Comparative Analysis of Trait Diversity and Fluxes: Desert Plants vs. Forest Plants

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Abstract

California's status as a biodiversity hotspot, hosting over 4,800 plant species, underscores the importance of understanding water-related plant traits to address ecological stability, climate change adaptation, and biodiversity maintenance. This study explores adaptive differences in water-related traits between California forest and desert plant species, proposing hypotheses that focus on water use efficiency and variability in trait expression. Using a combination of bar graphs and coefficient of variation tests, we assessed traits related to flux and drought resistance in various Californian forest and desert locations. Our results reveal desert plants generally store more water than forest plants and have evolved specialized mechanisms to conserve water, such as thicker cuticles and enhanced succulence. Contrary to initial hypotheses, not all water-related traits showed significant differences between forest and desert species, suggesting convergent adaptation strategies. Our findings provide insights into plant adaptations, emphasizing the balance between water traits and environmental pressures, which has significant implications for conservation and climate change resilience.

Introduction

California is a biodiversity hotspot, with a variety of ecosystems hosting over 4,800 plant species (Allen-Diaz, 2000). This biodiversity is key to ecological stability, impacting water regulation, carbon storage and habitat provision. Understanding water-related traits in plants is fundamental to understanding plant responses to increasingly common stressors, such as drought, and extreme temperatures. Differences in water-related traits between forest and desert plant species affect climate change adaptation, with plant adaptation strategies informing conservation efforts and response predictions. Investigating desert plants' efficient water usage will lead to sustainable agricultural practices by improving drought resistance and optimizing water usage. Moreover, identification and preservation of species with unique adaptations is crucial to biodiversity maintenance, and ecological balance.

Plants diversely adapt to water availability. High-density plant communities typically evolve broad leaves and taller growth structures, while desert plant communities evolve various traits including succulent leaves, and deep root systems. Current theory states these adaptations are primarily driven by environmental pressures, resulting in differences in water-use efficiency, leaf morphology, and root structure between forest and desert species. This is supported by studies, such as Wright et al. (2004), showing leaf economic traits including leaf mass per area, and nitrogen content vary along environmental gradients to optimize resource use. Additionally, Nicotra et al. (2010), highlights the plasticity of plant traits in response to environmental changes, underscoring the influence of environmental factors on plant physiology.

Studying adaptations enhances understanding of biodiversity, which is essential for ecosystem conservation and ensuring resilience to environmental disturbances. Furthermore, insights into plant adaptations inform agricultural practices, leading to development of drought, and stress resistant plants, ultimately contributing to food and economic security.

Research Questions and Expected Outcomes

In the context of our study, we aim to explore the adaptive differences in plant traits across varied ecosystems in California. Specifically, addressing the following questions:

I. Are there major differences in water related traits between California forest species and California desert species?

II. Is there high variability in water-related traits among desert plants?

III. Can traits of desert plants be correlated across species?

IV. Are fluxes more variable for desert plants than forest plants?

Based on the research questions, we propose the following hypotheses for our study:

I. There are major differences in water related traits between California forest species and California desert species.

II. There is high variability in water-related traits among desert plants.

III. The traits of desert plants will be correlated across species.

IV. Fluxes are more variable for desert plants than forest plants.

Materials and Methods

I. Comparing mean traits for differences between desert and forest species (Bar Graph)

   i. We identified traits related to flux and drought resistance, previously provided in Figure 1. We averaged one set consisting of the three California forests found in the dataset (Yosemite Forest Dynamics Plot, Angelo Coast Range Reserve, and San Joaquin Experimental Range) and another set containing the only California desert in the Dataset (Sweeney Granite Mountains Desert Research Center). We then calculated the mean values for the forest and desert groups and compared them using a bar graph. Additionally, we added 10% error bars to the graph to assess whether there was a significant difference between the values. If the error bars overlapped, the difference was considered not significant. We then removed the traits without significant differences and chose traits that had the most preexisting data for acting differently between deserts and forests.

