**Mojave National Preserve**

National Park Service
U.S. Department of the Interior

**Sweeney Granite Mountains Desert Research Center**

Natural Reserve System
UNIVERSITY OF CALIFORNIA

# Science Newsletter

## Using a Rock-Climbing Robot to Access Extreme Terrain Environments

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The Limbed Excursion Mechanical Utility Robot (LEMUR) is a rock-climbing robot (Figure 1), developed at the NASA Jet Propulsion Laboratory (JPL). It was designed to traverse extreme terrain environments that may be inaccessible to traditional wheeled rovers. Robotic explorations of other planetary surfaces, like Opportunity and Curiosity on Mars, are often restricted to investigating scientific targets on relatively flat surfaces. However, scientifically valuable geologic and biologic sites on other planetary surfaces may be located in places these rovers cannot approach. For example, on Mars access to steep cliff faces to study stratigraphy of Valles Marineris (*1*) or the icy terrain found in the polar region (*2*) are of great interest. Other unreachable surfaces by wheeled robotic platforms include the surface of Europa (*3*) o *4*), as well as microgravity environments on asteroid or cometary surfaces (*5*) o (*6 - 9*) have revealed the presence of skylights on the Moon and Mars that could serve as entrances to larger subterranean voids. These subsurface locations may contain unaltered geologic

**Figure 1. LEMUR scaling a nearly vertical granite outcrop at the Sweeney Granite Mountains Desert Research Center. Microspine gripper end effectors are attached to the chassis via seven degree-of-freedom limbs. A perception system consists of a camera and LIDAR mounted to a mast on the chassis. A safety line and a tethered power cable are also present above and below LEMUR.**

**In this Issue:**

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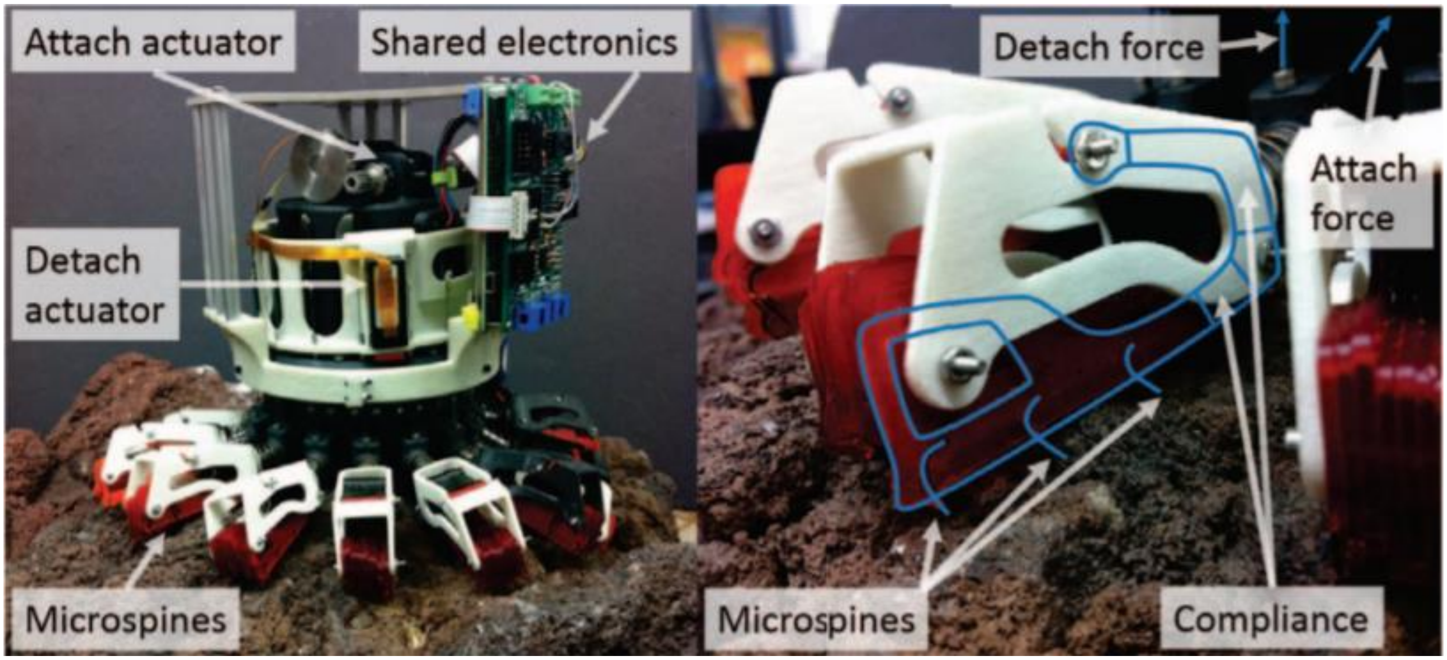

**Figure 2. A microspine gripper end effector suited to anchor LEMUR to rough surfaces (*11*).**

samples or well-preserved evidence of extant or extinct biologic activity (*10*). Delivering scientific instruments to these complex targets will be critical for investigations of high value targets.

Originally inspired by the adhesive properties of gecko feet, LEMUR is capable of climbing on a variety of surfaces through the use of various end effectors. These end effectors are designed with specific surface properties in mind and can be attached to the robot according to where it will be exploring. On LEMUR there are three end effectors that can be implemented: *1*) gecko adhesive end effectors grip smooth surfaces by taking advantage of van der Walls forces between the gripper and the surface (*11*), *2*) ice screw end effectors could be used to anchor LEMUR to icy surfaces (*12*), and *3*) microspine grippers are used to climb rough, rocky terrain (*11*). The microspine grippers tested during our recent field test at the Sweeney Granite Mountains Desert Research Center allow LEMUR to anchor itself to vertical or overhanging rough surfaces. Each microspine end effector contains hundreds of steel hooks embedded in toe-like cartridges, which contact the surface and are pulled inward to grip the rock - not unlike the mechanics of a rock climber's fingers while grabbing a climbing hold. The load applied to the end effector is shared across hundreds of microspine anchor points, which permits many microspines to fail to grip the surface while safely maintaining an anchor. Figure 2 shows an annotated image of a microspine gripper end effector (*11*). LEMUR climbs by incrementally moving its limbs; once a gripper has successfully anchored to the surface, the next limb in the climbing sequence detaches from the wall, actuates its seven-jointed limb to position the gripper over a new location, contacts the surface, and reengages the microspines to grip the surface.

LEMUR is equipped with a perception system (Figure 1) that generates context imagery and point cloud maps of the surface to provide input to gripper placement decisions. An artificial intelligence classifier identifies the safest route to a designated target based on properties of the surface, including its texture and the success of previous climbs on similar surfaces. During typical operations, LEMUR generates an initial map of the area, shown in Figure 3, and an operator directs LEMUR to a point of scientific interest. LEMUR chooses the safest path to this target and begins to climb autonomously, beginning scientific investigations upon arrival. During previous field expeditions, we demonstrated the integration of an instrument payload with LEMUR, consisting of an infrared spectrometer, an ultraviolet fluorescence and Raman spectrometer, and an X-Ray fluorescence spectrometer (*13*). LEMUR has a wingspan of approximately 1.5 m (with 70 cm limbs) and has a mass of approximately 24 kg.

