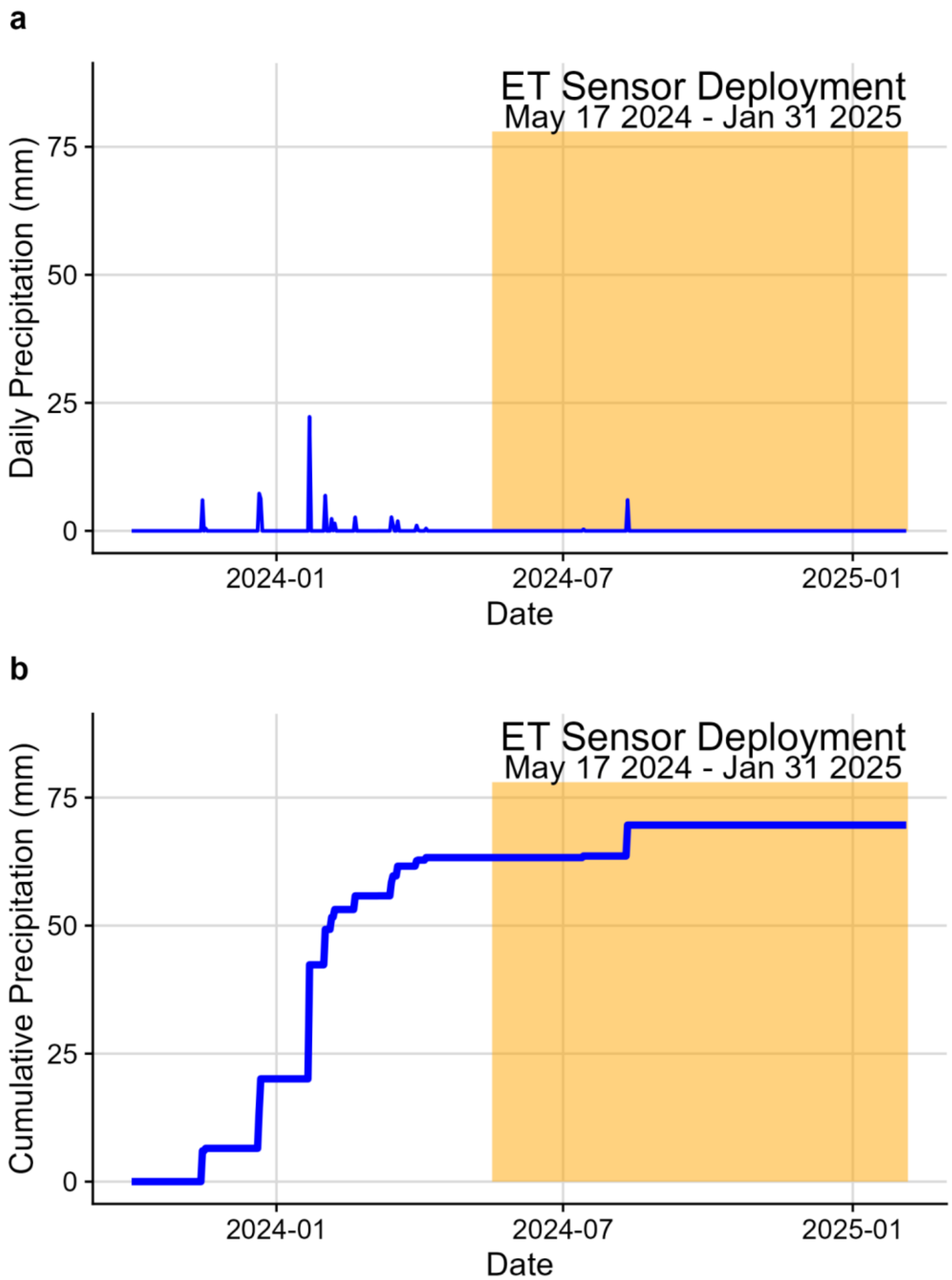

Figure 2.21. PRISM precipitation data during the ET sensor deployment period: (a) shows daily precipitation, while (b) presents the cumulative precipitation for the Water Year. ET sensors were installed in May 2024, and only 6.4 mm of precipitation fell during the ET sensor deployment period (~0.25 inch), indicating minimal rainfall contribution to ET across the deployment period. Additionally, the 2024 Water Year experienced exceptionally low total precipitation (77.32 mm or 3.04 inches).

Evapotranspiration (ET) Results

All mesquite bosque sites maintained consistent and sustained ET rates throughout the deployment period, providing strong evidence of continuous groundwater access during dry conditions (Figure 2.22). Borrego Springs (BS) Site 1 and Clark Dry Lake (CDL) Site 5 recorded the highest total monthly ET in June, indicating peak groundwater use in early summer. BS Sites 2 and 4 exhibited peak ET in July, further reinforcing the pattern of active mesquite groundwater use throughout the dry summer months. Across all sites, ET began to decline in November, signaling the end of the mesquite growing season as cooler winter temperatures set in.

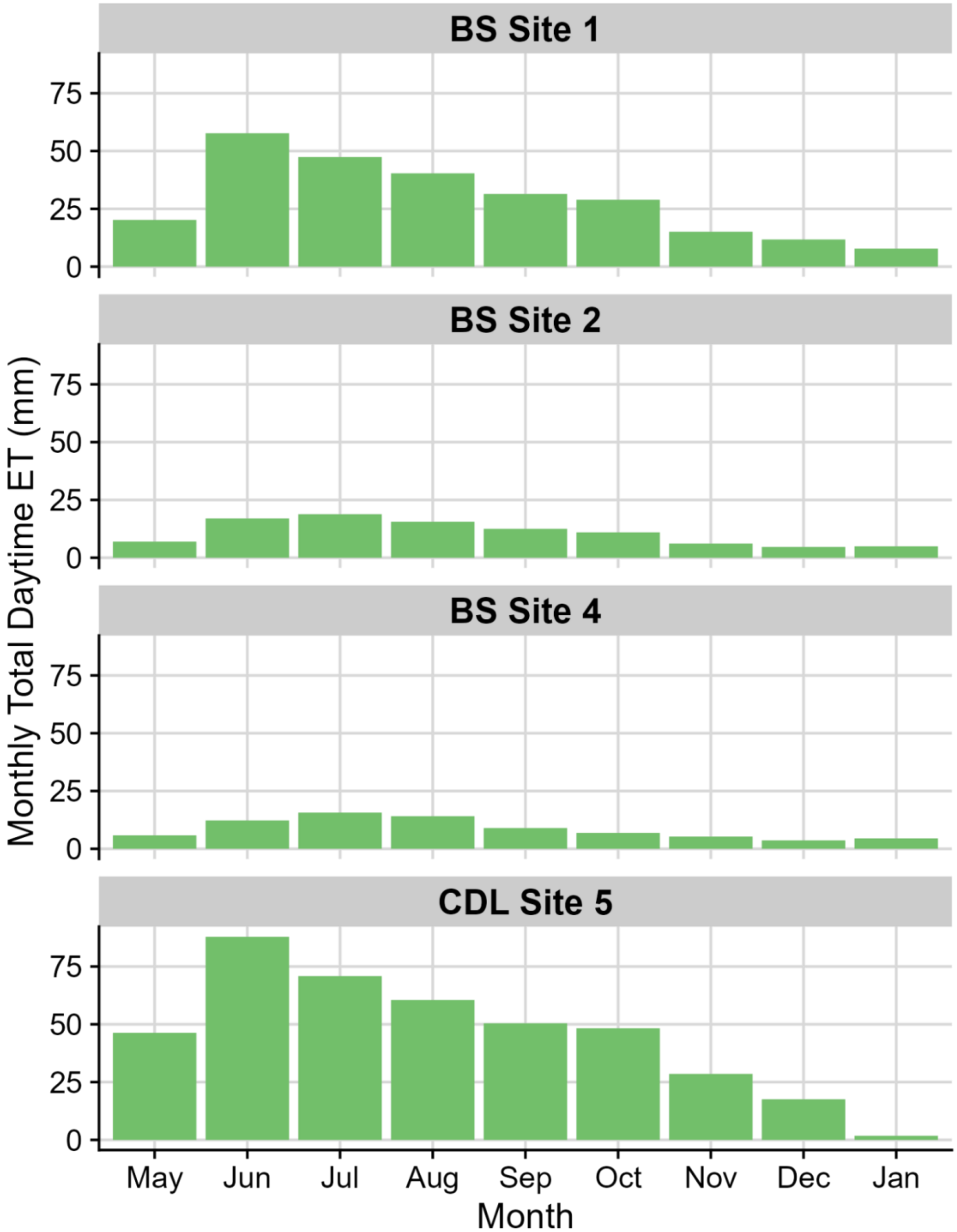

Figure 2.22. Monthly Total Evapotranspiration (ET) from each site. Sites 1 and 5 had the greatest total monthly ET in the month of June. Sites 2 and 4 had the highest ET in July. All sites displayed consistent, positive ET throughout the dry deployment period, indicating access to groundwater. BS: Borrego Springs; CDL: Clark Dry Lake.

Cumulative ET

To further evaluate groundwater reliance, we calculated cumulative ET across the deployment period to compare with total precipitation across the deployment period. At all sites, ET greatly exceeded the total rainfall received during the deployment period, confirming that mesquite continued to transpire despite minimal surface water input (Figure 2.23). Additionally, cumulative ET at all sites exceeded the total water year precipitation (~77.32 mm or 3.04 in), despite only being deployed for 8.5 months. This finding provides direct evidence that mesquite trees in Borrego Springs and Clark Dry Lake rely heavily on groundwater uptake during the dry months of the growing season (May - October).

BS Site 1 and CDL Site 5 had the highest cumulative ET rates overall, indicating healthy, productive vegetation with ample access to groundwater. Groundwater levels are estimated to range from 20–40 ft bgs at BS Site 1 and within 25 ft bgs at CDL Site 5. In contrast, BS Sites 2 and 4 are predicted to have deeper groundwater, and have lower cover and smaller stature of mesquite trees, which may explain their lower cumulative ET rates compared to Sites 1 and 5. However, it is important to recognize that the ET sensors were installed in mid-May, thus the total ET calculations do not account for ET from February through May. As mesquite leaf out in April, and reach peak biomass by early May, the total ET estimates provided for May through January are conservative, meaning that the total ET across all sites is likely higher. These results should be updated as soon as one full year of ET measurements become available.

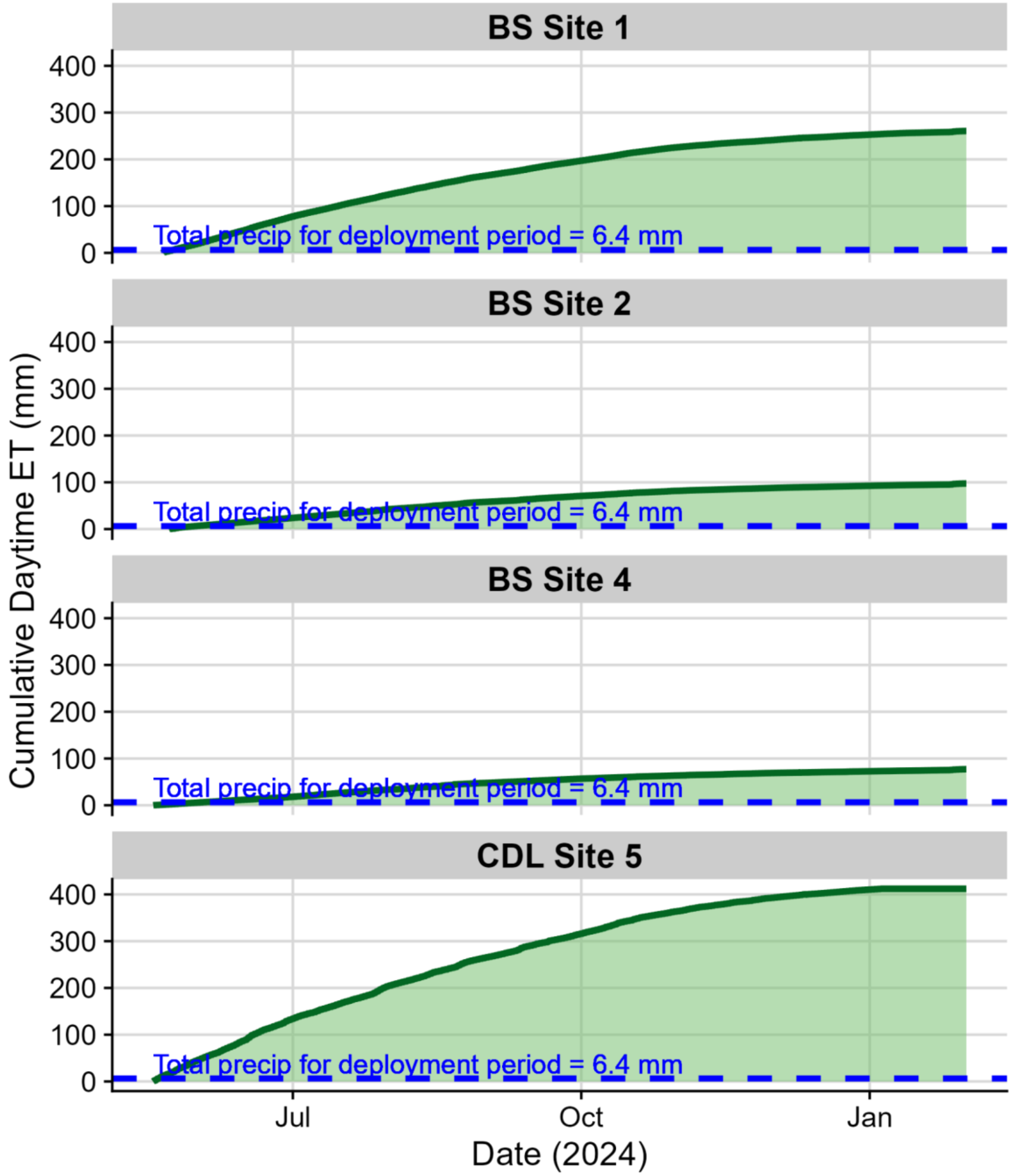

Figure 2.23. Cumulative Total Evapotranspiration (ET) from each site. The dotted lines show the total precipitation for the deployment period (6.4 mm or 0.25 in). All sites transpired far more than the total precipitation that fell during the deployment period, confirming groundwater use across the dry deployment period. BS: Borrego Springs; CDL: Clark Dry Lake.

Conclusion

The results from the ET sensors provide direct evidence of groundwater use by mesquite trees in the Borrego Springs Subbasin near the Borrego Sink and at Clark Dry Lake. Despite extremely low rainfall from May 2024 to January 2025, evapotranspiration (ET) rates remained consistently high across all monitored mesquite sites. This sustained ET, well beyond the amount of available rainfall, confirms that mesquite trees rely on groundwater to support growth and transpiration. These findings underscore the vital role of groundwater in sustaining mesquite habitats, particularly during the dry months of the growing season (May - October). They also highlight the importance of recognizing the mesquite bosque as a GDE within the Subbasin's water budget. We recommend continued ET monitoring to calculate total annual ET, and to detect potential shifts in groundwater availability or mesquite GDE health to minimize undesirable impacts.

The Borrego Springs Mesquite Bosque is a GDE: Summary of Evidence

The results of our GDE identification efforts confirm groundwater-dependent ecosystem (GDE) behavior across the 1,850-acre mesquite bosque habitat mapped in Borrego Springs, using multiple lines of evidence consistent with SGMA and GDE guidance (Eamus et al., 2016; Rohde et al., 2018). Groundwater depth mapping shows that mesquite trees occur where the regional aquifer is accessible at depths of 22–135 feet bgs. Isotopic analysis of 48 trees indicated consistent groundwater use across the dry season in 2023 and 2024, while water potential measurements demonstrated that mesquite experiences less water stress than non-phreatophytic vegetation. Remote sensing analyses revealed widespread GDE behavior across the habitat, and ET sensors recorded positive transpiration rates even during drought, confirming consistent groundwater access at all mesquite bosque sites. While it is not possible to verify GDE behavior at every individual mesquite tree, SGMA best practices advise that, in the absence of direct evidence to the contrary, potential GDEs should be assumed to be GDEs until proven otherwise (Rohde et al., 2018). Additional field data may help refine the extent of groundwater reliance, but the best available scientific evidence strongly confirms that mesquite trees in this area depend on groundwater.

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Appendix D4: Borrego Springs Subbasin Groundwater Dependent Ecosystems (Draft Final). (2020). Prepared by Driscoll, T., & Duverge, D. In *Groundwater Management Plan for the Borrego Springs Groundwater Subbasin January 2020*. Available at https://borregospringswatermaster.com/wp-content/uploads/2022/10/Exhibit-1_GMP.pdf

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3. Characterization of GDEs

Description of the Hydrologic Regime

The Borrego Springs Subbasin (Subbasin) is a semi-confined hydrologic system within the Borrego River Watershed. The Subbasin is shaped by an arid desert climate with hot, dry summers, mild winters, and low annual precipitation. Most precipitation occurs during winter frontal systems and summer monsoons, often in short, high-intensity spatially-limited bursts. Rainfall is highly variable, with greater amounts falling in the surrounding mountains, and runoff is channeled into the Subbasin through ephemeral streams (Faunt et al., 2015).

The surface hydrology is dominated by ephemeral flows, primarily in Coyote Creek, Borrego Palm Canyon, and Borrego Sink Wash. These channels experience seasonal flow during the wet months (November - March) and after summer monsoon storms (July–September). Historically, much of the runoff from these streams collected in the Borrego Sink, a topographic depression where groundwater once surfaced as springs and rushes, saltgrass, mesquite, and willows were abundant (Mendenhall, 1909, p. 82). However, anthropogenic alterations to the land surface and human-made barriers in the form of roads and structures have altered the flow of surface water.

The aquifer consists of unconsolidated alluvial deposits, including gravel, sand, silt, and clay, with three primary aquifers: the upper, middle, and lower aquifers (Faunt et al., 2015). Extensive groundwater pumping has led to significant declines in the regional aquifer, particularly in the northern and central portions of the basin, where extensive agricultural and municipal pumping have caused water levels to drop over 150 feet since pre-development conditions (Faunt et al., 2015). As a result of groundwater declines, groundwater no longer discharges to the surface near the Borrego Sink and the water table now lies below the surface. Reports of declining mesquite and shifts in vegetation types have been informally attributed to groundwater declines, however the lack of analysis of well data near the Borrego Sink made it historically difficult to assess potential connections between Groundwater Dependent Ecosystems (GDEs) and groundwater.

Historical Precipitation Trends

Introduction

To better understand how surface water availability to the mesquite bosque has changed over time we assessed historical trends in precipitation. Mesquite trees are facultative phreatophytes meaning that they can utilize both surface water and groundwater. Assessing shifts in surface water availability will help to contextualize changes in mesquite health over time.

Methods

Precipitation trends

To analyze historical trends in precipitation, monthly data were downloaded from PRISM September 1981 to December 2024 (PRISM Climate Group 2025; Resolution: 4-km, Dataset: AN81m). PRISM integrates ground-based weather station data into advanced interpolation techniques, making it a reliable source for climate and hydrological studies. We averaged climate data across two 4 km grid cells covering the mesquite bosque in Borrego Springs near the Borrego Sink. The latitude and longitude of the two grid centers were 33.2468, -116.2848 and 33.2402, -116.3312. We used monthly data to assess monthly rainfall and cumulative water year precipitation. We also divided the year into the winter season (December - March), dry season (May and June), and monsoon season (July - September) to assess trends in cumulative precipitation across these periods.

Results

Precipitation trends

Between 1981 and 2024, total water year precipitation at the Borrego Springs study area averaged 102.5 mm (4.03 in) with about 70% falling during the December - March winter rainy season. Much of the remaining rainfall occurs during the July - September summer growing season. The rainy seasons are separated by dry periods, with the May - June dry period typically the driest (Figure 3.1).

There was not a significant trend in water year precipitation between 1981 and 2024. There was also no trend in total winter precipitation (December through March) or summer rainfall (July through September) (Figure 3.2).

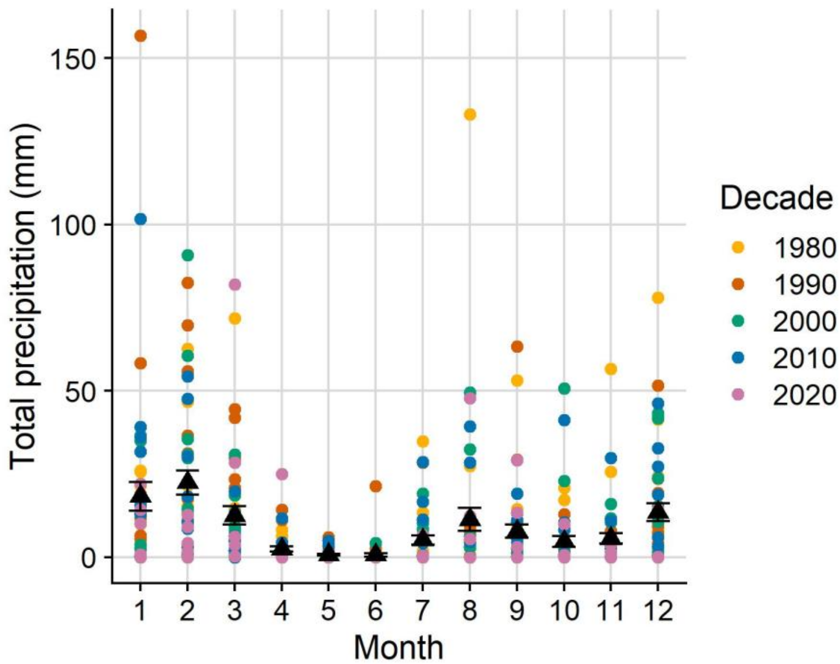

Figure 3.1. Monthly rainfall from January 1981 to December 2024, colored by decade. The points represent raw data, the black triangles indicate the mean, and the black error bars show the standard error.

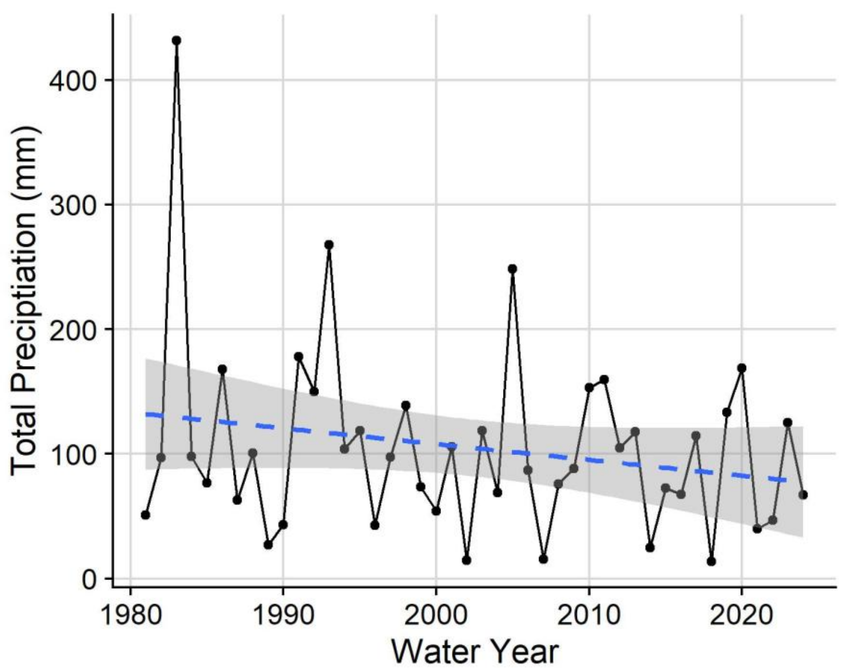

Figure 3.2. Total precipitation across the 1981 - 2024 water years.

Conclusion

These findings suggest that there have not been dramatic declines in precipitation which might explain the decline in mesquite bosque health and cover. While there was a trend towards lower water year precipitation, this trend was not statistically significant. It is worth noting that roads and other structures have changed the flow of surface water and thus may contribute to declines in surface water availability despite the lack of a significant trend in precipitation. In summary, these data indicate that declines in surface water are not a likely source for detected changes in mesquite bosque health (see **4. Potential Adverse Impacts to GDEs**).

Baseline Groundwater Levels

Introduction

To assess whether there are "significant and unreasonable" effects to the mesquite bosque GDE, a baseline condition for groundwater depth is needed. To determine the baseline, we explored groundwater levels across different water years, seasonal variation in groundwater levels, and average depths to groundwater across two time periods.

Methods

To better understand historical and contemporary well depths in the vicinity of the mesquite bosque in Borrego Springs, we acquired data from West Yost and the California Department of Water Resources (https://wdl.water.ca.gov/; Figure 3.3, Table 3.1).

Groundwater levels across precipitation conditions

To assess groundwater levels across different types of water years (wet, dry, average) we selected wells with data from the 10 years preceding SGMA (2005 - 2010) and which were within 50 m of mesquite bosque habitat which resulted in three wells: MW-5, MW-3, and 11S06E01C001S (see Table 3.1 for well information). We used PRISM precipitation data to identify years as being wet, dry, or average. We downloaded PRISM data from October 1952 through September 2015 (PRISM Climate Group 2025; Resolution: 4-km, Dataset: AN81m). We averaged climate data across two 4 km grid cells covering the mesquite bosque in Borrego Springs near the Borrego Sink. The latitude and longitude of the two grid centers were 33.2468, -116.2848 and 33.2402, -116.3312. We used monthly data to determine cumulative water year precipitation (October 1 - September 30).

Seasonal variation in groundwater levels

To test for seasonal variation, we required wells with monthly data across time, which necessitated the use of post-SGMA data from wells within the Wastermaster's monitoring network. To ensure relevance to the mesquite bosque, we chose wells within 50 m of mesquite bosque habitat which resulted in the selection of MW-3 and MW-5 (see Table 3.1 for well information). We selected MW-5B for analysis over MW-5A due to being a shallower well, but groundwater depths between the two wells are nearly identical. We decomposed the groundwater depth data into interannual variation (trend over time), intra-annual variation (seasonality), and residual variation using the Seasonal and Trend decomposition using Loess method (STL; function 'stl,' package *Stats*; Cleveland et al. 1990).

Defining the baseline

To define the most appropriate baseline period, we assessed groundwater conditions across two time periods: historical (1953 - 1963) and contemporary pre-SGMA (2005 - 2015). We selected all wells within 50 m of the mesquite bosque habitat which resulted in eight wells (MW-3, MW-5A, MW-5B, 11S06E01C001S, 7N1, 11S06E11M001S, 12G, 11S06E11D002S; see Table 3.1 for well information). Because groundwater depths between MW-5A and MW-5B are nearly identical, we selected only MW-5B for analysis so as not to bias the averages. Due to data limitations, a different subset of wells is included for the historical period (11S06E11D002S, 11S06E11M001S, 7N1) and the contemporary pre-SGMA period (MW-3, MW-5B, 11S06E01C001S, 12G). We assessed the average groundwater levels across water years and the range in these averages. All analyses were performed in R (R Core Team, 2024; v. 4.3.3).

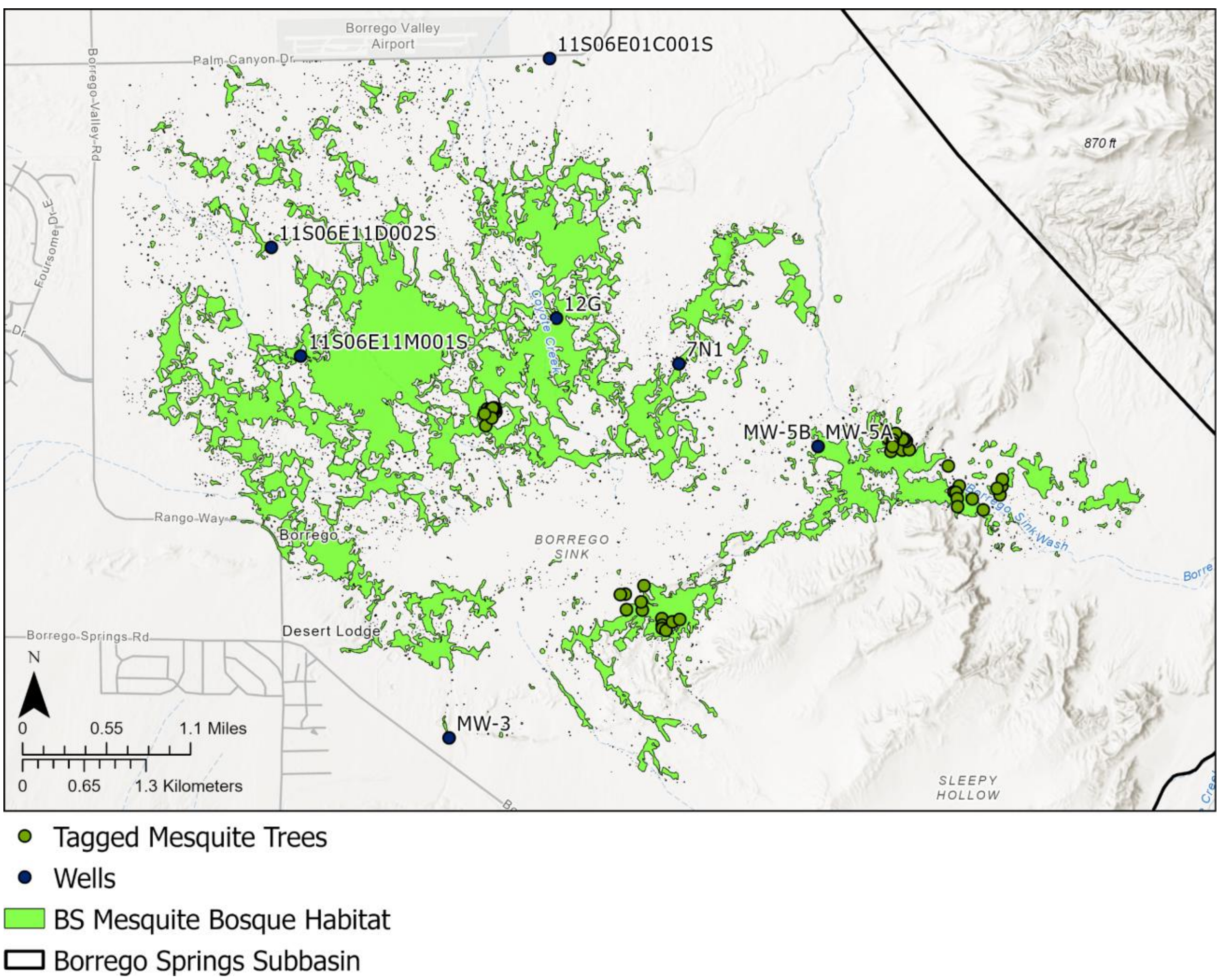

Figure 3.3 Map of the wells assessed for baseline groundwater level.

Table 3.1. Identifying information and data source for the examined wells.

State Well Number	Local Well Name	Latitude	Longitude	Data Source
Borrego Springs				
11S06E01C001S	11S06E01C001S	33.25725	-116.3047	DWR
11S06E11D002S	11S06E11D002S	33.2423	-116.3311	DWR
11S06E11M001S	11S06E11M001S	33.2337	-116.3283	DWR
11S06E12G001S	12G	33.2367	-116.3041	DWR
11S07E07N001S	7N1	33.2331	-116.2925	DWR
11S06E23J002S	MW-3	33.20316	-116.3143	West Yost
11S07E07R001S	MW-5A	33.22656	-116.2793	West Yost
11S07E07R002S	MW-5B	33.22656	-116.2793	West Yost

Results

Groundwater levels across precipitation conditions

Across the 10-year pre-SGMA period, there was one particularly wet year (2005), several average years (2006, 2009, 2012 - 2013), and one particularly dry year (2014), but we largely did not see commensurate changes in groundwater depths (Fig 3.4). Instead, for wells 11S06E01C001S and MW-5B, there is only a steady decline in groundwater levels. In contrast, MW-3 remained fairly static over time and even increased in the latter years when drier conditions were prevalent. These findings demonstrate that interannual variability in groundwater levels is a small component of the shifts in groundwater levels over time and that direct anthropogenic drivers (i.e., pumping) are at play.

Seasonal variation in groundwater levels

To delve deeper into variation in groundwater levels over time, we assessed seasonal, intra-annual variability. We detected seasonal variation in groundwater levels (Fig 3.5, Seasonal panel), but found that the seasonal pattern is largely obscured by the trend in groundwater levels across years (Fig 3.5, Trend panel), particularly for MW-5B. MW-5B saw a net change in groundwater levels of 0.3 ft within a year with the highest groundwater levels found in January and the lowest groundwater levels found in September. MW-3 had slightly greater seasonal variation with a net fluctuation of 3 ft within a year with the highest groundwater levels found in February and the lowest groundwater levels found in October.

Defining the baseline

We looked at two different ten-year windows to assess the range in groundwater levels and select an appropriate baseline for the mesquite bosque habitat (Table 3.2). The historical period (1953 - 1963) includes the earliest publicly available well data that we could find. The average depth to groundwater across all water years was 25.5 ft bgs. When looking at the variation in average groundwater levels across water years and across wells, the highest average groundwater level was 5.3 ft bgs (1953; 11S06E11M001S) and the lowest groundwater level was 59.6 ft bgs (1958; 11S06E11D002S). For the contemporary pre-SGMA period (2005 - 2015), the average depth to groundwater across all water years was 69.5 ft bgs and average groundwater levels ranged from 49.4 ft bgs (2009; MW-5B) to 102.8 ft bgs (2015; 11S06E01C001S). See Appendix B.1 Table B.1 for average groundwater levels across wells and water years.

Limitations

There are only three wells with available data for the historical period used to define this baseline (1953 - 1963), all of which are north of the Borrego Sink but located within the mapped mesquite bosque. The proposed upper limit of the baseline range (59.6 ft bgs) is the water year average of only one well (11S06E11D002S) which had an average depth to groundwater of 25.4 ft bgs the year before (1957) and 45.9 the year after (1959), indicating possible effects of pumping due to the highly variable groundwater depths. However, there are no quality flags in the well data and thus we do not feel comfortable removing these data at this time.

Based on the remote sensing analyses in **Changes in Mesquite Bosque Health**, mesquite productivity declined between 1984 and 2015 indicating that the mesquite bosque was more productive in the 1980s relative to 2015. It was in 1989 that the depth to groundwater began to be consistently greater than 50 ft bgs (Appendix B.1 Table B1). Hence, it is likely that our estimate of 59.6 ft bgs is on the high end and that a more shallow value may be more appropriate but we see the baselines identified here as a starting point for an adaptive approach and thus they may require modifications.

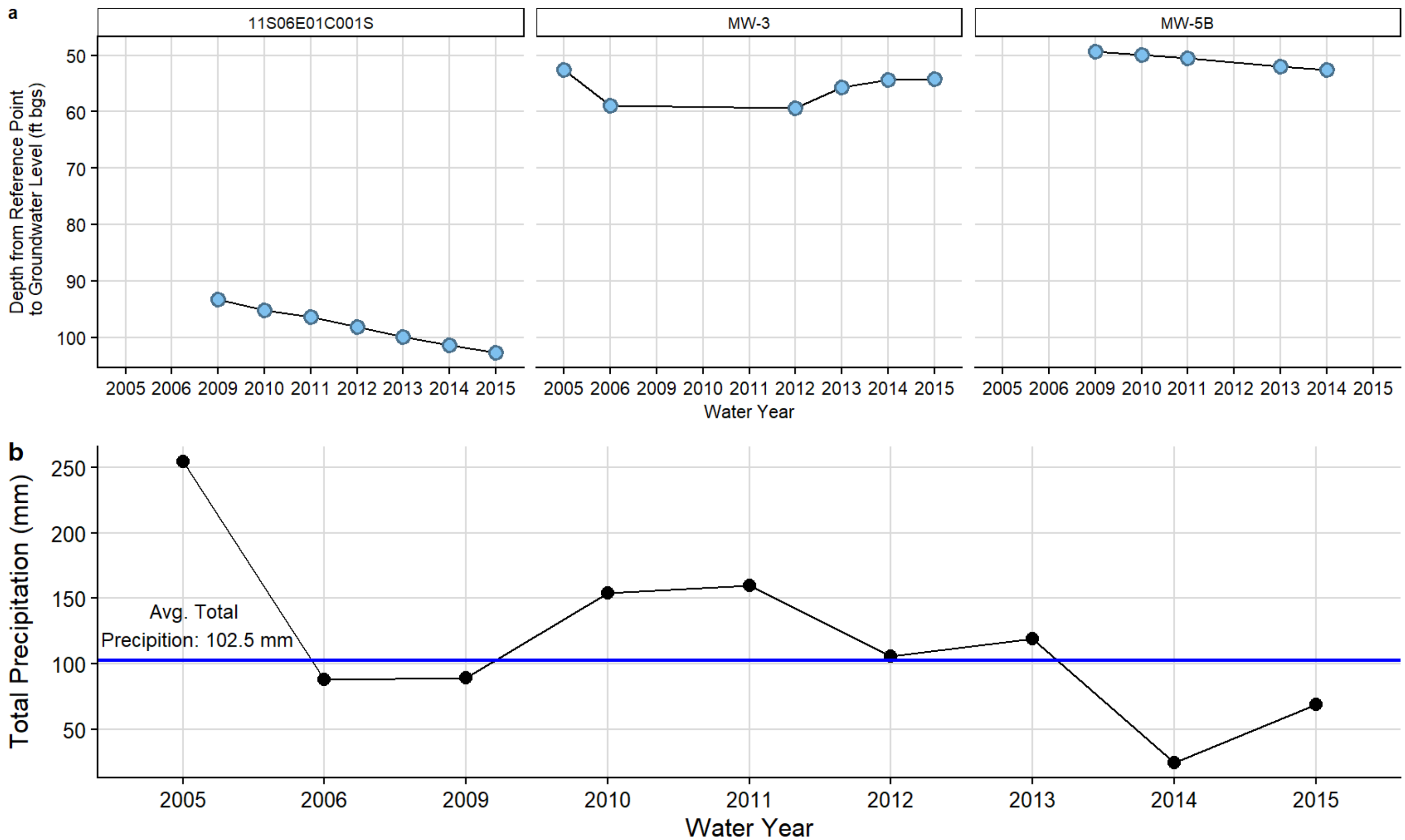

Figure 3.4. Groundwater levels across precipitation conditions. Groundwater levels for three wells with data ranging from water years 2005 to 2015 (a). Total precipitation for water years 2005 to 2015 with the average total precipitation derived from PRISM data between 1981 and 2024 (PRISM Climate Group, 2025; see **Historical Precipitation Trends** section) (b).

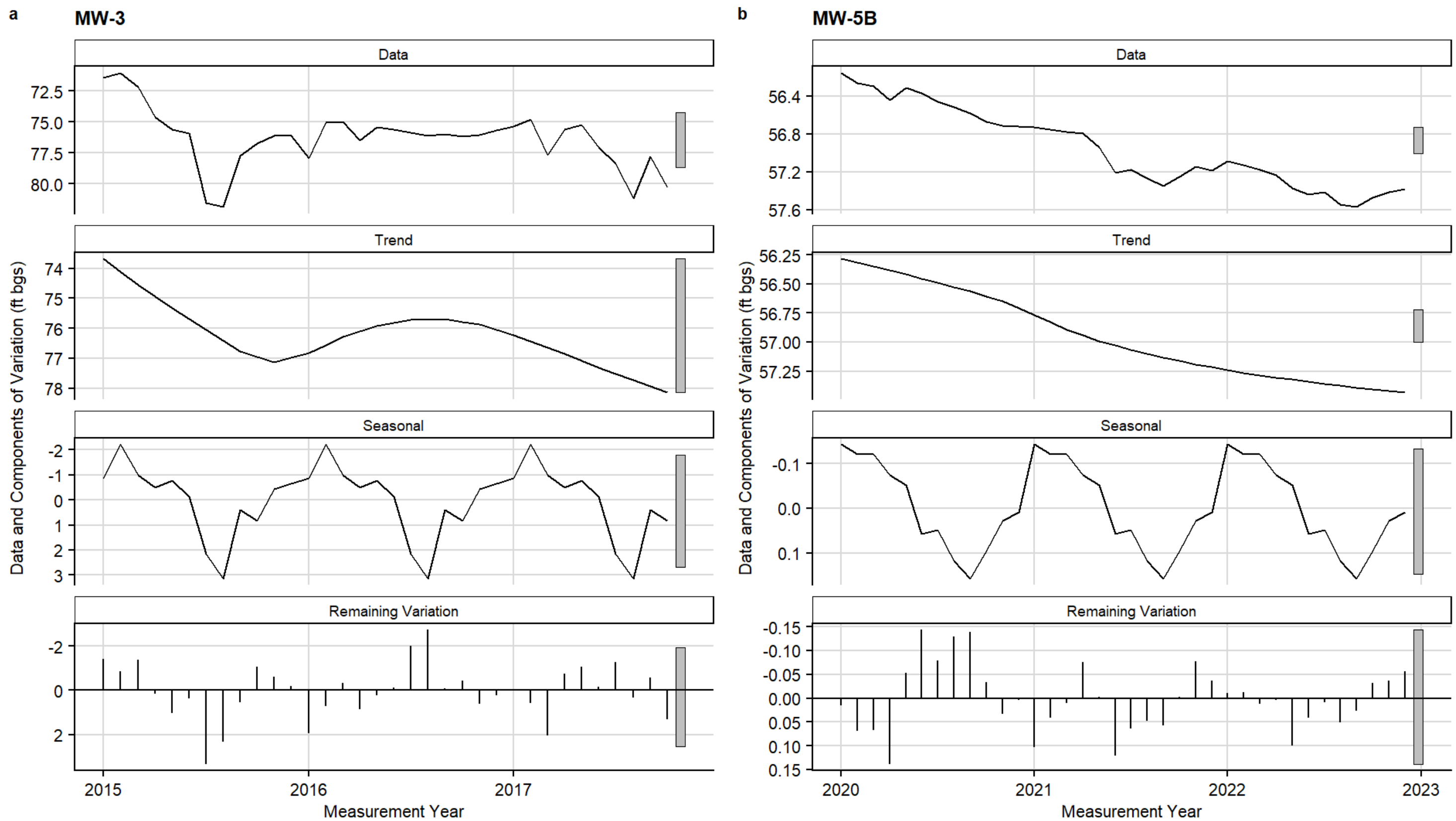

Figure 3.5. Seasonal trends in well depths. The decomposition of the data (Data panel) into its trend across years (Trend panel), intra-annual seasonal variation (Seasonal panel), and the remaining variation (Remaining Variation panel). The gray bars to the right of each panel represent the relative importance of the component to the pattern of the data. When the bar is similar in size to the bar found in the Data panel, the component has a strong impact on the pattern of the data. When the bar is larger than the bar found in the Data panel, the component has a lesser impact on the pattern of the data. For instance, the impact of seasonal variation is less than the impact of the trend over years for MW-5B.

Table 3.2. Average groundwater levels across possible baseline periods. Average groundwater levels for the 10 water years encompassed by the Historical Baseline period and the Contemporary Pre-SGMA Baseline period.

Water Year	Avg. Depth from Reference Point to Groundwater Level (ft bgs)	Number of Wells	Number of Measurements
Historical Baseline (1953 - 1963)			
1953	5.3	1	1
1954	18.1	3	7
1955	19.4	3	4
1956	26.5	3	5
1957	23.8	3	4
1958	36.4	3	9
1959	33.6	3	13
1960	28.1	3	4
1961	29.2	3	6
1962	30.4	3	6
1963	29.8	3	6
Contemporary Pre-SGMA Baseline (2005 - 2015)			
2005	52.6	1	1
2006	58.9	1	2
2009	72.2	4	8
2010	72.6	2	2
2011	73.5	2	3
2012	78.7	2	3
2013	69.2	3	5
2014	69.4	3	87
2015	78.5	2	23

Conclusion

In summary, we found low interannual variability and low seasonal, intra-annual variability as these patterns were largely obscured by an overall decline in groundwater levels over time. Additionally, we saw large differences in the historical well depths compared to the period of time preceding SGMA such that historical groundwater levels were much higher than recent times. These findings suggest that a historical baseline is more appropriate as the contemporary data represents conditions that have already shifted and would create a baseline biased towards unhealthy conditions (Figure 3.6). For that reason, we suggest a baseline of 59.6 ft bgs and suggest that groundwater levels below this level could cause significant and unreasonable effects to the mesquite bosque GDE in Borrego Springs.

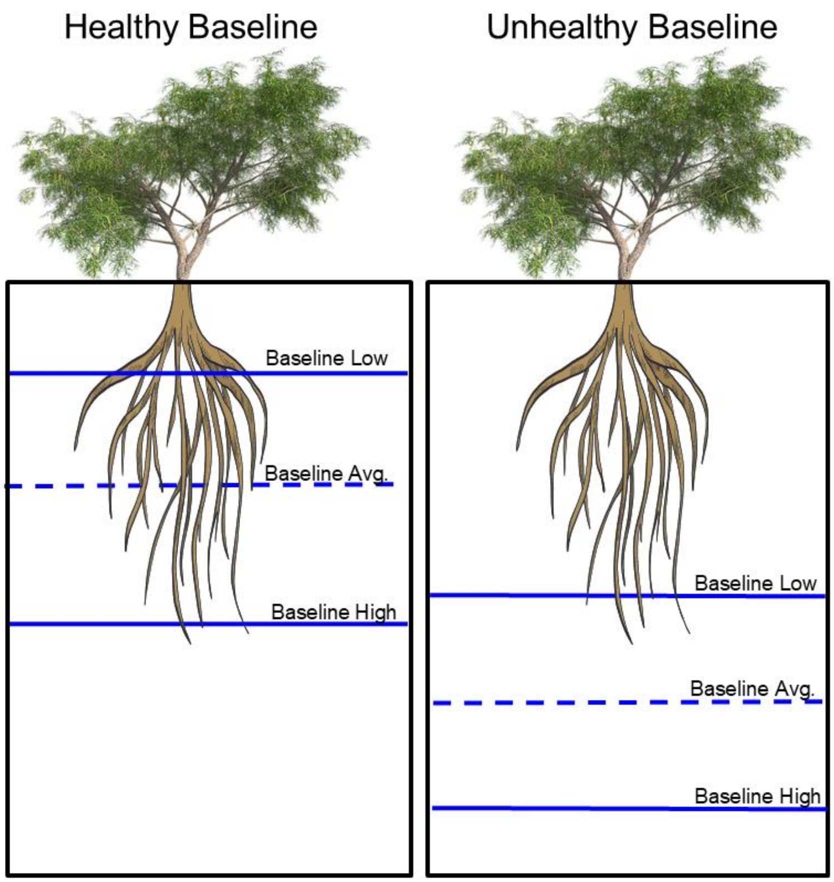

Figure 3.6. Defining the baseline. A healthy baseline is based on groundwater conditions in a natural state while an unhealthy baseline is derived from conditions altered by anthropogenic drivers (i.e., pumping).