II. Testing trait CVs between desert and forest species (CV Test)

   i. We identified traits related to flux and drought resistance, previously provided in Figure 1. We conducted a Coefficient of Variation test on one set consisting of the three California forests found in the dataset (Yosemite Forest Dynamics Plot, Angelo Coast Range Reserve, and San Joaquin Experimental Range) and another set containing the only California desert in the Dataset (Sweeney Granite Mountains Desert Research Center). We then compared the CV Values using a bar graph and added 10% error bars to the graph to assess whether there was a significant difference between the values. If the error bars overlapped, the difference was considered not significant. We then removed the traits without significant differences and chose traits that had the most preexisting data for acting differently between deserts and forests.

III. Comparing Ecostress evapotranspiration between desert and forests (QGIS)

   i. We took the three Californian forest locations and the one California desert location from the dataset and plotted a square encompassing the areas. We then input the ranges into A*pp*EEARS, using a date range from May 30th to September 30th, 2018-2023, as this roughly outlines the summer months for 5 years. We selected a central date to compare the data, focusing on dates around the Summer Solstice in 2022 (approximately June 20th) at around noon. We then found the highest ET (Evapotranspiration) for each of the four regions and averaged the forests and deserts separately, allowing us to observe that forests generally had higher levels of ET.

Figure 1. Table containing predictions of drought and flux-related reactions for certain traits

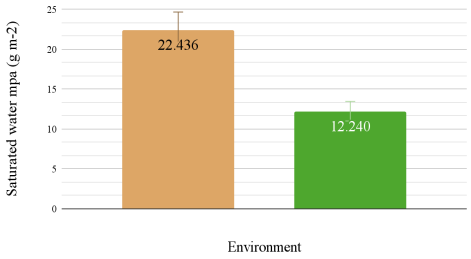
#	Trait	Symbol	Unit	Flux-related traits	Drought resistance
1.	Stomatal area	S	µm2		✓+
2.	Epidermal cell area	E	µm2	✓-	✓-
3.	Maximum anatomical stomatal conductance	Gmax	mmol m-2 s-1	✓+	✓+
4.	Trichome density	TD	n µm-2		✓-
5.	Stomatal differentiation rate	i	N/A		✓+
6.	Leaf area	LA	cm^2	✓-	✓+
7.	Leaf mass per area	LMA	$g\ m^{-2}$	✓+	✓-
8.	Leaf thickness	*LT*	mm	✓+	✓-
9.	Leaf density	LD	$g\ cm^{-3}$		✓-
10.	Leaf dry matter content	LDMC	$g\ g^{-1}$		✓-
11.	Saturated water content	*SWC*	$g\ g^{-1}$		✓+
12.	Saturated water mass per area	*SWMA*	$g\ m^{-2}$	✓+	✓+
13.	Percentage loss area (dry)	PLAdry	%		✓+
14.	Petiole area	*PA*	cm^2	✓+	
15.	Petiole to leaf area ratio	*PA:LA*		✓+	
16.	Wood density	*WD*	$g\ cm^{-3}$		✓-
17.	Huber Value (sapwood area to leaf ratio)				✓+
18.	Nitrogen per leaf mass	N_{area}	$g\ m^{-2}$	✓+	
19.	Carbon isotope discrimination	D13C	‰	✓+	✓-
20.	Carbon 13 isotope concentration	*d13C_per mil*			✓+
21.	Water potential at turgor loss point	π_{tlp}	MPa	✓+	✓-
22.	Electron transport rate per area	$J_{max\ area}$	$\mu mol\ m^{-2}\ s^{-1}$	✓+	
23.	Maximum rate of carboxylation per area	$Vc_{\ max\ area}$	$\mu mol\ m^{-2}\ s^{-1}$	✓+	
24.	Maximum height***	H_{max}	m	✓+	✓-
25.	Diameter at breast height	*DBH*_cm		✓+	✓-

Results

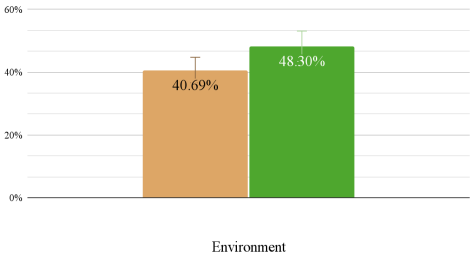
Mean Values

Coefficient of Variation (CV)

