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Fog and dew impacts the hydrological balance in a montane chaparral community

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Research Article

Keywords: dew deposition, evapotranspiration, eddy covariance, stable isotope, water balance

Posted Date: April 18th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1399511/v1

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Abstract

The dry climate of southern California chaparral can cause substantive water stress on ecosystems that limits productivity throughout the year. From the mid-20th century, fog-days have happened less frequently and with decreasing levels of thickness in southern California (Witiw & LaDochy 2008), yet summer fog and higher winter precipitation have been found as key factors that explain the compositional diversity of the maritime chaparral community (Vasey et al. 2014). While the meteorological impact of fog lessens surface radiation in chaparral, the seasonal influence of year-round fog events on chaparral species remained uncertain. In particular, the effect of fog and dew on chaparral water supply and water stress has not been well understood. This includes for chamise (*Adenostoma fasciculatum*) and redshank (*A. sparsifolium*), two common, co-occurring species in semi-arid montane chaparral communities of southern California. Evaluating evapotranspiration, precipitation, and fog and dew from an eddy covariance tower system we estimated seasonal daily contributions of fog and dew water in a watershed at Sky Oaks Biological Field Station Reserve, California, USA, from May 2019 to April 2020. A leaf wetness sensor (LWS) measured the amount of water deposited during fog conditions or dew events, showing the highest deposition and longest duration in spring, and the lightest and shortest fog and dew presence during summer. The fog and dew water deposition typically peaked between 00:00 and 06:00 and totaled 97.3 mm y^{-1} during the study period. Despite the low fog and dew deposition rates in the summer (20.5 mm) it was the only season when the amount of fog and dew water was greater than precipitation (10.3 mm). Based on stable isotope measurements, chamise absorbed more water from atmospheric sources (rain and fog + dew) than redshank across seasons, yet redshank had a higher foliar uptake capacity for liquid water than chamise in laboratory tests. This study suggests that the importance of fog and dew as a water source is species dependent, and that fog and dew water input may influence community structure and overall water balance in semi-arid shrublands. The intensity and frequency of fog and dew occurrence under future climate conditions may therefore be important to the future structure and functioning of this chaparral ecosystems.

Introduction

While fog inputs have been studied extensively in some ecosystems, a study of year-round fog and dew deposition in semi-arid shrublands such as the southern California chaparral is absent. Chaparral occurs in semi-arid regions of North American with a Mediterranean-type climate (Rundel 2018) and is a water-limited ecosystem (Mooney 1989). In arid and semi-arid regions of the world, fog and/or dew can represent a substantial portion of the hydrological input (Ingraham and Matthews 1995, Dawson 1998, Corbin et al. 2005, Fischer et al. 2009, Ewing et al. 2009, Ritter et al. 2009, Roth-Nebelsick et al. 2012, Wang et al. 2019). In particular, it has been shown to be important in fog-dominated desert ecosystems like the coastal Namib desert (Hachfeld & Jürgens 2000, Shanyengana et al. 2002) or the high-altitude Chilean Atacama Desert (Cereceda et al. 2008). And fog can modulate climate through effects on net solar radiation and humidity. For communities that are severely limited in productivity by water and nutrient availability, fog and dew can provide an important alternative source of water in addition rainfall

and snow melt, soil storage, and groundwater (Eller et al. 2013, Gotsch et al. 2014). Fog and dew can also be a vector for nutrient deposition and uptake (Templer et al. 2015, Weiss-Penzias et al. 2016, Weathers et al. 2020).

Fog impacts the terrestrial water balance by suppressing evapotranspiration with lower vapor pressure deficit (VPD) and through reductions in temperature and radiation. Water can directly enter a plant through absorption by the leaves, or indirectly when the canopy accumulated fog or dew water drips onto the soil surface (Dawson 1998, Weathers et al. 2020). Direct and indirect water input from fog or dew can help mitigate plant stress during drought (Ingraham & Matthews, 1995, Dawson 1998, Burgess & Dawson 2004, Corbin et al. 2005), increasing soil moisture and therefore soil metabolic processes, leading to increased ecosystem respiration and productivity. Because fog prevalence occurs in large semi-arid and Mediterranean areas, (Dawson 1998, Fischer et al. 2009), fog can have significant contributions to the stand water balance and may reduce ecosystem water loss (but see Burgess & Dawson 2004).

The regional climate model of coastal fog based on 20th century reanalysis demonstrates a recent decline in fog and a projected similar decline in the future (Snyder et al., 2003, IPCC, 2007, O'Brien 2011, O'Brien et al. 2013), though there are large uncertainties associated with under-representation of terrestrial, atmospheric, and oceanic interactions in the model. Specifically, the decrease of fog amount and duration in southern California is likely related to the Pacific Decadal Oscillation and sea surface temperatures along the eastern North Pacific (LaDochy & Witiw 2012, Schwartz et al. 2014). Any decrease in plant moisture, whether from decreasing precipitation, fog, or dew or from increased evapotranspiration, that affects ecosystem productivity, may impact southern California's floristic richness and diversity (Raven & Axelrod, 1978, Corbin et al. 2005, Fischer et al. 2009, Coates et al. 2015, Pivovaroff et al. 2016) and has the potential to shift the location of suitable endemic species.

Eddy covariance can be used to determine fluxes of CO_2, water vapor and energy. However, few studies have compared water use determined by eddy covariance to water inputs from rainfall, fog and dew and measurements of fog and dew moisture inputs to montane chapparal systems are rare. This study is designed to determine how seasonal dependence of fog and dew water impacts the water balance in a montane chaparral community near San Diego, California.

Our main objectives are to:

1. determine the annual water balance of montane chaparral by comparing evapotranspiration (ET) to precipitation and fog and dew water input
2. compare the effect of fog and dew on temperature, relative humidity (RH), VPD, and PAR that control chaparral gas exchange
3. compare stable isotope ratios in the xylem water to those measured from the rain, fog + dew, and groundwater to find the seasonal proportions of different water sources supporting the two endemic species

Materials And Methods

Site Description

The study was conducted at Sky Oaks Biological Field Reserve Station (see Fig. 1) located about 70 km east of the Pacific Ocean in San Diego County, California, USA (33°22'29.4"N, long. 116°37'16.0"W, elevation ~ 1400m a.s.l.). The local climate is Mediterranean, characterized by long hot and dry summers, and cool, moist winters. The study site is within a mosaic landscape of montane chaparral characterized by a varying fire history, and has been burned twice, once in 1997 and again in 2002 (Luo et al. 2007). *Adenostoma fasciculatum* (Hook. & Arn.), *Adenostoma sparsifolium* (Torrey), and *Ceanothus perplexans* (Trel.) are the dominant woody vegetation in the community.