Ecological Assessment of GDEs

Mesquite Bosque Health and Ecological Condition Assessment

Introduction

The mesquite bosque near the Borrego Sink spans approximately 1,850 acres and exhibits noticeable variations in health, productivity, and growth patterns across the landscape. These differences highlight the need for a comprehensive baseline assessment of the mesquite bosque's current ecological condition. Establishing this baseline aligns with the Sustainable Groundwater Management Act (SGMA) guidelines for assessing Groundwater Dependent Ecosystems (GDEs) and provides a foundation for long-term ecosystem monitoring and management.

Vegetation productivity is a widely recognized indicator of ecological condition, as it reflects the availability of water and nutrients necessary to support ecosystem functions (Kooistra et al., 2024). Ecosystems with high vegetation productivity sustain diverse plant and animal communities, provide essential ecosystem services, and demonstrate resilience to environmental stressors (Costanza et al., 2007). Mesquite bosque GDEs rely on stable groundwater availability to maintain their productivity and ecological functions and these woodlands can provide key ecosystem services such as habitat support, carbon sequestration, and soil stabilization.

To evaluate vegetation productivity and ecological health in the Borrego Springs mesquite bosque, we used remote sensing techniques to calculate cumulative Normalized Difference Vegetation Index (NDVI) across the 2019 - 2024 water years. This approach allowed us to estimate the total green biomass growth each year, providing insight into the ecological health of this groundwater-dependent ecosystem.

Remote Sensing for Assessing Ecological Health

Remote sensing provides an efficient, scalable approach to monitor ecosystems over large areas and extended time frames. NDVI is a widely used remote sensing metric for assessing vegetation health or "greenness," as it correlates with key biophysical properties such as leaf area, chlorophyll content, vegetation cover, structure, and overall productivity (Tucker, 1979). Sentinel-2 satellite imagery, with its 10 m resolution (i.e., a pixel size of 10 m × 10 m) and frequent revisit time (every five days), is commonly used to calculate NDVI, and enables year-round monitoring of vegetation. Integrating NDVI over key periods, such as growing seasons or water years, provides valuable insights into overall vegetation productivity and overall ecosystem health. However, because the Sentinel-2 dataset for Borrego Springs begins in 2018, high-resolution analysis is only possible from that year onward. For a long-term assessment of mesquite bosque health from 1984 to the present, see the **Potential Adverse Effects** section.

Using Cumulative NDVI as a Proxy for Annual Vegetation Productivity

Cumulative NDVI is calculated by summing all NDVI values for each pixel over an entire year. This metric acts as a proxy for gross primary productivity (GPP)—the total green biomass produced over the course of a year for a given area. GPP is directly related to ecosystem health, as higher GPP values typically indicate more productive and healthier vegetation. By analyzing cumulative NDVI, we can assess vegetation productivity and ecological conditions within the mesquite bosque.

Methods

Area of Interests (AOIs)

We calculated cumulative annual NDVI for all pixels in the Borrego Springs (BS) mesquite bosque polygon (~1,850 acres) and compared it with the cumulative annual NDVI for pixels in the Clark Dry Lake (CDL) mesquite bosque (~227 acres). At Clark Dry Lake site, groundwater is located within 25 feet of the surface, which provides a reference for healthy, groundwater-connected mesquite habitats.

Data Acquisition

We used Google Earth Engine to obtain Sentinel-2 satellite imagery for each Area of Interest (AOI) covering each water year from 2019 - 2024 (water year corresponds to October 1 - September 30). Each water year's collection of images was processed separately. Cloud and shadow pixels were removed to ensure data accuracy. For each image, we calculated the NDVI and then summed the NDVI values for each pixel across the entire water year to calculate the cumulative NDVI.

Categorizing Cumulative NDVI into Productivity Categories

To classify high, moderate, and low vegetation productivity, we used cumulative NDVI values from CDL for each water year as a reference for healthy mesquite ecosystems (Table 3.3). High vegetation productivity was defined as cumulative NDVI values greater than or within 10% of the CDL average cumulative NDVI for each given year. Moderate productivity included NDVI values within 50% of the CDL average, while low productivity encompassed NDVI values below 50% of the CDL average.

Table 3.3. Descriptions of categories used to define productivity in the mesquite bosque habitats.

Vegetation Productivity Category	Meaning	Classification Formula
High Productivity	High NDVI values indicate robust vegetation with high productivity, dense and healthy vegetation, and/or high habitat quality.	Cumulative NDVI greater than or within 10% of the CDL reference site mean.
Moderate Productivity	Moderate NDVI values indicate moderate productivity, indicating sparser vegetation and moderate habitat quality.	Cumulative NDVI within 50% of the CDL reference site mean.
Low Productivity	Low NDVI values indicate sparse or low productivity vegetation, indicative of ecological stress and low habitat quality.	Cumulative NDVI below 50% of the CDL reference site mean.

Results

In 2023, the Borrego Springs mesquite bosque contained 99.29 acres of high-productivity vegetation, 829.82 acres of moderate productivity, and 1,288.45 acres of low productivity. In comparison, the Clark Dry Lake mesquite bosque comprised 132.34 acres of high productivity, 99.98 acres of moderate productivity, and 39.77 acres of low productivity (Table 3.4). While the Borrego Springs mesquite bosque had a comparable acreage of high productivity vegetation to Clark Dry Lake, it encompassed significantly larger areas of moderate and low productivity habitat, reflecting its larger size and greater variability in productivity.

In 2024, an extremely dry year, the Borrego Springs mesquite bosque experienced declines in high and moderate productivity vegetation, with 82.23 acres classified as high productivity, 589.61 acres as moderate productivity, and 1,545.73 acres as low productivity. In contrast, Clark Dry Lake showed relatively stable patterns, with 136.81 acres of high productivity, 99.71 acres of moderate productivity, and 35.57 acres of low productivity (Table 3.4).

Table 3.4. Mesquite productivity acreage. Summary of total acreage found in each productivity category for Borrego Springs (BS) and Clark Dry Lake (CDL) for the 2019 - 2024 water years.

Year	High Productivity (Acres)	Moderate Productivity (Acres)	Low Productivity (Acres)
Borrego Springs			
2019	329.34	998.28	889.94
2020	302.92	1,037.42	877.22
2021	117.03	1,134.47	966.06
2022	94.30	760.48	1,362.77
2023	99.29	829.82	1,288.45
2024	82.23	589.61	1,545.73
Clark Dry Lake			
2019	138.47	107.57	26.06
2020	143.58	105.99	22.53
2021	136.30	110.16	25.64
2022	132.24	103.15	36.70
2023	132.34	99.98	39.77
2024	136.81	99.71	35.57

Across 2019 - 2024, the Borrego Springs mesquite bosque exhibited a consistent decline in the acreage of high and moderate productivity vegetation, aligning with reports of widespread mesquite decline and mortality (Figure 3.7; see **Field Assessments of Live and Dead Trees**). Meanwhile, the Clark Dry Lake mesquite bosque remained stable, with little change in its high and moderate productivity vegetation (Figure 3.7). For a full description of changes in mesquite health from 1984 - present, see the **Potential Adverse Effects** section.

Figures 3.8 and 3.9 illustrate the spatial distribution of high, moderate, and low productivity vegetation in the Borrego Springs mesquite bosque for the 2023 and 2024 water years. The locations of high and moderate productivity vegetation (shown in darker green tones) were consistent across 2023 and 2024, with notable hotspots of high productivity vegetation around the Borrego Sink, where groundwater is closer to the surface.

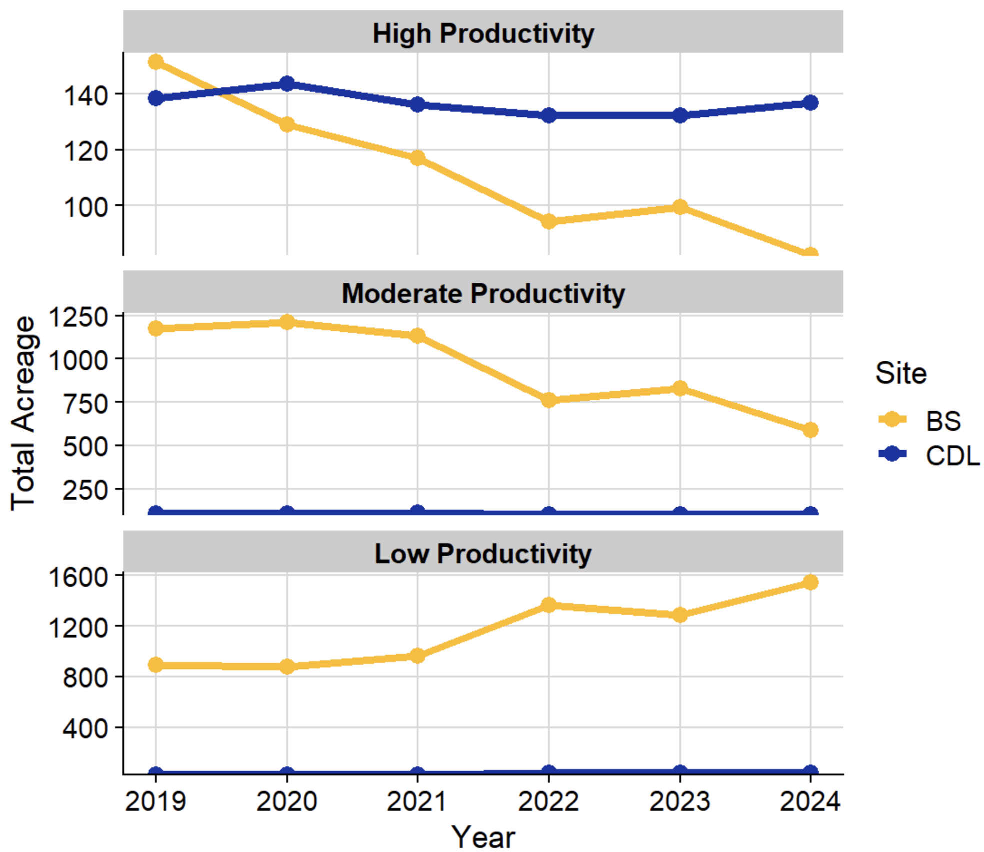

Figure 3.7. Mesquite bosque productivity over time. Total acreage of high, moderate, and low productivity vegetation at the Borrego Springs (BS) and Clark Dry Lake (CDL) mesquite bosques from 2019-2024. In Borrego Springs, the amount of high and moderate productivity mesquite has declined consistently across the time frame, while Clark Dry Lake has remained stable.

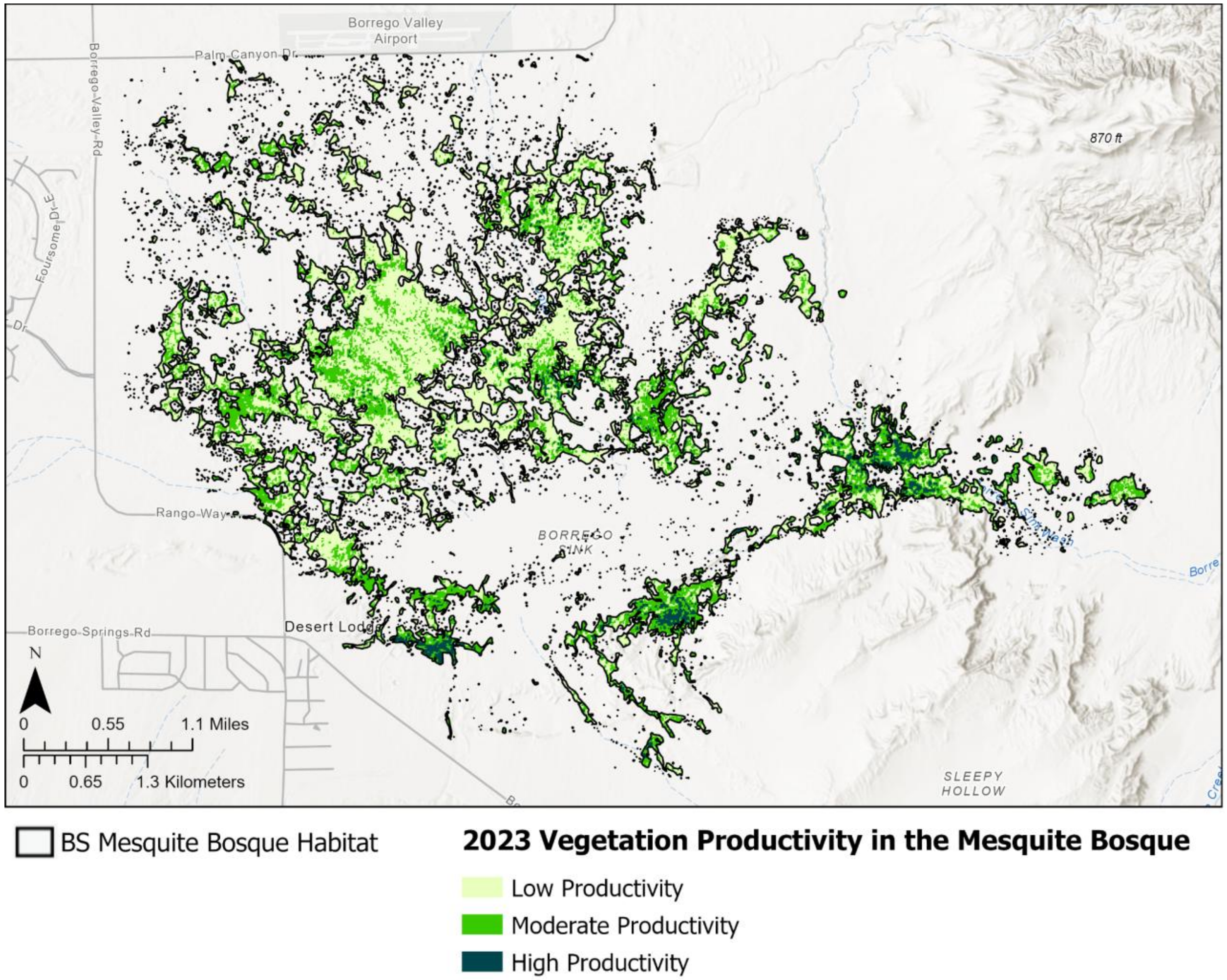

Figure 3.8. 2023 mesquite bosque productivity. Vegetation productivity assessment for the 2023 water year in the mesquite bosque habitat near the Borrego Sink. Areas in darker green tones had high cumulative NDVI in 2023, indicating high vegetation productivity. Over 929 acres of the mesquite bosque habitat were considered moderate to high vegetation productivity in 2023.

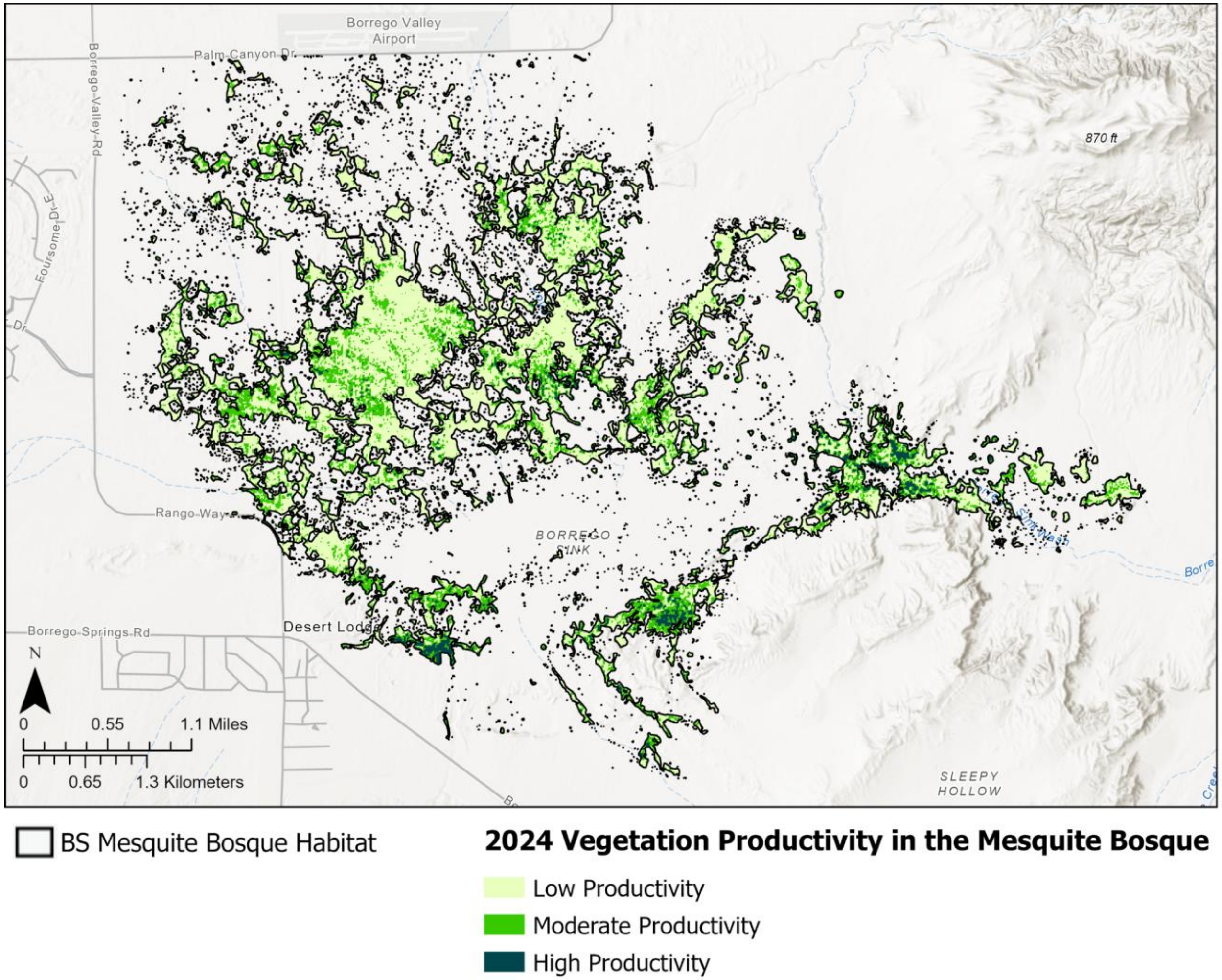

Figure 3.9. 2024 mesquite bosque productivity. Vegetation productivity assessment for the 2024 water year in the mesquite bosque habitat near the Borrego Sink. Areas in darker green tones had high cumulative NDVI in 2024, indicating high vegetation productivity. Over 672 acres of the mesquite bosque habitat were considered moderate to high vegetation productivity in 2024.

Conclusion

The results indicate that the mesquite bosque in Borrego Springs recently supported a comparable amount of high-productivity vegetation as the Clark Dry Lake mesquite bosque while containing significantly more moderate-productivity vegetation than Clark Dry Lake. However, over the past six years, the extent of both moderate- and high-productivity vegetation has consistently declined in the Borrego Springs mesquite bosque. This decline not only reflects the mesquite bosque's high susceptibility to decreasing groundwater levels but also suggests a corresponding reduction in the ecosystem services provided by these woodlands. Despite this decline, the mesquite bosque remains a crucial ecological feature in Borrego Springs, as it is the only extensive woody tree habitat in the Borrego Springs Subbasin. Its presence is vital for maintaining biodiversity, offering shade and refuge in an otherwise arid landscape, and supporting important ecosystem services. As the sole expansive woody tree habitat in the region, the mesquite bosque provides essential habitat for wildlife, enhances local biodiversity, stores atmospheric carbon in its biomass, and helps prevent erosion with its deep root systems, all of which contributes to ecosystem stability.

Given that the mesquite bosque spans 1,850 acres, it is essential to implement conservation and restoration measures to sustain its ecological functions and services before further degradation occurs. As mesquite bosques are highly sensitive to groundwater fluctuations, monitoring their productivity provides a valuable indicator of both ecosystem stability and groundwater conditions in the Borrego Springs Subbasin (Rohde et al., 2018). Conservation and management efforts should prioritize maintaining groundwater availability and enhancing bosque health to preserve the critical ecological functions these unique woodlands provide.

Field Assessments of Live and Dead Trees

Introduction

Because we found high susceptibility of the mesquite bosque Groundwater Dependent Ecosystem (GDE) to changing groundwater levels, it is important to collect biological data to assess GDE response and potential effects. Biological survey data provide valuable information for evaluating these effects while also serving as early indicators of undesirable results for GDEs. Water stress caused by declines in the depth to groundwater can reduce photosynthesis and growth and increase the mortality of leaves and branches (Stromberg et al., 1992; Kaufmann, 1990, Campbell et al., 2017). Hence, we assessed the coverage of live and dead mesquite trees at both the primary Borrego Springs site (Site 1) and the primary Clark Dry Lake site (Site 5), which serves as a comparison due to its comparatively higher groundwater levels and location in a groundwater basin that has not been subjected to overpumping.

Methods

To assess the cover of live and dead mesquite trees, two crosshair transects composed of four 25 m belt transects (2 m wide) were randomly placed within mesquite bosque at each of the two primary sites (Figure 3.10). The center of the crosshair point was located in the field using GPS, and each of the belt transects were walked with a 2 m dowel for 25 m in each cardinal direction. Live, dead, and standing dead mesquite that intersected the 2 m dowel were counted between 12 and 14 April 2023.

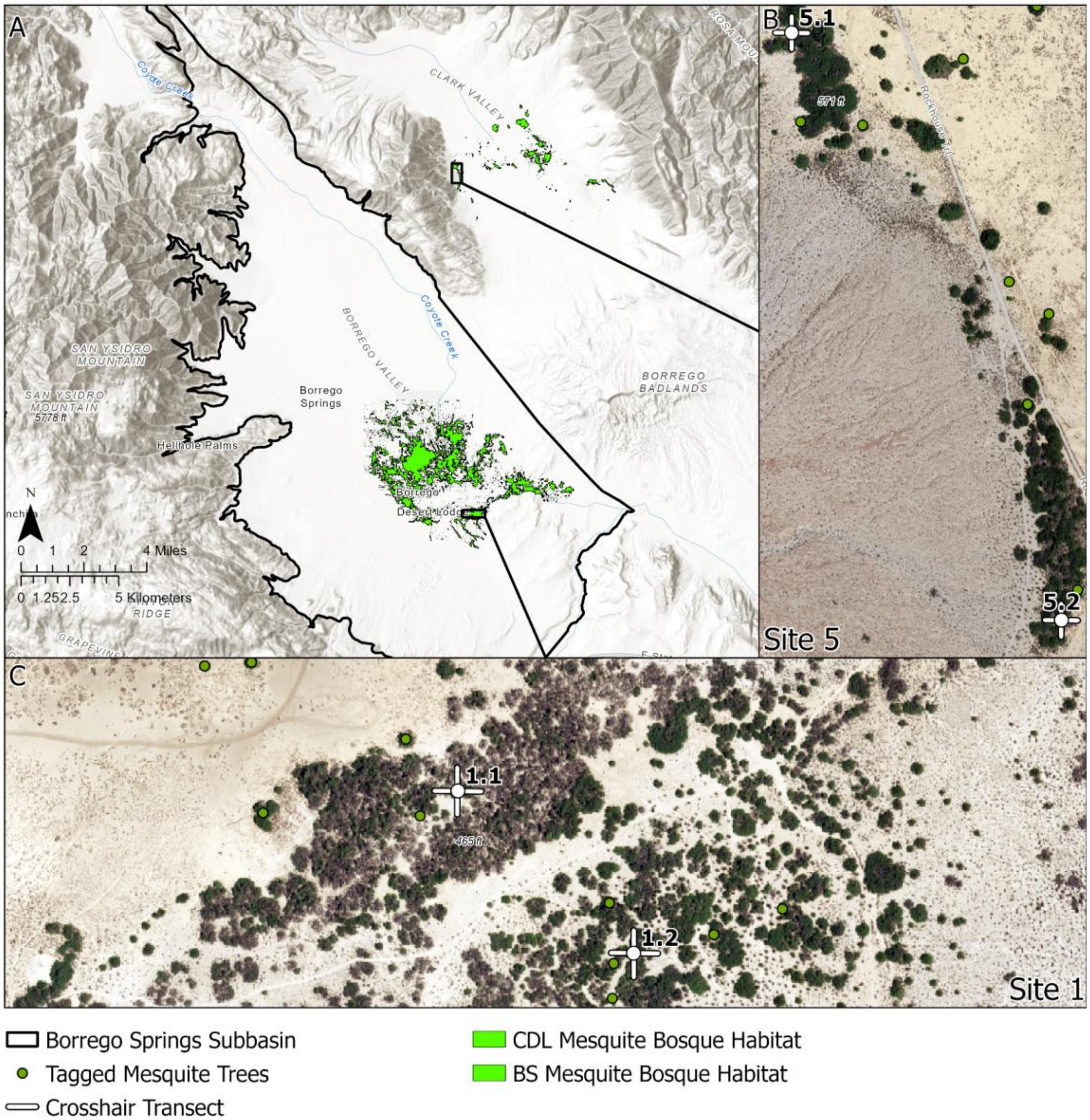

Figure 3.10. Live mesquite cover transects. Location of the crosshair transects used to assess live and dead mesquite coverage at the two primary sites (Sites 1 and 5). Base imagery of insets B - C from the National Agriculture Imagery Program (NAIP) taken 22 - 23 April 2016.

Results

At the primary Borrego Springs site (Site 1), we detected ten living trees and nine dead trees (including standing dead and down dead) at sampling location 1.1, resulting in 53% of living trees. At sampling location 1.2 at Site 1 we found ten living trees and zero dead trees, resulting in 100% of living trees. At the primary Clark Dry Lake site (Site 5), we found nine and twelve living trees at the two sampling locations and zero dead trees resulting in 100% live trees at both sampling locations (5.1 and 5.2).

These findings highlight spatial variability in living and dead tree presence at the Borrego Springs site, including an area with live tree cover similar to the Clark Dry Lake site.

Conclusion

These findings highlight the negative effects of declining groundwater levels on the mesquite bosque near the Borrego Sink. The mesquite bosque near Clark Dry Lake, which has experienced minimal declines in the depth to groundwater, had 100% live coverage, highlighting that the lower coverage of live mesquite near the Borrego Sink results from changes in the groundwater level. However, some areas within the Borrego Springs bosque still maintain high live tree coverage, indicating variability in tree health across the region. Without intervention to slow groundwater depletion near the Borrego Sink, we expect the coverage of live mesquite in this region to continue to decline. In summary, the coverage of live and dead mesquite is a simple but effective method to provide a metric of mesquite health and provide an important warning of significant effects of declines in depth to groundwater to the mesquite bosque.

Plant Surveys of the Mesquite Bosques

Borrego Springs Mesquite Bosque near the Borrego Sink

Between 2023 and 2024, the San Diego Natural History Museum (SDNHM) documented a total of 162 plant species in the Borrego Springs mesquite bosque based on surveys, voucher specimens, and verified iNaturalist observations, 142 of which are native, 20 are non-native, and 7 are classified as rare or on a watchlist (CNPS, 2025; see Table 3.5 and Appendix B.2 Table B2 for full species list). There were 17 plants with specimens mapped to the project area but excluded from the checklist because of vague localities or questionable georeferences (see Appendix B.2 Table B3). Notable findings included two sensitive species: *Cryptantha ganderi* (California Rare Plant Rank 1B.1) and *Cleomella palmeri* (2B.2). SDNHM noted that several areas of the Borrego Springs mesquite bosque show signs of decline, with numerous dead, fallen, and stressed trees, suggesting that the understory may have once been more diverse than what is currently observable.

Table 3.5. Borrego Springs Rare and Watchlist Plants of the mesquite bosque.

Family	Scientific Name	Common Name	CRPR*
Apodanthaceae	*Pilostyles thurberi*	Thurber's Pilostyles	4.3
Boraginaceae	*Cryptantha ganderi*	Gander's Cryptantha	1B.1
Boraginaceae	*Johnstonella costata*	Ribbed Johnstonella	4.3
Cleomaceae	*Cleomella palmeri*	Jackass-Clover	2B.2
Fabaceae	*Astragalus crotalariae*	Salton Milkvetch	4.3
Fabaceae	*Astragalus lentiginosus borreganus*	Borrego Milkvetch	4.3
Solanaceae	*Lycium parishii*	Parish's Desert Thorn	2B.3

* California Rare Plant Rank 1B: Plants rare, threatened, or endangered in California and elsewhere
California Rare Plant Rank 2B: Plants rare, threatened, or endangered in California but common elsewhere
California Rare Plant Rank 4: Plants of limited distribution, a watch list
0.1: Seriously threatened in California (over 80% of occurrences threatened / high degree and immediacy of threat)
0.2: Moderately threatened in California (20-80% occurrences threatened / moderate degree and immediacy of threat)
0.3: Not very threatened in California (less than 20% of occurrences threatened / low degree and immediacy of threat or no current threats known)

Clark Dry Lake Mesquite Bosque

Between 2023 and 2024, SDNHM documented a total of 193 plant species in the Clark Dry Lake mesquite bosque based on surveys, voucher specimens, and verified iNaturalist observations, 176 of which are native, 17 are non-native, and 7 are classified as rare or on a watchlist (see Table 3.6 and Appendix B.2 Table B4 for full species list). There were seven plants with specimens mapped to the project area but excluded from the checklist because of vague localities or questionable georeferences (see Appendix B.2 Table B5). Among the new finds were three sensitive species: *Johnstonella costata* (ranked 4.3), *Cleomella palmeri* (2B.2), and *Johnstonella angelica* (not yet ranked). An unusual discovery was *Ambrosia x platyspina*, a new hybrid record for San Diego County, believed to be a cross between *Ambrosia dumosa* and *Ambrosia salsola*, two common species in the region. The most notable find was a population of *Johnstonella angelica* discovered on the eastern side of Clark Dry Lake. This is only the second U.S. observation of this plant, with the first at the Steele/Burnand Anza-Borrego Desert Research Center in Borrego Springs in 2019. The discovery supports the hypothesis that *J. angelica* is native to the U.S. and warrants consideration for rare-plant listing. This finding has been published in *Madroño* (Donovan & Rebman 2024).

Table 3.6. Clark Dry Lake Rare and Watchlist Plants of the mesquite bosque.

Family	Scientific Name	Common Name	CRPR*
Boraginaceae	*Cryptantha ganderi*	Gander's Cryptantha	1B.1
Boraginaceae	*Johnstonella angelica*	Angelic Johnstonella	†
Boraginaceae	*Johnstonella costata*	Ribbed Johnstonella	4.3
Cleomaceae	*Cleomella palmeri*	Jackass-Clover	2B.2
Fabaceae	*Astragalus crotalariae*	Salton Milkvetch	4.3
Fabaceae	*Astragalus lentiginosus borreganus*	Borrego Milkvetch	4.3
Polemoniaceae	*Eriastrum harwoodii*	Wooly star	1B.2

* California Rare Plant Rank 1B: Plants rare, threatened, or endangered in California and elsewhere
California Rare Plant Rank 2B: Plants rare, threatened, or endangered in California but common elsewhere
California Rare Plant Rank 4: Plants of limited distribution, a watch list
0.1: Seriously threatened in California (over 80% of occurrences threatened / high degree and immediacy of threat)
0.2: Moderately threatened in California (20-80% occurrences threatened / moderate degree and immediacy of threat)
0.3: Not very threatened in California (less than 20% of occurrences threatened / low degree and immediacy of threat or no current threats known)
† Only the second occurrence in the U.S. and rare plant ranking is recommended (Donovan & Rebman 2024)

Comparison of the Two Sites

Of the 176 native plants at the Clark Dry Lake mesquite bosque and the 142 native plants at the Borrego Springs mesquite bosque, 122 species are shared between both locations. Differences in species composition may be attributed to environmental factors: Clark Dry Lake's proximity to rocky slopes contrasts with Borrego Springs's flatter, more disturbed environment near urban infrastructure. Some of the 54 native taxa found at Clark Dry Lake and not at Borrego Springs are more typical of rocky slopes than of flats and bottomlands, such as *Encelia farinosa* var. *phenicodonta*, *Senecio mohavensis, Astragalus palmeri, Sphaeralcea ambigua* var. *rugosa, Cleomella arborea,* and *Nicotiana obtusifolia*. Clark Dry Lake's mesquite bosques are also associated with sand dunes, while the Borrego Springs bosque includes an extensive mesquite forest on flat land, showing significant signs of decline. This degradation may have reduced the historical plant diversity in the area. The Borrego Springs mesquite bosque is also closer to the census designated area of Borrego Springs, and is surrounded by the airport, a dump, a water treatment facility, and residences. It is therefore not surprising that the checklist for the Borrego Springs mesquite bosque has a higher percentage of non-native taxa, at 12.3%, than Clark Dry Lake, at 8.8%.

Wildlife Surveys of the Mesquite Bosques

Introduction

Groundwater-dependent ecosystems (GDEs) provide critical habitat for a wide range of wildlife, particularly in arid environments where surface water is scarce. The mesquite bosque habitats of Borrego Springs and Clark Dry Lake are prime examples of such ecosystems, supporting diverse assemblages of mammals, birds, reptiles, and invertebrates. These woodlands are sustained by groundwater, and as regional water tables decline due to groundwater pumping and climate variability, understanding how wildlife utilizes these habitats is essential for assessing ecosystem health and guiding conservation efforts. Establishing a baseline inventory of species presence, distribution, and habitat use allows for future comparisons as conditions change, while long-term monitoring helps identify vulnerable species and assess ecosystem resilience. To create a comprehensive wildlife inventory, we combined camera traps, bird surveys, and participatory science sources (e.g., iNaturalist and eBird) to document wildlife use of the mesquite bosque habitats in Borrego Springs and at the comparison site near Clark Dry Lake.

Methods

Wildlife Cameras

To document wildlife presence, we deployed seven cameras at both the primary Borrego Springs site (Site 1) and at the primary Clark Dry Lake site (Site 5) (Figure 3.11). Initially, four cameras were deployed at each site from 31 May 2023 to 20 November 2024. In December 2023, three additional cameras were installed to expand coverage. Additionally, in December 2023, two cameras deployed at Site 1 and one camera deployed at Site 5 were moved to new points to improve habitat coverage. Overall, camera traps were in use from May 2023 to November 2024. Images from March 2023 to March 2024 were processed by UC Irvine master's students, and images from March 2024 to November 2024 were processed using Wildlife Insights AI identification and verified by UC Irvine master's students.

Bird Surveys

To assess avian diversity in the mesquite bosques, a team of UC Irvine master's students conducted avian point count surveys at eight survey points, four at a Site 1 and four at Site 5 (Figure 3.11). Each survey consisted of a five-minute observation period at each point, during which all detected bird species were recorded. Surveys were conducted three times, once in December 2023, February 2024, and April 2024.

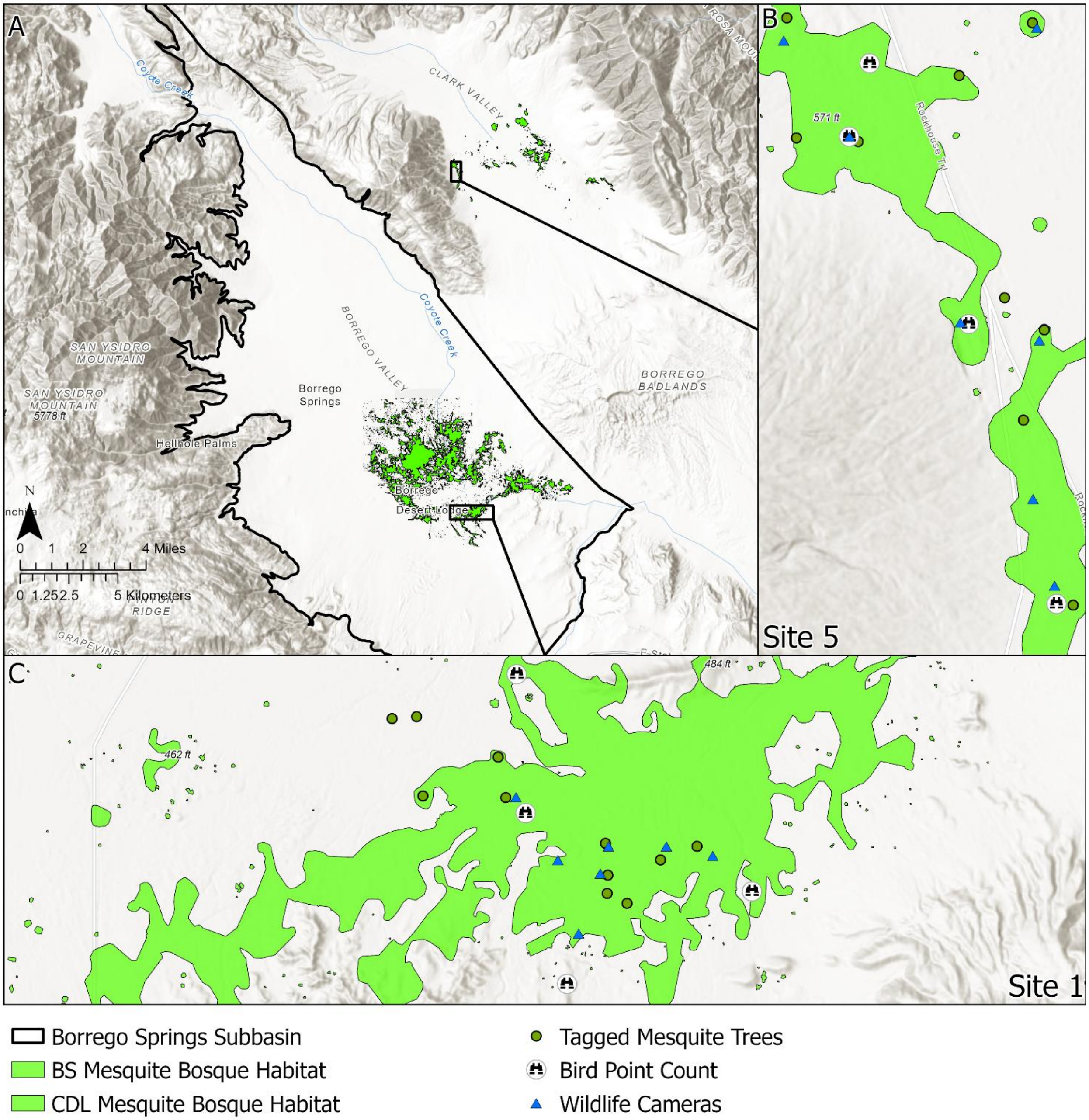

Figure 3.11. Map of the bird point count and wildlife camera locations at Sites 1 and 5.

Species Inventory

We created a species inventory for the mesquite bosque in Borrego Springs near the Borrego Sink and near Clark Dry Lake by compiling data from wildlife cameras, bird surveys, and participatory science

efforts (iNaturalist and eBird). This inventory serves as a baseline for future comparison and will guide future monitoring.
We utilized the California Natural Diversity Database and the International Union for the Conservation of Nature's Red List to include each species' current status. Species status data was included in the inventory for all observations identified to at least species level. The California Natural Diversity Database's Special Animals List was used to provide status data on all taxa (CNDDB 2025). The Special Animals list includes, amongst information from other agencies, information from the California Endangered Species Act (CESA) and the California Department of Fish and Wildlife (CDFW). We focused on California-specific lists as we deemed this information most relevant. Species not included in the Special Animals List status were cross-referenced with the IUCN Red List.

Participatory Science Observations

Christmas Bird Count: The Audubon Society's Christmas Bird Count is the USA's longest-running participatory science bird count and has been contributing valuable information for bird conservation for a century. It is held all over the country between December 14th and January 5th every year. Each bird count takes place within a defined spatial radius; the Anza-Borrego radius contains both Clark Dry Lake and Borrego Springs study areas. Organizers for each survey radius coordinate with volunteer counters to station them in different areas throughout the radius. The counters then record every bird seen or heard that could be identified while moving throughout their area on a specified day. Many utilized eBird to log their data while in the field. Each area reports the number of individuals of each species seen to the organizer, who compiles the count-by-area data and creates a complete species list for the radius. In the Anza-Borrego radius, the Clark Dry Lake area overlaps with part of our Site 5 location, while the North Mesquite and South Mesquite areas overlap with our Site 1 location. We incorporated data from these areas from the 2014 and 2017 counts in our Species Inventory.

iNaturalist Observations: We used the interactive mapping tool on the iNaturalist Observations page to visually identify and manually select all publicly available iNaturalist observations located within a polygon boundary of the mesquite bosque habitat at both sites (iNaturalist, 2025). Observations were filtered to exclude plant observations, as that data was already provided by the SDNHM's Plant Checklists. They were also filtered to only include observations that were "Research Grade," meaning that the identification had been confirmed by at least two independent sources. This helps to reduce inaccuracies, one of the main downsides to utilizing participatory science data. We recorded the method of observation, including sightings, tracks, and calls for each species observed at CDL and BS from the available 2009 to 2025 data.

eBird: eBird is a taxa-specific participatory science platform created by the Cornell Lab of Ornithology that allows users to log bird checklists and keep track of the species they have observed over time. We requested archived data and filtered it to contain only those observations which were located within 50 meters of the mapped mesquite bosque habitats in Borrego Springs or Clark Dry Lake Mesquite. Finally, we recorded each species observed at CDL and BS from 2015 to 2025.

Results

Wildlife Cameras

Camera traps were most effective at capturing medium to large mammals. Coyotes, desert cottontails, and black-tailed jackrabbits were the most common species observed on cameras. Less common sightings include gray foxes, bobcats, roadrunners, hummingbirds, and small mammal species (see Appendix B.3 for a selection of photos). One American badger was observed in July 2023 (Figure 3.12). One camera at Clark Dry Lake was angled to point at the ground and captured the only herpetofauna in our dataset: two species of lizard (western whiptail and desert spiny lizard) and one species of snake (Sonoran gopher snake) (see Appendix B.3 for photos). Overall, the camera traps captured 24 unique species and six groups of a higher taxonomic rank which could not be identified to species.

Figure 3.12. An American badger, *Taxidea taxus*, photographed by camera trap carrying a squirrel at the Clark Dry Lake Mesquite Bosque in July 2023.

Bird Surveys

Surveys documented many migratory and resident bird species in both mesquite bosque locations. Bird abundance and species diversity increased throughout winter and peaked in spring . A significant portion of the birds were also insectivorous, suggesting that many were attracted to the bosques due to the abundance of insects the mesquite trees provide (Johnson et al. 2018). Additionally, the team found the diversity and abundance of birds were similar between Borrego Springs and Clark Dry Lake. This indicates that despite the Borrego Springs Subbasin's groundwater table declining, the mesquite bosque habitat continues to provide significant benefits to the avian fauna.

Species Inventory

We documented 276 different subspecies, species, and genera in the Borrego Springs mesquite bosque habitat near the Borrego Sink and 120 in the mesquite bosque habitat near Clark Dry Lake, including 43 at risk species between the two locations (Table 3.7; see Appendix B.3 for a selection of photos and Table B.6 for the full species list). There was a total of 30 overlapping observations between the two sites, indicating both sites have high, and also relatively unique, wildlife biodiversity.

Table 3.7. Animal and fungus biodiversity. The total number of animal and fungus subspecies, species, and genera found in the Borrego Springs area near the Borrego Sink, near Clark Dry Lake, and the observations that overlapped between the two sites.

Taxa	Borrego Springs Total	Clark Dry Lake Total	Overlapping Observations
Amphibian	1	0	0
Bird	205	65	3
Fungus	2	3	2
Invertebrate	42	40	17
Mammal	11	7	6
Reptile	15	5	2
Total	**276**	**120**	**30**

Conclusion

Through the camera traps, bird surveys, and participatory science datasets, we documented 276 different subspecies, species, and genera in the Borrego Springs mesquite bosque habitat near the Borrego Sink and 120 in the mesquite bosque habitat near Clark Dry Lake, including 43 at risk species between the two locations. These findings illustrate that despite groundwater declines and some mesquite mortality, the Borrego Springs mesquite bosque continues to provide essential habitat for wildlife. However, as groundwater levels continue to decline, ongoing monitoring will be essential to track changes in species composition and ecosystem resilience. These findings will help inform conservation strategies to protect mesquite bosques and the wildlife they support in the face of environmental change.

Quantification of Mesquite Groundwater Transpiration

Understanding Mesquite Dependence on Groundwater

The results provided in previous sections of this report addressed critical knowledge gaps regarding mesquite health and water use patterns. As facultative phreatophytes, mesquite trees can access both deep groundwater and surface water from recent rainfall, but the overwhelming finding from the field, remote sensing, and evapotranspiration (ET) work indicates that live mesquite near the Borrego Sink are strongly dependent on groundwater for their survival. While mesquite trees can utilize surface water when available, the arid climate and limited precipitation characteristic of Borrego Springs are unlikely to sustain this habitat in the long term if groundwater levels continue to decline.

While accounting for GDEs in the Borrego Springs Subbasin (Subbasin) water budget is a critical aspect of the Sustainable Groundwater Management Act (SGMA), quantifying and understanding the mesquite bosque's dependence on groundwater requires more than accounting for an outflow. It requires recognizing the complex and dynamic relationship between Groundwater Dependent Ecosystems (GDEs) and aquifers. Groundwater depth and mesquite water use fluctuate seasonally and in response to climatic conditions and groundwater pumping. While mesquite may adapt to short-term changes through compensatory root growth, long-term groundwater decline can lead to irreversible ecological impacts, including mesquite mortality and shifts in plant community composition toward less groundwater-dependent species. These changes alter biodiversity, disrupt ecosystem services, and reduce the overall resilience of the mesquite bosque. Recognizing these dynamics, and their spatial patterns across the landscape, is essential for sustainable water management in the Subbasin.

In the following section, we provide estimates of mesquite groundwater transpiration (ETgw) using the best available science from OpenET. OpenET models show significant variability in ETgw estimates for the Borrego Springs mesquite bosque, ranging from 3.71 to 1,332.75 acre-feet per year, depending on the model and year analyzed. The ensemble model, which integrates multiple approaches, estimates ETgw between 130.34 and 770.49 acre-feet per year. Given the high uncertainty in these estimates, we recommend conservatively allocating at least 645 acre-feet per year of groundwater use to the mesquite bosque GDE in the Subbasin water budget. This estimate provides a precautionary buffer until more precise data becomes available via ET sensors.

To improve accuracy and better inform groundwater management, we recommend continued ET sensor monitoring throughout a full water year and under varying climate conditions. Additionally, the depth to groundwater should be continually monitored near the mesquite bosque, and well depth thresholds should account for mesquite water requirements. The long-term health of the mesquite bosque GDE and the biodiversity it supports depends on proactive groundwater management. Without such efforts, declining groundwater levels will place this unique GDE at significant risk.

OpenET Estimates of ETgw

Introduction

The studies informing groundwater management planning in the Borrego Springs Subbasin previously dismissed the presence of GDEs. Consequently, decision-makers generally assumed that evapotranspiration from non-irrigated landscapes was equal to the localized annual precipitation and did not significantly impact groundwater storage. However, our field research, remote sensing data, and ET sensor results confirm that the mesquite bosque is a GDE and must be recognized as a beneficial user of groundwater in the Subbasin water budget.

To provide an initial estimate of mesquite groundwater use and its potential impact on the Subbasin water budget, we estimated annual groundwater transpiration (ETgw) for the mesquite bosque habitat from 2015 to 2023 using simplified water balance equations and OpenET data.

