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Fog Monitoring on the Point Loma Peninsula at Cabrillo National Monument

2023 Annual Report

Fog partially obscures a landscape of coastal sage scrub at Cabrillo National Monument.
NPS

Fog monitoring on the Point Loma Peninsula at Cabrillo National Monument: 2023 annual report

Science Report NPS/SR—2024/162

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Abstract

Cabrillo National Monument (CABR) is a unit of the National Park System located on the Point Loma peninsula in San Diego, CA, USA. Despite its small size (0.65 terrestrial km^2), the monument attracts 851,000 annual visitors (IRMA SRSS Reports 2011-2020), and acts as an "urban island", providing habitat for unique algal, plant and animal species in an area of increasing development and urbanization. The park is situated in a Mediterranean climate, characterized by hot, dry summers and wet winters. This climate supports rare habitats and plant communities, such as coastal sage scrub, maritime succulent scrub, and southern maritime chaparral. Since most precipitation occurs in the winter, fog and low cloud cover are vital sources of water for the survival of animals and vegetation in the dry summer months. It is unknown how climate change may impact fog dynamics and microclimates at the park. This information is crucial for resource management decision-making. Specifically, to create tailored strategies for future revegetation plans, including the establishment of rare and unique native plants. Thus, we designed and implemented a fog monitoring system consisting of two cameras, four weather stations, and twelve leaf wetness sensors at the park to investigate whether microclimates differ on small spatial scales (< 5 km), including differences in elevational gradient and across sides of the Point Loma peninsula. This report provides the first annual summary of the findings collected from July 2022 to May 2023. Results suggest that the ocean-facing side of the peninsula experiences more fog compared to the bay-facing side and that higher elevations experience less fog.

Acknowledgements

This project was funded in-part by the Cabrillo National Monument Foundation, the Scientists in Parks program, Environment for the Americas, Conservation Legacy, Southern California Research Learning Center, and the Ecological Society of America. We thank these organizations for their support of the National Park Service and for providing opportunities for future generations of scientists. We express sincere thanks to those who have made this program outstanding and contributed to its success.

Introduction

Cabrillo National Monument (CABR) is a unit of the National Park System located at the southern tip of the Point Loma peninsula in San Diego, CA, USA. Since three sides of the park are surrounded by water and the fourth abuts a Navy base, the park acts as an "urban island", providing habitat for unique plant and animal species in an area of increasing urbanization and isolation. Further, the park contains rare and fragile coastal sage scrub, maritime succulent scrub, and southern maritime chaparral habitats (Hudgens et al. 2020). Despite its small size (0.65 terrestrial km^2), the monument attracts 851,000 annual visitors (IRMA, SRSS Reports, mean visitation 2011–2020), and contains a variety of microhabitats with differing vegetation community composition (Appendix 1). High volumes of visitors create social trails and distribute non-native plants throughout the park which require extensive restoration efforts. Due to the high-quality habitats present at the park, it is critical to understand the effects of climate and community composition on restoration success.

The Mediterranean climate at the park is characterized by cool, wet winters and dry, warm summers (Figure 1 and Figure 2). Average annual rainfall at CABR is 24.1 cm (9.5 in), and much of the rainfall occurs between the months of November and March (Figure 2). During the dry summer months, fog is the primary source of moisture. Marine fog is a low-lying cloud that interacts with other factors like ocean evaporation, temperature, and atmospheric pressure. It provides water and decreases solar radiation on vegetation and wildlife (Fischer et al. 2009). Specifically, fog is an important source of water for vegetation in Mediterranean climates, especially during the summer months when there is typically little rainfall and high temperatures. Coastal vegetation is supplied with water and nutrients by fog drip, where water from the condensation of fog moisture on leaves and stems of plants drips into the soil. Animals also use accumulated fog moisture for water on the peninsula because there are no natural sources of fresh water. Fog also cools surface air temperatures, especially on the west coast of the United States (Schwartz et al. 2014). Fog dynamics are relatively unknown and in a warming climate (IPCC 2022), understanding current and future fog amounts, durations, and timing will inform land management in Mediterranean ecosystems.

There are many approaches to fog monitoring, which include both remote monitoring of fog via imagery, and in situ measures of fog water deposition. Methods for remote fog monitoring include the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellite (GOES) observations. GOES data has been used to analyze both high and low cloud/fog cover in coastal California communities and how these factors impact the environment during the dry months of June and September (Torregrosa et al. 2016, Clemesha et al. 2021). Cameras can visually confirm fog presence. Haze presence and absence can be analyzed via image processing. Systems can range from trail cameras, used in this program, or more sophisticated methods with targets placed at a set distance from the camera that become obscured in heavier fog so that fog density can be visually assessed. Some in situ approaches of fog monitoring include the use of leaf wetness sensors, which assess, in mV, the trace amounts of water deposited onto leaves by fog. Fog can also be monitored using a fog harvesting system, which captures water with a mesh net or wire harp and directs the water into gutters underneath the net where it is measured by volume (Kowalski et al. 2021).

