In partnership with the University of New Mexico and Sevilleta LTER

BOSQUE ECOSYSTEM MONITORING PROGRAM (BEMP)
SITE MONITORING REPORT FOR 2023

2023 ANNUAL SITE MONITORING TECHNICAL REPORT

Submitted

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1 Introduction

Objective

To collect and analyze abiotic and biotic data at BEMP sites in the Rio Grande Bosque while involving K-12 and university students in learning about and monitoring this ecosystem.
All data and reports are available on the BEMP website, www.BEMP.org.

Scope of Work (updated from previous reports)

The Bosque Ecosystem Monitoring Program (BEMP) combines long-term ecological research with community outreach by involving K-12 teachers, their students, and students from the University of New Mexico in monitoring key indicators of structural and functional change in the Rio Grande riparian forest, or "bosque." In 1996, BEMP began as a program of the University of New Mexico's Department of Biology (under NSF Grant No. DEB-9420510, Amendment No. 004) and quickly became a collaboration between the University of New Mexico and Bosque School in Albuquerque, with fewer than 200 participants in its first year. Before the COVID-19 pandemic, BEMP was averaging approximately 9,000 participants annually. The BEMP outdoor education experience builds science skills, educates the community about the bosque ecosystem, and helps create a constituency for stewardship of the bosque. BEMP findings derived from student-gathered data are used by government agencies to inform multi-million dollar management decisions that impact the riparian corridor.

The 2023 reporting period covers 33 BEMP sites along 250 miles of the Rio Grande, including 32 sites within the Middle Rio Grande (Figure 1.1 and Table 1.1). Through the stakeholder driven and strategic location of these sites, BEMP studies the ecological drivers and effects of fire, flooding, climate change, and human alteration on the bosque ecosystem. Two-thirds of BEMP sites were installed by BEMP staff at the request of natural resource and water managers to monitor the long-term ecological impacts of restoration projects such as mechanical clearing, wood chipping, bank-lowering, and more recently, post burn recovery. The other third were installed to facilitate research opportunities or at the request of schools or other partners.

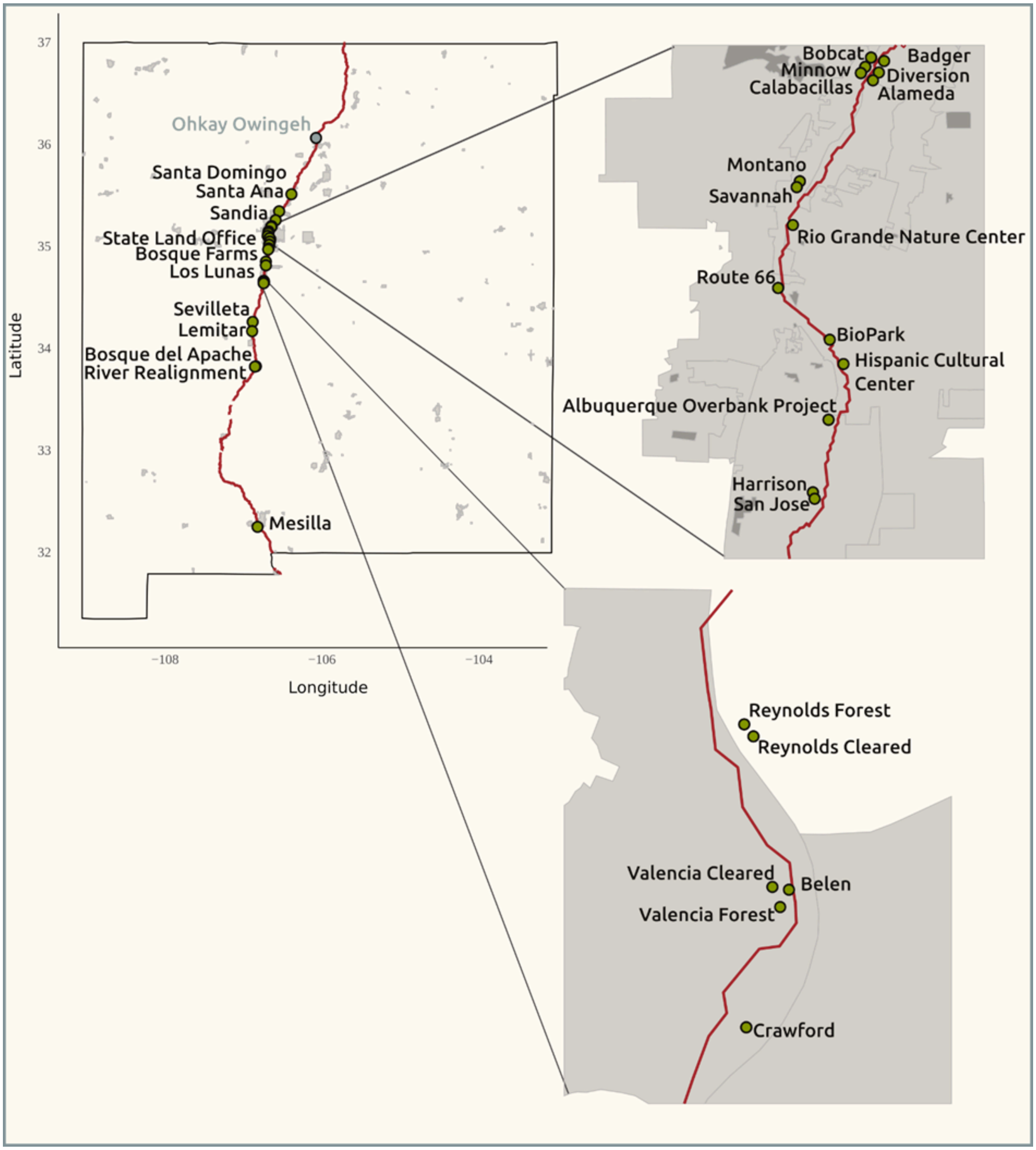

Figure 1.1. Map of 33 active BEMP sites along the Rio Grande; Ohkay Owingeh was not an active site for all of 2023.

Table 1.1. BEMP sites and locations along the Rio Grande by Reach, listed from north to south.
* denotes inactive site (either no longer active or temporarily inactive)

Site number	Site name	Latitude	Longitude	Reach
9	Ohkay Owingeh*	36.0618	-106.0761	Cochiti
24	Santo Domingo*	35.50989	-106.3896	Cochiti
5	Santa Ana	35.34284	-106.5458	Angostura
32	Sandia	35.255	-106.5907	Angostura
22	Bobcat	35.19705633	-106.6439494	Angostura
21	Badger	35.1956	-106.6402	Angostura
12	Minnow	35.19315094	-106.646915	Angostura
10	Diversion	35.1908	-106.6429	Angostura
11	Calabacillas	35.19056822	-106.6491626	Angostura
1	Alameda	35.1875	-106.6459	Angostura
17	Montano	35.14528819	-106.6803699	Angostura
6	Savannah	35.14285294	-106.6819814	Angostura
2	Rio Grande Nature Center (RGNC)	35.127	-106.6854	Angostura
20	Route 66	35.1006408	-106.6914783	Angostura
23	BioPark	35.079	-106.668	Angostura
8	Hispanic Cultural Center (HCC)	35.06881267	-106.6580575	Angostura
29	Albuquerque Overbank Project (AOP)	35.04546	-106.6657	Angostura

13	Harrison	35.01505603	-106.6736953	Angostura
31	San Jose	35.012375	-106.6728	Angostura
28	Valle de Oro	34.97895	-106.6801	Angostura
30	State Land Office (SLO)	34.96785	-106.6856	Angostura
27	Bosque Farm	34.848851	-106.714722	Isleta
3	Los Lunas	34.81236936	-106.714458	Isleta
19	Reynolds Forest	34.66054583	-106.7429525	Isleta
18	Reynolds Cleared	34.65966431	-106.7421328	Isleta
15	Valencia Cleared	34.64863444	-106.7391728	Isleta
4	Belen	34.6484315	-106.7377022	Isleta
16	Valencia Forest	34.64716225	-106.738482	Isleta
25	Crawford	34.63835	-106.74277	Isleta
14	Sevilleta	34.25834233	-106.8831845	San Acacia
7	Lemitar	34.16703188	-106.8899486	San Acacia
34	River Realignment	33.8227	-106.8419	San Acacia
33	Bosque del Apache (BDA)	33.8197	-106.8539	San Acacia
26	Mesilla	32.248328	-106.821014	South of San Marcial

BEMP monitors biotic and abiotic variables at our research sites. Our abiotic datasets include: depth to groundwater; water level in ditches and drains; precipitation; above- and below-ground temperature; and water quality in the Rio Grande. Our biotic datasets include litterfall; vegetation cover; surface-active arthropod richness and abundance; and tamarisk leaf beetle distribution, abundance and impact.

Timing of Data Collection (from previous reports)

Depth to groundwater, water level in nearby ditches and/or drains, precipitation, and litterfall are collected monthly, during the week of the third Tuesday of each month. Surface-active arthropods are collected three times each year, in the spring, summer, and fall. Vegetation cover is surveyed once each year in August-September. Tamarisk leaf beetle monitoring is conducted during the week of monthly monitoring from May-August, with some sites collected through September. BEMP collects other datasets as funding permits, including water quality of the river, ditches, and groundwater; fuel load/woody debris; cottonwood sex and diameter at breast height; cottonwood phenology; sunflower phenology; and seedling counts.

Site Updates

High river flows from May through early July, 2023 resulted in the inundation of numerous sites by overbank and seep flooding. Flooded sites were (north to south): in Bernalillo County: Minnow (Site #12), Diversion (Site #10), Alameda (Site #1), Route 66 (Site #20), Bio Park (Site #23), Hispanic Cultural Center (Site #8), Albuquerque Overbank Project (Site #29), Harrison (Site #13), San Jose (Site #31) and State Land Office (Site #30); in Valencia County: Bosque Farms (Site #27), Los Lunas (Site # 3), Reynolds Cleared (Site #18), Reynolds Forest (Site #19), Valencia Cleared (Site #15), Valencia Forest (Site #16), Belen (Site #4), and Crawford (Site #25) and in Socorro County: Bosque del Apache (Site #33) and River Realignment (Site #34). Collections were modified to accommodate the amount of flood water at each site while maintaining field crew safety. BEMP was unable to secure permission to monitor Santo Domingo (Site #24) from the local tribal authorities starting in June 2023.

In February 2023, there was a small, rapidly-contained fire at the Los Lunas BEMP site. The fire was primarily in the center of the site, scorching the center well and burning B, D, and E litterfall tubs and a few pitfall traps. The fire scorched the ground and a few cottonwoods but it was a low severity fire. This area flooded in April of 2023 and remained inundated through June. This allows for a comparison of post-fire recovery following flooding. Pictures and data visualizations of the Reynolds Forest and Los Lunas sites post-fire are in the last section of 6 Litterfall and Vegetation Cover, post-burn assessment.

2 Importance of long-term data, community science, and education outreach
(from previous reports)

BEMP's mission is community science, education, and stewardship: equitable and inclusive hands-on student research essential to the management of the Rio Grande ecosystem.

The long-term data generated by BEMP have been used in informing predictive models, assessing restoration projects, tracking shifts in native and exotic vegetation, understanding bosque response to different ecosystem drivers (e.g., fire, flooding, clearing, impacts of climate change, introduction of biocontrol species), determining what ecotones are present, and how to transition former riparian areas to sustainable semi-arid ecosystems. Long-term monitoring of these sites is critical for understanding how the ecosystem responds to land management strategies and climate variability under rapidly changing means and variances. Long term data is necessary for effectively applying adaptive management and developing best practices strategies.

BEMP involves community members and students of all ages, from pre-K through high school, college, and graduate school to life-long learners volunteering in the program. Our primary focus is on elementary, middle , and high school students that participate in monthly fieldwork (long term educational engagement) to collect groundwater, precipitation, and litterfall data, as well as going out once or twice each year to participate in monitoring arthropods. Students have opportunities to participate in other data collections, including water quality, tamarisk leaf beetle, and monitoring fuel load. BEMP involves UNM undergraduate and graduate students in a semester-long internship experience through an upper division biology BEMP course, BIOL 408/508, where they learn about the bosque ecosystem, develop independent projects applying BEMP data, work with K-12 students and teachers, and play an integral role in regular field and lab work. The work of K-12 students in the field is facilitated and quality controlled by BEMP staff as well as the UNM interns. Having now played a role in our community for a couple of decades, we are starting to see the long-term impacts of our programming. Each year, there are a few UNM students in the BEMP course that had previously participated in BEMP as elementary, middle, and/or high school students. These students are often reconnected to their former schools and sites. BEMP has been part of a meaningful story for many students and community members. BEMP helps students connect with their local landscape, learn science through hands-on research, and communicate or present their understanding through math, writing, art, and other forms of expression. Several former BEMP students now have jobs with our partner agencies, including Bernalillo County

Water Utility Authority, City of Albuquerque Open Space, Middle Rio Grande Conservancy District, and New Mexico Interstate Stream Commission.

3 Outreach

BEMP hosted two events during 2023 to present new data, visualizations, and analyses: the Crawford Symposium and the Luquillo-Sevilleta Virtual Spanish Symposium. Both of these events feature student presentations. BEMP staff and students present BEMP data to managers, professionals, and students several times throughout the year depending on conference availability. In 2023, BEMP data were shared at conferences and workshops including the RiversEdge West Planting for the Future Conference, Climate Adaptation Science Center Fall Science Meeting, Audubon, Sevilleta All Hands Meeting, and the Rio Grande Basin Study. BEMP staff co-hosted a tour with the Rio Grande Basin Study of sites in the San Acacia and Isleta Reaches in June 2023. BEMP participated in multiple workshops, addressing issues around water, climate, fire, and vegetation, including workshops through the MRG Endangered Species Collaborative Program, Whitfield Wildlife Conservation Area, Rio Grande Basin Study, Valle de Oro National Wildlife Refuge and EJ-40 Air Network, Wetland Stakeholder Work Group, and San Acacia Science Forum.

STEM pathways and workforce development through BEMP

Over the last several years, the COVID-19 pandemic has had an unprecedented effect on the educational (and broader) sphere. Despite the many variations of learning that schools, teachers and community partners readjusted to, BEMP education did its best to meet our community's needs at every turn. Taking all necessary precautions to ensure public health and safety, BEMP education reached 5,900 students and adults through in-person contacts alone, engaging 56 different schools and community organizations throughout April of last year to today.

Instruction was provided in-person and remotely at field locations and in outdoor and on campus classrooms, through field monitoring collections, and in study-trips. We also offered an ongoing array of educational programming provided online through printable and electronic platforms, including self-led activities and video lessons. Through lessons focused on water quality and storm impacts, phenological observation, ecosystem monitoring, climate change, scientific processes, graphing and data analysis, students obtained a deeper understanding of nature while developing career-based skills in the sciences, public-speaking and presentation delivery. Moreover, university students participating in the Biology 408/508 internship course conducted field and lab work during this time, engaging in an array of scientific, procedural and collection based skill sets as well as educating younger students and expanding their professional experience as Albuquerque's upcoming workforce.

If this time has taught us anything, it is the deep value of engaging audiences through our broader ecosystem, encouraging us all to see ourselves connected to, rather than separate from, one another and our more-than-human world.

4 Temperature

During the 2022-2023 reporting period, we collected data from OnSet temperature loggers at nine BEMP sites. Three loggers were initially installed at each selected site: a canopy air temperature logger attached to a tree near the canopy rain gauge, a canopy subsurface logger buried underground near the canopy rain gauge, and an open subsurface logger buried near the open rain gauge. Temperature data are logged hourly and downloaded annually by BEMP staff.

Complete temperature monitoring methodology can be found online at: https://secureservercdn.net/45.40.146.38/659.541.myftpupload.com/wp-content/uploads/2017/09/TempLoggerDownloadandDeploy.pdf

Data were run through a visual QA/QC to make sure plots follow the general expected seasonal patterns and historical trends. The data were then checked for the number of NA (missing data points) by site over time and for any points more than three standard deviations (SD) away from the z-score transformed data. The number of data points flagged as outside the three SD were minimal given the volume of data. Data points collected on the same day as the logger was handled for download were eliminated as they did not account for the full day, and as the logger position was disturbed in the download process.

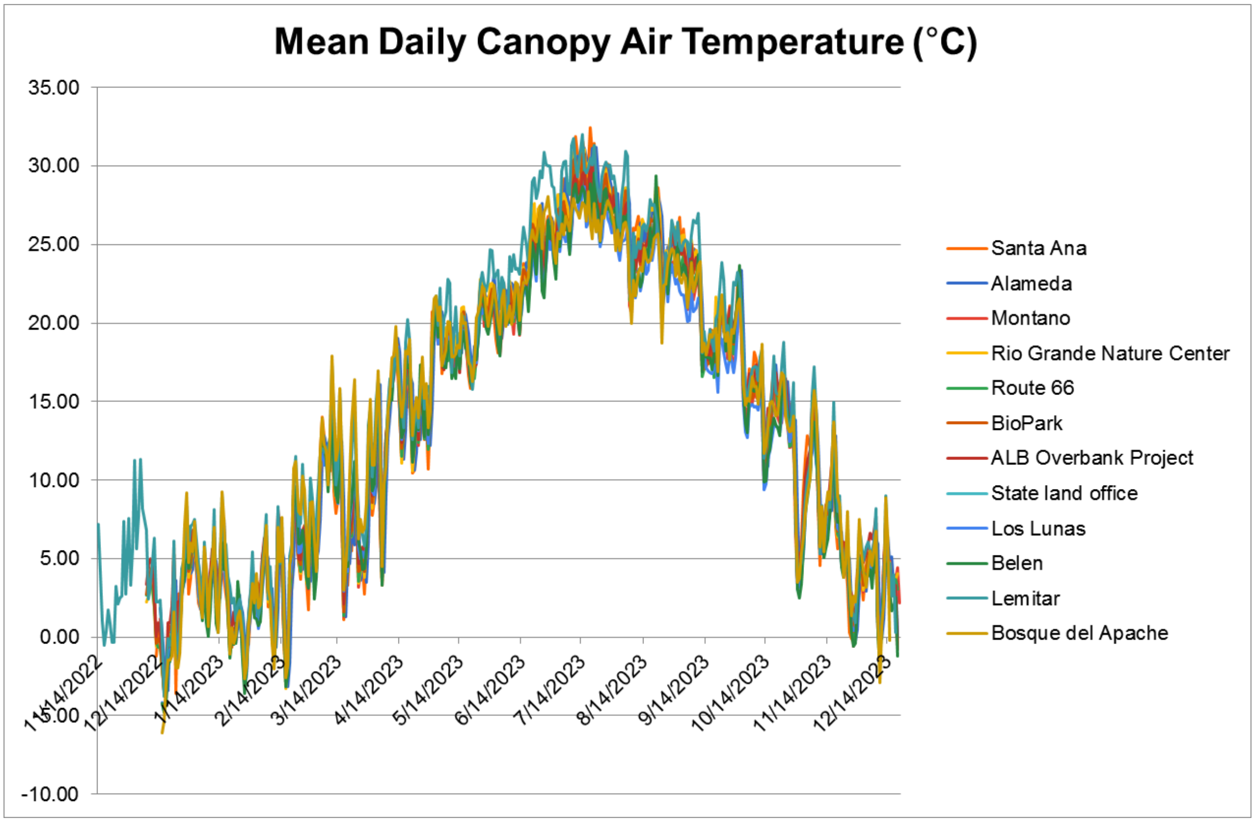

Figure 4.1. Mean daily air temperature (°C) under a canopy from December 2022 through December 2023 at Santa Ana, Albuquerque sites (Alameda, Montano, Rio Grande Nature Center, Route 66, BioPark, and State Land Office), Los Lunas, Belen, Lemitar, and Bosque del Apache.

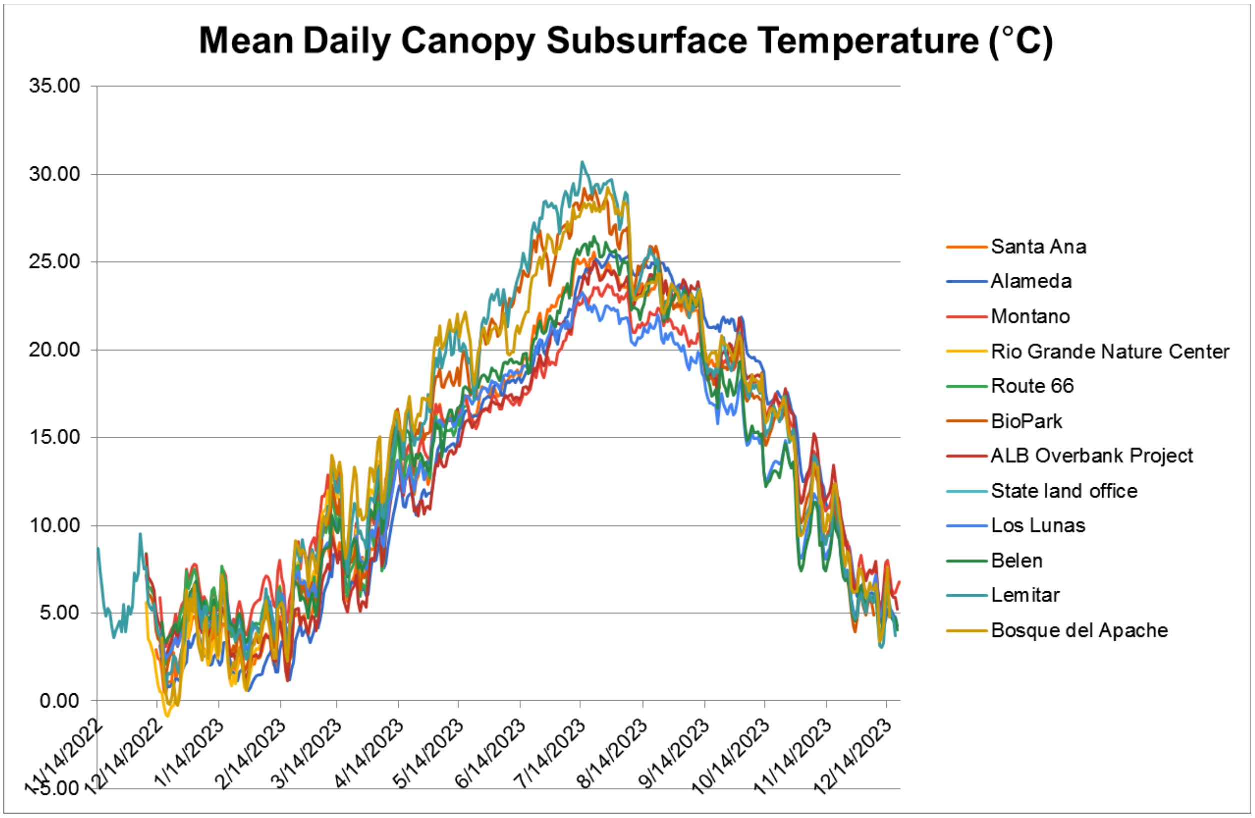

Figure 4.2 Mean daily subsurface temperature (°C) under a canopy from December 2022 through December 2023 at Santa Ana, Albuquerque sites (Alameda, Montano, Rio Grande Nature Center, Route 66, BioPark, and State Land Office), Los Lunas, Belen, Lemitar, and Bosque del Apache.

