Title
Ventura Marsh Milk-vetch (Astragalus pycnostachyus var. lanosissimus) 2023 Experimental Seeding Report

Authors
Chapman, Wayne
Stratton, Lisa
Wilhelm-Safian, Claire

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(Astragalus pycnostachyus var. *lanosissimus)*

2023 Experimental Seeding Report

Coal Oil Point Reserve & Campus Lagoon, Santa Barbara, CA
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Cheadle Center for Biodiversity and Ecological Restoration
Claire Wilhelm-Safian, Lisa Stratton, Wayne Chapman

Introduction

Ventura marsh milk-vetch (*Astragalus pycnostachyus* var. *lanosissimus*) is a federally endangered plant in the pea family and adapted to sites generally characterized by sandy soils and an available sub-terranean water source for most of the year. With its annual dieback in the winter, it appears to be adapted to winter disturbance and flooding followed by resprouting and new seedling germination in the spring. The specific cues for seedling germination have not proved to be consistent in the field where wet years may not trigger as much germination as dry years and flooded conditions may trigger more germination than less disturbed sites.

Since Ventura marsh milk-vetch (milk-vetch, hereafter) was rediscovered in Oxnard in 1997 plants have been planted and monitored on Coal Oil Point Reserve on the NW portion of Devereux Slough and around the Dune Pond. After initial vigor, both populations were lost due, it appeared, to colonization of open sites by willows and ruderal natives or lost due to drought or flooding. Based on the success of milk-vetch on the sandy site on North Campus Open Space, the Cheadle Center proposed that a more comprehensive study designed to explore other potential outplanting sites on Coal Oil Point Reserve and adjacent to the campus lagoon in a back-dune swale at East Depression. With funding from USFWS Ventura Field Office, in the fall of 2022 and winter of 2023 sites were identified, index wells were established and seeds were spread in sandy sites that appeared to be potentially suitable.

Methods

Four plots were established at Coal Oil Point Reserve and two at Lagoon Island in December of 2022 (Figure 1 & 2). Plot sites were chosen based on elevation, lack of encroaching vegetation, accessibility, and/or potential sub-terranean water availability, and ranged in size from 13.0 m^2 to 95.1 m^2. One cup of unprocessed Ventura Marsh milk-vetch seed and chaff was spread at each location. After a lack of germination, another cup was added to each previously established plot in March 2023, and an additional five plots were established at COPR, each sown with one cup of seed (Figure 1). The amount of pure seed in a cup of chaff and fruits was estimated by counting the number of seeds in three 1 gram samples, and weighing the mass of three 1 cup samples of collected material, then multiplying the average seeds per gram by the average grams per cup. It was estimated that there are approximately 2706 seeds per cup of chaff and fruits (see Table 1).

Table 1: Estimation of seeds by volume of collected chaff and fruiting material.

Estimate of Seeds/Gram of Chaff + Fruit		Estimate of Grams/Cup of Chaff + Fruit	
Sample	Seeds/gram	Sample	grams/cup
1A	76.5	1B	19.4085
2A	213	2B	17.8678
3A	148	3B	18.3895
Average	145.8333	Average	18.5553

$$\frac{145.8333\ seeds}{1\ gram} \times \frac{18.5553\ grams}{1\ cup} = 2705.973958\ seeds/cup$$

Ventura Marsh Milk-vetch Seeded Plots at Coal Oil Point Reserve

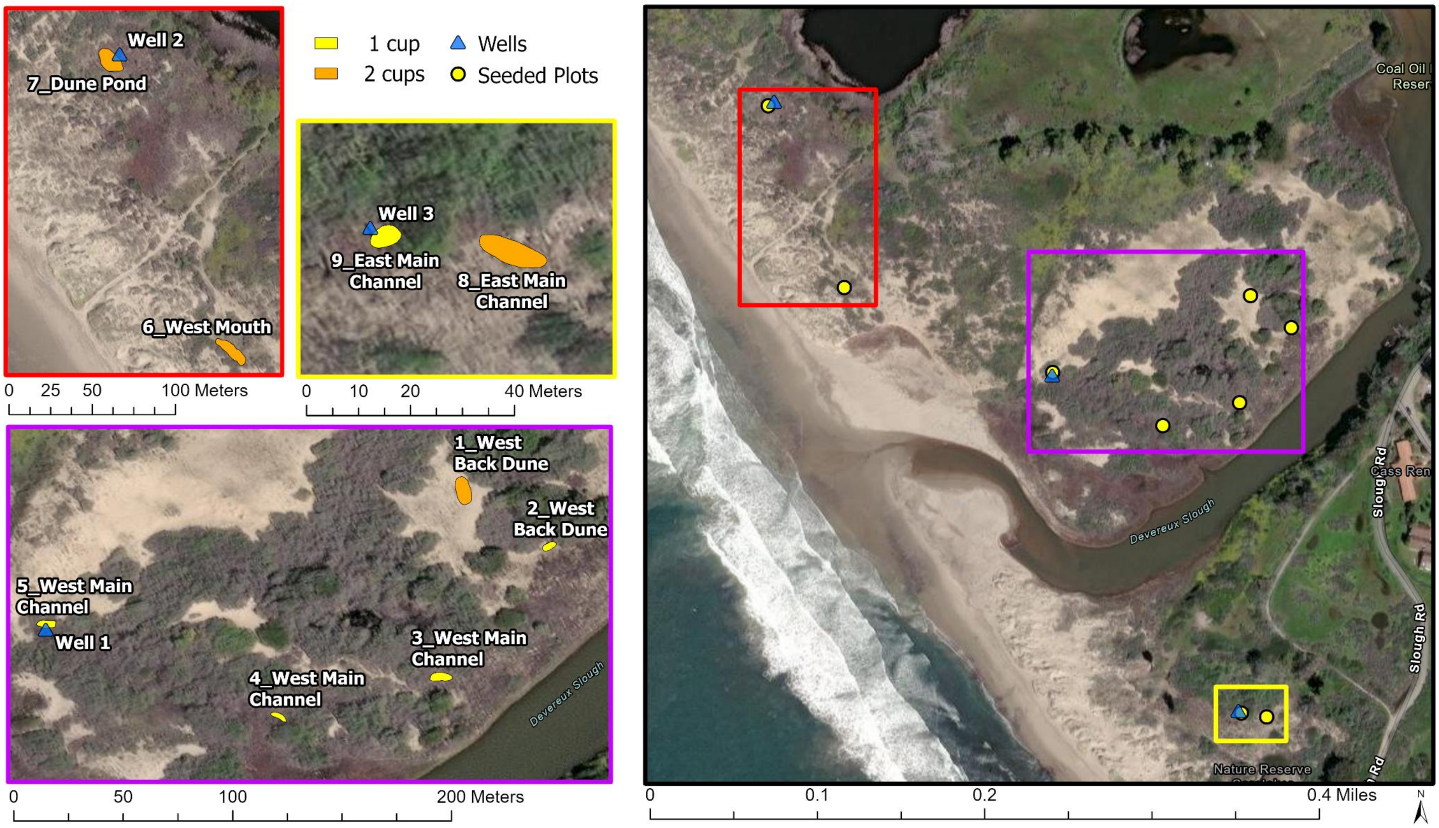

Figure 1: Map of seeded plots and wells on Coal Oil Point Reserve.