Methods

To estimate groundwater transpiration by mesquite, we used the water balance equation (Equation 3.1) proposed by Eamus et al. (2016), which states that:

$$\text{Groundwater transpiration } (ET_{gw}) = \text{Evapotranspiration (ET) - Precipitation (P)} \qquad (3.1)$$

Using Google Earth Engine scripts, we calculated ETgw by subtracting precipitation estimates from modeled ET values provided by OpenET (Melton et al. 2022). OpenET is an open-access platform that integrates remote sensing data, such as vegetation indices (e.g., NDVI) and land surface temperature, with climate variables, including temperature, humidity, and solar radiation, to estimate ET. In Borrego Springs, OpenET provides monthly ET estimates at a 30 m resolution (i.e., a pixel size of 30 m × 30 m), which is suitable for landscape-scale analysis but lacks the precision needed for tree-level assessments. For the mesquite bosque habitats near the Borrego Sink and in Clark Dry Lake, we calculated annual ETgw for each water year from 2015 to 2023 (October 1–September 30).

Open ET Limitations

While OpenET is widely used in agricultural settings, its accuracy declines when estimating ET for natural vegetation. This is due to the scarcity of direct ET measurements in natural ecosystems, requiring models to rely on satellite, meteorological, soil, and vegetation datasets. These models may not fully capture the complexities of natural ecosystems, particularly in arid environments like Borrego Springs where sparse vegetation cover can lead to underestimation of ET due to the 30 m resolution.

Studies have shown that OpenET can be applied to natural ecosystems, but error rates are significantly higher than in croplands. For instance, relative error rates can be around 35% for forests and up to 50% for shrublands. Given these uncertainties, OpenET estimates should be interpreted as an approximate range rather than a precise value.

Results

Estimates of Groundwater Transpiration

We estimated groundwater transpiration (ETgw) for each 30 m x 30 m pixel within mesquite bosque habitats near the Borrego Sink and Clark Dry Lake for all water years from 2015 to 2023. Table 3.8 presents the ETgw estimates from each OpenET model, revealing significant variability across models and between years. This variation reflects fundamental differences in how each model calculates ET, as well as interannual fluctuations driven by precipitation patterns, vegetation vigor, and climate conditions.

The high degree of variability underscores the challenges of accurately estimating ET in natural ecosystems, where conditions are complex and dynamic. Given the acknowledged 30–50% error rates for natural landscapes, we recommend considering the full range of modeled ET estimates. To ensure long-term sustainability, we suggest allocating at least 645 acre-feet per year of groundwater use to the mesquite bosque GDE in the Subbasin water budget—potentially more, as improved data becomes available. This estimate is based on the All-Year Model Average (430.45 acre-feet) plus a 50% error margin (215.23 acre-feet), resulting in a total of 645.68 acre-feet, rounded to 645 acre-feet for simplicity.

Table 3.8. Groundwater transpiration estimates. Estimates of groundwater transpiration (ETgw) for the Borrego Springs and Clark Dry Lake mesquite bosque habitats, as calculated by each OpenET model from 2015-2023. See https://etdata.org/methodologies/ for more information about each model.

	Model	Ensemble-mean	DisALEXI	eeMETRIC	geeSEBAL	PT-JPL	SIMS	SSEBop	Model Averages
Site	Water Year	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)
Borrego Springs	2015	547.22	349.84	198.09	1,072.90	1,028.81	29.20	434.34	522.91
	2016	339.55	197.32	136.17	565.89	1,100.21	14.72	259.15	373.29
	2017	446.97	408.98	94.83	870.27	1,252.09	3.71	286.86	480.53
	2018	770.49	455.24	320.57	1,099.89	1,332.75	12.03	667.94	665.56
	2019	175.47	167.74	39.12	301.43	1,096.31	5.63	188.00	281.96
	2020	261.52	219.58	88.56	379.61	767.27	9.90	459.42	312.27
	2021	597.53	354.57	238.76	896.17	1,081.24	14.53	605.59	541.20
	2022	490.31	174.09	273.14	761.65	1,076.15	7.41	397.87	454.37
	2023	130.34	64.29	39.30	564.62	752.61	5.86	136.45	241.92
								All-year Average	**430.45**

	Model	Ensemble-mean	DisALEXI	eeMETRIC	geeSEBAL	PT-JPL	SIMS	SSEBop	Model Averages
Site	Water Year	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)	Total ETgw (ac-ft/yr)
Clark Dry Lake	2015	70.37	54.97	32.96	115.32	186.80	0.64	20.06	68.73
	2016	48.70	36.74	20.90	78.53	194.02	1.02	10.35	55.75
	2017	58.13	59.65	23.01	100.81	215.96	1.11	10.59	67.04
	2018	104.23	71.07	37.62	133.20	241.93	6.29	43.92	91.18
	2019	28.81	19.73	10.40	56.73	194.81	0.76	9.28	45.79
	2020	56.10	60.32	27.42	81.83	188.10	0.89	34.32	64.14
	2021	84.70	43.37	41.74	117.77	214.27	2.19	49.43	79.07
	2022	61.15	30.05	34.42	76.74	220.20	2.14	18.94	63.38
	2023	23.81	13.50	9.16	57.77	165.47	1.53	5.16	39.49
								All-year Average	**63.84**

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4. Potential Adverse Impacts to GDEs

Chronic Lowering of Groundwater Levels

Introduction

Under SGMA, there are six groundwater conditions that could lead to undesirable impacts on Groundwater Dependent Ecosystems (GDEs), one of which is the chronic lowering of groundwater levels. If there is little change in groundwater levels from baseline conditions (**Baseline Groundwater Conditions** section) then there are likely not detrimental effects for the mesquite bosque GDE. This analysis addresses long-term and short-term rates of changes in groundwater levels and the magnitude of change to assess possible effects to the mesquite bosque GDE. We assess trends in groundwater depth at wells in Borrego Springs near the Borrego Sink and at a nearby comparison site, Clark Dry Lake, which is in the Ocotillo-Clark Groundwater Basin, and which has not been subjected to overpumping. We focus our assessment of the magnitude of change on those wells located within 50 m of mesquite bosque habitat in Borrego Springs near the Borrego Sink.

Methods

To assess changes in well depths over time in the vicinity of the mesquite bosque in both Borrego Springs and near Clark Dry Lake, we acquired data from West Yost (acquired November 2023), the California Department of Water Resources (https://wdl.water.ca.gov/; accessed December 2024), and San Diego County (County of San Diego, Planning & Development Services, Historical Groundwater Level Monitoring Database; accessed February 2025) (Figure 4.1, Table 4.1).

We removed any points flagged for quality and removed clear signatures of pumping that resulted in anomalous data points, and which were not flagged in the dataset already. To detect these signatures, we looked for rebounds of over 20 feet between consecutive measurements within a year that occurred before April or after October so as not to include possible drawdowns by phreatophytes during their growing season. This resulted in five data points being removed for well 10S06E35N001S between 1965 and 1970 and three data points being removed for Well 3 between 2018 and 2022.

Rate of Change

To assess trends in the depth to groundwater we selected wells with greater than 10 time points on which to run linear regressions with measurement depth as the independent variable and the depth to groundwater as the dependent variable. This resulted in 14 models for wells in Borrego Springs and two models for wells near Clark Dry Lake.

Magnitude of Change

To assess the magnitude of change in groundwater levels, we selected all wells within 50 m of the mesquite bosque habitat in Borrego Springs which resulted in eight wells from the original 20 (MW-3, MW-5A, MW-5B, 11S06E01C001S, 7N1, 11S06E11M001S, 12G, 11S06E11D002S; see Table 3.1 for well information in the **Baseline Groundwater Conditions** section). We plotted these wells alongside the baseline average and range to assess the susceptibility of the mesquite bosque GDE to adverse effects resulting from changes in groundwater levels. All analyses were performed in R (R Core Team, 2024; v. 4.3.3).

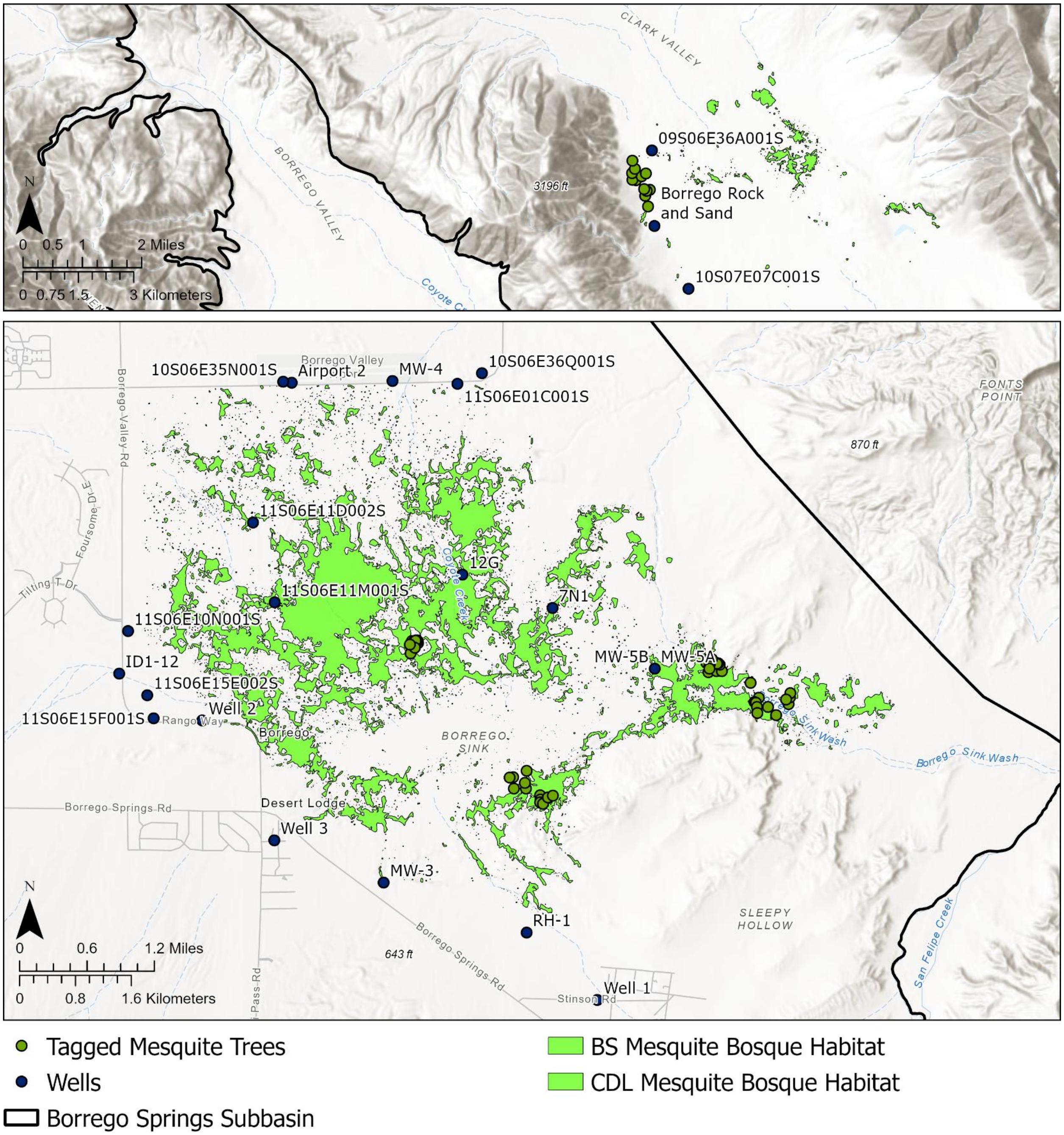

Figure 4.1. A map of wells assessed for groundwater trends. Wells 1 - 3 are anonymized for privacy reasons, so the coordinates presented here have been altered.

Table 4.1. Well depths. Identifying information, depth to groundwater, and data source for the examined wells. Groundwater depth data from DWR and San Diego County are the most recent data available while the data from West Yost were acquired in November 2023. The asterisk accompanying some values in the Local Well Name column indicates that this well has been anonymized for privacy reasons.

State Well Number	Local Well Name	Latitude	Longitude	Reference Point Elevation (ft)	Groundwater Level Elevation (ft)	Depth from Reference Point to Groundwater Level (ft bgs)	Date of Measurement	Data Source
Borrego Springs								
10S06E35N001S	10S06E35N001S	33.2575	-116.3272	522.23	522.23	94.75	2009-06-09	DWR
10S06E36Q001S	10S06E36Q001S	33.2584	-116.3016	533.36	533.36	72.79	1980-08-08	DWR
11S06E01C001S	11S06E01C001S	33.25725	-116.3047	519.42	519.42	Dry	2021-04-28	DWR
11S06E10N001S	11S06E10N001S	33.2306	-116.3472	524.24	524.24	124.16	2009-03-11	DWR
11S06E11D002S	11S06E11D002S	33.2423	-116.3311	502.23	502.23	83.47	2009-03-10	DWR
11S06E11M001S	11S06E11M001S	33.2337	-116.3283	489.23	489.23	Unable to measure	2009-03-10	DWR
11S06E15E002S	11S06E15E002S	33.2237	-116.3447	522.25	522.25	Dry	2009-03-11	DWR
11S06E15F001S	11S06E15F001S	33.2212	-116.3439	522.25	522.25	Dry	2009-03-11	DWR
11S06E12G001S	12G	33.2367	-116.3041	477.23	477.23	62.5	2009-03-26	DWR

11S07E07N001S	7N1	33.2331	-116.2925	477.23	477.23	Dry	2009-03-26	DWR
10S06E35N001S	Airport 2	33.25738	-116.3261	517.49	516.91	Unable to measure	2024-04-16	DWR
11S06E16A002S	ID1-12	33.22603	-116.3483	533.2	532.65	148.6	2024-04-16	DWR
11S06E25A001S	RH-1	33.19812	-116.2959	526.9	526.32	59.88	2024-04-17	DWR
11S06E23J002S	MW-3	33.20316	-116.3143	523.36	522.65	77.63	2023-11-14	West Yost
10S06E35Q001S	MW-4	33.25756	-116.3131	517.33	517.75	111.46	2023-11-14	West Yost
11S07E07R001S	MW-5A	33.22656	-116.2793	466.11	466.45	58.68	2023-11-13	West Yost
11S07E07R002S	MW-5B	33.22656	-116.2793	464.8	465.14	58.33	2023-11-13	West Yost
NA	Well 1*	NA	NA	562.65	560	93.1	2023-11-14	West Yost
NA	Well 2*	NA	NA	509.85	508.85	108.85	2023-11-13	West Yost
NA	Well 3*	NA	NA	542.22	539.82	93.09	2023-11-16	West Yost
Clark Dry Lake								
10S07E07C001S	10S07E07C001S	33.3243	-116.2905	556.9	529.36	27.54	2024-06-11	San Diego County
09S06E36A001S	09S06E36A001S	33.3525	-116.2994	572.33	550.94	21.39	2009-03-09	DWR
NA	Borrego Rock and Sand	33.33711	-116.2988	553.1	529.77	23.33	2024-06-11	San Diego County

Results

Rate of Change

Long-term trends

There were nine wells with available data ranging from the mid-1950s until the mid-2000s which we used to assess long-term trends in groundwater depth near the Borrego Sink. Six of the nine wells had sufficient data for statistical analysis and of these six wells all showed significant declines in groundwater levels ranging from around four feet per decade to over 12 feet per decade (Table 4.2, Figure 4.2). There was one well with available long-term data at the nearby comparison site Clark Dry Lake ranging from the mid-1950s to the mid-2000s. This well showed a significant decline in groundwater levels though the magnitude of this change is less than those wells facing declines in Borrego Springs (-0.83 feet per decade; Table 4.2, Figure 4.3) and likely results from regional hydroclimatic change as this groundwater basin (Ocotillo-Clark Groundwater Basin) has not experienced overpumping.

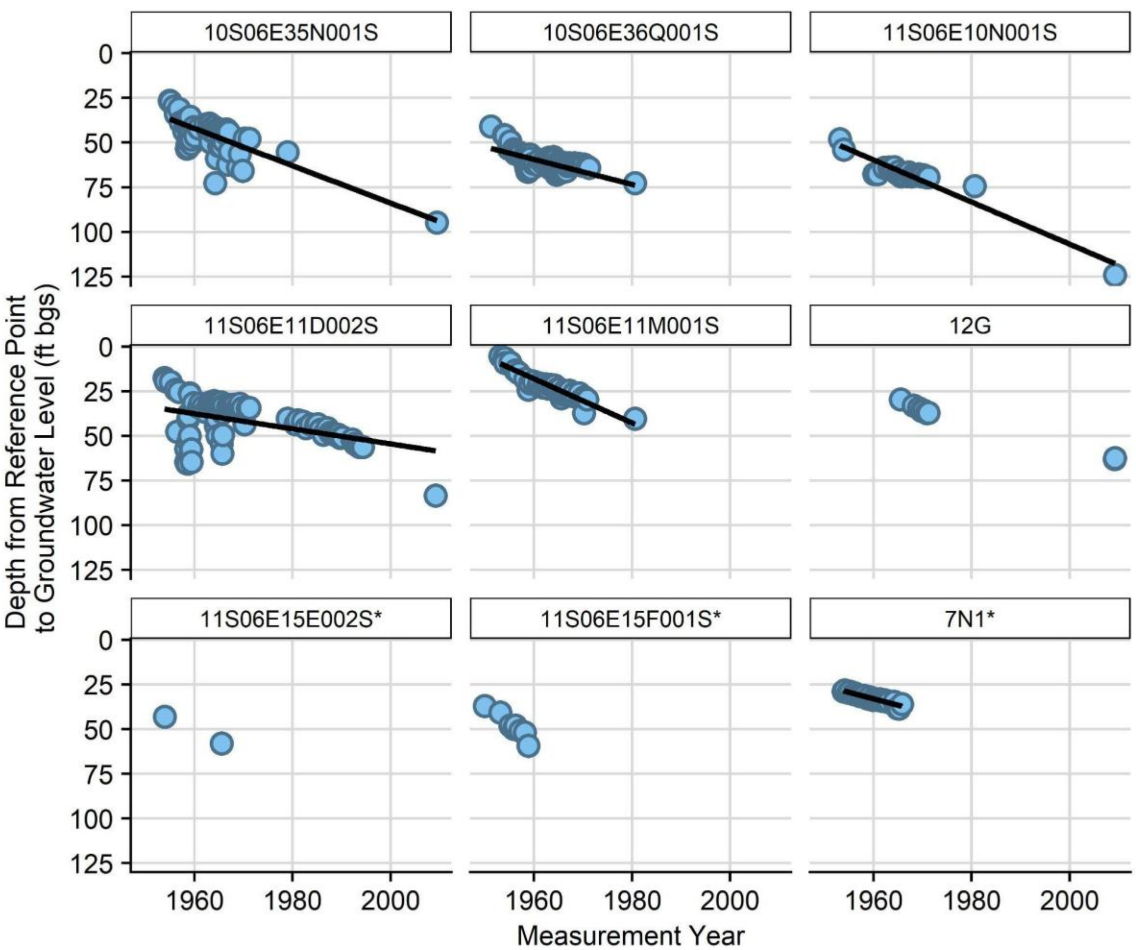

Figure 4.2. Long-terms trends in well depths in Borrego Springs. The depth from a reference point to the groundwater level for nine wells in Borrego Springs with data ranging from the 1950s to the mid-2000s. A black trendline indicates that there were greater than 10 measurement dates and that the relationship between groundwater depth and time was assessed with a linear model (Table 4.2). A solid line indicates a significant relationship. An attempt was made to measure the groundwater depth for well 11S06E11M001S (second row, second column) on 2009-03-10 but the US Geological Survey team was unable to get the tape in the casing. The asterisks indicate the well was dry at the last measurement date. Well 11S07E07N001S (7N1; third row, third column) was last measured 2009-03-10 and 2009-03-26. Well 11S06E15E002S and 11S06E15F001S were last measured 2009-03-11.

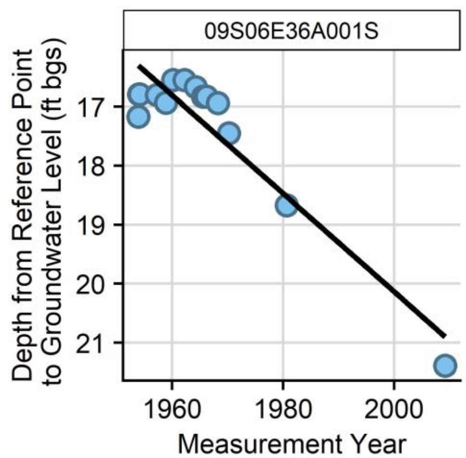

Figure 4.3. Long-terms trends in well depths near Clark Dry Lake. The depth from a reference point to the groundwater level for a well near Clark Dry Lake with data from the mid-1950s to the mid-2000s. A black trendline indicates that there were greater than 10 measurement dates and that the relationship between groundwater depth and time was assessed with a linear model (Table 4.2). A solid line indicates a significant relationship.

Table 4.2. Groundwater depth rate of change. For those wells with greater than 10 data points, we ran linear regressions assessing the change in depth to groundwater over time. The slope in feet/day (Slope ft/day) column indicates the slope derived from the linear regression while the slope in feet per year and feet per decade have been calculated. A bolded p-value indicates a significant relationship between the depth to groundwater and time at a significance level of 0.05.

State Well Number	Local Well Name	Slope (ft/day)	Slope (ft/year)	Slope (ft/decade)	P-value	R^2
Borrego Springs						
Long-Term Trends (mid-1950s to mid-2000s)						
10S06E35N001S	10S06E35N001S	-0.0032	-1.18	-11.85	>**0.001**	0.35
10S06E36Q001S	10S06E36Q001S	-0.0019	-0.70	-7.00	>**0.001**	0.45
11S06E10N001S	11S06E10N001S	-0.0032	-1.18	-11.79	>**0.001**	0.91
11S06E11D002S	11S06E11D002S	-0.0012	-0.42	-4.23	>**0.001**	0.18
11S06E11M001S	11S06E11M001S	-0.0034	-1.23	-12.35	>**0.001**	0.87
11S07E07N001S	7N1	-0.0020	-0.72	-7.20	>**0.001**	0.92
Short-Term Trends (mid-2000s to present)						
11S06E01C001S	11S06E01C001S	-0.0044	-1.62	-16.19	>**0.001**	0.999
11S06E23J002S	MW-3	-0.0055	-2.02	-20.18	>**0.001**	0.61
10S06E35Q001S	MW-4	-0.0038	-1.40	-13.99	>**0.001**	0.999
11S07E07R001S	MW-5A	-0.0016	-0.60	-5.98	>**0.001**	0.90
11S07E07R002S	MW-5B	-0.0015	-0.56	-5.58	>**0.001**	0.98
NA	Well 1	-0.001	-0.41	-4.08	0.21	0.17
NA	Well 2	-0.0016	-0.60	-5.96	>**0.001**	0.91
NA	Well 3	0.0008	0.29	2.88	0.30	0.047
Clark Dry Lake						
Long-Term Trends (mid-1950s to mid-2000s)						
09S06E36A001S	09S06E36A001S	0.000227800	0.08314700	0.8314700	>**0.001**	0.87
Short-Term Trends (mid-1990s to present)						
10S07E07C001S	10S07E07C001S	-0.0003	-0.1054485	-1.054485	>**0.001**	0.67

Short-term trends

There were an additional 11 wells in the Borrego Sink area which we used to assess more recent trends in groundwater depth (mid-2000s to now). Eight of the 11 wells had sufficient data for statistical analysis and of these, six wells showed significant declines in groundwater levels ranging from 5.5 feet per decade to over 20 feet per decade (Table 4.2, Figure 4.4). There were two additional wells near Clark Dry Lake with data ranging from the mid-1990s to the present. Only one of these wells had sufficient data for analysis and this well showed a decline in groundwater levels over time, though this rate was similarly low compared to the long-term groundwater trends explored at this location (-1.05 feet per decade; Table 4.2, Figure 4.5).

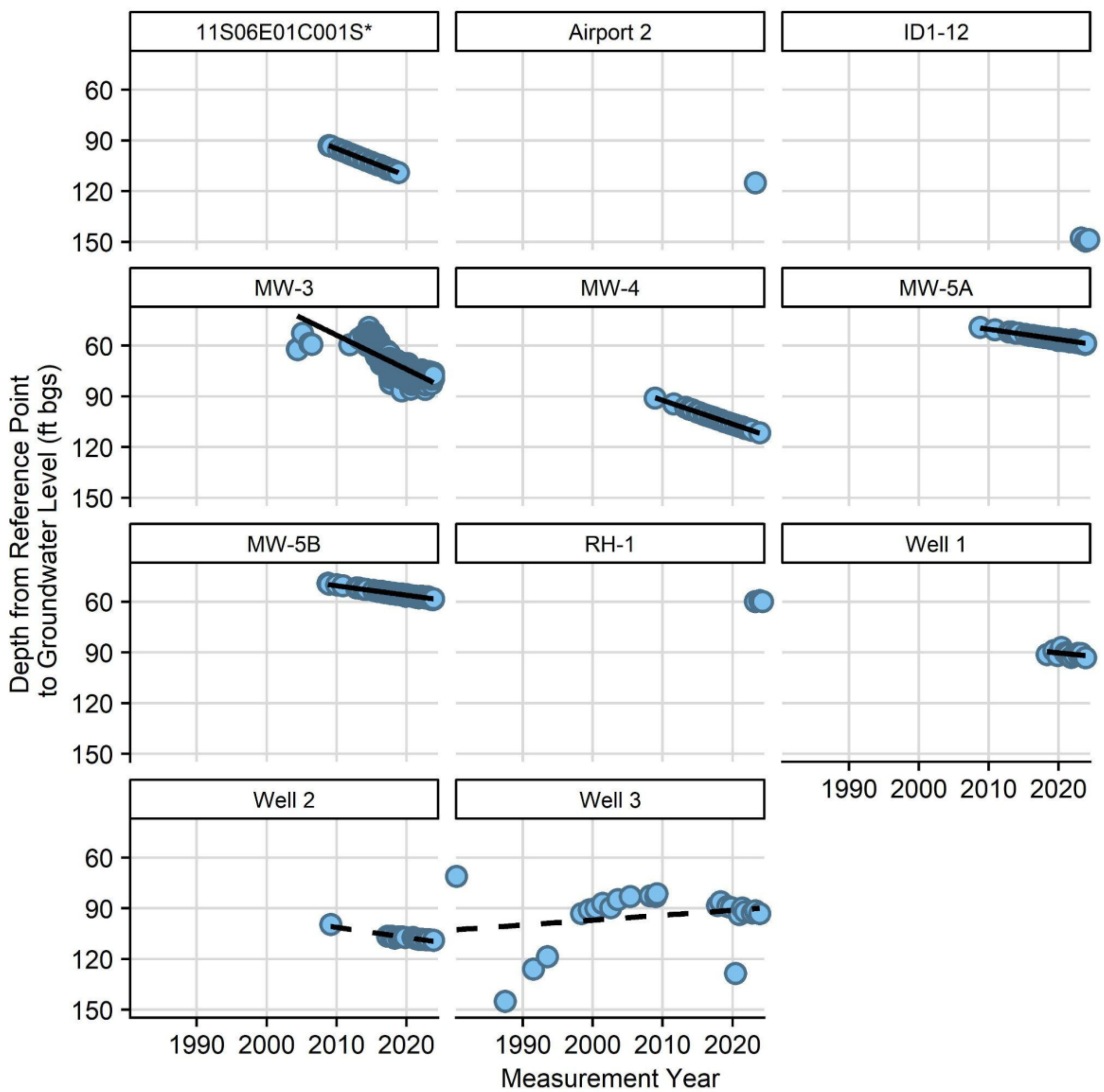

Figure 4.4. Short-terms trends in well depths in Borrego Springs. The depth from a reference point to the groundwater level for eleven wells in Borrego Springs with data largely ranging from the mid-2000s to present, with the exception of Well 3 with data into the mid-1980s. A black trendline indicates that there were greater than 10 measurement dates and that the relationship between groundwater depth and time was assessed with a linear model (Table 4.2). A solid line indicates a significant relationship while a dashed line indicates a non-significant relationship. The asterisks indicate the well was dry at the last measurement date. Well 11S06E01C001S (first row, first column) was measured on 30 April 2019, 29 October 2019, 29 April 2020, 28 October 2020, and 29 April 2021 and was dry at each measurement. Note that the Airport 2 is no longer able to be measured.

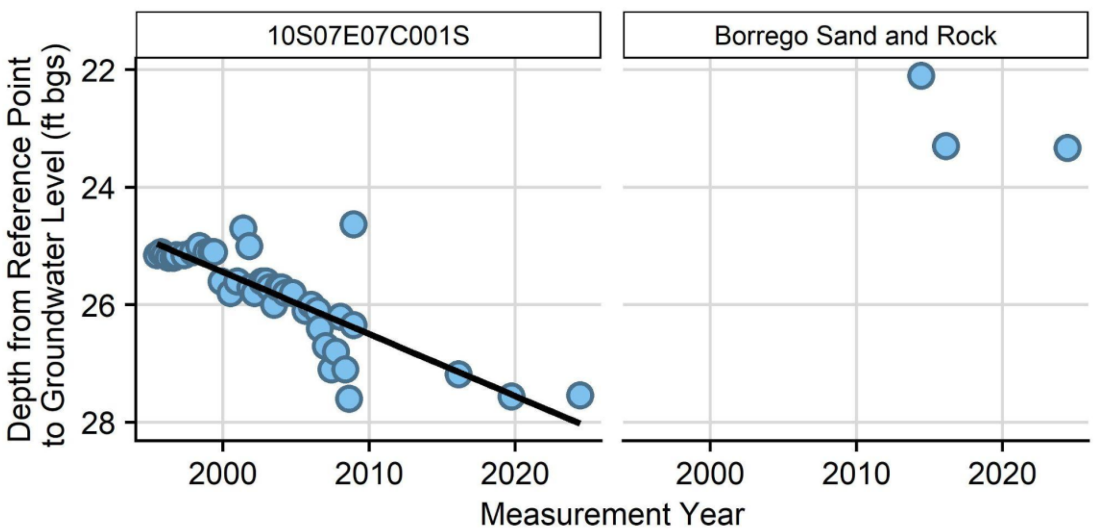

Figure 4.5. Short-terms trends in well depths near Clark Dry Lake. The depth from a reference point to the groundwater level for two wells near Clark Dry Lake with data from the mid-1990s to the present. A black trendline indicates that there were greater than 10 measurement dates and that the relationship between groundwater depth and time was assessed with a linear model (Table 4.2). A solid line indicates a significant relationship.

Magnitude of Change

Of the eight wells, one well (11S06E01C001S) had groundwater levels greater than the upper limit of the baseline range (59.6 ft bgs) since the beginning of monitoring, three wells crossed the upper limit of the baseline range during their monitoring period (11S06E11D002S, 12G, MW-3), and the remaining four wells showed downward trends leading near the upper limit of the baseline range (Figure 4.4). Based on these data, we assigned a susceptibility rating of "High GDE Susceptibility to Undesirable Effects" to each well (see Table 4.3 for rationale).

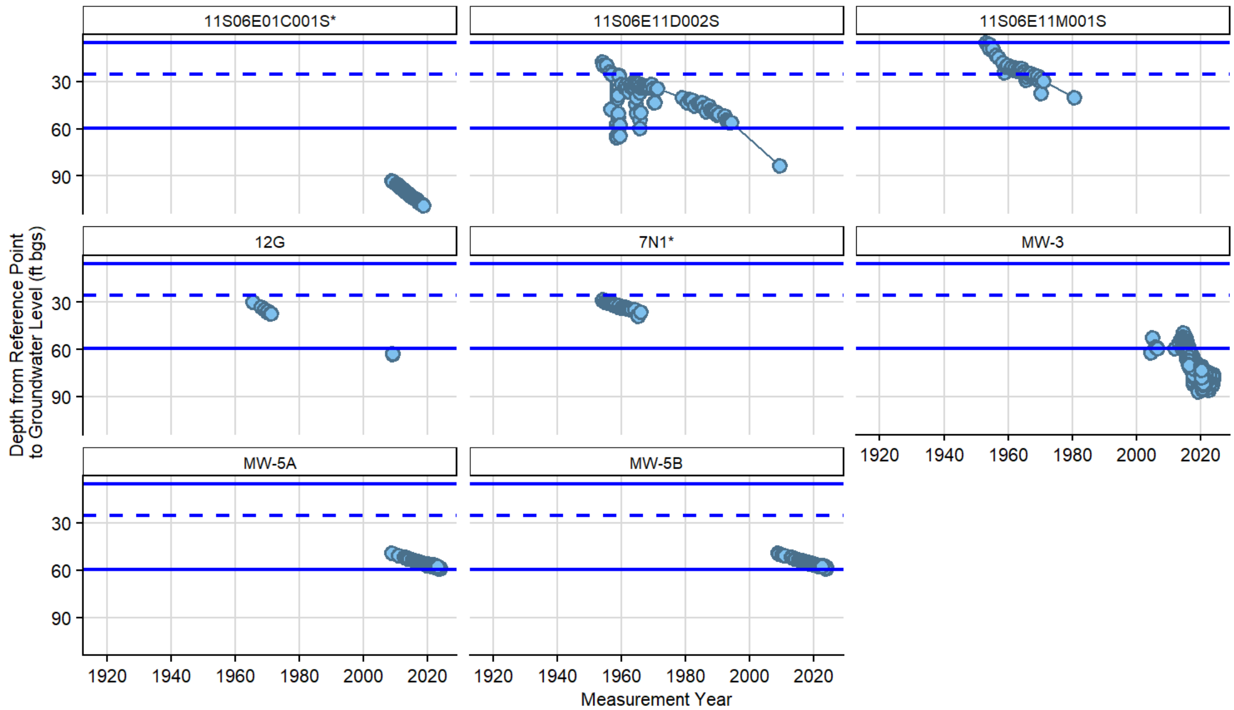

Figure 4.6. Magnitude of well depth change. The depth from a reference point to the groundwater level for eight wells in Borrego Springs that are within 50 m of mesquite bosque. The blue horizontal lines indicated the range (solid lines: 5.3 ft bgs and 59.6 ft bgs) and average (dotted lines: 25.5 ft bgs) baseline groundwater levels determined in **Baseline Groundwater Conditions**. The asterisks indicate the well was dry at the last measurement date. Well 11S06E01C001S (first row, first column) was measured on 30 April 2019, 29 October 2019, 29 April 2020, 28 October 2020, and 29 April 2021 and was dry at each measurement. Well 11S07E07N001S (7N1; third row, third column) was last measured 2009-03-10 and 2009-03-26.

Table 4.3. GDE susceptibility based on well data. The susceptibility of the eight wells located within 50 m of mesquite bosque habitat in Borrego Springs near the Borrego Sink.

State Well Number	Local Well Name	Susceptibility Rating	Rationale
Borrego Springs			
11S06E01C001S	11S06E01C001S	High GDE Susceptibility to Undesirable Effects	Groundwater levels consistently deeper than the upper limit of the baseline range
11S06E11D002S	11S06E11D002S	High GDE Susceptibility to Undesirable Effects	Declining trend that has surpassed the upper limit of the baseline range
11S06E11M001S	11S06E11M001S	High GDE Susceptibility to Undesirable Effects	Declining trend; no recent data
11S06E12G001S	12G	High GDE Susceptibility to Undesirable Effects	Declining trend that has surpassed the upper limit of the baseline range
11S07E07N001S	7N1	High GDE Susceptibility to Undesirable Effects	Declining trend; currently dry
11S06E23J002S	MW-3	High GDE Susceptibility to Undesirable Effects	Declining trend that has surpassed the upper limit of the baseline range
11S07E07R001S	MW-5A	High GDE Susceptibility to Undesirable Effects	Declining trend that is approaching the upper limit of the baseline range
11S07E07R002S	MW-5B	High GDE Susceptibility to Undesirable Effects	Declining trend that is approaching the upper limit of the baseline range

Conclusion

The high rate of groundwater declines and the strong magnitude of change in groundwater levels indicates a high likelihood of adverse effects on the mesquite bosque near the Borrego Sink. The rate of groundwater decline was much greater for wells in Borrego Springs compared to wells in Clark Dry Lake. The slow rate of decline at Clark Dry Lake, rather than resulting from overpumping, likely resulted from protracted drought conditions of the contemporary period which lessened aquifer recharge. As the mesquite bosque near Clark Dry Lake has remained healthy, this suggests that the demonstrated rates of change are not causing adverse effects to the mesquite bosque at this site and/or that the lowered groundwater levels are still within the range of acceptable conditions for the mesquite bosque at this site. In contrast, when examining wells within 50 m of the mesquite bosque habitat near the Borrego Sink, we saw levels that either exceeded the baseline groundwater level range on the upper limit (59.6 ft bgs) or were trending towards exceeding 59.6 gt bgs. The only wells in recent times with groundwater levels that have not exceeded 59.6 ft bgs are MW-5A and MW-5B, which are located near some of the healthier mesquite bosque GDE. However, even these wells indicate that the mesquite bosque in that area is highly susceptible to change because the current conditions and trend suggest that their future groundwater levels (within the next five years) will exceed the baseline range. In summary, recent conditions demonstrate that detrimental effects to the mesquite bosque GDE are occurring and will continue to occur without actions to reduce the decline of groundwater levels.

Changes in Mesquite Bosque Health

Introduction

The Sustainable Groundwater Management Act (SGMA) requires agencies to evaluate the potential adverse effects of groundwater conditions on Groundwater Dependent Ecosystems (GDEs) to ensure sustainable resource management. This analysis focuses on long-term trends in mesquite bosque health in relation to groundwater availability near the Borrego Sink using remote sensing techniques.

Methods

To assess potential adverse effects on the mesquite bosque GDE, we analyzed long-term trends in mesquite bosque health using remote sensing data. Specifically, we utilized Landsat imagery, which provides the most comprehensive, long-term record of vegetation data available from 1984 to 2024. Landsat's 30-meter spatial resolution (i.e., a pixel size of 30 m × 30 m) is well-suited for monitoring vegetation health at both the patch and landscape scale, though it is not suited for assessing individual trees.

We focused our analysis on two time periods:

1. Long-term Changes (1984 - 2015)
2. SGMA Implementation Period (2015 - 2024)

The analysis targeted the dry season (May 1- June 30), which is the driest period in Borrego Springs (see **Historical Precipitation Trends** section). During this time, mesquite trees are most likely to rely on groundwater, making it a critical window for evaluating their ecological health and groundwater access (Klausmeyer et al., 2018). GDEs are particularly sensitive to changes in groundwater availability, and the health of phreatophytic vegetation like mesquite is closely linked to groundwater conditions.

Data Acquisition

We used Google Earth Engine to obtain Landsat satellite imagery (30 m resolution; i.e., a pixel size of 30 m × 30 m) for the Borrego Springs mesquite bosque covering each time period. To enhance data accuracy, we removed cloud and shadow pixels. For each image, we calculated the Normalized Difference Vegetation Index (NDVI), a widely used metric for assessing vegetation health, where higher values indicate healthier vegetation and lower values signal stress or reduced vitality (Tucker, 1979). We then filtered for the dry season (May 1–June 30) and computed the average dry period NDVI for each year. This period was selected to capture the vegetation's response to groundwater availability during times of minimal surface moisture.

Calculation of Change Over Time

To evaluate long-term changes in mesquite health during the dry period, we analyzed the trend in NDVI over each time period using Mann-Kendall's Tau (MK Tau) statistical test. This non-parametric method identifies monotonic trends, which are consistent, non-reversing increases or decreases, without assuming linearity (Kendall, 1948). This approach is particularly effective for detecting gradual, persistent shifts in vegetation health that could be obscured by short-term fluctuations in climate or other environmental factors.

The MK Tau statistic ranges from -1 to +1:

- A Tau value close to -1 indicates a consistent downward trend, indicating that mesquite dry period health is declining over time, which is linked to reduced groundwater availability and other anthropogenic impacts. We classified tau values from -1 to -0.5 as strong, consistent declines, and tau values from -0.5 to -0.25 as moderate, consistent declines.
- A Tau value near +1 suggests a consistent upward trend, indicating improving dry period health, possibly due to more favorable ecological conditions or stable groundwater access. We classified tau values from 1 to 0.5 as strong, consistent increases, and tau values from 0.5 to 0.25 as moderate, consistent increases.
- A Tau value near zero indicates no significant change, implying that mesquite health has remained stable, which can indicate good ecological conditions or stable groundwater access. We classified tau values from -0.25 to 0.25 as no change.

Results

Long-term Changes in Mesquite Health (1984-2015)

Over the past four decades (1984 - 2015), approximately 36 acres of mesquite have improved, 331 acres have remained stable, and 1,846 acres have declined (note that total acreages calculated here are impacted by Landsat's 30 m pixel size, which can overestimate the acreage of the finer scaled mesquite bosque polygons). The most significant mesquite declines are concentrated south of Palm Canyon Drive, west of Borrego Valley Road, and along Rango Way, where urban development, roads, and former agricultural activity have likely contributed to habitat deterioration (shown in red in Figure 4.7). This widespread decline in mesquite NDVI during dry periods aligns with documented reports of mesquite die-off and declining groundwater levels, particularly in areas affected by human disturbance (see photos in Figure 4.9). The areas of mesquite stability and improvement coincide with current strongholds of healthy mesquite habitat, particularly around the Borrego Sink, where groundwater is closer to the surface (shown in tan and blue in Figure 4.7; see photos in Figure 4.10). Notably, the mesquite bosque habitat near the wastewater treatment plant shows some of the strongest increases in mesquite health over time.

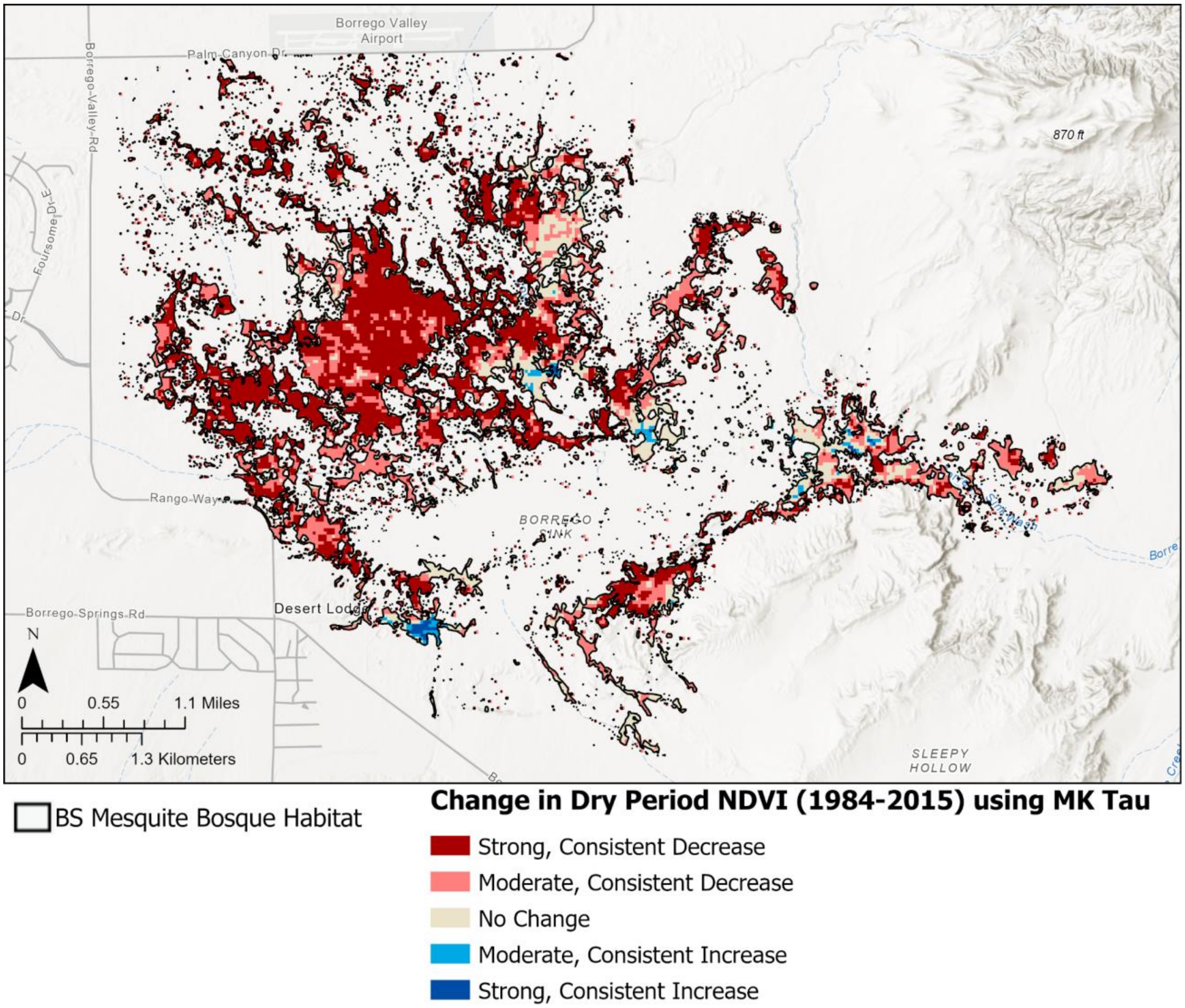

Figure 4.7. Long-term changes (1984-2015) in dry period NDVI in the Borrego Springs mesquite bosque. Areas in red have consistently declined over the past four decades, while areas in tan have remained stable, and areas in blue have consistently improved. Approximately 1,846 acres of mesquite have declined, 331 acres have remained stable, and 36 acres have improved.

SGMA Period Trends (2015–2024)

Since the implementation of SGMA, 266 acres of mesquite have improved, 1,350 acres have remained stable, and 598 acres have declined. Compared to the longer historical time frame, fewer areas show signs of decline, indicating that most mesquite degradation occurred before SGMA was enacted.

However, approximately 600 acres continue to deteriorate (shown in red in Figure 4.8), likely due to persistent groundwater level decreases and reduced groundwater availability, which are specified as undesirable effects under SGMA. Notably, the areas where mesquite has remained stable or improved during the SGMA period closely align with long-term strongholds, primarily concentrated around the Borrego Sink, where groundwater is closer to the surface (shown in tan and blue in Figure 4.8).