There are several potential processes that cause fog formation at this location. Radiation fog forms primarily overnight from radiative cooling of the surface and near-surface layer of the atmosphere. Fog can form when the cooled air reaches saturation (Price 2019). It is typical for radiation fog to form during the fall and winter. Fog will not form if the temperature is above the dewpoint temperature. Upslope fog is a common fog type at higher elevation. Wind moves moisture rich air upslope and, as it rises, it expands and cools adiabatically. If the dewpoint is reached, fog can form. Similar to fog, dew forms when surface temperature is lower than or equal to the dew point temperature; however, it is more likely to form under calm conditions or in the absence of floating particles upon which water vapor can condense (Agam & Berliner 2006). Unfortunately, our approach could not separate fog from dew formation. Where we cannot separate the water input, or where the processes are similar, we will use the term “fog and dew”.

Environmental measurements

Most micrometeorological variables were measured every 10 s and averaged for half-hour periods. The instrumentation used included Vaisala temperature and humidity probes (HMP45C, Vaisala Inc., Helsinki, Finland) to measure relative humidity and air temperature at 5.8 and 2.5 m and a quantum sensor to determine photosynthetically active radiation (PAR; LI-190SB, Li-COR Inc). Precipitation was measured by a tipping rain gauge (TR525, Texas Electronics Inc., Dallas, TX, USA) at 2.3 m.

Evapotranspiration measurements

Evapotranspiration (ET) was derived from the latent heat flux determined by eddy covariance above the canopies from 17-May-2019 to 16-May-2020 (Baldocchi et al. 1988). The eddy covariance instrumentation included a three-dimensional sonic anemometer (Windmaster Pro, Gill Instruments Ltd., Lymington, Hampshire, UK) for the high-frequency (10 Hz) wind components and temperature and an open path analyzer (LI-7500, Li-COR Inc., Lincoln, NE, USA) at 4.5m above ground surface for the concentrations of water vapor. The raw water vapor fluctuations were then recorded as mean voltages, multiplied to the requisite calibration constant, then converted to densities (Vourlitis & Oechel, 1997). The vapor, energy, and momentum fluxes were calculated with a coordinate rotation of the vertical and lateral wind vectors and stored using a CR23X datalogger (Campell Scientific Ltd., Logan, UT, USA) on an offline server, the 400 s running mean was used to compute 30 min averages with digital recursive filtering

technique (McMillen, 1988). Continuous eddy covariance calculations were made with flux computation from high-frequency raw data performed with the EddyPro® software (v.7.0.6). These half-hourly values for ET averaged into hourly intervals then summed on daily time steps (mm H_2O m^{-2} d^{-1}).

Data gaps were primarily caused by power and data transmission outages and by data rejection following quality assessment during data processing. We removed unrealistic flux values and non-compliant conditions in post-processing. Gap-filling was performed with the 'ReddyProc' (v.1.2.2) package in 'R' (v.4.0.4) and Rstudio (v.1.4.1106). Gaps in ET were filled using the mean diurnal variation technique, an interpolation wherein the missing data are replaced with the adjacent days mean value at that time of day. We chose a 7-day window to fill daytime gaps and a 14-day window for nighttime gaps (Zhao & Huang 2015). The data in the measurement period was processed on standard seasons for the year, divided into summer (June 1st to August 31st), autumn (September 1st to November 30th), winter (December 1st -February 29th), and spring (March 1st to May 31st).

Fog and dew measurements

We quantified fog and dew input by the accumulation of water vapor on a Leaf Wetness Sensor (LWS, Campbell Scientific, Inc.®; Logan, UT, USA) which is designed to measure the dielectric conductance of the sensor's upper surface. The sensor has a 2500 mV excitation voltage that produces an output voltage ranging from 250 mV for a dry sensor to 1250 mV for a submerged sensor. In the laboratory, a calibration curve was developed by fitting a nonlinear regression that best described the relationship between the output voltage from the LWS and varying water film thicknesses (mm of H_2O). This relationship was used to find the combined fog and dew deposition in the field. We multiplied the total stand LAI to the LWS to find the calculated fog and dew added on an aerial basis.

Stable water isotope analysis

Fog and dew are typically enriched in heavier isotopes compared to groundwater and rainfall in the same area (Ingraham & Matthews 1995). Rainfall samples collected before and during this investigation were used to create a local meteoric water line (LMWL) described by the equation:

$\delta^2H = 7.71\ \delta^{18}O + 10.7$ (Eq. 1)

From 17-Sep-2018 to 16-Aug-2019, we analyzed the stable isotope ratios of hydrogen and oxygen for various water pools in the local watershed, including fog and dew water, rainwater, snow, groundwater and xylem waters extracted from the two plant species, chamise and redshank. A fog collector (Fischer et al. 2009) erected 2 m off the ground consisted of vertically oriented monofilament fishing lines (ShurStrike® 1/8 lb) to form a cylinder harp. The collector arms were extended in four cardinal directions and had a round `roof ' to exclude rainfall from being mixed with the fog water collected. Fog accumulated on the fishing line and dripped into a trough that directed water into an air-tight 2 L high-density polyethylene (HDPE) bucket. A layer of > 1 cm mineral oil was added to the container to prevent evaporation of fog water between sampling periods from causing subsequent isotopic fractionation (Scholl et al. 2010). Samples were transferred to 2-mL glass bottles with poly-seal caps and kept frozen

at about 0°C until analyzed. Additionally, groundwater samples (sample below 100m) were collected from a well previously implemented at the site and in conjunction with isotope sampling from the Temecula USGS well site. Stable isotope compositions of precipitation and groundwater samples were analyzed with a LGR spectroscopy liquid water isotope analyzer (Los Gatos Research Inc, CA, USA) at San Diego State University. Stable isotope ratios were expressed in delta notation (‰ or per mil) traceable to the Vienna Standard Mean Ocean Water (V-SMOW).

Non-photosynthetic tissues were removed from chamise and redshank and fitted into an airtight glass vial. We used cryogenic vacuum distillation (West et al. 2006) to extract xylem water from the plant tissue, after which the water was shipped to the University of California, Berkeley for stable isotope analysis. The samples were collected from three individuals from each species once a month for almost a year (n = 66).

The proportional use of plant source water was found using the two-compartment linear mixing model of Phillips & Gregg (2001). The mixing model assumes that water comes from two isotopically distinct sources (i.e. fog + dew/rainwater vs. ground water).

$$\mathrm{P}_{\mathrm{fog+dew/rain}} = \frac{\delta^{18}\mathrm{O}_{\mathrm{vegetation}} - \delta^{18}\mathrm{O}_{\mathrm{groundwater}}}{\delta^{18}O_{\mathrm{fog+dew/rain}} - \delta^{18}\mathrm{O}_{\mathrm{groundwater}}} \text{ (Eq. 2)}$$

Recent studies suggest that a cryogenically extracted sample introduces an artificial evaporation signal in deuterium (Chen et al. 2020, Allen & Kirchner 2021); so we chose to use the oxygen isotope.

Foliar uptake capacity

On 23-May-2019, we determined the capacity for foliar water uptake for each species by excising shoots and measuring the direct water absorption (Limm et al. 2009). Young and mature leaves were collected from seven individuals of each species 2h after sunset under typical conditions for fog and dew formation. The surface of the stem was sealed with the adhesive Parafilm M® No. 807-6 to prevent moisture loss from the exposed end during the measurements.