At Coal Oil Point Reserve, plots 1, 2, 3, 4, and 5 were located in back dune habitat along the western side of the main channel of Devereux Slough (see Figure 1). Plots 1, 2, and 5 were characterized by mostly open sand with a few small forbs, while plots 3 and 4 had higher vegetation cover, primarily *Distichlis spicata* (see Table 2 for a full list of plant species). Plots 6 and 7 were located just behind the foredune habitat on either side of the publicly accessible Dune Pond trail. Plot 6 was near the mouth of the slough and was mostly open sand with some small *Baccharis pilularis* shrubs. Plot 7 was on the south edge of the Dune Pond, a fresh to brackish sag pond which holds water year-round. This area was dominated by annual species and one stand of *Baccharis glutinosa.* Plots 8 and 9 were located on the eastern side of the main channel in a swale in between the foredunes and upland coastal sage scrub habitat.

At the Campus Lagoon, plots 10 and 11 were located on either side of the publicly accessible trail in the eastern depression between Lagoon Island and Campus Point (see Figure 2). Plot 10 was on the north side of the trail at the toe of a south-facing slope, in coastal sage scrub habitat. Plot 11 was on the south side of the trail in a backdune swale around a cluster of *Juncus* sp. behind the foredune habitat near the beach.

Table 2: Information about each seeding plot, including area, seed spread, and pre-existing plant species. California rare plants are marked with an asterisk and non-native species are bolded.

Plot Name	Area (m^2)	Amount of Seed Spread	Date of Seeding	Associated Species
1 West Back Dune	59.7682	2 cups (~5412 seeds)	12/1/22, 3/9/23	*Claytonia perfoliata, Chenopodium littoreum*, **Schismus arabicus,** Camissoniopsis micrantha, Lupinus arboreus, Eschscholzia californica, Cryptantha clevelandii, Heterotheca grandiflora, Camissoniopsis cheiranthifolia, Phacelia ramosissima, **Acacia sp.***
2 West Back Dune	14.6005	1 cup (~2706 seeds)	3/9/23	*Chenopodium littoreum*, Cryptantha clevelandii, Salix lasiolepis, Heterotheca grandiflora, Acmispon maritimus, Camissoniopsis micrantha*
3 West Main Channel	27.4186	1 cup (~2706 seeds)	3/9/23	*Distichlis spicata, **Sonchus asper,** Quercus agrifolia, Toxicodendron diversilobum*
4 West Main Channel	12.9525	1 cup (~2706 seeds)	3/9/23	*Distichlis spicata, Toxicodendron diversilobum, Ambrosia psilostachya, Camissoniopsis cheiranthifolia, **Sonchus sp.**, Schoenoplectus americanus, Quercus agrifolia, Salix lasiolepis*
5 West Main Channel	21.2599	1 cup (~2706 seeds)	3/9/23	*Ambrosia psilostachya, Acmispon maritimus, Cryptantha clevelandii, Camissoniopsis micrantha, Toxicodendron diversilobum, Salix lasiolepis, **Lysimachia arvensis***
6 West Mouth	80.8893	2 cups (~5412 seeds)	12/1/22, 3/9/23	*Baccharis pilularis, Cryptantha clevelandii, Ambrosia psilostachya, Heterotheca grandiflora*
7 Dune Pond	95.0829	2 cups (~5412 seeds)	12/1/22, 3/9/23	*Baccharis glutinosa, Oenothera elata ssp. hookeri, Ambrosia psilostachya, Phacelia ramosissima, Erigeron canadensis, **Polypogon monspeliensis, Rumex crispus, Plantago lanceolata***
8 East Main Channel	40.7974	2 cups (~5412 seeds)	12/1/22, 3/9/23	***Bromus diandrus,** Cryptantha clevelandii, Amsinckia spectabilis, Phacelia ramosissima, Camissoniopsis micrantha, Chenopodium littoreum*, Eschscholzia californica, **Acacia sp.***
9 East Main Channel	15.9339	1 cup (~2706 seeds)	3/9/23	*Phacelia ramosissima, Baccharis pilularis, Eschscholzia californica, Camissoniopsis micrantha, **Lysimachia arvensis,** Cryptantha clevelandii*
10 Lagoon North	16.7671	1 cup (~2706 seeds)	3/9/23	*Juncus sp., Baccharis pilularis, **Oxalis pes-caprae, Polypogon monspeliensis,** Rhus integrifolia*
11 Lagoon South	38.20604	2 cups (~5412 seeds)	12/1/22, 3/9/23	*Eschscholzia californica, Juncus sp., Phacelia ramosissima, Lupinus arboreus, Atriplex lentiformis, **Bromus diandrus,** Ambrosia psilostachya, **Oxalis pes-caprae,** Distichlis spicata, Amsinckia menziesii*

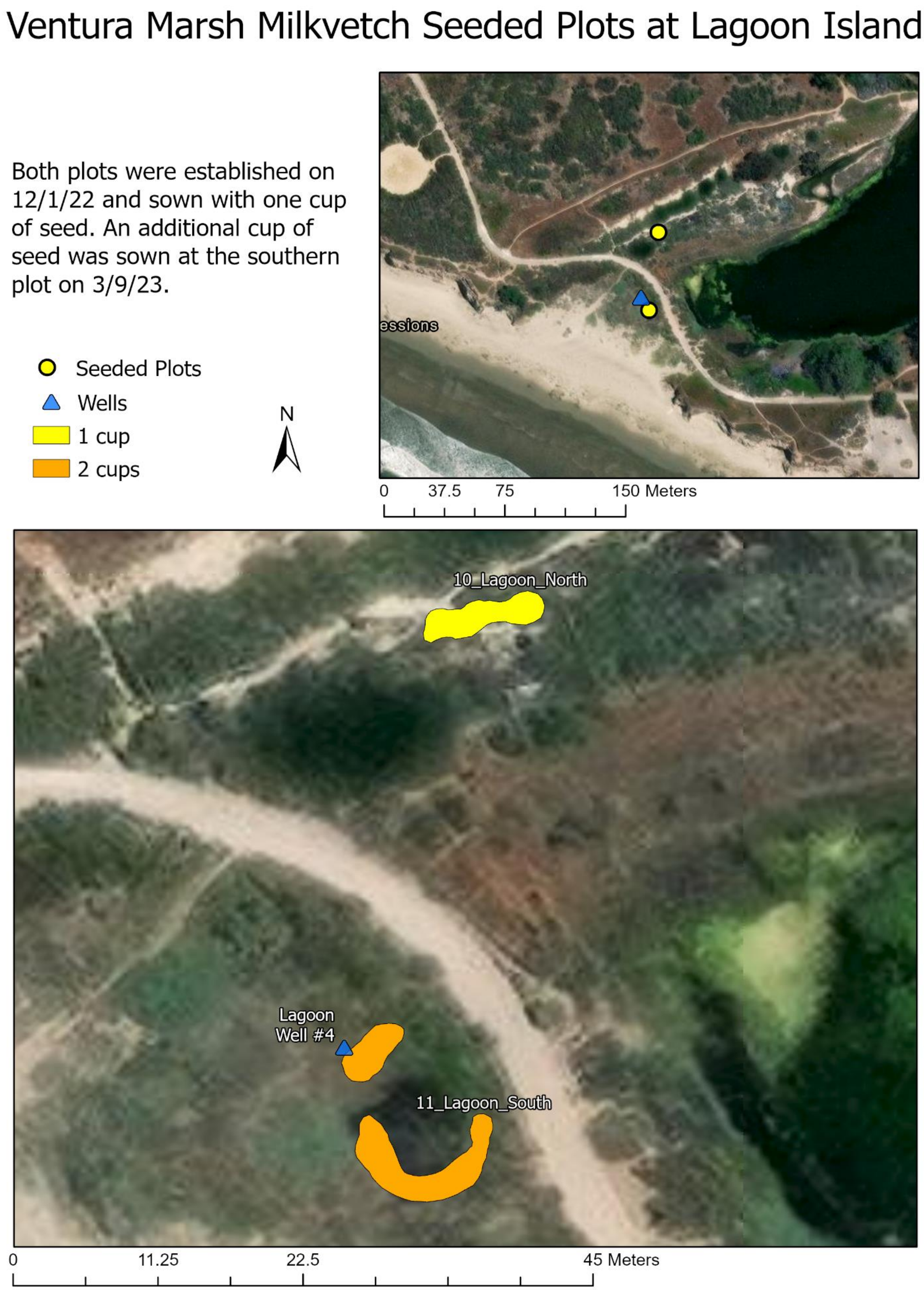

Figure 2: Map of seeded plots and wells at Lagoon Island.