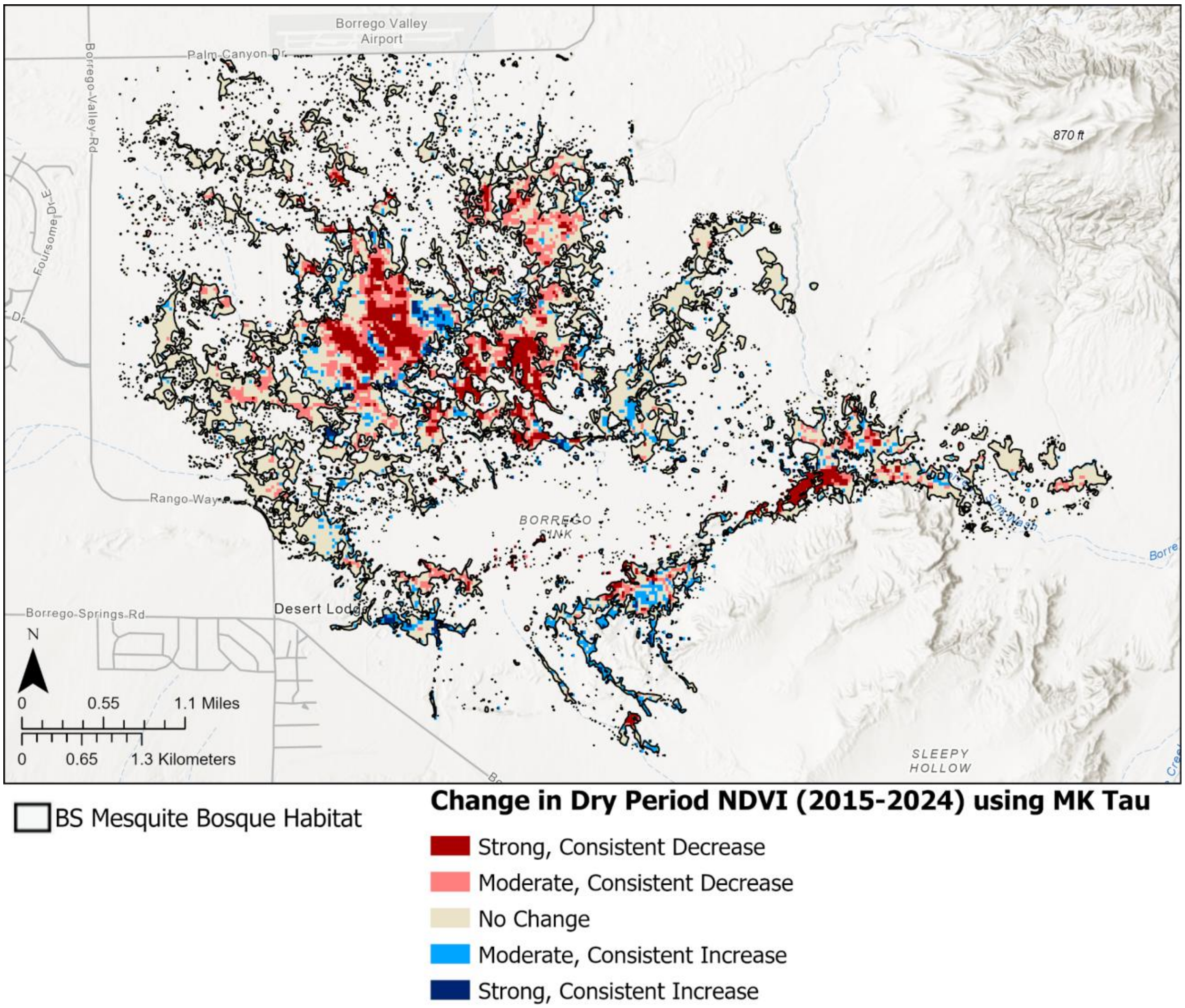

Figure 4.8. SGMA Implementation Period (2015-2024) changes in dry period NDVI in the Borrego Springs mesquite bosque. Nearly 600 acres have shown consistent declines since the implementation of SGMA, demonstrating undesirable consequences of groundwater pumping (shown in red), while areas in tan have remained stable, and areas in blue have consistently improved.

Figure 4.9. Examples of mesquite bosque habitat that have experienced declines in health. Photos were taken by the GDE Project team in 2023 and 2024.

Figure 4.10. Examples of healthy mesquite bosque habitat that show stability or improvements in health. Photos were taken by the GDE Project team in 2023 and 2024.

Additional Drivers of Adverse Effects on the Mesquite Bosque

While groundwater depletion remains the dominant and ongoing driver of mesquite bosque degradation (Stromberg et al., 1992), other factors have also contributed to the decline of this GDE. Human development—including agriculture, landfill expansion, and the construction of residences and roads—has significantly altered land surface dynamics within mesquite bosque habitat. These impacts are particularly pronounced in the northern (off Palm Canyon Drive), western (off Borrego Valley Road, Rango Way, and Yaqui Pass Road), and eastern (near the landfill) regions. Direct removal of mesquite trees, modifications to the land surface and surface water flow, and soil disturbance have collectively reduced habitat quality. Additionally, increased soil compaction and erosion from land use changes further stress the mesquite bosque GDE. Off-road vehicle activity and the creation of dirt roads throughout much of the habitat continue to cause widespread physical damage.

Beyond these direct human disturbances, climate change poses an escalating threat. Rising temperatures, shifting precipitation patterns, and increased frequency of extreme weather events may exacerbate mesquite stress, particularly during already dry periods. Disease and pest outbreaks, which can be opportunistic in weakened tree populations, further compound the risk.

Groundwater depletion amplifies the mesquite bosque's vulnerability to all of these stressors. When mesquite trees experience chronic water stress due to declining groundwater levels, they become less resilient to disease, pests, and extreme climatic conditions. Additionally, reduced root-zone moisture exacerbates soil erosion and degradation, making habitat loss more severe and recovery more difficult. Thus, while sustainable groundwater management is critical, mesquite bosque conservation must also address broader environmental threats. Immediate habitat protection measures—such as restricting development, limiting vehicle access, and preventing further land-use disturbances—are essential to safeguarding this unique groundwater-dependent ecosystem.

Conclusion

By analyzing dry-season NDVI trends and applying the Mann-Kendall Tau test, we identified areas where mesquite health is declining (red), stable (tan), or improving (blue). The continued decline of 600 acres of mesquite from 2015 to 2024 suggests that groundwater conditions are still deteriorating, indicating ecosystem degradation and undesirable effects across the SGMA implementation period. The most significant declines in mesquite health align with areas of substantial human disturbance and groundwater level reductions, indicating that many mesquite trees may have lost access to groundwater over the past 40 years. If groundwater depletion persists, habitat degradation will continue, threatening both the bosque and the biodiversity it supports.

To mitigate further groundwater disconnection and address these compounding threats, we recommend establishing minimum groundwater thresholds for wells near the mesquite bosque and implementing conservation measures to protect healthy, stable mesquite areas. These measures should include restricting construction, development, and vehicle use within the habitat to prevent further degradation. Proactive groundwater management, coupled with comprehensive conservation strategies that address human impact and climate-related challenges, will be essential to preserving the long-term health of this groundwater-dependent ecosystem and ensuring its resilience in the face of future environmental changes.

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5. Monitoring and Management Recommendations

Here we provide a set of activities and options that would allow the vested stakeholders in Borrego Springs to employ a data-driven approach to groundwater extraction decision-making in light of obligations under the Sustainable Groundwater Management Act (SGMA) associated with potential undesirable outcomes for the identified Groundwater Dependent Ecosystem (GDE). This is not an exhaustive list, and it is assumed that the activities below will lead to a greater understanding of the system, supporting a long-term adaptive management approach to integrating GDE dynamics into the Subbasin governance of groundwater. Importantly, as an integrating concept, we recommend that the watermaster use the goal of understanding the geometry of groundwater depths (groundwater depth rasters) as a vehicle for integrating information about GDEs as compared to a reliance on storage of the system as a whole.

Hydrological Monitoring Recommendations

To ensure the long-term sustainability of the mesquite bosque as a Groundwater Dependent Ecosystem (GDE) post-SGMA implementation, we recommend the following hydrological monitoring measures:

1. **Continued monitoring of key wells**
    - **MW-5A/B**: These wells should continue to be monitored as primary indicators of groundwater levels influencing the mesquite bosque.
    - **Other Relevant Wells**: Additional wells 11S06E12G001S (last measured in 2009), 11S06E11D002S (last measured in 2009), and 11S06E11M001S (last attempt to measure was in 2009 but it was unsuccessful) in the vicinity of the mesquite bosque should be prioritized for continued monitoring to capture spatial variability in groundwater conditions affecting the GDE.
2. **Establishment of a minimum threshold for key wells**
    - A minimum threshold for wells near the mesquite bosque should be set based on historical groundwater level data. Between 1953 and 1963, the depth to groundwater across three wells with available data ranged from 5.3 ft bgs to 59.6 ft bgs, with an average depth of **25.5 ft bgs**.
    - To prevent adverse impacts on the mesquite bosque, we recommend using the maximum baseline depth of **59.6 ft as a minimum threshold**, ensuring that groundwater levels do not decline below this point for extended periods. It is likely that our estimate of 59.6 ft bgs is on the high end and that a more shallow value may be

more appropriate, but we see the baselines identified here as a starting point for an adaptive approach and thus they may require modifications.
   - To provide more effective annual decision-making we recommend that the thresholds be established associated with rates of annual decline at key sites in addition to the depth threshold above. One way to accomplish this is by leveraging hydrologic modeling of groundwater depth and remotely sensed performance of the mesquite bosque to assess where rapid declines have occurred or are most problematic.
3. **Tracking groundwater trends using depth to groundwater rasters**
   - Developing and maintaining depth-to-groundwater rasters for each water year will provide a broader understanding of groundwater trends and potential impacts on the mesquite bosque. These rasters can be created by subtracting the groundwater elevation rasters created by West Yost from a digital elevation model (available from USGS).
   - These maps will help track seasonal and long-term fluctuations in groundwater availability, allowing for adaptive management responses if declining trends are observed near the mesquite bosque.
   - Additionally, these maps will support the Watermaster in analyzing groundwater decline patterns under different pumping scenarios, which is essential for minimizing impacts on GDEs, which are spatially limited in the Subbasin.

Biological Monitoring Recommendations

1. **Continued monitoring of the mesquite bosque via remote sensing**
   - Remote sensing provides an affordable method for large-scale monitoring of the mesquite bosque over time. We recommend continued monitoring of mesquite bosque NDVI to track the spatial patterns in ecosystem productivity, health, and groundwater use. Cumulative NDVI across the water year provides the most accurate depiction of overall mesquite bosque productivity and health, and mean NDVI across the dry season (May 1 - June 30) provides the most accurate depiction of mesquite health during peak groundwater use. Evaluating mesquite performance alongside changes in groundwater depth is essential for adaptive management of the system.
2. **Continued monitoring of the mesquite bosque live and dead tree cover using field surveys**
   - Conducting repeated surveys of live and dead mesquite coverage is a cost-effective way to track coverage and assess undesirable effects. We suggest surveys be conducted at

selected sites every two to three years so that changes could be tracked over time, related to groundwater conditions, and used to validate the remote sensing assessments (which should be the leading response variable to plant mortality).

3. **Continued monitoring of evapotranspiration (ET) sensors**
   - The ET sensors provide real time monitoring of water fluxes in the mesquite bosque and can be maintained at an affordable, and low maintenance level. We recommend the continued monitoring of the established ET sensors to track water use over time, which can provide information on ecosystem health and groundwater conditions. We recommend routine checks and data collection every 3 - 5 months.
4. **Continued monitoring of mesquite bosque biodiversity**
   - Declines in mesquite bosque health and habitat quality will negatively impact the local plant and wildlife communities that depend on the mesquite. See Appendix C for recommendations for a three-tier monitoring plan.

Management Recommendations

1. **Designating the mesquite bosque GDE as a beneficial user of groundwater**
   - We recommend the allocation of at least 645 acre-feet of groundwater use per year specifically to the mesquite bosque GDE in the Subbasin water budget for planning purposes. We recommend continued ET monitoring (remote sensing with *in situ* ET sensors for ground truthing) to provide more accurate estimates of groundwater use across multiple years and climate conditions.
2. **Conservation of high and moderate productivity mesquite**
   - We recommend prioritizing the conservation of high- and moderate-productivity mesquite, shown in Figures 3.8 and 3.9. These areas provide high quality habitat for dependent flora and fauna, as well as valuable ecosystem services for Borrego Springs.
   - We recommend initiating restoration and mitigation planning in areas with strong potential for mesquite regeneration and sustained performance. This includes locations influenced by anthropogenic factors, such as those near the wastewater treatment plant.
3. **Minimize soil surface disturbance in mesquite bosque habitats**
   - We recommend minimizing vehicle use and off-roading where possible in mesquite bosque habitats to prevent further degradation to this sensitive ecosystem.
   - We recommend that Anza-Borrego Desert State Parks review driving trails that cross through mesquite bosque habitat to assess where these roads intersect with sensitive

and/or high-quality habitat and close unofficial trails or trails that could be causing harm to the mesquite bosque.

4. **Potential strategies to improve groundwater conditions**
    - SGMA provides an opportunity to address pre-SGMA impacts. As highlighted in TNC's Ventura County Case Study, removal of invasive species that use groundwater, such as tamarisk, has been shown to improve groundwater conditions. Implementing targeted tamarisk removal projects in the Borrego Sink vicinity could enhance groundwater availability for the honey mesquite and support the broader ecosystem. However, the extent of tamarisk within this area is minimal and thus its removal would not be the only action required to address groundwater declines.
    - We recommend an explicit exercise to understand scenarios surrounding the spatial pattern of groundwater elevation change given different pumping scenarios associated with the planned pumping drawdown. This Subbasin is sufficiently simple to allow for the Watermaster to use integrated budgeting of storage relative to the performance of different pumpers but also has sufficient complexity that the differential pumping in the Subbasin influences the spatial pattern of hydraulic head (pressure associated with the characteristics of the Subbasin and pumping that affect how water flows). How the spatial pattern of head pressure leads to flow influencing groundwater elevations near the Borrego Sink may be the key to the sustainability of the GDE during the period of drawdown to a safe yield.

6. Conclusions

Through multiple lines of evidence using the best available scientific methods and datasets, the GDE Project has demonstrated that the Borrego Springs mesquite bosque is actively using groundwater (thus a GDE by SGMA definition). While the mesquite bosque is indeed in declining health, we have demonstrated that a significant portion of the mesquite bosque is still considered a highly productive habitat that hosts unique flora and fauna that are dependent on the mesquite trees and the benefits they provide. Importantly, declines in mesquite bosque health are largely attributable to declines in groundwater depths. Our estimated maximum baseline of 59.6 ft bgs as a minimum threshold is already being exceeded by many key wells in the vicinity of the mesquite bosque near the Borrego Sink and will be exceeded in the near future by other wells (i.e., MW-5A/B). We urge the Borrego Springs Watermaster and other relevant management and conservation groups to take immediate actions to protect and conserve the mesquite bosque and its reliant biodiversity. As a beneficial user of groundwater, we recommend allocation of 645 acre-feet of groundwater in the Subbasin water budget, the establishment of minimum thresholds in nearby wells (which are at or exceeding first baseline estimates), and additional conservation actions to protect high quality habitat.

Appendices

Appendix A. Identification of GDEs

A.1. Mapping the GDEs

Methods

Image classification

To identify the coverage of mesquite within our study area we used object-based supervised classification in ArcGIS Pro (v. 3.1.0) with the Support Vector Machine (SVM) as our supervised classification approach. Supervised image classification involves the researchers creating training samples which the software then learns from to classify the entire image into set categories (Table A1). We used the default settings for SVM within ArcGIS. We classified 0.7 m resolution National Agriculture Imagery Program imagery (NAIP) visualized in the near infrared as this provided greater contrast between the mesquite and perennial shrubs. The NAIP imagery came from 22 and 23 April 2016 and was mosaicked in Google Earth Engine. This year was selected because it was the closest year to SGMA implementation (2015) that contained high quality imagery when plants were active.

We conducted the supervised image classification for our two primary sites separately. In the Borrego Springs Subbasin, we used the Palm Canyon Drive and Borrego Valley Road as our north and west bounds, respectively. To the south and east, we used the extent of mesquite within the Borrego Springs Subbasin as our bounds (Figure A1). At Clark Dry Lake, we included the expanse between the feet of the two mountain ranges bounding the lake to the east and west (Figure A1). Training samples took the form of polygons (Table A1). There were some spots in the Clark Dry Lake area that had been mapped by the County of San Diego (SanGIS, 2022) as mesquite bosque that were challenging to determine from aerial imagery whether the vegetation was mesquite or creosote bush, so our partners at the San Diego Natural History Museum investigated on the ground. After classification, classes other than Live Mesquite were reclassified as Barren to simplify validation, as only the Live Mesquite category was of interest. For validation, we used 100 random assessment points per category (equal stratification for Live Mesquite and Barren) for each primary site. We report user's accuracy, producer's accuracy, overall accuracy, and kappa (Congalton 1991). User's accuracy indicates the probability that a classified object actually represents that category according to the validation data. Overall accuracy is the percentage of true positives. Kappa evaluates the performance of the classification compared to random assignment where values closer to one indicate the classification is better than random assignment (Viera & Garrett 2005). The Borrego Springs supervised image classification had an overall accuracy of 96% and the Clark Dry Lake supervised image classification had an overall accuracy of 95% (Table A2). The kappa coefficient for the Borrego Springs supervised image classification was 0.92 and the kappa coefficient for the Clark Dry Lake supervised image classification was 0.9 (Table X).

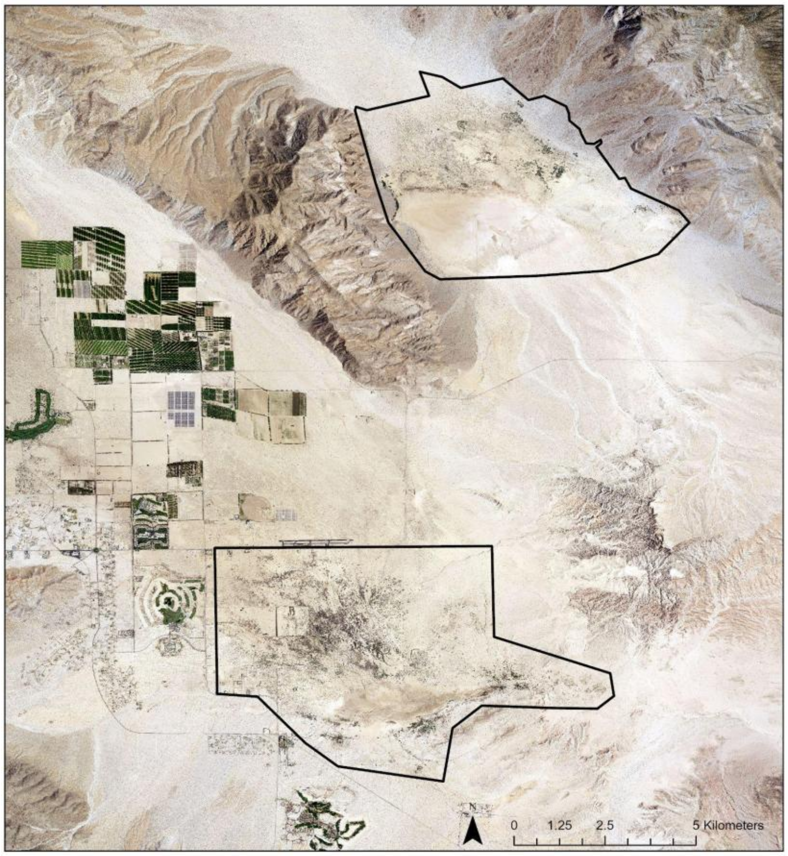

Figure A1. The areas across which image classification was performed.

Table A1. The categories and cover of training samples at each primary site.

Site	Category	No. of Samples	% of Pixels
Borrego Springs	Barren	47	42.9
	Dead Mesquite	86	1.7
	Live Mesquite	71	2.5
	Shrubland	33	52.7
	Shadow	15	0.1
Clark Dry Lake	Barren	9	91.7
	Live Mesquite	18	0.2
	Shrubland	8	8.1
	Shadow	3	0.02

Table A2. Results of the confusion matrix. Columns indicate what the object actually was based on validation data and the rows represent what the pixel was classified as.

Site		**Bareground**	**Live Mesquite**	**User's Accuracy (%)**
Borrego Springs	Bareground	99	1	99
	Live Mesquite	7	93	93
	Producer's Accuracy (%)	93.4	98.9	**Overall Accuracy** = 96% **Kappa** = 0.92
Clark Dry Lake		Bareground	Live Mesquite	User's Accuracy (%)
	Bareground	100	0	100
	Live Mesquite	10	90	90
	Producer's Accuracy (%)	90	100	**Overall Accuracy** = 95% **Kappa** = 0.9

Mapping of the mesquite bosque

The image classification was used alongside on-the-ground field observations to redraw the boundaries of mesquite bosque in the Borrego Sink area and Clark Dry Lake. These new boundaries were compared to those from a map created by the City and County of San Diego as well as the San Diego Association of Governments in 1995 which characterizes vegetation communities according to the Holland system (Holland 1986, SanGIS 2022).

To redraw the boundaries of the mesquite bosque we first selected only the polygons produced during image classification with an area greater than 5 m^2 in order to minimize the presence of shrubs which may have been inaccurately classified. We next created a 5 m buffer around the resultant polygons. Then we aggregated the resultant polygons that were within 10 m from each other to include only polygons with a minimum size of 400 m^2 after aggregation and a minimum hole size of 1000 m^2. The buffering and aggregating steps were done to ensure we mapped a mesquite bosque ecosystem rather than individual, isolated mesquite trees. Next, to produce polygons with a simplified shape, we simplified the polygons with the "Retain Critical Bends (Wang-Müller)" simplification algorithm with a 25 m simplification tolerance and a minimum area of 1000 m^2. We then eliminated polygon holes smaller than 50,000 m^2 and used the Dissolve tool to merge all overlapping polygons. Next, we aggregated polygons within 50 m of each other to better capture the mesquite bosque habitat, which includes interstitial space and associated understory vegetation in addition to live mesquite trees. Finally, as the habitat map methods may have excluded isolated individual trees, we ensured that any mesquite trees that were identified in the live mesquite tree map were also included in the habitat map.

To quantitatively assess the resultant mesquite bosque habitat area, we used the vegetative alliances assigned by the Manual of California Vegetation (Sawyer et al. 2009), which is distributed by the California Native Plant Society and the California Department of Fish and Wildlife and employs a quantitative assignment system adopted by state and federal agencies. The mesquite thickets alliance (also known as the *Prosopis glandulosa - Prosopis velutina - Prosopis pubescens* Woodland Alliance) is equivalent to Holland's mesquite bosque grouping originally used to map the mesquite bosque in 1995 and the most stringent membership qualifications stipulate an absolute cover of mesquite greater than 2% (Sawyer et al. 2009). To ensure our map met this qualification we selected the image classification polygons found only within the map area and then divided the total area of those polygons by the total area of the mapped mesquite bosque. For the Borrego Springs map, we found an absolute cover of 16.6% mesquite by area. For the Clark Dry Lake, we found an absolute cover of 36.4% mesquite by area. Hence, our mapping effort is conservative as it includes land surface with cover considerably higher than the minimum threshold of 2% identified by the Manual of California Vegetation definition for the mesquite thickets alliance (Sawyer et al. 2009).

References

Holland, R. F. (1986). *Preliminary descriptions of the terrestrial natural communities of California*. State of California, The Resources Agency, Department of Fish and Game.

San Diego Geographic Information Source (SanGIS). (2022). "ECO_VEGETATION_CN" Layer. Regional Vegetation to illustrate the vegetation communities and disturbed areas throughout San Diego County. Available at https://gis-sangis1.hub.arcgis.com/pages/download-data. Version: 13 October 2022.

Sawyer, J., Keeler-Wolf, T., & Evens, J. (2009). A manual of California vegetation, 2nd Edition. (p. 1300). Sacramento, CA. *California Native Plant Society*. Online version available at https://vegetation.cnps.org/

A.2. Sampling Conditions

Methods

Precipitation prior to field sampling

We assessed precipitation conditions prior to measuring water potential and collecting twigs and soil for isotopic analysis to confirm dry surface soil conditions. We used the Elementary School weather station in Borrego Springs and the Clark Dry Lake weather station near Clark Dry Lake to determine the cumulative precipitation in the 14 days leading up to the first date of the sampling campaign and the dates of precipitation in these windows (https://anzaborrego.ucnrs.org/weather/).

Field collected soil moisture during sampling campaigns

In 2024, when sampling soils for soil water for isotopic analysis we additionally collected subsamples to determine soil moisture. Depths at which we collected soil moisture were identical to the depths at which soil was collected for isotopic analysis. Because the soil is homogenized before subsampling, soil moisture reflects a range of depths: 0–10 cm (0–3.9 in), 10–40 cm (3.9–15.7 in), 40–70 cm (15.7–27.6 in), 70–100 cm (27.6–39.4 in), and 100–150 cm (39.4–59.1 in). Two replicates were collected at each depth range. In total, 22 soil cores were collected across the mesquite study sites, and sandy, well-drained soils were consistently observed across all depths and sites. There were no signs of clay layers, waterlogged soils, or any impermeable layers indicative of a perched aquifer. Soils were collected in tins and kept on ice until being stored at 4°C prior to processing. Briefly, soil wet weight and soil dry weight were measured to assess gravimetric soil moisture using the following equation: (soil wet weight – soil dry weight) / soil dry weight. Soil dry weight was determined by drying soils at 105°C for 48 hours.

Continuous soil moisture during the study period

We installed continuous soil moisture sensors at the primary Borrego Springs site in June 2023. Soil moisture sensors (CS655, Campbell Scientific Inc.) were installed at 30 cm (11.8 in), 50 cm (19.7 in), 70 cm (27.6 in), 90 cm (35.4 in), 110 cm (43.3 in), 130 cm (51.2 in), and 150 cm (59.1 in). Soil moisture data was collected via a CR800 data logger (CS655, Campbell Scientific Inc.) and loggers were powered by a 15 W solar panel. During installation, sandy, well-drained soils were observed throughout all depths. No evidence of clay layers, waterlogged soils, or any impermeable layers indicative of a perched aquifer was encountered. We confirmed the soil moisture sensors were operating correctly using rainfall data from the Elementary School Weather Station to test that soil moisture values increased following significant rainfall (Figure A2).

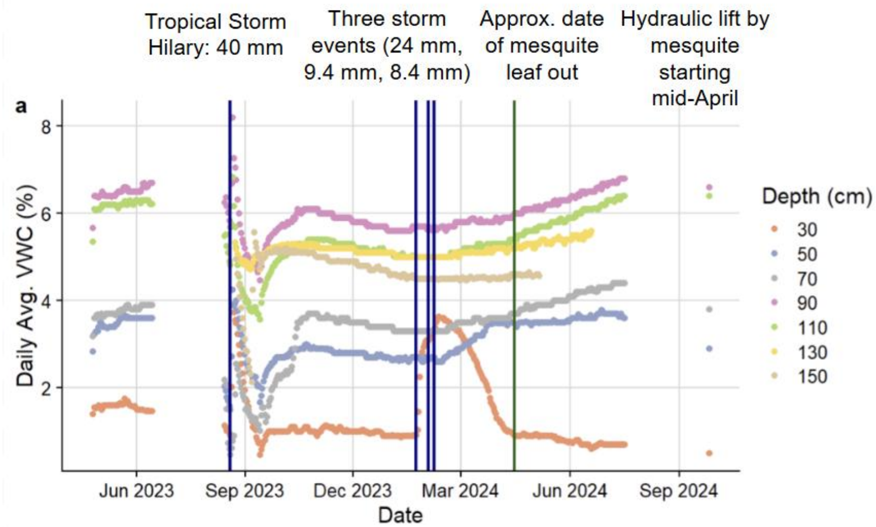

Figure A2. Daily average volumetric water content from the soil moisture sensors located at Site 1 with black vertical lines indicating storm events and a green vertical line indicating the approximate time of mesquite leaf out (mid-April).

Results

Precipitation prior to field sampling

There was no precipitation in the 14 days preceding sampling of the Clark Dry Lake site (Site 5). In Borrego Springs, there was 0.25 mm (0.01 in) of precipitation registered 10 days before the April 2023 sampling campaign and 1.02 mm (0.04 in) of precipitation registered 14 days before the August 2023 sampling campaign.

Field collected soil moisture during sampling campaigns

Average soil moisture progressively declined throughout the dry season, particularly in the uppermost soil layers (Figure A3). In April 2024, the highest soil moisture was found at 10 cm (3.9 in) at Sites 1 and 5, at 40 cm (15.7 in) at Site 4, and 100 cm (39.4 in) at Sites 2 and 3, showing variability in soil moisture across the soil profile. In May, the highest soil moisture could be found at 40 cm (15.7 in) at Site 5, 70 cm (27.6 in) at Sites 2 and 3, and 150 cm (59.1 in) at Sites 1 and 4, indicating drying down of the uppermost soil layers. By August, only Site 4 had the highest soil moisture at 70 cm (27.6 in), while the remaining sites had the highest soil moisture at 150 cm (59.1 in). This indicates a drying down of the uppermost portion of the soil profile during the dry season and a likely role of hydraulic lift in increasing soil moisture at deeper soil depths.

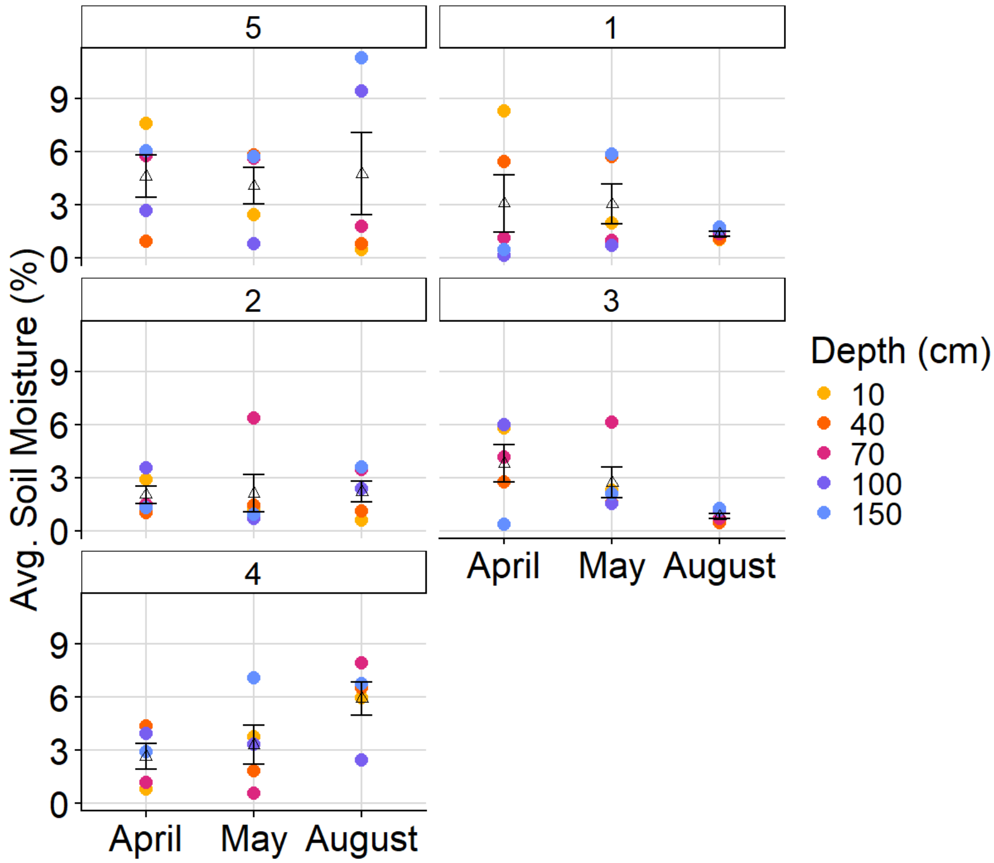

Figure A3. Field collected soil moisture averaged across the two replicate samples collected for each depth. The triangle represents the average across depths while the error bars indicate the standard error.

Continuous soil moisture during the study period

Following winter rain events in late 2023 and early 2024, where the final date of winter rainfall over 1 mm (0.04 in) was 1 April 2024 near the Borrego Sink, a dry down period was initiated where stable, low soil moisture values were found (Figure A2). A steady increase in soil moisture following the leafout period (mid-April) was captured, suggesting a role of hydraulic lift in increasing soil moisture at deeper depths (>50 cm or 19.7 in) (Figure A2).

Conclusion

The top 150 cm (59.1 in) of the soil profile was dry at the time of sampling events and throughout the dry season as evidenced by both the soil moisture of soils collected during sampling in 2024 and daily volumetric water content data from soil moisture sensors between June 2023 and September 2024.

A.3. Isotopic Analysis

Methods

Sample collection for isotopic analysis

Plant water

Mature mesquite and creosote twigs with fully expanded leaves were selected from sunlit branches near the outer canopy. Twigs were cut approximately in 1–2 cm (0.39–0.79 in) lengths, with a maximum thickness of 1.2 cm (0.47 in) diameter. To minimize the effects of evaporation of water from the twigs, vials were quickly filled with cut twigs and capped with minimal headspace. Vials were then sealed with parafilm and were refrigerated until analysis.

Soil surface water

Soils were collected within two times the approximate diameter at breast height of tagged mesquite trees. Soil cores were augered using an 8 cm (3.15 in) diameter and 10 cm (3.94 in) tall manual auger. To minimize the effects of evaporation of water from the soil, jars were quickly filled and capped with minimal headspace, sealed with parafilm, and refrigerated until analysis.

Groundwater

We used a bailer to sample the well near Clark Dry Lake and fill one dram glass vials which were quickly filled and capped with minimal headspace, sealed with parafilm, and refrigerated until analysis. West Yost collected samples from both non-pumping wells (i.e., monitoring wells) and active pumping wells (i.e., private wells). For non-pumping wells, a portable pump is lowered slowly down the well, positioning the intake at the predetermined selected sampling depth. For active pumping wells, samples were taken from the designated sampling outlet. The location of this outlet varies by well.

Analysis of water isotopes in field samples

Water isotopes were analyzed by the University of Wyoming Stable Isotope Facility. Water samples were analyzed for their $\delta^{18}O$ and $\delta^{2}H$ isotopic composition using a Thermo Scientific Delta V Plus isotope ratio mass spectrometer coupled to a Thermo Flash HT high-temperature conversion elemental analyzer (TC/EA) via a ConFlo IV open split interface at the University of Wyoming Stable Isotope Facility. Samples were introduced into the TC/EA via a Thermo AI 1310 liquid autosampler. The TC/EA converted water molecules into CO and H_2 gases at 1420°C. These gases were separated chromatographically and introduced into the mass spectrometer for isotopic analysis. Quality assurance and quality control (QA/QC) procedures, including the use of reference materials and statistical analysis, were employed to ensure data accuracy and precision.

We detected four samples with values outside three standard deviations from the mean across all trees, indicating they were outliers (tree 5-9 in April 2023, trees 3-4 and 3-7 in May 2023, and tree 1-4 in April 2024); these points were therefore removed. We also removed two trees from Site 3 (3-8 and 3-12) and two trees from Site 5 (5-8 and 5-11) in April 2023 because these samples were flagged by the University of Wyoming Stable Isotope Facility as having data of intermediate quality.

Isotope mixing model

Well water was collected from three anonymous private wells and four monitoring wells (MW-3, MW-4, MW-5A, and MW-5B) in the Borrego Springs Subbasin between 12 and 16 November 2023 by West Yost. All wells generally fall on the same function as the Global Meteorologic Water Line (GMWL) (Figure A4), providing confidence in the robustness and consistency of samples. The GMWL is the global annual average relationship between hydrogen and oxygen isotopes in natural water sources that originate from precipitation, and we would expect well samples to fall on or near this line. The sampled wells show slight deviation from the GMWL likely arising from consistent localized variation from the GMWL and/or the impacts of pumping on the aquifer.

MW-5A was selected over MW-5B due to previously raised concerns over MW-5B not representing the regional aquifer (Appendix D4, 2020), though we do not agree with that assertion as our results demonstrate that MW-5A and MW-5B share similar isotopic signatures with minimal standard deviation, suggesting they are both representative of the regional aquifer.

Our hypothesis testing to identify the water that plants are utilizing using mixing models relies on looking for water in plant tissues that is not consistent with surface soil water, which is more enriched (less negative). The sampled wells exhibit a distinct and consistent isotopic signature across the area, which is consistently less enriched (more negative) than the soil water signature. This indicates that there is a clear distinction between groundwater and surface water isotopic signatures in Borrego Springs. MW-3 and MW-5A are closest to the mesquite bosque habitat and are thus the most accurate representatives of the regional aquifer in the study area.

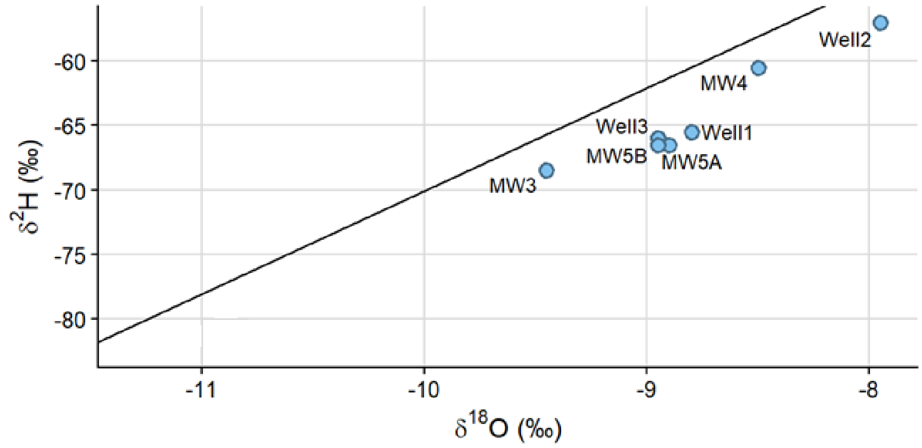

Figure A4. Isotopic composition of sampled wells. The relationship between $\delta^{18}O$ and $\delta^{2}H$ across well water samples. The black line indicates the Global Meteoric Water Line (GMWL), which is described by the equation: $\delta^{2}H = 8 \cdot \delta^{18}O + 10$, and represents the mean global relationship between $\delta^{2}H$ and $\delta^{18}O$ in precipitation. The alignment of the well water samples on the GMWL line indicates groundwater that originated as precipitation through recharge processes.

Tables and Figures

Table A3. Isotopic composition of the seven wells sampled by West Yost in November 2023. Two replicate samples were collected for each well during the sampling event and the average is shown. The asterisk accompanying some values in the Local Well Name column indicates that this well has been anonymized for privacy reasons.

State Well Number	Local Well Name	Latitude	Longitude	Reference Point Elevation (ft)	Ground-water Level Elevation (ft)	Depth from Reference Point to Ground-water Level (ft bgs)	Date of Measure-ment	Deuterium-excess		$\delta^{18}O$		$\delta^{2}H$	
								Avg. (‰)	Std. Dev. (‰)	Avg. (‰)	Std. Dev. (‰)	Avg. (‰)	Std. Dev. (‰)
11S06E23J002S	MW-3	33.20316	-116.3143	523.36	522.65	77.63	11/14/2023	7.1	2.12	-9.4	0.35	-68	0.91
10S06E35Q001S	MW-4	33.25756	-116.3131	517.33	517.75	111.46	11/14/2023	7.5	0.71	-8.5	0.04	-61	0.21
11S07E07R001S	MW-5A	33.22656	-116.2793	466.11	466.45	58.68	11/13/2023	4.7	1.56	-8.9	0.28	-67	0.69
11S07E07R002S	MW-5B	33.22656	-116.2793	464.8	465.14	58.33	11/13/2023	5.1	1.27	-8.9	0.06	-67	0.3
NA	Well 1*	NA	NA	562.65	560	93.1	11/14/2023	4.9	1.56	-8.8	0.24	-65	0.14
NA	Well 2*	NA	NA	509.85	508.85	108.85	11/13/2023	6.6	0.57	-7.9	0.08	-57	0.02
NA	Well 3*	NA	NA	542.22	539.82	93.09	11/16/2023	5.6	0.57	-9	0.06	-66	0.19

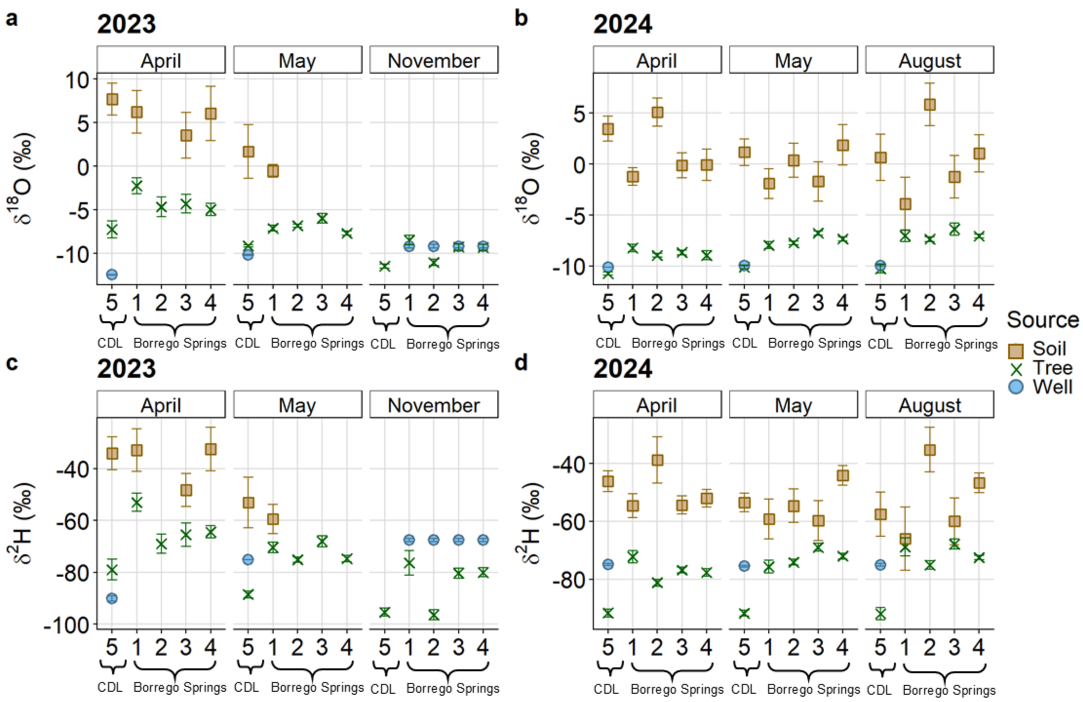

Figure A5. Isotopic composition of the sampled trees, soils, and well water. $\delta^{18}O$ (a and b) and $\delta^{2}H$ (d and c) of the soil water (brown squares), tree tissue water (green crosses), and well water (blue circles) at the five sentinel sites in Borrego Springs and the reference site at Clark Dry Lake. Well water is a value derived from the most-adjacent well sample possible (an average of MW-3 and MW-5A for Sites 1 - 4 and 10S07E07C001S for Site 5). These data indicate a mixed water source for mesquite at all locations. The soil, tree, and well water data are represented by the mean (point) and standard error (error bars).

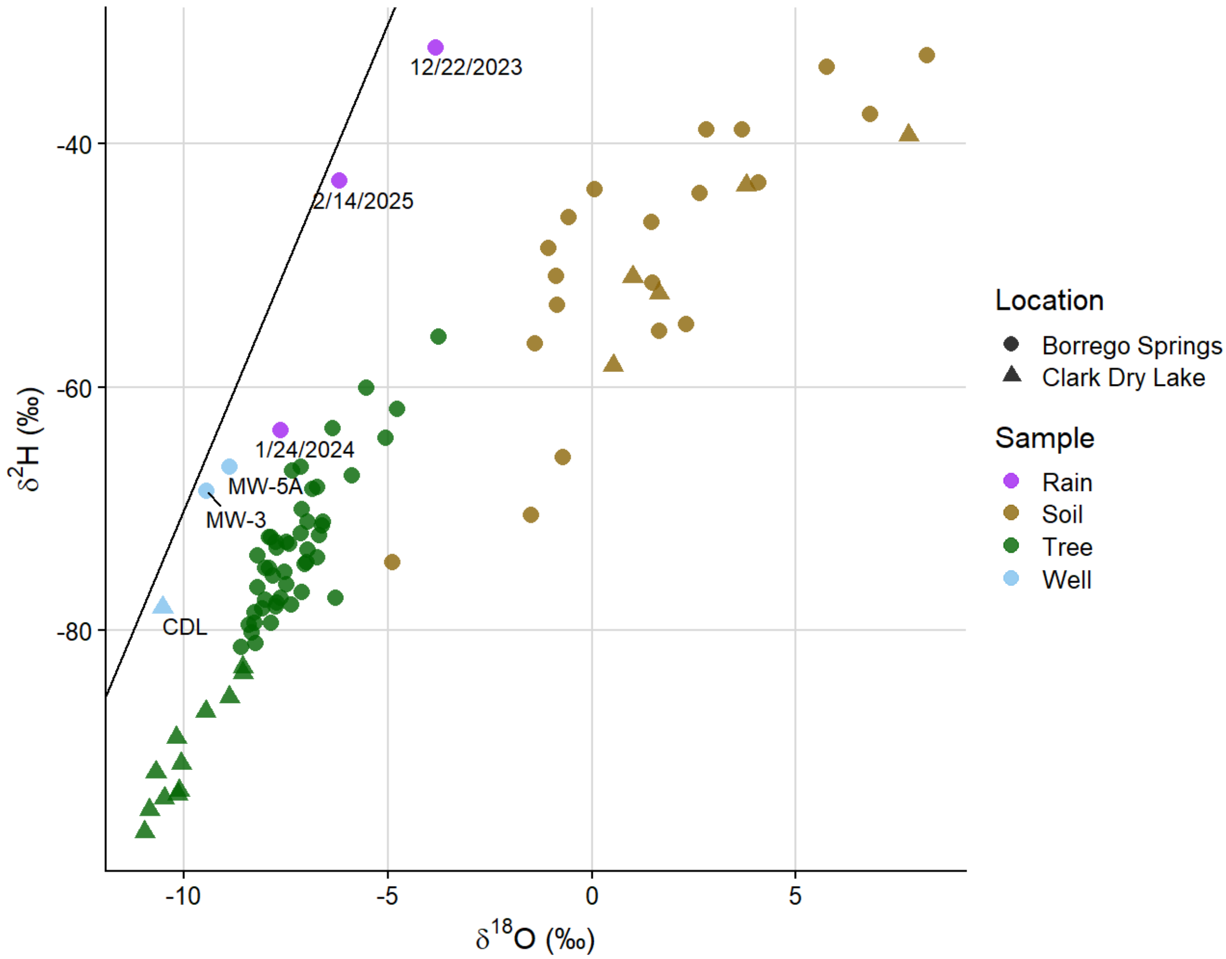

Figure A6. The relationship between δ^{18}O and δ^2H across all sample types across all six sampling campaigns for Sites 1 through 5 averaged at the level of the individual. The well labeled CDL is State Well ID 10S07E07C001S). The black line indicates the Global Meteoric Water Line (GMWL), which is described by the equation: $\delta^2H = 8 \cdot \delta^{18}O + 10$, and represents the mean global relationship between δ^2H and δ^{18}O in precipitation. The alignment of the well water samples (blue) and the precipitation samples (purple) on the GMWL line indicates groundwater that originated as precipitation through recharge processes. Points to the right of this line indicate the influence of evaporation. The brown points representing soil water are farther to the right and of a lower slope than the GMWL, indicating a stronger effect of evaporation on their isotopic signature relative to the green points. The green points representing mesquite water are also to the right of the line but show little overlap with the brown points, indicating an isotopic signature that can only be explained by the mixing of soil water and well water sources.