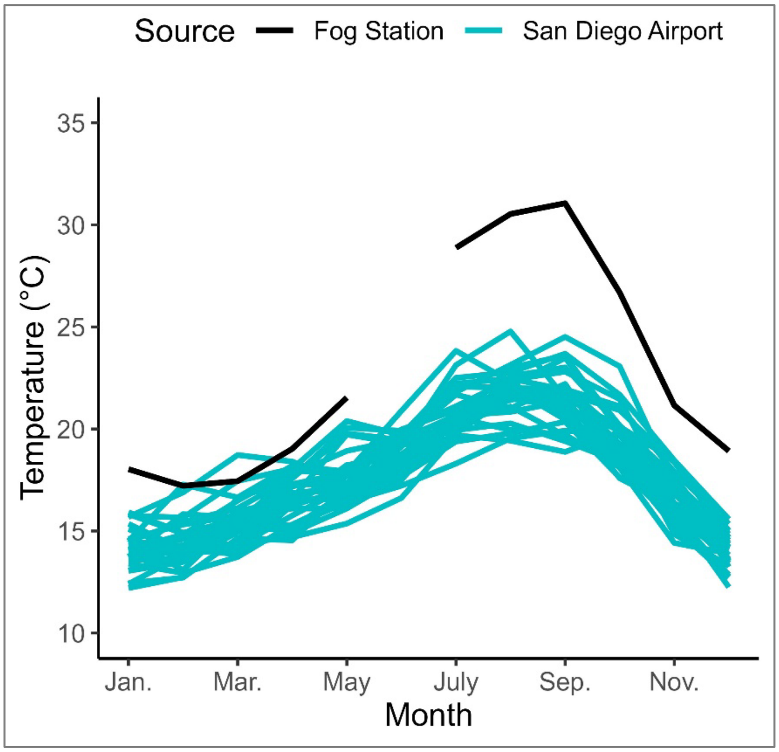

Figure 1. Time series of average temperature (°C) per month across four Fog Monitoring Stations at Cabrillo National Monument (black, 2022-2023) and local climatological data from the San Diego Airport (blue, 1995-2023). Temperatures are warmest between the months of June and October.

Fog data, whether it is measured remote or in situ, can be applied to a variety of natural resource management decisions, most notably vegetation management. Data from fog monitoring programs can be used to design vegetation management plans based on water availability, as well as plan for success in a rapidly changing climate using the Resist-Accept-Direct approach to natural resource management (Schuurman et al. 2020).

Fog monitoring efforts at CABR were started by Dr. Linh Anh Cat, who funded these stations through a National Park Service grant with funding and support from the Southern California Research Learning Center. Four fog monitoring stations were designed, assembled, and deployed at CABR by two Scientists-in-Parks Interns in Summer 2022: Taro Katayama and Brent Wilder (see Fog Monitoring SOP). The stations were deployed in July 2022, maintained monthly by Volunteer-in-Parks Jay Simpson, and the latest data were retrieved by Scientists-in-Parks Intern Virginia Javier in May 2023. This annual report was developed by Virginia Javier and Lauren Pandori in Summer 2023. Data collected are the start to a long-term study to document fog presence and intensity over time. Information gathered is used to evaluate if fog microclimates exist in the park and to guide critical decisions concerning management of rare coastal sage scrub.

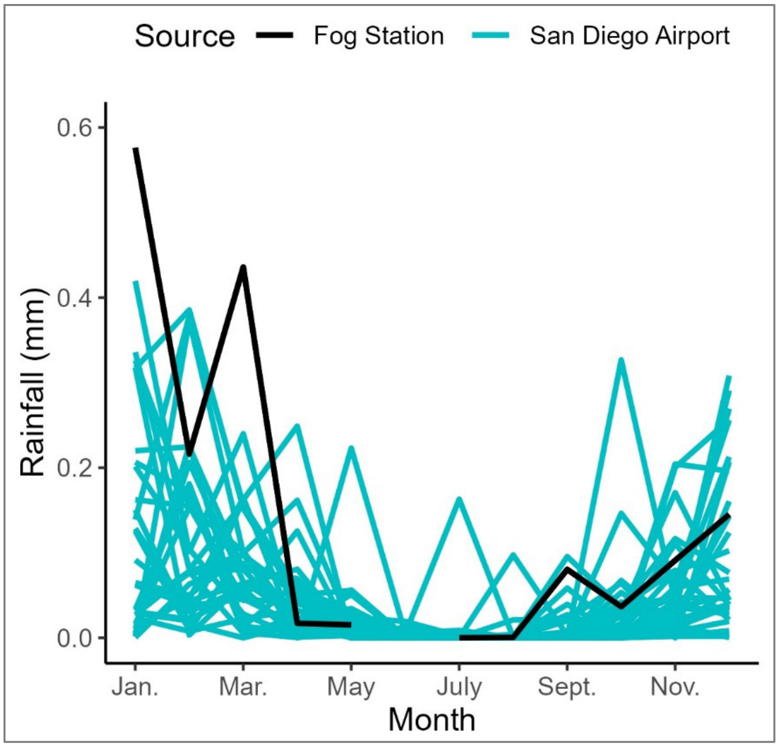

Figure 2. Time series of the sum of monthly precipitation (in mm) averaged across four Fog Monitoring Stations at Cabrillo National Monument (black, 2022-2023) and local climatological data at the San Diego Airport (blue, 1995-2023). Rain is lowest in the summer (April - August).

In this annual report, we provide a summary of fog monitoring program data collected between July 2022 and May 2023, establish a relationship between leaf wetness sensor readings and water deposited, and investigate whether fog microclimates exist at the park. More specifically, we aim to answer the following questions:

1. Do fog microclimates exist along an elevational gradient?
2. Do fog microclimates exist between the sides of the Point Loma Peninsula facing the Pacific Ocean and San Diego Bay?

We hypothesized that, based on the way fog rolls into the monument, the ocean-facing side of the peninsula experiences more fog compared to the bay-facing side, and that, across an elevational gradient, the higher elevation stations will have less fog presence and intensity.

Methods

Site Selection

The park is situated on the Point Loma Peninsula in San Diego, CA (USA). The ocean-facing side of the park contains wave cut platforms and a gently sloping marine terrace that faces the Pacific Ocean. The bay-facing side of the park contains steep slopes and cliffs and faces the San Diego Bay.

Stations were deployed to capture park microclimates and are named after landmarks in their proximity (Figure 3). The ocean-side, low elevation station is lowest in elevation (Tide Pool, 15 m above sea level) and is adjacent to Lot 1 in the coastal area on the ocean side of the peninsula. Proceeding up the ocean-facing hillside, there are two additional stations: ocean-side, mid-elevation (New New, 51 m) and ocean-side, high elevation (Event Bluff, 120 m). The ocean-side, mid-elevation station is located across the street from the Sea Cove parking lot in the coastal area, while the ocean-side, high elevation station is just below the bluffs adjacent to the historic Old Point Loma Lighthouse. These three stations encompass a vertical gradient and measure the rate of fog deposition as it is swept uphill from the Pacific Ocean towards the San Diego Bay. To measure differences in ocean- and bay-side microclimates, the bay-side, mid-elevation (Spicy Bunker, 49 m) station is adjacent to a searchlight structure at the end of the Bayside Trail and is similar in elevation to the ocean-side, mid-elevation station on the ocean-side (51 m). These two stations were also both placed on south-facing slopes, exposing both stations to full sun. We used these four stations to determine if fog microclimates differ on either side of the Point Loma peninsula, and to measure differences in fog deposition across an elevation gradient on the ocean-facing side of the peninsula.