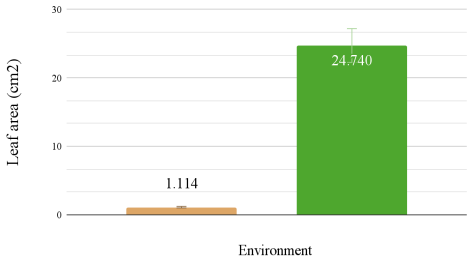
Saturated Water Mass per Area — Fig. 2



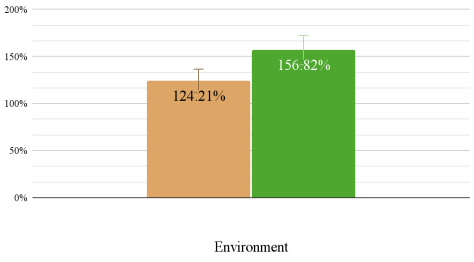
Saturated Water Mass per Area - CV — Fig. 3



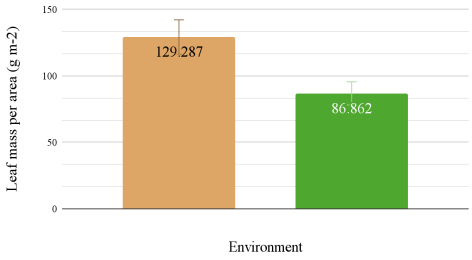
Leaf Area — Fig. 4



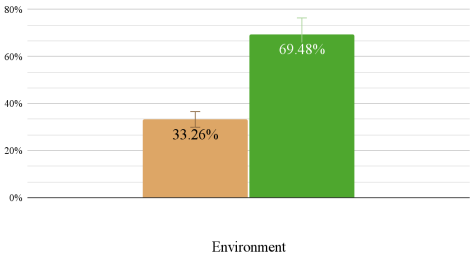
Leaf Area - CV — Fig. 5



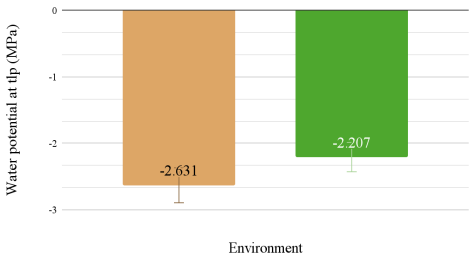
Leaf Mass per Area — Fig. 6



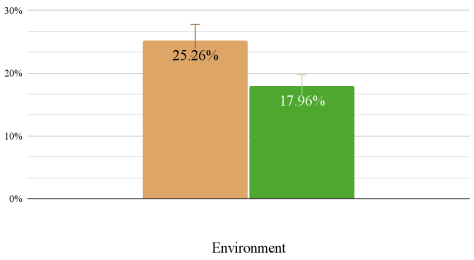
Leaf Mass per Area - CV — Fig. 7



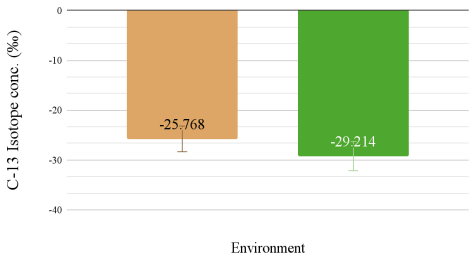
Water Potential at Turgor Loss Point — Fig. 8



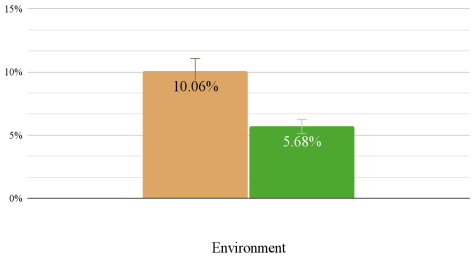
Water Potential at Turgor Loss Point - CV — Fig. 9