References

Appendix D4: Borrego Springs Subbasin Groundwater Dependent Ecosystems (Draft Final). (2020). Prepared by Driscoll, T., & Duverge, D. In *Groundwater Management Plan for the Borrego Springs Groundwater Subbasin January 2020*. Available at https://borregospringswatermaster.com/wp-content/uploads/2022/10/Exhibit-1_GMP.pdf

A.4. Remote Sensing Approaches of GDE Behavior Appendix

Methods

Areas of Interest (AOIs)

For each remote sensing approach, we compared vegetation behavior across three areas of interest (AOIs): the Borrego Springs mesquite bosque (the potential GDE), the Clark Dry Lake mesquite bosque (a known GDE), and a nearby non-GDE habitat (Figure A7). By analyzing vegetation behavior in these distinct regions, we aimed to determine whether the Borrego Springs mesquite bosque exhibits patterns consistent with groundwater reliance (i.e., resembling the Clark Dry Lake GDE), or patterns more characteristic of surface water use (i.e., resembling the non-GDE habitat).

AOIs:
Potential GDE: Borrego Springs Mesquite Habitat Polygons (BS)
Known GDE: Clark Dry Lake Mesquite Habitat Polygons (CDL)
Non-GDE: A polygon of non-GDE community near Coyote Creek (non-GDE)

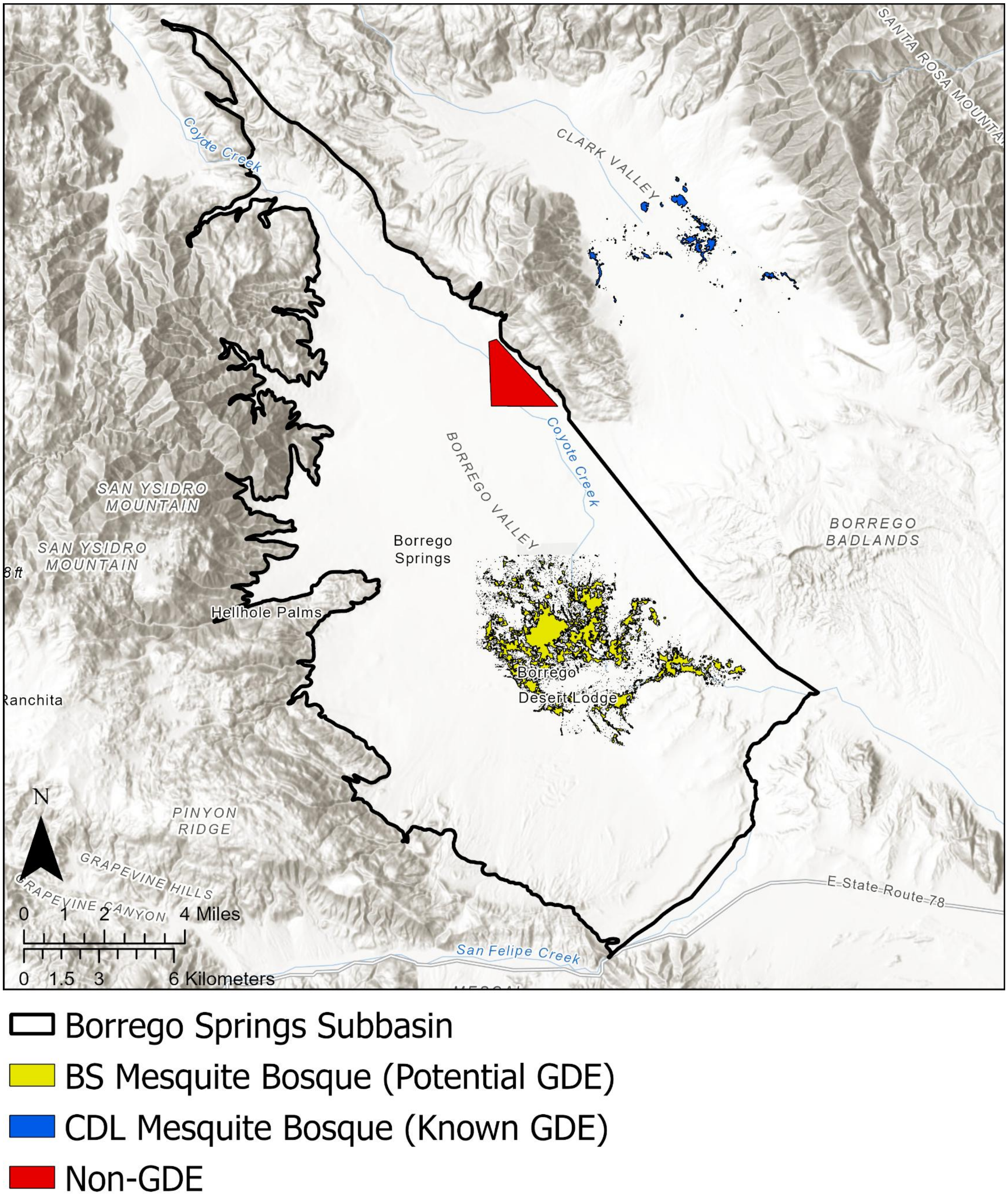

Figure A7. Map of the areas of interest (AOIs) used in the remote sensing approaches, including the Borrego Springs (BS) mesquite bosque potential GDE, the Clark Dry Lake (CDL) mesquite bosque known GDE, and the Non-GDE polygons.

Dry Period Identification

To identify relevant dry period dates within the mesquite growing season (April through November) for Approaches 1 and 2, we analyzed PRISM daily climate data (PRISM Climate Group, 2025). To validate the PRISM rainfall data, we cross-referenced it with rainfall and surface soil moisture data collected from weather stations in Borrego Springs (https://anzaborrego.ucnrs.org/weather/).

Approach 1 Methods: Change in NDVI across an extended dry period

This approach uses changes in NDVI (Normalized Difference Vegetation Index) to identify vegetation that maintains or increases greenness during prolonged dry periods, particularly from days 50 to 80 of the growing season drought. NDVI measures the amount of green biomass in vegetation, which correlates with plant health and photosynthetic activity. Plants rely on water to maintain and grow their green biomass, so those that maintain or increase their greenness during extended droughts are likely utilizing groundwater.

During dry periods with no rainfall or insufficient soil moisture, most plants struggle to photosynthesize and may enter dormancy or begin to senesce, resulting in a steady decline in NDVI as green biomass diminishes. However, plants with access to groundwater can continue photosynthesizing and growing, even without rain. This groundwater access allows them to maintain or even increase their NDVI, remaining green and productive through the dry conditions (Eamus et al. 2015; Gou et al. 2015).

To detect this behavior, we used Google Earth Engine to analyze NDVI data collected from Sentinel 10 m resolution imagery during a dry period within the growing season characterized by consistently dry surface soils (we illustrate 25 May - 24 June 2024, corresponding to days 50-80 of the 2024 summer drought as an example in this Appendix). We filtered Sentinel imagery for the selected dry period dates for each AOI. Next, we calculated NDVI for each image available and masked all pixels with mean NDVI <0.1 during the dry period to eliminate areas with little to no live vegetation from the analysis. We then computed Mann Kendall's tau across the dry period for each pixel to evaluate how NDVI values changed over this time.

Mann-Kendall's tau is a statistical test employed for detecting monotonic trends in a dataset (Kendall 1948). Monotonic trends refer to a consistent directional change in a dataset over time, characterized by either consistent increase or decrease without significant fluctuations. Kendall's tau quantifies the strength and direction of the monotonic trend: a positive tau value signifies an increasing monotonic trend, whereas a negative value indicates a decreasing trend. Tau values near zero indicate the absence of a monotonic trend meaning NDVI either fluctuated or remained stable over time.

Assumption

Vegetation without access to groundwater (non-GDE) is expected to show negative tau values (tau ≤ 0), indicating a decline in greenness as the plants deplete available moisture. In contrast, groundwater-dependent vegetation (GDE) should exhibit positive or stable tau values (tau > 0), reflecting stable or increasing greenness due to groundwater availability that supports continued growth.

For 2024, this approach identifies 397 acres of mesquite near Borrego Sink that likely have access to groundwater (Figure A8).

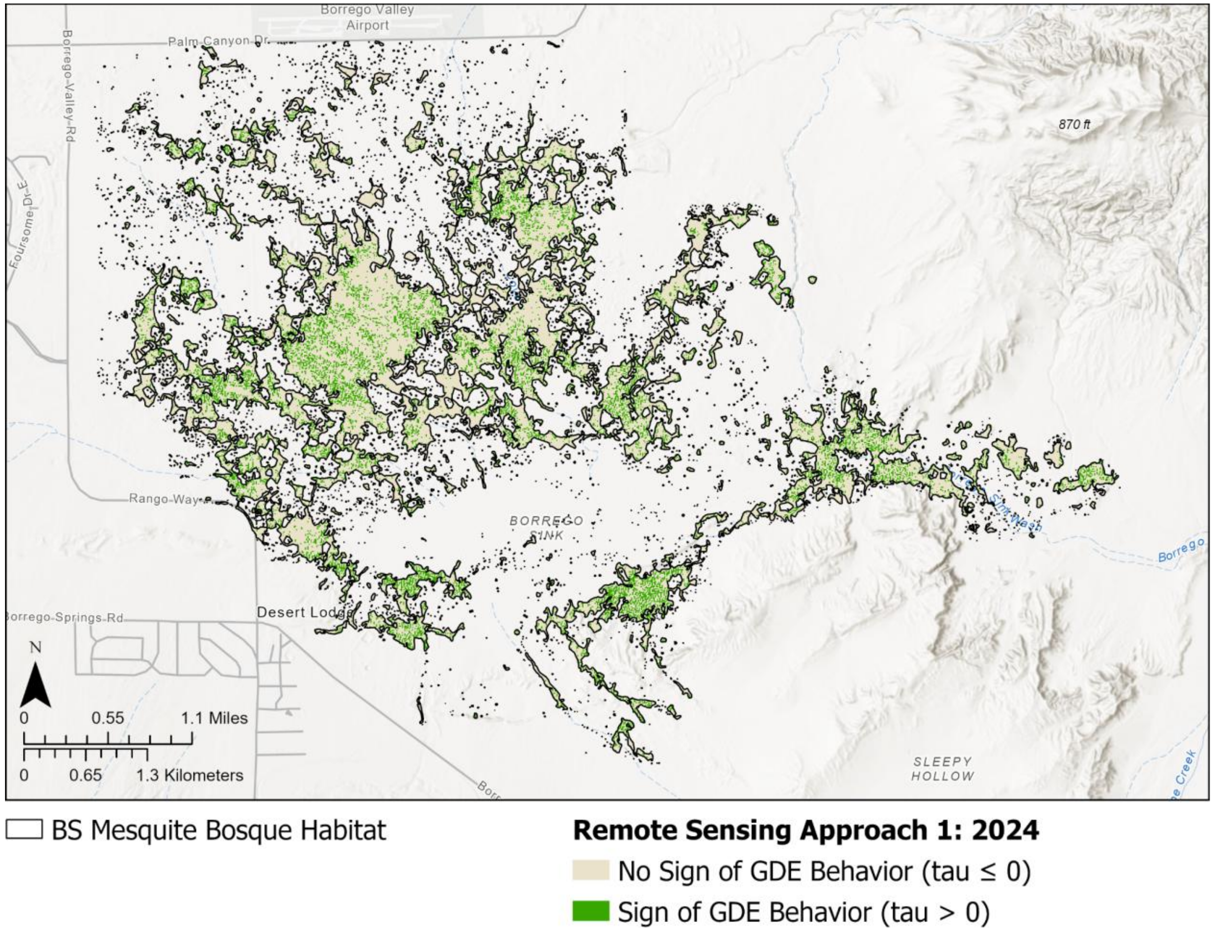

Figure A8. Map of the spatial extent of GDE behavior identified in Approach 1, which analyzes the change in NDVI across an extended dry period (25 May - 24 June 2024,) for the BS mesquite bosque using Mann Kendall's tau. Positive tau indicates an increase in NDVI, which could only be supported by groundwater access. Areas shown in green indicate live vegetation that had tau values > 0, illustrating hotspots of GDE behavior throughout most of the BS mesquite bosque. Approach 1 identifies 397 acres of GDE mesquite.

Approach 2: Comparison of maximum NDVI across dry period

Approach 2 builds on the same principles as Approach 1 but focuses on identifying vegetation that survives through an extreme dry period with high temperatures, specifically days 80-120 of the growing season drought. Plants require water to survive, and without rainfall or adequate soil moisture, they cannot photosynthesize and may enter senescence or dormancy. When low soil moisture coincides with high temperatures over extended periods, plants face heat stress, wilting, and potential dormancy or death. As a result, NDVI values typically decrease to near zero after prolonged dry spells, indicating the loss of live vegetation. However, plants with access to groundwater can continue to survive through such periods, maintaining higher NDVI values (Gou et al. 2015; Eamus et al. 2016).

To investigate this behavior, we used Google Earth Engine to analyze NDVI data collected from Sentinel 10 m resolution imagery during extreme dry periods within the growing season (we illustrate 24 June - 3 August 2024, corresponding to days 80-120 of the 2024 summer drought as an example). During this time, the average daily maximum temperature in the Borrego Springs mesquite bosque was 111°F (43.9°C). We filtered the imagery for the selected dry period dates for each AOI. Then we calculated the maximum NDVI for each AOI across the time period. By calculating the maximum NDVI for each pixel during this dry period, we can assess the amount of live, photosynthetically active vegetation across the landscape.

Assumption

We expect non-GDE vegetation to show low NDVI values, indicating a lack of live vegetation. In contrast, groundwater-dependent ecosystems (GDEs) should display higher NDVI values, reflecting the persistence of live vegetation despite severe heat and dry soil conditions.

For 2024, this approach identifies 268 acres of mesquite near Borrego Sink that likely have access to groundwater (Figure A9).

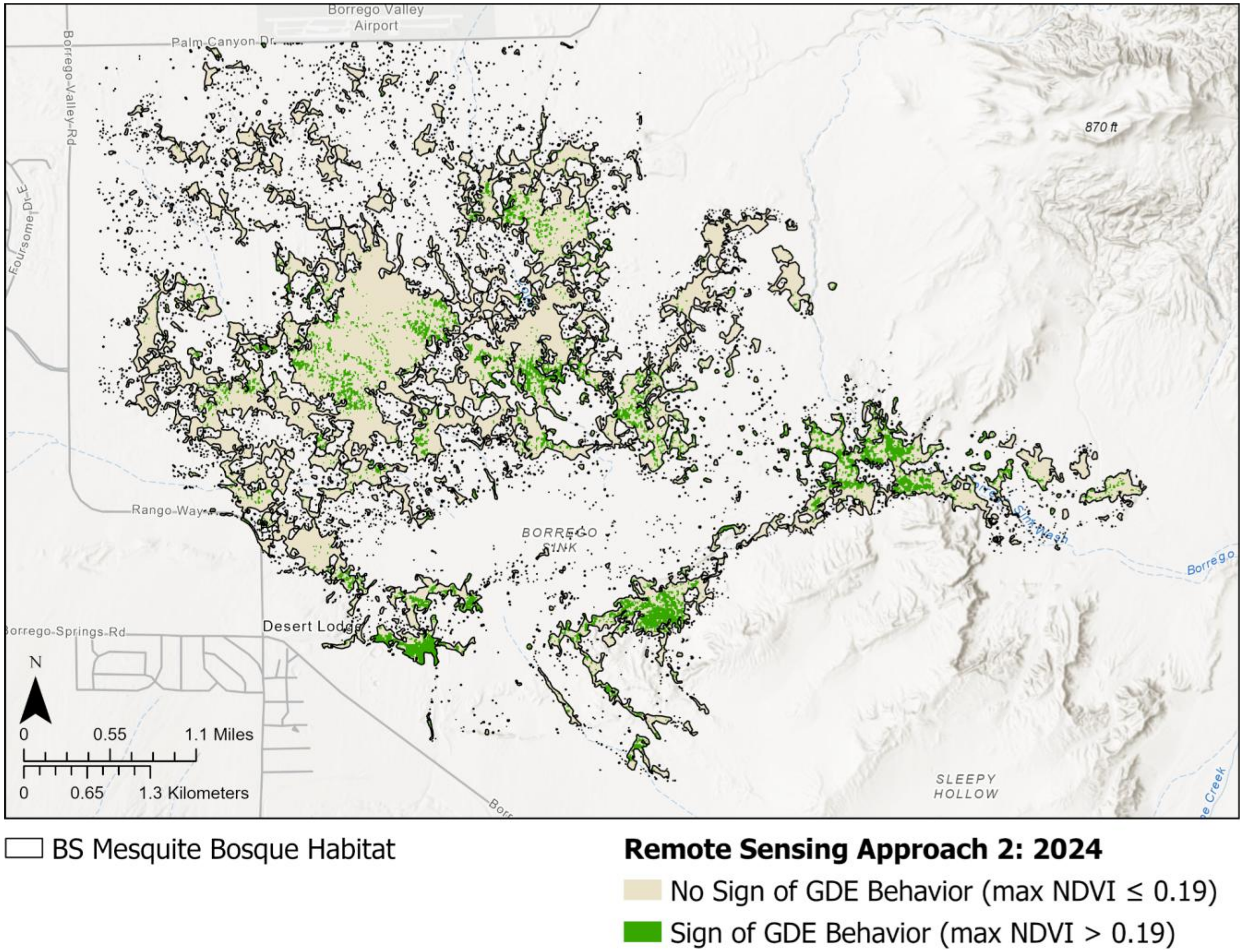

Figure A9. Map of the spatial extent of GDE behavior identified in Approach 2, which analyzes the maximum NDVI across an extended dry period further into the 2024 water year (24 June - 3 August 2024) for the BS mesquite bosque. Areas shown in green indicate vegetation that has NDVI values greater than 0.19 across the dry period, indicating live vegetation that is likely supported by groundwater access. Approach 2 identifies 268 acres of GDE mesquite.

Approach 3: Comparison of cumulative NDVI across the water year

Approach 3 aims to identify vegetation with unusually high annual productivity, which is often an indicator of groundwater access. Plants with more consistent access to water typically exhibit higher photosynthetic activity throughout the year. Cumulative annual NDVI is a reliable proxy for Gross Primary Productivity (GPP), as it reflects the overall photosynthetic activity of vegetation over the entire year (Ricotta et al. 1999). As a result, groundwater-dependent ecosystems (GDEs) generally show higher GPP and, therefore, higher cumulative NDVI values (Eamus et al. 2016).

To explore this behavior, we used Google Earth Engine to analyze cumulative annual NDVI across the water year as a proxy for GPP (we illustrate the 2024 water year, from 1 October 2023 - 30 September 2024 as an example). We filtered Sentinel 10 m resolution satellite imagery for the water year dates for each AOI. We then calculated the cumulative NDVI by summing all values for each pixel across the water year. By calculating cumulative NDVI, we can assess the relative productivity of GDEs compared to non-GDEs. Higher cumulative NDVI values signify greater photosynthetic activity throughout the year, indicative of robust vegetation growth under favorable environmental conditions. Conversely, lower cumulative NDVI values suggest diminished photosynthetic activity, reflective of less favorable or challenging environmental conditions throughout the year.

Assumption

We expect non-GDE vegetation to exhibit low cumulative annual NDVI, reflecting low photosynthetic activity throughout most of the year. In contrast, GDEs should show higher cumulative NDVI, indicating greater overall productivity and enhanced drought resilience due to groundwater access.

For 2024, this approach identifies 73 acres of mesquite near Borrego Sink that likely have access to groundwater (Figure A10).

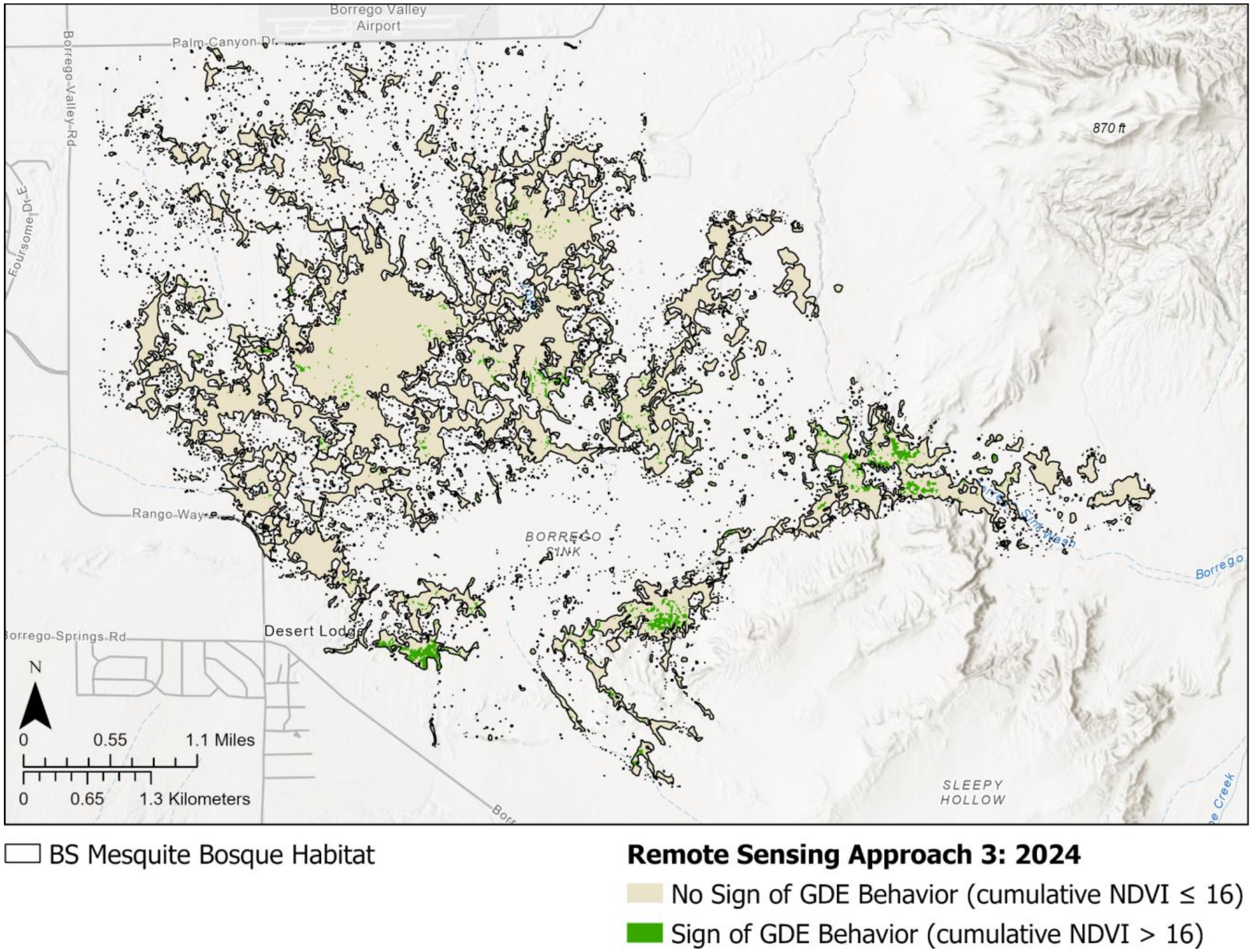

Figure A10. Map of the spatial extent of GDE behavior identified in Approach 3, which analyzes the cumulative NDVI across the 2024 water year (1 October 2023 - 30 September 2024) for the BS mesquite bosque. Areas shown in green indicate vegetation that has cumulative NDVI values greater than 16 across the water year, indicating live vegetation that is likely supported by groundwater access. Approach 3 identifies 73 acres of GDE mesquite.

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Appendix B. Characterization of GDEs

B.1. Baseline Groundwater Levels

Table B1. Average groundwater levels across wells and water years.

Water Year	State Well Number	Local Well Name	Avg. Depth from Reference Point to Groundwater Level (ft bgs)	Number of Measurements
1953	11S06E11M001S	11S06E11M001S	5.3	1
1954	11S06E11D002S	11S06E11D002S	18.5	2
1954	11S06E11M001S	11S06E11M001S	7.3	3
1954	11S07E07N001S	7N1	28.6	2
1955	11S06E11D002S	11S06E11D002S	19.7	1
1955	11S06E11M001S	11S06E11M001S	9.0	1
1955	11S07E07N001S	7N1	29.3	2
1956	11S06E11D002S	11S06E11D002S	35.9	2
1956	11S06E11M001S	11S06E11M001S	13.4	1
1956	11S07E07N001S	7N1	30.1	2
1957	11S06E11D002S	11S06E11D002S	25.4	1
1957	11S06E11M001S	11S06E11M001S	14.8	1
1957	11S07E07N001S	7N1	31.2	2
1958	11S06E11D002S	11S06E11D002S	59.6	6
1958	11S06E11M001S	11S06E11M001S	18.1	1
1958	11S07E07N001S	7N1	31.6	2
1959	11S06E11D002S	11S06E11D002S	45.9	9
1959	11S06E11M001S	11S06E11M001S	22.4	2
1959	11S07E07N001S	7N1	32.5	2
1960	11S06E11D002S	11S06E11D002S	31.6	1
1960	11S06E11M001S	11S06E11M001S	19.6	1
1960	11S07E07N001S	7N1	33.3	2

1961	11S06E11D002S	11S06E11D002S	33.0	2
1961	11S06E11M001S	11S06E11M001S	21.4	2
1961	11S07E07N001S	7N1	33.3	2
1962	11S06E11D002S	11S06E11D002S	35.1	2
1962	11S06E11M001S	11S06E11M001S	22.0	2
1962	11S07E07N001S	7N1	34.0	2
1963	11S06E11D002S	11S06E11D002S	32.3	2
1963	11S06E11M001S	11S06E11M001S	22.4	2
1963	11S07E07N001S	7N1	34.6	2
1964	11S06E11D002S	11S06E11D002S	37.6	7
1964	11S06E11M001S	11S06E11M001S	22.1	2
1964	11S07E07N001S	7N1	34.8	1
1965	11S06E11D002S	11S06E11D002S	38.6	8
1965	11S06E11M001S	11S06E11M001S	25.5	3
1965	11S06E12G001S	12G	29.7	1
1965	11S07E07N001S	7N1	38.5	2
1966	11S06E11D002S	11S06E11D002S	38.4	4
1966	11S06E11M001S	11S06E11M001S	25.9	2
1966	11S07E07N001S	7N1	36.0	1
1967	11S06E11D002S	11S06E11D002S	33.5	6
1967	11S06E11M001S	11S06E11M001S	25.4	2
1968	11S06E11D002S	11S06E11D002S	33.3	2
1968	11S06E11M001S	11S06E11M001S	26.8	2
1968	11S06E12G001S	12G	33.1	1
1969	11S06E11D002S	11S06E11D002S	32.9	2
1969	11S06E11M001S	11S06E11M001S	26.2	1
1969	11S06E12G001S	12G	34.5	1
1970	11S06E11D002S	11S06E11D002S	40.5	3
1970	11S06E11M001S	11S06E11M001S	31.7	3
1970	11S06E12G001S	12G	35.9	2

1971	11S06E11D002S	11S06E11D002S	34.6	2
1971	11S06E11M001S	11S06E11M001S	29.6	1
1971	11S06E12G001S	12G	37.2	2
1979	11S06E11D002S	11S06E11D002S	40.3	1
1980	11S06E11D002S	11S06E11D002S	43.4	1
1980	11S06E11M001S	11S06E11M001S	40.4	1
1981	11S06E11D002S	11S06E11D002S	41.3	1
1982	11S06E11D002S	11S06E11D002S	42.0	1
1983	11S06E11D002S	11S06E11D002S	44.7	2
1984	11S06E11D002S	11S06E11D002S	44.4	1
1985	11S06E11D002S	11S06E11D002S	45.1	2
1986	11S06E11D002S	11S06E11D002S	49.4	1
1987	11S06E11D002S	11S06E11D002S	47.0	2
1988	11S06E11D002S	11S06E11D002S	49.1	2
1989	11S06E11D002S	11S06E11D002S	50.3	2
1990	11S06E11D002S	11S06E11D002S	50.8	1
1992	11S06E11D002S	11S06E11D002S	53.2	2
1993	11S06E11D002S	11S06E11D002S	55.9	2
1994	11S06E11D002S	11S06E11D002S	56.2	1
2004	11S06E23J002S	MW-3	62.1	2
2005	11S06E23J002S	MW-3	52.6	1
2006	11S06E23J002S	MW-3	58.9	2
2009	11S06E01C001S	11S06E01C001S	93.3	3
2009	11S06E11D002S	11S06E11D002S	83.5	1
2009	11S06E12G001S	12G	62.7	2
2009	11S07E07R002S	MW-5B	49.4	2
2010	11S06E01C001S	11S06E01C001S	95.2	1
2010	11S07E07R002S	MW-5B	50.0	1
2011	11S06E01C001S	11S06E01C001S	96.4	2
2011	11S07E07R002S	MW-5B	50.6	1

2012	11S06E01C001S	11S06E01C001S	98.1	2
2012	11S06E23J002S	MW-3	59.4	1
2013	11S06E01C001S	11S06E01C001S	99.9	2
2013	11S06E23J002S	MW-3	55.7	1
2013	11S07E07R002S	MW-5B	51.9	2
2014	11S06E01C001S	11S06E01C001S	101.4	2
2014	11S06E23J002S	MW-3	54.3	83
2014	11S07E07R002S	MW-5B	52.6	2
2015	11S06E01C001S	11S06E01C001S	102.8	1
2015	11S06E23J002S	MW-3	54.1	22

B.2. Plant Surveys of the Mesquite Bosques

Table B2. Checklist of vascular plant taxa at Borrego Sink showing the date of the first SDNHM observation or the year of the historical collection or iNaturalist observation; nativity; and California Rare Plant Rank.

Evidence of Presence						
SDNHM Survey	**Other Source**	**Family**	**Latin Name**	**Common Name**	**Native**	**CRPR**
3/10/2023		Agavaceae	*Hesperocallis undulata*	Desert Lily	Yes	
3/10/2023		Amaranthaceae	*Allenrolfea occidentalis*	Iodine Bush	Yes	
	2023 iNat	Amaranthaceae	*Amaranthus albus*	White Tumbleweed	No	
9/21/2023		Amaranthaceae	*Amaranthus fimbriatus*	Fringe Amaranth	Yes	
3/5/2024		Amaranthaceae	*Atriplex canescens canescens*	Four-wing Saltbush	Yes	
3/10/2023		Amaranthaceae	*Atriplex canescens laciniata*	Caleb Saltbush	Yes	
4/14/2023		Amaranthaceae	*Atriplex hymenelytra*	Desert-Holly	Yes	
3/10/2023		Amaranthaceae	*Atriplex lentiformis*	Big Saltbush	Yes	
3/10/2023		Amaranthaceae	*Atriplex polycarpa*	Many-Fruit Saltbush	Yes	
3/23/2023		Amaranthaceae	*Chenopodiastrum murale*	Nettle-Leaf Goosefoot	No	
3/27/2023		Amaranthaceae	*Salsola paulsenii*	Barbwire Russian-Thistle	No	
3/10/2023		Amaranthaceae	*Suaeda nigra*	Bush Seepweed	Yes	
3/5/2024		Amaranthaceae	*Tidestromia suffruticosa oblongifolia*	Salton Sea Honeysweet	Yes	
3/10/2023		Apodanthaceae	*Pilostyles thurberi*	Thurber's Pilostyles	Yes	4.3
	2023 iNat	Arecaceae	*Washingtonia filifera*	California Fan Palm	Yes	
3/10/2023		Asteraceae	*Ambrosia dumosa*	White Bur-Sage, Burro-Weed	Yes	
3/18/2024		Asteraceae	*Ambrosia salsola salsola*	Cheesebush, Burrobrush	Yes	

3/10/2023		Asteraceae	*Baileya pauciradiata*	Short-Ray Desert Marigold	Yes	
4/5/2023		Asteraceae	*Calycoseris wrightii*	White Tack-Stem	Yes	
	2011 Collection	Asteraceae	*Centaurea melitensis*	Tocalote	No	
3/10/2023		Asteraceae	*Chaenactis carphoclinia carphoclinia*	Pebble Pincushion	Yes	
3/10/2023		Asteraceae	*Chaenactis stevioides*	Desert Pincushion	Yes	
3/10/2023		Asteraceae	*Dicoria canescens*	Desert Dicoria	Yes	
3/10/2023		Asteraceae	*Encelia farinosa*	Brittlebush, Incienso	Yes	
3/14/2023		Asteraceae	*Encelia frutescens frutescens*	Rayless Encelia	Yes	
3/10/2023		Asteraceae	*Geraea canescens*	Desert Sunflower	Yes	
3/10/2023		Asteraceae	*Isocoma acradenia eremophila*	Desert Alkali Goldenbush	Yes	
3/10/2023		Asteraceae	*Laennecia coulteri*	Coulter's Fleabane	Yes	
3/18/2024		Asteraceae	*Logfia depressa*	Dwarf Cottonrose	Yes	
3/10/2023		Asteraceae	*Malacothrix glabrata*	Desert Dandelion	Yes	
4/14/2023		Asteraceae	*Monoptilon bellioides*	Mohave Desert Star	Yes	
	2020 iNat	Asteraceae	*Oncosiphon pilulifer*	Stinknet	No	
3/10/2023		Asteraceae	*Palafoxia arida arida*	Desert Spanish-Needle	Yes	
3/10/2023		Asteraceae	*Pectis papposa papposa*	Chinch Weed	Yes	
3/10/2023		Asteraceae	*Perityle emoryi*	Emory's Rockdaisy	Yes	
3/10/2023		Asteraceae	*Psathyrotes ramosissima*	Turtleback	Yes	
3/5/2024		Asteraceae	*Rafinesquia neomexicana*	Desert Chicory	Yes	
3/10/2023		Asteraceae	*Sonchus oleraceus*	Common Sow-Thistle	No	
4/5/2023		Asteraceae	*Stephanomeria pauciflora*	Brownplume Wirelettuce	Yes	
3/14/2023		Asteraceae	*Volutaria tubuliflora*	Egyptian Knapweed	No	

	2022 iNat	Bignoniaceae	*Chilopsis linearis arcuata*	Desert-Willow	Yes	
3/5/2024		Boraginaceae	*Amsinckia tessellata tessellata*	Desert Fiddleneck	Yes	
3/18/2024		Boraginaceae	*Cryptantha barbigera barbigera*	Bearded Cryptantha	Yes	
3/5/2024		Boraginaceae	*Cryptantha ganderi*	Gander's Cryptantha	Yes	1B.1
3/10/2023		Boraginaceae	*Cryptantha maritima maritima*	White-Hair Cryptantha	Yes	
3/7/2024		Boraginaceae	*Cryptantha maritima pilosa*	Tufted Haired Cryptantha	Yes	
	2008 Collection	Boraginaceae	*Cryptantha nevadensis*	Nevada Cryptantha	Yes	
3/10/2023		Boraginaceae	*Eremocarya micrantha micrantha*	Small-Flowered Eremocarya	Yes	
3/10/2023		Boraginaceae	*Johnstonella angustifolia*	Narrow-Leaf Johnstonella	Yes	
3/27/2023		Boraginaceae	*Johnstonella costata*	Ribbed Johnstonella	Yes	4.3
3/5/2024		Boraginaceae	*Pectocarya heterocarpa*	Chuckwalla Pectocarya	Yes	
3/5/2024		Boraginaceae	*Pectocarya peninsularis*	Peninsular Pectocarya	Yes	
3/27/2023		Boraginaceae	*Pectocarya platycarpa*	Broad-Fruit Pectocarya	Yes	
3/18/2024		Boraginaceae	*Pectocarya recurvata*	Recurved Pectocarya	Yes	
3/10/2023		Brassicaceae	*Brassica tournefortii*	Wild Turnip	No	
3/5/2024		Brassicaceae	*Caulanthus lasiophyllus*	California Mustard	Yes	
3/10/2023		Brassicaceae	*Descurainia pinnata*	Western Tansy Mustard	Yes	
3/10/2023		Brassicaceae	*Dithyrea californica*	California Spectacle-Pod	Yes	
3/10/2023		Brassicaceae	*Lepidium lasiocarpum lasiocarpum*	Sand Peppergrass	Yes	
3/10/2023		Brassicaceae	*Sisymbrium irio*	London rocket	No	
3/27/2023		Brassicaceae	*Streptanthella longirostris*	Long-Beak Twist-Flower	Yes	

3/10/2023		Cactaceae	*Cylindropuntia echinocarpa*	Silver Cholla	Yes	
	2017 iNat	Cactaceae	*Cylindropuntia ganderi*	Gander's cholla	Yes	
3/5/2024		Cactaceae	*Cylindropuntia ramosissima*	Branched Pencil Cholla	Yes	
3/14/2023		Cactaceae	*Ferocactus cylindraceus*	California Barrel Cactus	Yes	
3/14/2023		Cactaceae	*Mammillaria tetrancistra*	Yaqui Mammillaria	Yes	
	2022 iNat	Cactaceae	*Opuntia basilaris basilaris*	Beavertail Prickly Pear	Yes	
4/5/2023		Campanulaceae	*Nemacladus glanduliferus*	Glandular Threadplant	Yes	
3/10/2023		Caryophyllaceae	*Achyronychia cooperi*	Onyx Flower, Frost Mat	Yes	
	1933 Collection	Caryophyllaceae	*Loeflingia squarrosa*	California Loeflingia	Yes	
4/5/2023		Cleomaceae	*Cleomella obtusifolia*	Mojave Stinkweed	Yes	
3/18/2024		Cleomaceae	*Cleomella palmeri*	Palmer's Jackass-Clover	Yes	2B.2
4/15/2024		Convolvulaceae	*Cuscuta californica papillosa*	Rough Chaparral Dodder	Yes	
	2020 iNat	Cyperaceae	*Bolboschoenus maritimus*	Sea Clubrush	Yes	
3/10/2023		Ehretiaceae	*Tiquilia palmeri*	Palmer's Tiquilia	Yes	
3/10/2023		Ehretiaceae	*Tiquilia plicata*	Plicate Tiquilia	Yes	
3/10/2023		Euphorbiaceae	*Croton californicus*	California Croton	Yes	
9/21/2023		Euphorbiaceae	*Ditaxis serrata serrata*	Yuma Silverbush	Yes	
3/10/2023		Euphorbiaceae	*Euphorbia micromera*	Sonora Sandmat	Yes	
3/10/2023		Euphorbiaceae	*Euphorbia polycarpa*	Small-Seed Sandmat	Yes	
3/10/2023		Euphorbiaceae	*Euphorbia setiloba*	Yuma Spurge	Yes	
3/10/2023		Euphorbiaceae	*Stillingia spinulosa*	Annual Stillingia	Yes	
3/10/2023		Fabaceae	*Acmispon strigosus*	Strigose Bird's-foot Trefoil	Yes	

3/10/2023		Fabaceae	*Astragalus aridus*	Parch Locoweed	Yes	
3/10/2023		Fabaceae	*Astragalus crotalariae*	Salton Milkvetch	Yes	4.3
3/5/2024		Fabaceae	*Astragalus didymocarpus dispermus*	Desert Dwarf Locoweed	Yes	
3/10/2023		Fabaceae	*Astragalus lentiginosus borreganus*	Borrego Milkvetch	Yes	4.3
3/10/2023		Fabaceae	*Dalea mollis*	Hairy Prairie Clover	Yes	
3/5/2024		Fabaceae	*Dalea mollissima*	Soft Prairie Clover	Yes	
3/10/2023		Fabaceae	*Lupinus arizonicus*	Arizona Lupine	Yes	
3/5/2024		Fabaceae	*Lupinus shockleyi*	Desert Lupine	Yes	
	2011 Collection	Fabaceae	*Melilotus indicus*	Indian Sweetclover	No	
3/10/2023		Fabaceae	*Neltuma odorata*	Honey Mesquite	Yes	
	2017 iNat	Fabaceae	*Olneya tesota*	Ironwood	Yes	
3/18/2024		Fabaceae	*Parkinsonia aculeata*	Mexican Palo Verde	No	
3/5/2024		Fabaceae	*Parkinsonia florida*	Blue Palo Verde	Yes	
3/10/2023		Fabaceae	*Psorothamnus emoryi emoryi*	Dyebush	Yes	
3/14/2024		Fabaceae	*Psorothamnus schottii*	Indigo Bush	Yes	
3/10/2023		Fabaceae	*Psorothamnus spinosus*	Smoke Tree	Yes	
4/5/2023		Fabaceae	*Senegalia greggii*	Catclaw Acacia	Yes	
	2021 iNat	Fabaceae	*Senna armata*	Spiny Senna	Yes	
	2016 iNat	Fabaceae	*Senna artemisioides coriacea*	Broad-leaf Desert Cassia	No	
3/14/2023		Fouquieriaceae	*Fouquieria splendens splendens*	Ocotillo	Yes	
3/10/2023		Geraniaceae	*Erodium cicutarium*	Red-Stem Filaree/Storksbill	No	
4/5/2023		Geraniaceae	*Erodium texanum*	Desert Filaree/Storksbill	Yes	
	2019 iNat	Heliotropiaceae	*Heliotropium curassavicum oculatum*	Alkali Heliotrope	Yes	

3/5/2024		Hydrophyllaceae	*Eucrypta micrantha*	Small-Flower Eucrypta	Yes	
3/10/2023		Hydrophyllaceae	*Phacelia crenulata ambigua*	Notch-Leaf Scorpion-Weed	Yes	
3/10/2023		Hydrophyllaceae	*Phacelia crenulata minutiflora*	Cleft-Leaf Phacelia	Yes	
3/10/2023		Hydrophyllaceae	*Phacelia distans*	Wild-Heliotrope	Yes	
	2017 iNat	Hydrophyllaceae	*Phacelia ivesiana*	Ives' Phacelia	Yes	
9/21/2023		Krameriaceae	*Krameria bicolor*	White Rhatany	Yes	
	2017 iNat	Lamiaceae	*Salvia columbariae*	Chia	Yes	
3/23/2023		Loasaceae	*Mentzelia desertorum*	Desert Stick-Leaf	Yes	
3/5/2024		Malvaceae	*Eremalche exilis*	Trailing Mallow	Yes	
3/10/2023		Malvaceae	*Eremalche rotundifolia*	Desert Five-Spot	Yes	
3/10/2023		Malvaceae	*Sphaeralcea angustifolia*	Narrow-Leaf Globemallow	Yes	
3/5/2024		Montiaceae	*Calyptridium monandrum*	Common Pussypaws	Yes	
3/10/2023		Montiaceae	*Cistanthe ambigua*	Desert Pot Herb	Yes	
3/10/2023		Nyctaginaceae	*Abronia villosa*	Hairy Sand Verbena	Yes	
3/10/2023		Nyctaginaceae	*Allionia incarnata incarnata*	Typical Trailing Windmills	Yes	
3/5/2024		Onagraceae	*Camissoniopsis pallida pallida*	Pale Yellow Sun Cup	Yes	
3/10/2023		Onagraceae	*Chylismia claviformis peirsonii*	Peirson's Evening-Primrose	Yes	
3/10/2023		Onagraceae	*Eremothera boothii condensata*	Desert Lantern	Yes	
3/27/2023		Onagraceae	*Eulobus californicus*	False-Mustard	Yes	
3/10/2023		Onagraceae	*Oenothera deltoides*	Dune Evening-Primrose	Yes	
3/10/2023		Orobanchaceae	*Aphyllon cooperi*		Yes	
3/10/2023		Papaveraceae	*Eschscholzia minutiflora*	Pygmy Gold-Poppy	Yes	

3/14/2023		Phrymaceae	*Diplacus bigelovii bigelovii*	Bigelow's Monkey Flower	Yes	
	2008 Collection	Plantaginaceae	*Antirrhinum filipes*	Desert Snapdragon	Yes	
3/10/2023		Plantaginaceae	*Plantago ovata fastigiata*	Woolly Plantain	Yes	
3/14/2023		Poaceae	*Aristida adscensionis*	Six-Weeks Three-Awn	Yes	
9/21/2023		Poaceae	*Bouteloua aristidoides aristidoides*	Needle Grama	Yes	
3/10/2023		Poaceae	*Bouteloua barbata barbata*	Six-Weeks Grama	Yes	
	2011 Collection	Poaceae	*Bromus rubens*	Foxtail Chess, Red Brome	No	
	2011 Collection	Poaceae	*Bromus tectorum*	Cheat Grass, Downy Brome	No	
3/10/2023		Poaceae	*Hilaria rigida*	Big Galleta	Yes	
		Poaceae	*Phalaris minor*	Little-Seed Canary Grass	No	
3/10/2023		Poaceae	*Schismus arabicus*	Arabian Schismus	No	
3/10/2023		Polemoniaceae	*Aliciella latifolia latifolia*	Broad-Leaf Gilia	Yes	
4/15/2024		Polemoniaceae	*Eriastrum eremicum eremicum*	Desert Woolly-Star	Yes	
3/10/2023		Polemoniaceae	*Langloisia setosissima setosissima*	Bristly Langloisia	Yes	
3/10/2023		Polemoniaceae	*Loeseliastrum matthewsii*	Desert Calico	Yes	
3/23/2023		Polemoniaceae	*Loeseliastrum schottii*	Schott's Calico	Yes	
3/14/2023		Polygonaceae	*Chorizanthe brevicornu brevicornu*	Brittle Spineflower	Yes	
3/14/2023		Polygonaceae	*Chorizanthe corrugata*	Corrugate Spineflower	Yes	
3/5/2024		Polygonaceae	*Chorizanthe rigida*	Rigid Spineflower	Yes	
3/10/2023		Polygonaceae	*Eriogonum inflatum*	Desert Trumpet	Yes	

3/10/2023		Polygonaceae	*Eriogonum thomasii*	Thomas's Buckwheat	Yes	
3/10/2023		Polygonaceae	*Eriogonum trichopes*	Little Trumpet	Yes	
3/10/2023		Resedaceae	*Oligomeris linifolia*	Lineleaf Whitepuff	Yes	
	2020 iNat	Solanaceae	*Datura wrightii*	Sacred Datura	Yes	
3/5/2024		Solanaceae	*Lycium brevipes brevipes*	Common Desert Thorn	Yes	
3/18/2024		Solanaceae	*Lycium fremontii*	Fremont's Desert Thorn	Yes	
3/10/2023		Solanaceae	*Lycium parishii*	Parish's Desert Thorn	Yes	2B.3
3/23/2023		Solanaceae	*Nicotiana clevelandii*	Cleveland's Tobacco	Yes	
3/10/2023		Tamaricaceae	*Tamarix aphylla*	Athel Tamarisk	No	
4/5/2023		Tamaricaceae	*Tamarix ramosissima*	Saltcedar	No	
3/10/2023		Viscaceae	*Phoradendron californicum*	Desert Mistletoe	Yes	
9/21/2023		Zygophyllaceae	*Kallstroemia californica*	California Caltrop	Yes	
3/10/2023		Zygophyllaceae	*Larrea tridentata*	Creosote Bush	Yes	
3/7/2024		Zygophyllaceae	*Tribulus terrestris*	Puncture Vine	No	

Table B3. Excluded plant specimens in Borrego Springs. Seventeen specimens were mapped to the Borrego Sink project area but excluded from the listed flora because of vague localities or unreliable georeferencing.