The focus of our field demonstration at Sweeney Granite Mountains Desert Research Center (Figure 4) was to test the graspability of the microspine grippers on relatively smooth rock surfaces during long climbing operations on a rock type with limited data in the perception system's classifier database. Previous field tests in basalt lava tube caves tested LEMUR's capability to grip relatively porous, rough surfaces. In contrast, the granite rocks at the Sweeney Granite Mountains Desert Research Center field site are non-porous, smooth, and easily flake off, posing a greater challenge for LEMUR to remain anchored onto the surface without slipping. This granite outcrop could be considered an analog for other granite sites in the solar system (*14*), however, the site was primarily selected to demonstrate autonomous operations on a relatively smooth vertical surface - sharply contrasting previous porous, rough basaltic lava tube field sites.

Figure 5 shows a sequence of images of LEMUR climbing approximately 4.2 meters over seven hours, collected during autonomous operations. Our test demonstrated successful implementation of the LEMUR perception system on an unclassified target over a long duration with minimal human intervention. These tests simulate the autonomous navigation employed during planetary missions, where it becomes impractical for human operators to command robotic movements due to bandwidth restrictions or substantial input time delays. This successful demonstration of autonomous climbing on a relatively smooth vertical site brings LEMUR one step closer to serving as a robotic platform for future scientific investigations on other planetary surfaces.

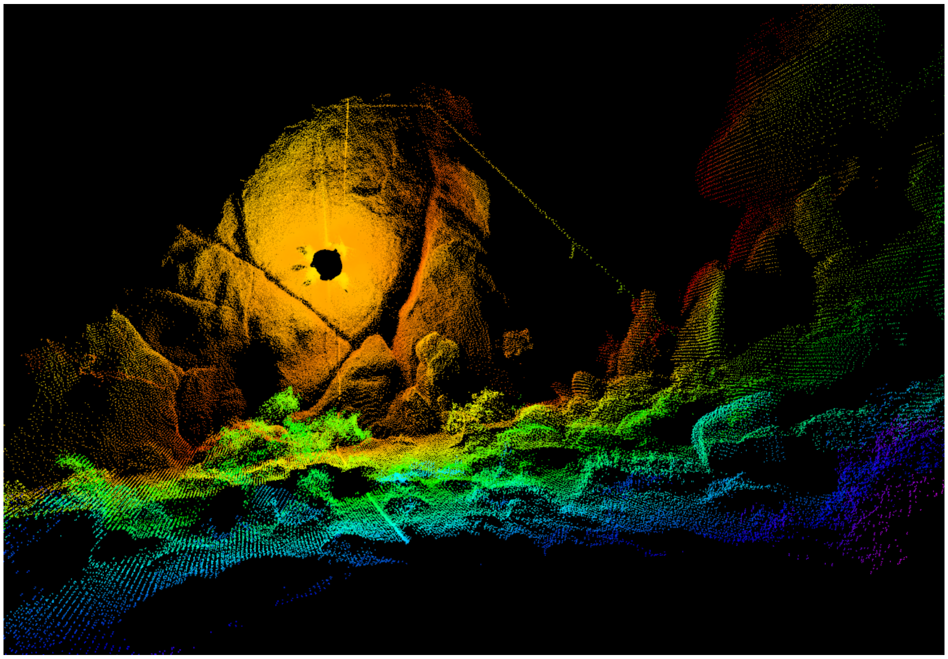

**Figure 3. A point cloud map used as an input to autonomous navigation. The points have a resolution of 30 mm in the climbing workspace and the range of the perception system extends from 0.1 – 30 m. A photograph associated with this point cloud is presented in Figure 5.**

**Figure 4. JPL robotics engineers observing and recording progress of LEMUR at one of our test sites in the Granite Mountains.**

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**Figure 5. A sequence of photographs of LEMUR showing climbing progress at Sweeney Granite Mountains Desert Research Center. LEMUR climbed approximately 4.2 meters in seven hours.**

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*Acknowledgements*

This work was carried out at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under contract with the National Aeronautics and Space Administration. Government sponsorship acknowledged. The authors wish to thank Tasha La Doux and Jim Andre for logistical support and field site recommendations. The authors also thank the NASA Planetary Science and Technology through Analog Research Program (PSTAR) for funding under NNH14ZDA001N.

*Additional Information*

JPL News: For Climbing Robots, the Sky's the Limit:
https://www.jpl.nasa.gov/news/news.php?feature=7449

Video: NASA Climbing Robot Scales Cliffs and Looks for Life:
https://www.youtube.com/watch?v=q2SKa9IEG4M

Video: Granite Mountain LEMUR Climbing (Autonomous):
https://www.youtube.com/watch?v=zEd-ut1xzZ8

# Mojave Climate Hidden in Lake Mud

Matthew E. Kirby [1], Stefanie A. Mayer [1], William T. Anderson [2], Brenna Hess [1], Corey Stout [1], Jennifer Palermo [1], Jenifer Leidelmeijer [1], Hogan Rangel [1], Gregory Weisberg [1], and Amanda Shellhorn [1]

Earth's climate is changing (*1*). How it changed in the past and why it changed is at the forefront of scientific research today. Changing climate is of particular interest for regions of the Earth where water is scarce. Understanding how and why water availability changed in the past provides insight to how water availability may change in the future and thus improve water management practices. This understanding is particularly important for water-stressed, arid regions.

Mojave National Preserve is located in one of the most arid regions on the planet. Surprisingly, there is abundant geological evidence that large lakes existed throughout the Mojave in the geologically recent past, specifically the late Glacial (15,000-11,700 years) and into the early Holocene (11,700-8,000 years). However, the finer details (e.g., centennial to sub-centennial scales) of climatic change across the Mojave over the past 15,000 years remain less developed because the occurrence of high quality paleoclimatic evidence is rare or incomplete in arid environments (*2, 3*). Previously, researchers have used pack rat middens, wetland spring deposits, and lake mud to reconstruct past climatic change in the Mojave region (*2-5*). Here, I focus on lake mud.