In order to monitor the depth to groundwater and water quality at select seeding sites, four test wells were installed in March: three at Coal Oil Point Reserve and one at Lagoon Island. The wells were five feet deep and an inch wide and equipped with a Solinst Levelogger® 5 hanging at the bottom of each well, which measured barometric pressure (giving water depth) and temperature at fifteen-minute intervals. On a monthly basis, data was downloaded from the levelogger and compensated for ambient barometric pressure. At the same time, a manual measurement of the water level was collected using a measuring tape marked with a wet erase marker. In addition, water temperature (℃), dissolved oxygen (mg/L and %), conductivity (µS/cm), and salinity (ppt) were measured using a YSI Pro2030 Meter.

A photo showing installation of the West Main Channel index well at plot 5.


A photo of the installed index well at plot 11 Lagoon South.

Three soil samples were collected from a depth of two feet at each of the seeding sites. Percent soil moisture was found using the gravimetric method by measuring the wet weight of each soil sample, drying it for 24 hours in an oven, subtracting the dry weight, and dividing the resulting value by the dry weight. An aqueous suspension of each soil sample was tested for conductivity using an Oakton CON 700 meter and for pH using an Apera PH60 digital tester.

An additional two topsoil samples each were collected from plots 5, 6, 7, and 8, from within 2-4 inches of the surface. Another seven samples were collected from milk-vetch sites on North Campus Open Space, in order to compare with older, established populations. These were processed by Fruit Growers Lab and tested for a wide range of soil characteristics. The results on soil salinity, saturation, chlorides, and sodium adsorption rate are of interest.

Milk-vetch seedling germination and survivorship were monitored once a month. Each individual was counted and assigned a vigor rating (1: healthy, 2: minor health defects, 3: serious health defects, 4: dead). Invasive plants were hand weeded only if they were growing near milk-vetch seedlings. Once the milk-vetch entered its bloom period in the summer, any flowering individuals were recorded. Since the height a seedling reaches in its first year indicates a higher likelihood of survival into adulthood, any individuals over one foot in height were also documented.

Results

COPR Seedling Population

At Coal Oil Point Reserve, there was germination in most plots by April, but the majority of seedlings had died by mid-summer (see Figure 3). Plots 6, 7, and 8 had the highest germination, with over 100 seedlings in each (see Figure 4). However, by the end of the year, the only plots with living seedlings were plots 6 and 7. These two plots flooded after a rainstorm in late March, killing much of the pre-existing vegetation. Following the disturbance, both plots saw a spike in milk-vetch germination. By mid-April, the flood water had receded at plot 6, and 226 new seedlings had sprouted. A small amount of standing water remained at plot 7, but by the following month, 8 new seedlings had germinated. Germination was more gradual at plot 7 compared to plot 6 post-flood, but both seem to have benefitted from the stochastic disturbance.

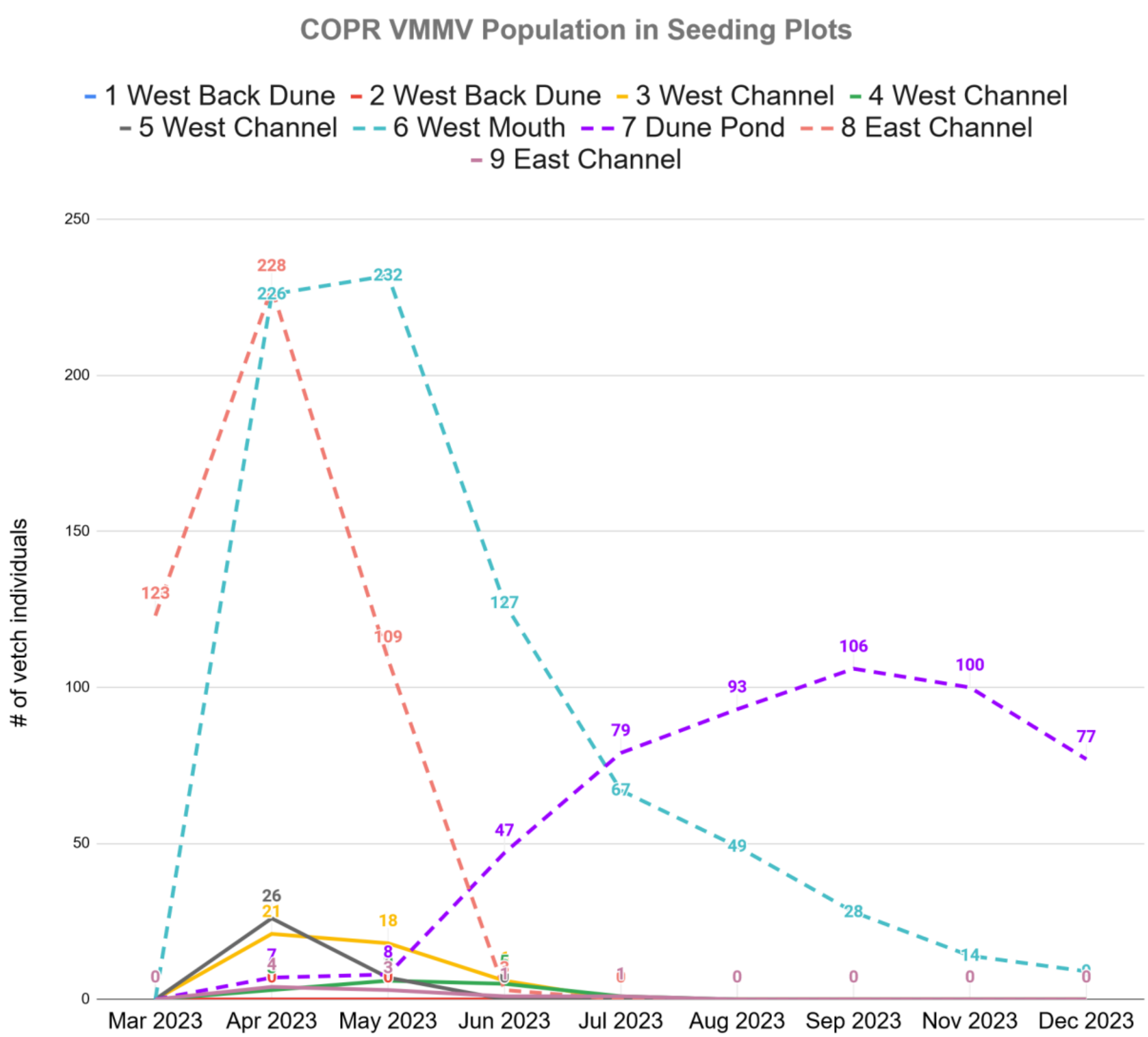

Figure 3: A graph of living seedlings at COPR over the course of the year.