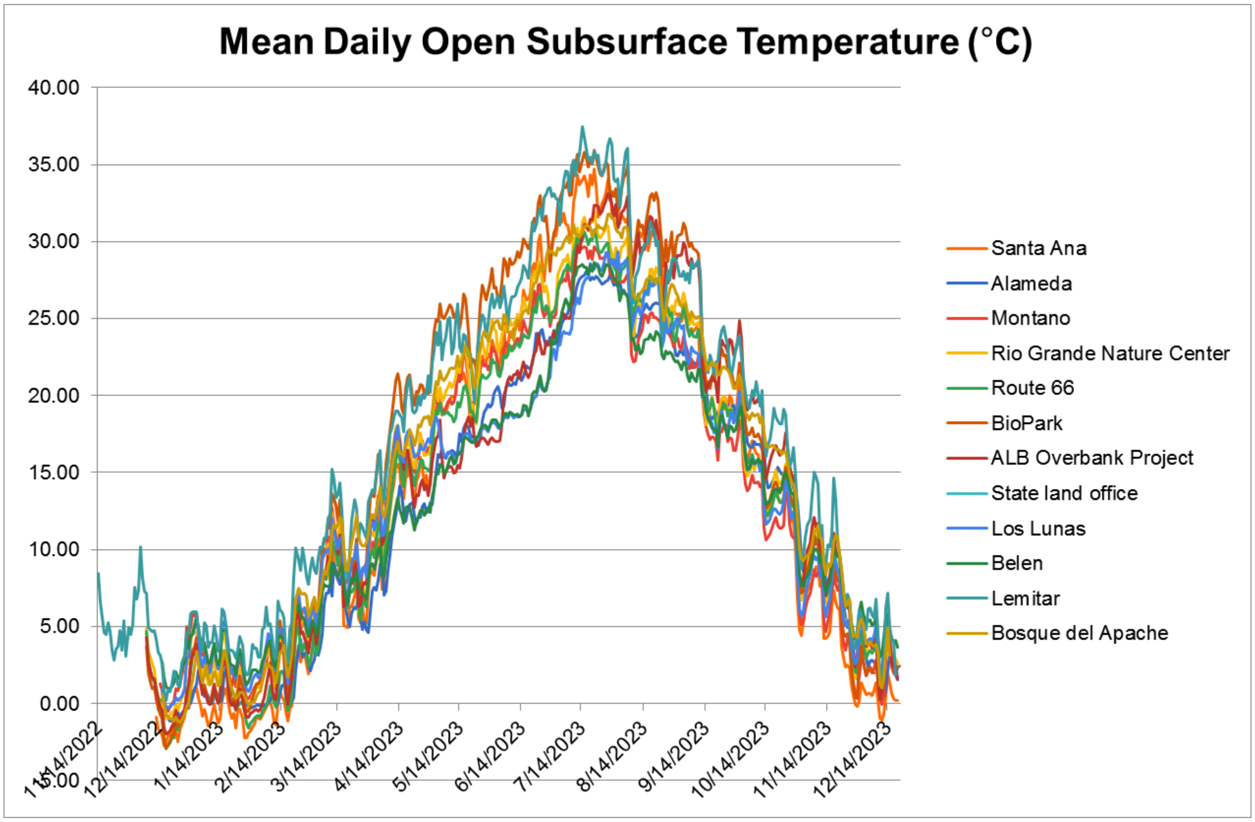

Figure 4.3 Mean daily subsurface temperature (°C) in the open from December 2022 through December 2023 at Santa Ana, Albuquerque sites (Alameda, Montano, Rio Grande Nature Center, Route 66, BioPark, and State Land Office), Los Lunas, Belen, Lemitar, and Bosque del Apache.

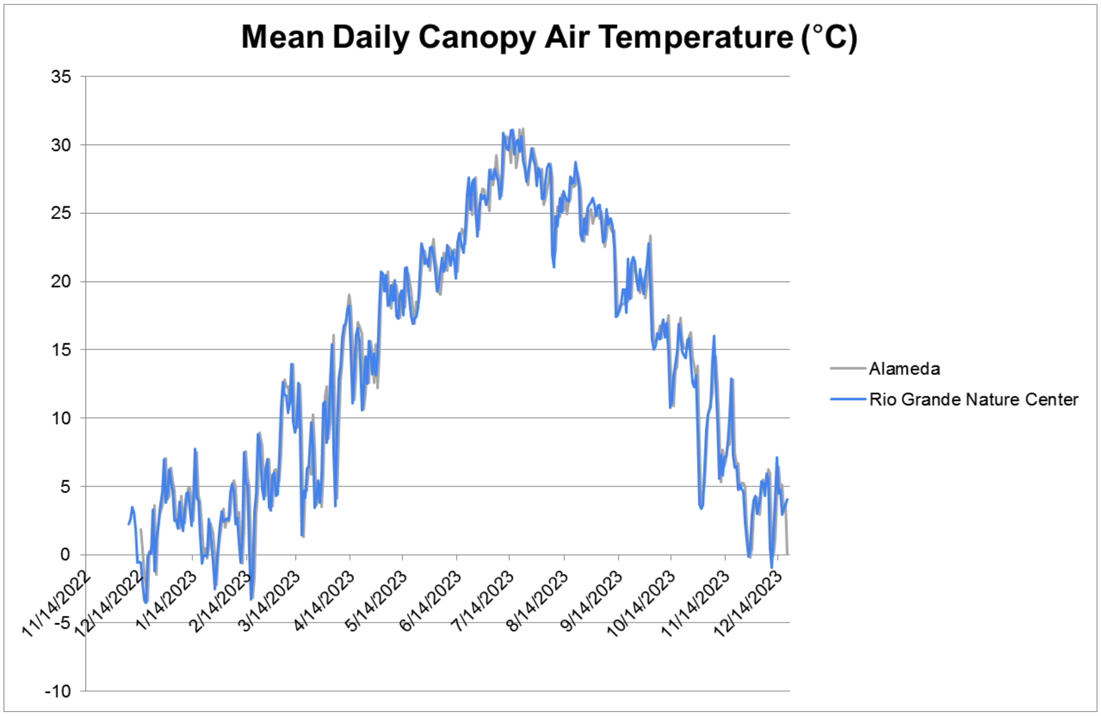

Figure 4.4 Mean air temperatures at Alameda (high canopy cover) and RGNC (low canopy cover) in Albuquerque.

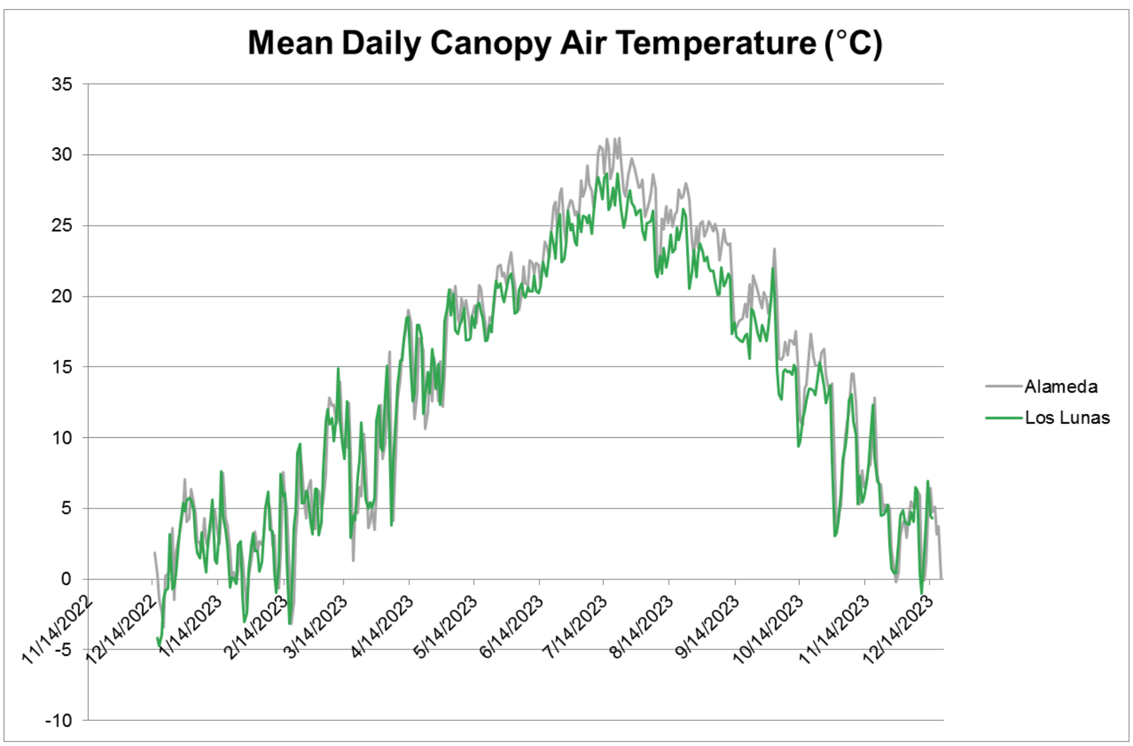

Figure 4.5 Mean air temperatures at Alameda (high canopy cover, urban area) and Los Lunas (high canopy cover, rural area).

Air temperatures show that the warmest sites fluctuate between the southernmost sites (Lemitar and Bosque del Apache), sites with low canopy cover (Santa Ana, Rt 66), and urban sites near bridges (Alameda, Rt 66).

Canopy loss is expected to expose affected areas to increased solar radiation, resulting in local elevated temperatures. This is expected to occur in regions where the dominant canopy trees (cottonwoods) die and are not replaced either through natural recruitment or plantings. As a result, microclimates within these areas will undergo noticeable shifts.

By comparing data from the subsurface temperature loggers beneath the existing canopy and in exposed areas within the same site, we not only gain insight into the insulating capacity of canopy trees within this ecosystem but will also be able to anticipate temperature shifts occurring in areas experiencing canopy loss without replacement.

The importance of canopy is demonstrated through a comparison of two Albuquerque sites, Alameda and RGNC (Figure 4.4). While RGNC is buffered by more farm fields and Candelaria Preserve, the cottonwood cover at Alameda is three times higher than at RGNC. Alameda is 1km (0.65 miles) south of the Alameda Bridge and 0.65 km (0.35 miles) north of Paseo del Norte Bridge. RGNC is 0.25 km (1 mile) south of the Montano Bridge and 0.25km (1 mile) north of I-40. Both sites are easily accessible and in the heart of the City. RGNC, with its declining canopy and sparse understory cover, is on average 0.11 °C warmer than Alameda with a maximum of 1.62 °C warmer. When considering the impact of urban areas on temperatures of the bosque, two sites with similar canopy cover were compared: Alameda and Los Lunas (almost 30 miles to the south) (Figure 4.5). Alameda is on average 1 °C warmer than Los Lunas with a maximum difference of 3.88 °C warmer.

5 Precipitation

Precipitation is measured at all of our sites, except for Bosque Farms (due to repeated vandalism). At each site, two Tru-Chek precipitation gauges are installed on a post; one under the forest canopy, and one out in the open. Each rain gauge is monitored and emptied by BEMP staff and community scientists once per month. A small amount of oil is added to the empty gauge to prevent evaporation and to ensure capture of the full month's precipitation.

More details on our methods for collecting precipitation data can be found here: https://github.com/BEMPscience/bemp_data/tree/master/precipitation

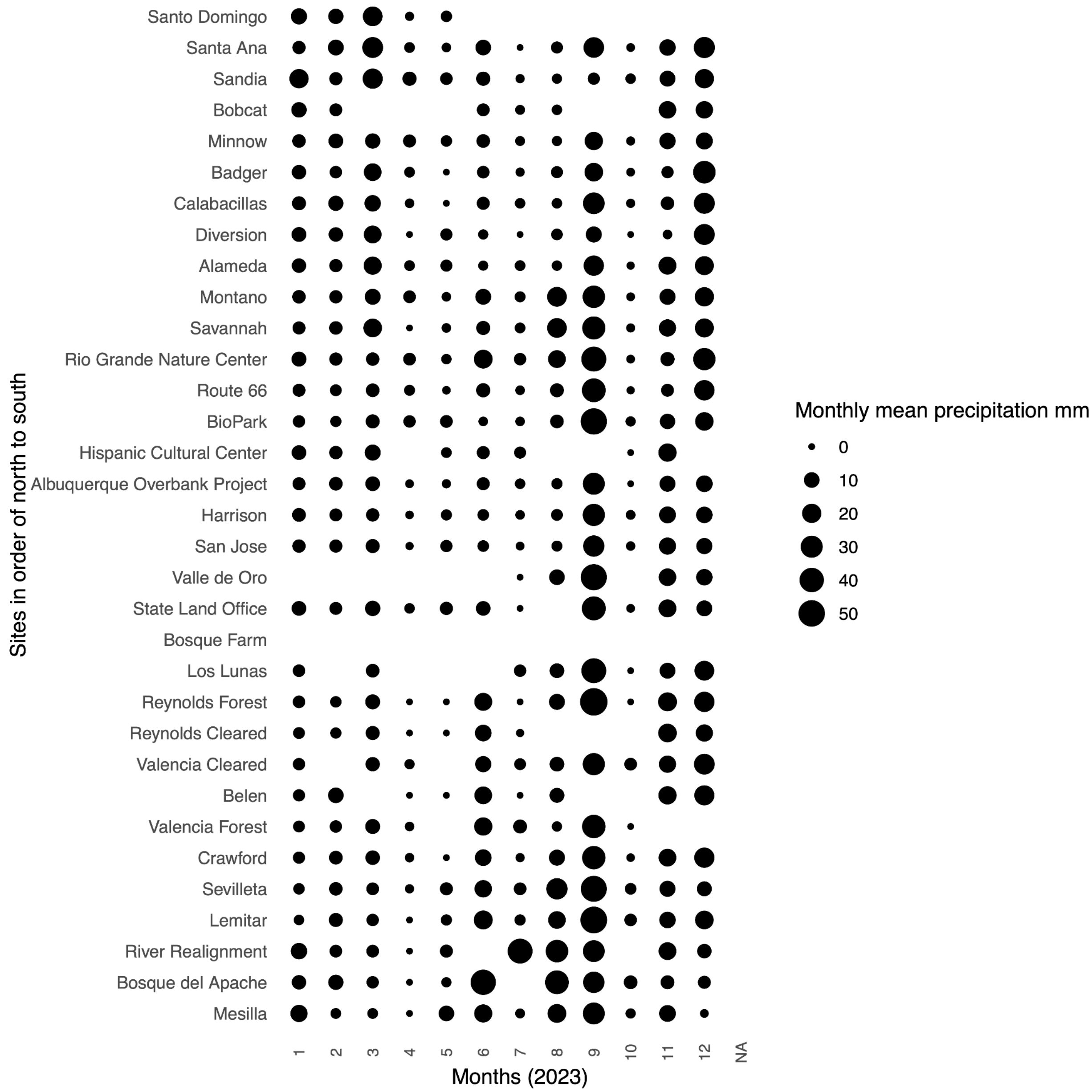

Figure 5.1 Mean monthly precipitation (mm) at each site for 2023.

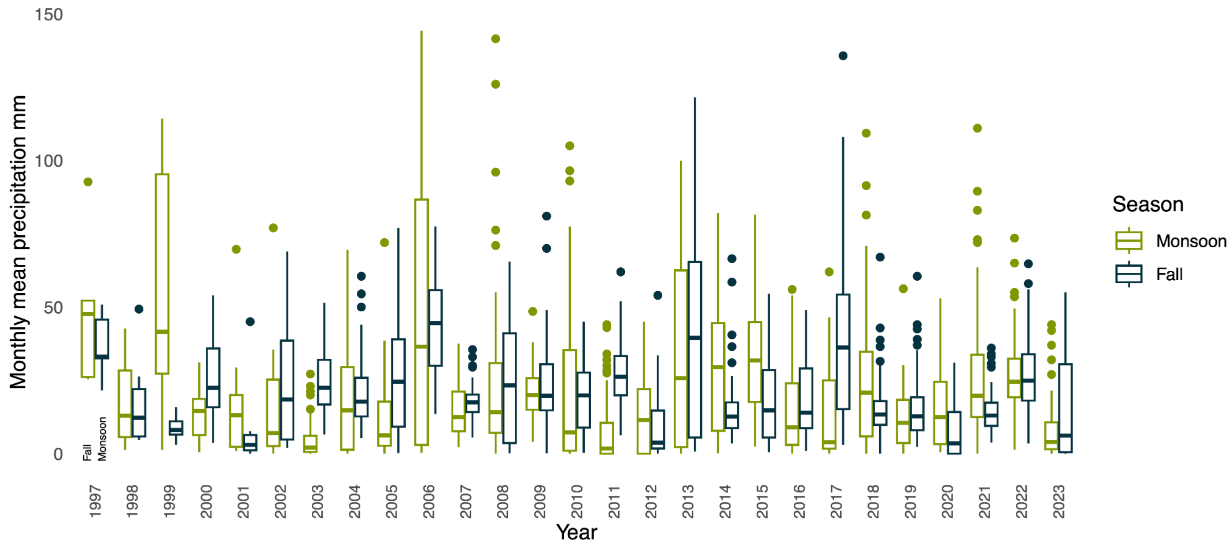

Figure 5.2 Boxplot of precipitation divided into the monsoon season (June - August) and fall storms (September-October). The number of sites has increased over time, starting with 3 sites in 1997 and reaching a maximum of 34 sites by 2018 and then dropping to 32 by 2023.

Long term precipitation trends

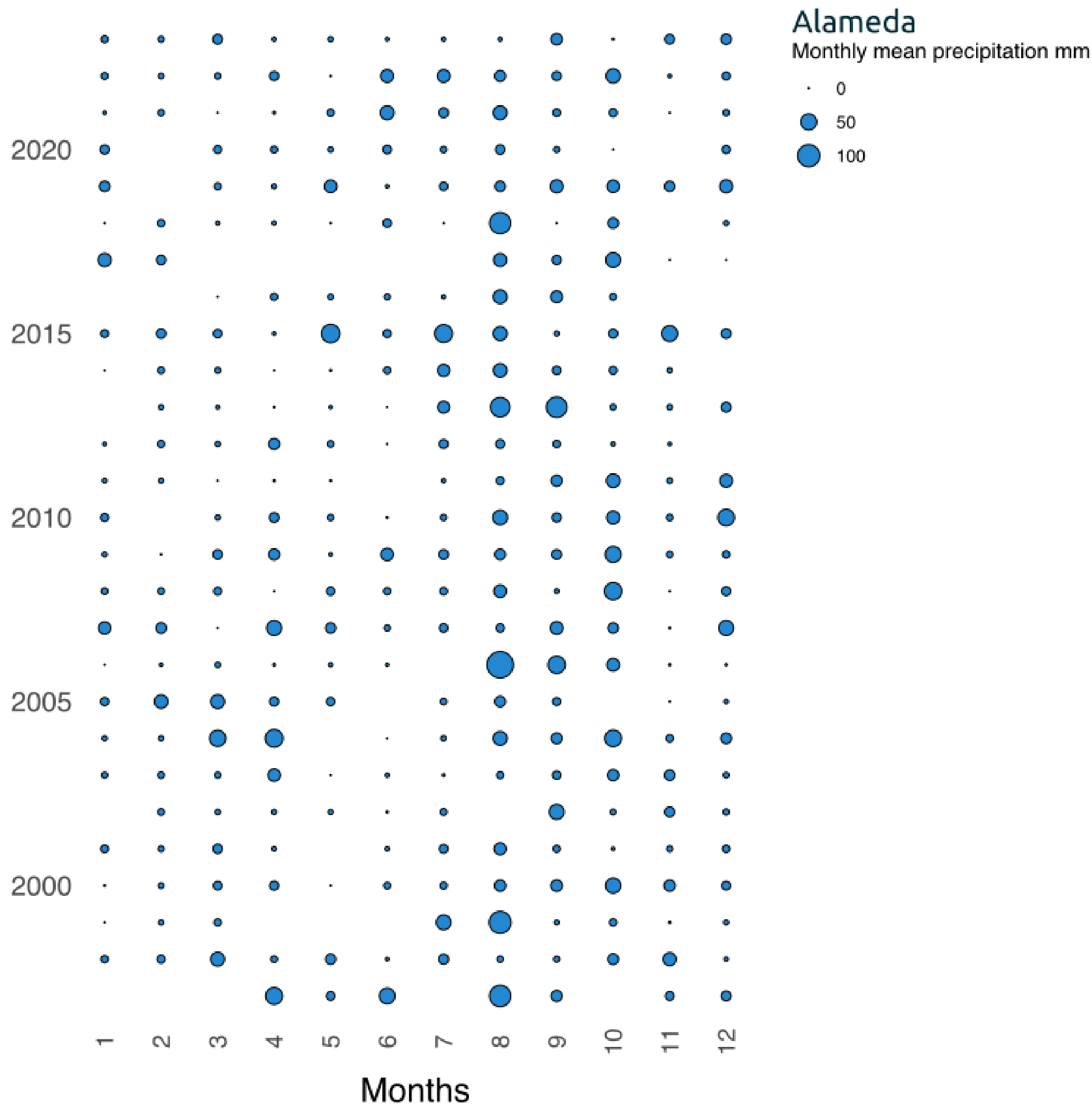

Figure 5.3 Mean monthly precipitation at Alameda from 1997 through 2023.

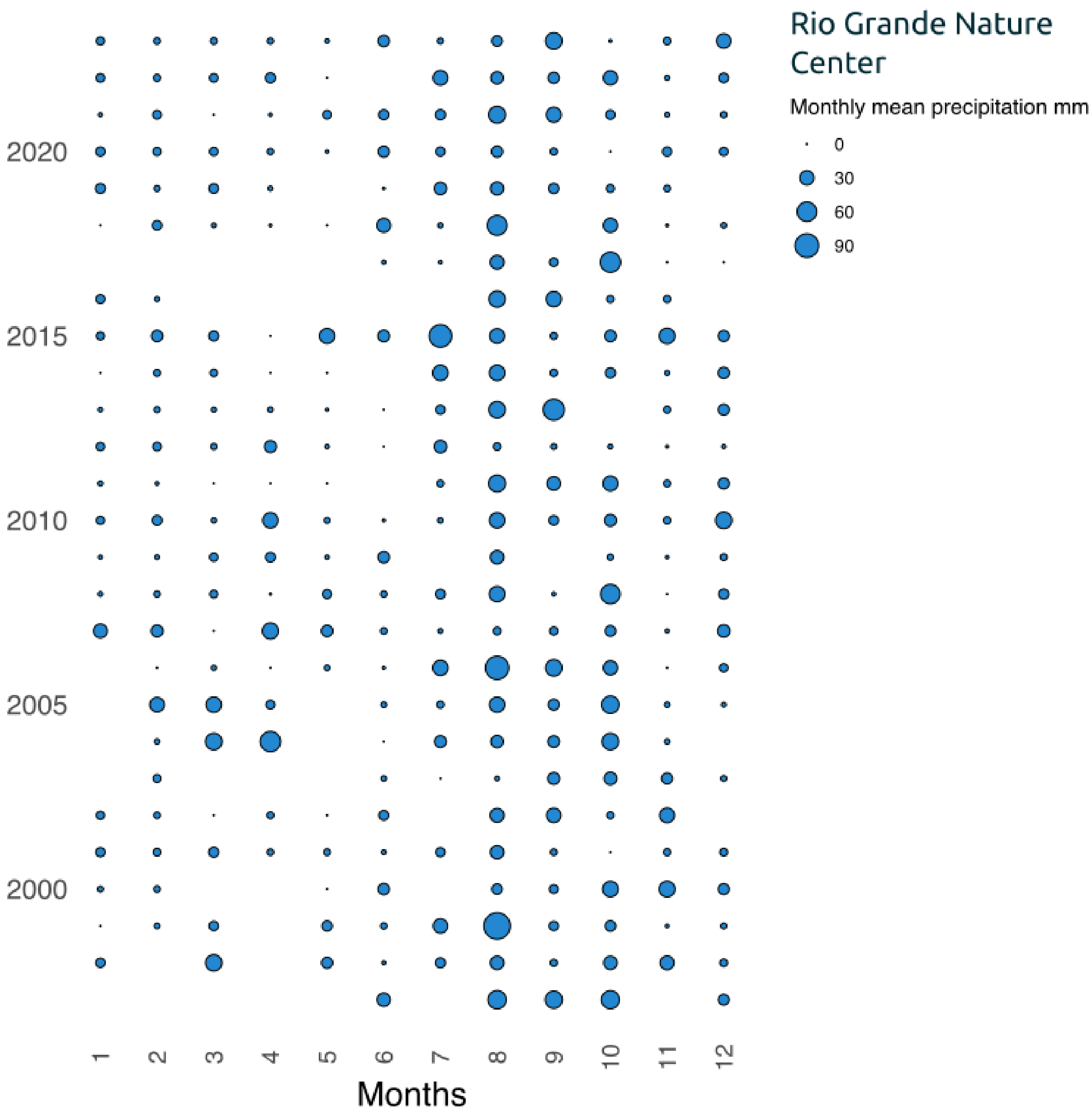

Figure 5.4 Mean monthly precipitation at RGNC from 1997 through 2023.