Figure 3. Map of the four fog monitoring station locations at Cabrillo National Monument (San Diego, CA, USA). Three fog monitoring stations encompass an elevation gradient on the ocean side of the Point Loma peninsula (ocean-side low elevation, ocean-side mid-elevation and ocean-side high elevation). These stations measure fog deposition as it is swept uphill from the Pacific Ocean towards San Diego Bay. To measure differences in fog deposition on the ocean- and bay-sides of the peninsula, the ocean-side, mid-elevation (51 m) and bay-side, mid-elevation (49 m) stations are placed on either side of the peninsula at similar elevations. Overall, these four stations measure differences in fog microclimates in the park.

Fog Monitoring Stations

Each of the four fog monitoring stations is equipped with three dielectric leaf wetness sensors (Campbell Scientific - METER Environment), which assess, in mV, the trace amounts of water deposited onto leaves by fog (Figure 4). These 12 x 5.8 cm leaf-shaped panels were secured flat (i.e., leaf panels were parallel to the ground) to nearby plants using plastic zip ties and imitate characteristics of the leaves of spatial dominant shrubs (e.g., *Rhus integrifolia*). The heights at which the leaf wetness sensors were secured were tested. Initially, the leaf wetness sensors were at a height of 1 meter across all sites. However, there were low signals from the ocean-side, mid-elevation station because of how thick the vegetation is. All the sensors were then moved to the top of surrounding vegetation. To differentiate the contributions of fog and rainfall to water deposition, we installed meteorological instrumentation at each station. Campbell ClimaVUE 50 weather stations and Campbell CR800 data loggers were deployed at the ocean-side, mid-elevation and bay-side, mid-elevation sites. The ocean-side, high elevation and ocean-side, low elevation stations were equipped with Davis Vantage Pro 2 weather stations and retrofitted with third-party communication devices (Meteo-Pi) and open-source software (Weewx). Stations were powered using solar panels which were connected to a 12V battery and metered with a charge controller.

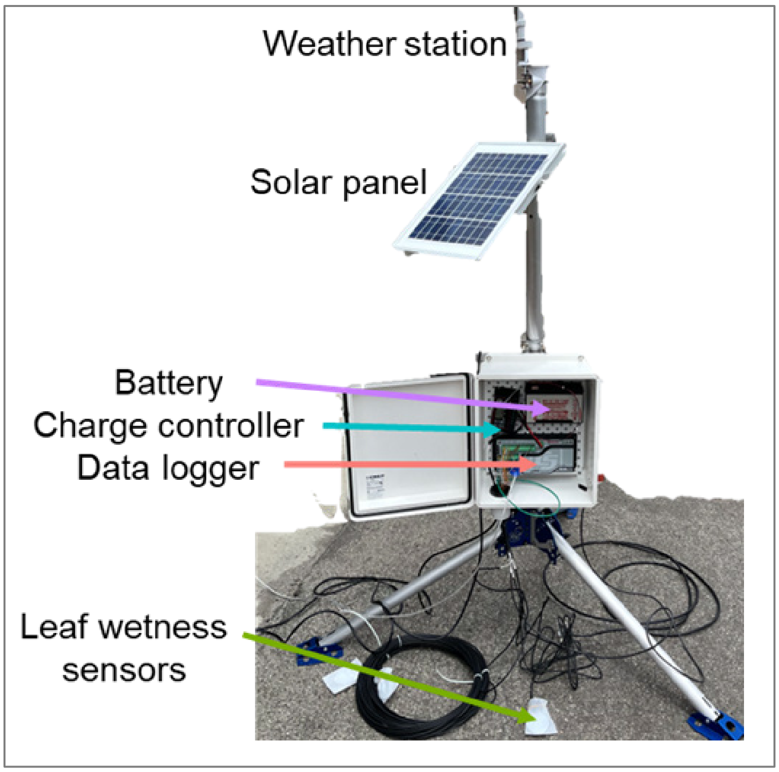

Figure 4. Schematic of a fog monitoring station at Cabrillo National Monument. Fog monitoring stations are made up of a weather station (Campbell ClimaVUE 50 or Davis Vantage Pro 2), data logger, and three dielectric leaf wetness sensors. They are powered by 12 V batteries charged by a solar panel and metered with a charge controller.

Leaf wetness and meteorological data were collected at ten-minute intervals for the duration of the study period (July 2022 – May 2023); this project is expected to continue for as long as funding and staffing allows. During monthly maintenance, solar panels were cleaned and checked for proper positioning, leaf wetness sensors were sprayed with UV protectant (as recommended for longevity by Campbell Scientific representatives), batteries were checked, data logging and operation of the unit were confirmed, and desiccant packs were checked and replaced when necessary. There was one instance of weak battery voltage, but data collection was not interrupted. This was the result of the solar panel being knocked out of its original position. A general overview was done to ensure that all wires were still properly connected and no corrosion was present. Data was collected at 2- to 3-month intervals for the duration of the study period. Data processing and clean-up are detailed in the Fog Monitoring SOP (Appendix 2) and CABR-Fog-Monitoring-2023 GitHub repository.

Trail Cameras

Trail cameras (Browning Strike Force & Dark Ops HD) powered by solar panels (Browning Solar Camera Power Pack) were placed on the bay- and ocean-facing sides of the Point Loma Peninsula at CABR to visually confirm fog presence during system development. The trail cameras take a picture every 10 minutes or if there are any movements detected during daylight hours. The pictures are consolidated into a timelapse video. Data was downloaded at 3- to 5-month intervals for the duration of the study period.