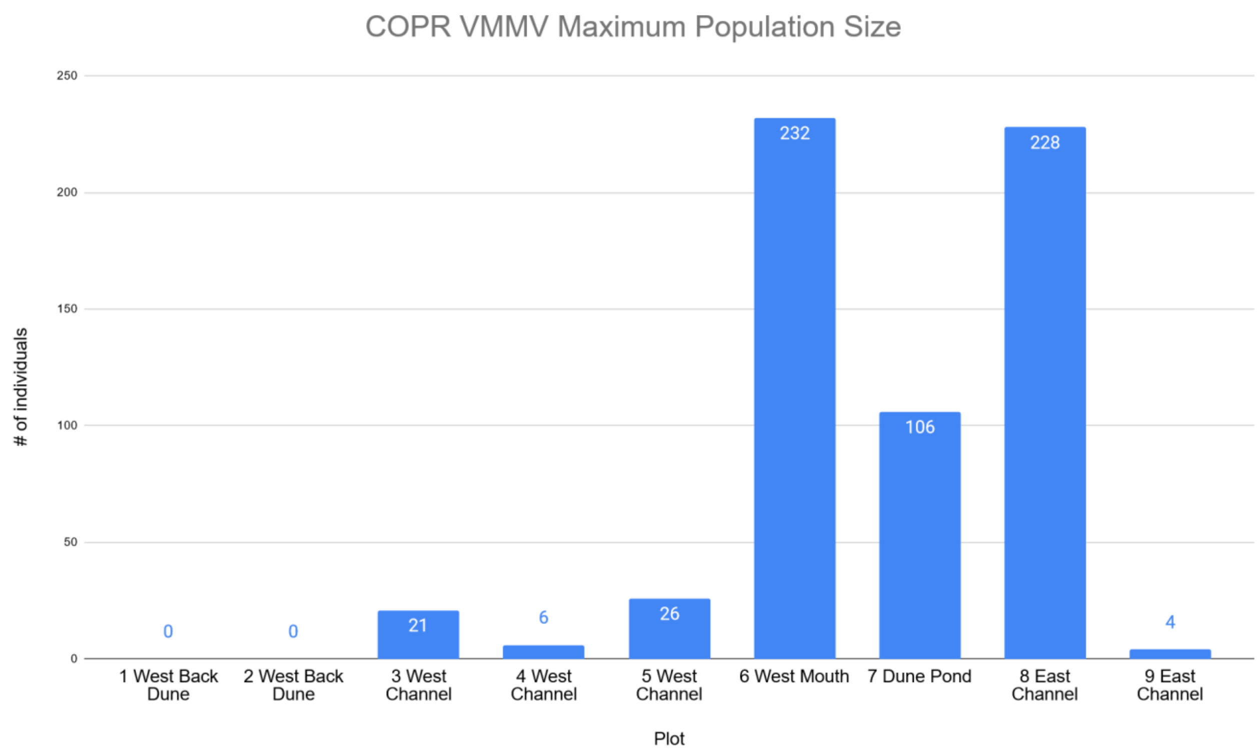

Figure 4: A bar chart showing the maximum population size at a single point in time at each plot.

Plot 6, circled in red, flooded in late March.


Plot 7, circled in red, flooded in late March.


Plot 7 in mid-April; most of the flood water receded, but still some ponding.

Lagoon Seedling Population

The Campus Lagoon seeding sites did not fare as well as any of those at COPR. Thirty-six seedlings germinated at plot 11 South in April, but the population quickly declined. The milk-vetch never reached reproductive maturity and remained small, less than two inches tall. The depth to groundwater in the index well associated with this plot increased to four feet early in the year, and it was running dry throughout most of the summer. While the abundance of wetland species such as *Juncus acutus* and *Juncus patens* suggested a high water table, during well installation a coarse rocky layer was found around four feet deep, which may contribute to higher drainage than expected. The lack of persistent groundwater within five feet of the surface likely prevented seedlings from thriving at this site.

Only two seedlings germinated at the plot 10 North. While these individuals were first recorded in August, they most likely germinated earlier in the year and were overlooked due to their small size. Both were very small and unhealthy, with pale discoloration from lack of water and/or nutrients. This site had more compacted clay soils than all other seeding sites.

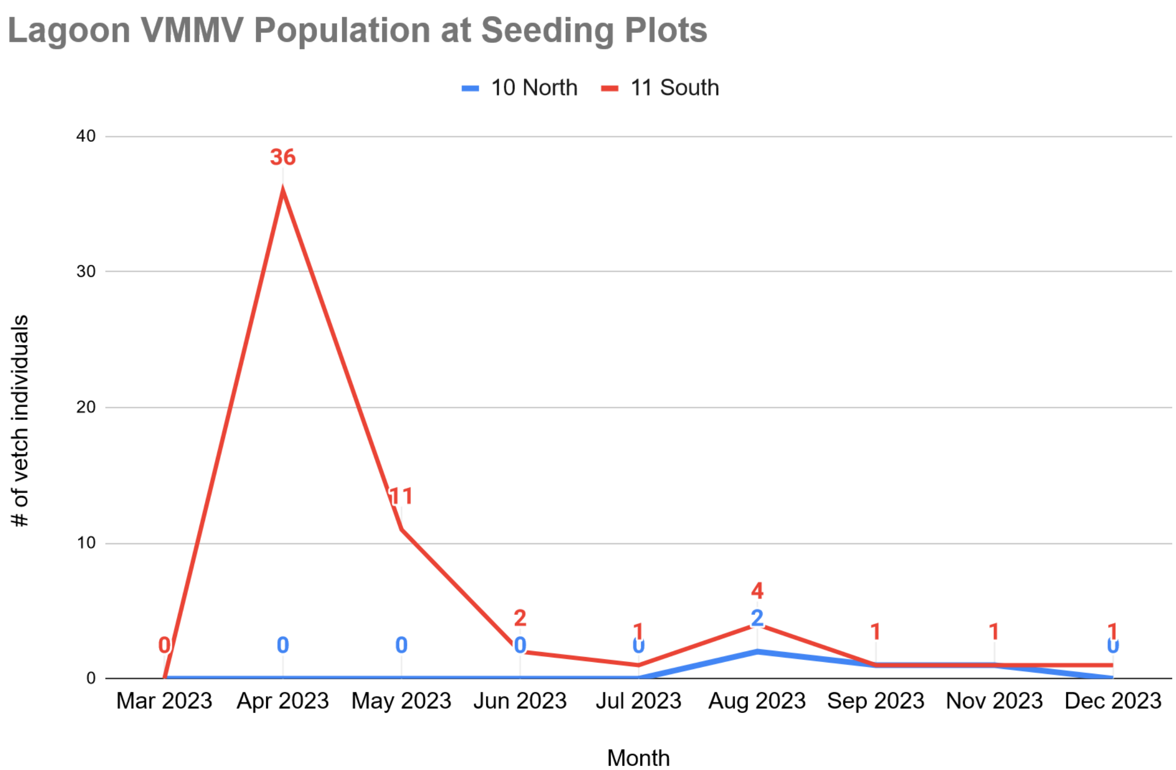

Figure 5. A graph of living seedlings at the Lagoon plots over the course of the year.

Index Well Data

The water level in the index wells declined steadily throughout the year in all sites (Figure 6). The Dune Pond well had the highest water table, which may have contributed to the relative success of the milk-vetch at plot 7. The West Main Channel well associated with plot 5 had a consistently lower water level, by about a half-foot in the summer. The East Main Channel well associated with plot 9 ran dry in August and the water table never rose above five feet deep afterwards. As discussed earlier, the Lagoon well ran dry by April, though there was some fluctuation in water level in the fall, between 0.1 and 0.6 feet. The average vigor of milk-vetch seedlings in associated plots was negatively correlated with well water depth (r = -0.563600757), indicating that as the water table dropped, so did the health of the milk-vetch (Figure 7).