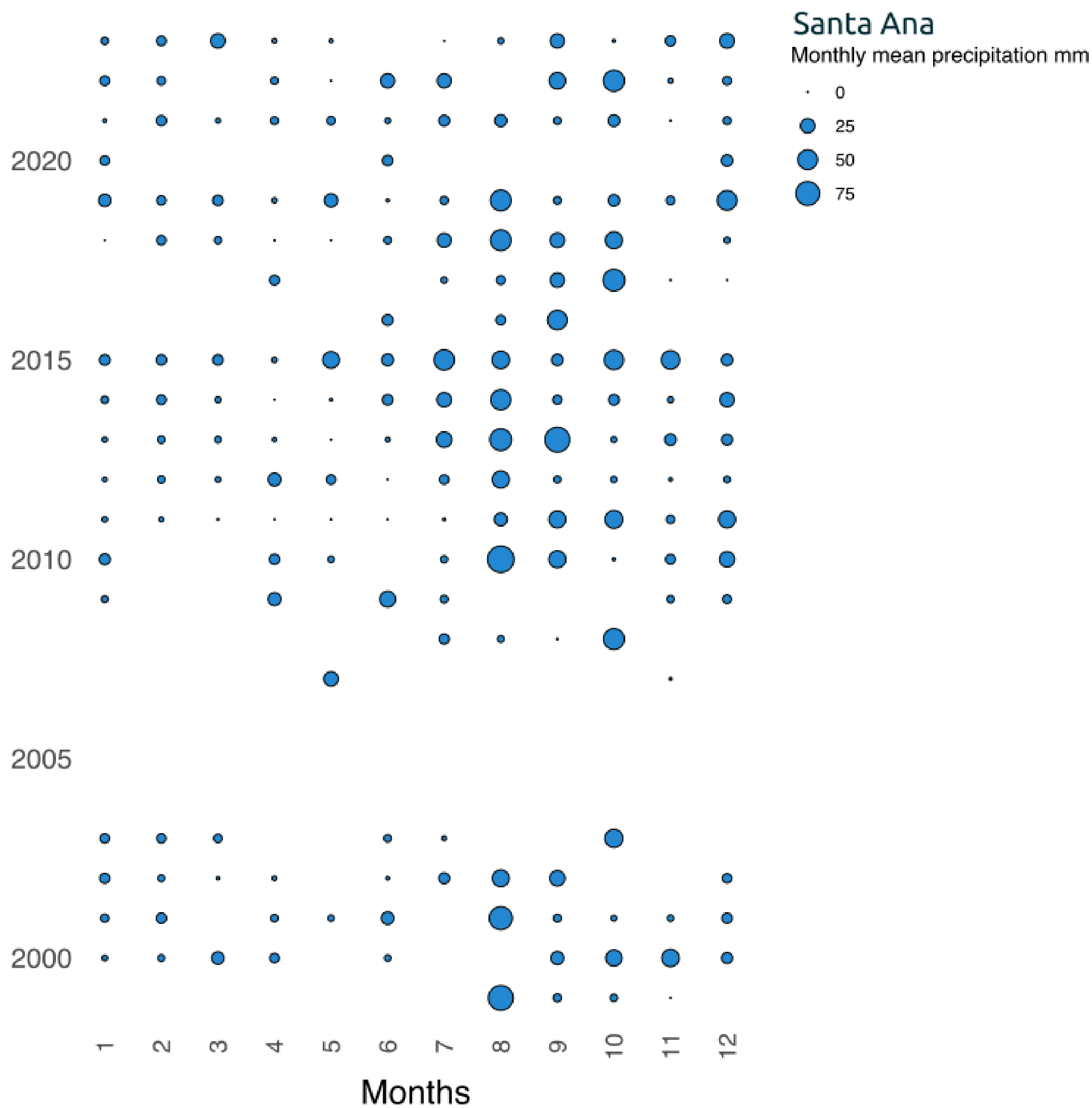

Figure 5.5 Mean monthly precipitation at Santa Ana from 1999 through 2023.

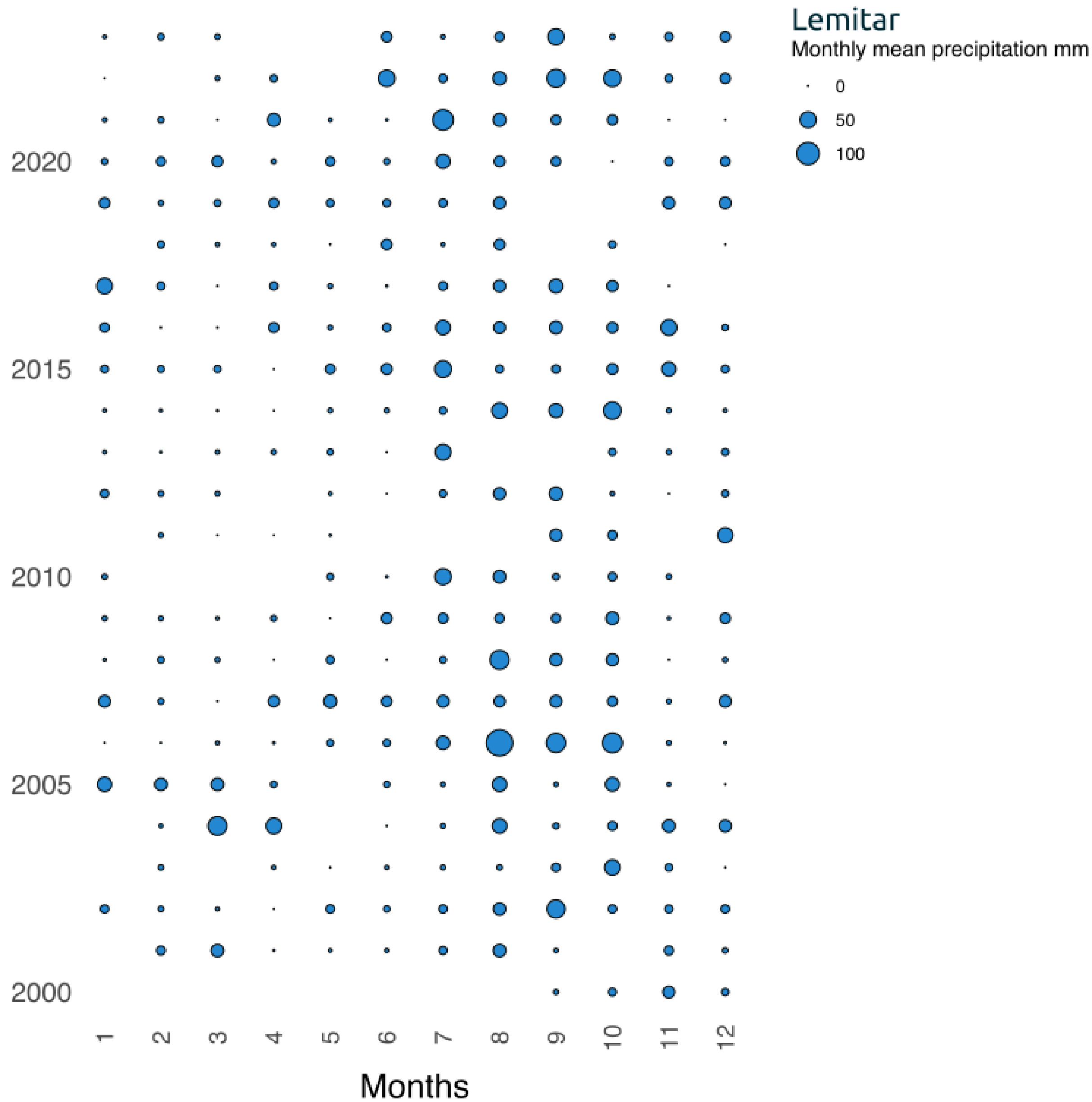

Figure 5.6 Mean monthly precipitation at Lemitar from 2000 through 2023.

While 2023 was a dry year, it is illustrative of the predicted shift towards greater precipitation events in the fall, after the historic monsoon season (mid-June to mid-September). Peak rainfall at most sites occurred in September. We compared monsoon season rains (typically defined as mid-June through September, but we used data from June-August) to fall rains (we used September and October rainfall). Even with the unevenness of having 3 months in the "monsoon" season and only two months in the "fall" season, we can see evidence of this potential shift of higher mean precipitation in fall, although it is not a strong shift in our data at this point. The reduction of snowpack runoff, earlier snowmelt, and later fall storms will likely have an impact on the germination and growth of many different native riparian plants.

6 Depth to groundwater

Depth to groundwater is monitored at all BEMP sites except the Pueblos of Santa Ana and Santo Domingo. Pueblo of Sandia groundwater data are proprietary and must be requested through the Pueblo's Department of Natural Resources. Each month, BEMP staff along with UNM interns, K-12 students, and teachers monitor the five groundwater wells at BEMP sites. The nearby ditch/drain is also monitored and USGS river flow data are downloaded based on the monitoring day from the closest gauge to the north of each site.

Full monitoring methods can be found at:
https://github.com/BEMPscience/bemp_data/tree/master/depth_to_groundwater_data

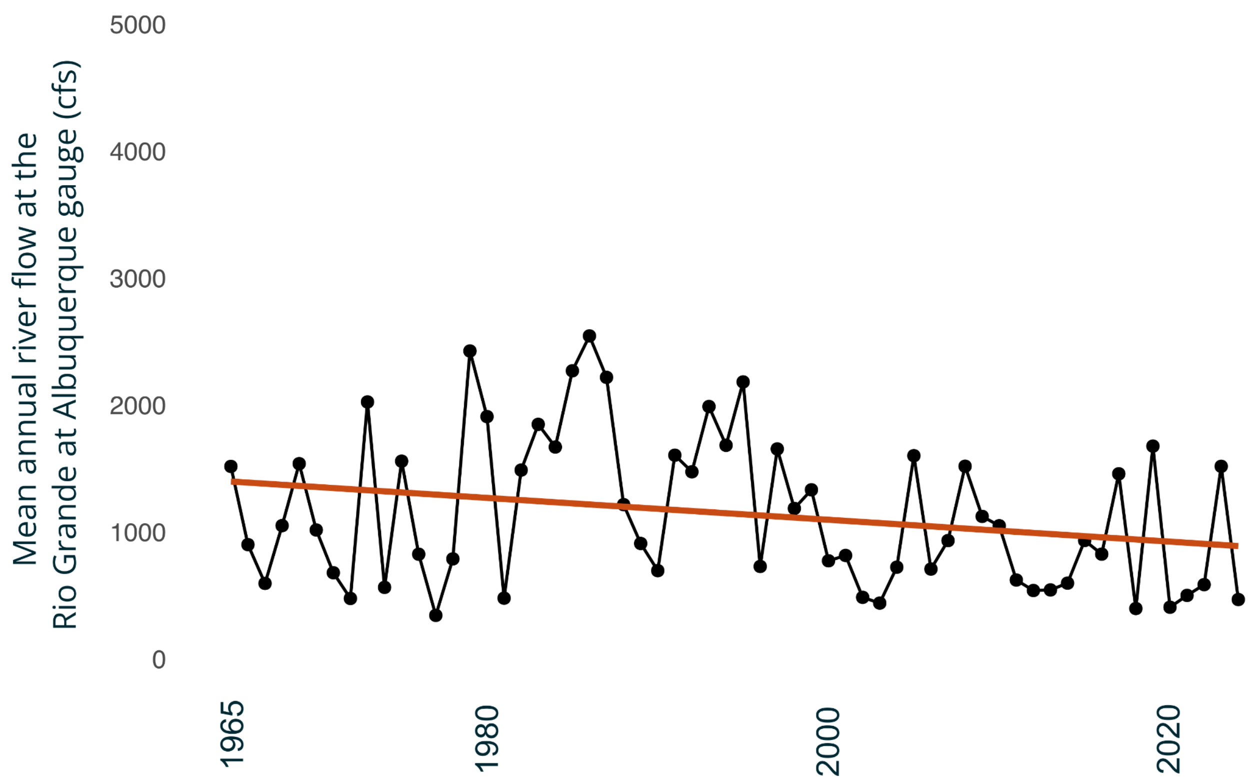

Figure 6.1 Mean annual river flow at the Albuquerque gauge over time. It is important to note that the Albuquerque gauge is located below Cochiti Dam which has regulated flows to the Rio Grande south of the dam since 1975. Prior to Cochiti Dam's construction, it was not unusual to see flows in the Rio Grande through Albuquerque peaking at or above 10 kcfs.

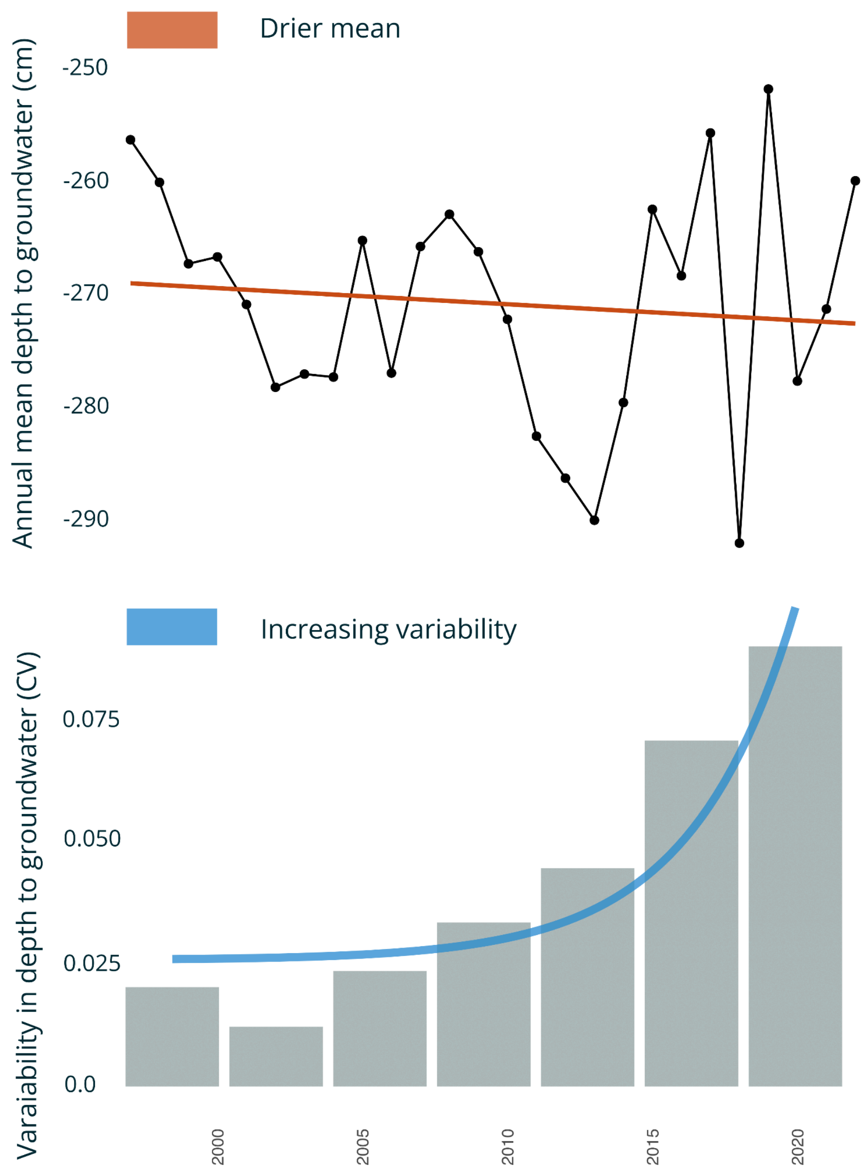

Figure 6.2 Figures showing the annual mean depth to groundwater and variability in depth to groundwater for the Alameda site.

The rapid changes in the mean and variance brought on by human-caused climate change may drive ecosystems into transition (riparian to semi-arid or arid). Climate change can cause more variability in snowpack between years, on top of overall declines in snowpack, leading to variability in river flow levels. Not all sites are impacted equally by this variability. For example, in response to high river flow, aggradation in some areas of the river can increase the likelihood of overbank flooding. Flooding can also lead to the Rio Grande flowing in sub-channels, increasing the proximity of some areas of the bosque to the river and thus decreasing depth to groundwater more drastically. Soil profiles can also change the permeability of the soil, causing varying responses to changes in river flow.

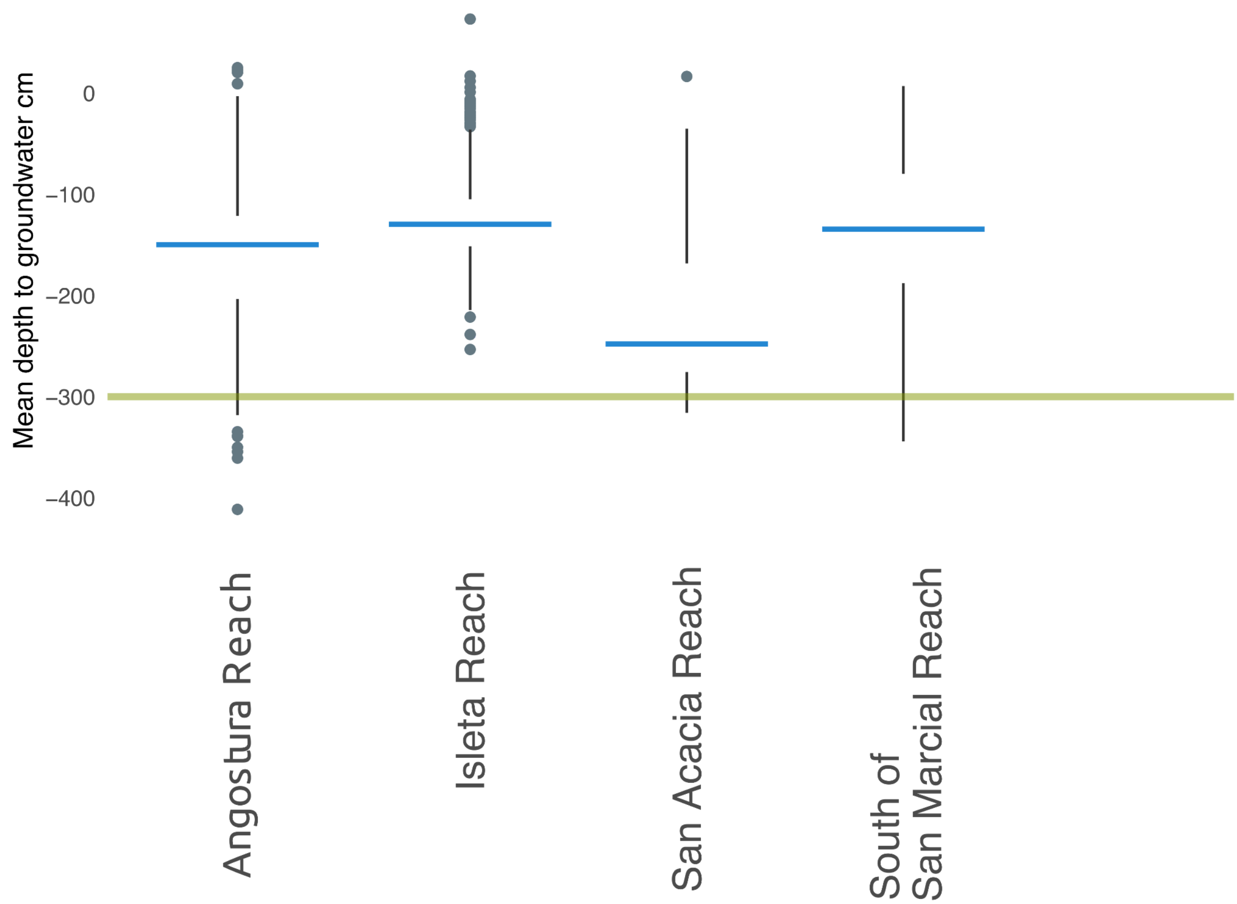

Figure 6.3 Mean depth to groundwater (cm) of BEMP sites with ten or more years of data organized by reaches of the Middle Rio Grande. Reaches are arranged north to south from left to right.

Angostura reach includes all sites within Albuquerque plus Sandia Pueblo; scouring due to proximity to Cochiti Dam as well as topography causes the riverbed in this reach to be the most degraded. The riverbed starts aggrading in lower Albuquerque and is more aggraded in the southern reaches. San Acacia is the most aggraded and experiences regular overbank flooding but also experiences longer periods of river drying. This, in addition to the placement of one

BEMP site (Lemitar) outside the levee, leads to the San Acacia Reach having the lowest mean monthly mean depth to groundwater. There is also greater variability in mean monthly mean depth to groundwater in the southern reaches than the Angostura Reach. This could be due to supplemental flows in the Angostura Reach preventing regular river drying, as groundwater levels are tightly correlated with river flow; although, 2022 and 2023 saw unusual summer drying in this reach.

Figure 6.5 Spark line plot of the mean monthly depth to groundwater across all BEMP sites. Time from 1997 to 2023 runs across the x-axis and the y-axis is depth to groundwater in cm. Sites are arranged from north to south by center point latitude.

Angostura Reach

The Angostura Reach comprises 19 sites. From north to south they are Santa Ana Pueblo, Sandia Pueblo, Bobcat, Badger, Minnow, Diversion, Calabacillas, Alameda, Montano, Savannah, Rio Grande Nature Center, Route 66, BioPark, Hispanic Cultural Center, Albuquerque Overbank Project, Harrison, San Jose, Valle de Oro NWR, and State Land Office. Groundwater data are not collected at Santa Ana. Groundwater data from Sandia Pueblo must be requested through the Pueblo's Natural Resources Department.

Isleta Reach

The Isleta reach comprises eight sites: Bosque Farms, Los Lunas, Reynolds Forest, Reynolds Cleared, Valencia Cleared, Belen, Valencia Forest, and Crawford. Similar groundwater fluctuations are exhibited by all sites throughout the Isleta reach, with peaks reflecting spikes in groundwater corresponding to recent flood events (2023, 2019, 2017) behaving more or less the same at all these sites. Los Lunas, which sees much higher peaks during recent flood events, is the sole exception. This is due to the site's positioning between the main river channel and a trough or flowing channel that fills during high flow events.

San Acacia and South of San Marcial Reaches

There are four BEMP sites that lie in the San Acacia Reach. These are Sevilleta, Lemitar, Bosque Del Apache, and River Realignment. The mean for this reach is the lowest of all the reaches, although this is skewed by the Lemitar site that is outside the levee system. As a result, Lemitar is less influenced by the river flow and there is a lower overall depth to groundwater and lower variability. As we go further south we get to an aggraded area of the Rio Grande that has many drying events as well as extreme flooding. This is shown by the variability in groundwater depth at the Bosque del Apache site in Figure 6.5.

Changes in mean and variance of depth groundwater in the shallow riparian aquifer.