In the laboratory a leaf was weighed, completely submerged for 180 minutes under water, patted dry and weighed again. To measure and potentially correct for the effectiveness of completely removing excess water on the leaf, the same leaf was briefly air-dried and weighed. It was then briefly submerged, patted dry and weighed again according to the Limm et al. (2009) protocol. ImageJ (US National Institutes of Health, Bethesda, Md.) captured the total leaf area and standardized the foliar uptake capacity per cm^2 of leaf area. The leaf water uptake capacity (LWC) per leaf area was calculated. We used a one-sample t-test ($\alpha = 0.05$) to determine if a leaf sample absorbed significantly more than 0 mg water cm^{-2}.

Results

We found the total number of hours for rain and fog + dew for the site (see Fig. 2). A rain event was recorded when the tipping rain bucket presented a signal over 0 mm. The presence and duration of fog

and dew was measured by the LWS and was only considered when there was no measurable precipitation by the tipping rain bucket. During the spring season, rainfall events occurred most frequently in the month of March (n = 4.8 d). Rain was at its lowest in the summer, with no rainfall in June or August and its occurrence in the month of July being only 4.5 hr. Rainfall duration, overall, ranged from 0.2–4.8 d in a month. Conversely, fog and dew were 3.5 × greater than rain occurrence and occurred throughout the year. Fog and dew occurrence was also at its most prevalent in the spring, with March showing the most with 312 hr. Summer was also the season with the least amount of fog; its appearance in August being only 4 hrs.

Climatic variables under foggy and clear conditions

For the study period, the presence or absence of fog correlates with hourly temperature, RH, vapor pressure deficit (VPD), and daytime PAR, during foggy and clear sky periods (see Fig. 3). During the measurement period, VPD significantly differed with a mean of 0.2 and 0.1 kPa under foggy and rainy periods compared to 1.9 kPa under clear periods. Through the year, the mean PAR was reduced considerably to 155 ± 3.2 (foggy) and 119 ± 7.9 (rainy) compared to 516 ± 5.4 μmol m^{-2} s^{-1} during clear periods. RH mirrored but was temporally delayed from this pattern with the highest values between 17:00 and 19:00. Fog and dew and rain occurrences are typically associated with high RH values (85.7 ± 25.9, 90.9 ± 36%) (see Fig. 3) while clear periods had a mean RH of 30.8 ± 14.3%. Overall, these results indicate that fog and dew correlated with an indirect impact on the watershed budget in reduced transpiration demand from the vegetative canopy.

Diurnal patterns of the total amounts of ET, rain, and fog plus dew

The range of wetness conditions produced a LWS probe output voltage ranging from 256 to 715 mV in the laboratory. LWS voltage increased non-linearly as the water content increased (see Fig. 4). Changes in LWS output voltage were strongly correlated to the measured water content on the sensor (fog and dew (mm) = $8.8 \times 10^{-7} mV^2 - 2.6 \times 10^{-5}$ mV − 0.036, $r^2 = 0.95$, p-value < 0.001). The mean diurnal voltage output was converted to calculate water content using this laboratory-derived equation. From May 2018 through April 2019, the LWS was deployed at the field site and used to continuously measure the wetness conditions in the chaparral stand.

Annual daily evapotranspiration of the chaparral stand peaked with 44 mm at 11:00, whereas fog and dew deposition peaked at 6.7 mm at 04:00 (see Fig. 5). Though rainfall might not typically have a diurnal pattern, we found that rainfall occurred mostly during the daytime in all the seasons. The nocturnal (20:00 to 08:00) ET contributed up to 21% of total annual ET and was most pronounced in spring at 32%, and lowest in the summer with 11% of the total annual ET fluxes. During the study year, nearly 70% of the total fog and dew deposition occurred nocturnally (see Fig. 5 to define nocturnal), with a slight seasonal difference, ranging from 68% in the summer to 79% in the spring respectively, of fog and dew water accumulation at night. fog and dew frequently occurs from 18:00 to 09:00 and had the most amount

from midnight until morning (00:00 to 06:00) and lightest in mid-afternoon (≈ 14:00) (Fig. 5). Though there seems to be an additional, smaller peak for ET at midnight, this could be explained because of the high seasonal fog and dew deposition. Daytime ET had no strong variation comparing the seasons, but afternoon ET in the spring was the highest while nighttime was lowest in summer. Overall, fog and dew water accounts for ~ 25% of the total water input for the study period (see Fig. 6). From the perspective of a simple water balance, this chaparral system had a net water loss of 86.1 mm in summer and 14.7 mm in winter respectively; there was a net water gain of 39.8 mm in autumn and 58.8 mm in spring. The influx or the combination of rain and fog and dew amount to 25.7 mm in summer, 109 mm in autumn, 85.3 mm in winter and 187.4 mm in spring. Nearly all seasons had higher values of rainfall than fog and dew deposition, except for summer where rain was 5.2 mm and fog and dew water was 20.5 mm. Overall, there was a net water loss of 2.3 mm from the system.

Stable water isotope analysis

The stable isotopic signature for two types of source water (fog, dew and rain versus groundwater) and xylem water from the two chaparral species (chamise and redshank) varied throughout the season during May 2018 – April 2019 (see Fig. 7A). The isotopic mixing model calculation shows that throughout the year, while both species rely on groundwater, chamise's water uptake is more seasonally dynamic and more susceptible of switching to the fog, dew and rainwater source if it becomes available (see Fig. 7B). Two general patterns were noted from the isotope analysis:

1. Redshank has a stronger reliance on groundwater throughout the year. This species' dependence on groundwater was only slightly reduced when surface water was more readily available during the peak wet season in winter.
2. Chamise displays a seasonal resilience in its water uptake from fog, dew, and rain waters, with a stronger dependence on groundwater only toward the end of the long, dry season when the most severe drought stress developed in autumn.

During the summer, when fog and dew occurrence was infrequent and duration was limited, redshank obtained between 53–86% of its water (mean = 67%) from groundwater. In spring and winter, when fog, dew, and rainwater were more available, fog, dew, and rainwater accounted between 40–62% with a mean of 52% of chamise's total water use. Autumn and spring showed similar patterns of water acquisition, with spring showing the highest reliance on groundwater, obtaining between 68–88% (mean = 76%) of groundwater. Autumn had the heaviest reliance on groundwater for chamise, yet between 27–36% (mean = 31%) was fog, dew, and rainwater. Only in winter did redshank use fog, dew, and rainwater of a comparable proportion to the groundwater as chamise, with a mean of 59 ± 10%. Redshank consistently relies heavily on groundwater, with a mean proportion > 70% of its total water use throughout the year.

These analyses showed that (1) chamise displays a stronger dependence on groundwater in intensive, water stress conditions, but otherwise had no apparent seasonal dependence for either source and (2) redshank strongly relied on groundwater throughout the year though when rainfall or fog and dew otherwise occurred in the peak wet season, the grou ndwater dependence abated.

Foliar uptake capacity

Redshank exhibited significant foliar uptake capacity during the 180-min submergence in the laboratory ($p < 0.05$) (see Fig. 8) while chamise was not significant in foliar uptake ($p > 0.05$). The latter consistently showed negative values for uptake.