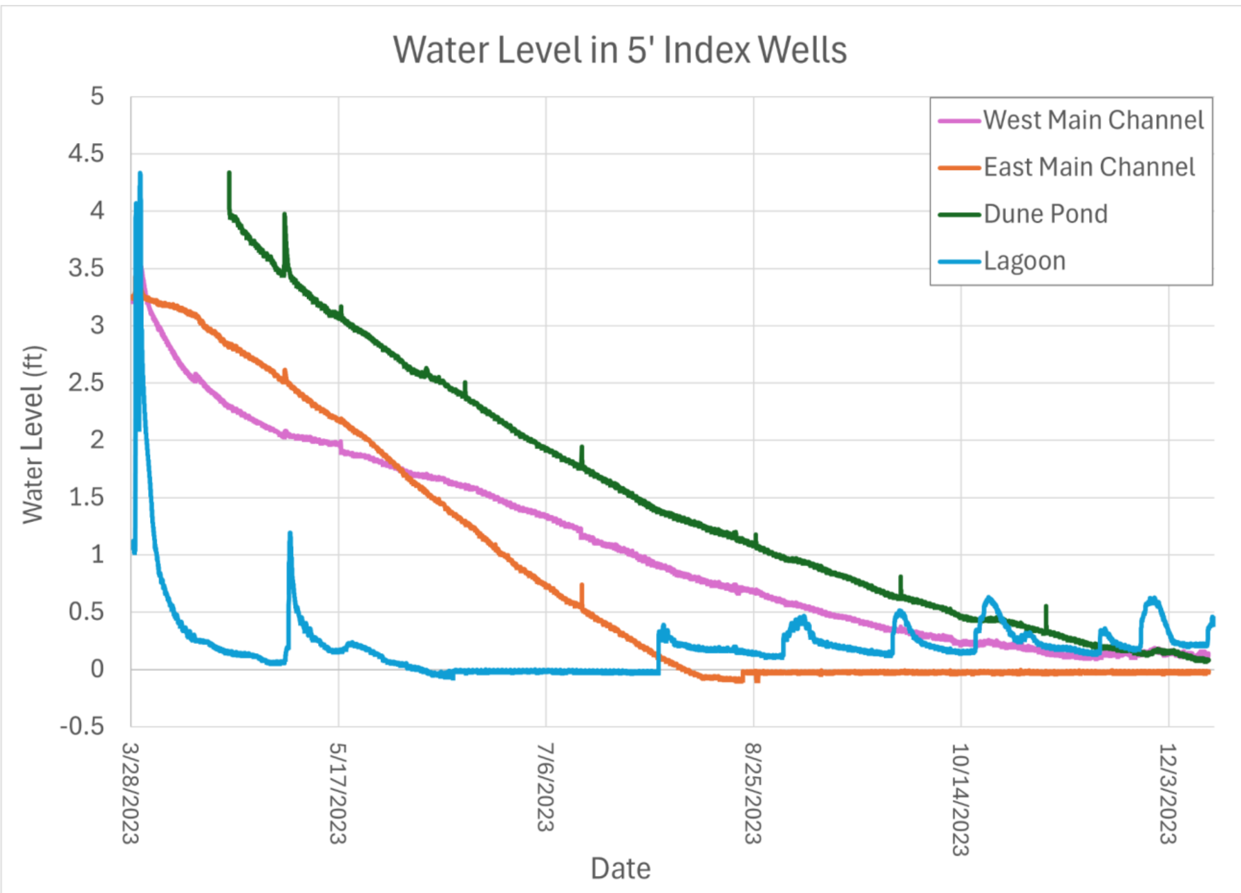

Figure 6. Line graph of the water level over time in each index well. Data collected from Levelogger pressure transducers.

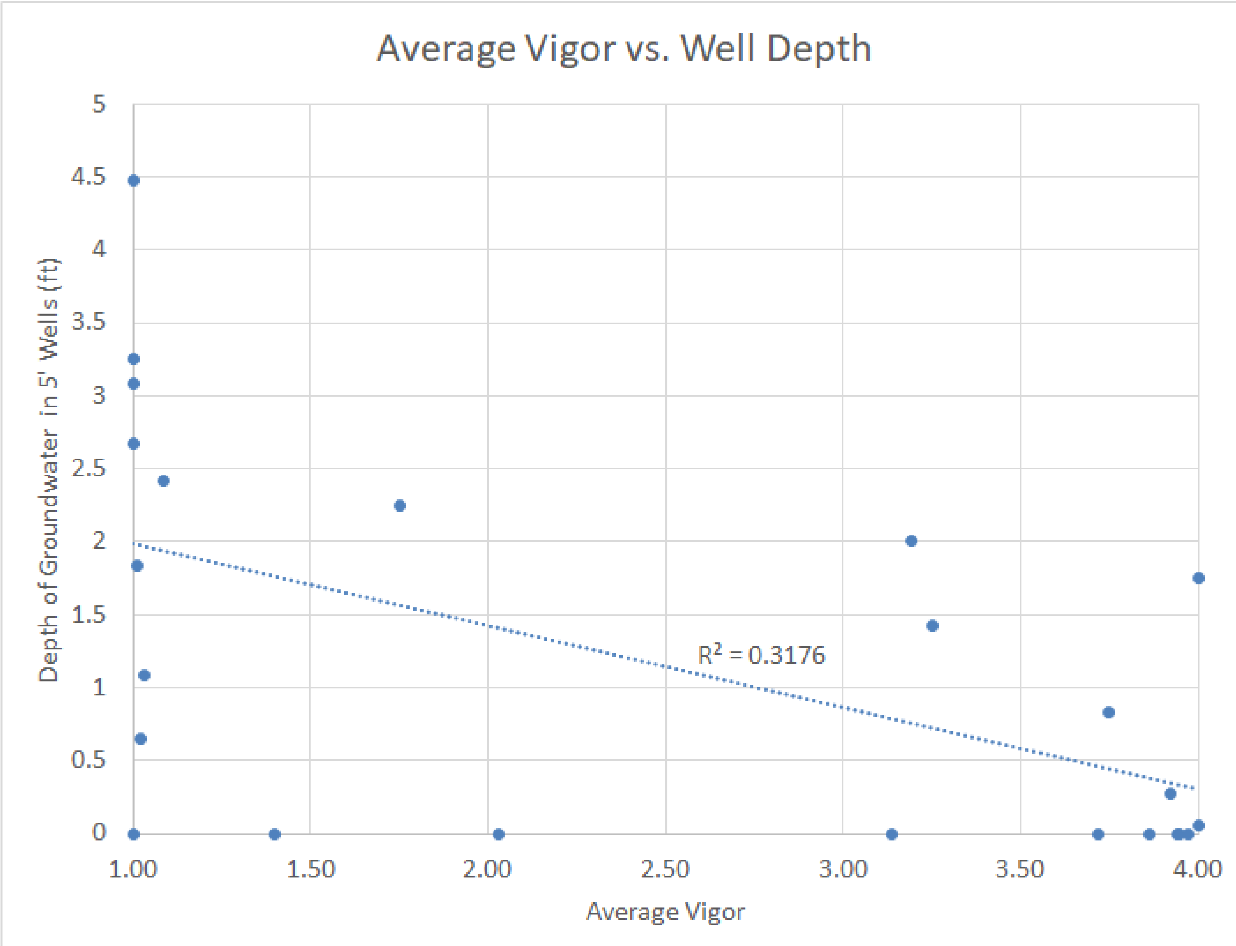

Figure 7. Scatter plot of average vigor of seedlings vs manual measurements of well depths.

Groundwater salinity, electrical conductivity, temperature, and dissolved oxygen were sampled in the index wells monthly. The averages are displayed in table 3. However, it should be noted that, due to the Lagoon well consistently running dry, the groundwater could only be sampled with the YSI meter once.

Table 3. Averages and standard deviations of well groundwater measurements.