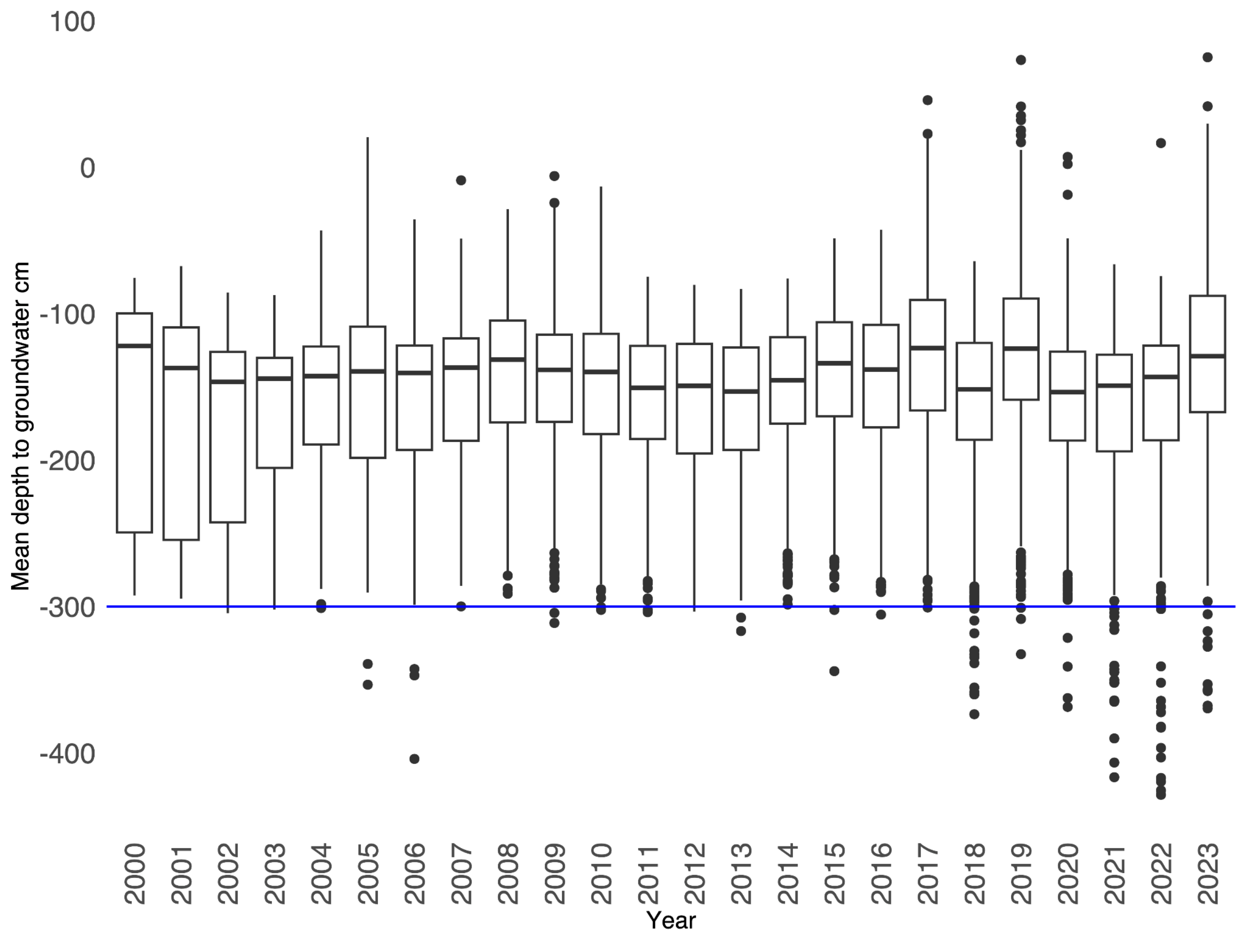

Figure 6.6 Boxplot of the mean monthly depth to groundwater across all BEMP sites from 2000 to 2023. The solid blue line is at 300 cm to show the threshold for established cottonwood trees. The black dots show the increasing number of outliers, especially toward drying events or declining groundwater. The flood events corresponding to high river flows in recent years (2017, 2019, and 2023) also have months with extremely low groundwater levels.

7 Litterfall and Vegetation Cover

Litterfall is any plant material that falls to the ground. BEMP litterfall data are categorized into leaves, reproductive parts, and wood from dominant tree species. It is collected monthly and then dried for 48 hours before being sorted and weighed. Litterfall is used to gauge plant productivity (leaves), reproductive effort (buds, flowers, seeds), and stress or senescence (wood).

Full monitoring methods can be found at:
https://github.com/BEMPscience/bemp_data/tree/master/leaf_litterfall

Vegetation cover surveys are conducted in August-September each year by a team of botanists and BEMP staff. Line intercept methods are used to monitor plant species along ten 30 meter transects at each of 27 sites. Herbarium work (identification of species) has been completed for 2023 data, which were entered, checked, and are being QA/QCed. Preliminary data through 2023 are included in this report.

Full monitoring methods can be found at:

https://github.com/BEMPscience/bemp_data/tree/master/additional_data_sets/vegetation_surveys/methods

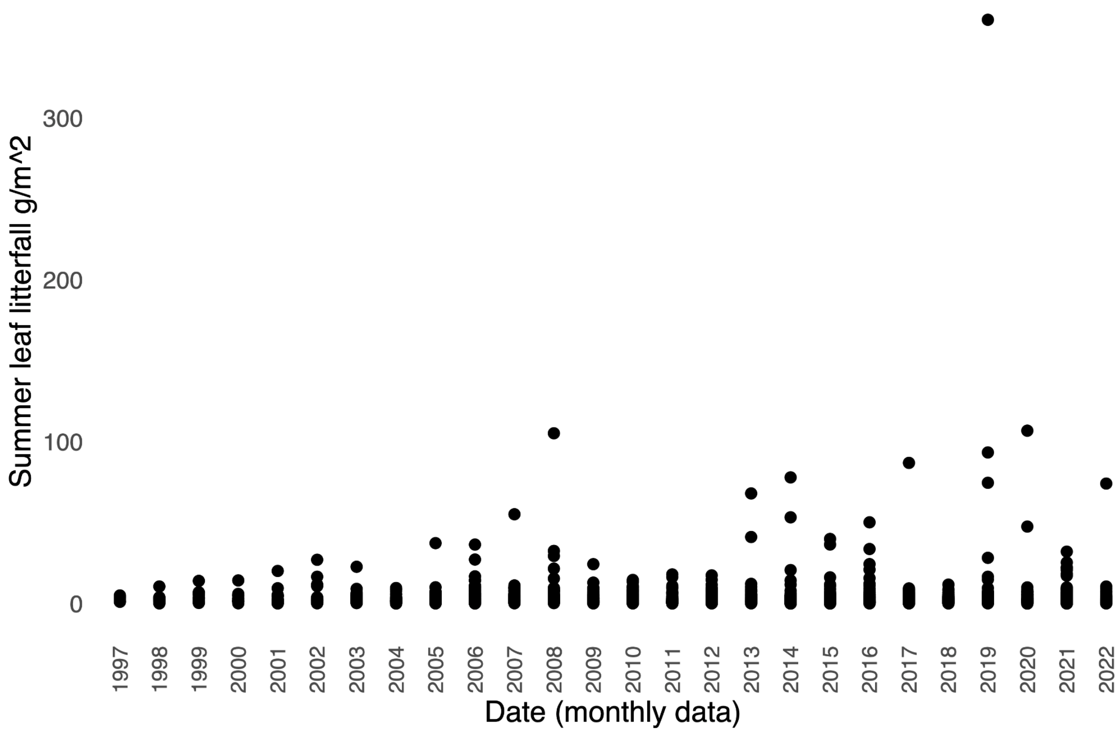

Figure 7.1 Change in leaf fall (g/m^2) during summer months, or "green fall", represents early leaf drop due to stress (e.g., heat, drought, defoliator outbreak, physical force from storms).

Most leaf fall biomass at BEMP sites is composed of cottonwood leaves. The shift toward increasing summer leaf drop most likely represents increasing stress on cottonwoods, although saltcedar early leaf drop due to defoliation from the tamarisk leaf beetle is a contributor to these numbers. Increasing outliers for higher leaf drop during flood years could also be due to the impact of long inundation periods (and potential anoxia) following years without.

Monthly litterfall of select plants.

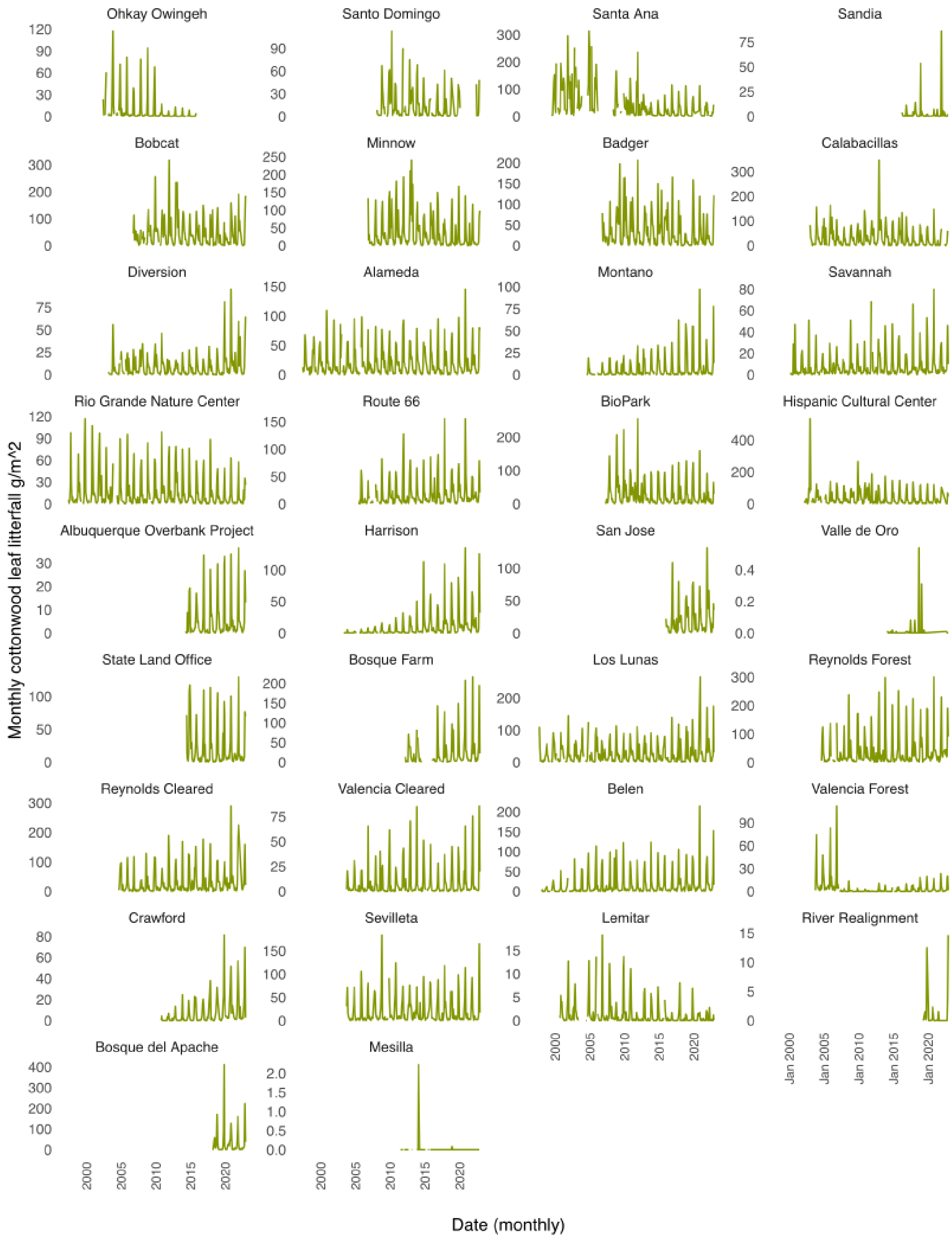

Figure 7.2 Monthly cottonwood leaf fall (g/m^2) shown across years for each site (listed north to south).

Annual litterfall trends

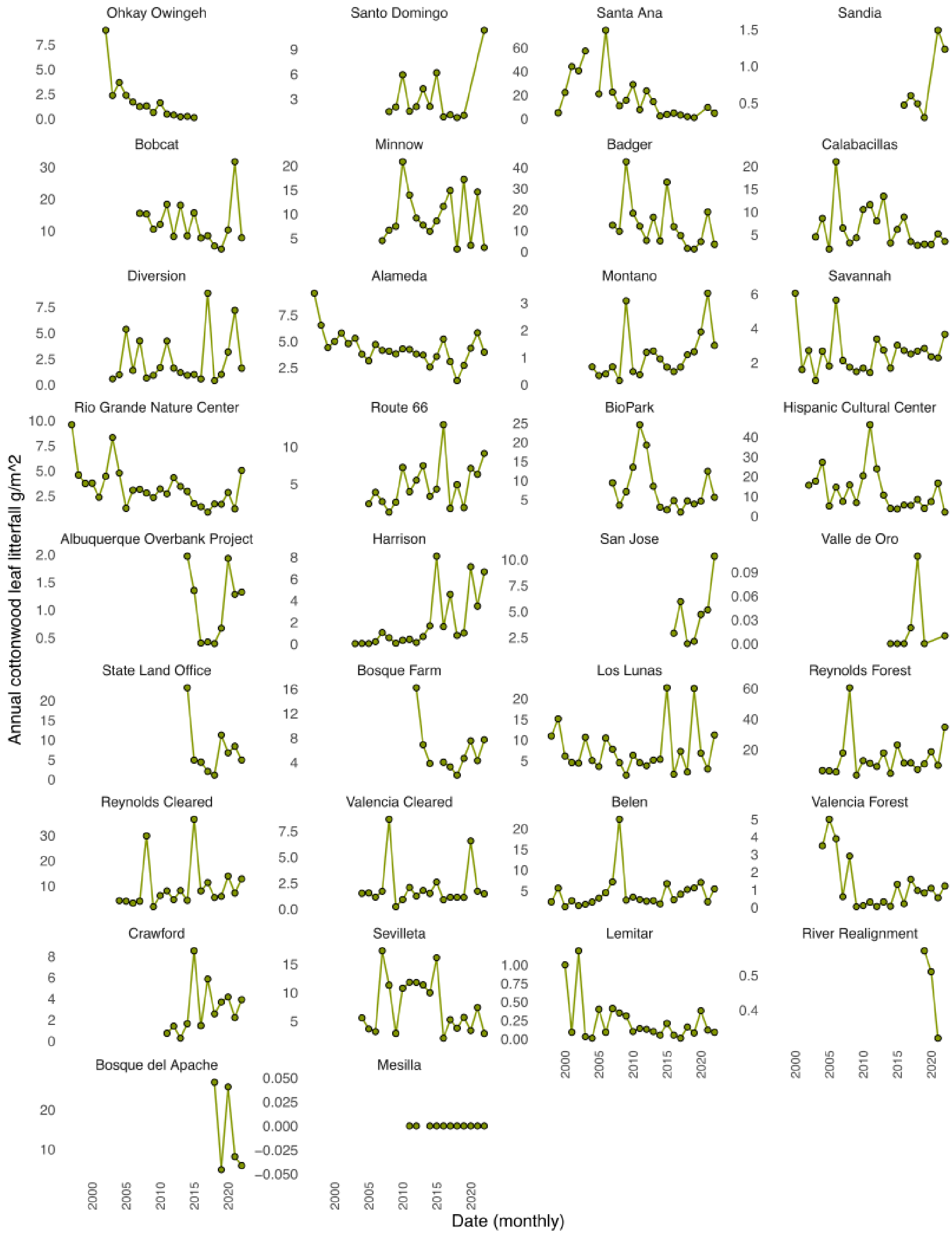

Figure 7.3 Annual sum of cottonwood leaf fall (g/m^2) across years for each site (listed north to south).

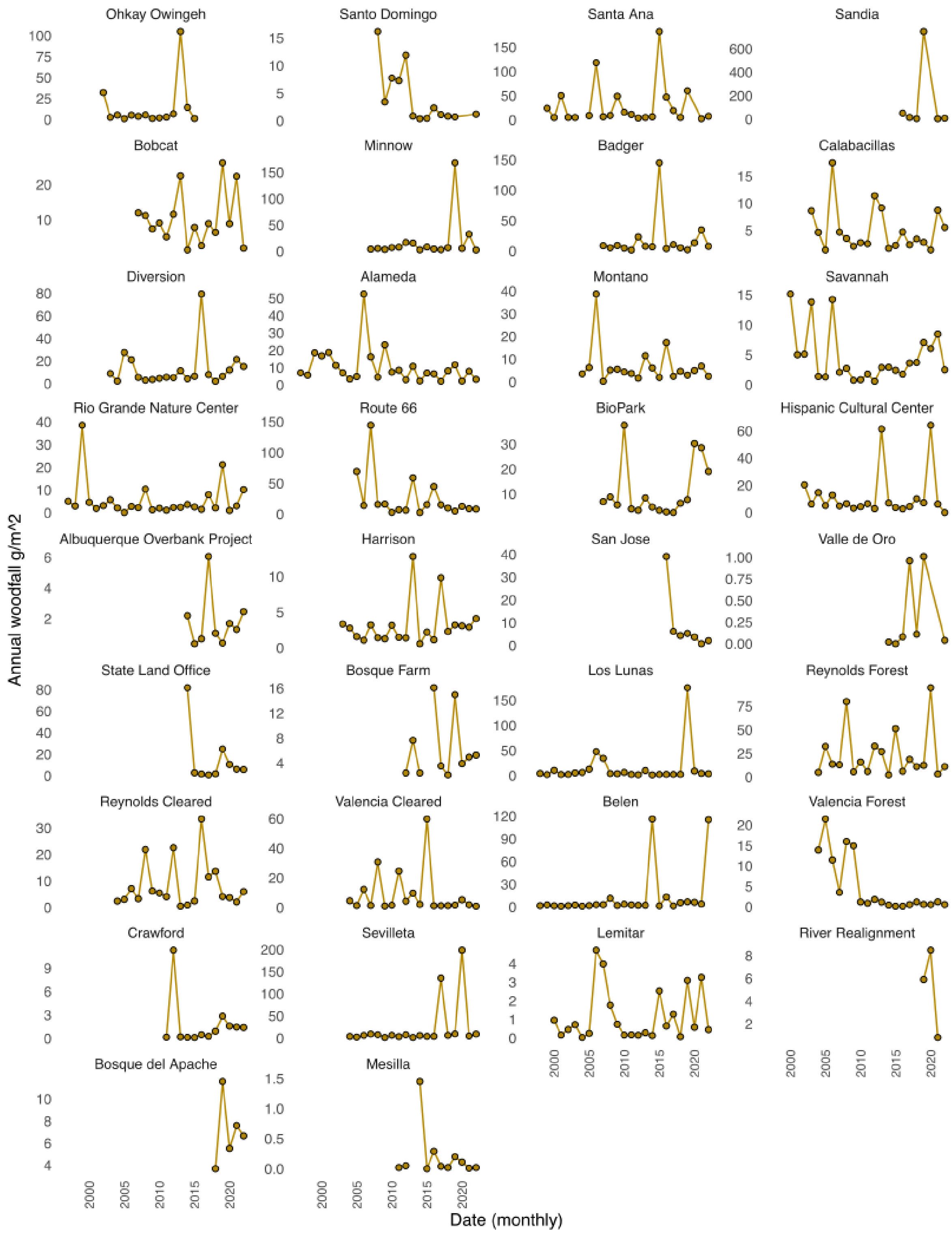

Figure 7.4 Annual sum of wood fall (g/m^2) across years for each site (listed north to south).

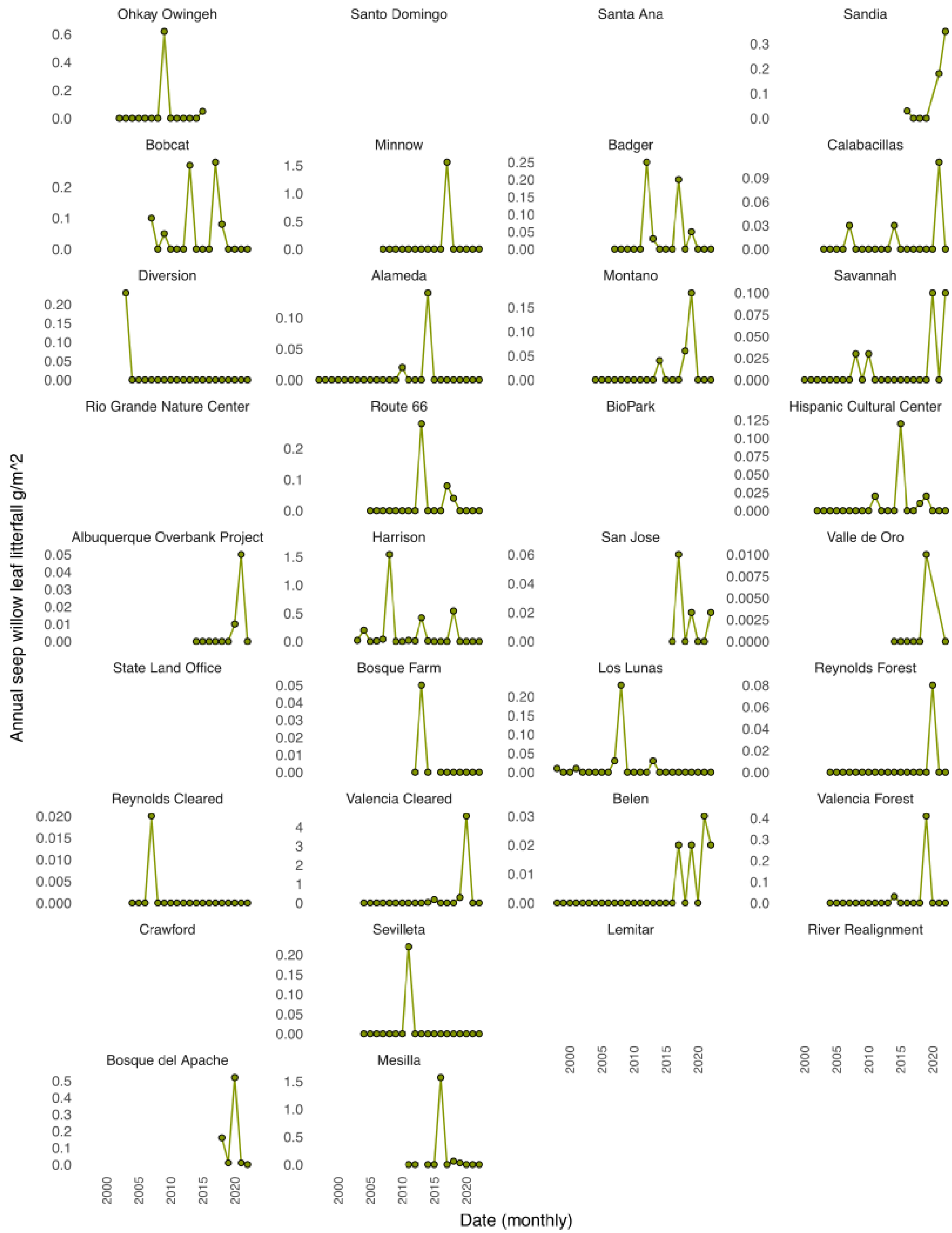

Figure 7.5 Annual sum of seepwillow (*Baccharis*) leaf fall (g/m^2) across years for each site (listed north to south). Y-axis is on a free-scale to better show data at individual sites.