Discussion

It appears that fog and dew input have been underestimated when comparing total water sources in the chaparral of southern California. For example, during our study period, total fog and dew water amounts to about a fourth of annual water input at this site. As the high mountain ridges that parallel the coast generally block fog from entering the interior, it is especially important that cooling surface temperatures allow dew formation. When dewpoint temperatures or relative humidity rise sufficiently (dew point temperatures are higher than surface temperatures), water vapor begins to condense. This is particularly prominent for montane chaparral in the spring. In the winter, the total amount of fog and dew remains the same, however fog and dew persists and is present both earlier in the evening and later into the morning compared to autumn fog and dew. Spring fog and dew results in higher deposition of water while sharing similar temporal periods as winter fog and dew. Furthermore, because fog and dew deposition occurs mainly during the morning (Dawson 1998) thereby supporting early morning transpiration.

The pattern of fog and dew utilization is consistent with previous research on root distribution of *Adenostoma* species in that redshank have deeper fine root distribution compared to chamise (Redtfeldt & Davis 1996). Differences in fog and dew water use by the two species is likely dependent on rooting patterns, the physiological demand for water, and how well water can be collected and directed into the shoots (Dawson 1998). The fine root distribution in near surface soil horizon for chamise could explain the stronger reliability on ephemeral fog and dew rather than the more consistent groundwater (Paddock III et al. 2013). Notably, the fine root biomass of redshank has been shown to be highest in the spring (500 g m^{-2}) and lowest in late summer (100 g m^{-2}) matching the high soil moisture levels that occur from fog and dew and rain at the research site (Kummerow 1983). Chamise consistently used precipitation (fog + dew + rain) and groundwater in equal proportions except during the autumn (driest time of the year) when chamise's dependence on groundwater became more apparent. Redshank shows consistent reliance on groundwater year-round, but also appears to be using precipitation (i.e. fog, dew, and rainwater) in the wetter season (winter). Though chamise shows no signs of foliar uptake in our laboratory experiment, it is possible that the architecture of the fascicles (Ju et al. 2012) could have redirected fog and dew water on the leaves into stemflow under field conditions. Differences in the proportion of fog and dew water used by various species is likely determined by the leaf conductivity in rehydration and canopy architecture and direction of fog and dew input to the root system (Dawson & Pate 1996).

As demonstrated by our isotope data, the patterns of seasonal water acquisition by redshank and chamise suggest the potential of other chaparral species may also be using fog and dew water uptake

and such strategy may be more common than previously thought for plants in semi-arid ecosystems and particularly in Californian chaparral communities. It is possible that foliar uptake is advantageous for not just shrubs, but also for herbaceous, understory species. It is telling that higher atmospheric precipitation (fog, dew, and rainfall) utilizing chamise is a dominant, indicator species in nearly all chaparral (McPherson & Muller 1969) while the less surface moisture reliant redshank are considered a remnant of the Holocene era (Wiens et al. 2012).

Climate change models predict a “new normal” of reduced winter precipitation and higher air temperatures for the Southwestern United States (McAfee and Russell, 2008) and increased probability of drought-like conditions throughout the 21st century (Cayan et al. 2010). This places further emphasis on the importance of understanding the patterns of and controls on seasonal water sources and use. Therefore, seasonal fog conditions constraining current evapotranspiration may be lessened in the future due to decreasing fog-events. While previous studies have shown the importance of fog in maintaining ecosystems that range from prairie grasses (Corbin et al. 2005) to redwood forests (Dawson 1998) to the Channel Islands (Fischer & Still 2007) along California shores, it was perceived that southern California “largely lacks regular fog and provides few opportunities for the development of such communities” (Rundel 2018). Fog has been shown critical across diverse ecosystems (Cameron et al. 1997, Weathers, 1999, Burgess & Dawson 2004, Breshears et al. 2008, Scholl et al. 2010, Wang et al. 2019) and shows mitigation of water stress in chaparral communities (Vasey et al. 2012). The total amount of precipitation over the study period was around 408 mm compared to the total amount of fog and dew water 97.3 mm. The fog and dew water input was relatively consistent throughout the year, unlike rainfall which is highly seasonal. While the input of fog and dew water is smaller than rainfall, it still is an important secondary source of water. As climate conditions become drier and conditions preceding fog events such as the Santa Ana winds are reducing in the winter (Hughes et al. 2009) we can expect hydrology for montane chaparral systems to change accordingly.

Declarations

Acknowledgements

We would like to thank the SanGIS for the spatial data used to provide the isohyetal map. Thank you to Pablo Bryant for providing maintenance and support of the Sky Oaks Biological Field Station of the SDSU Field Stations Office. We would like to thank Andrea Fenner and Kyle Lunneberg for maintaining eddy covariance towers, collecting, and reducing eddy covariance flux data, and in advising and reviewing the figures and text and to Dr. Donatella Zona and members of the Global Change Research Group for many helpful discussions and input related to this manuscript.

Funding We would like to thank the funding provided by the National Oceanic and Atmospheric Administration – Cooperative Science Center for Earth System Sciences and Remote Sensing Technologies (NOAA-CESSRST) under the Cooperative Agreement Grant #: NA16SEC4810008, and the San Diego State University Joint Doctoral Program in Ecology.

Conflicts of interest/Competing interests The authors declare that they have no conflict of interest.

Ethics approval Not applicable

Consent to participate Not applicable

Consent for publication Not applicable

Availability of data and material The data was deposited in the Dryad repository under the reference number https://doi.org/10.25338/B8063P.

Code availability The code generated during the study are available from the corresponding author on reasonable request.

Authors' contributions

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Figures

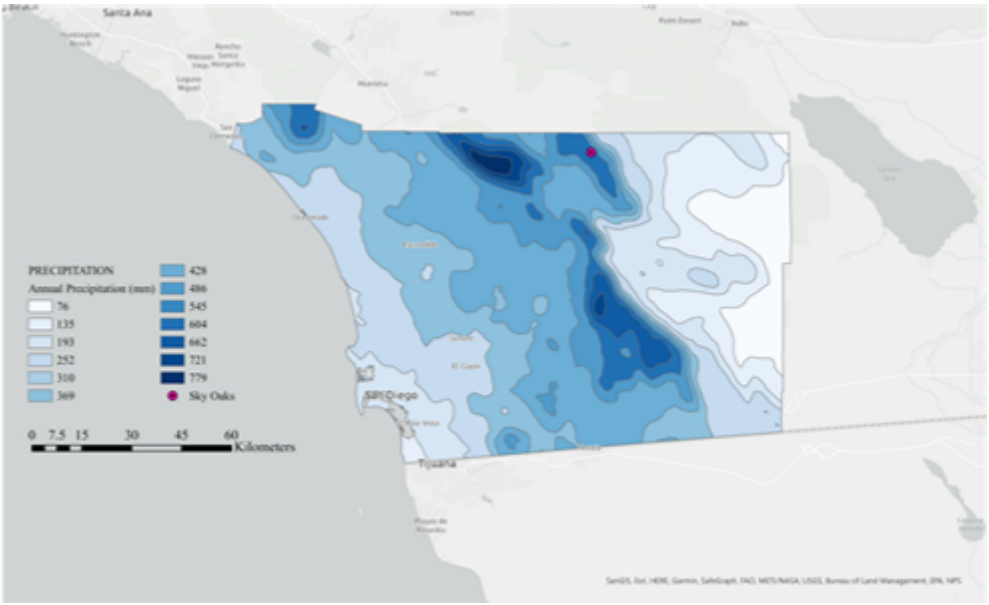


Figure 1

An isohyetal map of the annual mean precipitation (1970-2004) of San Diego County, California, USA.