Well	Avg Electrical Conductivity (µS/cm)	StdDev of EC	Avg Salinity (ppt)	StdDev of Salinity	Avg Temp (°C)	StdDev of Temp	Avg Dissolved Oxygen (%)	StdDev DO%
West Main Channel	280.66	132.79	0.15	0.11	18.46	2.89	6.43	2.27
Dune Pond	1668.75	493.92	0.94	0.27	19.09	2.97	12.31	13.83
East Main Channel	1174	556.84	0.68	0.36	17.35	1.75	11.62	17.28
Lagoon	569	-	0.3	-	16.5	-	5.6	-

The Leveloggers in the index wells also collected temperature data at 15-minute intervals (Figure 8). This more continuous data shows that the groundwater in the West Main Channel and Dune Pond wells was around two degrees warmer in the summer months than that of the East Main Channel or Lagoon. The former two sites are in full sun and sheltered from the ocean winds by the foredunes. On the other hand, the East Main Channel site is shaded and the Lagoon site is adjacent to open beach, bearing the brunt of the cooler ocean temperatures. The YSI temperature readings had a weak negative correlation with the average vigor at the associated site (r = -0.1051). While temperature was strongly positively correlated with population density (r = 0.8459), this may be explained by phenology. The peak of the milk-vetch population is usually in the summer when one would expect groundwater temperatures to be higher.

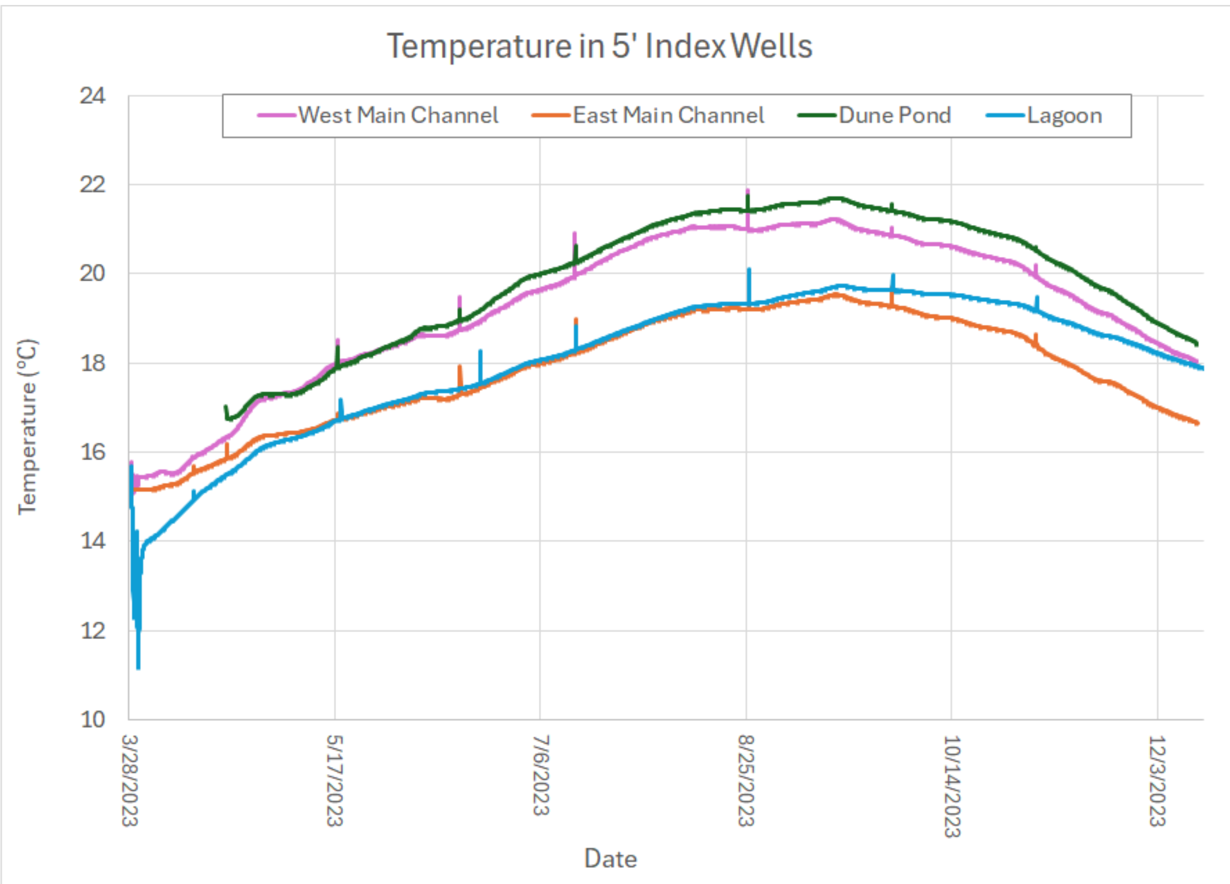

Figure 8. Line graph of the temperature over time in each index well. Data collected from Levelogger pressure transducers.

As expected, groundwater electrical conductivity and salinity measurements were highly correlated (r = 0.9883). Both metrics were higher at the Dune Pond and East Main Channel than the Lagoon or West Main Channel (Figure 9). However, electrical conductivity had a slightly stronger correlation with population density (r = 0.4739) than salinity with population density (r = 0.3512) (Figure 10). The milk-vetch seems to prefer saltier groundwater with higher electrical conductivity.

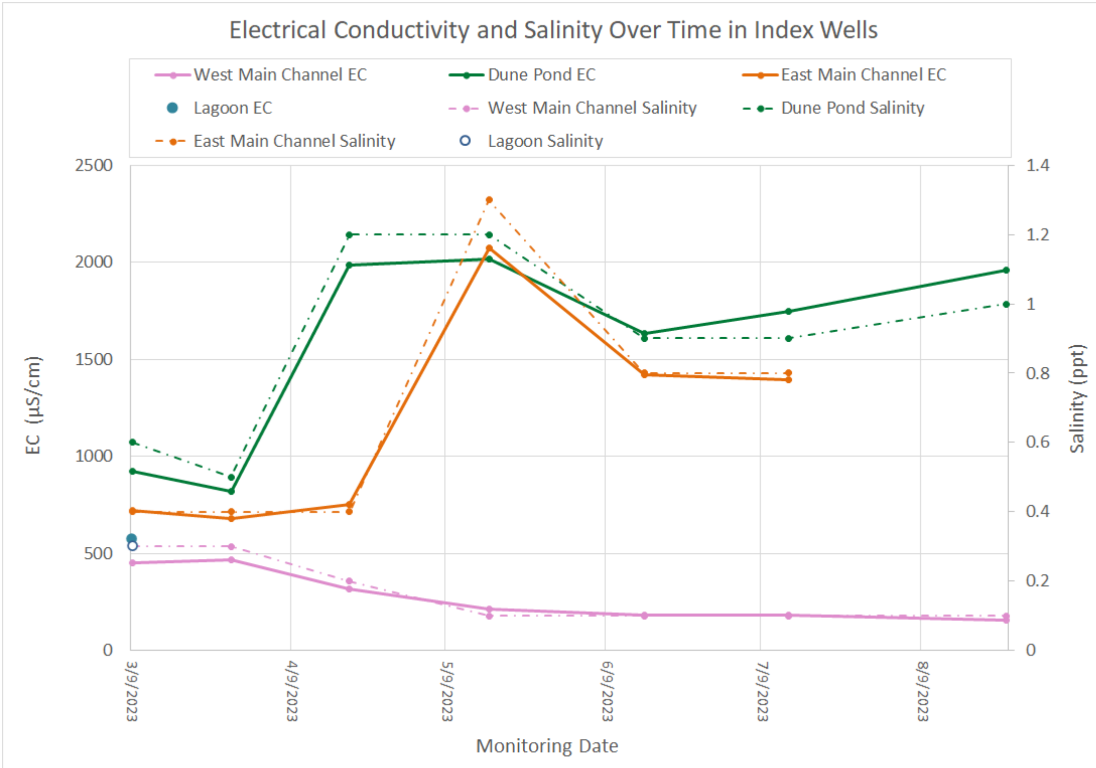

Figure 9. Line graph of the groundwater electrical conductivity and salinity over time in each index well.