Carbon 13 Isotope Concentration — Fig. 10



Carbon 13 Isotope Concentration - CV — Fig. 11



Key

Desert Species

Forest Species

Figure 2. Bar graph showing comparison between Desert and Forest mean saturated water mass per area.	Figure 3. Bar graph showing comparison between Desert and Forest CV of saturated water mass per area
Figure 4. Bar graph showing comparison between Desert and Forest mean leaf area.	Figure 5. Bar graph showing comparison between Desert and Forest CV of leaf area.
Figure 6. Bar graph showing comparison between Desert and Forest mean leaf mass per area.	Figure 7. Bar graph showing comparison between Desert and Forest CV of leaf mass per area.
Figure 8. Bar graph showing comparison between Desert and Forest mean water potential at turgor loss point.	Figure 9. Bar graph showing comparison between Desert and Forest CV of water potential at turgor loss point.
Figure 10. Bar graph showing comparison between Desert and Forest mean carbon 13 isotope concentration.	Figure 11. Bar graph showing comparison between Desert and Forest CV of carbon 13 isotope concentration.

Discussion

Our experiment provides intriguing insights into the adaptive strategies of California forest and desert species, challenging some initial hypotheses while confirming others. As shown in Figures 2-11, desert plants generally store more water than forest plants (Figure 2), supporting the notion that desert species have evolved specialized mechanisms to conserve water, such as thicker cuticles and enhanced succulence. However, the variation in saturated water mass per area (Figure 3) was unexpectedly similar across ecosystems, suggesting that forests also possess considerable internal variability in their water retention strategies. Furthermore, Figure 4 illustrates that desert plants have extremely small leaves to reduce transpiration, while forest plants have larger leaves to facilitate photosynthesis. This observation aligns with Givnish (1987), which proposes that leaf size is crucial for adapting to environmental constraints. Additionally, Figure 5 shows a slightly higher coefficient of variation (CV) of leaf area in forests, pointing to greater structural variability that supports a wide range of light capture strategies, as noted in research by Canham et al. (1990).

Several surprising patterns emerged that deviate from traditional expectations, prompting a reconsideration of some established notions. While we anticipated that forest species would exhibit higher mean leaf mass per area (LMA), Figure 6 indicates that desert species have a greater mean LMA, suggesting denser leaves to minimize water loss. In contrast, forests exhibit higher LMA variability (Figure 7), allowing adaptive responses to diverse microhabitats. Figure 8 shows that deserts have a lower mean water potential at the turgor loss point, reflecting their ability to endure dehydration. This adaptability is underscored by a higher CV of water potential at turgor loss point in deserts (Figure 9), highlighting a more pronounced range of drought resistance strategies. Regarding carbon assimilation, Figures 10 and 11 reveal slightly higher carbon-13 isotope concentration and CV in desert plants, indicating diverse carbon fixation strategies, as corroborated by Ehleringer and Monson (1993). These deviations raise intriguing questions about the evolutionary pressures shaping these adaptations. Future studies could explore the genetic basis of these traits or examine the role of phenotypic plasticity in facilitating adaptive responses, offering deeper insights into the physiological underpinnings of these patterns.

Conclusion

Contrary to our initial hypothesis, not all water-related traits exhibited significant differences between California forest species and desert species, suggesting an intriguing convergence in their adaptive strategies. Desert plants, with their smaller leaves and petioles, are finely tuned to minimize water loss and enhance efficiency in arid conditions. Yet, forest species, with their higher evapotranspiration levels, cycle more water and support greater photosynthesis, indicating a different set of strategies for their lush environments. Despite these contrasts, both ecosystems show similar internal variability in water traits, reflecting diverse approaches to environmental fluctuations. Forests demonstrate more structural variation, while deserts exhibit greater drought tolerance, highlighting the adaptability and resilience of these plant communities. This study illuminates the potential of plants to evolve robust mechanisms for survival across different habitats, reinforcing the delicate balance and intricate interconnections between water traits and environmental adaptations. Our findings provide a nuanced understanding of how these ecosystems function, contributing valuable insights into their complex dynamics and offering a foundation for future research aimed at understanding the implications of climate change on these vital landscapes.

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