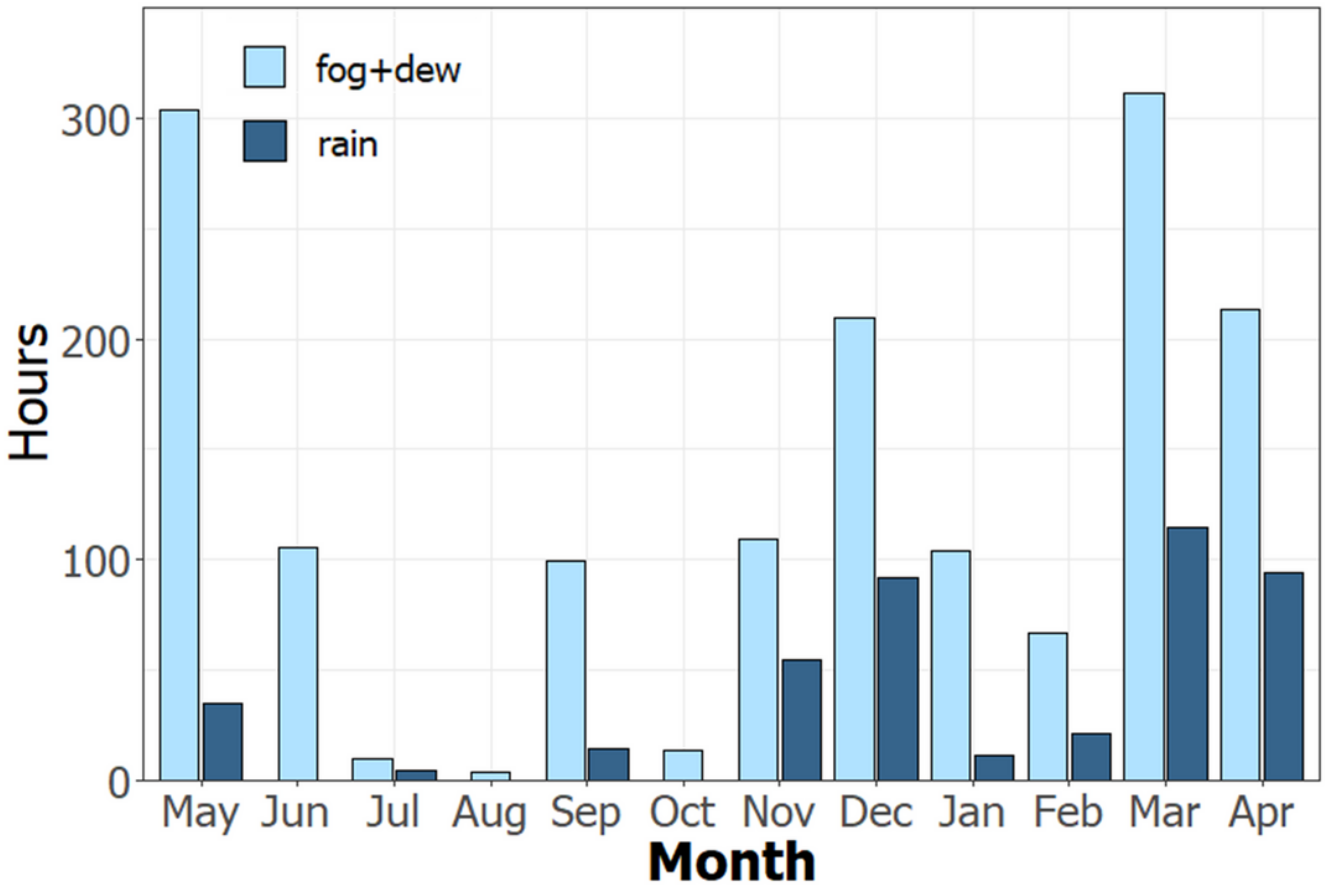


Figure 2

The total number of fog+dew and rain hours for each month for the montane chaparral in San Diego County, California, USA. Fog+dew and rain were determined from the Leaf Wetness Sensor above a threshold of 270 mV and a tipping rain bucket respectively.