Data Analysis

The data analysis script is stored in the project's GitHub repository.

Data processing and analyses were completed using RStudio and supplementary packages (de Mendiburu 2023, Ooms 2023, Urbanek 2022, Firke 2021, R Core Team 2021, RStudio Team 2020, Wickham & Bryan. 2019, Wickham et al. 2019, Seyednasrollah 2018, Grolemund & Wickham 2011).

Climate data in Figure 1 and Figure 2 were summarized Local Climatological Data sourced from the San Diego International Airport (station USW00023188) and accessed from the National Centers for Environmental Information (NOAA 2024).

In this study, we present data on fog deposition only. To separate fog deposition from rain, we filtered for observations where no rain was recorded by the weather station, and there were readings from the leaf wetness sensors. We then calculated the mean leaf wetness reading at half-hour intervals for each station by taking the average reading (in mV) across three consecutive leaf wetness sensor readings. These readings were converted to approximate volumes of water present (in mL) through correlative experiments (Appendix 3).

To compare fog deposition across sites, we calculated the number of hours of fog each day across station locations. We used an ANOVA, followed by a Tukey HSD test, to determine if the median number of fog hours differs across stations.

Results

Over the study period (July 2022 – May 2023), meteorological and leaf wetness sensor data were recorded at 10-minute intervals at four fog monitoring stations at Cabrillo National Monument. Although not evaluated statistically, there were observed differences in leaf wetness intensity both across an elevational gradient and across the sides of the peninsula. On the ocean side of the peninsula, leaf wetness intensity decreased as elevation increased (Figure 5). The average leaf wetness reading for the ocean-side, low elevation station was 44 mV, while the average reading for the ocean-side, high elevation station was 36 mV. There were also differences in leaf wetness intensity between the ocean- and bay-sides of the peninsula. The mean intensity at the bay-side, mid-elevation station was 9 mV, and mean intensity at the ocean-side, mid-elevation station was 35 mV. These results show that higher elevations experience less fog. In our statistical evaluation of fog duration, we found that the bay-side experiences 2–3 fewer hours of fog than the ocean-side (ANOVA $P < 0.01$, Appendix 4), standardized at mid-elevation (Figure 6). With this information, it is evident that the bay-side of the peninsula experiences less fog than the ocean-side. There was no significant difference in fog duration between stations on the ocean side of the peninsula.

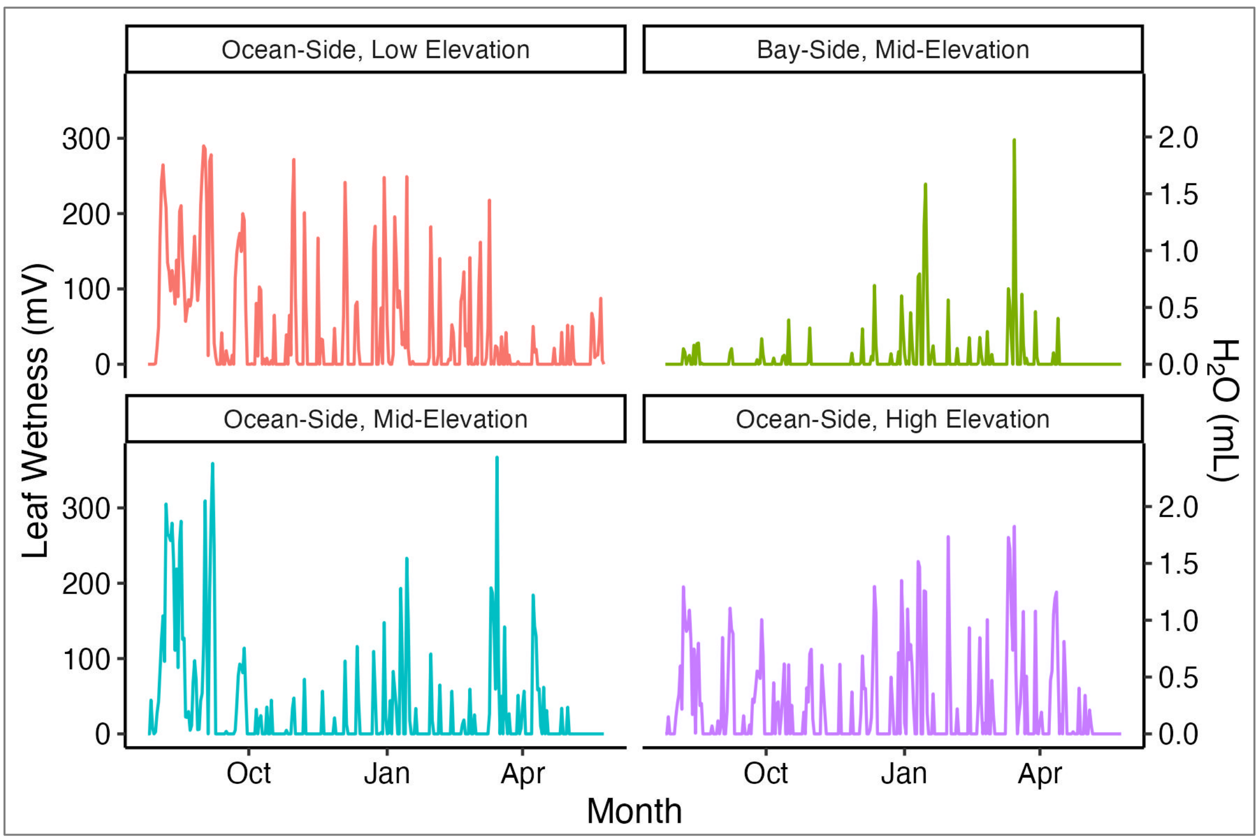

Figure 5. Time series of average leaf wetness (mV) and average calculated water deposition (mL) for the four fog monitoring stations. Values presented are the 30-minute average leaf wetness in mV and mL (calculated as described in Appendix 3) values across 3 replicate sensors and three 10-min intervals, between July 2022 and May 2023. Leaf wetness decreases as elevation increases. At similar elevations, the ocean-side station had higher leaf wetness readings than the bay-side.