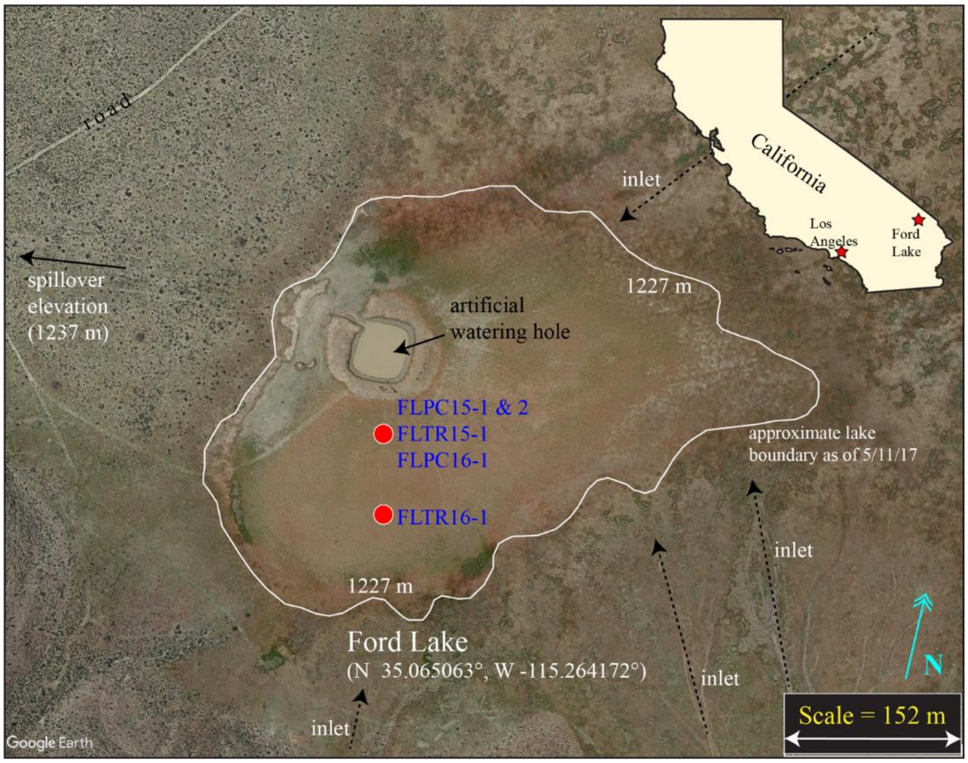

**Figure 1. Ford Lake Google Earth image map. Approximate modern lake boundary is highlighted in white. Relevant core and trench sites are marked as well as inlets and the lake spillover elevation. Modified from (*14*).**

Why study lake mud? Like the pages in a history book, lake mud also tells a story. This story is possible because the mud accumulates from year to year in lake basins. The layers contain a variety of materials that reflect the history of conditions in the lake and its surrounding environment, including: floods, pluvials (long periods of above average wetness), drought (long periods of below average wetness), fire, and vegetation change. Lake mud is a combination of: *1*) washed in weathered and eroded rock; *2*) organic debris such as charcoal, leaves, and organisms living in the water; *3*) organic and inorganic minerals precipitated within the water such as snail shells and calcite crystals, respectively; and, *4*) eolian (wind-blown dust) materials. Each of these materials tells a story. Figuring out what story they tell depends on a variety of factors such as sediment preservation, climatic sensitivity, quantity of materials, and age resolution (e.g., how much time the sediments preserve).

To date, most lake studies in the Mojave have focused on the large lakes that receive run-off from the Mojave River such as Soda Lake, Silver Lake, and Cronese Lakes (*2, 6*). The Mojave River drains the San Bernardino Mountains. As a result, the lake basins fed by the Mojave River record a combination of coastal climate (i.e., run-off from the San Bernardino Mountains) and Mojave climate. Unraveling these two contributing climatic signals is very difficult. In this project, I use mud from Ford Lake (Figure 1), which is a lake that receives no runoff from the San Bernardino Mountains but instead gets all of its water directly from within the Mojave Desert. Using this record, 8,650 years of precipitation history is inferred for Mojave National Preserve.

Modern climate is critical to understanding past climate. Climate is loosely defined as the average temperature and precipitation for a region over at least a 30-year interval. The modern climate of coastal southern California is described as Mediterranean with winter dominant precipitation (*7*). The Mojave Desert Region climate, however, is seasonal with 66% of the rainfall occurring during winter months (Pacific frontal systems) and 34% during the summer months (monsoonal and dissipating tropical cyclones) (*8-10*). What role summer precipitation played in the region's past hydrologic budget – such as during the late Holocene (4,200 years through modern) – is a matter of debate (*2, 4, 11, 12*). Today, however, neither the monsoon nor dissipating tropical cyclones affect the region's annual hydrologic budget in terms of filling, or sustaining, playa lakes. It is generally agreed that winter, not

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summer, precipitation dictates the formation and persistence of lakes in the Mojave Desert (*11, 13*). As a result, we focus on winter precipitation as the predominant moisture-source interpretation for Ford Lake sediments. We note, however, that it is not possible to separate the winter from summer precipitation components using our various sediment analyses. Therefore, changes in summer contributions versus winter contributions over time cannot be evaluated for Ford Lake.

Ford Lake is an ephemeral lake located in the southeastern portion of Mojave National Preserve, approximately 290 km northeast of Los Angeles, California (Figure 1). We estimated the maximum historical lake depth at ~10 m using the difference between the lowest elevation of the Thompson Wash berm, elevation ~1237 m, and the modern lake bottom, elevation ~1227 m (Figure 2) (*14*). The Thompson Wash berm is the lowest elevation along the lake's perimeter where spillover would likely occur. Based on satellite images and Google Earth historical images, there has been no standing water – aside from a small human made watering hole – in Ford Lake over the past 20 years. Consequently, it is difficult to speculate on Ford Lake's true historic lake depth or range of depth.

Three sediment pound cores and two trench cores were collected at Ford Lake in 2015 (*14*) and 2016. Core FLPC15-1 & 2, FLTR15-1, and FLPC16-1 (Site 1) were all collected from the same location (Figure 1). Trench core FLTR16-1 (Site 2) was collected approximately 100 m south of the latter sites (Figure 1). In all, we collected 355 cm of sediment from Site 1; whereas, we collected only 150 cm of sediment at the Site 2 trench. The focus of this report is the 355 cm section from Site 1.