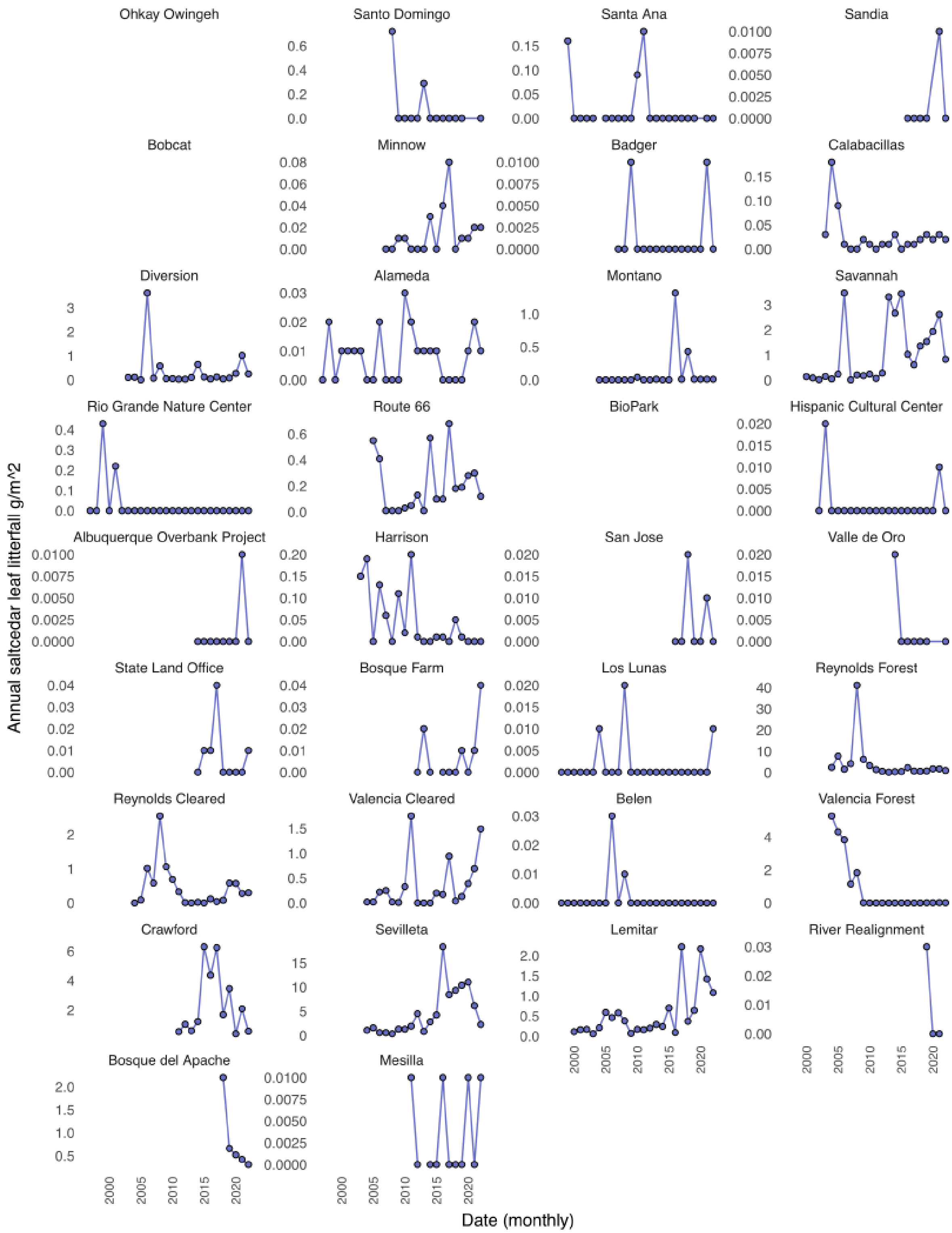

Figure 7.6 Annual sum of saltcedar leaf fall (g/m^2) across years for each site (listed north to south). Y-axis is on a free-scale to better show data at individual sites.

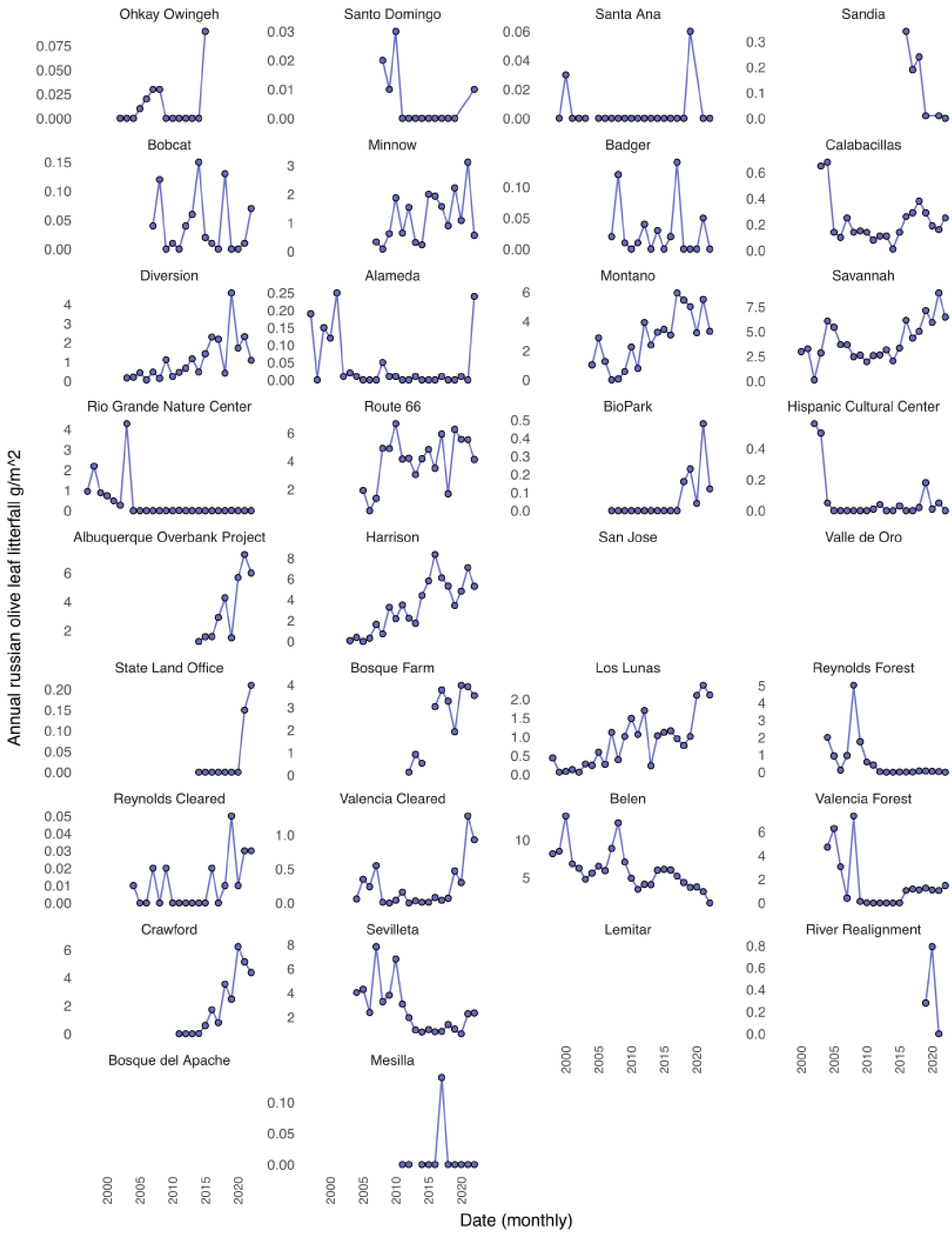

Figure 7.7 Annual sum of Russian olive leaf fall (g/m^2) across years for each site (listed north to south). Y-axis is on a free-scale to better show data at individual sites.

Annual vegetation cover

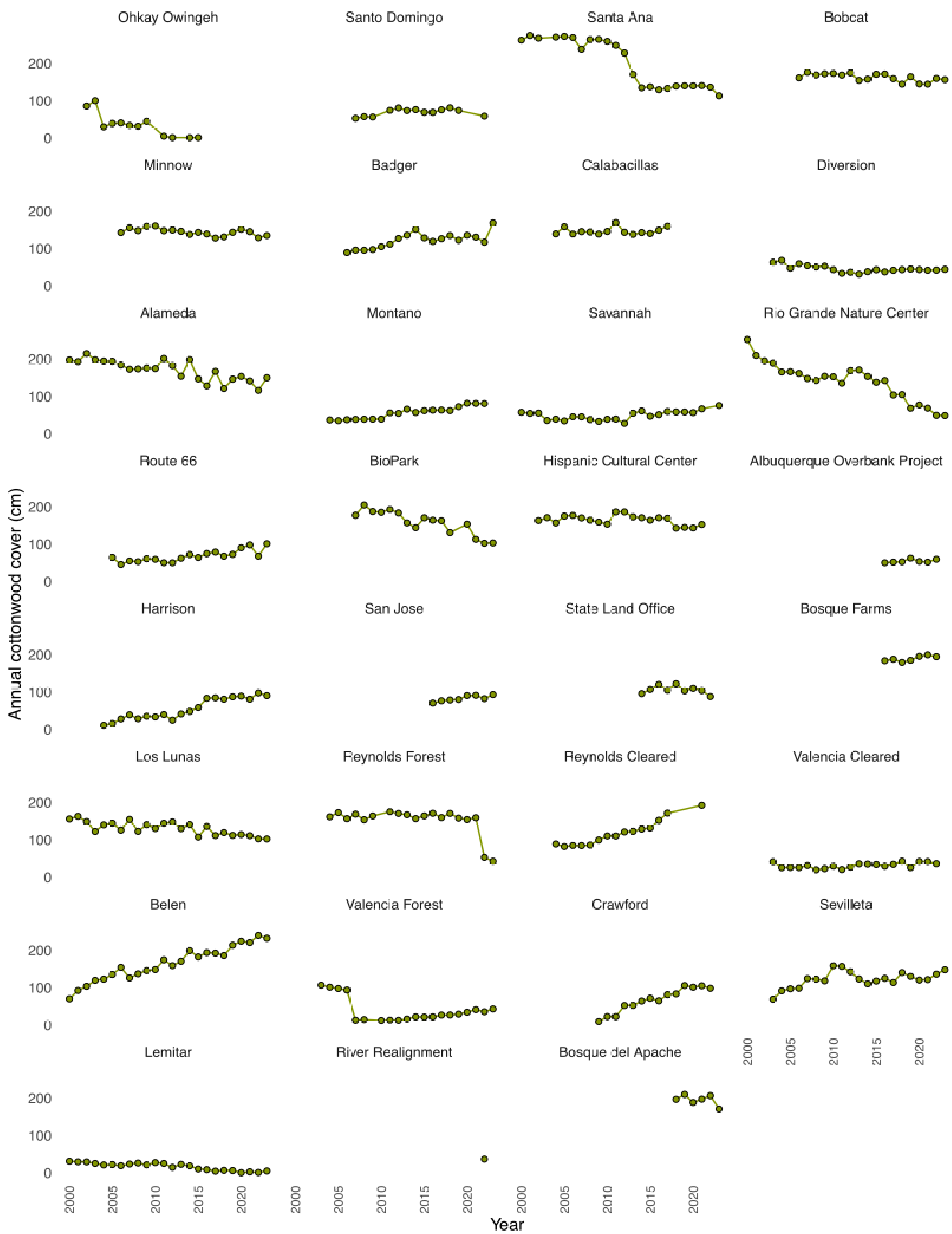

Figure 7.8 Annual cottonwood tree cover across BEMP sites. Sites are ordered from north to south. Typically sites north of I25/I40 have declining cover due to lower groundwater levels.

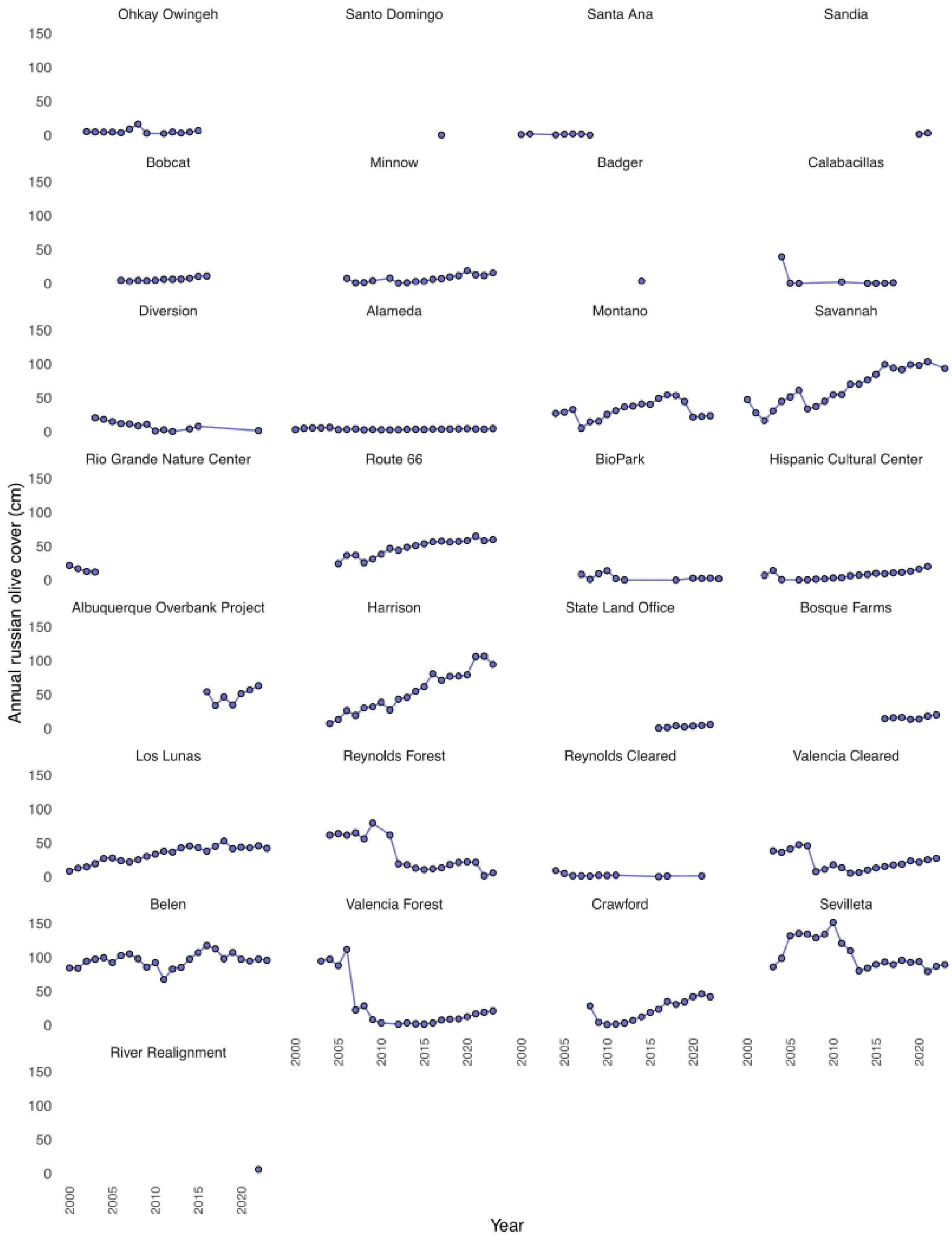

Figure 7.9 Annual Russian olive tree cover across BEMP sites. Sites are ordered from north to south. Russian olive cover continues to increase over time; however, the impact of exotic removal efforts show up as sharp decreases in cover.

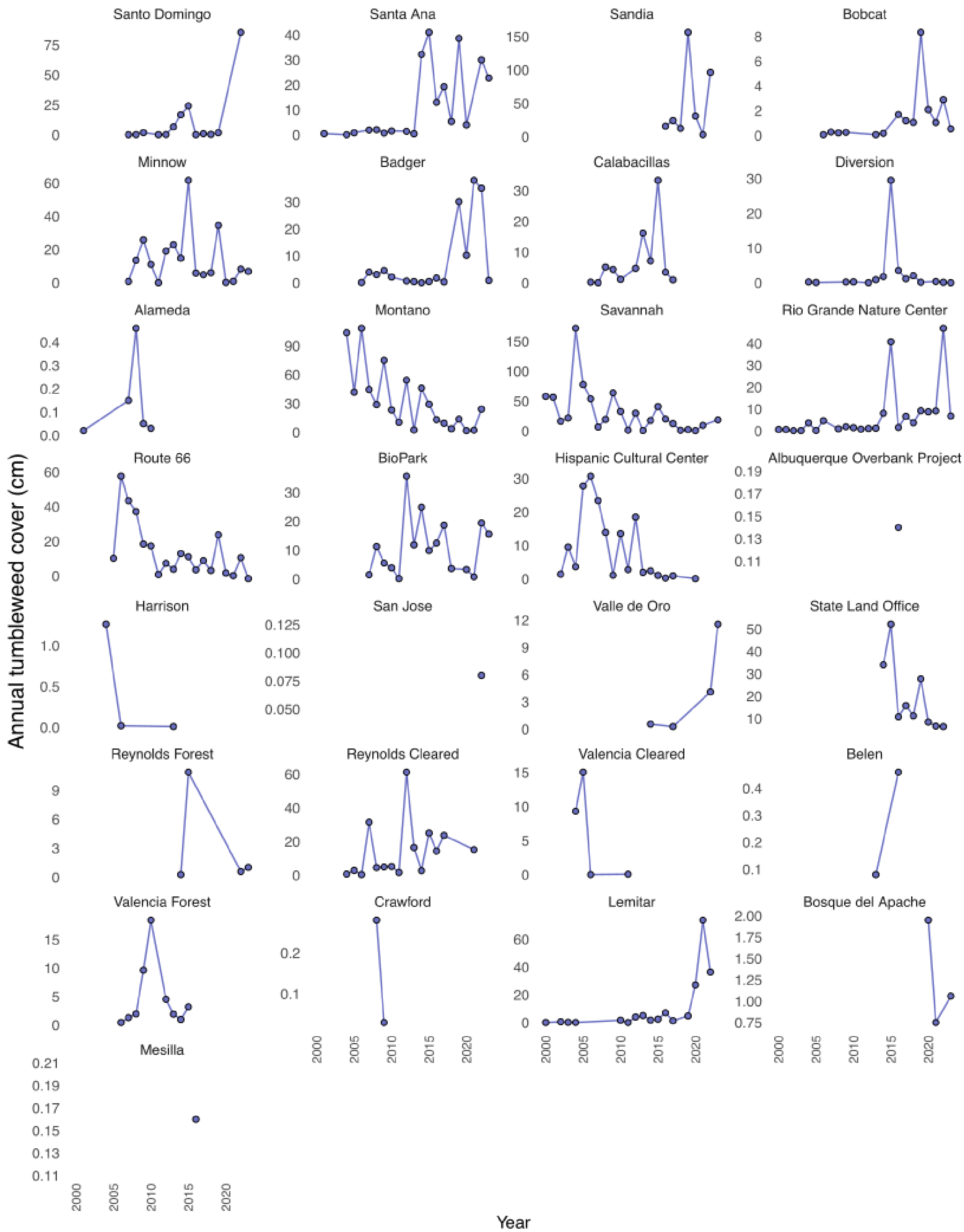

Figure 7.10 Annual tumbleweed cover across all BEMP sites. Tumbleweed cover varies quite a bit due to the interactions of exotic removal efforts, fire, and flooding.

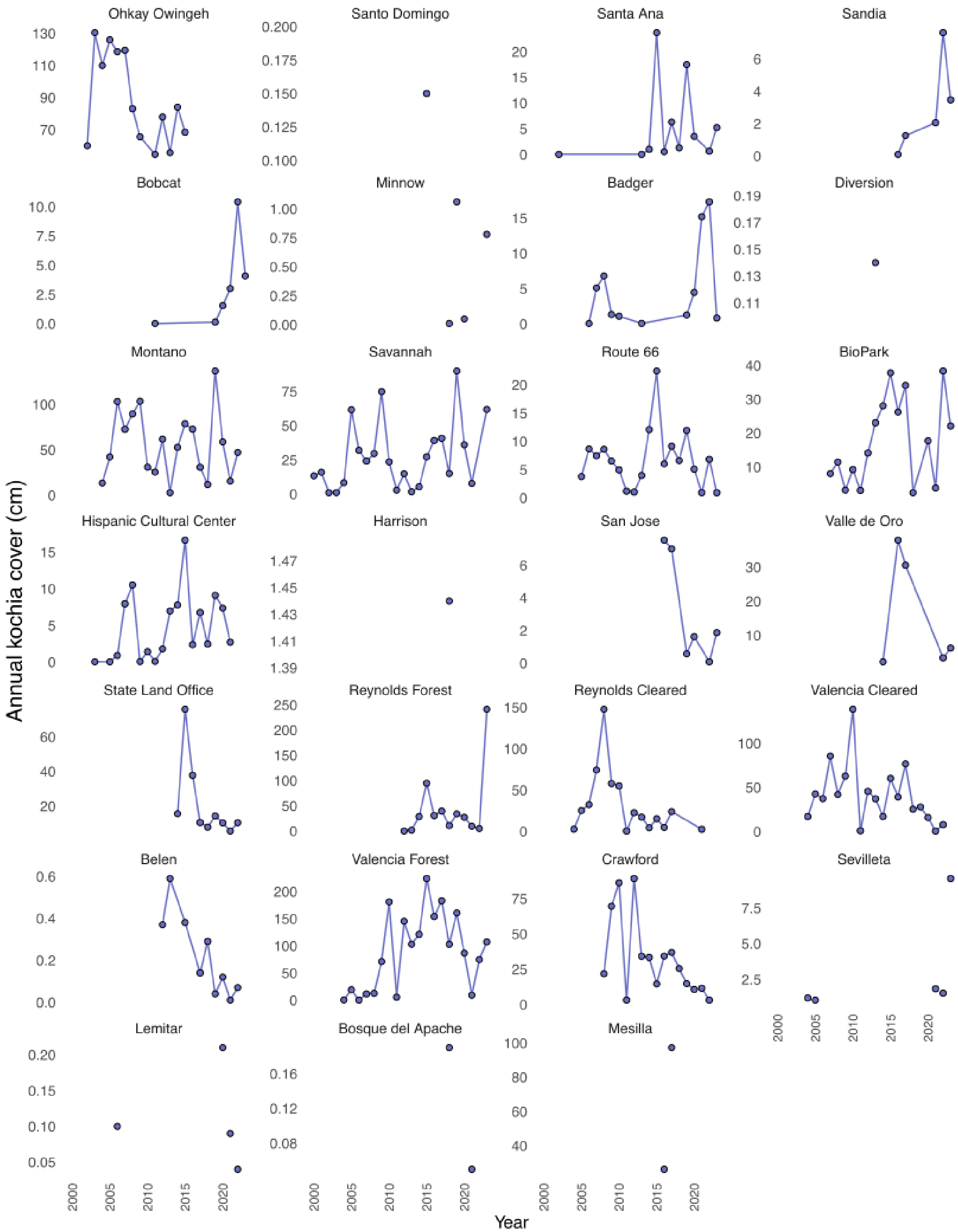

Figure 7.11 Annual kochia cover across all BEMP sites. Kochia cover is highly variable (similar to tumbleweed) due to the interactions of exotic removal efforts, fire, and flooding. In many places kochia is still persistent despite efforts to remove it but its cover relative to other plants is reduced.

Sites with higher groundwater are great for both bank-lowering and pole-planting projects or represent areas where bank-lowering or swales have been incorporated. These sites more often support younger trees and show increasing cottonwood cover. Sites with greater depths to groundwater or perched sites have little to no cottonwood recruitment and cover is decreasing over time. The sharp drop in cottonwood cover at Santa Ana starting in 2009 was part of a larger, expanding die-off of the bosque in that area. With the decrease in cottonwood cover (now 57% reduced from what it was in 2000) opening the canopy, squirrel grass, tumbleweed, and kochia started to increase in cover starting in 2011. The sharp decline in cottonwood cover at Valencia Forest in 2007 and at Reynolds Forest in 2022 were both due to fires in the Belen area. At both sites, this led to an increase in kochia and tumbleweed. Some sites have a slow, steady decline (Bobcat, Minnow, Los Lunas, Lemitar); others have a decline with small yet sharp drops due to localized fires (Ohkay Owingeh, BioPark, HCC). Alameda and Rio Grande Nature Center (RGNC) have more noticeable downward trends that are due to the dying cottonwood branches and trees at these sites. The cottonwood cover has declined by 25% at Alameda and by 80% at RGNC since the surveys done in 2000. As a non-flood site, the encroaching vegetation at RGNC is a mix of upland vegetation and invasive exotics, mostly tumbleweed. Tumbleweed has increased by over 800% at RGNC in the last 10 years. These downward trends in cottonwoods are also seen in the litterfall data, though leaf fall is more sporadic, as tree productivity responds more quickly to environmental changes. The spikes in wood fall also underline the cottonwood senescence at sites but are less indicative than cover as branches must actually fall into one of ten 40-cm diameter tubs at each site. Changes in fuel load will also be indicative of cottonwood health.