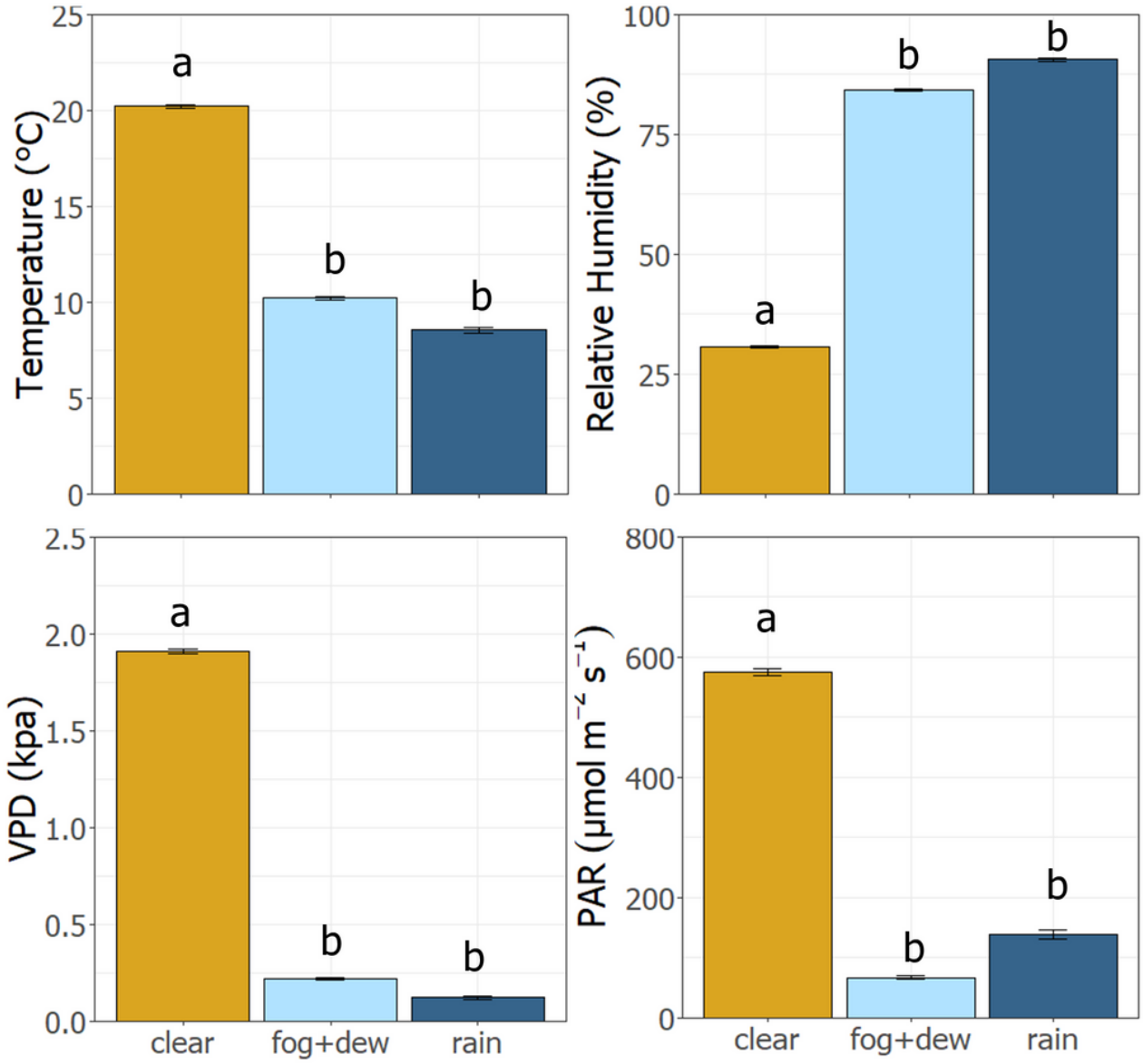


Figure 3

Comparison of meteorological variables indicative of evaporative demand between clear, fog+dew, and rain conditions. Error bars are standard error. Identical letters indicate non-significance.

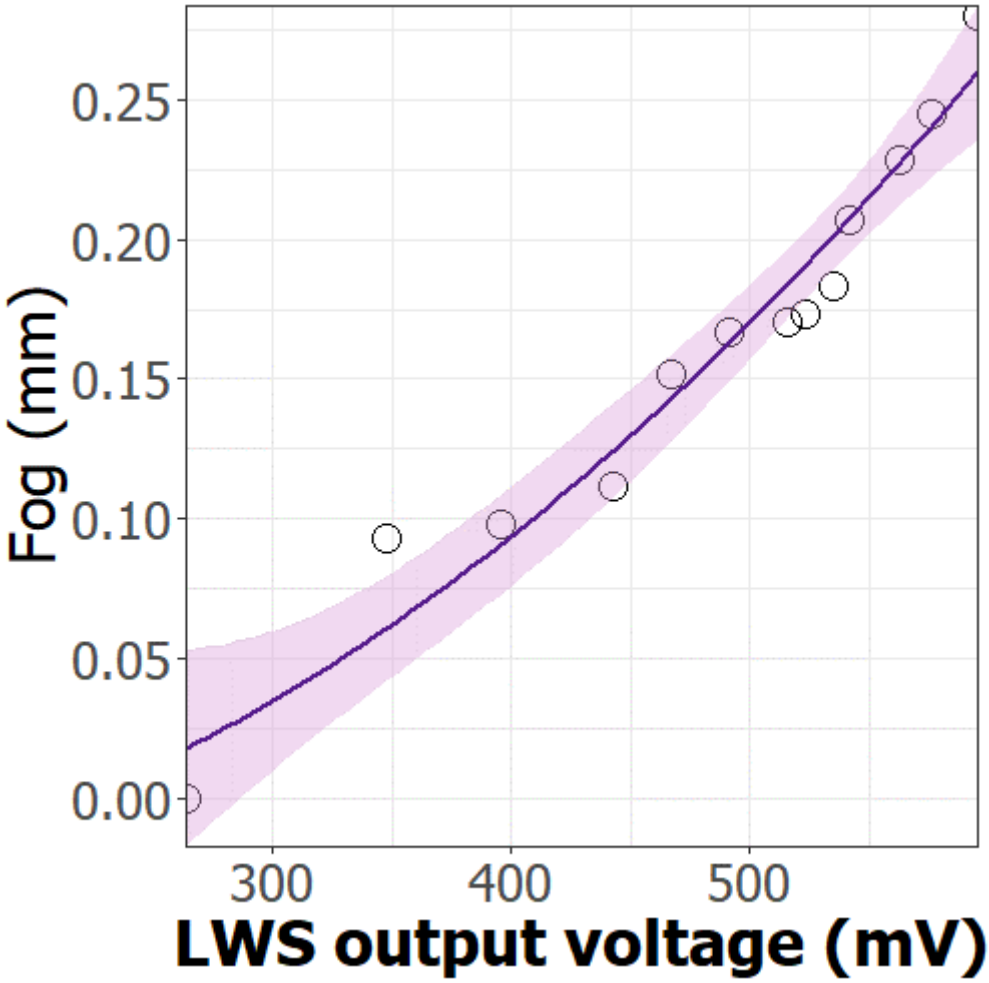


Figure 4

Relationship between leaf wetness sensor output voltage (mV) and fog+dew amount (mm) ($8.8 \times 10^{-7} mV^2 - 2.6 \times 10^{-5}$ mV – 0.036, r^2 = 0.95, p-value = 0.001). Shaded area represents 95% confidence interval of the quadratic polynomial regression estimate.