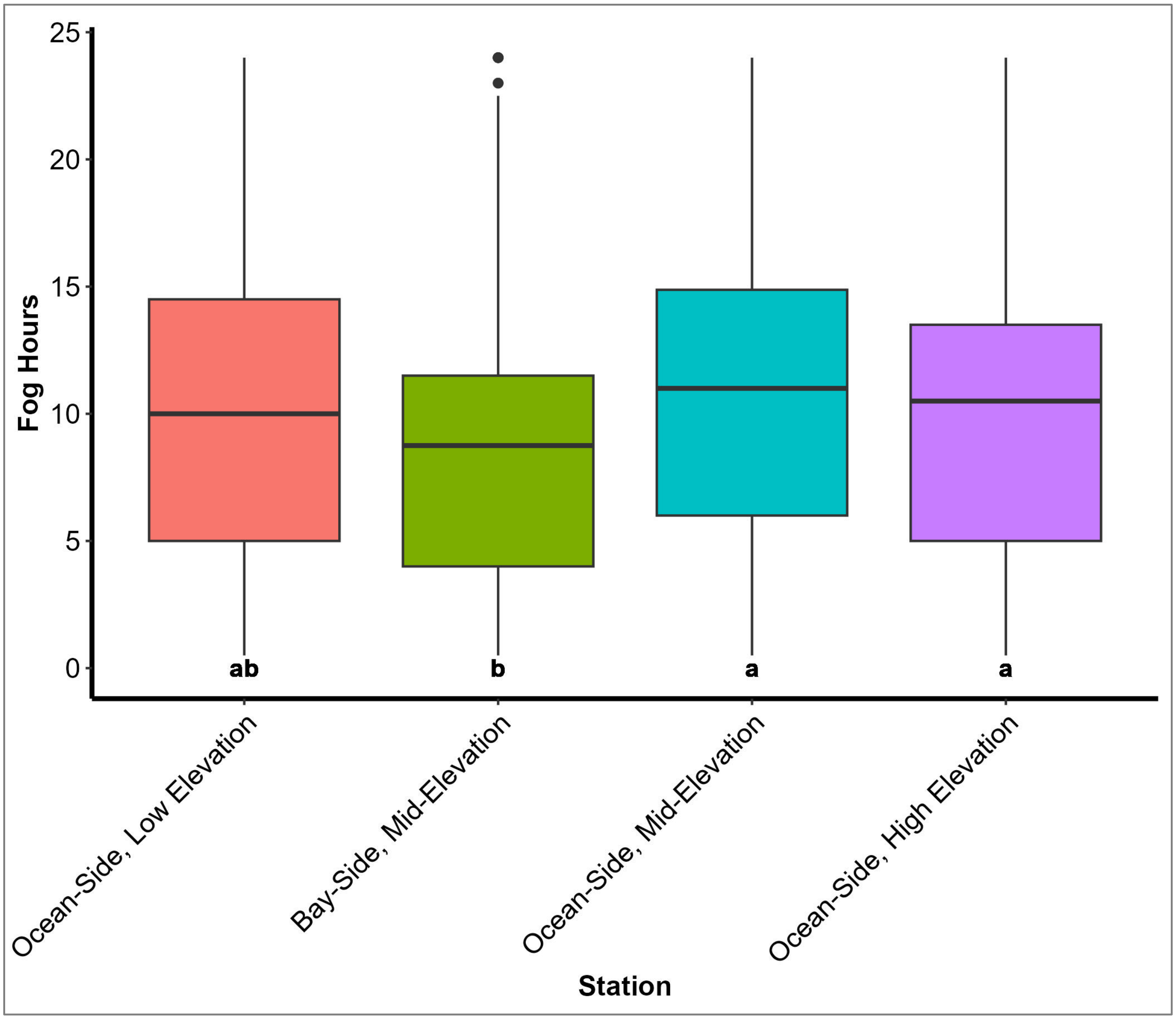

Figure 6. Daily median hours of fog between July 2022 and May 2023 differ across four replicate stations at Cabrillo National Monument (ANOVA $p < 0.01$). The bay-side, mid-elevation station receives around 2 fewer hours of fog than the mid-elevation station on the ocean-side of the peninsula (Tukey HSD, $p < 0.01$). There is no significant difference in the hours of fog presence between stations on the ocean side of the Point Loma peninsula.

Discussion

Fog is a critical source of water for plants and animals in coastal California ecosystems that has not been well-researched by the National Park Service. Prior studies conducted by Channel Islands National Park in partnership with the U.S. Geological Survey focused on fog deposition on island oaks. Specifically, these studies aimed to understand the effects of fog moisture deposition on plant species associated with island oaks that create cloud forests on Santa Rosa Island. The Cabrillo National Monument fog monitoring program is distinguishable from this program in that it quantifies fog spatially and temporally across the peninsula and is not deployed under trees. Long term monitoring of fog dynamics is the first step to understanding both current conditions at the park and providing data for researchers to inform natural resource managers on both possible microclimates on the peninsula and broader-scale patterns that will impact the landscape.

When transformation or major change is anticipated or detected, the Resist-Accept-Direct (RAD) framework can guide natural resource management decisions (Schuurman et al. 2020). To summarize, managers can resist transformation by working to maintain or restore ecosystems based on historical or acceptable current conditions; accept transformation by allowing change without intervention; or direct transformation by actively shaping ecosystem processes towards desired new conditions (Schuurman et al. 2020). With the limited information gathered thus far, we recommend CABR accept changes in long-term fog patterns and endorse continued collection and analysis of fog conditions at the park.

Current conditions of this snapshot of fog hours and leaf wetness suggest that exposure to fog and fog hours differs significantly between the ocean- and bay-sides of the peninsula. These same metrics don't significantly differ between stations along an elevational gradient on the ocean side of the peninsula. Restoration efforts on the bay-side of the peninsula should consider less exposure to the shade and moisture provided from fog, and species selected and investment in watering efforts should be considered carefully, especially when re-vegetating the social trails along the heavily visited Bayside Trail.