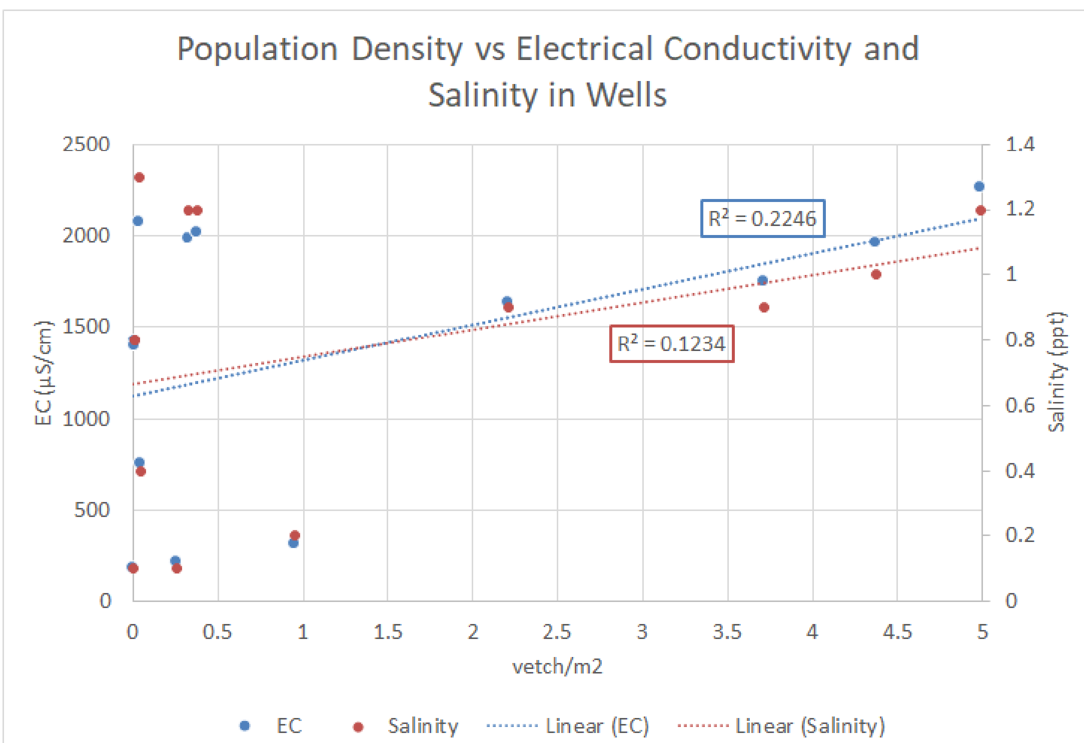

Figure 10. Scatter plot of population density vs groundwater electrical conductivity and salinity.

Groundwater dissolved oxygen levels followed a similar trend throughout the year (Figure 11). The Dune Pond well had much higher dissolved oxygen than other wells in March and April, following the flooding event. The first data point on the graph represents a measurement of the floodwater itself, rather than groundwater. The dissolved oxygen did not lower to levels comparable to the other wells until May. Population density was weakly negatively correlated with groundwater dissolved oxygen (r = -0.2580) (Figure 12).

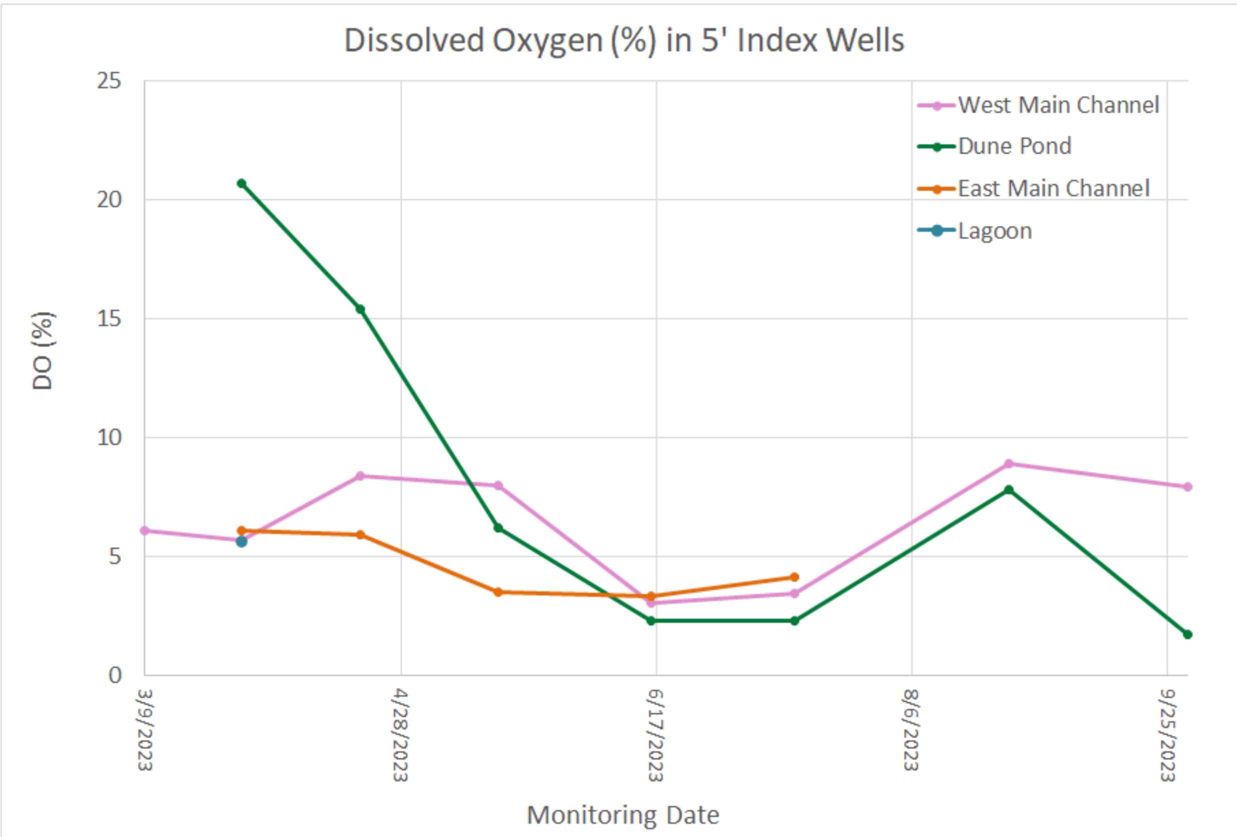

Figure 11. Line graph of the groundwater dissolved oxygen over time in each index well.