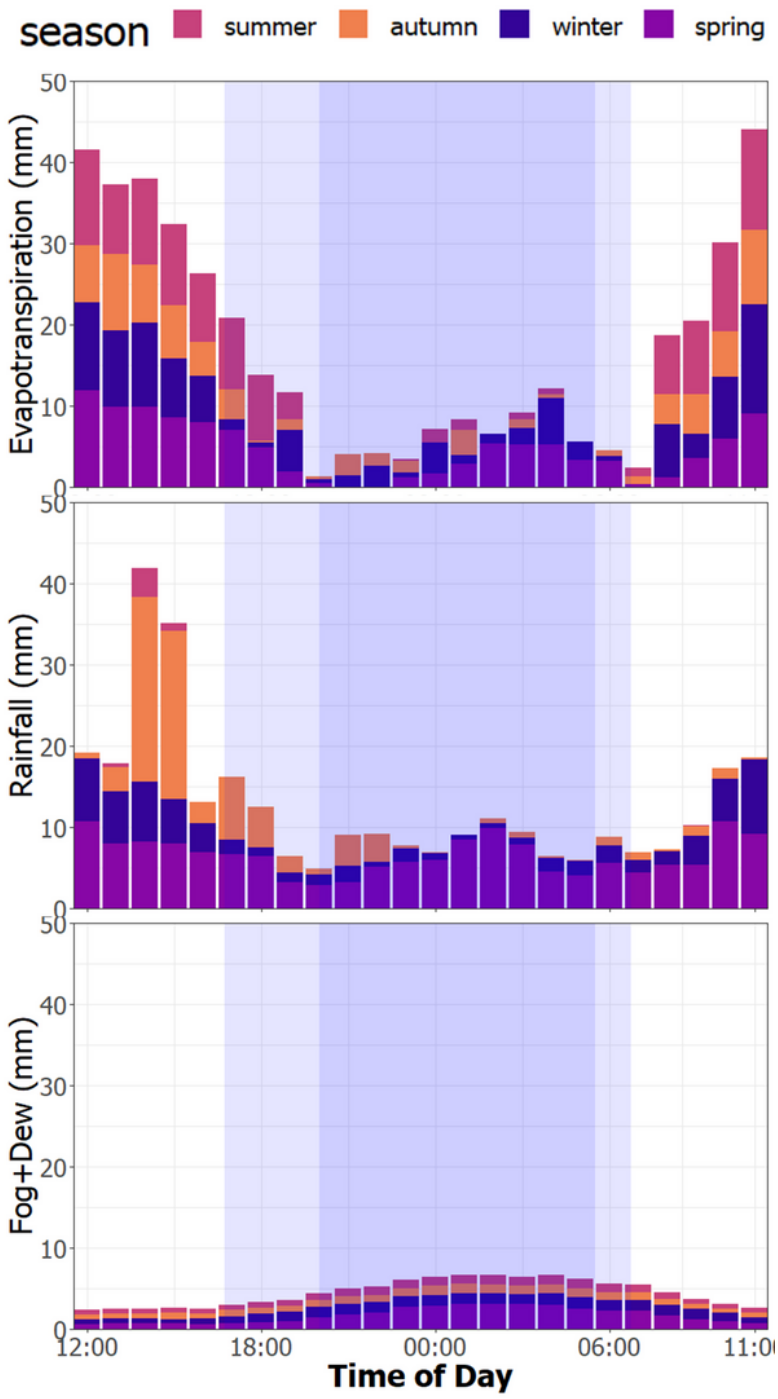


Figure 5

The sum hourly measurements of ET, rain, fog+dew for the year. The site had 65 days of fog and 18 days of rain. The darker shaded area was the minimum summer night (19:59-05:41); the lighter shaded area was maximum winter night (16:46-06:47).

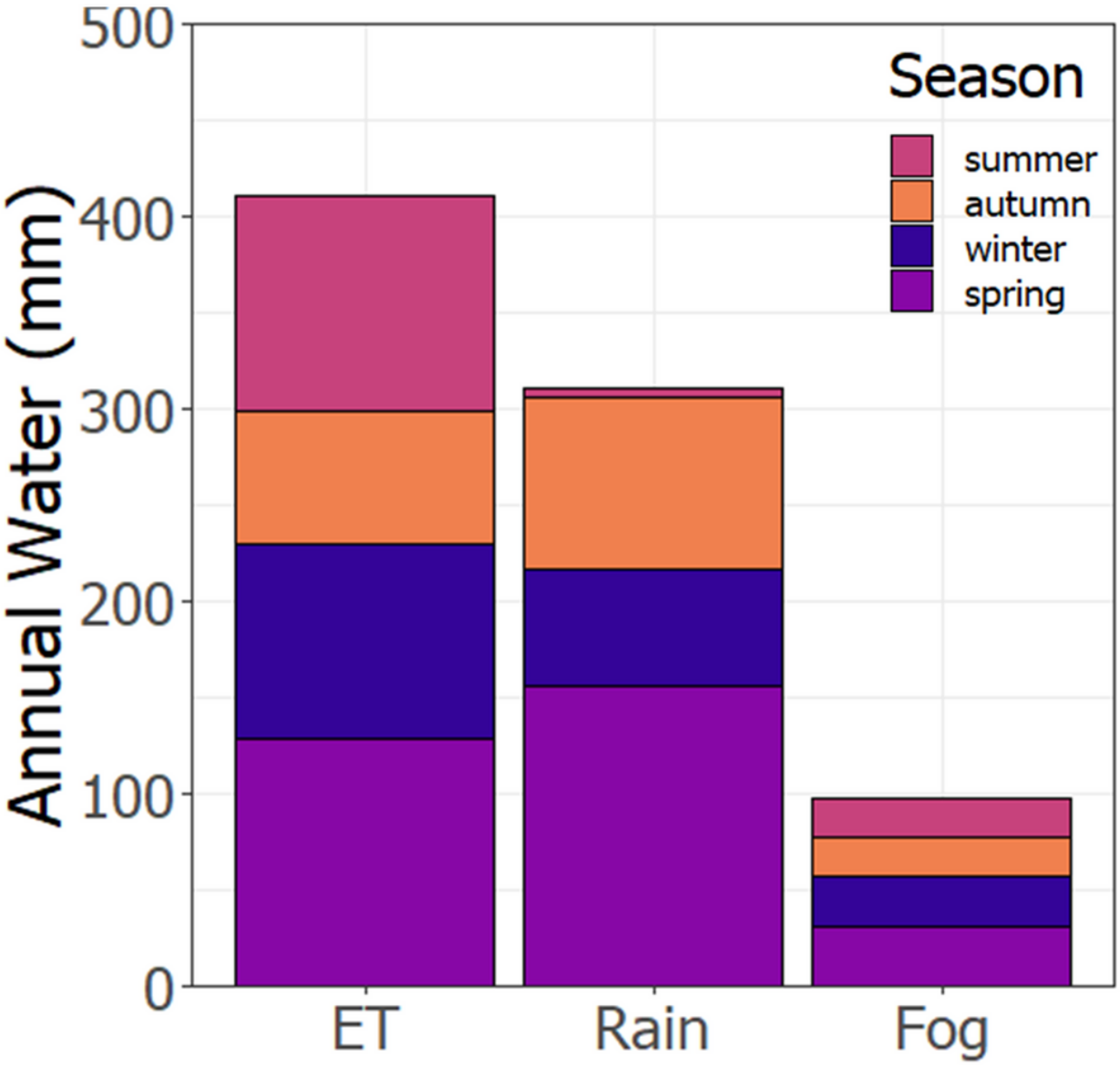


Figure 6

The annual evapotranspiration, precipitation, and fog+dew (mm) found over the course of the study for the chaparral stand from May 2019 to April 2020.