Seepwillow (*Baccharis* spp., also known as false willow or mule fat) is an important native understory shrub that has declined in this ecosystem. Seepwillow leaf fall is low compared to other species and the occasional peaks in leaf fall are still relatively small, representing leaves falling into tubs that are not always captured each year. Sites with steady seepwillow productivity levels include San Jose, a USACE-requested site with created swales that still successfully flood during higher river flows. San Jose has low saltcedar productivity, no Russian olive, and slowly increasing cottonwoods and coyote willows. Kochia and tumbleweed were only high immediately following swale construction and have remained low since then.

Exotic species such as saltcedar and Russian olive show a sporadic increase in productivity at many sites over time, with drops in productivity following targeted exotic removal projects. Russian olive cover is increasing at different rates across most sites, with drops due to management practices. Saltcedar is more sporadic than Russian olive, due to both mechanical removal and the changing outbreak cycle of the tamarisk leaf beetle. Some sites show gradual declines, like Russian olive at Belen and Sevilleta, where old growth stands are slowly dying back, or saltcedar at Crawford, which is being outcompeted by cottonwood after new establishment and repeated flooding.

Post burn assessment

Exotic recovery is particularly apparent at sites where treatment has not occurred (e.g., sites around the San Juan Chama Diversion Project Dam were cleared in 2004). Both Russian olive and saltcedar are slowly increasing. Sites with high TLB abundance show saltcedar recovery in years following TLB outbreaks. Post-burn areas that experienced flooding show native understory recovery (Los Lunas, which had no tumbleweed or kochia) while post-burn areas that did not experience flooding have high cover of exotic tumbleweed and kochia (Sandia, Reynolds Forest, Valencia Forest) (Figures 7.10 & 7.11). Both kochia and tumbleweed went from extremely low cover to abundant following the 2007 fire at Valencia Forest (Figures 7.10 & 7.11); while tumbleweed cover has been cyclic since then, kochia cover has remained relatively high (Figure 7.11). Yerba mansa has been declining in Los Lunas, but was recovering from the February 2023 fire by the time August vegetation surveys were completed. Reynolds Forest has a lower yerba mansa cover, but by August 2023, it had completely recovered from the April 2022 fire (Figure 7.12).

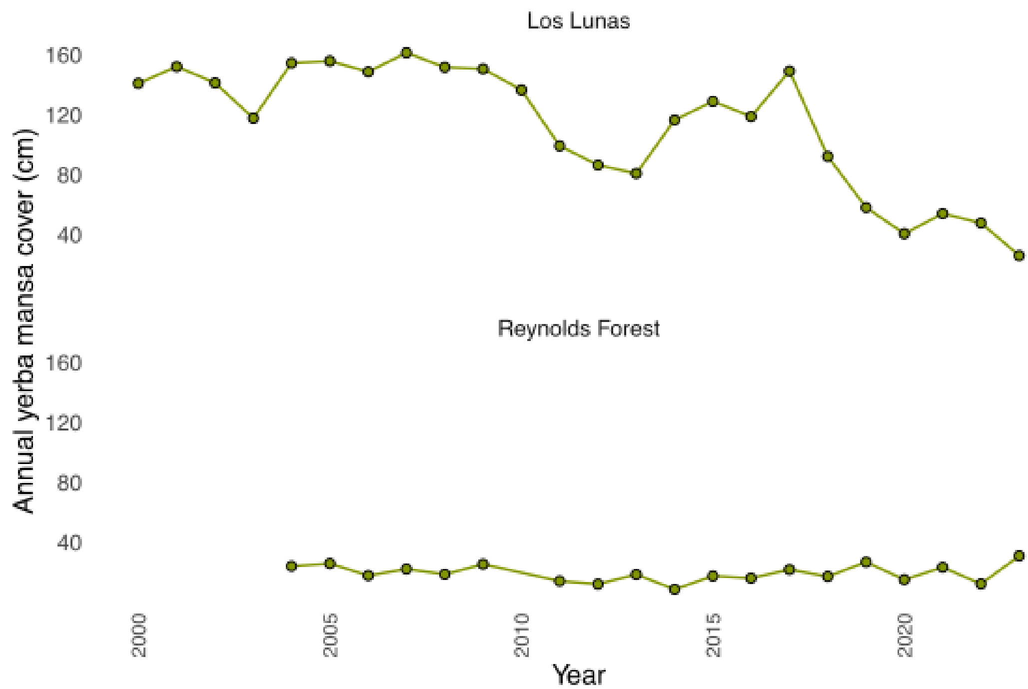

Figure 7.12 Annual yerba mansa cover at Los Lunas (partially burned in February 2023) and Reynolds Forest (severely burned in April 2022). Recovery happened quickly at both sites.

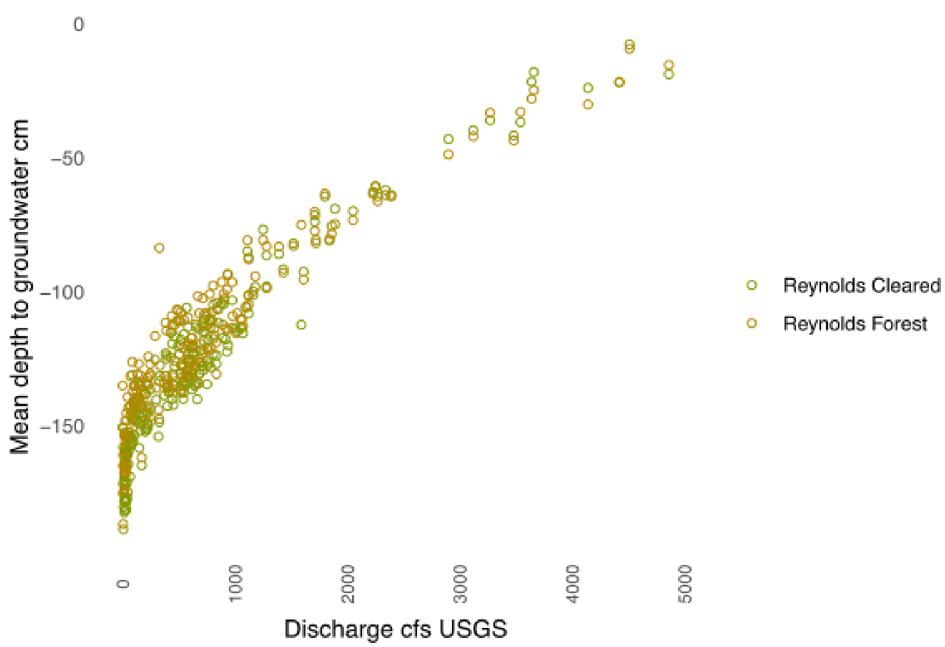

Figure 7.13 Mean depth to groundwater (cm) vs river flow (cfs) across years at Reynolds Cleared and Reynolds Forest. Groundwater levels are tightly correlated with river flow. Impacts of the Big Hole fire on groundwater can be assessed at the Reynolds Forest site.

Reynolds Forest BEMP site, May 17, 2022 (~1 month after the Big Hole fire); burned cavity from tree stump

Reynolds Forest BEMP site, May 17, 2022 (~1 month after the Big Hole fire)

Reynolds Forest BEMP site, May 17, 2022 (~1 month after the Big Hole fire); yerba mansa regrowth

Reynolds Forest BEMP site, June 22, 2022 (~2 months post fire); cottonwood resprouts in foreground, some golden currant resprouts, and thick kochia recruitment

Los Lunas BEMP site near center well, March 7, 2023, 1 week post-fire

UNM interns entering Los Lunas BEMP site, April 18, 2023, ~ 2 months post fire, floods starting

Los Lunas site, August 18, 2023, ~6 months post fire, 2 months post flood; yerba mansa regrowth

8 Surface-Active Arthropods

Surface active arthropods are monitored 3 times per year, in early May, late June, and early September through the use of pitfall traps. This report includes data through 2021. 2022 and 2023 arthropod samples are being processed, entered and checked. Full monitoring methods can be found at:
https://github.com/BEMPscience/bemp_data/tree/master/surface_active_arthropods

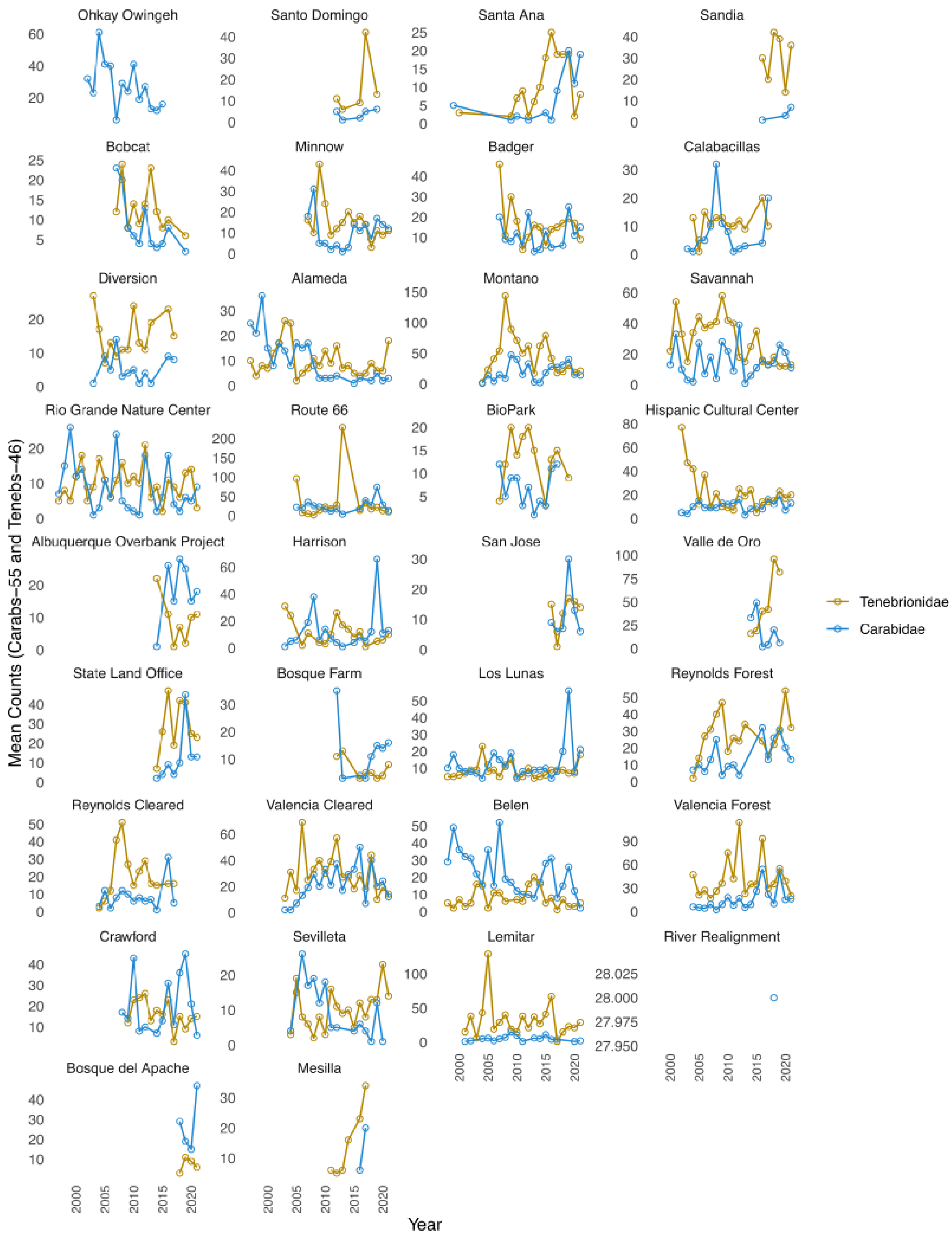

Figure 8.1 Annual mean darkling beetle (Tenebrionidae) and ground beetle (Carabidae) abundance across all sites.

Trends of surface active arthropods over time.

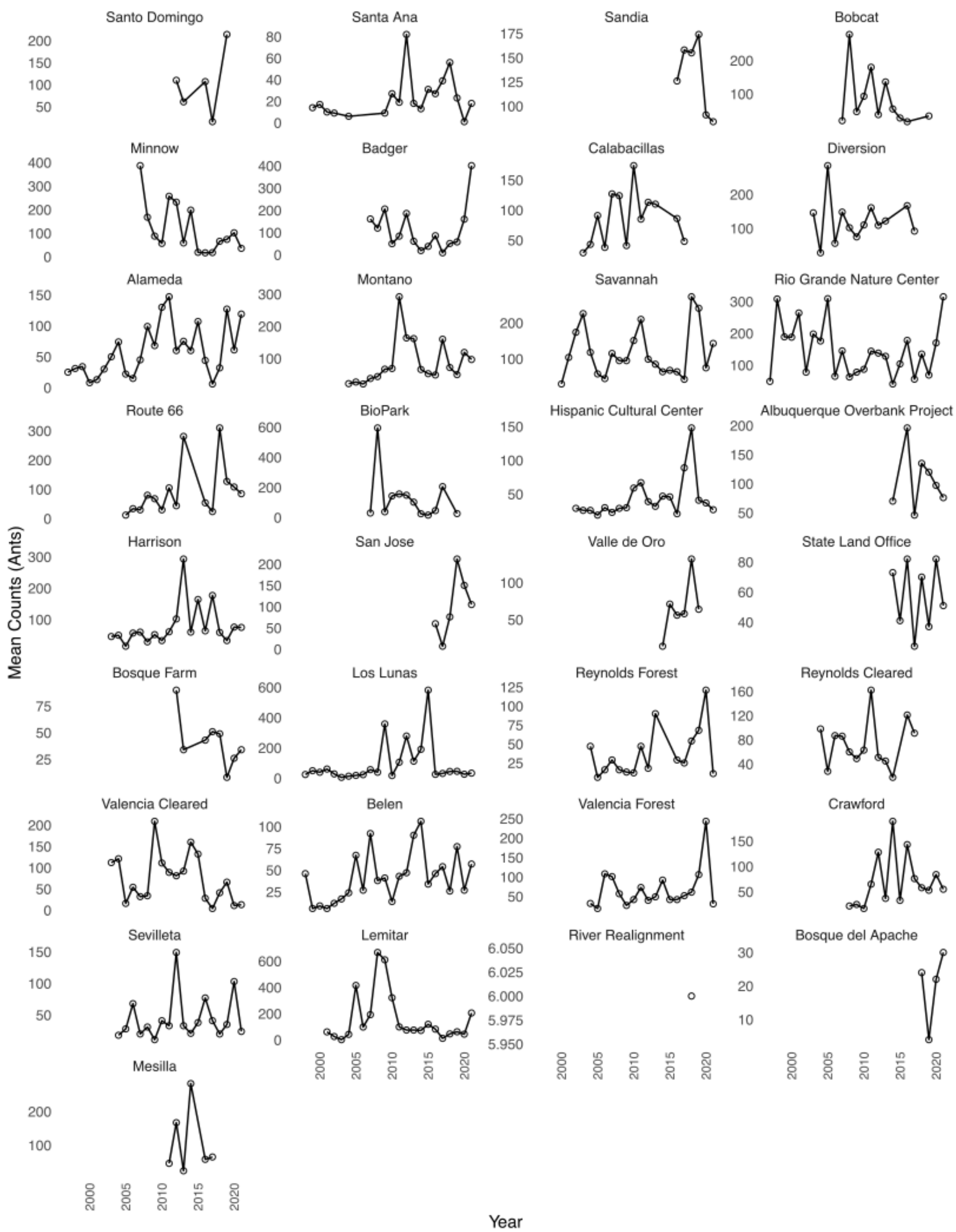

Figure 8.2 Annual mean ant (Formicidae) abundance across sites.

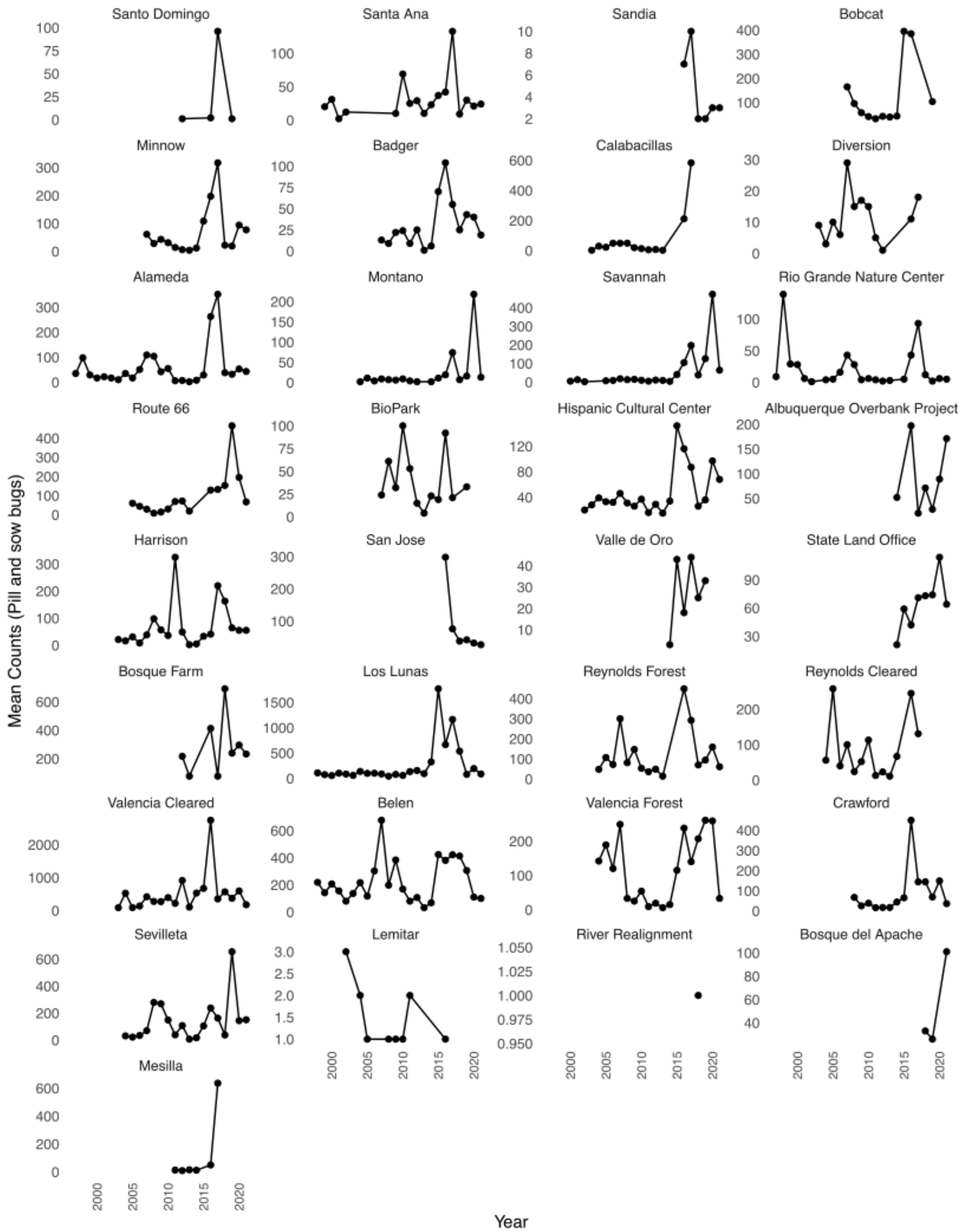

Figure 8.3 Annual mean Isopoda abundance across sites.

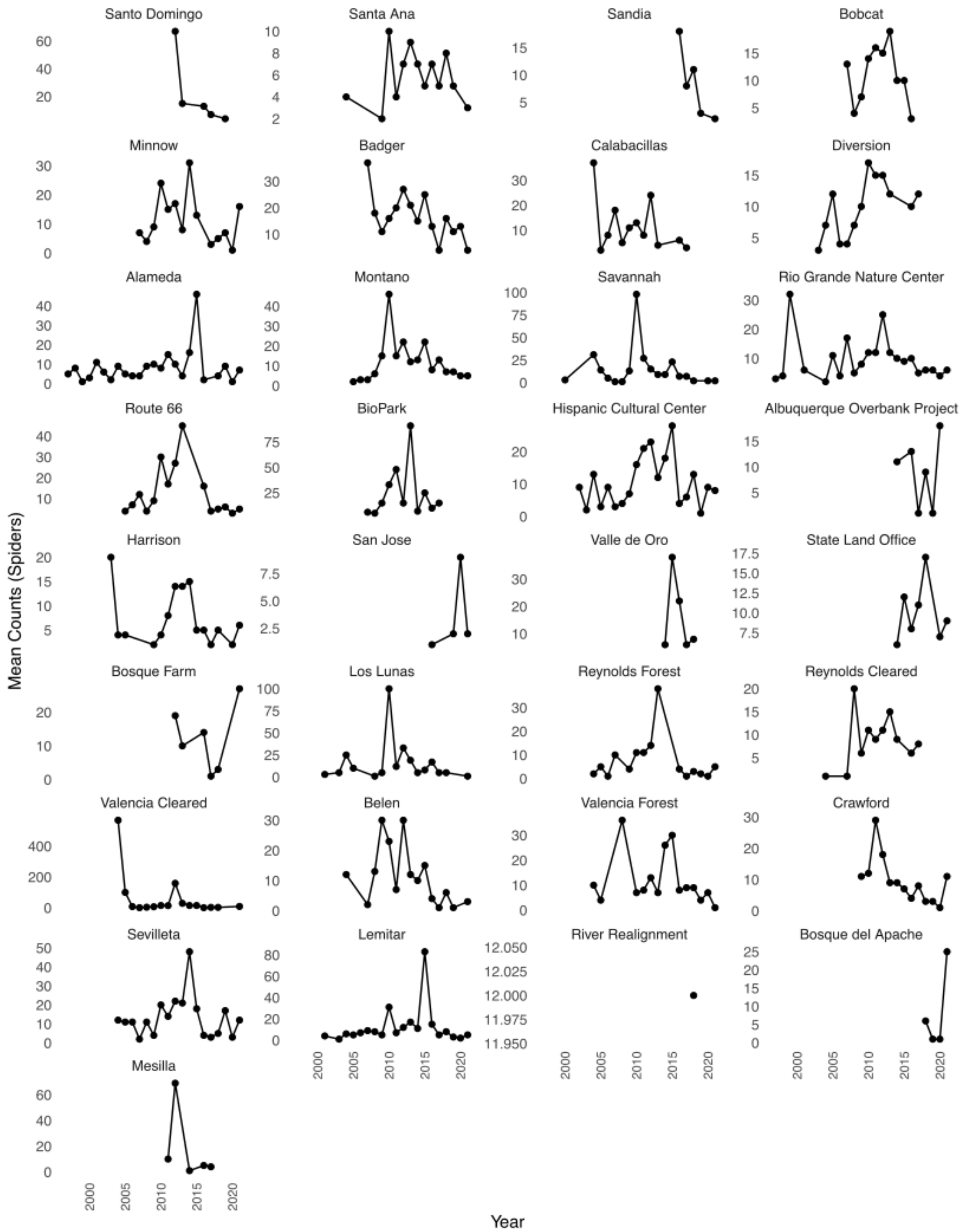

Figure 8.4 Annual mean spider (Araneae) abundance across sites.