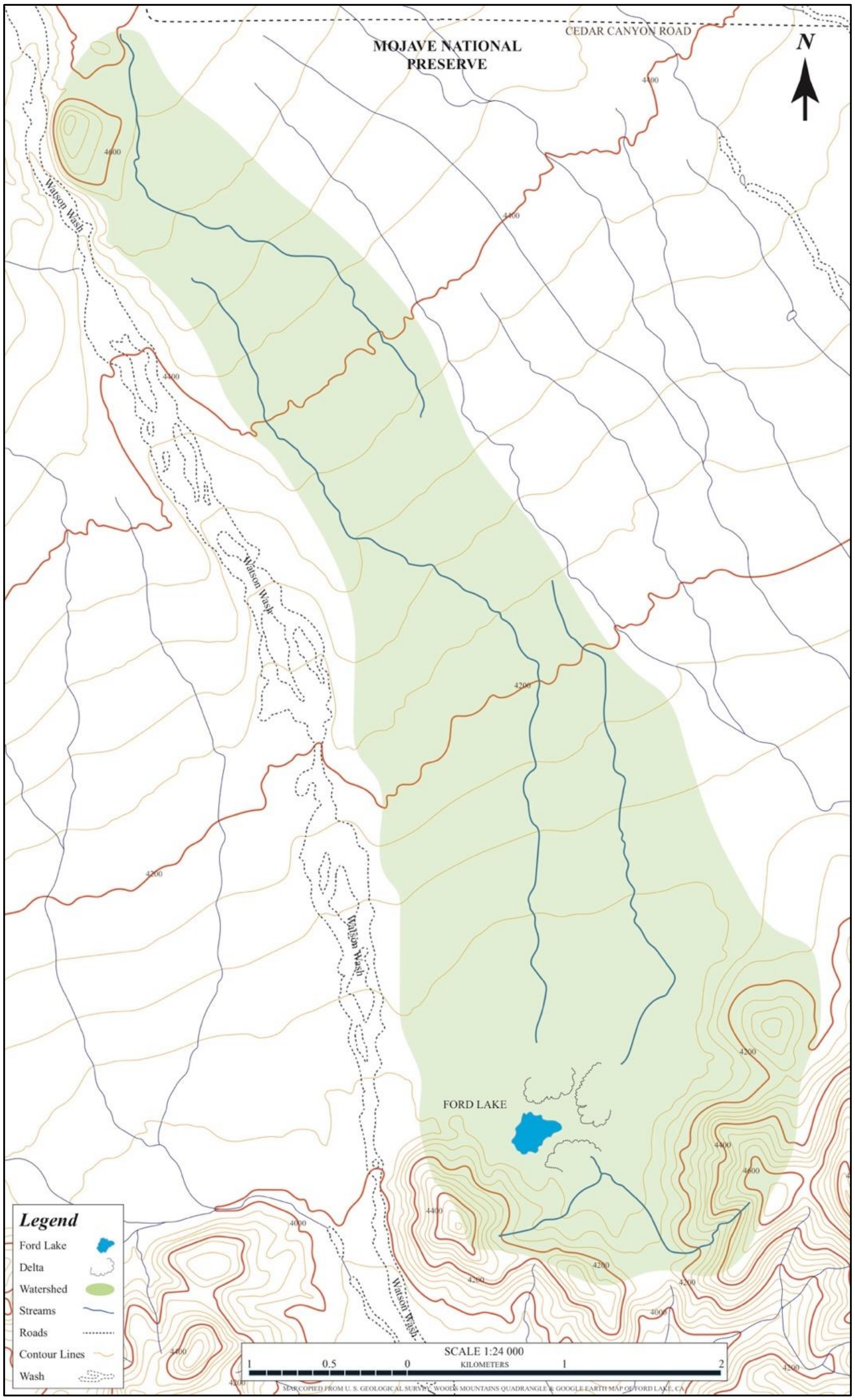

**Figure 2. Ford Lake location with the drainage basin (watershed) highlighted in light green. Modified from (*14*).**

The sediment from the surface down to 322 cm is predominantly a massive brown clayey silt with minor sand. There are visible organics throughout much of the section including small twigs, roots, and seeds. There is a sharp lithologic change at 322 cm from a clayey silt to a silty-gravelly sand with little to no clay. We do not provide a stratigraphic profile because, with the exception of the lower 33 cm (322-355 cm), the sediment is largely homogenous and nondescript. Due to the nature of the sampling, we could not identify sedimentary structures such as mud cracks, laminae, or cross bedding. All data are shown by Figure 3.

All sediments were visually described either in the field (trenches) or back in the lab (pound cores). Magnetic susceptibility, percent water content, percent total organic matter via loss-on-ignition (LOI) 550 ºC (*15*), percent total carbonate via loss-on-ignition 950 ºC (*15*), and grain size were measured at 1 cm contiguous intervals (e.g., 0-1 cm = 0.5 cm, 1-2 cm = 1.5 cm, etc).

Overlapping data points between cores FLPC15-2 and FLPC16-1 were averaged to account for small differences typical of basin sedimentation, even when taken from nearly the same location (Figure 1). Percent total sand (62.5-2000 microns (1000 microns = 1 mm)) and percent coarse-to-very coarse sand (500-2000 microns) were standardized to assess standard deviations from the mean value over time. In other words, once standardized, zero becomes the mean and values above and below zero represent standard deviations from the mean value. The standardization calculation does not include the sediment from 322-355 cm. The latter are not included because the bottom 33 cm represent a significantly different depositional environment characterized by silty-gravelly sand, not representative of the upper 322 cm of the core.

Age control for the Ford Lake sediment was established using Accelerator Mass Spectrometry (AMS) carbon-14 ($^{14}$C) dating. Thirteen samples consisting of discrete organic pieces (>74 microns in diameter) such as seeds, roots, and charcoal were sampled at various depths. All samples were pretreated with an acid-base-acid wash to remove any carbonate and labile organics. Dating analyses were conducted at the W. M. Keck Carbon Cycle Accelerator Mass Spectrometry Laboratory located on the University of California-Irvine campus under the direction of Dr. John Southon. Ages were converted from radiocarbon years to calendar years before present using Calib 7.1 (*16*). Of the 13 dates obtained for this project, only five were used to construct an age model; all five were from charcoal. An age model is the conversion of depth to calendar years before present (Present = 1950 AD or 0 calendar years before present (cy BP)) (Table 1, Figure 4). The eight dates that were removed were from seeds and roots. All of the seeds provided modern ages, suggesting contamination of surface material during the coring process. The modern lake surface is littered with cow dung and likely includes undigested seeds. The lake environment was very windy during the coring process. Our coring requires extraction of the mud in the field and thus brief exposure to dust and other flying debris. We suspect that these seeds reflect contamination during this brief exposure. Roots are risky for dating because they grow down from the surface and thus reflect material younger than the age of the sediment in which they are found. Once we discovered the uselessness of the seed and root dates, we wet sieved (≥ 74 microns) over 250 individual samples at 1 cm contiguous intervals. Each sample was then examined under a binocular microscope to locate and extract microscopic charcoal. This extremely time-consuming task resulted in five $^{14}$C samples, producing a stratigraphically intact age-depth relationship (Figure 4). In general, charcoal is considered a reliable material to date in arid environment settings. It is important to note, however, that radiocarbon dating detrital charcoal is also subject to potential errors such as *1*) a lag between the fire's age and the age of charcoal deposition in the lake, *2*) windblown charcoal that does not reflect local fire activity, and *3*) bioturbation of younger charcoal into older sediments (and vice versa). Unfortunately, we cannot evaluate these potential errors without additional age control. As a result, a simple age/depth linear model was used to calculate an age model (Figure 4).

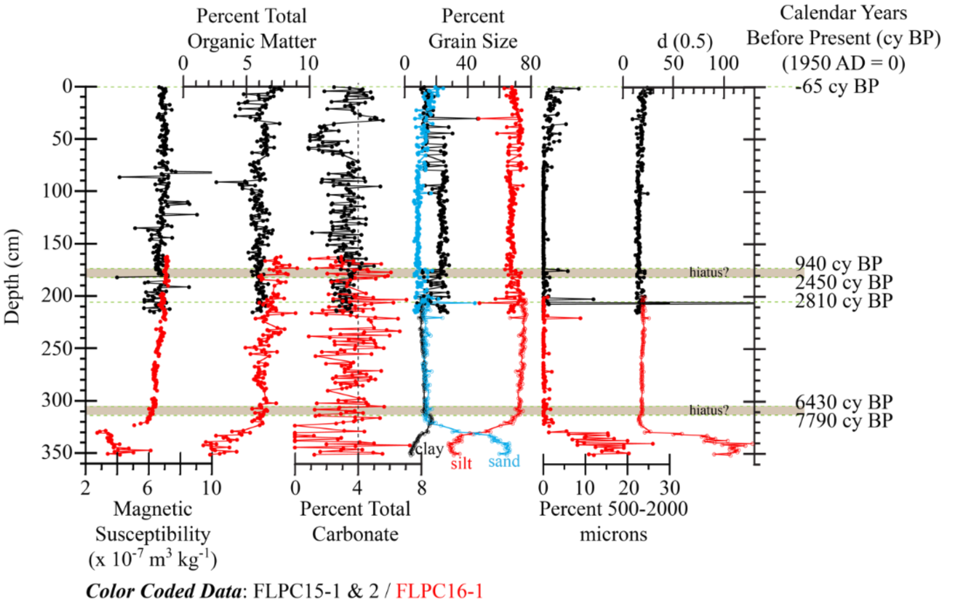

**Figure 3. All core data plotted versus depth (cm). Black data points represent cores FLPC15-1 & 2; red data points represent core FLPC16-1. Age control points are shown by a dashed light green line. d (0.5) is the average grain size in microns. Less than 4 % total carbonate values are interpreted as the absence of carbonate.**