Collection Year	Family	Latin Name	Common Name	Native
1933	Acanthaceae	*Justicia californica*	Chuparosa, Beloperone	Yes
1993	Amaranthaceae	*Atriplex canescens macilenta*	Salton Saltbush	Yes
1899	Amaranthaceae	*Atriplex elegans var. fasciculata*	Wheelscale	Yes
1933	Asteraceae	*Baccharis salicifolia*	Mule-Fat, Seep-Willow	Yes
1932	Asteraceae	*Baileya pleniradiata*	Woolly Marigold	Yes

1935	Asteraceae	*Bebbia juncea aspera*	Rush Sweetbush	Yes
1933	Asteraceae	*Chaenactis fremontii*	Desert Pincushion	Yes
1998	Asteraceae	*Dimorphotheca sinuata*	Blue-Eye Cape-Marigold	No
1935	Asteraceae	*Helianthus petiolaris canescens*	Gray Sunflower	Yes
1993	Asteraceae	*Prenanthella exigua*	Egbertia	Yes
1937	Asteraceae	*Stephanomeria exigua exigua*	Small Wreath-Plant	Yes
1938	Hydrophyllaceae	*Pholistoma membranaceum*	White Fiesta Flower	Yes
1932	Lamiaceae	*Condea emoryi*	Desert-Lavender	Yes
1933	Namaceae	*Nama demissa demissa*	Purple Mat	Yes
1941	Poaceae	*Festuca octoflora*	Tufted Fescue	Yes
1993	Polygonaceae	*Eriogonum deflexum deflexum*	Desert Skeleton Weed	Yes
1940	Solanaceae	*Physalis crassifolia*	Greene's Ground-Cherry	Yes

Table B4. Checklist of vascular plant taxa at Clark Dry Lake showing the date of the first SDNHM observation or the year of the historical collection or iNaturalist observation; nativity; and California Rare Plant Rank.

Evidence of Presence						
SDNHM Survey	**Other Source**	**Family**	**Latin Name**	**CommonName**	**Native**	**CRPR**
3/9/2023		Agavaceae	*Hesperocallis undulata*	Desert Lily	Yes	
3/9/2023		Amaranthaceae	*Allenrolfea occidentalis*	Iodine Bush	Yes	
9/22/2023		Amaranthaceae	*Amaranthus fimbriatus*	Fringe Amaranth	Yes	
	2009 Collection	Amaranthaceae	*Atriplex canescens canescens*	Four-wing Saltbush	Yes	
2/23/2024		Amaranthaceae	*Atriplex canescens laciniata*	Caleb Saltbush	Yes	
3/9/2023		Amaranthaceae	*Atriplex elegans fasciculata*	Wheelscale	Yes	
3/9/2023		Amaranthaceae	*Atriplex hymenelytra*	Desert Holly	Yes	
3/9/2023		Amaranthaceae	*Atriplex polycarpa*	Cattle Saltbush	Yes	
3/9/2023		Amaranthaceae	*Blitum nuttallianum*	Nuttall's Poverty Weed	Yes	
3/6/2024		Amaranthaceae	*Chenopodiastrum murale*	Nettle-Leaf Goosefoot	No	
3/6/2024		Amaranthaceae	*Salsola paulsenii*	Barbwire Russian-Thistle	No	
3/9/2023		Amaranthaceae	*Suaeda nigra*	Bush Seepweed	Yes	
	2021 iNat	Amaranthaceae	*Tidestromia suffruticosa oblongifolia*	Arizona honeysweet	Yes	
	1993 Collection	Apocynaceae	*Asclepias subulata*	Rush Milkweed, Ajamete	Yes	

3/9/2023		Asteraceae	*Ambrosia dumosa*	White Bur-Sage, Burro-Weed	Yes	
3/27/2023		Asteraceae	*Ambrosia salsola*	Cheesebush	Yes	
3/19/2024		Asteraceae	*Ambrosia x platyspina*	(Seaman) Strother & B.G.Baldwin	Yes	
3/13/2023		Asteraceae	*Baileya pauciradiata*	Short-Ray Desert Marigold	Yes	
3/27/2024		Asteraceae	*Bebbia juncea aspera*	Rush Sweetbush	Yes	
3/9/2023		Asteraceae	*Calycoseris wrightii*	White Tack-Stem	Yes	
3/9/2023		Asteraceae	*Chaenactis carphoclinia carphoclinia*	Pebble Pincushion	Yes	
3/9/2023		Asteraceae	*Chaenactis fremontii*	Desert Pincushion	Yes	
3/9/2023		Asteraceae	*Chaenactis stevioides*	Desert Pincushion	Yes	
3/6/2024		Asteraceae	*Dicoria canescens*	Desert Dicoria	Yes	
3/6/2024		Asteraceae	*Encelia farinosa farinosa*	Brittlebush, Incienso	Yes	
3/27/2024		Asteraceae	*Encelia farinosa phenicodonta*	Purple-Eye Incienso	Yes	
3/27/2023		Asteraceae	*Encelia frutescens frutescens*	Rayless Encelia	Yes	
3/9/2023		Asteraceae	*Geraea canescens*	Desert Sunflower	Yes	
3/9/2023		Asteraceae	*Isocoma acradenia eremophila*	Alkali Goldenbush	Yes	
3/24/2023		Asteraceae	*Lactuca serriola*	Prickly Lettuce	No	
3/9/2023		Asteraceae	*Logfia arizonica*	Arizona Cottonrose	Yes	
3/9/2023		Asteraceae	*Logfia depressa*	Dwarf Cottonrose	Yes	

3/6/2024		Asteraceae	*Logfia filaginoides*	California Cottonrose	Yes	
3/9/2023		Asteraceae	*Malacothrix glabrata*	Desert Dandelion	Yes	
3/9/2023		Asteraceae	*Monoptilon bellioides*	Mojave Desert Star	Yes	
3/13/2023		Asteraceae	*Palafoxia arida arida*	Desert Spanish-Needle	Yes	
3/9/2023		Asteraceae	*Pectis papposa papposa*	Chinchweed	Yes	
3/9/2023		Asteraceae	*Perityle emoryi*	Emory's Rock Daisy	Yes	
3/9/2023		Asteraceae	*Pluchea sericea*	Arrowweed	Yes	
3/9/2023		Asteraceae	*Rafinesquia neomexicana*	Desert Chicory	Yes	
3/27/2023		Asteraceae	*Senecio mohavensis*	Mojave Groundsel	Yes	
3/9/2023		Asteraceae	*Sonchus oleraceus*	Common Sow-Thistle	No	
3/24/2023		Asteraceae	*Stephanomeria exigua exigua*	Small Wreath-Plant	Yes	
3/18/2024		Asteraceae	*Stylocline micropoides*	Desert Nest-Straw	Yes	
3/19/2024		Asteraceae	*Trichoptilium incisum*	Yellowhead	Yes	
4/4/2023		Asteraceae	*Volutaria tubuliflora*	Tubular Knapweed	No	
3/9/2023		Boraginaceae	*Amsinckia intermedia*	Rancher's Fiddleneck	Yes	
3/9/2023		Boraginaceae	*Amsinckia tessellata tessellata*	Checker Fiddleneck	Yes	
3/9/2023		Boraginaceae	*Cryptantha barbigera barbigera*	Bearded Cryptantha	Yes	
3/6/2024		Boraginaceae	*Cryptantha barbigera fergusoniae*	Palm Dprings Cryptantha	Yes	
3/13/2023		Boraginaceae	*Cryptantha ganderi*	Gander's Cryptantha	Yes	1B.1

3/9/2023		Boraginaceae	*Cryptantha maritima maritima*	White-Hair Cryptantha	Yes	
3/6/2024		Boraginaceae	*Cryptantha maritima pilosa*	Tufted Haired Cryptantha	Yes	
4/2/2024		Boraginaceae	*Cryptantha muricata jonesii*	Jones's Prickly Cryptantha	Yes	
3/13/2023		Boraginaceae	*Eremocarya micrantha micrantha*	Small-Flowered Eremocarya	Yes	
3/27/2024		Boraginaceae	*Johnstonella angelica*	Angelic Johnstonella	Yes	
3/9/2023		Boraginaceae	*Johnstonella angustifolia*	Narrow-Leaf Johnstonella	Yes	
2/23/2024		Boraginaceae	*Johnstonella costata*	Ribbed Johnstonella	Yes	4.3
3/9/2023		Boraginaceae	*Pectocarya heterocarpa*	Chuckwalla Pectocarya	Yes	
3/9/2023		Boraginaceae	*Pectocarya peninsularis*	Peninsular Pectocarya	Yes	
3/13/2023		Boraginaceae	*Pectocarya platycarpa*	Broad-Fruit Pectocarya	Yes	
3/6/2024		Boraginaceae	*Pectocarya recurvata*	Recurved Pectocarya	Yes	
3/9/2023		Brassicaceae	*Brassica tournefortii*	Wild Turnip	No	
3/9/2023		Brassicaceae	*Caulanthus lasiophyllus*	California mustard	Yes	
2/23/2024		Brassicaceae	*Descurainia pinnata*	western tansy mustard	Yes	
3/13/2023		Brassicaceae	*Dithyrea californica*	California Spectacle-Pod	Yes	
3/9/2023		Brassicaceae	*Lepidium lasiocarpum lasiocarpum*	Sand Peppergrass	Yes	
3/9/2023		Brassicaceae	*Lepidium oblongum*	Veiny/Wayside Peppergrass	Yes	
3/9/2023		Brassicaceae	*Sisymbrium irio*	London Rocket	No	

2/23/2024		Brassicaceae	*Streptanthella longirostris*	Long-Beak Twist-Flower	Yes	
4/14/2023		Cactaceae	*Cylindropuntia echinocarpa*	Silver Cholla	Yes	
3/27/2023		Cactaceae	*Cylindropuntia ganderi ganderi*	Gander's cholla	Yes	
3/9/2023		Cactaceae	*Cylindropuntia ramosissima*	Branched Pencil Cholla	Yes	
3/6/2024		Cactaceae	*Ferocactus cylindraceus*	California Barrel Cactus	Yes	
3/6/2024		Cactaceae	*Opuntia basilaris basilaris*	Beavertail Cactus	Yes	
3/27/2024		Campanulaceae	*Nemacladus glanduliferus*	Glandular Threadplant	Yes	
3/27/2024		Campanulaceae	*Nemacladus orientalis*	Eastern Glandular Threadplant	Yes	
3/27/2024		Campanulaceae	*Nemacladus tenuis tenuis*	Desert Threadplant	Yes	
3/9/2023		Caryophyllaceae	*Achyronychia cooperi*	Onyx Flower, Frost Mat	Yes	
	2020 iNat	Caryophyllaceae	*Loeflingia squarrosa*	Spreading Pygmyleaf	Yes	
4/2/2024		Cleomaceae	*Cleomella arborea*	Bladderpod	Yes	
3/20/2024		Cleomaceae	*Cleomella palmeri*	Jackass-Clover	Yes	2B.2
3/27/2023		Convolvulaceae	*Cuscuta californica papillosa*	Rough Chaparral Dodder	Yes	
4/3/2024		Cucurbitaceae	*Cucurbita palmata*	Coyote Melon	Yes	
3/9/2023		Ehretiaceae	*Tiquilia palmeri*	Palmer's Tiquilia	Yes	
3/27/2023		Euphorbiaceae	*Croton californicus*	California Croton	Yes	
3/27/2024		Euphorbiaceae	*Ditaxis lanceolata*	Desert Silverbush	Yes	

3/9/2023		Euphorbiaceae	*Ditaxis serrata serrata*	Yuma Silverbush	Yes	
3/9/2023		Euphorbiaceae	*Euphorbia micromera*	Sonoran Sandmat	Yes	
3/9/2023		Euphorbiaceae	*Euphorbia polycarpa*	Small-Seed Sandmat	Yes	
3/9/2023		Euphorbiaceae	*Euphorbia setiloba*	Yuma Sandmat	Yes	
3/13/2023		Euphorbiaceae	*Stillingia spinulosa*	Annual Stillingia	Yes	
3/9/2023		Fabaceae	*Acmispon maritimus brevivexillus*	Humble Lotus	Yes	
3/9/2023		Fabaceae	*Acmispon strigosus*	Strigose Bird's-foot Trefoil	Yes	
2/23/2024		Fabaceae	*Astragalus aridus*		Yes	
3/13/2023		Fabaceae	*Astragalus crotalariae*	Salton Milkvetch	Yes	4.3
2/23/2024		Fabaceae	*Astragalus didymocarpus dispermus*	Desert Dwarf Locoweed	Yes	
3/24/2023		Fabaceae	*Astragalus lentiginosus borreganus*	Borrego Milkvetch	Yes	4.3
3/27/2024		Fabaceae	*Astragalus nuttallianus imperfectus*	Small-Flower Milkvetch	Yes	
4/2/2024		Fabaceae	*Astragalus palmeri*	Palmer's Locoweed	Yes	
3/9/2023		Fabaceae	*Dalea mollis*	Hairy Prairie Clover	Yes	
3/9/2023		Fabaceae	*Dalea mollissima*	Soft Prairie Clover	Yes	
3/9/2023		Fabaceae	*Lupinus arizonicus*	Arizona Lupine	Yes	
3/19/2024		Fabaceae	*Lupinus concinnus*	Bajada Lupine	Yes	
4/13/2023		Fabaceae	*Lupinus shockleyi*	Purple Desert Lupine	Yes	

3/9/2023		Fabaceae	*Neltuma odorata*	Honey Mesquite	Yes	
3/6/2024		Fabaceae	*Psorothamnus emoryi emoryi*	White Dalea	Yes	
3/9/2023		Fabaceae	*Psorothamnus schottii*	Indigo Bush	Yes	
3/27/2023		Fabaceae	*Psorothamnus spinosus*	Smoke Tree	Yes	
3/9/2023		Fabaceae	*Senegalia greggii*	Catclaw Acacia	Yes	
3/6/2024		Fouquieriaceae	*Fouquieria splendens splendens*	Ocotillo	Yes	
3/9/2023		Geraniaceae	*Erodium cicutarium*	Red-Stem Filaree/Storksbill	No	
3/9/2023		Geraniaceae	*Erodium texanum*	Desert Filaree/Storksbill	Yes	
2/23/2024		Heliotropiaceae	*Heliotropium curassavicum*	Salt Heliotrope	Yes	
3/9/2023		Hydrophyllaceae	*Emmenanthe penduliflora penduliflora*	Whispering Bells	Yes	
3/9/2023		Hydrophyllaceae	*Eucrypta micrantha*	Small-Flower Eucrypta	Yes	
3/6/2024		Hydrophyllaceae	*Phacelia crenulata ambigua*	Notch-Leaf Phacelia	Yes	
3/9/2023		Hydrophyllaceae	*Phacelia crenulata minutiflora*	Cleft-Leaf Phacelia	Yes	
3/9/2023		Hydrophyllaceae	*Phacelia distans*	Wild-Heliotrope	Yes	
4/13/2023		Hydrophyllaceae	*Phacelia ivesiana*	Ives's Phacelia	Yes	
3/9/2023		Krameriaceae	*Krameria bicolor*	White Rhatany	Yes	
3/9/2023		Lamiaceae	*Condea emoryi*	Desert Lavender	Yes	
4/13/2023		Lamiaceae	*Salvia columbariae*	Chia	Yes	

3/6/2024		Loasaceae	*Mentzelia affinis*	Hydra Stickleaf	Yes	
3/27/2023		Loasaceae	*Mentzelia desertorum*	Desert Stick-Leaf	Yes	
4/4/2023		Loasaceae	*Mentzelia involucrata*	Sandblazing Star	Yes	
9/22/2023		Loasaceae	*Petalonyx thurberi thurberi*	Thurber's Sandpaper Plant	Yes	
3/9/2023		Malvaceae	*Eremalche exilis*	Trailing Mallow	Yes	
3/9/2023		Malvaceae	*Eremalche rotundifolia*	Desert Five-Spot	Yes	
4/2/2024		Malvaceae	*Sphaeralcea ambigua rugosa*	Roughleaf Desert Mallow	Yes	
3/6/2024		Malvaceae	*Sphaeralcea angustifolia*	Narrow-Leaf Globemallow	Yes	
3/9/2023		Molluginaceae	*Hypertelis umbellata*		No	
4/4/2023		Montiaceae	*Calyptridium monandrum*	Common Pussypaws	Yes	
3/13/2023		Montiaceae	*Cistanthe ambigua*	Desert Pot Herb	Yes	
3/9/2023		Namaceae	*Nama demissa demissa*	Desert Purple Mat	Yes	
2/23/2024		Namaceae	*Nama hispida spathulata*	Rough Purple Mat	Yes	
3/9/2023		Nyctaginaceae	*Abronia villosa villosa*	Desert Sand-Verbena	Yes	
3/27/2023		Nyctaginaceae	*Allionia incarnata incarnata*	Typical Trailing Windmills	Yes	
9/22/2023		Nyctaginaceae	*Allionia incarnata villosa*	Hairy Trailing Windmills	Yes	
9/22/2023		Nyctaginaceae	*Boerhavia triquetra intermedia*	Five-wing Spiderling	Yes	
9/22/2023		Nyctaginaceae	*Boerhavia wrightii*	Wright's Spiderling	Yes	

2/23/2024		Onagraceae	*Camissoniopsis pallida pallida*	Pale Yellow Sun Cup	Yes	
3/9/2023		Onagraceae	*Chylismia claviformis peirsonii*	Peirson's Evening-Primrose	Yes	
3/9/2023		Onagraceae	*Eremothera boothii condensata*	Shredding Suncup	Yes	
3/27/2024		Onagraceae	*Eremothera chamaenerioides*	Willow-Herb Evening-Primrose	Yes	
3/9/2023		Onagraceae	*Eulobus californicus*	False-Mustard	Yes	
3/13/2023		Onagraceae	*Oenothera deltoides deltoides*	Annual Evening Primrose	Yes	
3/24/2023		Orobanchaceae	*Aphyllon cooperi*	Desert Broomrape	Yes	
3/9/2023		Papaveraceae	*Eschscholzia minutiflora*	Pygmy Gold-Poppy	Yes	
3/27/2023		Papaveraceae	*Eschscholzia parishii*	Parish's Gold-Poppy	Yes	
3/19/2024		Phrymaceae	*Diplacus bigelovii bigelovii*	Bigelow's Monkey Flower	Yes	
3/27/2024		Plantaginaceae	*Mohavea confertiflora*	Ghost Flower	Yes	
3/9/2023		Plantaginaceae	*Plantago ovata fastigiata*	Woolly Plantain	Yes	
3/9/2023		Poaceae	*Aristida adscensionis*	Six-Weeks Three-Awn	Yes	
3/28/2023		Poaceae	*Aristida californica*	California Three-Awn	Yes	
3/9/2023		Poaceae	*Bouteloua aristidoides*	Needle Grama	Yes	
3/9/2023		Poaceae	*Bouteloua barbata barbata*	Six-Weeks Grama	Yes	
3/9/2023		Poaceae	*Bromus rubens*	Foxtail Chess, Red Brome	No	
3/9/2023		Poaceae	*Festuca bromoides*	Brome Fescue	No	

3/27/2024		Poaceae	*Festuca octoflora*	Tufted Fescue	Yes	
3/9/2023		Poaceae	*Hilaria rigida*	Big Galleta	Yes	
3/9/2023		Poaceae	*Hordeum murinum glaucum*	Glaucous Barley	No	
3/24/2023		Poaceae	*Phalaris minor*	Lesser Canary Grass	No	
3/9/2023		Poaceae	*Schismus arabicus*	Arabian Schismus	No	
3/9/2023		Poaceae	*Schismus barbatus*	Mediterranean Schismus	No	
3/27/2024		Polemoniaceae	*Aliciella latifolia latifolia*	Broad-Leaf Gilia	Yes	
4/4/2023		Polemoniaceae	*Eriastrum eremicum eremicum*	Desert Woolly-Star	Yes	
3/24/2023		Polemoniaceae	*Eriastrum harwoodii*	Wooly star	Yes	1B.2
4/4/2023		Polemoniaceae	*Gilia stellata*	Star Gilia	Yes	
3/27/2024		Polemoniaceae	*Langloisia setosissima setosissima*	Bristly Langloisia	Yes	
3/6/2024		Polemoniaceae	*Linanthus jonesii*	Jones' Linanthus	Yes	
	2017 iNat	Polemoniaceae	*Loeseliastrum matthewsii*	Desert Calico	Yes	
3/9/2023		Polemoniaceae	*Loeseliastrum schottii*	Schott's Calico	Yes	
3/9/2023		Polygonaceae	*Chorizanthe brevicornu brevicornu*	Brittle Spineflower	Yes	
3/27/2024		Polygonaceae	*Chorizanthe rigida*	Devil's Spineflower	Yes	
3/9/2023		Polygonaceae	*Eriogonum inflatum*	Desert Trumpet	Yes	
3/9/2023		Polygonaceae	*Eriogonum thomasii*	Thomas's Buckwheat	Yes	
3/27/2024		Polygonaceae	*Eriogonum trichopes*	Little Trumpet	Yes	

3/9/2023		Polygonaceae	*Pterostegia drymarioides*	Granny's Hairnet	Yes	
3/9/2023		Resedaceae	*Oligomeris linifolia*	Narrow-Leaf Oligomeris	Yes	
3/19/2024		Solanaceae	*Datura discolor*	Devil's Trumpets	Yes	
3/9/2023		Solanaceae	*Lycium brevipes brevipes*	Common Desert Thorn	Yes	
4/13/2023		Solanaceae	*Nicotiana clevelandii*	Cleveland's Tobacco	Yes	
4/4/2023		Solanaceae	*Nicotiana obtusifolia*	Desert Tobacco	Yes	
4/4/2023		Solanaceae	*Physalis crassifolia*	Thickleaf Groundcherry	Yes	
4/13/2023		Tamaricaceae	*Tamarix aphylla*	Athel Tamarisk	No	
	2024 iNat	Tamaricaceae	*amarix cf. ramosissim*		No	
3/9/2023		Viscaceae	*Phoradendron californicum*	Desert Mistletoe	Yes	
3/6/2024		Zygophyllaceae	*Fagonia laevis*	California fagonbush	Yes	
4/13/2023		Zygophyllaceae	*Fagonia pachyacantha*	Sticky Fagonia	Yes	
3/9/2023		Zygophyllaceae	*Kallstroemia californica*	California Caltrop	Yes	
3/9/2023		Zygophyllaceae	*Larrea tridentata*	Creosote Bush	Yes	

Table B5. Excluded plant specimens at Clark Dry Lake. Seven specimens were mapped to the Clark Dry Lake project area but excluded from the listed flora because of vague localities or unreliable georeferencing.

Collection Year	Family	Latin Name	Common Name	Native
2002	Acanthaceae	*Justicia californica*	Chuparosa, Beloperone	Yes
2001	Apocynaceae	*Funastrum hirtellum*	Trailing Townula	Yes
2002	Asteraceae	*Lepidospartum squamatum*	Scale-Broom	Yes
1938	Crossosomataceae	*Crossosoma bigelovii*	Bigelow's Ragged Rock Flower	Yes
1938	Ehretiaceae	*Tiquilia plicata*	Plicate Tiquilia	Yes
2009	Nyctaginaceae	*Mirabilis laevis crassifolia*	Coastal Wishbone Plant	Yes
1938	Simmondsiaceae	*Simmondsia chinensis*	Jojoba, Goatnut	Yes

B.3 Wildlife Surveys of the Mesquite Bosques

Figure B1. A Variegated Meadowhawk, *Sympetrum corruptum*, photographed at Clark Dry Lake Mesquite Bosque in January 2025.

Figure B2. A LeConte's Thrasher, *Toxostoma lecontei*, photographed during a SDNHM plant survey at BS in April 2024 by Daniel Donovan.

Figure B3. A Sonoran Gopher Snake, *Pituophis catenifer affinis*, was seen on a camera trap at CDL in July 2024.

Figure B4. A Greater Roadrunner, *Geococcyx californianus*, seen running between Honey Mesquite trees via camera trap at BS in March 2024.

Figure B5. A pair of Bobcats, *Lynx rufus,* photographed via camera trap at CDL in September 2023.

Figure B6. Two Desert Cottontail Rabbits, *Sylvilagus audubonii*, seen at CDL via camera trap in October 2023.

Figure B7. A Western Whiptail, *Aspidoscelis tigris,* seen amongst Honey Mesquite branches at CDL via camera trap in June 2024.

Figure B8. A Black-Tailed Jackrabbit, *Lepus californicus,* seen on camera trap at BS in December 2023.

Figure B9. A Coyote, *Canis latrans,* posing for a camera trap at BS in December 2023.

Figure B10. A Common Poorwill, *Phalaenoptilus nuttallii,* captured at a camera trap at BS. Seen on the ground in the mesquite bosque at night in March 2024.

Figure B11. One of several Long-Eared Owls, *Asio otus*, that flew out from the Honey Mesquite at CDL during a November 2024 site visit.

Figure B12. A Desert Spiny Lizard, *Sceloporus magister,* photographed by a wildlife camera at Clark Dry Lake in March 2024.

Figure B13. Desert cockroaches, *Arenivaga investigata*, (male + female in nymph form) in the mesquite bosque on the property of Candice Hansen Koharcheck (quarter mile NW of the intersection of Yaqui Pass Rd and Rango Way). 18 November 2022 at 4:55pm. Photo by Lori Paul.

Figure B14. California Tree Frog, *Pseudacris cadaverina,* in the mesquite bosque near the Borrego Sink. 7 March 2011. Photo by Lori Paul.

Figure B15. Mating Marine Blue butterflies, *Leptotes marina*, in the mesquite bosque near Clark Dry Lake. 26 April 2024 at 10:41am. Photo by Lori Paul.

Table B6. List of wildlife (amphibians, birds, fungus, invertebrates, mammals, and reptiles seen in the Borrego Springs (BS) and Clark Dry Lake (CDL) study areas.

Location	Taxa	Latin Name	Common Name	Status	List/ Organization	Source	Method of Observation
BS	Amphibian	*Anaxyrus boreas halophilus*	California Toad			iNat	Sighting (Photo)
BS	Bird	*Empidonax traillii*	Willow Flycatcher	Endangered	CESA	iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Vireo bellii pusillus*	Bell's Vireo (Least)	Endangered	CESA	eBird	Reported
CDL, BS	Bird	*Buteo swainsoni*	Swainson's Hawk	Threatened	CESA	iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Riparia riparia*	Bank Swallow	Threatened	CDFW, CESA	eBird	Sighting (media), Reported
CDL, BS	Bird	*Toxostoma bendirei*	Bendire's Thrasher	Species of Special Concern	CDFW	iNat, eBird, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Limnodromus griseus*	Short-billed Dowitcher			eBird	Sighting (media)
BS	Bird	*Contopus cooperi*	Olive-sided Flycatcher			eBird	Reported
CDL, BS	Bird	*Lanius ludovicianus*	Loggerhead Shrike	Species of Special Concern	CDFW	iNat, CBC, eBird, Bird Point Count, Camera Trap	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Selasphorus rufus*	Rufous Hummingbird			eBird	Reported, Sighting (media)
BS	Bird	*Calidris minutilla*	Least Sandpiper			eBird	Sighting (media), Reported

BS	Bird	*Charadrius vociferus*	Killdeer			iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Limnodromus scolopaceus*	Long-billed Dowitcher			eBird	Sighting (media), Reported
BS	Bird	*Tringa melanoleuca*	Greater Yellowlegs			eBird	Sighting (media), Reported
BS	Bird	*Anser albifrons*	Greater White-fronted Goose	Species of Special Concern	CDFW	eBird	Sighting (media)
BS	Bird	*Artemisiospiza belli belli*	Bell's Sparrow	Watch List	CDFW	CBC, eBird	Reported, Sighting (media)
BS	Bird	*Cistothorus palustris*	Marsh Wren	Species of Special Concern	CDFW	eBird	Sighting (media), Reported
BS	Bird	*Accipiter striatus*	Sharp-shinned Hawk	Watch List	CDFW	iNat, eBird	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Aquila chrysaetos*	Golden Eagle	Fully Protected Species	CDFW	eBird	Reported
BS	Bird	*Ardea alba*	Great Egret			eBird	Sighting (media), Reported
BS	Bird	*Ardea herodias*	Great Blue Heron			eBird	Sighting (media), Reported
BS	Bird	*Artemisiospiza belli ssp. canescens*	Mojave Bell's Sparrow	Watch List	CDFW	iNat	Sighting (Photo)
CDL	Bird	*Asio otus*	Long-eared owl	Species of Special Concern	CDFW	iNat, CBC, Bird Incidental	Sighting (Photo), Reported

CDL, BS	Bird	*Astur cooperii*	Cooper's Hawk	Watch List	CDFW	iNat, CBC, eBird	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Athene cunicularia*	Burrowing Owl	Least Concern, Candidate Endangered	CESA, CDFW	CBC, eBird	Reported
BS	Bird	*Branta bernicla*	Brant	Species of Special Concern	CDFW	eBird	Sighting (media), Reported
BS	Bird	*Buteo regalis*	Ferruginous Hawk	Watch List	CDFW	eBird	Sighting (media), Reported
CDL, BS	Bird	*Calypte costae*	Costa's Hummingbird			iNat, CBC, eBird, Bird Point Count, Bird Incidental	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Chaetura vauxi*	Vaux's Swift	Species of Special Concern	CDFW	eBird	Reported, Sighting (media)
CDL, BS	Bird	*Circus hudsonius*	Northern Harrier	Species of Special Concern	CDFW	CBC, eBird	Reported
CDL, BS	Bird	*Falco columbarius*	Merlin	Watch List	CDFW	iNat, CBC, eBird	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Falco mexicanus*	Prairie Falcon	Watch List	CDFW	iNat, CBC, eBird	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Icteria virens*	Yellow-breasted Chat	Species of Special Concern	CDFW	eBird	Reported, Sighting (media)
BS	Bird	*Junco hyemalis*	Dark-eyed Junco	Watch List	CDFW	eBird	Reported, Sighting (media)

BS	Bird	*Junco hyemalis [oreganus Group]*	Dark-eyed Junco (Oregon)	Watch List	CDFW	eBird	Reported
BS	Bird	*Leiothlypis luciae*	Lucy's Warbler	Species of Special Concern	CDFW	iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Leiothlypis virginiae*	Virginia's Warbler	Watch List	CDFW	eBird	Reported, Sighting (media)
BS	Bird	*Myiarchus tyrannulus*	Brown-crested Flycatcher	Watch List	CDFW	iNat	Sighting (Photo)
BS	Bird	*Nannopterum auritum*	Double-crested Cormorant	Watch List	CDFW	eBird	Reported
BS	Bird	*Pandion haliaetus*	Osprey	Watch List	CDFW	eBird	Reported, Sighting (media)
BS	Bird	*Parabuteo unicinctus*	Harris's Hawk	Watch List	CDFW	eBird	Sighting (media), Reported
BS	Bird	*Plegadis chihi*	White-faced Ibis	Watch List	CDFW	eBird	Reported, Sighting (media)
CDL, BS	Bird	*Polioptila melanura*	Black-tailed Gnatcatcher	Watch List	CDFW	iNat, CBC, eBird, Camera Trap, Bird Point Count, Bird Incidental	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Progne subis*	Purple Martin	Species of Special Concern	CDFW	eBird	Reported, Sighting (media)
CDL, BS	Bird	*Pyrocephalus rubinus*	Vermilion Flycatcher	Species of Special Concern	CDFW	eBird	Reported, Sighting (media)
BS	Bird	*Setophaga petechia*	Yellow Warbler	Species of Special Concern	CDFW	eBird, Bird Point Count	Reported, Sighting (media)

CDL, BS	Bird	*Spinus lawrencei*	Lawrence's Goldfinch			iNat, eBird, Bird Point Count	Sighting (Photo), Sighting (media), Reported
CDL, BS	Bird	*Thryomanes bewickii*	Bewick's Wren	Species of Special Concern	CDFW	CBC, eBird, Camera Trap, Bird Point Count	Reported, Sighting (media)
BS	Bird	*Toxostoma crissale*	Crissal Thrasher	Species of Special Concern	CDFW	iNat, CBC, eBird	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Toxostoma lecontei*	LeConte's Thrasher	Species of Special Concern	CDFW	SDNHM, iNat, CBC, eBird	Survey, Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Xanthocephalus xanthocephalus*	Yellow-headed Blackbird	Species of Special Concern	CDFW	iNat, eBird	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Actitis macularius*	Spotted Sandpiper			eBird	Reported, Sighting (media)
BS	Bird	*Aeronautes saxatalis*	White-throated Swift			eBird, Bird Point Count	Reported, Sighting (media)
BS	Bird	*Agelaius phoeniceus*	Red-winged Blackbird			iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Aix sponsa*	Wood Duck			eBird	Reported, Sighting (media)
CDL, BS	Bird	*Amphispiza bilineata*	Black-throated Sparrow			iNat, CBC, eBird, Bird Point Count	Sighting (Photo), Calls, Reported, Sighting (media)

BS	Bird	*Anas acuta*	Northern Pintail			eBird	Reported, Sighting (media)
BS	Bird	*Anas crecca*	Green-winged Teal			eBird	Sighting (media), Reported
BS	Bird	*Anas crecca carolinensis*	Green-winged Teal (American)			eBird	Reported
BS	Bird	*Anas platyrhynchos*	Mallard			eBird	Sighting (media), Reported
BS	Bird	*Anas platyrhynchos (Domestic type)*	Mallard (Domestic type)			eBird	Reported
BS	Bird	*Anser caerulescens*	Snow Goose			eBird	Sighting (media)
BS	Bird	*Anthus rubescens*	American Pipit			eBird	Reported, Sighting (media)
BS	Bird	*Archilochus alexandri*	Black-chinned Hummingbird			eBird	Reported
BS	Bird	*Artemisiospiza belli canescens*	Bell's Sparrow (canescens)			eBird	Reported, Sighting (media)
CDL, BS	Bird	*Artemisiospiza nevadensis*	Sagebrush Sparrow			iNat, CBC, eBird	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Auriparus flaviceps*	Verdin			iNat, CBC, eBird, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Aythya affinis*	Lesser Scaup			eBird	Sighting (media), Reported
BS	Bird	*Aythya collaris*	Ring-necked Duck			iNat, eBird	Sighting (Photo), Reported
BS	Bird	*Bombycilla cedrorum*	Cedar Waxwing			CBC, iNat, eBird	Reported

BS	Bird	*Branta canadensis*	Canada Goose			eBird	Sighting (media), Reported
BS	Bird	*Bubo virginianus*	Great Horned Owl			iNat, CBC	Sighting (Photo), Calls, Reported, Sighting (media)
CDL, BS	Bird	*Buteo jamaicensis*	Red-tailed Hawk			iNat, CBC, eBird, Camera Trap, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Buteo lineatus*	Red-shouldered Hawk			eBird	Reported
BS	Bird	*Butorides virescens*	Green Heron			eBird	Sighting (media), Reported
BS	Bird	*Calamospiza melanocorys*	Lark Bunting			eBird	Sighting (media), Reported
BS	Bird	*Calcarius lapponicus*	Lapland Longspur			eBird	Reported
BS	Bird	*Calidris bairdii*	Baird's Sandpiper			eBird	Sighting (media)
BS	Bird	*Calidris mauri*	Western Sandpiper			iNat, eBird	Sighting (Photo), Sighting (media), Reported
CDL, BS	Bird	*Callipepla californica*	California Quail			iNat, eBird	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Callipepla gambelii*	Gambel's Quail			iNat, CBC, eBird	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Calypte anna*	Anna's Hummingbird			CBC, eBird	Reported, Sighting (media)

CDL, BS	Bird	*Campylorhynchus brunneicapillus*	Cactus Wren			iNat, CBC, eBird	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Cardellina pusilla*	Wilson's Warbler			iNat, eBird, Bird Point Count, Bird Incidental	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Cathartes aura*	Turkey Vulture			iNat, CBC, eBird, Bird Point Count, Bird Incidental	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Catharus guttatus*	Hermit Thrush			eBird	Reported
CDL, BS	Bird	*Catherpes mexicanus*	Canyon Wren			eBird	Reported
BS	Bird	*Charadrius semipalmatus*	Semipalmated Plover			eBird	Reported
BS	Bird	*Chondestes grammacus*	Lark Sparrow			eBird	Sighting (media), Reported
BS	Bird	*Chordeiles acutipennis*	Lesser Nighthawk			iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Chroicocephalus philadelphia*	Bonaparte's Gull			eBird	Sighting (media), Reported
BS	Bird	*Colaptes auratus*	Northern Flicker			eBird	Reported
BS	Bird	*Colaptes auratus [cafer Group]*	Northern Flicker (Red-shafted)			eBird	Reported
BS	Bird	*Columba livia*	Rock Dove			iNat, eBird	Sighting (Photo), Reported, Sighting (media)

BS	Bird	*Columbina passerina*	Common Ground Dove			iNat, eBird, Camera Trap	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Contopus sordidulus*	Western Wood-Pewee			eBird	Reported, Sighting (media)
CDL, BS	Bird	*Corthylio calendula*	Ruby-crowned Kinglet			CBC, eBird	Reported, Sighting (media)
CDL, BS	Bird	*Corvus corax*	Common Raven			iNat, CBC, eBird, Bird Point Count, Bird Incidental	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Cygnus columbianus*	Tundra Swan			eBird	Reported, Sighting (media)
BS	Bird	*Dolichonyx oryzivorus*	Bobolink			eBird	Sighting (media), Reported
BS	Bird	*Dryobates scalaris*	Ladder-backed Woodpecker			eBird	Sighting (media), Reported
BS	Bird	*Dumetella carolinensis*	Gray Catbird			iNat, eBird	Sighting (Photo), Sighting (media)
BS	Bird	*Egretta thula*	Snowy Egret			eBird	Reported, Sighting (media)
CDL, BS	Bird	*Empidonax difficilis*	Western Flycatcher			iNat, eBird, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Empidonax hammondii*	Hammond's Flycatcher			eBird	Reported

CDL, BS	Bird	*Empidonax wrightii*	Gray Flycatcher			iNat, CBC, eBird, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Eremophila alpestris*	Horned Lark			eBird	Reported, Sighting (media)
BS	Bird	*Euphagus cyanocephalus*	Brewer's Blackbird			eBird	Sighting (media), Reported
BS	Bird	*Falco peregrinus*	Peregrine Falcon			iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Falco sparverius*	American Kestrel			CBC, eBird, Bird Point Count, Bird Incidental	Reported, Sighting (media)
BS	Bird	*Fulica americana*	American Coot			eBird	Reported
BS	Bird	*Gallinago delicata*	Wilson's Snipe			iNat, eBird	Sighting (Photo), Sighting (media), Reported
CDL, BS	Bird	*Geococcyx californianus*	Greater Roadrunner			iNat, CBC, eBird, Camera Trap, Bird Point Count, Bird Incidental	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Geothlypis tolmiei*	MacGillivray's Warbler			iNat, eBird	Sighting (Photo), Sighting (media), Reported

BS	Bird	*Geothlypis trichas*	Common Yellowthroat			iNat, eBird	Sighting (Photo), Sighting (media), Reported
CDL, BS	Bird	*Haemorhous mexicanus*	House Finch			iNat, CBC, eBird, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Himantopus mexicanus*	Black-necked Stilt			eBird	Reported, Sighting (media)
BS	Bird	*Hirundo rustica*	Barn Swallow			iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Hirundo rustica erythrogaster*	Barn Swallow (American)			eBird	Sighting (media), Reported
CDL, BS	Bird	*Icterus bullockii*	Bullock's Oriole			iNat, eBird, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Icterus cucullatus*	Hooded Oriole			iNat, eBird, Bird Point Count	Sighting (Photo), Sighting (media), Reported
CDL, BS	Bird	*Icterus parisorum*	Scott's Oriole			eBird	Reported
BS	Bird	*Larus delawarensis*	Ring-billed Gull			eBird	Reported
CDL, BS	Bird	*Leiothlypis celata*	Orange-crowned Warbler			iNat, eBird, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Leiothlypis ruficapilla*	Nashville Warbler			iNat, eBird	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Lophodytes cucullatus*	Hooded Merganser			eBird	Sighting (media), Reported

BS	Bird	*Mareca americana*	American Wigeon			eBird	Reported, Sighting (media)
BS	Bird	*Mareca strepera*	Gadwall			eBird	Sighting (media), Reported
BS	Bird	*Megaceryle alcyon*	Belted Kingfisher			eBird	Reported, Sighting (media)
BS	Bird	*Melospiza georgiana*	Swamp Sparrow			eBird	Sighting (media)
BS	Bird	*Melospiza lincolnii*	Lincoln's Sparrow			iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Melospiza melodia*	Song Sparrow			iNat, eBird	Sighting (Photo), Sighting (media), Reported
CDL, BS	Bird	*Mimus polyglottos*	Northern Mockingbird			iNat, CBC, eBird, Camera Trap, Bird Point Count, Bird Incidental	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Molothrus aeneus*	Bronzed Cowbird			iNat	Sighting (Photo)
BS	Bird	*Molothrus ater*	Brown-headed Cowbird			iNat, eBird, Bird Point Count	Sighting (Photo), Sighting (media), Reported
CDL, BS	Bird	*Myiarchus cinerascens*	Ash-throated Flycatcher			iNat, eBird, Camera Trap, Bird Point Count	Sighting (Photo), Reported
BS	Bird	*Numenius phaeopus*	Whimbrel			eBird	Reported

BS	Bird	*Nycticorax nycticorax hoactli*	Black-crowned Night Heron (American)			eBird	Reported
CDL, BS	Bird	*Oreoscoptes montanus*	Sage Thrasher			iNat, eBird	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Oxyura jamaicensis*	Ruddy Duck			eBird	Reported
BS	Bird	*Passer domesticus*	House Sparrow			CBC, eBird	Reported, Sighting (media)
CDL, BS	Bird	*Passerculus sandwichensis*	Savannah Sparrow			iNat, eBird	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Passerella iliaca*	Fox Sparrow			eBird	Sighting (media), Reported
BS	Bird	*Passerella iliaca [unalaschcensis Group]*	Fox Sparrow (Sooty)			eBird	Reported
CDL, BS	Bird	*Passerina amoena*	Lazuli Bunting			iNat, eBird	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Passerina caerulea*	Blue Grosbeak			iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Petrochelidon pyrrhonota*	Cliff Swallow			eBird, Bird Point Count	Sighting (media), Reported
CDL, BS	Bird	*Phainopepla nitens*	Phainopepla			iNat, CBC, eBird, Bird Point Count, Bird Incidental	Sighting (Photo), Reported, Sighting (media)

BS	Bird	*Phalaropus lobatus*	Red-necked Phalarope			eBird	Sighting (media)
CDL	Bird	*Pheucticus ludovicianus*	Rose-breasted Grosbeak			iNat	Sighting (Photo)
CDL, BS	Bird	*Pheucticus melanocephalus*	Black-headed Grosbeak			eBird, Bird Point Count	Reported, Sighting (media)
BS	Bird	*Pipilo chlorurus*	Green-tailed Towhee			eBird	Reported, Sighting (media)
CDL, BS	Bird	*Pipilo maculatus*	Spotted Towhee			iNat, CBC, eBird	Sighting (Photo), Reported
CDL, BS	Bird	*Piranga ludoviciana*	Western Tanager			iNat, eBird, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Podiceps nigricollis*	Eared Grebe			eBird	Sighting (media), Reported
BS	Bird	*Podilymbus podiceps*	Pied-billed Grebe			eBird	Reported, Sighting (media)
CDL, BS	Bird	*Polioptila caerulea*	Blue-gray Gnatcatcher			iNat, eBird, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Pooecetes gramineus*	Vesper Sparrow			iNat, eBird, Bird Incidental	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Porzana carolina*	Sora			iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Psaltriparus minimus*	Bushtit			eBird	Reported
BS	Bird	*Quiscalus mexicanus*	Great-tailed Grackle			eBird	Sighting (media), Reported

BS	Bird	*Rallus limicola*	Virginia Rail			eBird	Reported, Sighting (media)
BS	Bird	*Recurvirostra americana*	American Avocet			eBird	Sighting (media), Reported
CDL, BS	Bird	*Salpinctes obsoletus*	Rock Wren			iNat, CBC, eBird, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Sayornis nigricans*	Black Phoebe			CBC, eBird	Reported, Sighting (media)
BS	Bird	*Sayornis nigricans [nigricans Group]*	Black Phoebe (Northern)			eBird	Reported
CDL, BS	Bird	*Sayornis saya*	Say's Phoebe			iNat, CBC, eBird, Bird Point Count, Bird Incidental	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Setophaga coronata*	Yellow-rumped Warbler			CBC, eBird, Bird Point Count	Reported, Sighting (media)
CDL, BS	Bird	*Setophaga coronata auduboni*	Yellow-rumped Warbler (Audubon's)			CBC, eBird	Reported, Sighting (media)
BS	Bird	*Setophaga coronata coronata x auduboni*	Yellow-rumped Warbler (Myrtle x Audubon's)			eBird, iNat	Sighting (media)
CDL, BS	Bird	*Setophaga nigrescens*	Black-throated Gray Warbler			iNat, eBird	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Setophaga occidentalis*	Hermit Warbler			eBird	Reported

BS	Bird	*Setophaga townsendi*	Townsend's Warbler			iNat, eBird	Sighting (Photo), Sighting (media), Reported
CDL, BS	Bird	*Sialia currucoides*	Mountain Bluebird			iNat, CBC, eBird	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Sialia mexicana*	Western Bluebird			iNat, eBird	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Spatula clypeata*	Northern Shoveler			eBird	Reported
BS	Bird	*Spatula cyanoptera*	Cinnamon Teal			eBird	Sighting (media), Reported
BS	Bird	*Spatula discors*	Blue-winged Teal			eBird	Sighting (media), Reported
BS	Bird	*Spinus pinus*	Pine Siskin			eBird	Sighting (media)
CDL, BS	Bird	*Spinus psaltria*	Lesser Goldfinch			iNat, eBird	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Spiza americana*	Dickcissel			iNat, eBird	Sighting (Photo), Sighting (media)
CDL, BS	Bird	*Spizella breweri*	Brewer's Sparrow			iNat, CBC, eBird	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Spizella passerina*	Chipping Sparrow			eBird	Reported, Sighting (media)
CDL, BS	Bird	*Stelgidopteryx serripennis*	Northern Rough-winged Swallow			eBird	Reported, Sighting (media)
BS	Bird	*Streptopelia decaocto*	Eurasian Collared-Dove			eBird	Sighting (media), Reported

CDL, BS	Bird	*Sturnella neglecta*	Western Meadowlark			CBC, eBird	Reported, Sighting (media)
BS	Bird	*Sturnus vulgaris*	European Starling			CBC, eBird	Sighting (media), Reported
BS	Bird	*Tachycineta bicolor*	Tree Swallow			eBird	Reported, Sighting (media)
BS	Bird	*Tachycineta thalassina*	Violet-green Swallow			iNat, eBird	Sighting (Photo), Sighting (media), Reported
CDL, BS	Bird	*Toxostoma redivivum*	California Thrasher			iNat, eBird, Bird Point Count	Sighting (Photo), Sighting (media), Reported
BS	Bird	*Tringa solitaria*	Solitary Sandpiper			eBird	Reported, Sighting (media)
BS	Bird	*Troglodytes aedon*	Northern House Wren			eBird, Bird Point Count	Reported, Sighting (media)
BS	Bird	*Turdus migratorius*	American Robin			eBird	Reported, Sighting (media)
CDL, BS	Bird	*Tyrannus verticalis*	Western Kingbird			iNat, eBird	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Vireo bellii*	Bell's Vireo			iNat, eBird	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Vireo cassinii*	Cassin's Vireo			eBird	Reported, Sighting (media)
BS	Bird	*Vireo gilvus*	Warbling Vireo			iNat, eBird	Sighting (Photo), Sighting (media), Reported