In 2021 approximately 26,000 arthropods consisting of over 170 unique arthropod identifications were reported from BEMP sites. Belen (site# 4) had the lowest arthropod richness with 36 unique arthropod identifications, and State Land Office (site #30) had the highest richness with 56 unique arthropod identifications. Of the total arthropods identified, over 18,000 individuals were identified as Isopoda making these animals the dominant species collected in pitfall traps for 2021. Isopods are terrestrial crustaceans with two species found in the Middle Rio Grande, *Armadillidium vulgare* (pill bugs) and *Porcellio laevis* (sow bugs). These species are exotic decomposers introduced globally, and in our ecosystem, they fill niches previously dominated by crickets and other decomposers. Despite their exotic origin, these animals serve a valuable ecosystem function by aiding in the decomposition of leaf litter and fallen woody debris. Their sensitivity to moisture also makes them useful bioindicators. Pill bugs are known to be more tolerant of drier conditions while sow bugs tend to prefer relatively more mesic micro habitats. In 2021 approximately 15,000 pill bugs and 3,000 sow bugs were identified at BEMP sites. Unsurprisingly two of the most arid sites monitored, Sandia (site #32) and Lemitar (site #7) had fewer than ten pill bugs identified in 2021 (Figure 8.3).

Other indicator species include the darkling beetles (Tenebrionidae) and ground beetles (Carabidae). Tenebrionids can tolerate a variety of habitats but many are well adapted for arid environments where they are generalist omnivores feeding on fresh and decaying plant matter as well as decaying animals and occasionally fungi. Carabids form one of the most diverse families of beetles in North America, and although their diets can vary, a majority are predaceous and many are well adapted for mesic environments. At several sites where flooding has been known to occur, including Harrison (site # 13), Los Lunas (site # 3), Belen (site# 4), and Crawford (site# 25), increases in carabids following the flood events in 2017 and 2019 were documented. More arid sites, including Lemitar (site #7) and Sandia (site #32), tend to be dominated by the more xeric tenebrionids (Figure 8.1).

Ants (Formicidae) are a hyperdiverse family of insects. Species from the Middle Rio Grande form subterranean, eusocial colonies where they play important roles in ecosystems by helping to aerate soil, helping to disperse seeds, creating seed banks within their colonies, and eating a variety of living and dead organisms while being an important food source to other predators. Due to the subterranean habits of these arthropods, certain species, such as acrobat ants, (*Crematogaster* spp.) are better adapted to survival in areas prone to flooding than other species commonly encountered in more arid environments such as harvester ants (*Pogonomyrmex* spp.). *Crematogaster* spp. were identified from 19 of the 24 sampled sites in 2021 and *Pogonomyrmex* spp. were identified from 11 of the 24 sampled sites in 2021. Tracking the occurrences of these and other ants throughout the Middle Rio Grande is important for monitoring shifts in the bosque ecosystem.

The spider, *Marinarozelotes barbatus* (Koch, 1866), has been collected at several BEMP sites located within Albuquerque since 2016. This spider is native to the Mediterranean region and was previously only documented in California within the United States before its discovery in New Mexico. Specimens have been found in pit traps at the Albuquerque Overbank Project , Harrison, San Jose, and State Land Office sites. Additionally, evidence of this spider has been documented at the BioPark BEMP site during a targeted collection effort in 2020. In 2021, this species was once again observed in traps from Albuquerque Overbank Project , Harrison, and San Jose sites. BEMP sites will continue to be monitored for evidence of this exotic species to track potential range expansions.

9 Tamarisk Leaf Beetle

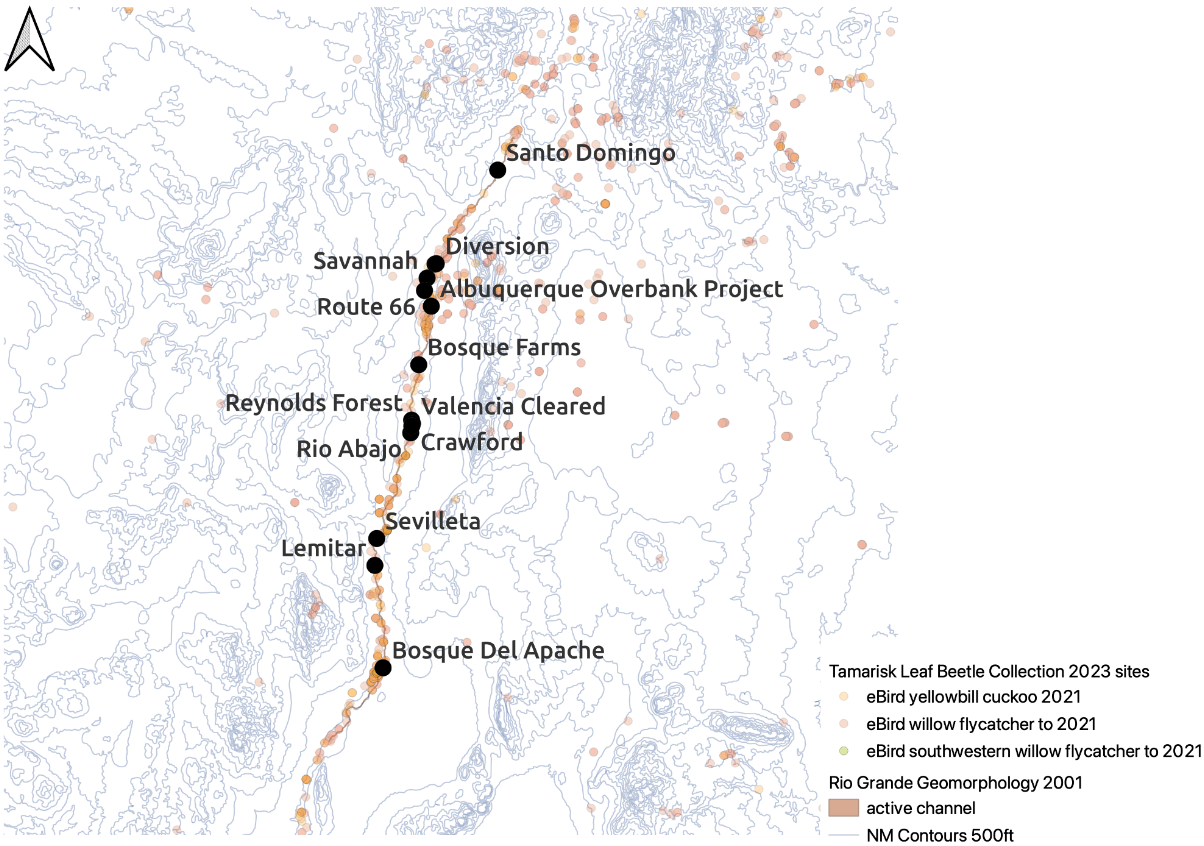

Figure 9.1 Current tamarisk leaf beetle monitoring sites for 2023 in bold. 500 foot contour intervals are in pale blue. Black circles are TLB collection sites. Tan-brown circles are ebird data from 2021 that are species of interest.

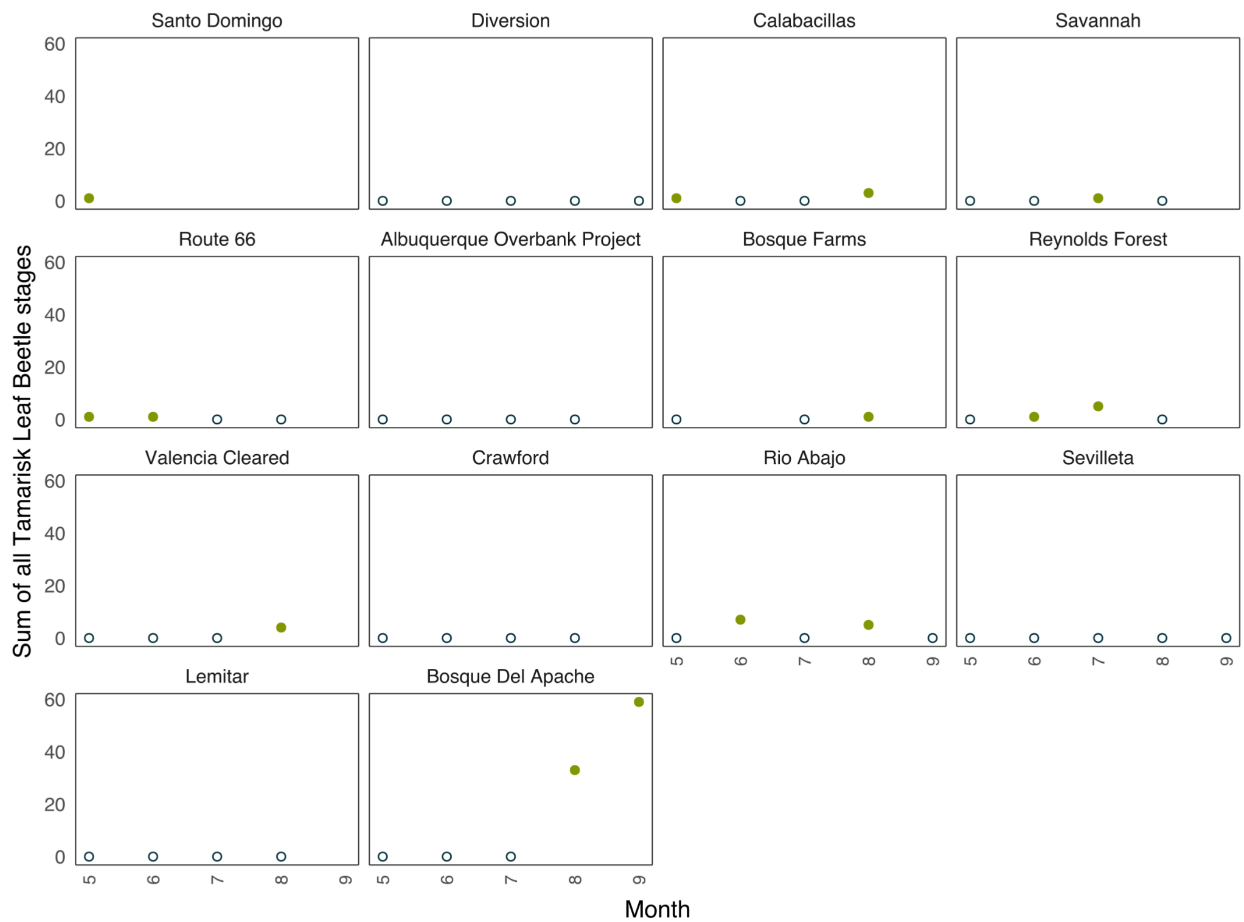

Figure 9.2 Total tamarisk leaf beetle for all life stages found at sites from May through August or September (four sites) 2023. All life stages include egg masses, early and late larvae, and adults. Hollow dots represent zeros; blanks indicate no collection. Sites are arranged from north to south.

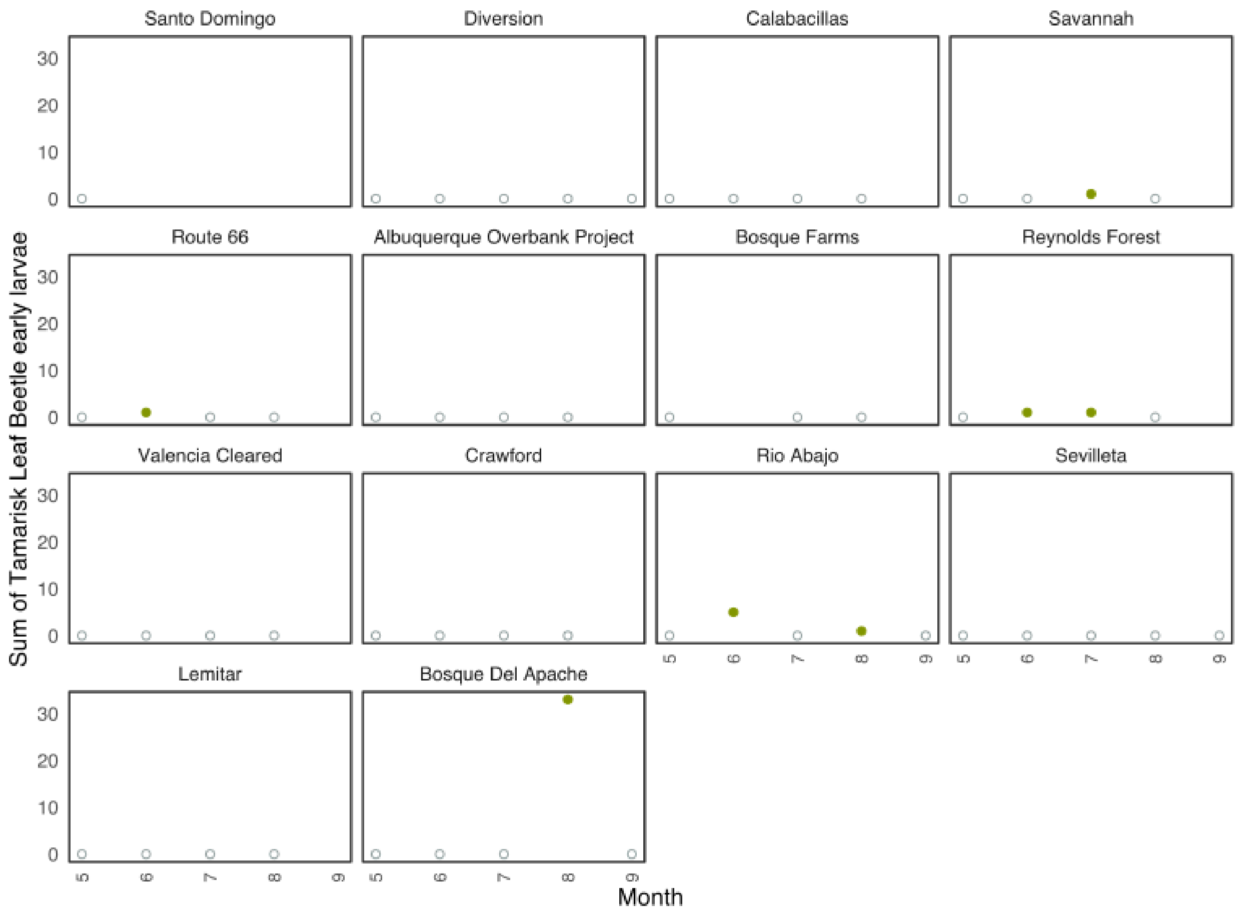

Figure 9.3 Total tamarisk leaf beetle early stage larvae found at sites from May through August or September (four sites) 2023. Hollow dots represent zeros; blanks indicate no collection. Sites are arranged from north to south.

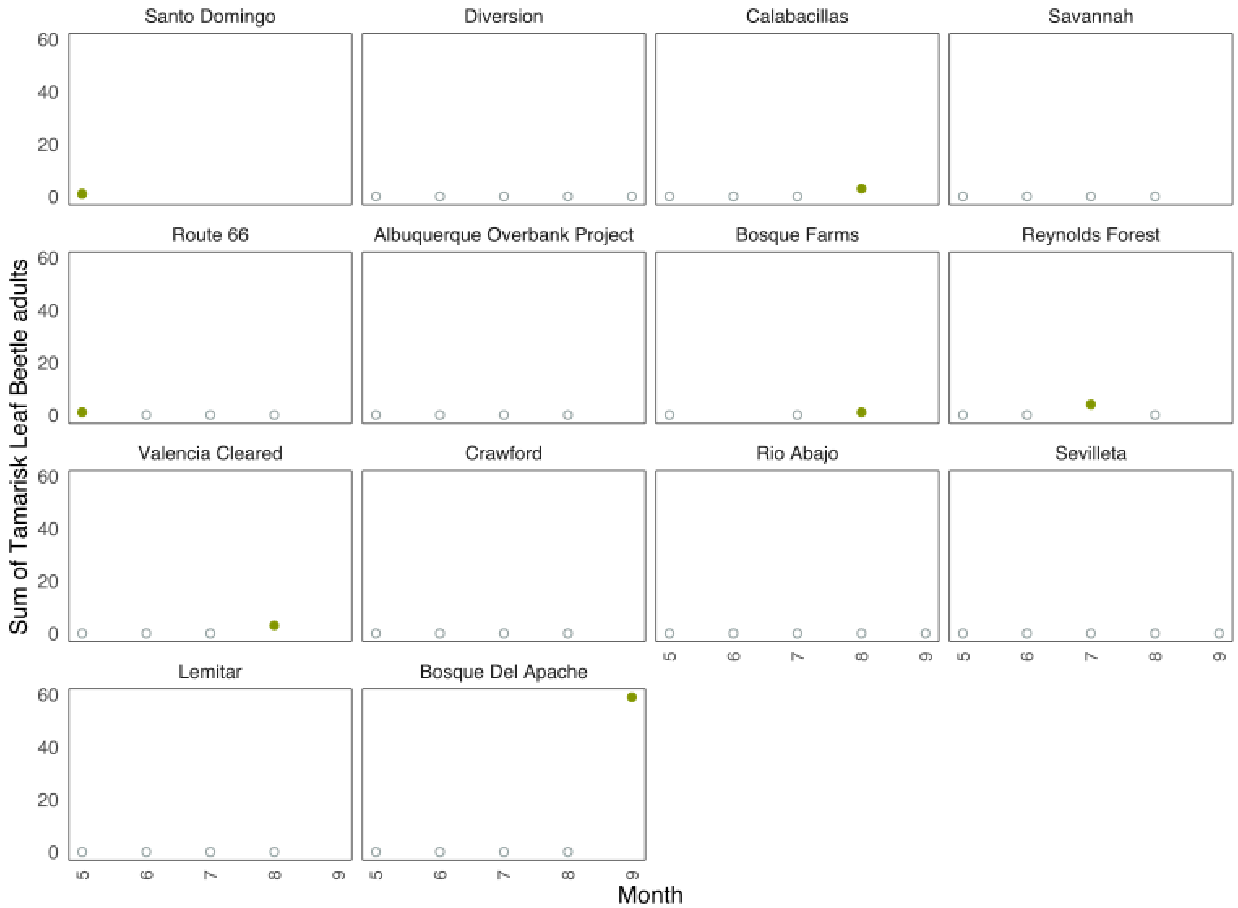

Figure 9.4 Total tamarisk leaf beetle adults found at all sites from May through August or September (four sites) 2023. Hollow dots represent zeros; blanks indicate no collection. Sites are arranged from north to south.

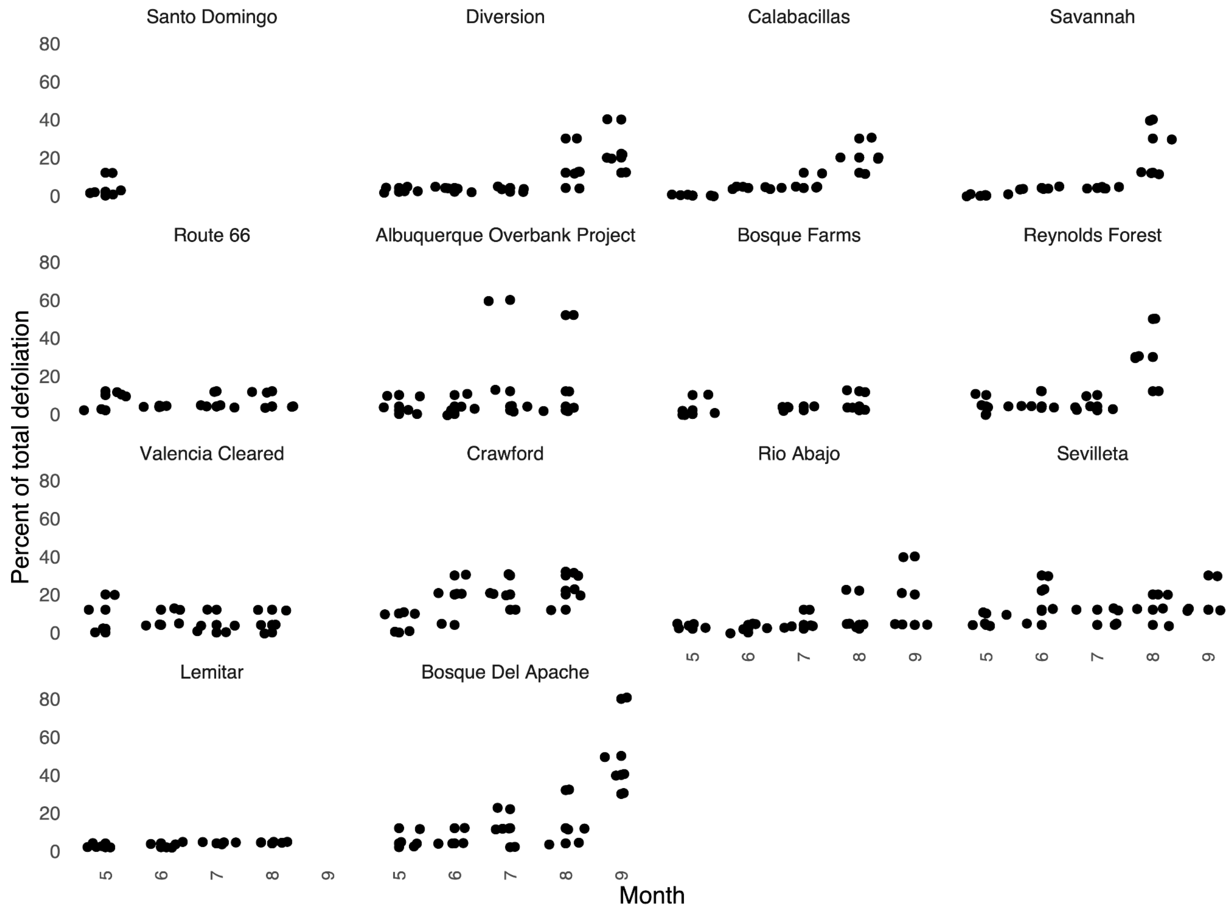

Figure 9.5 Percent total defoliation shown by tree across the sample sites for 2023. Total defoliation includes defoliation by both TLB and other defoliators.

Tamarisk leaf beetle (TLB) abundance was extremely low or absent at most sites in 2023. While many sites flooded, even sites that remained dry had low TLB abundance. Defoliation at many sites was dominated by the tamarisk leaf hopper, which was abundant this year. Bosque del Apache was the only site that had a large TLB presence, especially in September.