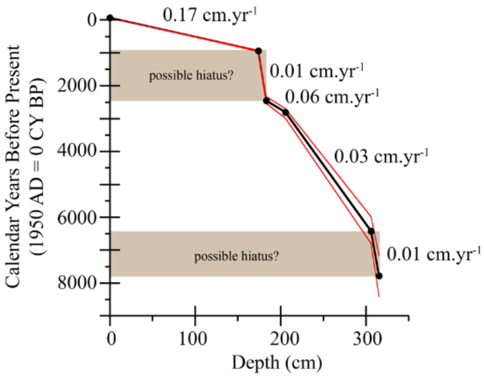

**Figure 4. Age-depth plot with sedimentation rates shown. Hiatuses are highlighted in light gray.**

Figure 4 shows the age model used for the discussion. There are two apparent hiatus intervals (7790-6430 and 2450-940 cy BP) interpreted as either/or periods of non-deposition, erosion, or slow deposition. Notably, there is no visual or sedimentological evidence for these hiatuses (Figure 3). This is not entirely unexpected considering the lake's likely ephemeral history combined with wave action mixing, bioturbation, and desiccation influences (e.g., deflation or the removal of sediment by wind action during desiccation). It is also important to note that the inherent errors associated with radiocarbon dating of detrital charcoal could account for some of this hiatus evidence. However, without additional dates, we cannot evaluate these potential errors. Thus, at face value, the age data suggest either/or periods of non-deposition, erosion (hiatuses), or slow deposition during two intervals in the Holocene. These intervals are highlighted on Figure 4, characterized by sedimentation rates of 0.01 cm.yr-1 (Figure 4). Interestingly, the timing of these events, interpreted here as prolonged periods of aridity (or drying), are in approximate agreement with the Late Holocene Dry Period identified throughout the western United States (*17-20*) and an early-to-mid Holocene dry period identified in coastal southern CA (Lower Bear Lake, Lake Elsinore), the Mojave Desert (Silver Lake), and the CA Central Valley (Tulare Lake) (*11, 18, 21, 22*).

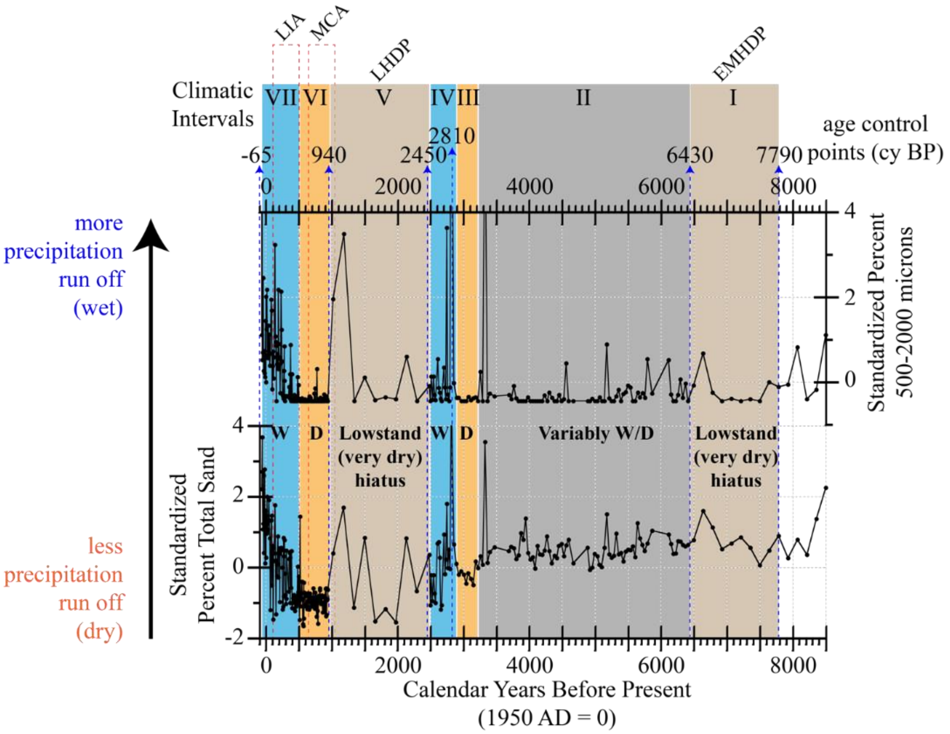

**Figure 5. Percent total sand and 500-2000 micron sand plotted versus age in calendar years before present. Climatic Intervals I-VII highlighted in various colors. Age control points are shown by dashed blue lines. W = wet; D = dry. LIA = Little Ice Age / MCA = Medieval Climatic Anomaly timing as defined by (*39*). LHDP = Late Holocene Dry Period (*19*). EMHDP = Early-to-mid Holocene dry period.**

In Mediterranean climates such as the Pacific Southwest United States (pswUS), the mobilization and transport of sediment, particularly coarse sediment (i.e., sand size), is strongly linked to precipitation-related runoff (*23-29*). Modern and historical (i.e., 20th century) research on the rivers of the pswUS confirms this strong connection to climate at both interannual and multi-decadal timescales. Scaling up, it is reasonable to conclude that hydroclimatic processes control the sediment mobilization signal at centennial to millennial timescales for the study region as well (*23, 30*). This sediment-climate connection is caused by increases in river discharge, which enhances the transport of coarse sediment during individual wetter-than-average winters (*23, 24, 26, 30*). With these modern studies in mind, (*21*) compared percent sand, Lake Elsinore lake level, San Jacinto River discharge, and the Pacific Decadal Oscillation (PDO) index over the 20th century. Their analysis revealed that small changes in sand content (generally < 15-20 %) shows a positive correlation with the San Jacinto River discharge, Lake Elsinore lake level, and the PDO index. The PDO is a multi-decadal oscillation of Northeast Pacific sea surface temperatures, which act to modulate the position of winter storm tracks across the western United States (*9, 31*). In other words, greater river discharge (and higher lake levels) are associated with higher sand content and vice versa. A similar 20th century comparison between percent sand and river discharge was observed for Zaca Lake, also in the pswUS (*17*).

From these modern and 20th century studies, we contend that the predominant driver of changes in coarse sediment in pswUS lakes is hydroclimate, particularly variability in winter season precipitation linked to overall winter wetness. Therefore, we interpret higher percent total sand as reflecting greater precipitation-related runoff (i.e., intensity and/or storm duration) and vice versa. We cannot assign a specific wetness value to percent sand; however, we can use changes in percent sand as a scaling tool for relative changes in wetness. In other words, higher percent sand content is interpreted to reflect relatively wetter conditions and vice versa for lower percent sand. Therefore, throughout the discussion below, we use low percent sand values to infer intervals of diminished runoff and thus drier climates and vice versa for high percent sand (*17, 21, 32, 33*).