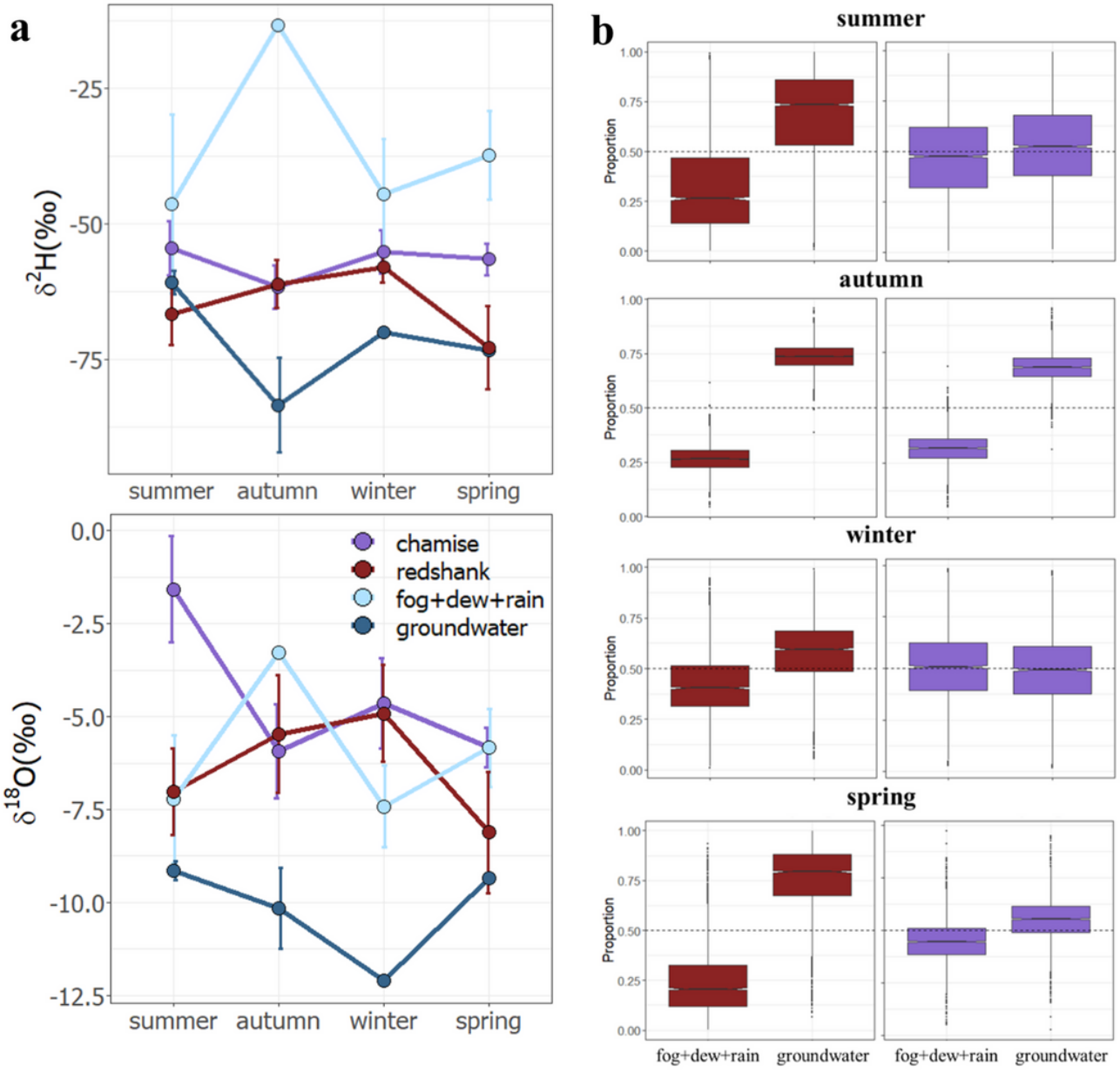


Figure 7

a) The stable isotopic signature of chamise and redshanks compared to the fog+dew+rain and groundwater signatures. **B)**. The hydrology isotope was used to estimate the proportional contribution to plant water use.

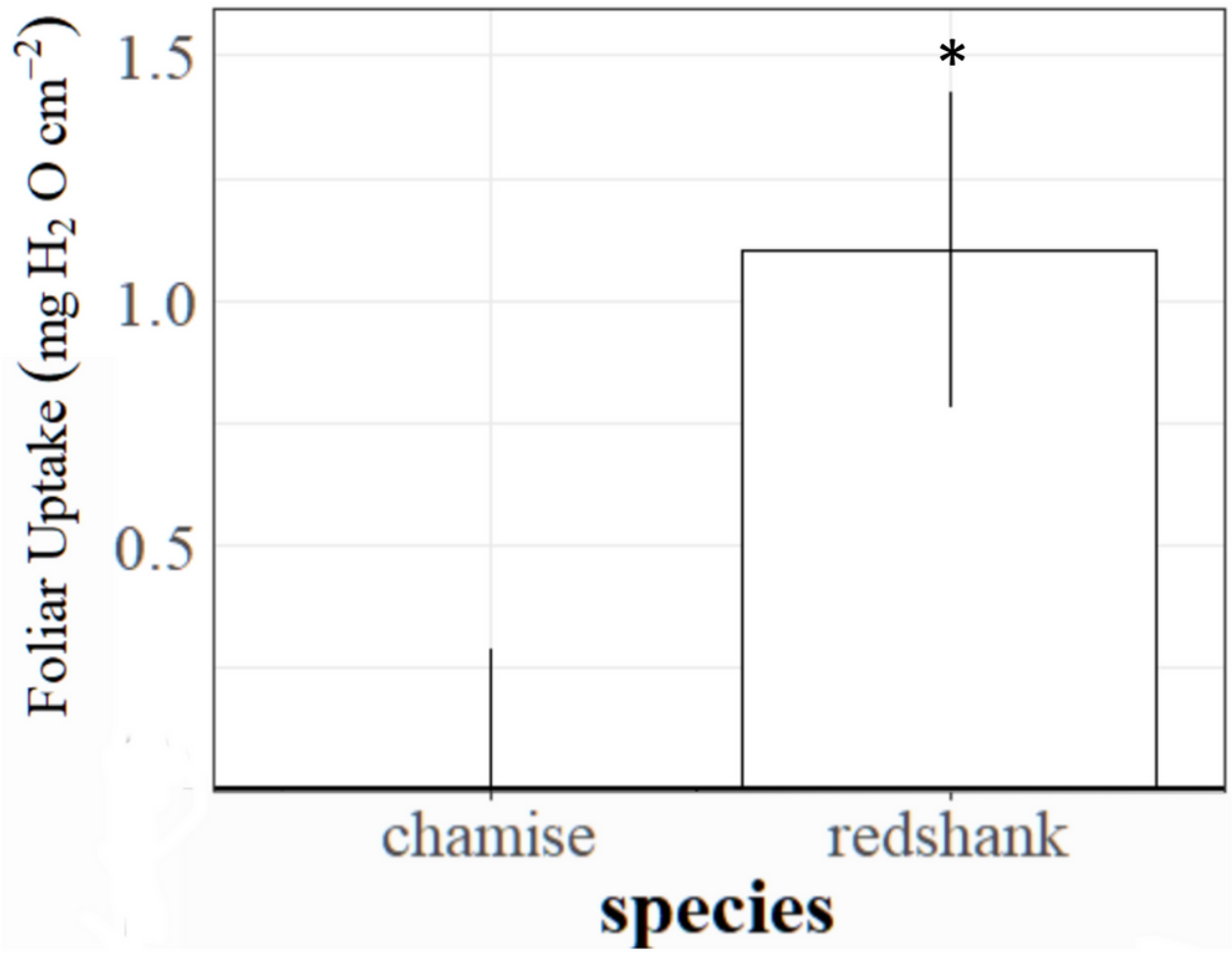


Figure 8

The mean (±SE) foliar uptake capacity of excised photosynthetic shoots of each species standardized by projected area (n=7). The asterisk (*) means p-value < 0.05.