BS	Bird	*Zenaida asiatica*	White-winged Dove			iNat, CBC, eBird, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
CDL, BS	Bird	*Zenaida macroura*	Mourning Dove			iNat, CBC, eBird, Bird Point Count, Bird Incidental	Sighting (Photo), Tracks, Reported, Sighting (media)
BS	Bird	*Zonotrichia atricapilla*	Golden-crowned Sparrow			eBird	Reported
CDL, BS	Bird	*Zonotrichia leucophrys*	White-crowned Sparrow			iNat, CBC, eBird, Camera Trap, Bird Point Count	Sighting (Photo), Reported, Sighting (media)
BS	Bird	*Zonotrichia leucophrys gambelii*	White-crowned Sparrow (Gambel's)			eBird	Reported, Sighting (media)
BS	Bird	*Zonotrichia leucophrys leucophrys/oriantha*	White-crowned Sparrow (Dark-lored)			eBird	Reported
BS	Bird	*Zonotrichia leucophrys oriantha*	White-crowned Sparrow (oriantha)			eBird	Reported
CDL, BS	Bird	*Callipepla gambelii × californica*	Gambel's × California Quail			iNat, eBird	Sighting (Photo), Reported, Sighting (media)
CDL	Bird	*Setophaga coronata coronata*	Yellow-rumped Warbler (Myrtle)			eBird	Reported, Sighting (media)
BS	Bird	*Toxostoma redivivum × crissale*	California x Crissal Thrasher			iNat, eBird	Sighting (Photo), Sighting (media), Reported

BS	Bird	*Tyto furcata*	American Barn Owl			eBird	Sighting (media), Reported
BS	Bird	*Tyto furcata [tuidara Group]*	American Barn Owl (American)			eBird	Reported
CDL	Fungus	*Agaricus deserticola*	Gasteriod Agaricus			iNat	Sighting (Photo)
CDL, BS	Fungus	*Montagnea arenaria*	Desert Inkcap			iNat	Sighting (Photo)
CDL, BS	Fungus	*Podaxis pistillaris*	Desert Shaggymane			iNat	Sighting (Photo)
CDL	Invertebrate	*Atlides halesus*	Great Purple Hairstreak			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Danaus gilippus*	Queen Butterfly			iNat	Sighting (Photo)
BS	Invertebrate	*Erythemis collocata*	Western Pondhawk			iNat	Sighting (Photo)
BS	Invertebrate	*Libellula croceipennis*	Neon Skimmer			iNat	Sighting (Photo)
BS	Invertebrate	*Perithemis intensa*	Mexican Amberwing			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Sympetrum corruptum*	Variegated Meadowhawk			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Vanessa cardui*	Painted Lady			iNat	Sighting (Photo)
BS	Invertebrate	*Gryllodes sigillatus*	Tropical House Cricket			iNat	Sighting (Photo)
CDL	Invertebrate	*Agapostemon melliventris*	Honey-tailed Striped Sweat Bee			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Anconia integra*	Alkali Grasshopper			iNat	Sighting (Photo)
CDL	Invertebrate	*Andrena palpalis*	Blue-Phacelia Miner			iNat	Sighting (Photo)
CDL	Invertebrate	*Aphis nerii*	Oleander Aphid			iNat	Sighting (Photo)

CDL, BS	Invertebrate	*Apis mellifera*	Western Honey Bee			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Asbolus verrucosus*	Desert Ironclad Beetle			iNat	Sighting (Photo)
BS	Invertebrate	*Asphondylia auripila*	Large Creosote Gall Midge			iNat	Sighting (Photo)
CDL	Invertebrate	*Asphondylia floccosa*	Saltbush Woolly Stem Gall Midge			iNat	Sighting (Photo)
BS	Invertebrate	*Asphondylia foliosa*	Creosote Leafy Bud Gall Midge			iNat	Sighting (Photo)
BS	Invertebrate	*Brachynemurus sackeni*	Sacken's Antlion			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Brephidium exilis*	Western Pygmy-Blue			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Burnsius albezens*	White Checkered-Skipper			iNat	Sighting (Photo)
BS	Invertebrate	*Carios kelleyi*				iNat	Sighting (Photo)
CDL	Invertebrate	*Cibolacris parviceps*	Cream Grasshopper			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Coccinella septempunctata*	Seven-spotted Lady Beetle			iNat	Sighting (Photo)
CDL	Invertebrate	*Copestylum fornax*				iNat	Sighting (Photo)
BS	Invertebrate	*Cysteodemus armatus*	Inflated Beetle			iNat	Sighting (Photo)
BS	Invertebrate	*Dymasia dymas ssp. imperialis*	Imperial Checkerspot			iNat	Sighting (Photo)
CDL	Invertebrate	*Echinargus isola*	Reakirt's Blue			iNat	Sighting (Photo)
BS	Invertebrate	*Edrotes ventricosus*				iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Eleodes armata*	Armored Stink Beetle			iNat	Sighting (Photo)
CDL	Invertebrate	*Erynnis funeralis*	Funereal Duskywing			iNat	Sighting (Photo)
BS	Invertebrate	*Eupompha elegans*	Elegant Blister Beetle			iNat	Sighting (Photo)
CDL	Invertebrate	*Eupompha elegans elegans*				iNat	Sighting (Photo)

BS	Invertebrate	*Euproserpinus phaeton*	Phaeton Primrose Sphinx			iNat	Sighting (Photo)
CDL	Invertebrate	*Gryllus lineaticeps*	Variable Field Cricket			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Hadrurus arizonensis*	Desert Hairy Scorpion			iNat	Sighting (Photo)
CDL	Invertebrate	*Hemiargus ceraunus*	Ceraunus Blue			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Hesperopsis libya*	Mojave Sootywing			iNat	Sighting (Photo)
BS	Invertebrate	*Heteranassa mima*				iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Hyles lineata*	White-lined Sphinx			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Largus californicus*	California Bordered Plant Bug			iNat	Sighting (Photo)
CDL	Invertebrate	*Leptotes marina*	Marine Blue			iNat	Sighting (Photo)
CDL	Invertebrate	*Ligurotettix coquilletti*	Desert Clicker Grasshopper			iNat	Sighting (Photo)
BS	Invertebrate	*Loxosceles deserta*	Desert Recluse			iNat	Sighting (Photo)
CDL	Invertebrate	*Lytta magister*	Master Blister Beetle			iNat	Sighting (Photo)
CDL	Invertebrate	*Metepeira foxi*				iNat	Sighting (Photo)
BS	Invertebrate	*Mirolepisma deserticola*				iNat	Sighting (Photo)
BS	Invertebrate	*Nathalis iole*	Dainty Sulphur			iNat	Sighting (Photo)
BS	Invertebrate	*Notibius puberulus*				iNat	Sighting (Photo)
BS	Invertebrate	*Paravaejovis spinigerus*	Dune Devil Scorpion			iNat	Sighting (Photo)
BS	Invertebrate	*Phodaga alticeps*				iNat	Sighting (Photo)
CDL	Invertebrate	*Pogonomyrmex californicus*	California Harvester Ant			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Pontia protodice*	Checkered White			iNat	Sighting (Photo)
CDL	Invertebrate	*Saropogon albifrons*	UNK			iNat	Sighting (Photo)

BS	Invertebrate	*Schinia niveicosta*	Spanish Needles Flower Moth			iNat	Sighting (Photo)
BS	Invertebrate	*Schistocerca nitens*	Gray Bird Grasshopper			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Scolia nobilitata*	Noble Scoliid Wasp			iNat	Sighting (Photo)
BS	Invertebrate	*Solenopsis xyloni*	Southern Fire Ant			iNat	Sighting (Photo)
CDL	Invertebrate	*Stagmomantis limbata*	Arizona Mantis			iNat	Sighting (Photo)
CDL	Invertebrate	*Systasea zampa*	Arizona Powdered-Skipper			iNat	Sighting (Photo)
BS	Invertebrate	*Tachardiella larreae*	Creosote Lac Scale			iNat	Sighting (Photo)
BS	Invertebrate	*Thermobia domestica*	Firebrat			iNat	Sighting (Photo)
CDL	Invertebrate	*Trichodes ornatus*	Ornate Checkered Beetle			iNat	Sighting (Photo)
CDL	Invertebrate	*Trimerotropis pallidipennis*	Pallid-winged Grasshopper			iNat	Sighting (Photo)
CDL, BS	Invertebrate	*Veromessor pergandei*	Black Harvester Ant			iNat	Sighting (Photo)
CDL	Invertebrate	*Zelus renardii*	Leafhopper Assassin Bug			iNat	Sighting (Photo)
CDL, BS	Mammal	*Ovis canadensis nelsoni*	Peninsular Bighorn Sheep	Threatened, Fully Protected Species	CESA, CDFW	iNat	Sighting (Photo)
CDL, BS	Mammal	*Taxidea taxus*	American Badger	Species of Special Concern	CDFW	iNat, Camera Trap	Sighting (Photo)
CDL, BS	Mammal	*Ammospermophilus leucurus*	White-tailed Antelope Squirrel			iNat	Sighting (Photo), Tracks
CDL, BS	Mammal	*Canis latrans*	Coyote			iNat, Camera Trap	Sighting (Photo), Calls, Tracks
BS	Mammal	*Dipodomys deserti*	Desert Kangaroo Rat			iNat	Tracks

BS	Mammal	*Dipodomys merriami*	Merriam's Kangaroo Rat			iNat	Tracks
CDL, BS	Mammal	*Lepus californicus*	Black-tailed Jackrabbit			iNat, Camera Trap	Sighting (Photo)
CDL	Mammal	*Lynx rufus*	Bobcat			iNat, Camera Trap	Tracks
BS	Mammal	*Odocoileus hemionus*	Mule Deer			iNat	Sighting (Photo)
BS	Mammal	*Procyon lotor*	Common Raccoon			iNat	Tracks, Sighting (Photo)
CDL, BS	Mammal	*Sylvilagus audubonii*	Desert Cottontail			iNat, Camera Trap	Sighting (Photo), Tracks
BS	Mammal	*Vulpes macrotis*	Kit Fox			iNat	Sighting (Photo)
BS	Reptile	*Phrynosoma mcallii*	Flat-tailed Horned Lizard	Species of Special Concern	CDFW	iNat	Sighting (Photo)
BS	Reptile	*Arizona elegans occidentalis*	California Glossy Snake	Species of Special Concern	CDFW	iNat	Sighting (Photo)
BS	Reptile	*Arizona elegans eburnata*	Desert Glossy Snake			iNat	Sighting (Photo)
CDL	Reptile	*Aspidoscelis tigris*	Western Whiptail			iNat, Camera Trap	Sighting (Photo)
BS	Reptile	*Callisaurus draconoides rhodostictus*	Mojave Zebra-tailed Lizard			iNat	Sighting (Photo)
BS	Reptile	*Coleonyx variegatus*	Western Banded Gecko			iNat	Sighting (Photo)
CDL, BS	Reptile	*Crotalus cerastes*	Sidewinder			iNat	Sighting (Photo)
CDL, BS	Reptile	*Crotalus cerastes laterorepens*	Colorado Desert Sidewinder			iNat	Sighting (Photo)

CDL	Reptile	*Crotalus ruber*	Red Diamond Rattlesnake			iNat	Sighting (Photo)
BS	Reptile	*Dipsosaurus dorsalis ssp. dorsalis*	Northern Desert Iguana			iNat	Sighting (Photo)
BS	Reptile	*Lichanura orcutti*	Coastal Rosy Boa			iNat	Sighting (Photo)
BS	Reptile	*Masticophis flagellum piceus*	Red Coachwhip			iNat	Sighting (Photo)
BS	Reptile	*Phyllorhynchus decurtatus*	Western Leaf-nosed Snake			iNat	Sighting (Photo)
BS	Reptile	*Pituophis catenifer affinis*	Sonoran Gopher Snake			iNat, Camera Trap	Sighting (Photo)
BS	Reptile	*Rhinocheilus lecontei*	Long-nosed Snake			iNat	Sighting (Photo)
BS	Reptile	*Uta stansburiana ssp. elegans*	Western Side-blotched Lizard			iNat	Sighting (Photo)
CDL	Reptile	*Crotalus pyrrhus*	Southwestern Speckled Rattlesnake			iNat	Sighting (Photo)
BS	Reptile	*Sonora annulata*	Resplendent Desert Shovel-nosed Snake			iNat	Sighting (Photo)
CDL	Birds	*Catharus ustulatus*	Swainson's Thrush			Camera Trap	Sighting (Photo)
BS	Birds	*Phalaenoptilus nuttallii*	Common Poorwill			Camera Trap	Sighting (Photo)
CDL	Birds	*Selasphorus sasin*	Allen's Hummingbird			Camera Trap	Sighting (Photo)
CDL	Birds	*Strigiformes* sp.	Owl Species			Camera Trap	Sighting (Photo)
CDL, BS	Mammals	*Neotoma albigula*	White-throated Woodrat			Camera Trap	Sighting (Photo)
CDL	Mammals	*Otospermophilus beecheyi*	California Ground Squirrel			Camera Trap	Sighting (Photo)

BS	Mammals	*Urucyon cineoargenteus*	Gray Fox			Camera Trap	Sighting (Photo)
CDL	Reptiles	*Sceloporus magister*	Desert Spiny Lizard			Camera Trap	Sighting (Photo)

Appendix C. Recommendations for Future Wildlife Monitoring

Based on similar study areas, extended overdrafting of the groundwater table may cause unintended consequences to not only the mesquite but also to the local plant communities and overall biodiversity of the region (Mata-González et al., 2022; Stromberg & Rictcher, 1996). The Borrego Springs Subbasin is facing similar challenges, where groundwater declines have caused varying depths to groundwater across the Borrego Springs mesquite bosque ecosystem. Unexpected declines in groundwater can cause shifts in ecosystem composition. Therefore, we highly recommend enacting a monitoring plan in the mesquite bosque ecosystems, as mesquite trees rely on these groundwater reservoirs to survive. Changes in mesquite health and bosque habitat quality could negatively impact the local plant and wildlife communities who depend on the mesquite.

Potential Monitoring Methods

Future funding of the project could vary amongst years, so the plan for monitoring the mesquite bosques will be split into three tiers: low, medium, and high effort. In this section, we will detail the logistics for each of the monitoring methods, including the number of personnel, time, and materials required to perform them successfully. We also include trade-offs between the amount of effort and the power of monitoring methods. The following section details the recommended methods, including how each method can be adapted at each tier. We recommend carrying out the highest amount of monitoring possible, to best capture the biodiversity and habitat condition.

<u>Camera Traps</u>

Personnel: 2+

Average Hours: Constructing camera setup (1-2 hrs), replacing SD cards (0.5 hrs per camera), processing and analysis (dependent on design and experience; ~1 hr/100images)

Materials: Wildlife camera, camera strap, camera box, stake (if no trees are available to mount camera), rechargeable batteries, sd cards, shears or clippers for foliage, computer for processing, Wildlife Insights account (optional)

Camera traps, also referred to as trail cams or wildlife cameras, are motion triggered cameras that are set up to remotely monitor wildlife. They are frequently used to monitor large mammals and cryptic species that hide or flee from other survey methods. Once a camera trap is set up, it can be left running for several weeks before the batteries need to be replaced and the SD card needs to be collected. The images should be processed as soon as possible once they are collected so that adjustments to the camera placement can be made. If a camera is repeatedly triggered by a nearby plant, for example, the sd card can run out of room for images of wildlife. Image processing can be tedious, so we recommend utilizing a processing service such as Wildlife Insights to automatically sort out blank images and assist in identification.

Drift Net Camera Traps

Personnel: 2+

Average Hours: Constructing camera setup (one-time 2 hrs), constructing drift net in field (one-time 2 hrs), replacing SD cards (0.5 hrs per camera), processing and analysis (dependent on design and experience; ~1 hr/100images)

Materials: See the CDFW ArcGIS StoryMap (Toenies, 2022) for details. Two sets of the materials listed will be needed, one for each location. The main purchase from the Story Map is two Reconyx HP2X cameras ($660 each). These could be substituted for two Bushnell Corp. NatureView HD Max cameras with a 25 cm focal attachment ($250 each) used in another study by Martin et al. (2017), but it would require changing the size of the camera box or using the bucket setup from that study.

Normal camera traps are useful for identifying medium to large mammals but rarely capture herptiles or mammals smaller than rabbits. This gap in survey data can be addressed via drift net camera traps. This also requires motion detecting cameras, but they are aimed directly at the ground to spot any movement below them. By setting up a long barrier in the bosque, you can impede the normal path of creatures much smaller than it and direct them to its edge where the camera is placed. These nets are also designed to be short enough to allow for larger species to pass over them, thereby not disturbing the ecosystem in a meaningful way. This method will cost significantly more upfront than some of the others, but once they are set up, they only need to be visited to collect the SD cards and repair any damage which can be done when the other camera traps are collected. The camera box setups should be collected when they are not in use (outside of the established monitoring period), but the drift nets can be left to allow them to become a part of the natural habitat. More information on the setup can be found on the CDFW Story Map linked above (Toenies 2022).

Avian Point Count Surveys

Personnel: 1+

Average Hours: 2 per site visited at each location visit

Materials: Binoculars, timer, Merlin app, datasheet, field guide (if desired), spotting scope (if desired)

Avian point count surveys are a simple monitoring method that can find a wide diversity of birds in a relatively short time. It requires at least one person to visit the four survey points marked for each site between the hours of 0700 and 1100. There, they spend five minutes identifying every bird seen or heard from that spot. The Merlin app, by Cornell Labs, can run an audio recording and aid in identifying bird calls or songs. This survey method should be performed at least twice during Spring, the season when the most birds are present in Borrego Springs, CA. This is because it is when most non-resident birds of the area return to breed. Additionally, breeding adults tend to be easier to identify because many will sing more distinct songs and gain their brighter breeding plumages to attract mates. If funding allows, more than two surveys should be done in a single season to get a more accurate estimate of the diversity. Extra surveys could be done during other seasons to account for migratory species, but spring should still be prioritized. Additional survey sites could be added to the previously used Site 1 and Site 5, to better understand bird presence across different habitat conditions within the locations.

Since the bird counts are not time intensive, they can be done in tandem with other monitoring events (e.g., picking up camera trap data). One caveat of these surveys is that it is highly recommended to have someone with knowledge of the birds of the mesquite bosques in Borrego Springs, CA. Without an experienced birder, not as many birds will be correctly identified to species, and not as many conclusions about the changes in avian populations can be drawn.

<u>Photopoint Surveys</u>

Personnel: 1 in total
Average Hours: <1 per location
Materials: Camera/ Phone camera, Angle gauge (optional)

One of the quickest and easiest methods to monitor overall ecosystem health would be through conducting photopoint surveys while in the field. The points for each photo are already set through previous markers such as tree IDs, camera traps, or other survey points. However, it is still vital to document all photopoints for project consistency. We recommend using the same height and angle for each photo. To do so, implement a pole for a consistent height or have the same person take photos using their body dimensions as an informal measurement. The intensity of the project can range based on the desired parameters. At minimum, the photopoint surveys should be conducted yearly. However, to monitor seasonality, we recommend taking photos more frequently. Additionally, a higher number of photos taken per location will create a fuller picture on the overall ecosystem's health. While the results show at a slower rate, this method will allow visualization of long-term changes in vegetation composition over time. Photopoint angles are crucial to have reliable comparisons. To increase accuracy, tools such as an angle gauge can be used to ensure all photos can be accurately compared.

Invertebrate Beat Sheet Surveys

Personnel: 2+ per survey

Average Hours: 2 per survey

Materials: 1 Beat sheet, 1 Beater stick, 1 Wooden beat sheet frame, 1 Ruler (cm/mm for reference), Field guide (if desired), 1 Smartphone with a macro lens attachment (or a camera and a timer), and 2 Hand lenses. The estimated cost for a one-time purchase of all necessary supplies is approximately $100, excluding smartphones.

Documenting insect presence will allow us to make inferences about the mesquite bosque habitat's health and its ability to support desert wildlife. Beat Sheet Surveys are a simple field method, requiring limited supplies and training, to document invertebrate species present on the mesquite trees (Montgomery et al. 2021). Species targeted by this method include Lepidoptera (caterpillars), Hemiptera (true bugs, aphids, scale bugs), Coleoptera (beetles), and Ants (hymenoptera). Five mesquite trees should be included per survey at a site to adequately represent the area. For each tree, prepare the beat sheet by fitting it over the open wooden beat sheet frame and have one surveyor hold it under the branches of the tree. The sheet is divided into quadrants, which can be assigned to each surveyor for later counting. A second surveyor uses the beater stick to hit the tree branches for 10 seconds. Invertebrates are dislodged from the branches and fall onto the sheet below. All surveyors (2 or more) will count the number of insects on the beat sheet for 30 seconds after the beating stops. Record the number of insects seen on the sheet by order and different size classes. Species may also be photographed for later identification. Once completed, dump the insects back on the tree to the best of your ability. Make sure there are no insects or debris in the corner of the beat sheet before moving on to the next tree. The same five mesquite trees should be surveyed each year, to allow for comparison across years.

Invertebrate Light Trap Surveys

Personnel: 2+ per survey

Average Hours: 2 per survey

Materials: 2 White LED lights ($25), 2 UV LED lights ($35), Nylon cord, Supplies to hang lights (i.e. large binder clips or clothespins, if needed, 1 White twin-size top sheet, 1 Light sensor, 2 Smartphones with a macro lens attachments (~$40 per macro lens attachment) (or Cameras and a timer), Field guide (if desired). The estimated total cost for a one-time purchase of all necessary supplies is $170, excluding smartphones and light sensors.

Light trap surveys help document additional species, such as flying insects, which are not usually observed in beat sheet surveys. Species targeted include Lepidoptera (moths), Coleoptera (beetles), Trichoptera (caddisflies), and other phototactic invertebrates. These species are a crucial food source for bats and other insectivores (Law et al. 2019, Montgomery et al. 2021). We recommend the use of small, portable, rechargeable LED lights for their ease of use and practicality in the field when compared to mercury vapor light bulbs and larger, less portable light fixtures. Both white and UV LED lights should be used to attract the widest range of phototactic invertebrates (Infusino et al., 2017). The survey should be completed at three points within a site, considering microhabitats and surrounding vegetation. To prepare a landing surface, select two mesquite trees a few meters apart and tie a length of cord between the trees at about shoulder height. A white sheet can be hung over the cord with the LED lights, and the UV lights can be placed on the ground to shine on the sheet. Prior to turning on the lights, a surveyor should record light pollution (lumens/m^2). At least two surveyors, one working on each side of the sheet, will count, by order and size class, all insects that land on the lit sheet over a period of 15 minutes. Species may also be photographed for later identification. The survey setup is temporary and should be set up and removed at each point.

<u>BioBlitz</u>

Personnel: 1-2, and event volunteers (10-20) per BioBlitz event
Average Hours: Event preparation (4 hrs), BioBlitz onsite event (2 hrs), iNat project data review (2 hrs) per BioBlitz event
Materials: Computer access (for iNat project management), Smartphones (including volunteers, for events), Emergency Field Supplies (i.e., first aid and water, for events)

A bioblitz, utilizing volunteers to document biodiversity for all taxa present in a site at a location on a given day, is an inexpensive and effective way to collect a broad range of data in a short time with limited expertise. They proved to be especially helpful for documenting plant biodiversity. Observations also include animal tracks and pictures of less elusive species. Data can be collected, and statistics can be generated by setting up a free iNaturalist project. The project's setting should limit the observations accepted to the date and location of the bioblitz event to exclude observations from the general public. Projects can also limit what users can enter data if volunteer iNaturalist account names are known. Much of the time needed for event preparation is to plan, coordinate, and advertise the event. The iNaturalist project itself can be created relatively quickly. Volunteers will be expected to bring their own field supplies and smartphones. They can meet or carpool to the event location, where personnel can introduce the location and show volunteers the site boundaries. A site with Borrego Springs or Clark Dry Lake should be used, as the whole of Borrego Springs or Clark Dry Lake is too large an area to cover in an event. The personnel's primary role at the event will be to help new users with the iNaturalist app, suggest species identifications, and help volunteers in the event of an emergency. After the event, volunteers can upload their observations, as there is no wifi access at some sites. Personnel can then review the data within the iNaturalist project, comparing it to our species inventory or previous bioblitzes. Depending on the number of volunteers, more than one person may be needed to supervise the event. All other tasks could be completed by a single person.

Species Inventory

Personnel: 1 per annual data entry

Average Hours: Annual Data Entries for - Christmas Bird Count (2 hrs), iNaturalist (5 hrs), eBird (10 hrs), Species Status Update (5hrs)

Materials: Computer Access (including R and ArcGIS software for eBird data), Count-by-area data for the Anza-Borrego Christmas Bird Circle, eBird data, iNat website access, and Current CNDDB Special Animals List.

The existing species inventory can be updated with future data, to continue documenting biodiversity at the mesquite bosques. Alternatively, to compare biodiversity changes over time, the existing inventory can be used as a template to create new inventories covering future time periods (i.e the current inventory included data from 2009-2025, a new inventory could include data from 2025-future year). The count-by-area data can be requested from the Anza-Borrego Christmas Bird Count compiler, and the data for the "Clark Dry Lake," "North Mesquite," and "South Mesquite" areas entered. iNaturalist and ebird data can be acquired and processed for entry, per the methods detailed in the Species Inventory subsection of Section 1 above. The eBird data will require personnel trained in R and ArcGIS. Finally, species status can be updated as needed using CNDDB in future years to reflect changes in agency rankings.

Bat Surveys

Personnel: 2+

Average Hours: Sensor setup (1-2 hrs), SD card collection (0.5 hrs), processing and analysis (dependent on experience)

Materials: Audio sensor, batteries, SD card, metal stake, processing software

Bat surveys can be done visually or by using an audio recorder and processing software. Visual surveys may not always be practical since they must be done at night. Therefore, we will focus on acoustic surveys. The acoustic sensor is set up and left to record during the night and ideally should be deployed for several nights. The SD card is then collected, and the calls are processed using software like Kaleidoscope or SonoBat. These softwares are industry standard, but they are expensive, and positive identification requires significant expertise. Therefore, our recommendation for any bat monitoring is to collaborate with an established bat researcher by sharing the acoustic data for them to use in their research and for them to identify the species for the monitoring project.

Proposed Monitoring Tiers

Tier 1 (Low effort)

If the project only receives minimal funding, monitoring will still be vital for detecting changes to the bosque and diagnosing what can be done to aid the mesquite bosques. However, this will not be as effective as the other tiers, so scaling up from this plan where possible is highly encouraged. Below are the ways some methods can be tailored to a small budget.

Camera Traps

The most significant expenditure in camera trap monitoring is the labor-hours required to maintain the cameras and process the images. Therefore, in a limited budget scenario, fewer cameras can be deployed strategically to reduce the workload of data collection and analysis. If there is a target species or taxon, cameras should be deployed during a season of at least three months when the target is known to be most active. Other aspects of the target's biology and ecology can also inform the design. For small mammals, reptiles, and some birds, cameras can be set up close to the ground or angled to point down. General monitoring can be done with fewer cameras deployed for longer periods of time. Our 14-camera design allowed us to build a robust dataset but required hundreds of hours of image processing and camera maintenance over two years. As few as three cameras could be sufficient to monitor one site if the camera position is designed carefully. Keeping cameras active for as long as possible will increase the chances of observing less common species and deploying for less than six months may not yield enough observations for useful interpretation. Wildlife Insights or a similar service can drastically cut down on processing time by automatically sorting out blank images. Wildlife Insights is free to use for most users.

Photopoint surveys

Photopoint surveys can be conducted based on the desired metrics. For example, if the goal is to compare locations yearly, at minimum, only one photo a year per location would be necessary. However, one photo cannot capture the full extent of the locations' overall health. Additionally, yearly photos will only capture the mesquite bosque during one season if taken at the same time each year. This results in a gap-in-knowledge of how the mesquite bosque looks year-round. When any photos are taken, ensure the coordinates and cardinal directions the photo was taken are recorded on a document, or on the project's Geographic information system (GIS). To minimize costs, we recommend conducting photopoint surveys simultaneously with other surveys or while in the field for other purposes. While it is possible to achieve angle and height consistency using the photographer's body as a reference, it is not always reliable. Without proper tools the same photo angles are near impossible to achieve due to human error.

Bioblitz

An annual bioblitz event can take place at at least one site in the Borrego Springs location to document all present taxa within the mesquite bosque. The event can take place during the spring or after a bloom if the goal is to capture annual plant species. Alternatively, holding an event during late April to late May, the peak season for mesquite, will best capture animals. Event planning can take place relatively far in advance, allowing personnel to spread work across less demanding seasons. If possible, the event should be repeated each year to allow personnel to monitor changes in biodiversity between years.

Species Inventory

We recommend annually updating the species inventory with the Christmas Bird Count data, to capture winter bird diversity present at both Clark Dry Lake and Borrego Springs. This can be completed with relatively little effort and will allow bird diversity to be compared across years and locations. Updates should be made to a new version of the inventory each year, preserving the inventory from past years. A Christmas Bird Count only version of the current inventory could also be created for this purpose, with a sheet each year.

Bird Surveys

If only a few days can be spared for these surveys, it is recommended that at least two avian point count collection periods occur during spring to capture the abundance and diversity of the nesting season. The surveys should still be the same length (5 mins) and occur at the same points (4 per site). Since the surveys must occur between 0700 and 1100, only one location can be visited per day. To reduce the impact that different dates could have on the results of a single collection period, each location visit should occur on consecutive or near-consecutive days. Only one qualified observer is required, but having multiple will help increase the accuracy and efficacy of each survey. If there is not enough funding to perform surveys in other seasons too, that can be partially mitigated by utilizing the data from the Christmas Bird Count that occurs every December in Borrego Springs.

Tier 2 (Medium effort)

If a moderately sized grant is acquired for this project, the scope of the monitoring can be greatly increased. All the survey methods in Tier 1 can be scaled up to become more accurate than before. Additionally, new methods can be added to widen the scope of the species captured. Below are the changes and additions that could be included depending on the available budget.

Camera Traps

Deploying more cameras for longer periods of time will increase the reach of a camera monitoring program. An additional camera or two can be added to the design in the previous tier. Ideally, camera trap monitoring should continue for a full calendar year to capture seasonal variation in species richness and abundance and to improve the likelihood of capturing uncommon species. Additionally, a drift net camera could be added. Drift net cameras address a significant gap in what a traditional camera trap can capture because they specifically target small mammals and herpetofauna (see Tier 3 for more in-depth implementation information).

Photopoint surveys

Photopoint surveys can be elevated through increasing photo frequency. We recommend taking photos at least once per season (four times a year) at minimum. The photos may capture how the mesquite bosque's health changes each season. Additionally, instead of picking one photopoint, multiple points at each location, across different sites, will create a fuller picture of how the ecosystem looks. There will be discrepancies in other sections of the mesquite bosque that cannot be seen through one photo. The chosen photopoints should be spread out enough to show the full extent of the variability in the ecosystem. For example, choosing different microhabitats within the mesquite bosques with different species' fullness, richness, and locality can portray a more accurate visual of the locations' variability. With more photopoints, it is increasingly important to ensure proper coordinates are recorded alongside which direction relative to the geographic cardinal directions the photographer faces. The same photographer should be utilized every time a photo is taken. However, with long-term projects this may not be plausible due to unforeseen sickness, emergencies, and the possibility of personnel leaving. Therefore, we highly recommend an angle gauge to ensure the photography tool is consistent in each photo. An angle gauge costs can range from 5 to 40 dollars, with a higher price correlating to a higher convenience level.

Bioblitz

Bioblitz events can take place annually at at least one site in each location both after a bloom and during peak mesquite season to document all present taxa within the mesquite bosque. Event planning can take place relatively far in advance, allowing personnel to spread work across less demanding seasons. Holding an event during both time periods and at each location will allow personnel to compare annual plants and animals at the Borrego Springs location, with the Clark Dry Lake reference location. Holding events at multiple sites within Borrego Springs will also allow for comparison between sites experiencing different conditions. The events should be repeated each year to allow personnel to monitor changes in biodiversity between years.

Species Inventory

In addition to annually updating the species inventory with the Christmas Bird Count data, described in Tier 1, we recommend annual updates of the iNaturalist data described in the Potential Monitoring Methods section above for both locations. Adding this iNaturalist data to the Bioblitz would increase coverage across time and space, as each Bioblitz event will be limited to a single day and site. Comparisons across years and locations can also be made if the current species inventory template is expanded to include date(s) of observations in future years. That data could not be included in the current inventory, given the vast time span covered, but yearly inventories could be more detailed.

Bird Surveys

To increase the species richness of the avian observations, then more days need to be allocated to perform surveys in different seasons. We recommend first allocating extra survey days to winter because many birds migrate to the desert to overwinter. This may cost more time and money, but it will help account for species that are gone in the spring and help capture problems with the bosque that only occur seasonally. The same protocol should be followed as in tier 1, but if there is enough time/money, more than two collections should occur within each season to significantly increase the accuracy of the surveys.

Invertebrate Beat Sheet Surveys

Beat sheet surveys can be carried out by as few as two surveyors, once a year during the peak mesquite season. To reduce the number of field visits and travel time, these surveys can be completed in conjunction with the spring bird surveys or camera trap SD card collection. Beat sheet surveys at one site in each location can take place after bird surveys have completed for the day or throughout the same 0700 - 01100. If completing both survey types at points in close proximity we recommend beginning with the bird survey to avoid disturbing birds with the beat sheet survey.

Tier 3 (High effort)

This section details the ideal monitoring plan for the mesquite bosques. When money is not a limiting factor, almost every class of animals in the bosques can be accounted for. This gives monitors the greatest chance to detect a negative change in the bosque early and respond before it can worsen. If enough funding is received, all the additions below should be included. Even if not every monitoring method can be implemented, monitors should strive to include as many as possible as this will be the best way to ensure the long-term health and biodiversity of Borrego Springs.

Camera Traps

A fully or partially automated camera trap approach will cost more up-front but can be more cost-efficient over time than the traditional methods. Kissling et al. (2024) successfully automated their wildlife camera project. Their wireless 4G cameras, powered by 12V/2A solar panels submitted images to an internal server which used an AI model to automatically sort out blanks and identify species. Although the establishment cost of this method is significantly higher than traditional methods, Kissling et al. estimated their pilot was ~40% more cost effective over a 5-year period due to the money saved on staff costs. However, fully automating the process in this way requires a stable network connection to reach the cameras. Therefore, this style of set up could likely function at Borrego Springs but not at Clark Dry Lake where reception is limited to non-existent.

Drift Net Camera Traps

Drift net camera trap surveys are an ideal method to monitor reptiles, amphibians, and small mammals of the mesquite bosques compared to traditional camera trap techniques. At least one setup can be placed in each location and the cameras can be in use during the spring and summer months, when many reptiles are most likely to be active. This method has more setup costs and time than most other methods, but then they only need to be checked as often as the normal camera traps. These can be performed at the same time to reduce the number of visits. Once the monitoring season is over, the camera boxes will need to be collected, but the drift nets can remain unless they are likely to be damaged.

Photopoint Surveys

While photopoint surveys are a low-cost method of monitoring, there are ways that can amplify their results to make measuring more convenient and accurate. To capture any variability in mesquite bosque health, we recommend that photos should continue to be taken once a season. This allows for faster results, since the photos can be compared quarterly, instead of waiting seasonally or yearly. Additionally, we recommend taking multiple photos at each site or location per variable –mesquite fullness, richness of the area, and locality. This can range from 5 to 15 photos depending on how large and variable the site or location is. Another way to determine how many photos should be taken is by only adding them to places where other surveys are being performed. The photopoint pictures can serve to understand collected results and utilize already implemented markers creating consistency. Taking multiple photos would encapsulate changes in certain sections of the location that may not be seen through only one or two photos. Bringing an angle gauge to photopoint sites would allow for different photographers to take the photos with the confidence the photos will not be drastically different.

Species Inventory

We recommend adding annual eBird data updates to efforts previously described in Tier 1 and 2. Extracting and filtering the eBird data to our two mesquite bosques requires personnel skilled in both R and ArcGIS softwares, in addition to taking a comparatively longer time to complete than previous tiers. However, given the vast amount of data and increase in bird biodiversity documented by incorporating eBird data in the species inventory it is well worth the effort.

Bird Surveys

In the highest effort tier, avian point count surveys should be accounting for spatial variability in the bosques on top of the temporal variability. The surveys should occur at more sites in Borrego Springs to include areas with diverse levels of mesquite mortality. This could give another insight to how the declines in productive mesquite habitat affect bird abundance and diversity. At least three collection periods should occur during each season at this level, but if funding allows, more would be beneficial.

If endangered/threatened species are found to be nesting in the bosques, then monitors may consider performing nesting surveys for these species. This would require a staff member with the correct permit and many more hours to survey but should be considered if possible because any decline in the health of the bosque could lead to the extirpation of these species from the region.

Invertebrate Beat Sheets Surveys

We recommend continuing the beat sheet surveys as described in the second tier, with additional surveys carried out at as many sites as feasible. Borrego Springs contains Sites 1-4 and Clark Dry Lake contains Site 5. Ideally, efforts would increase from two surveys a year, at Site 1 and Site 5 during other field activities, to five surveys per year. All surveys should still be carried out during peak mesquite season.

Invertebrate Light Trap Surveys

Light trap surveys are unique among our proposed survey methods, as they require nighttime fieldwork and thus cannot be completed at the same time as other methods. Given the additional field visits and travel time required we recommend it only for the highest tier. Adding this survey method to the beat sheet survey increases the number or insect orders targeted, providing further insight into the bosques' health and ability to support diverse predators. Surveys should be completed at once a year, in the spring or after a bloom in each location at as many sites as resources allow.

Bat Surveys

The equipment and software required to complete bat surveys can be expensive. While the processing may be outsourced to a researcher's lab, acoustic sensors would still likely need to be purchased. However, little emphasis has been placed on bat monitoring to date, so addressing this critical gap is needed if the budget exists.

Summary of Monitoring Tiers

When deciding on a plan to monitor the mesquite bosques, it is easy to conclude some of the medium or high tier efforts are not worth the upfront costs or labor hours required to perform them consistently. While these surveys are not all easy, we urge monitors to consider putting the maximum effort into monitoring these habitats. The bosques are hubs of ecological activity in the harsh desert landscape that require active monitoring and management to protect them from anthropogenic issues. If a lower tier is the only option, monitoring efforts will still lead to a better understanding of biodiversity than if there were none. However, the difference in the number of species it is possible to observe using only Tier 1 methods compared to both Tier 2 or Tier 3 methods is vast. Even if they could reach the same number of species, the Tier 1 methods would take much longer to document them all. For example, in the current species inventory insect beat sheet surveys (Tier 2 and 3) were able to document seven orders and families of insects per location. The addition of light trap surveys (Tier 3) documented four different orders in one survey per location. Both methods are expected to capture many more when done in spring, as the past surveys were done in winter when insect abundance is low. A similar idea could be observed from the bird count data when you compare the 2023/2024 winter surveys to the 2024/2025 one. The previous capstone team performed two collections, once in December and once in February, whereas our team only had one in January. From this, 16 unique species were found in 2023/2024 compared to only 13 in 2024/2025. Then, with the additional spring collection the 2023/2024 team performed in April, their total increased to 30 unique species. As the effort increased, so did the observed avian biodiversity. Adding additional data sources to species inventory efforts will also better document biodiversity. The current inventory includes 45 species documented by the Christmas Bird Count (Tier 1), 261 species documented by iNaturalist (including SDNHM and iNat projects) (Tier 2), and 203 species documented by eBird (Tier 3). If monitors are working with very minimal funding, monitors should apply for more as opportunities arise, to help add more surveys or increase the scope of the ones already being implemented.

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Appendix D. Perched Aquifer Evaluation

The hypothesis that a perched aquifer may support the mesquite bosque near the Borrego Sink was initially proposed to explain the persistence of mesquite in the limited dataset used for the original GSP planning exercises. However, with more comprehensive vegetation mapping and remote sensing data now available, this issue is no longer a significant concern. Nonetheless, this appendix evaluates the proposition by reviewing the most current data to determine whether there is any credible evidence for a perched aquifer beneath the mesquite bosque. Our analysis finds no evidence to support the existence of a perched aquifer capable of supporting the mesquite bosque near the Borrego Sink. Data from well drill logs, airborne electromagnetic (AEM) surveys, repeated soil sampling, isotopic analyses, and groundwater depth measurements all fail to identify a widespread impermeable layer or a shallow perched water source in the area.

While perched aquifers may occur in and around the Borrego Springs Subbasin, they are typically spatially limited and short-lived. These aquifers are formed above impermeable layers such as clay or fractured bedrock, which trap water in localized zones, but their size and volume are constrained. Given the finite and ephemeral nature of perched aquifers, they are unlikely to provide a sustainable water source for a large ecosystem like the mesquite bosque over an extended period. The available data indicate that the mesquite bosque relies on the regional aquifer, where groundwater depths are estimated to range from 22 to 134 feet below ground surface, which is well within the documented rooting depths for mesquite species (39 to 175 feet bgs) (see **Mapping Depth to Groundwater)**. Not only was the perched aquifer hypothesis unsupported by the data available during the GSP analysis, but it is also inconsistent with the current best available scientific evidence.

History of the Perched Aquifer Argument

In the initial technical assessments supporting the Groundwater Management Plan (Borrego Water District and County of San Diego, 2020), a perched water feature was proposed to explain the restricted spatial distribution of phreatophytic species following the decline of the historically extensive groundwater-dependent ecosystem (GDE) that once dominated the low-elevation floor around the Borrego Sink in the Borrego Springs Subbasin.

This hypothesis emerged to reconcile an apparent contradiction in the original technical analyses conducted during the Groundwater Sustainability Planning process. Specifically, the assessments identified a mismatch between groundwater depth and mesquite rooting depth, as well as a significantly reduced spatial distribution of mesquite compared to historical records. In our 2023 Technical Memorandum, we demonstrated that the conclusions regarding mesquite GDEs were based on errors in the data. Assumptions concerning mesquite rooting depth were not consistent with documented rooting depths throughout the southwestern U.S. Appendix D4 assumed mesquite rooting depths of 15 ft, while actual documented depths for mesquite species span 39 - 175 ft (see **Mapping Depth to Groundwater)**. Additionally, the mapping dataset used to estimate mesquite distribution only covered the mesquite bosque found on State Park lands (13.2 acres of mesquite quoted in Appendix D4), whereas the actual current acreage of mesquite bosque spans up to approximately 1,850 acres (see **Mapping the GDEs)**. As a result, the explanatory mechanism of a perched water feature is no longer necessary, as the original contradiction in the data has been resolved. Further data collection and analysis from the GDE Project Team has confirmed that mesquite near the Borrego Sink in Borrego Springs are utilizing groundwater and thus are considered GDEs under SGMA.

What is a perched aquifer?

A perched aquifer is a localized zone of water trapped above the regional aquifer by an impermeable layer, such as clay or rock, which prevents the water from moving deeper into the ground (Figure D1). These aquifers typically form in areas with specific geological conditions, such as faults, hilly or mountainous terrain, and alluvial fans, and are spatially confined to the area directly above the impermeable layer. Perched aquifers are recharged when fluctuating groundwater or recent rainfall infiltrates the soil but is unable to pass through the barrier, causing water to accumulate above it. At the surface, perched aquifers may create temporary areas of standing water, often surrounded by dense plant growth, particularly after rainfall. However, perched aquifers tend to dry out quickly as the water evaporates or is absorbed by plants. As a result, they are often short-lived and do not provide a consistent or reliable water source for long-term vegetation growth.

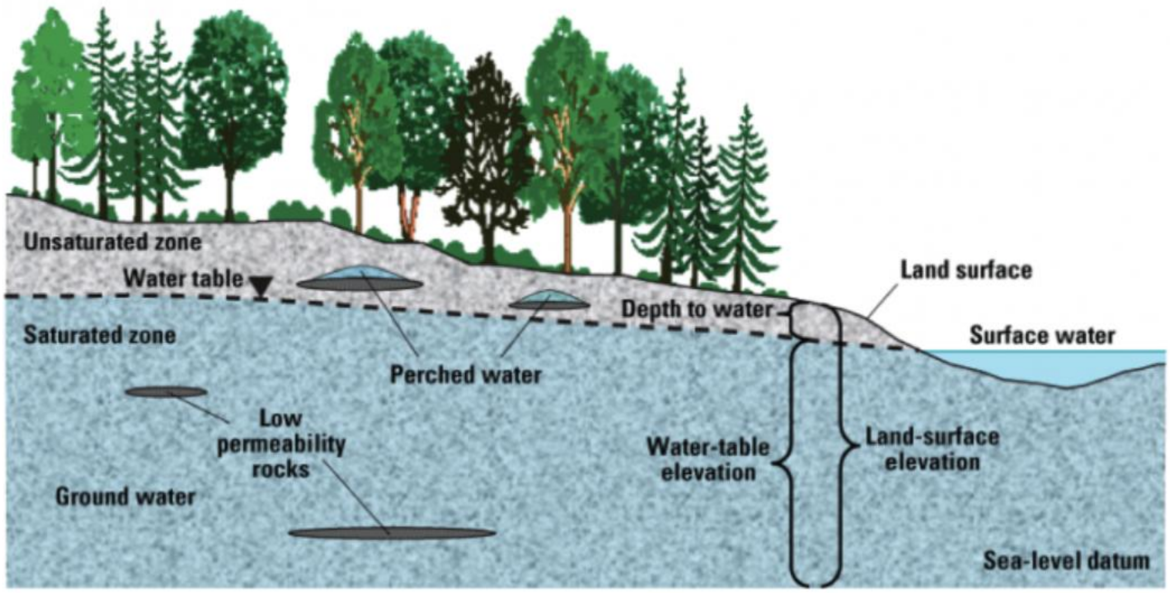


Figure D1. Perched aquifer schematic. Schematic cross-section showing the occurrence of perched aquifers above an unconfined aquifer. *Source: D.T. Snyder, U.S. Geological Survey Scientific Investigations Report 2008–5059, Estimated Depth to Ground Water and Configuration of the Water Table in the Portland, Oregon Area*

Are perched aquifers considered GDEs?

Perched aquifers can be replenished by fluctuating or laterally flowing groundwater, by rainfall infiltration, or a combination of the two. According to The Nature Conservancy's Best Practices for Identifying GDEs Under SGMA document (2019), if a perched aquifer is replenished by groundwater at any time, it is still considered a GDE. However, if a perched aquifer is solely supported by precipitation, it is not a GDE (The Nature Conservancy, 2019).