Long-term monitoring programs are important tools in determining areas of the park to invest staff time, funding, and nursery plants to carry out the NPS mission: "The National Park Service preserves unimpaired the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations." Natural resource managers will be better informed on where to allocate resources to re-vegetation efforts that are likely to succeed with reduced watering support after new native plants are out-planted. Looking forward, the fog monitoring program will provide novel information on localized fog conditions at the park and potentially provide data for larger-scale analysis of future fog conditions in the broader San Diego County area or southern California. Additionally, fog data could be used in analysis of heat events that coincide with extreme low tides that have led to mass mortality of intertidal organisms in other areas of the west coast. Additional funding would provide the means to maintain capacity and turn this project into a long-term monitoring program that would benefit reef-to-ridge natural resource management at southern California park units.

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Appendix 1: Vegetation Communities at CABR

We anticipate that fog microclimates align with vegetation sub-types at the park. To test this hypothesis, we examined the frequency of observations of plant species adjacent to each fog monitoring station from the most recent survey year of the Mediterranean Coast Inventory and Monitoring Network (MEDN) Vegetation Monitoring Program (Tiszler et al. 2016). Site 076 is closest to the ocean-side, high elevation station and the 2021 survey year data was analyzed. Site 053 is closest to the ocean-side, low elevation station and the 2017 survey year data was analyzed. Site 018 is closest to the bay-side, mid-elevation station and the 2021 survey year data was analyzed. Site 045 is closest to the ocean-side, mid-elevation station and the 2016 survey year data was analyzed (Figure 7).

Data available upon request by contacting network staff through the Contact Us (U.S. National Park Service) (nps.gov) section of the Network Website, or in the DataStore - MEDN Native Vegetation Monitoring Program Database (CABR) (nps.gov).

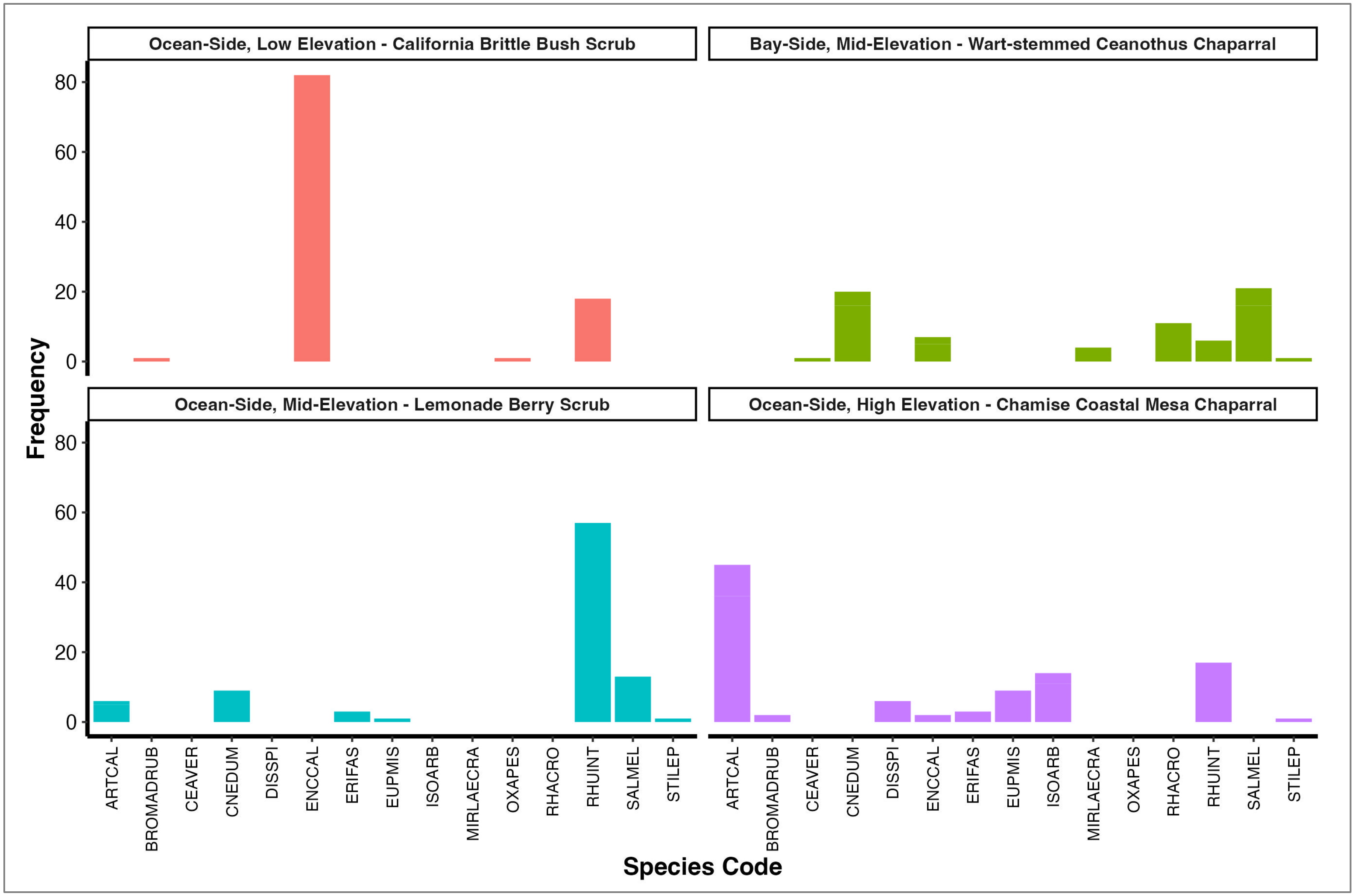

Figure 7. Dominant plant species differ across fog monitoring sites at CABR. Values presented are the frequency of observations along transects monitored by the MEDN Vegetation Monitoring Program at CABR. At the ocean-side, high elevation station, *Artemisia californica* has the highest frequency. At the ocean-side, mid-elevation station, *Rhus integrafolia* has the highest frequency. At the bay-side, mid-elevation station, *Cneoridium dumosum* and *Salvia mellifera* are similarly the highest frequencies. At the ocean-side, low elevation station, *Encelia californica* has the highest frequency.