Using this grain size interpretation, we divide the Ford Lake grain size data into seven climatic intervals beginning at 7790 cy BP (Figure 5): I) a very dry early-to-mid Holocene dry period (7790-6430 cy BP), II) a variably wet/dry mid Holocene (6430-3200 cy BP), III) a dry interval (3200-2850 cy BP), IV) a wet interval (2850-2450 cy BP), V) a very dry Late Holocene Dry Period (2450-940 cy BP), VI) a dry Medieval Climatic Anomaly (940-500 cy BP), and VII) a wet Little Ice Age through Modern (500 cy BP-modern). However, a lack of age control younger than 940 cy BP cautions a direct correlation between intervals VI and VII to the MCA and LIA.

Although our age model is based on only five data points, the approximate agreement between Climatic Intervals I and V with other regional evidence for significant Holocene aridity provides some confidence that our age model is appropriate. As mentioned above, the timing of climatic intervals I and V, interpreted here as prolonged periods of aridity (or drying), are in approximate agreement with the Late Holocene Dry Period identified throughout the western United States (*17-20*) and an early-to-mid Holocene dry period identified in coastal southern CA (Lower Bear Lake, Lake Elsinore), the Mojave Desert (Silver Lake), and the CA Central Valley (Tulare Lake) (*11, 18, 21, 22*). Moreover, the Medieval Climatic Anomaly (MCA) and the Little Ice Age (LIA) have been identified as dry and wet, respectively, at a variety of lake sites in the coastal southwest US, including sites within the Mojave. These similarities across the region

**Table 1. Radiocarbon dates. Ages used for the age model are highlighted in light orange.**

| UCIAMS # | Sample name | Average Depth (cm) | Fraction Modern | ± | D$^{14}$C (‰) | ± | $^{14}$C age (PB) | ± | Material Dated | Used for age model? | Upper 2 sigma | Lower 2 sigma | median probability (Calib v 7.1) | Relative area under probablity distribution | Sedimentation rate (cm/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Surface | 0 | | | | | | | | yes (upper surface) | | | -65 | | |
| 163592 | FLPC15-1 21-22cm | 21.5 | 1.257 | 0.002 | 256.7 | 2.0 | -1830 | 15 | seeds | no - reworked verbena | | | | | |
| 163593 | FLPC15-1 56-58cm | 57 | 1.081 | 0.002 | 81.2 | 1.7 | -625 | 15 | seeds | no - reworked verbena | | | | | |
| 163594 | FLPC15-1 87-89cm | 88 | 1.086 | 0.002 | 86.2 | 1.7 | -660 | 15 | seeds | no - reworked verbena | | | | | |
| 163595 | FLTR15-1 119-120cm | 119.5 | 1.031 | 0.002 | 30.7 | 1.9 | -240 | 20 | root | no - root | | | | | |
| 163596 | FLPC15-1 173-175cm (0.28mgC) | 174 | 0.880 | 0.002 | -120.2 | 1.6 | 1030 | 15 | charred wood/wood | yes | 961 | 927 | 944 | 1.000 | 0.17 |
| 163597 | FLPC15-1 194-196cm (0.056mgC) | 195 | 1.109 | 0.003 | 109.0 | 3.5 | -825 | 30 | woody material/roots? | no - root | | | | | |
| 163598 | FLPC15-1 211-212, 213-214cm (0.021mgC) | 212.5 | 1.068 | 0.010 | 67.6 | 9.8 | -520 | 80 | charred wood/woody material or roots? | no - root | | | | | |
| 202437 | FLTR16-1 44-46cm | 45 | 1.081 | 0.002 | 81.0 | 2.5 | modern | | Large seed or woody piece - reworked | no - reworked | | | | | |
| 202432 | FLPC16-1 182-186cm (0.033mgC) | 183.5 | 0.742 | 0.004 | -258.4 | 4.3 | 2400 | 50 | fine charcoal pieces | yes | 2542 | 2341 | 2452 | 0.749 | 0.01 |
| 202433 | FLPC16-1 204-208cm (0.021mgC) | 206 | 0.716 | 0.007 | -283.7 | 7.0 | 2680 | 80 | fine charcoal pieces | yes | 2992 | 2697 | 2805 | 0.950 | 0.06 |
| 202434 | FLPC16-1 221-222cm (0.075mgC) | 221.5 | 1.033 | 0.003 | 33.0 | 3.1 | modern | | woody piece; root or aquatic (suspected as bad when picked) | no - root | | | | | |
| 202435 | FLPC16-1 304-308cm (0.017mgC) | 306 | 0.497 | 0.011 | -503.1 | 11.2 | 5620 | 190 | fine charcoal pieces | yes | 6805 | 5989 | 6426 | 0.984 | 0.03 |
| 202436 | FLPC16-1 313-318cm (0.013mgC) | 315.5 | 0.422 | 0.017 | -577.8 | 17.0 | 6930 | 330 | fine charcoal pieces | yes | 8411 | 7166 | 7787 | 1.000 | 0.01 |

**Notes:** Radiocarbon concentrations are given as fractions of the Modern standard, D$^{14}$C, and conventional radiocarbon age, following the conventions of Stuiver and Polach (Radiocarbon, v. 19, p.355, 1977).

Sample preparation backgrounds have been subtracted, based on measurements of $^{14}$C-free wood.

All results have been corrected for isotopic fractionation according to the conventions of Stuiver and Polach (1977), with d$^{13}$C values measured on prepared graphite using the AMS spectrometer. These can differ from d$^{13}$C of the original material, and are not shown.

**Comments:** These samples were treated with acid-base-acid (1N HCl and 1N NaOH, 75°C) prior to combustion.

The large uncertainties for the FLPC16-1 182-186cm, 204-208cm, 304-308cm and 313-318cm results are due the very small sample sizes.

Samples labeled "Modern" contain excess 14C, probably from mid-20th century atmospheric thermonuclear weapons tests.

To convert fraction Modern to calendar age go to http://calib.org/CALIBomb/

suggest that the Ford Lake site captures both the MCA and the LIA signals. For example, Lake Elsinore (*21*), Cronese Lakes (*2*), Silver Lake (*34*), Zaca Lake (*17*), and Abbott Lake (*35*) all indicate a wet LIA. Conversely, evidence for a dry but variable MCA is inferred at Cronese Lakes (*2*), Zaca Lake (*17*), and Abbott Lake (*35*).

Finally, there is ample evidence for human activity and occupation in the immediate vicinity of Ford Lake (*36*). As a remote water source in the eastern Mojave Desert, Ford Lake likely served as an important resource patch for early humans. Our new data suggest that Ford Lake existed on and off – as a viable and reliable water source – for at least 8650 calendar years. If accurate, this result suggests that Ford Lake may contain a longer human occupation record than surmised from the existing artifacts (*36*).

Our results suggest that water availability in the Mojave Desert is related to the same large-scale ocean-atmosphere dynamics that we have inferred for other Holocene California sites. This spatial coherence between disparate sites suggests that any future climate change that reduces winter precipitation in California will also reduce winter precipitation in the Mojave Desert. Climate models project a shift to a more arid southwest United States (*37, 38*). As an already water-stressed region, the delicate and niche-based ecosystem of the Mojave Desert likely faces a challenging future. How we choose to manage this future as a society remains an open question.

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*Acknowledgements*

Thank you to Dr. Troy Ford and the Ford Family for access to their homestead site. Funds for this project were provided by the Western National Park Association (Grant #15-03).