External research finds no evidence of perched aquifers near the Borrego Sink

Well Drill Logs

To investigate the presence of a perched aquifer, we examined well drill logs from several wells installed in the mesquite bosque near the Borrego Sink (Figure D2). These well drill logs provide no evidence of widespread impermeable layers capable of supporting a perched aquifer. Logs from wells MW-5A and MW-5B, located closest to the mesquite bosque, indicate sandy soils with small amounts of gravel from 0–80 feet bgs (Figure D3). These sandy and gravelly soils are well-draining and do not form impermeable layers, making the formation of a perched aquifer in this area unlikely. Groundwater was found at 62 ft bgs for each of these wells. Similarly, the drill logs from wells located in 11S06E12 and 11S06E11, situated in the mesquite bosque north of the Borrego Sink, show no signs of widespread impermeable layers (Figure D4). Well located in 11S06E12 shows loose, sandy soil with gravel extending from 0–120 feet bgs with groundwater found at 65 ft bgs, further demonstrating the absence of any impermeable layers in this part of the habitat. Well located in 11S06E11, located on the western edge of the mesquite bosque north of the Borrego Sink, contains mixed clay and fine to medium-coarse sands throughout its depths. While clay layers are present in this well, the interspersal with sands suggests they are not continuous. Additionally, the absence of clay layers in nearby well located in 11S06E12 indicates that these clay deposits are not laterally extensive across the mesquite bosque. Overall, the well logs consistently reveal well-draining soils across the mesquite bosque, with no evidence of widespread impermeable, continuous layers necessary for the formation of a perched aquifer.

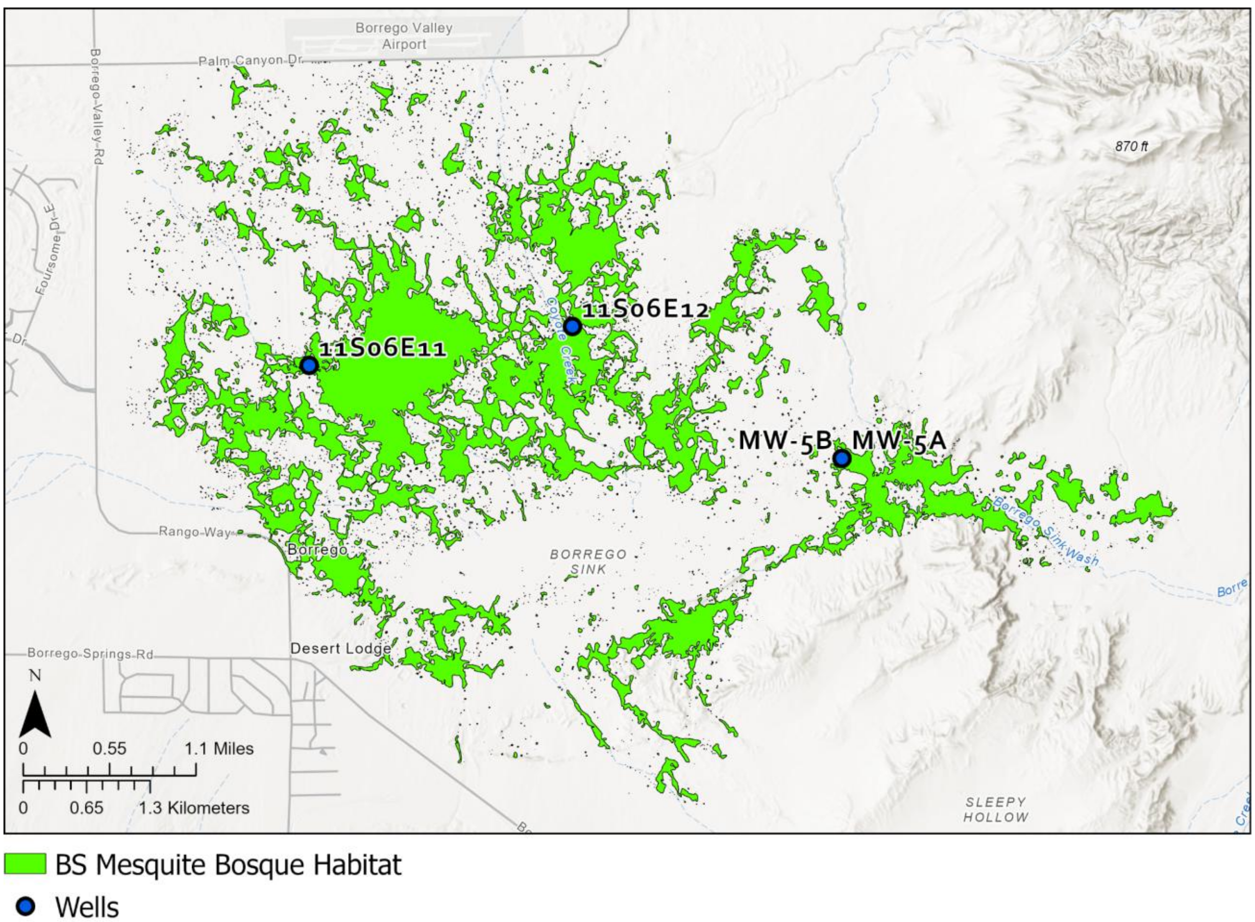
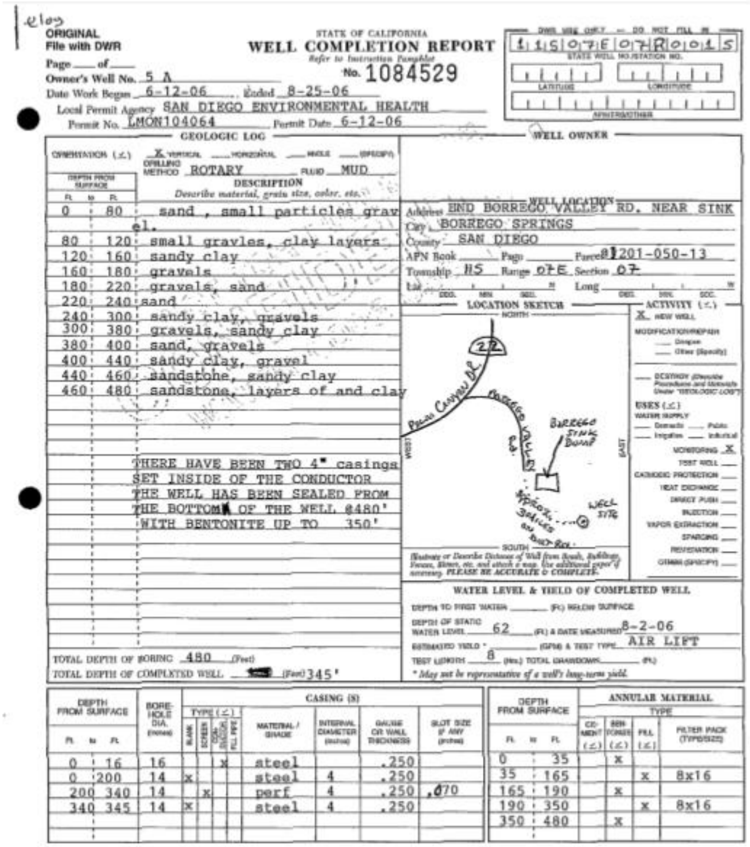


Figure D2. Well drill logs analyzed for signs of clay layers near the mesquite bosque habitat.

MW- 5A

MW- 5B



ORIGINAL
File with DWR
Page ___ of ___
Owner's Well No. 5 A
Date Work Began 6-12-06 Ended 8-25-06
Local Permit Agency SAN DIEGO ENVIRONMENTAL HEALTH
Permit No. LMON104064 Permit Date 6-12-06

STATE OF CALIFORNIA
WELL COMPLETION REPORT
Refer to Instruction Pamphlet
No. 1084529

STATE WELL NO./STATION NO. 11S07E07R0015

GEOLOGIC LOG

ORIENTATION (✓) X VERTICAL ___ HORIZONTAL ___ ANGLE ___ (SPECIFY)
DRILLING METHOD ROTARY FLUID MUD

From (ft)	To (ft)	Description (Describe material, grain size, color, etc.)
0	80	sand , small particles gravel.
80	120	small gravles, clay layers
120	160	sandy clay
160	180	gravels
180	220	gravels, sand
220	240	sand
240	300	sandy clay, gravels
300	380	gravels, sandy clay
380	400	sand, gravels
400	440	sandy clay, gravel
440	460	sandstone, sandy clay
460	480	sandstone, layers of and clay

THERE HAVE BEEN TWO 4" casings SET INSIDE OF THE CONDUCTOR THE WELL HAS BEEN SEALED FROM THE BOTTOM OF THE WELL @480' WITH BENTONITE UP TO 350'

TOTAL DEPTH OF BORING 480 (Feet)
TOTAL DEPTH OF COMPLETED WELL 345' (Feet)

WELL OWNER

WELL LOCATION
Address END BORREGO VALLEY RD. NEAR SINK
City BORREGO SPRINGS
County SAN DIEGO
APN Book ___ Page ___ Parcel 201-050-13
Township 11S Range 07E Section 07

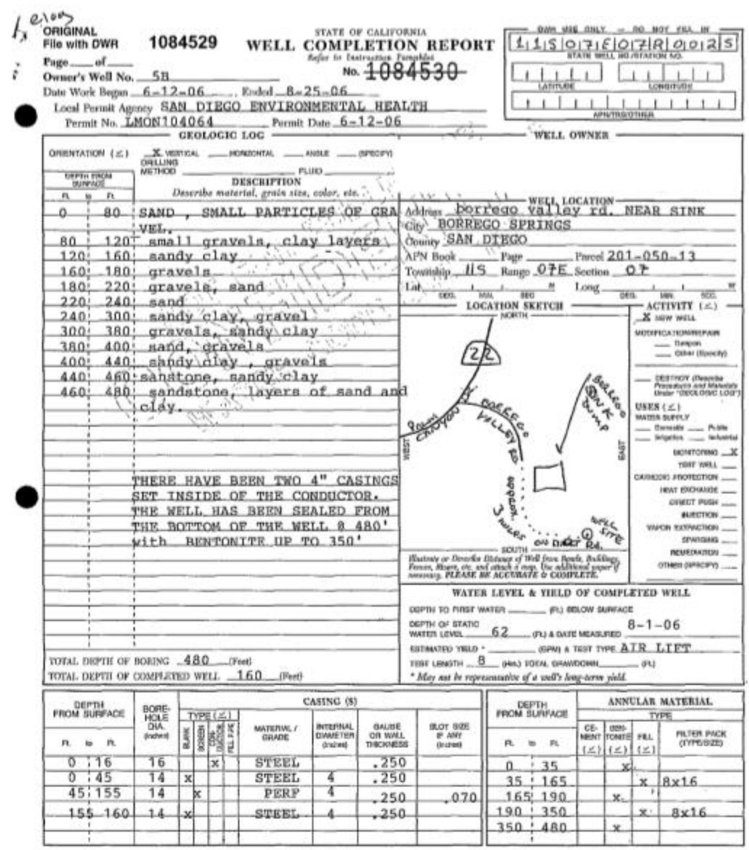
LOCATION SKETCH

ACTIVITY (✓) X NEW WELL
USES (✓) MONITORING X

WATER LEVEL & YIELD OF COMPLETED WELL
DEPTH OF STATIC WATER LEVEL 62 (Ft.) & DATE MEASURED 8-2-06
TEST TYPE AIR LIFT
TEST LENGTH 8 (Hrs.)

From (ft)	To (ft)	Bore-hole dia. (inches)	Type	Material / Grade	Internal diameter (inches)	Gauge or wall thickness	Slot size if any (inches)
0	16	16		steel		.250	
0	200	14	blank	steel	4	.250	
200	340	14	screen	perf	4	.250	.070
340	345	14	blank	steel	4	.250	

From (ft)	To (ft)	Annular material type	Filter pack (type/size)
0	35	X	
35	165	X	8x16
165	190	X	
190	350	X	8x16
350	480	X	



ORIGINAL
File with DWR
1084529
Page ___ of ___
Owner's Well No. 5B
Date Work Began 6-12-06 Ended 8-25-06
Local Permit Agency SAN DIEGO ENVIRONMENTAL HEALTH
Permit No. LMON104064 Permit Date 6-12-06

STATE OF CALIFORNIA
WELL COMPLETION REPORT
Refer to Instruction Pamphlet
No. 1084530

STATE WELL NO./STATION NO. 11S07E07R0025

GEOLOGIC LOG

ORIENTATION (✓) X VERTICAL ___ HORIZONTAL ___ ANGLE ___ (SPECIFY)

From (ft)	To (ft)	Description (Describe material, grain size, color, etc.)
0	80	SAND , SMALL PARTICLES OF GRAVEL,
80	120	small gravels, clay layers
120	160	sandy clay
160	180	gravels
180	220	gravels, sand
220	240	sand
240	300	sandy clay, gravel
300	380	gravels, sandy clay
380	400	sand, gravels
400	440	sandy clay , gravels
440	460	sanatone, sandy clay
460	480	sandstone, layers of sand and clay.

THERE HAVE BEEN TWO 4" CASINGS SET INSIDE OF THE CONDUCTOR. THE WELL HAS BEEN SEALED FROM THE BOTTOM OF THE WELL @ 480' with BENTONITE UP TO 350'

TOTAL DEPTH OF BORING 480 (Feet)
TOTAL DEPTH OF COMPLETED WELL 160 (Feet)

WELL OWNER

WELL LOCATION
Address borrego valley rd. NEAR SINK
City BORREGO SPRINGS
County SAN DIEGO
APN Book ___ Page ___ Parcel 201-050-13
Township 11S Range 07E Section 07

LOCATION SKETCH

ACTIVITY (✓) X NEW WELL
USES (✓) MONITORING X

WATER LEVEL & YIELD OF COMPLETED WELL
DEPTH OF STATIC WATER LEVEL 62 (Ft.) & DATE MEASURED 8-1-06
TEST TYPE AIR LIFT
TEST LENGTH 8 (Hrs.)

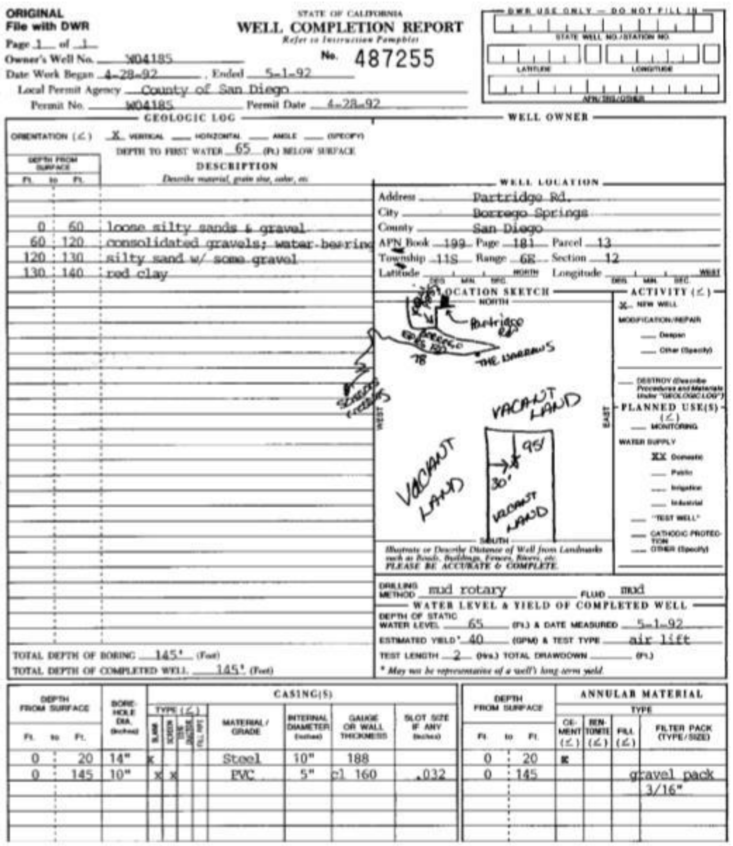
From (ft)	To (ft)	Bore-hole dia. (inches)	Type	Material / Grade	Internal diameter (inches)	Gauge or wall thickness	Slot size if any (inches)
0	16	16		STEEL		.250	
0	45	14	blank	STEEL	4	.250	
45	155	14	screen	PERF	4	.250	.070
155	160	14	blank	STEEL	4	.250	

From (ft)	To (ft)	Annular material type	Filter pack (type/size)
0	35	X	
35	165	X	8x16
165	190	X	
190	350	X	8x16
350	480	X	

Figure D3. Well completion reports for wells MW-5A and MW-5B**,** the wells closest to the mesquite bosque near the Borrego Sink show sandy, gravely layers, which are well-draining and permeable, and thus not capable of forming a perched aquifer. The regional aquifer groundwater level was found at 62 ft bgs.

UCIRVINE

11S06E12



ORIGINAL
File with DWR
Page 1 of 1
Owner's Well No. W04185
Date Work Began 4-28-92, Ended 5-1-92
Local Permit Agency County of San Diego
Permit No. W04185 Permit Date 4-28-92

STATE OF CALIFORNIA
WELL COMPLETION REPORT
Refer to Instruction Pamphlet
No. 487255

GEOLOGIC LOG
ORIENTATION (✓) X VERTICAL
DEPTH TO FIRST WATER 65 (Ft.) BELOW SURFACE

Depth from surface, Ft. to Ft.	Description (Describe material, grain size, color, etc)
0 – 60	loose silty sands & gravel
60 – 120	consolidated gravels; water-bearing
120 – 130	silty sand w/ some gravel
130 – 140	red clay

TOTAL DEPTH OF BORING 145' (Feet)
TOTAL DEPTH OF COMPLETED WELL 145' (Feet)

WELL LOCATION
Address Partridge Rd.
City Borrego Springs
County San Diego
APN Book 199 Page 181 Parcel 13
Township 11S Range 6E Section 12

LOCATION SKETCH

ACTIVITY (✓) X NEW WELL
PLANNED USE(S) XX Domestic

DRILLING METHOD mud rotary FLUID mud
WATER LEVEL & YIELD OF COMPLETED WELL
DEPTH OF STATIC WATER LEVEL 65 (Ft.) & DATE MEASURED 5-1-92
ESTIMATED YIELD* 40 (GPM) & TEST TYPE air lift
TEST LENGTH 2 (Hrs.) TOTAL DRAWDOWN (Ft.)
* May not be representative of a well's long term yield.

Depth from surface Ft. to Ft.	Bore-hole dia. (Inches)	Type	Material / Grade	Internal diameter (Inches)	Gauge or wall thickness	Slot size if any (Inches)
0 – 20	14"	x	Steel	10"	188	
0 – 145	10"	x x	PVC	5"	cl 160	.032

Depth from surface Ft. to Ft.	Annular material type	Filter pack (type/size)
0 – 20	x	
0 – 145		gravel pack 3/16"

11S06E11

ORIGINAL
File with DWR
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
WATER WELL DRILLERS REPORT
Do not fill in
No. 351023
Local Permit No. or Date W30421

(2) LOCATION OF WELL (See instructions):
County San Diego
Well address if different from above Yaqui Pass Road
Township 11S Range 6E Section 11
Distance from cities, roads, railroads, fences, etc Borrego Springs

WELL LOCATION SKETCH
(3) TYPE OF WORK: New Well X
(4) PROPOSED USE: Domestic
(5) EQUIPMENT: Rotary X
(7) CASING INSTALLED: Steel X

From ft.	To ft.	Dia.	Gage or Wall
0	265	5	.188

(8) PERFORATIONS: 170 – 265, size .060

(9) WELL SEAL: Was surface sanitary seal provided? Yes X If yes, to depth 50 ft.
Method of sealing Cement grout
(10) WATER LEVELS: Depth of first water, if known 40'
(11) WELL TESTS

(12) WELL LOG: Total depth 270 ft. Completed depth 265 ft.

from ft. to ft.	Formation (Describe by color, character, size or material)
0 - 45	Brown surface clay w/fine med sand
45 - 115	Med coarse to fine sand w/ thin streaks brown clay
115 - 135	Med fine to coarse sand
135 - 155	Med coarse to fine sand w/large streaks gray & blue clay
155 - 180	Blue-gray clay w/large streak coarse med to fine sand
180 - 200	Fine med to coarse sand w/ thin streaks brown clay
200 - 225	Coarse med to fine sand w/ thin streaks brown clay
225 - 245	Coarse med to fine sand w/ thin streaks brown & gray clay
245 - 270	Coarse med to fine sand w/ streaks red clay

Work started 8-28-1991 Completed 9-13-1991
WELL DRILLER'S STATEMENT: This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
NAME Coachella Valley Pump & Supply, Inc.
Address P.O. Drawer 000
City Indio, CA ZIP 92202
License No. 161541 Date of this report 10-14-91

CONFIDENTIAL NOT FOR PUBLIC USE WATER CODE SEC. 13752

Figure D4. Well completion reports for wells located in 11S06E12 and 11S06E11, which are located in the mesquite bosque north of the Borrego Sink. Well located in 11S06E12 shows sandy, gravely layers, which are well-draining and permeable, and groundwater was found at 65 ft bgs. Well located in 11S06E11 shows interspersed clay and sand layers, with groundwater found at 40 ft bgs. While clay layers are present in this well, the interspersal with sands suggests they are not continuous, and nearby well located in11S06E12 shows no sign of surface clay, indicating that the clay is not laterally expansive.

Airborne Electromagnetic Surveys (AEM) to Map the Subsurface

The Department of Water Resources contracted a team to conduct airborne electromagnetic (AEM) surveys across several subbasins in California. The data and detailed information from these surveys are publicly available at: SGMA Data Viewer

AEM surveys use electrical resistivity to map subsurface materials by measuring how strongly a material resists the flow of electric current. In this context, variations in resistivity reveal differences in subsurface composition, helping to identify materials based on their conductivity.

- **High resistivity** (shown in purple or red) indicates that the material resists electricity (Figure D5). This is typically associated with dense, impermeable materials such as rocks, clay, or dry, compacted soils. These layers are often associated with low water content because water conducts electricity well. High resistivity suggests that the subsurface layer is likely impermeable and may act as a barrier to water flow.

- **Low resistivity** (shown in blue or green) indicates that the material conducts electricity more readily, typically because it is saturated with water (Figure D5). Materials like sand, gravel, and other permeable soils that hold water tend to have low resistivity. Low resistivity suggests that the subsurface layer is likely saturated with groundwater, making it more permeable and capable of transmitting water.

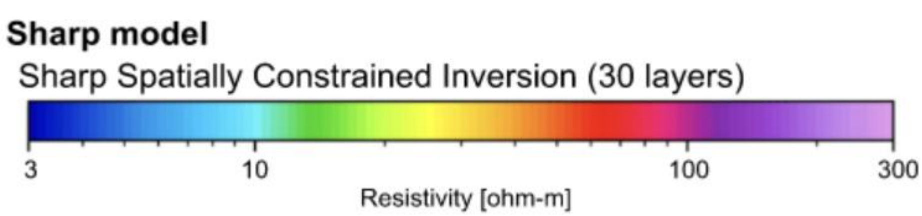


Figure D5. Resistivity scale bar, with low resistivity shown in blue and green tones, and high resistivity in red and purple tones.

Borrego Springs Subbasin Survey Results

Several AEM surveys were conducted across the Borrego Springs Subbasin, including multiple survey lines covering the area around the mesquite bosque near the Borrego Sink. The AEM data is corroborated by well monitoring data, which is represented in the profiles as vertical rectangles, with groundwater levels marked by blue triangles.

We present resistivity profiles from three AEM surveys near the mesquite bosque and Borrego Sink, along with one survey from a comparative area in the northern part of the Subbasin, where groundwater is deeper (Figure D6). Figures D7 - D10 show cross-sectional views of the subsurface, with colors indicating different levels of electrical resistivity:

- **High resistivity (purple/red):** Indicates rocky, clay-rich, or dense, impermeable soil layers.
- **Low resistivity (blue/green):** Represents permeable soils saturated with groundwater.

The AEM survey results reveal no evidence of impermeable layers that could form a perched aquifer around the Sink. Instead, the data indicates an unconfined aquifer with near-surface groundwater throughout the area. Across all flight lines near the Borrego Sink and the mesquite bosque, low resistivity (blue/green tones) is consistently observed, suggesting permeable, water-saturated soils (Figures D7 - D9). This interpretation is further supported by well monitoring data, where groundwater levels (blue triangles in the well profiles) align closely with the blue and green resistivity layers.

For comparison, we also present the resistivity profile for Flight Line 201800, which runs horizontally from Henderson Canyon, across the northern agricultural area, and through Coyote Creek near Henderson Canyon Road—an area where groundwater is significantly deeper than in the Borrego Sink region (Figure D10). This flight line displays high resistivity (purple tones) in Henderson Canyon, indicating rocky, dense, impermeable terrain that does not hold water. As the flight line moves across the agricultural area and Coyote Creek, moderate to high resistivity layers are shown near the surface (red and purple tones), which indicate dry, dense, or clay-rich soils that are not holding water. At deeper depths, lower resistivity layers are shown in light blue and green tones, corresponding to the deeper groundwater table.

These findings highlight the contrast between the Borrego Sink region, where permeable soils saturated with groundwater are found near the surface, and the northern part of the Subbasin, where deeper water tables and impermeable layers are more prominent.

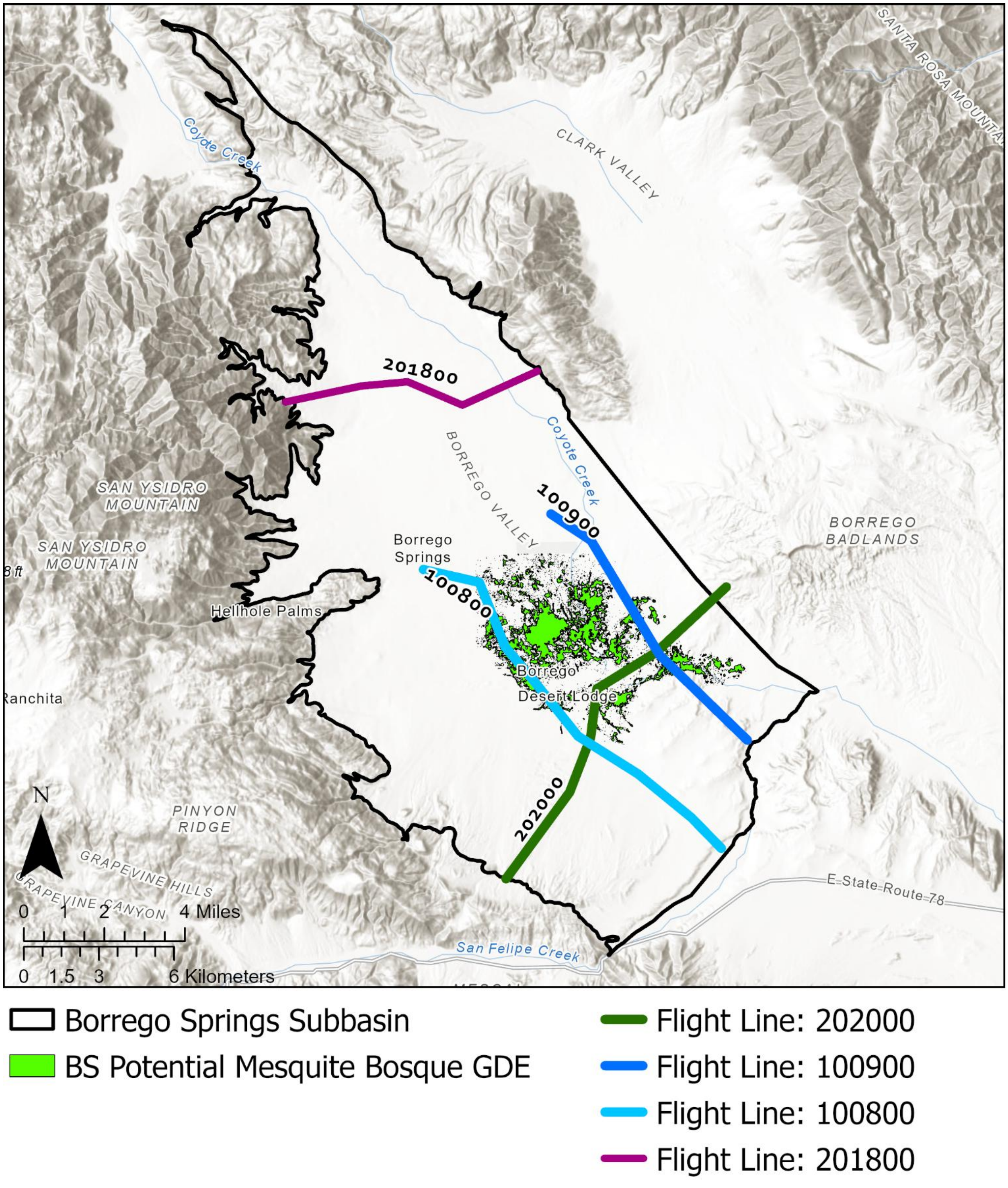


Figure D6. AEM flight lines discussed in this appendix. Flight Lines 202000, 100900, and 100800 are found in the Central and Southern Management Units near the mesquite bosque habitat near the Borrego Sink, and Flight Line 201800 is found in the Northern Management Unit.

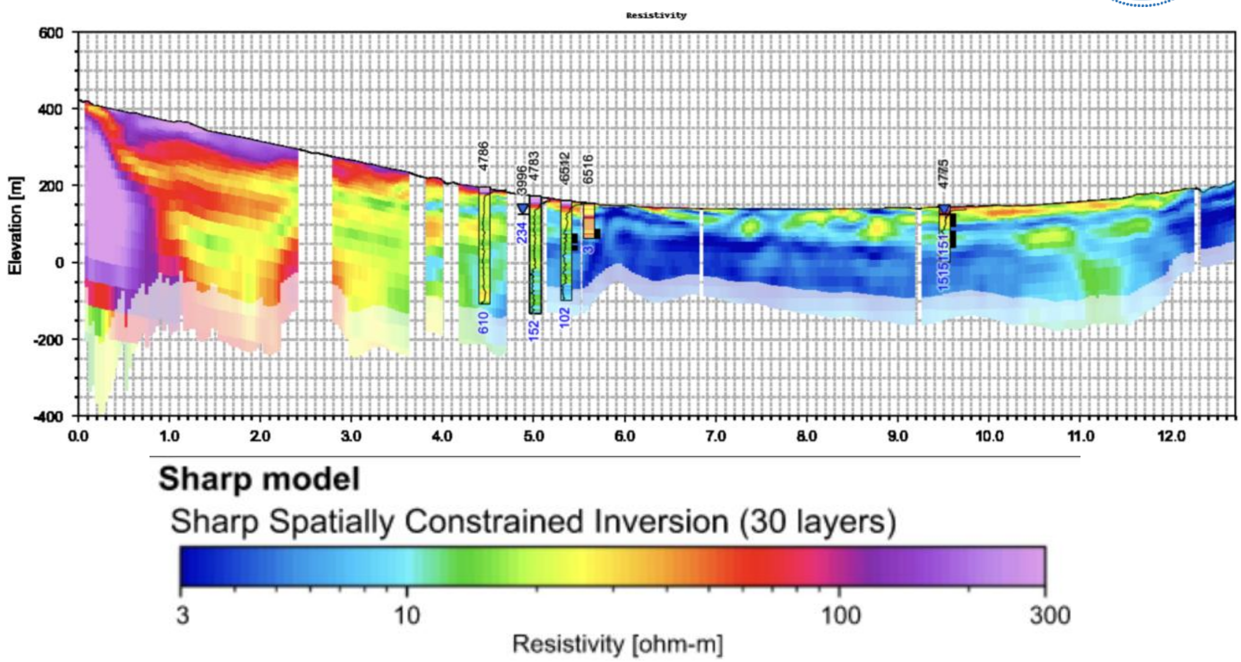


Figure D7. Resistivity profile from airborne electromagnetic (AEM) surveys from Flight Line 202000, which runs horizontally / diagonally across the Borrego Sink. The left side of the graph represents the mountainous regions in the southern part of the Subbasin (where high resistivity is shown in purple, indicating dense, impermeable materials), while the right side shows the eastern portion near well MW5A/B (labelled as 4775), near ABDSP land. The blue and green tones across the Borrego Sink area indicate low resistivity, suggesting permeable, groundwater-saturated soils.

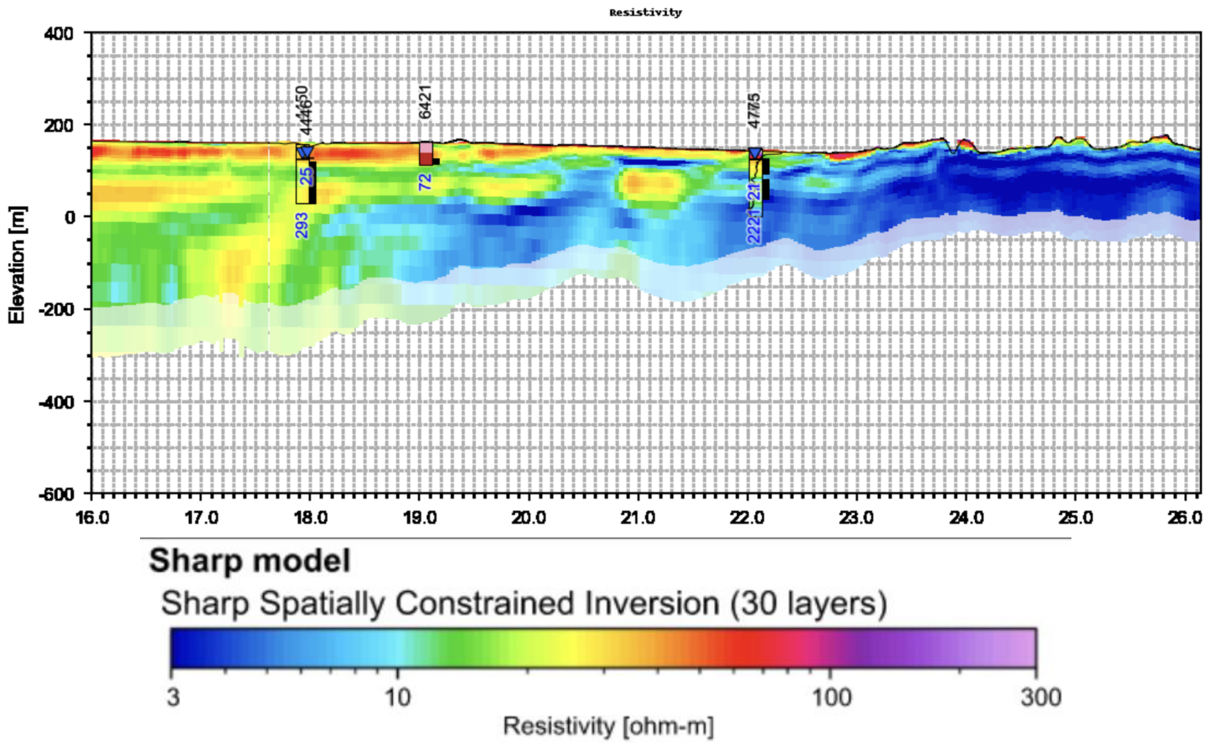


Figure D8. Resistivity profile from airborne electromagnetic (AEM) surveys from Flight Line 100900**,** which runs vertically from the landfill to the eastern portion of the Subbasin, near ABDSP land. The left side of the graph shows the area near the landfill, and the right side shows the eastern portion near well MW5A/B (labelled as 4775) in ABDSP land. The blue and green tones in the area east of the Borrego Sink indicate low resistivity material, which is indicative of permeable, groundwater-saturated soils.

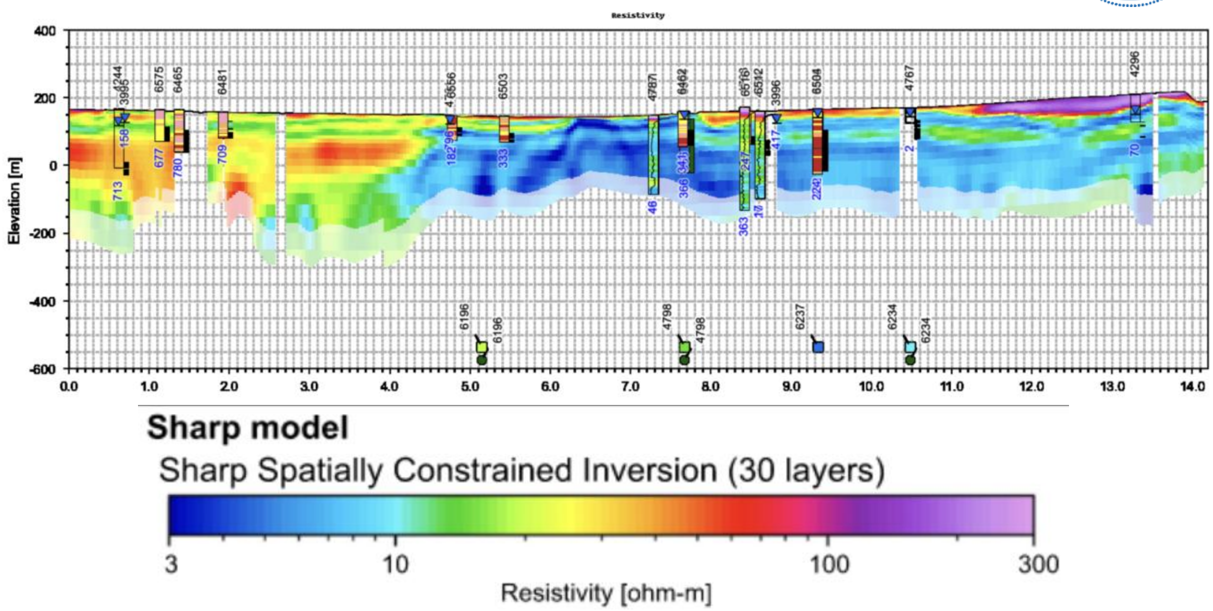


Figure D9. Resistivity profile from airborne electromagnetic (AEM) surveys from Flight Line 100800, which runs vertically from the Borrego Springs Resort, through the Borrego Sink, and to the eastern portion of the Subbasin. The left side of the graph represents the area near the Borrego Springs Resort, while the right side shows the eastern portion of the Subbasin. Blue and green tones indicate low resistivity across the western side of the Borrego Sink, highlighting permeable, groundwater-saturated soils.

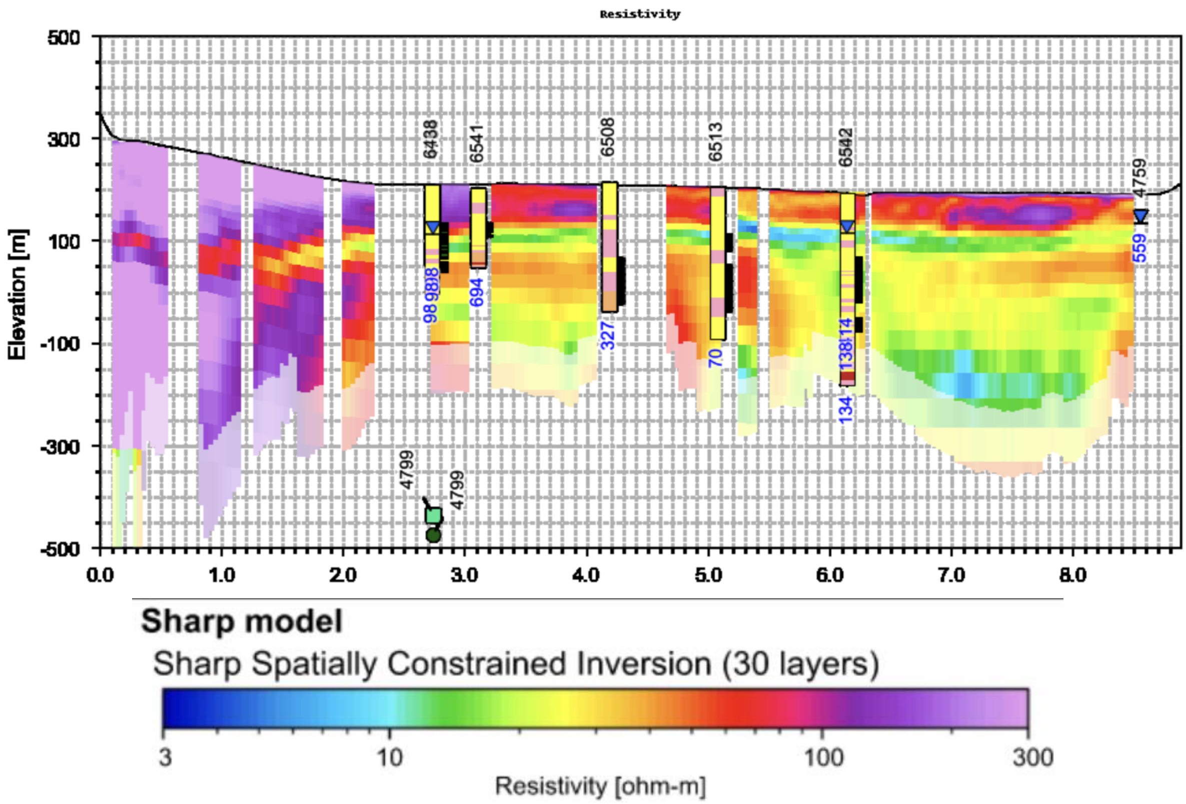


Figure D10. Resistivity profile from airborne electromagnetic (AEM) surveys from Flight Line 201800, which runs horizontally from Henderson Canyon, across the northern agricultural area, and through Coyote Creek near Henderson Canyon Road. On the left side of the graph, high-resistivity purple layers indicate the rocky, dense, and impermeable mountainous terrain near Henderson Canyon. In contrast, Coyote Creek on the right shows dry, clay-rich surface soils (purple and red), with deeper groundwater appearing in light blue.

GDE Project work finds no evidence of perched aquifers beneath the mesquite bosque

Collection of soil samples for isotope analysis

To determine the isotopic signature of soil water, we sampled soils to a depth of 1.5 meters at selected locations within the mesquite study sites. Soil sampling locations were positioned within twice the approximate diameter at breast height of tagged mesquite trees to ensure that the location represented soil water sources relevant to mesquite water use. In total, 22 soil cores were collected across the mesquite study sites, and sandy, well-drained soils were consistently observed across all depths and sites. There were no signs of clay layers, waterlogged soils, or any impermeable layers indicative of a perched aquifer.

The soil water samples were analyzed for isotopic composition, revealing consistently enriched isotopic signatures, particularly in surface soils **(see Isotopic Analysis and Appendix A.2. for detailed methods)**. This enrichment is attributed to evaporation, where lighter isotopes preferentially evaporate, leaving behind a higher proportion of heavier isotopes. The isotopic signatures across all depths indicate that the soil water originated from precipitation, infiltrated into the soil, and subsequently underwent evaporation. Importantly, the isotopic composition of the soil water samples shows no evidence of abnormal chemistry or isotopic anomalies that would suggest the presence of perched aquifers or water trapped by impermeable layers. The consistent isotopic patterns across sites and depths further confirm that the soils are well-drained and that the water dynamics are dominated by infiltration and evaporation processes, with no signs of long-term water retention in the surface soil. Furthermore, the isotopic signature of the sampled mesquite trees shows high similarity to the isotopic signature of the regional aquifer sampled from wells, confirming that mesquite trees are accessing groundwater from the regional aquifer rather than a perched water feature **(see Isotopic Analysis)**.

Installation of soil moisture sensors

In April 2023, we installed continuous soil moisture sensors at the primary Borrego Springs and Clark Dry Lake sites to investigate subsurface hydrological dynamics. The sensors were installed at depths of 10 cm (3.94 in), 30 cm (11.81 in), 50 cm (19.69 in), 70 cm (27.56 in), 90 cm (35.43 in), 110 cm (43.31 in), 130 cm (51.18 in), and 150 cm (59.06 in) to capture soil moisture profiles across a range of depths. During installation, sandy, well-drained soils were observed throughout all depths. No evidence of clay layers, waterlogged soils, or any impermeable layers indicative of a perched aquifer was encountered.

The continuous soil moisture data reveal distinct patterns of water infiltration and loss (from drainage, evaporation, and plant uptake). Following precipitation events, moisture levels increase sharply across all depths, as shown in Figure D11. However, this moisture drains rapidly, returning to baseline dry conditions within days. Such a rapid decline suggests that the soil is highly permeable and lacks features that would retain water, such as an impermeable clay layer or a perched aquifer.

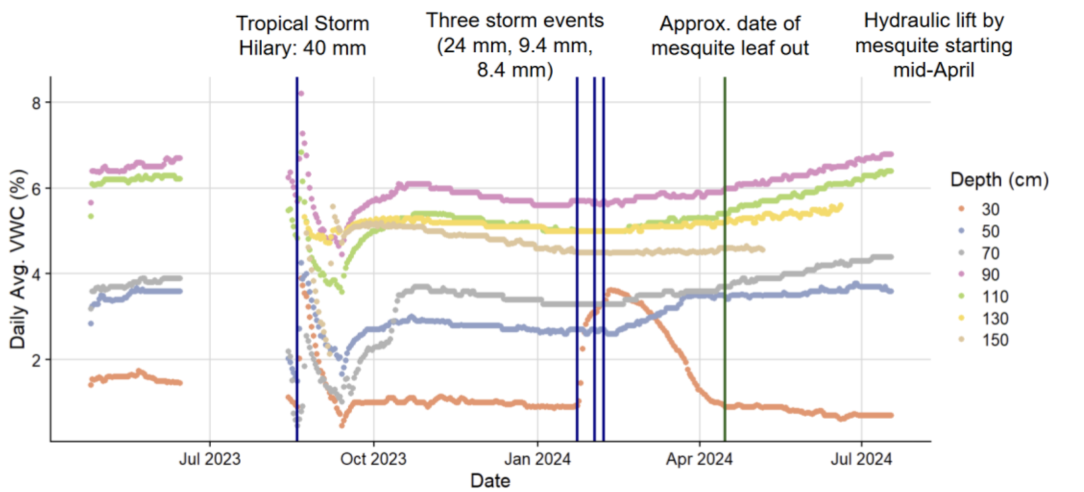


Figure D11. Soil moisture data from a sensor at Site 1, near the Borrego Sink. The data show rapid increases in surface soil moisture following rain events, followed by equally rapid decreases, characteristic of well-draining soils. This pattern indicates the absence of impermeable soil layers or perched aquifers.

Groundwater Depth from Wells

In the **Baseline Groundwater** section, we analyzed groundwater depth trends in wells near the mesquite bosque by the Borrego Sink. If these wells were connected to a perched aquifer, we would expect to see distinct fluctuations in response to precipitation events. However, during the 10-year pre-SGMA period, which included a particularly wet year (2005), several average years (2006, 2009, 2012–2013), and a particularly dry year (2014), groundwater depths in these wells did not exhibit short-term changes corresponding to climatic variations. Instead, wells 11S06E01C001S and MW-5B showed a steady, long-term decline in groundwater levels, indicating they are not influenced by perched aquifers, which typically display more pronounced seasonal and interannual variability. The lack of short-term fluctuations suggests that these wells are hydraulically connected to the regional aquifer, where groundwater levels are declining due to sustained pumping rather than increasing from direct recharge following precipitation events.

UCIrvine

References

Borrego Water District and County of San Diego. (2020). Groundwater Management Plan for the Borrego Springs Groundwater Subbasin January 2020 (Draft Final). Available at https://borregospringswatermaster.com/wp-content/uploads/2022/10/Exhibit-1_GMP.pdf

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Snyder, D. T. (2008). *Estimated depth to ground water and configuration of the water table in the Portland, Oregon area* (U.S. Geological Survey Scientific Investigations Report No. 2008–5059). U.S. Geological Survey. http://pubs.usgs.gov/sir/2008/5059/