Appendix 2: Fog Monitoring Program SOP

A preliminary SOP for the fog monitoring program is available upon request from the Resources Program Manager at Cabrillo National Monument (lauren_pandori@nps.gov). We plan to publish an updated SOP in the coming years as the program develops.

Appendix 3: Fog Threshold Experiments

We investigated multiple approaches to relating the amount of fog or fog water present to the fog intensity in millivolts (mV) as measured by the leaf wetness sensors.

The first approach to understanding this relationship was correlating leaf wetness in mV to fog present in pictures collected from the trail camera on the ocean side of the peninsula (Andrew's Finest Trail Camera station). Using RStudio (de Mendiburu 2023, Ooms 2023, Urbanek 2022, Firke 2021, R Core Team 2021, RStudio Team 2020, Wickham & Bryan 2019, Wickham et al. 2019, Seyednasrollah 2018, Grolemund & Wickham 2011), timelapse videos were converted into pictures based on the number of frames present in the video. Functions in the hazer package (Seyednasrollah 2018) were then used to calculate the daily average haze factor and global atmospheric light (A0). This process was applied to daily timelapse videos between January 20, 2023 and June 2, 2023. Linear regression analysis (leaf wetness as a function of haze factor) indicated that there is no significant correlation between leaf wetness and haze factor (R^2 = -0.002, p = 0.41, Figure 8). Thus, this approach was not used to quantify fog intensity.

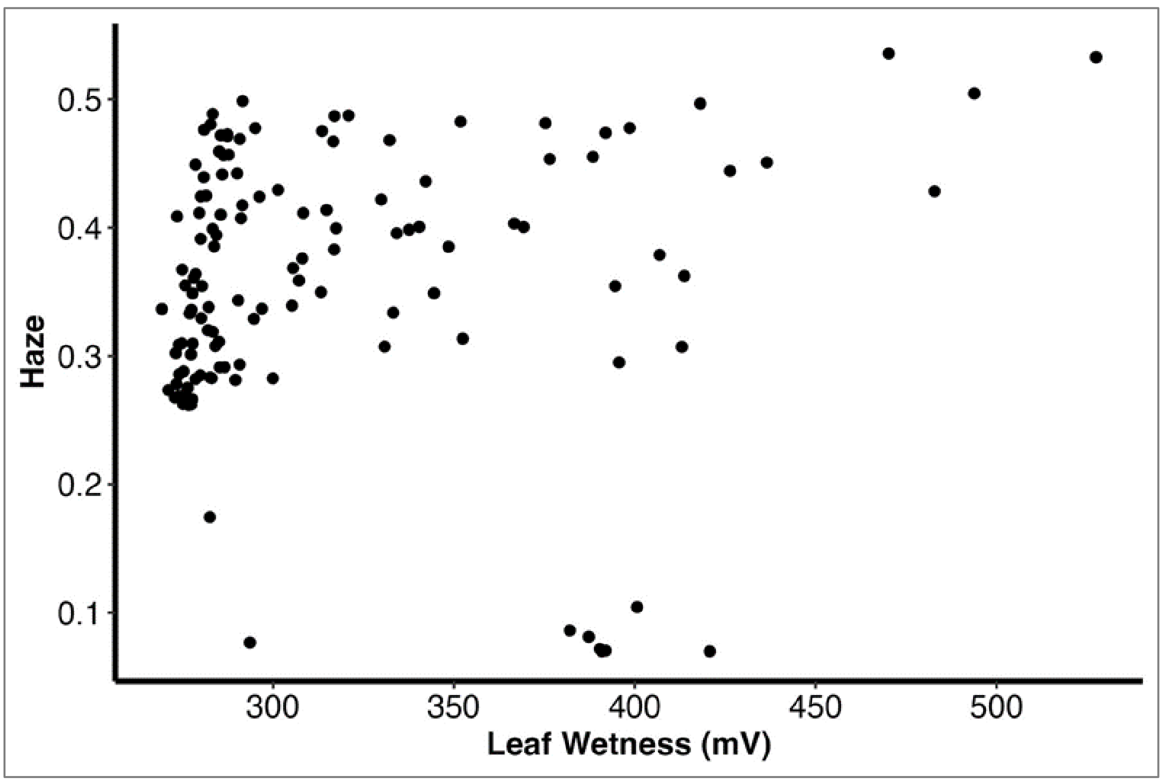

Figure 8. Scatterplot of leaf wetness (mV) and haze calculated using "Andrew's Finest" trail camera picture analysis through the hazer package in RStudio and fog monitoring station data. Values presented were recorded between January and June 2023. There is no clear correlation between haze and leaf wetness (linear regression, R^2 = -0.002, p = 0.41).

The second approach was a quantitative approach to understanding the relationship between a volume of water present on the leaf wetness sensors and the resulting reading in millivolts (mV). The product manual for the leaf wetness sensors (Campbell Instruments Dielectric Leaf Wetness Sensor) notes that there will be a baseline voltage measurement depending on the medium surrounding the sensor (e.g., air vs. water). Interpreting data requires understanding that the baseline mV reading is when there is no water on the sensor. Between June 22 and July 31, 2023, the ocean-side, low elevation fog station temporarily moved to a maintenance building at the park while the site of the station was under construction.

During this time, the station was used for the following experiment. The three leaf wetness sensors were weighed using a balance at the start of each 10-minute recording interval. One leaf wetness sensor was left dry during the duration of the study (66 ft sensor in Figure 9) to understand the baseline leaf wetness sensor reading in mV. Water was incrementally added to the remaining two leaf wetness sensors (17 ft & 50 ft sensors) at 10-minute intervals in the following amounts using a 3 mL dropper pipette (0.1 g, 0.5 g, 1 g, 1.5 g, 2.0 g, 2.5 g, 3.0 g). This process was repeated three times for each water weight, with a total of 21 10-minute intervals of measurements. The data was collected 50 minutes later to allow the LWS to fully dry. The y-intercept for this equation was used to set a baseline for leaf wetness sensor readings in the figures presented in the paper. Linear regression analysis indicated a significant, positive relationship between the volume of water on the leaf wetness sensors (in mL) and the leaf wetness sensor reading (in mV) (Figure 9, $R^2 = 0.95$, $p < 0.01$).