# Video technologies aid in the study of foundation plants: A case example using a shrub-annual facilitation system in the Mojave Desert

Jenna Braun [1]

The use of camera traps to study animal interactions has been increasing among ecologists. Already popular with hunters and land managers, camera traps are particularly useful for observing rare and elusive species because they can be deployed for long periods of time. They are commonly equipped with infrared and motion sensors, therefore are excellent for observing nocturnal animal behaviour. Camera traps are less likely to influence animal behaviour than live-trapping, as documented by research on rodent behaviour in the Mojave Desert reporting that live-trapping provided significantly different results than observational study with cameras (*1*). Newer camera models have video capability which improves data quality over static photo captures because they record complete behaviours and their duration. Video also provides multiple, dynamic views of an individual which facilitates more accurate species identification.

My colleagues and I have used video camera traps to examine the behavioural response of foraging animals along a gradient of fine-scale variation in density of *Ephedra*, a foundation plant in the Mojave Desert. Shrub cover can influence predation risk for rodents (*2*); therefore, we expected to see density-dependent foraging preferences. The use of video traps over photos or live-trapping allows for the measurement of behaviour duration as well as estimating frequency of visitation. Another advantage of video camera traps is that they record predator behaviours in the same location over time scales that cannot be achieved in situ (day vs. night, seasonal, etc). We have been able to capture video of both prey (rabbit) and predator (bobcat) species in the same location (Figure 1), and we have also observed small rodents engaging in florivory on an annual *Cryptantha* in the understory of *Ephedra* (Figure 2). These interactions between animals and shrubs, however, represent a minor subset of the complex interactions that function simultaneously to structure desert ecosystems and maintain biodiversity, the study of which is more challenging than simply recording pairwise interactions (*3*).

Shrubs are ubiquitous features on the Mojave Desert landscape and constitute the dominant physiognomic structure. These foundation plants positively influence the ecosystem by creating locally stable conditions for other species (*4*). Positive interactions between plant species, collectively termed facilitation, are fundamental processes driving plant community structure and dynamics (*5*). The most frequently documented mechanism of shrub facilitation is through the moderation of temperature extremes (*6*). Previous research from the Mojave Desert has documented additional mechanisms including improved understory soil fertility (*7, 8*) and water availability (*7*). These facilitative effects of desert shrubs often lead to concentrations of annual plants beneath the shrub canopy (*9*). If these annual plants flower, there is the potential for the shrub to alter pollinator visitation to the annual plants (Figure 3). This indirect interaction

**Figure 1. Camera traps can be used to study how predator-prey interactions are influenced by shrub density. Here a bobcat (*Lynx rufus*) and cottontail rabbit (*Sylvilagus audubonii*) use the same inter-shrub space at different times of day.**

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pathway is rarely examined in arid environments despite the substantial capacity for it to alter the annual's reproductive success. Here, I summarize our current research on facilitation mechanisms of foundation plants in the Granite Mountains area of the Mojave Desert made possible by the use of passive video technologies.

*Larrea tridentata* supports nearly 120 pollinator species, the second largest pollinator guild of any North American plant (*10*). During the bloom period *L. tridentata* continuously opens new flowers providing a stable source of nectar and pollen to pollinators even in years of drought (*11*). In the Sonoran Desert, *L. tridentata* has been shown to improve the recruitment of other desert perennials such as *Opuntia leptocaulis* (*12*) and *Peniocereus striatus* (*13*), and in the Mojave Desert, studies show that it facilitates co-occurring annuals (*14, 15*). *Larrea tridentata* and desert dandelion (*Malacothrix glabrata*), an annual in the Asteraceae, have overlapping bloom periods in the spring (*16*). We used these species as a model system to study how pollination services to annual plants are affected by physical association with a foundation shrub and how the effects change as the benefactor (*L. tridentata*) begins to bloom.

In desert ecosystems a substantial challenge to studying interactions between co-flowering plant species is the relatively short blooming period in any given area. There is only a narrow time frame in which to set up an experiment and achieve the replication required for scientific conclusions. Quantifying pollinator visitation is time intensive, particularly if visitation rates are low overall and insect pollinators are too small to trigger camera traps. To overcome these issues, we used Polaroid Cube+ video recorders to capture continuous HD videos (1080 p) of pollinator activity on potted transplants of *M. glabrata* (Figure 4). The use of video recordings to extend replication has also been used to study pollinator associations with cushion plants, such as *Silene acaulis* (*17, 18*). This approach also decreases physical interference by the observer as the Cubes are only three $cm^3$ in size.

**Figure 2. Video camera trap screenshot showing a nocturnal rodent engaging in florivory of *Cryptantha* sp. associated with *Ephedra*.**

Each study day, I placed six potted transplants just inside the canopy edge of *L. tridentata* and six pots two meters away in the open. A total of 60 pairs were tested prior to *L. tridentata* blooming, and the same 60 pairs were retested after *L. tridentata* had entered into full bloom. The cover and diversity of the naturally occurring annual community was recorded (Figure 2). The videos were supplemented with traditional in-situ pollinator observations to *L. tridentata*. Pan traps were set out each study day in the morning and collected in the early evening throughout the study period to track the arthropod communities.

At the study site located on the property of the Sweeney Granite Mountains Desert Research Center I was able to capture 303 observation hours within 20 sampling days. From the videos it is possible to count the number of flowers each individual pollinator visits even when multiple pollinators are foraging simultaneously. Additionally, measuring the precise duration of each visit can be easily achieved, which can be difficult *in-situ*.

There are several potential scenarios that may be revealed by the analysis of the pollinator visitation dataset. Shrubs are much larger than annuals and they may offer shelter or habitat to pollinators resulting in higher rates of pollinator visitation to understory annuals under the shrub. Alternatively, annuals growing under shrubs could be physically obscured from foraging pollinators thereby reducing visitation. For example, one study showed that shading by the shrub *Lonicera* decreases pollinator visitation and pollen deposition to its understory annuals (*19*). When *L. tridentata* and *M. glabrata* co-bloom there are additional effects that could arise from the foraging preferences of pollinators. Some plant species are considered "magnet species" because they are particularly attractive to pollinators; these magnet species can increase local pollinator abundances which also benefit their less attractive neighbours (*20, 21*). Flowering desert shrubs may act as magnets for the co-blooming annual understory because they offer conspicuous concentrations of floral resources for foraging pollinators. Conversely, *L. tridentata's* large floral display may concentrate pollinators, reducing visitation to the understory. Therefore, the balance of positive and negative interactions may be dependent on timing and there may be pressure for *M. glabrata* to time its blooming to avoid or coincide with *L. tridentata*. If *L. tridentata* reduces overall pollinator visitation to the annual understory throughout the season, then this may represent a previously unknown 'cost' of direct shrub facilitation. Alternatively, if *L. tridentata* generally improves pollinator visitation to annuals, then the shrub-annual association may be more beneficial than previously thought. Disentangling the mechanisms of positive and negative interactions that function simultaneously is critical to understanding the processes that determine consequences for plant fitness, e.g. net pollination outcome, within the shrub-annual relationship.