10 Water Quality

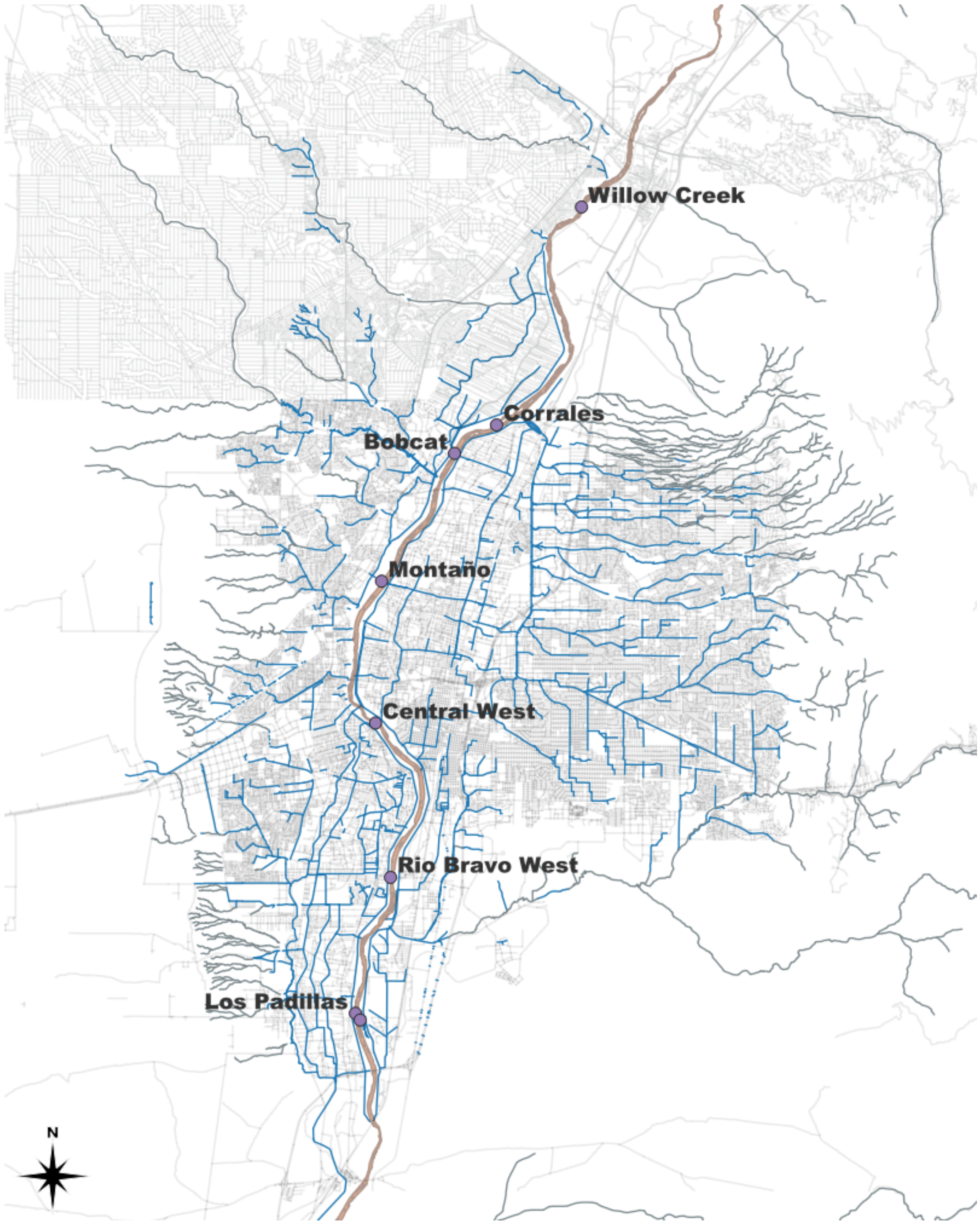

Figure 10.1. Storm water sampling locations for 2023. Additional GIS layers include arroyos, drains and ditches, city streets, and river center.

	Willow Creek	Corrales	Bobcat	Montano	Central West	Rio Bravo West	Los Padillas
February	3.1	7.4	6.3	6.3	4.1	27.2	31.8
March	7.5	2	7.5	7.5	6.3	8.4	9.7
April	<10	10	41	52	20	20	20
May	41	52	52	41	86	31	110
June	25.9	13.5	30.9	28.8	34.5	28.1	42.8
July	56.5	88.4	50.4	48	54.6	62.2	143.9
August	1607	2046	860	2909	2359	8164	261.3
September	85	118	121	63	216	63	313
October	39.9	160.7	119.8	261.3	971	369	9208
November	79.8	120.1	118.7	240	190.4	325.5	517.2
December	7.4	24.1	50.4	70.6	93.3	93.3	261.3

Table 10.1. *Escherichia coli* (MPN/100mL) samples with desired limit exceedances (88 MPN/100mL) highlighted in yellow and EPA limit exceedances (410 MPN/100mL) highlighted in orange. Sampling sites arranged from north to south.

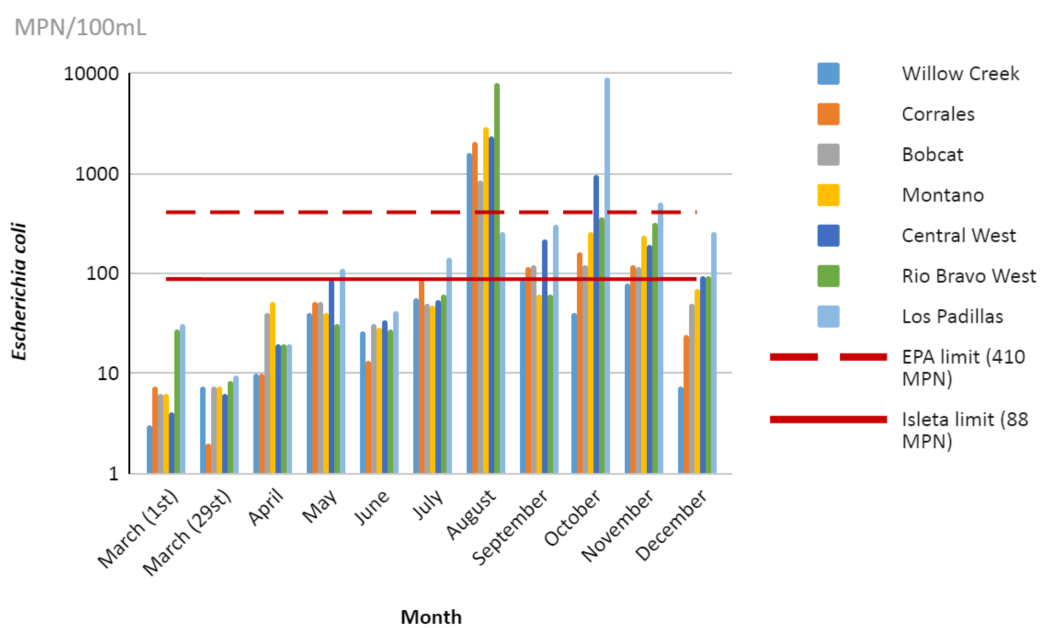

Figure 10.2 *Escherichia coli* (MPN/100mL) Log 10 scale at sampling sites across months.

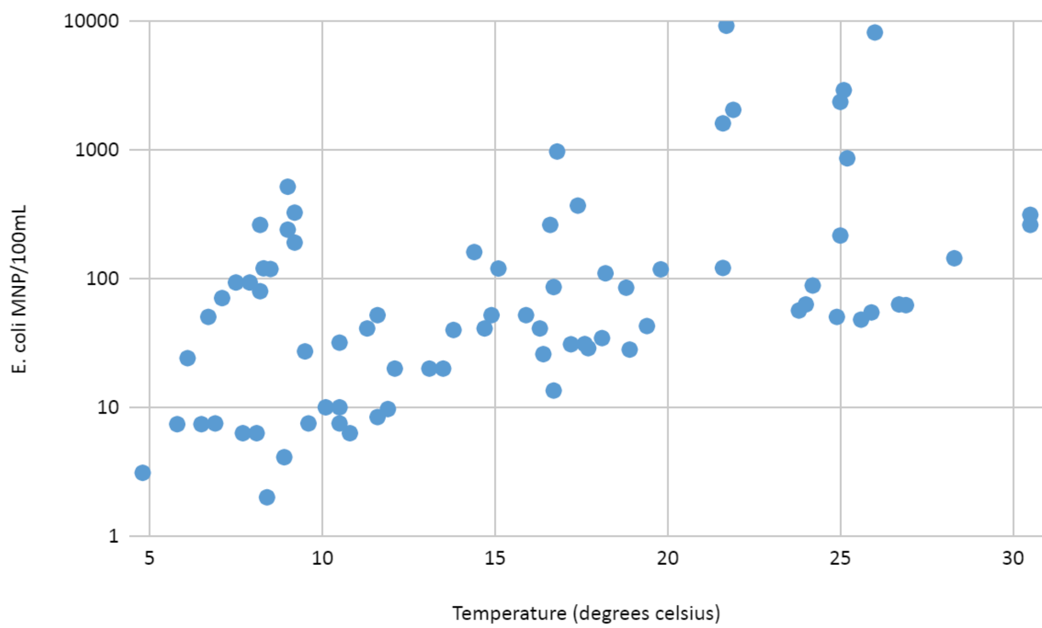

Figure 10.3 Log scale *Echeriachia coli* (MPN/100mL) vs. water temperature (degrees celsius).

Figure 10.4. Photo series of Rio Grande at Willow Creek sampling location facing upstream from March 1, 2023 – December 15, 2023, demonstrating variability in channel size and turbidity throughout the year.

BEMP is funded by the Mid Rio Grande Stormwater Quality Team to sample field parameters (specific conductance, dissolved oxygen, turbidity, and pH) and *Escherichia coli* levels in the Rio Grande. This sampling occurred monthly between March and December 2023 at seven locations seen in Figure 10.1. *Escherichia coli* levels exceeded the desired limits of 88 MPN/100mL and the EPA limits for a primary contact river of 410 MPN/100mL numerous times during the sampling season (Table 10.1, Figure 10.2). Levels of *E. coli* are seen to increase as water flows through Albuquerque, with the highest concentration typically occurring at the southernmost sampling locations, and are positively correlated with increased water temperatures (Table 10.1, Figures 10.2 – 10.3). Monthly changes in river channel and turbidity can be seen in Figure 10.4. Sampling methodologies, details on sample sites, and results are further detailed in the 2023 Annual Stormwater Quality Technical Report, available on request.

11 Bayesian Structural Equation Models (riparian plant cover)

BEMP is constructing a Bayesian (data driven and generative model) structural equation model (SEM) using Stan (probabilistic modeling language) linking depth to groundwater, precipitation, leaf litterfall response (a proxy for productivity), vegetation cover, fire, flood, temperature, and exotic removals. Below are a couple of simple examples of SEMs, looking at one ecosystem driver (fire). Preliminary results of the SEM (Figures 11.1, 11.2, 11.3) show that native wetland plants, wet meadow grasses, and drop seed grasses all have higher cover at sites that have not burned. Sites that have burned show a variable response to fire (positive, negative, and minimal) depending on other factors (such as depth to groundwater, flooding, or management decisions, like reseeding).

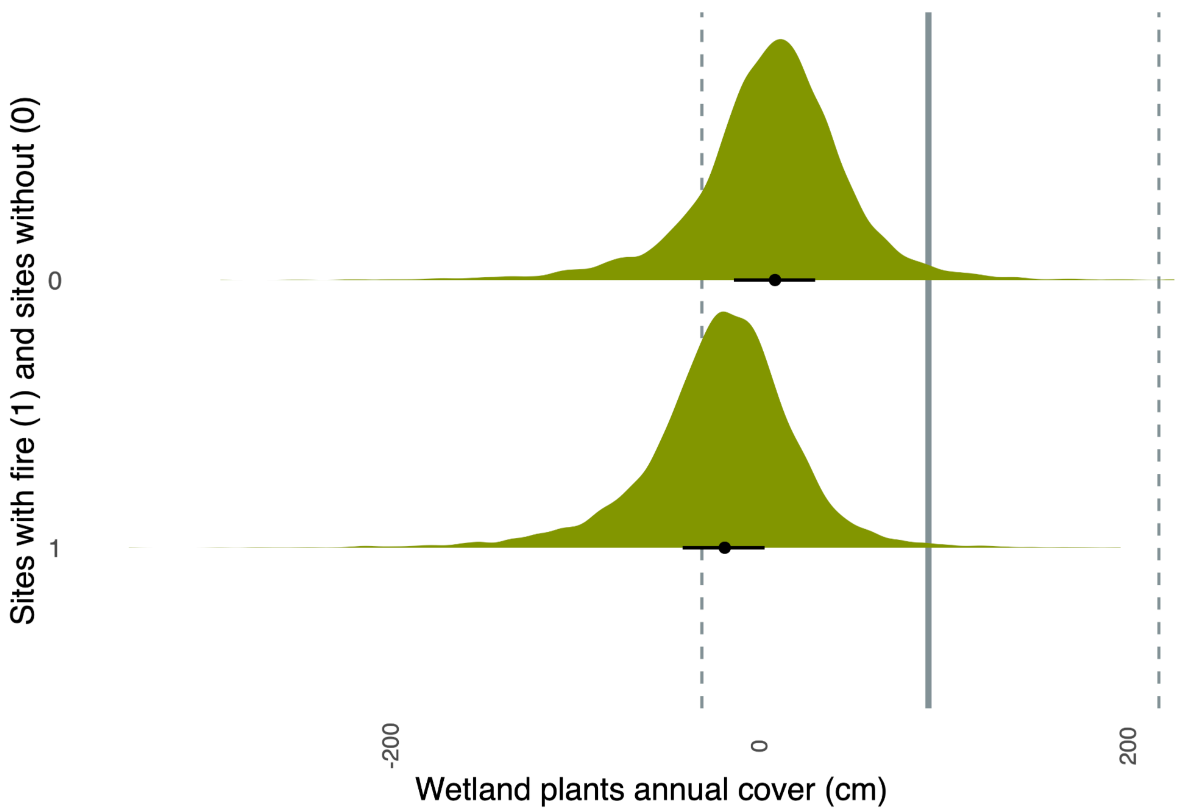

Figure 11.1 Wetland plant cover response to fire from the SEM. Posterior probability distribution (in green) with the 50% uncertainty intervals as black lines and point estimate as a black dot.

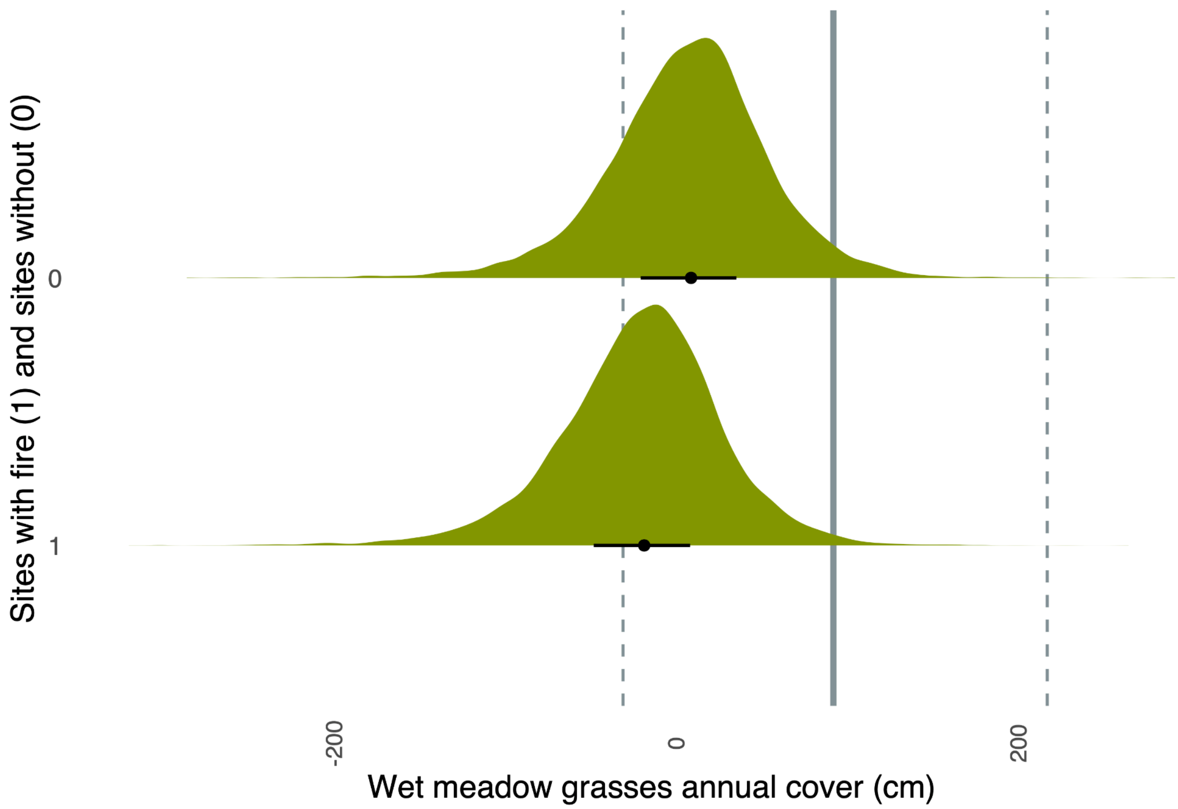

Figure 11.2 Wet meadow grasses cover response to fire from the SEM. Posterior probability distribution (in green) with the 50% uncertainty intervals as black lines and point estimate as a black dot.

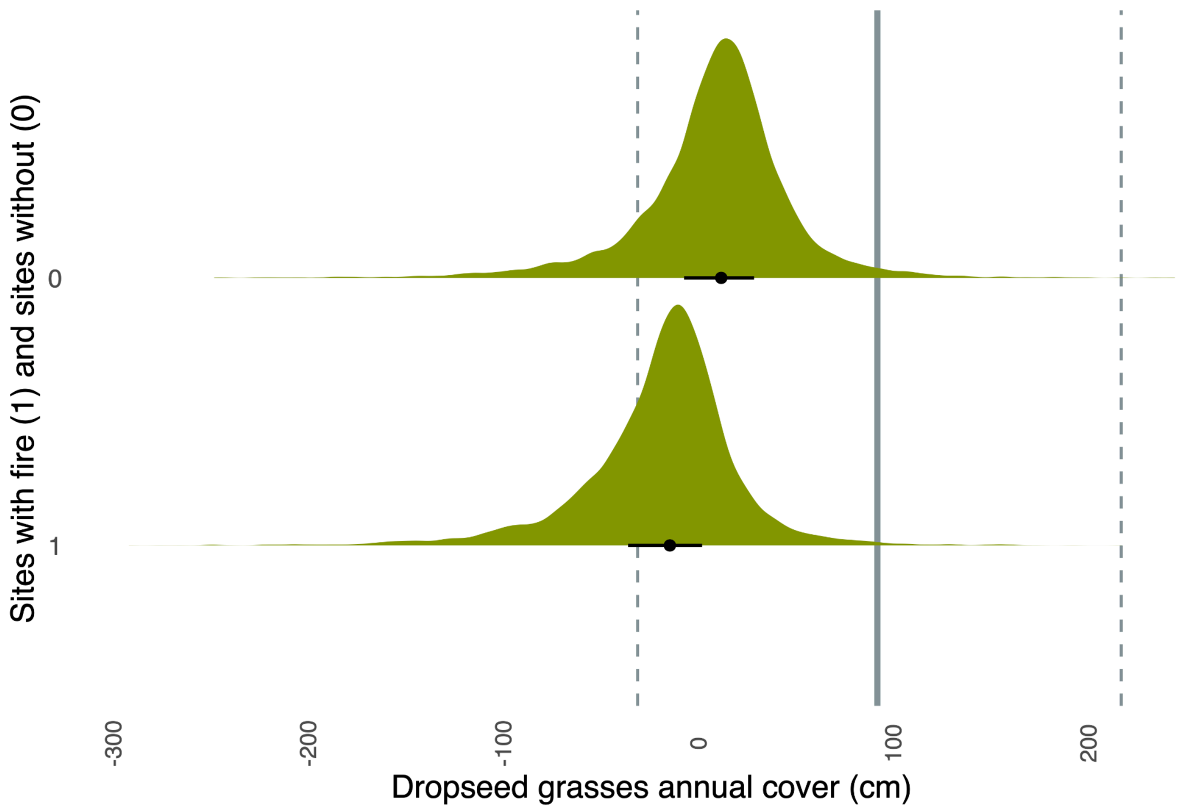

Figure 11.3 Dropseed grass (*Sporobolus* spp.) cover response to fire from the SEM. Posterior probability distribution (in green) with the 50% uncertainty intervals as black lines and point estimate as a black dot.

Kochia and tumbleweed have a different response to fire (Figure 11.4). Their combined cover increases at sites that have burned unless management action is taken to reduce their cover. This is particularly true at sites that have burned and do not flood within the same year.

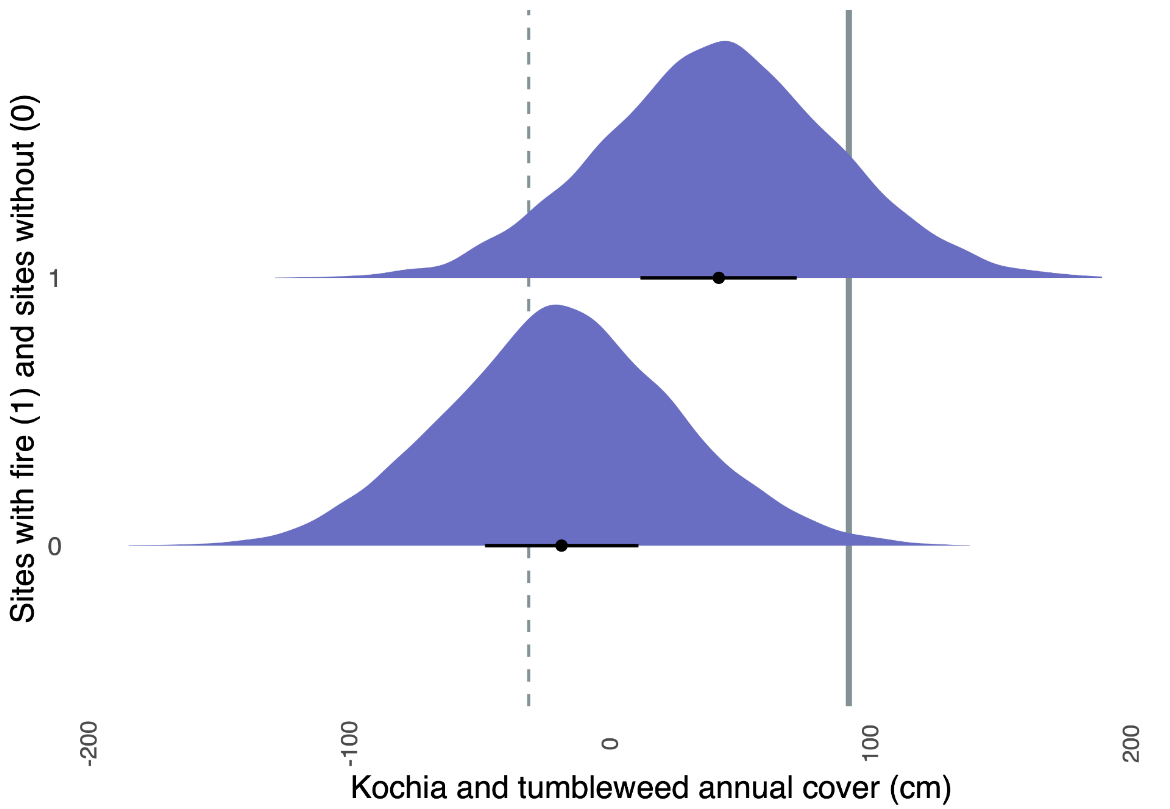

Figure 11.4 Kochia and tumbleweed cover response to fire from the SEM. Posterior probability distribution (in purple) with the 50% uncertainty intervals as black lines and point estimate as a black dot.

12 Implications for management

Data on depth to groundwater, precipitation, temperature, vegetation cover, litterfall, and indicator arthropod species are all critical for both determining what type of management strategies to use in different riparian areas and for monitoring the success of those strategies. Sites with higher groundwater levels are more likely to support successful cottonwood-willow restoration (e.g., San Jose), while sites with deeper groundwater levels require more earth-moving to establish deeper swales and wetlands in order to be successful (e.g., SLO). Establishing native vegetation following fires will depend greatly on the ability to get water on the site. Knowing what vegetation was on the site prior to the fire will aid in restoration efforts, as many native plants (e.g., golden currant, sedges, yerba mansa) are able to recover quickly after a fire, especially with stronger connections to groundwater. Without flooding, areas that were bare or disturbed generally support invasive exotics like tumbleweed and kochia following fires. These invasives can then persist for years.

Temperature data indicate that urban sites and sites with reduced canopy have warmer temperatures, directly impacting both vegetation and animals in those areas. The cooling benefits of a canopy are clearly seen at cottonwood and willow-dominated sites.

The shift to warmer temperatures, reduced spring river flows, and more variable precipitation events that occur later in the year will directly impact which species are able to thrive. Developing Bayesian SEMs to help inform management decisions, projects, and mitigation efforts will be key to maintaining ecosystem function with reduced water availability.