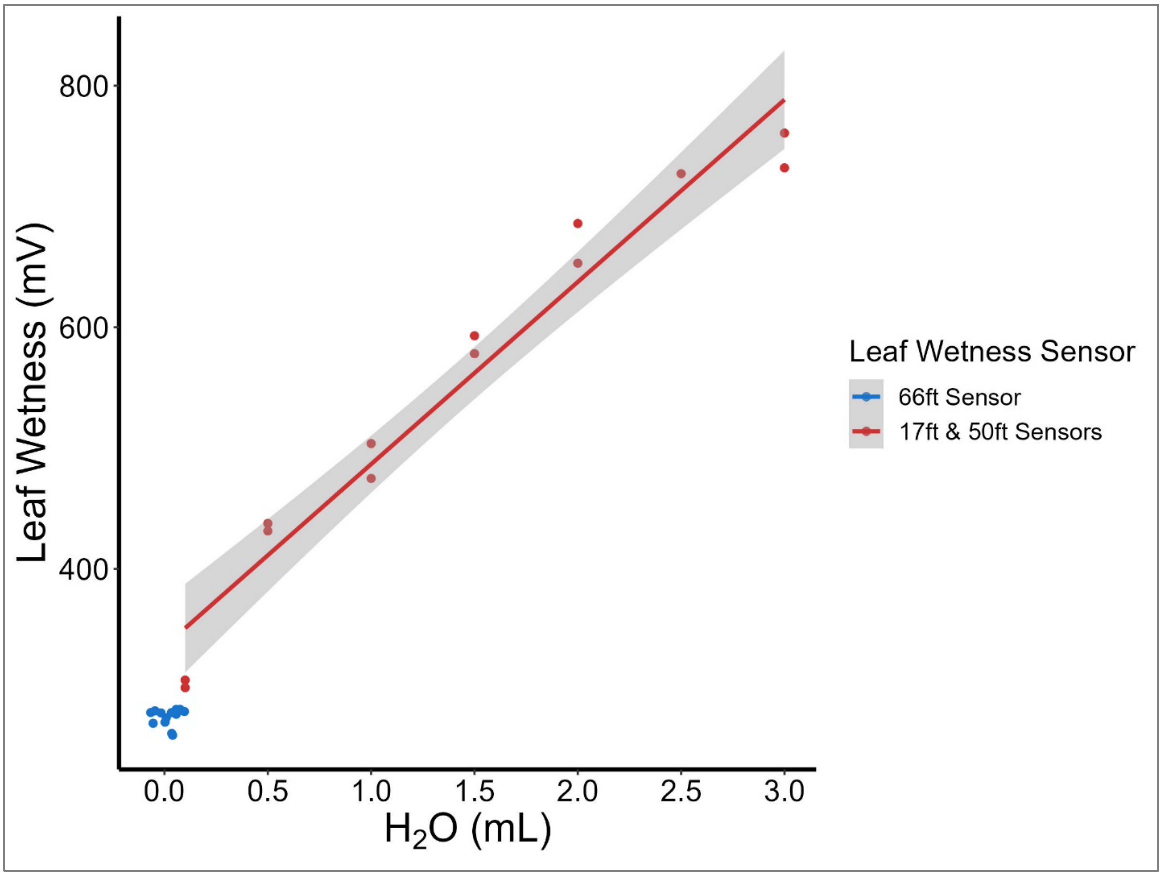

Figure 9. Scatterplot and regression line comparing leaf wetness (mV) and water amount (mL). Values presented were recorded in June 2023 through the leaf wetness sensor (LWS) experiment. The 17 ft and 50 ft sensors were each exposed to the same amount of water between 0.1 mL and 3.0 mL, three times each. The mV recordings of each water amount were averaged, and a linear regression analysis was performed. The 66 ft sensor acted as the control group and was not exposed to any water throughout the experiment and provided data to determine the baseline mV readings in the absence of water. There is a clear correlation; the more mV that are recorded through a LWS, the more water the LWS and vegetation are exposed to (linear regression, $R^2 = 0.95$, $p < 0.01$). Note that the x-values of the 66 ft sensor readings are jittered around 0 to show replication, as they otherwise overlap.

Appendix 4: Fog Duration Comparison Statistics

We processed weather station data by filtering for observations where no rain was recorded by the weather station, but leaf wetness recordings were present. We calculated mean leaf wetness at half-hour intervals. To compare fog deposition across sites, we calculated the number of hours of fog each day across station locations. We used an ANOVA, followed by a Tukey HSD test, to determine if the median number of fog hours differs across stations. Below are the detailed results of statistical tests (Table 1 and Table 2).

Table 1. ANOVA Results

Factor	Degrees of Freedom	Sum of Squares	Mean Squares	F-Value	P-Value
Station	3	423	140.98	4.45	0.004
Residuals	860	27249	31.68	–	–

Table 2. Tukey HSD Test Results

Comparison	Difference	Lower Confidence Interval	Upper Confidence Interval	P-Value
Ocean-High, Bay-Mid	1.64 *	0.23 *	3.06 *	0.01 *
Ocean-Low, Bay-Mid	1.34	-0.03	2.70	0.06
Ocean-Mid, Bay-Mid	1.81 *	0.38 *	3.23 *	0.01 *
Ocean-Low, Ocean-High	-0.30	-1.67	1.06	0.94
Ocean-Mid, Ocean-High	0.16	-1.27	1.59	0.99
Ocean-Mid, Ocean-Low	0.46	-0.92	1.85	0.82

* Results were found to be statistically significant (values also in red font).

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