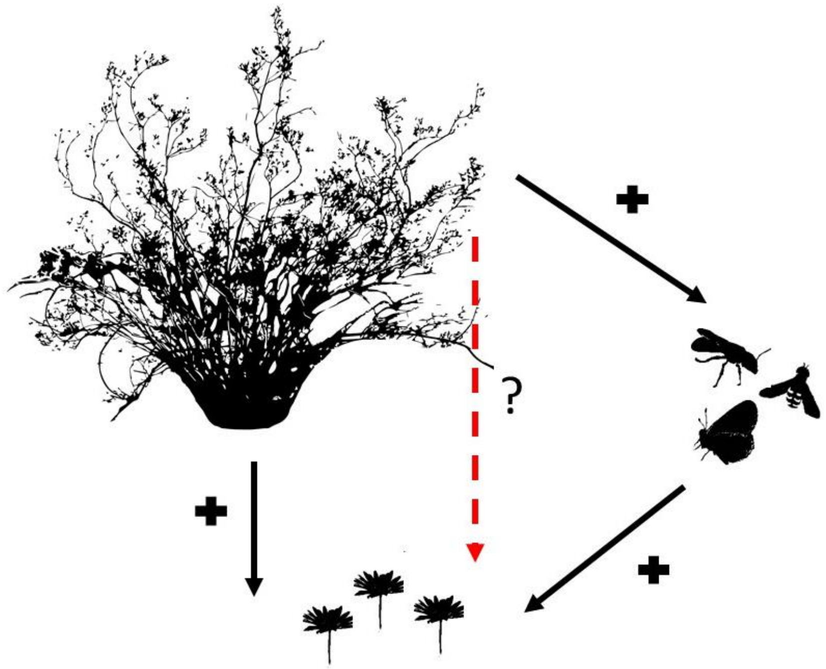

**Figure 3. Direct (solid) and indirect (dashed) interactions occur simultaneously in natural communities. In the Mojave Desert, shrubs directly facilitate annuals by providing shelter from harsh climate conditions. Shrubs also support pollinators by providing floral resources and pollinators directly benefit annuals. Shrubs can simultaneously alter pollinator visitation to the annuals resulting in an indirect positive or negative interaction.**

Decreases in the price and size of video recording and data storage devices has increased the capacity for using video technologies for a variety of research questions in the Mojave Desert. These methods are simple, effective and are likely to rapidly improve our understanding of complex multi-trophic interactions. Especially in arid environments where foundation shrubs act as keystone facilitators by offering direct and indirect benefits for associated plants, pollinators and animals (*6*), we can now document and understand those benefits even better, a necessary step to meeting the rising conservation challenges in the Mojave Desert.

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**Figure 4. We used Polaroid Cube+ video cameras to record pollinator visitation to *Malacothrix glabrata*. This method substantially increases the number of replicates that can be observed within a single day.**

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*Acknowledgements*

I would like to thank Dr. Christopher Lortie for his support and expertise in the design of these studies. I would also like to thank the Sweeney

# Scientific serendipity at Granite Mountain leads to description of novel ant hunting behaviors of spiders

Madison Sankovitz[1] and Jessica Purcell[1]

Scientific discovery can be a quirky thing. Some projects are grounded in well-developed theory and still don't pan out, while other spontaneous and serendipitous observations can lead to the discovery of a novel phenomenon. Two research groups from UC Riverside visited the Sweeney Granite Mountains Desert Research Center (Figure 1) for an academic retreat in October 2017. In the process of exploring the area and observing the many flora and fauna that the beautiful Mojave Desert has to offer, we stumbled upon an astonishing scene. A tiny drama played out at the entrance of a harvester ant (*Veromessor pergandei*) colony. We witnessed at least a dozen spiders (*Euryopis californica*) near this entrance an hour or two after sunset. Several spiders were actively attacking ants, and a close inspection revealed many silk-wrapped worker ants near the colony entrance. Since we were fortunate enough to have some expertise in both ants and spiders within the group (Figure 2), we realized that we were observing an unusual phenomenon, and we began to document our observations carefully. We did this by filming and photographing all interactions between the ants and spiders as well as noting and cataloging the observed behaviors. We also disrupted various interactions to determine whether the aggressor spider would resume its attack. Before leaving we collected spiders and ants for later identification.

After identifying the spiders and ants and conducting a literature review, we concluded that we had, indeed, observed a previously undescribed interaction. We wrote a note detailing the predation, and it was published in The Pan-Pacific Entomologist (*1*) along with beautiful illustrations by graduate student Amanda Hale (Figure 3). In general, predation of ants is relatively rare because ants tend to taste bad and to be very good at collective defense.

**Figure 1. An example of typical mixed succulent scrub found at the beautiful Granite Mountains Desert Research Center. Photo: M. Sankovitz.**

Readers might be familiar with the vigorous defensive behavior of ants if they have ever mistakenly stepped on an ant nest! To combat this protection, predators tend to employ highly specialized strategies. For example, horned lizards that feed on harvester ants avoid being stung by their prey by encasing them in a thick coat of mucus as soon as the ant enters the mouth.

Our observations revealed several behaviors that mitigate risk for the attacking spiders. First, we were intrigued to see a group of spiders around just one ant colony, although there is no shortage of harvester ant colonies around Granite Cove. We inspected several other ant nests in the area to confirm that the spiders were aggregating. Even though individual spiders appeared to attack alone, attacking the same colony may be a strategy that allows spiders to overwhelm the workers with simultaneous attacks. This strategy may also enable both successful and unsuccessful hunters to potentially reap the benefits of the attack. In addition, this attack by the spiders occurred in the evening, when temperatures had cooled and there were relatively few slow-moving worker ants around the nest entrance. This timing could both increase the chances of successful attacks and decrease the danger faced by predators. The attacks themselves consisted of spiders quickly immobilizing ants in silk and then biting to inject venom into their prey. Interestingly, the immobilized and moribund ants were then removed from the area by the spiders; we proposed that this was another behavior that would minimize the risk of a counter-attack by the ants. Many of the behaviors that we observed were similar to attack behaviors observed in other *Euryopis* spider species attacking other ant species, but most of these were observed in Europe. Thus, our study generalizes the evidence that *Euryopis* spiders specialize in consuming

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[1] University of California, Riverside

ants and have several interesting strategies to do so successfully. Additionally, it is a good starting point for investigating the possible ecological effects of this spider predation, a topic that has been studied in other species.

We were thrilled that our first academic retreat provided an opportunity to observe and describe a novel behavior. This became a fun, team-building exercise since five graduate students and one professor wrote the article together. The experience also reminded us how many things we don't yet know about the desert. Even at an excellent research station, there are still new biological phenomena awaiting discovery. The inhospitable appearance of the desert masks an amazing diversity of life with unique adaptations to the high temperature and low moisture extremes. The fact that these conditions are challenging to people means that there is much to learn about desert species.

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**Figure 2. Our team of researchers at Granite Cove. Left to right: Jay Arehart (visiting from CU Boulder), Elisa Henderson, Tierney Bougie, Prof. Alan Brelsford, Prof. Jessica Purcell, Amanda Hale, Mari West, Daniel Pierce, and Madison Sankovitz. Photo: M. Sankovitz.**

**Figure 3. *Euryopis californica* spider dragging a *Veromessor pergandei* worker. Illustration by Amanda Hale.**

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**Sweeney Granite Mountains Desert Research Center**

**Mojave National Preserve Science Newsletter is produced and published by Sweeney Granite Mountains Desert Research Center and the Division of Science and Resource Stewardship, Mojave National Preserve, National Park Service.**

**Archived at:**

http://www.nps.gov/moja/learn/science-newsletter.htm