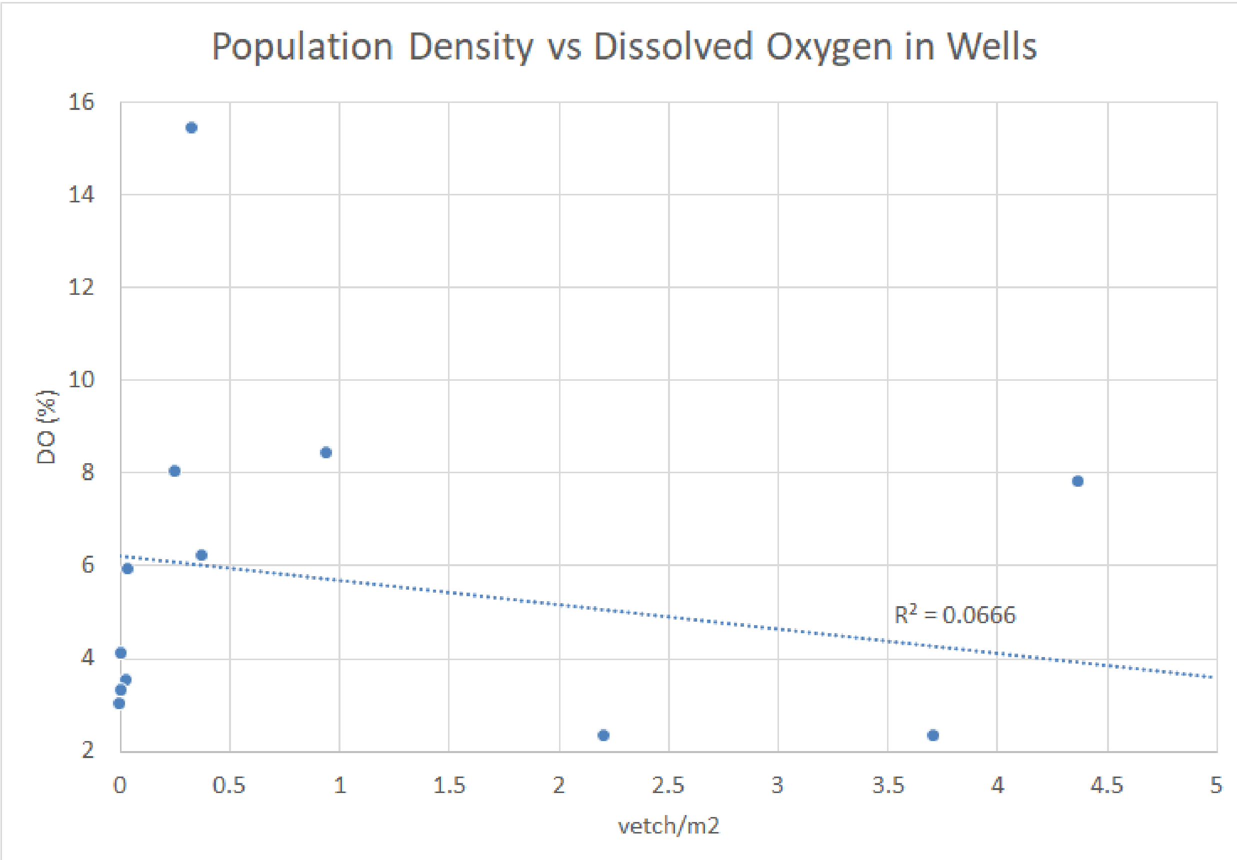

Figure 12. Scatter plot of population density vs groundwater dissolved oxygen.

Soil Sample Data

The average electrical conductivity, and moisture content of the 2-ft depth soil samples are shown in Table 4. These soil characteristics were compared with maximum population density (vetch/m^2), germination rate (% of seed estimate that germinated), and survivorship (% of germinants to live until the end of the year). One should note that survivorship is highly weighted towards plot 7 Dune Pond, which had a survival rate of 72.64%, an order of magnitude greater than the next highest plot 6 West Mouth (3.88%).

Table 4: Average measurements from 2-ft soil samples.

Plot	Average of EC us/cm	Average of pH	Average of % Moisture Content
1 West Back Dune	31.07	6.07	0.58%
2 West Back Dune	31.53	6.07	3.51%
3 West Main Channel	66.93	6.54	6.08%
4 West Main Channel	95.03	6.56	6.15%
5 West Main Channel	83.4	5.61	4.55%
6 West Mouth	180.13	5.8	8.76%
7 Dune Pond	152.67	7.94	3.97%
8 East Main Channel	101.4	6.73	0.69%
9 East Main Channel	51.03	7.29	2.22%
10 Lagoon North	4.69	5.35	48.82%
11 Lagoon South	120.77	7.31	0.90%

Electrical conductivity was highest at the two most successful seeding sites, 6 West Mouth and 7 Dune Pond (Figure 13). Soil electrical conductivity was moderately positively correlated with survivorship ($r = 0.4567$). The correlation was stronger with population density ($r = 0.6740$) and with germination rate ($r = 0.7197$) (Figure 14). The high electrical conductivity indicates high soil salinity, which further corroborates the milk-vetch’s preference for saltier sites.

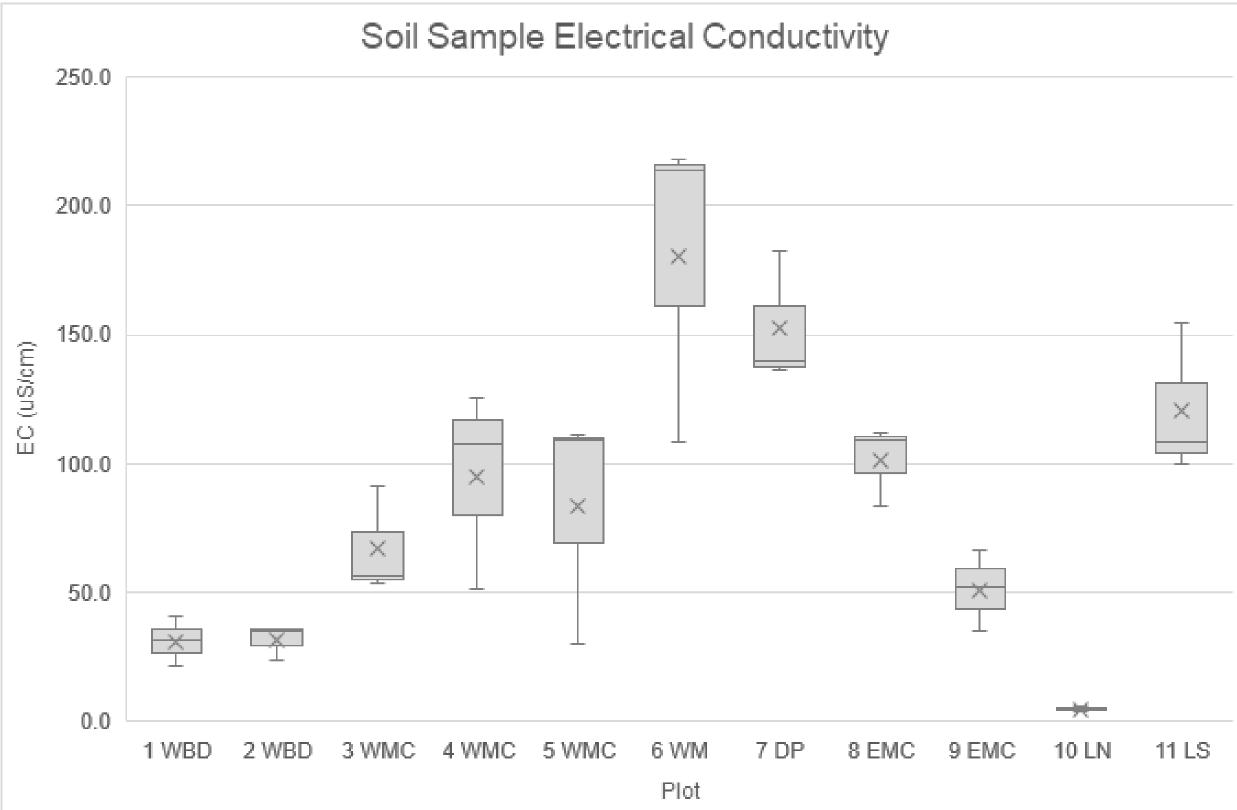

Figure 13. Electrical conductivity measurements of soil samples taken from 2-ft depth.

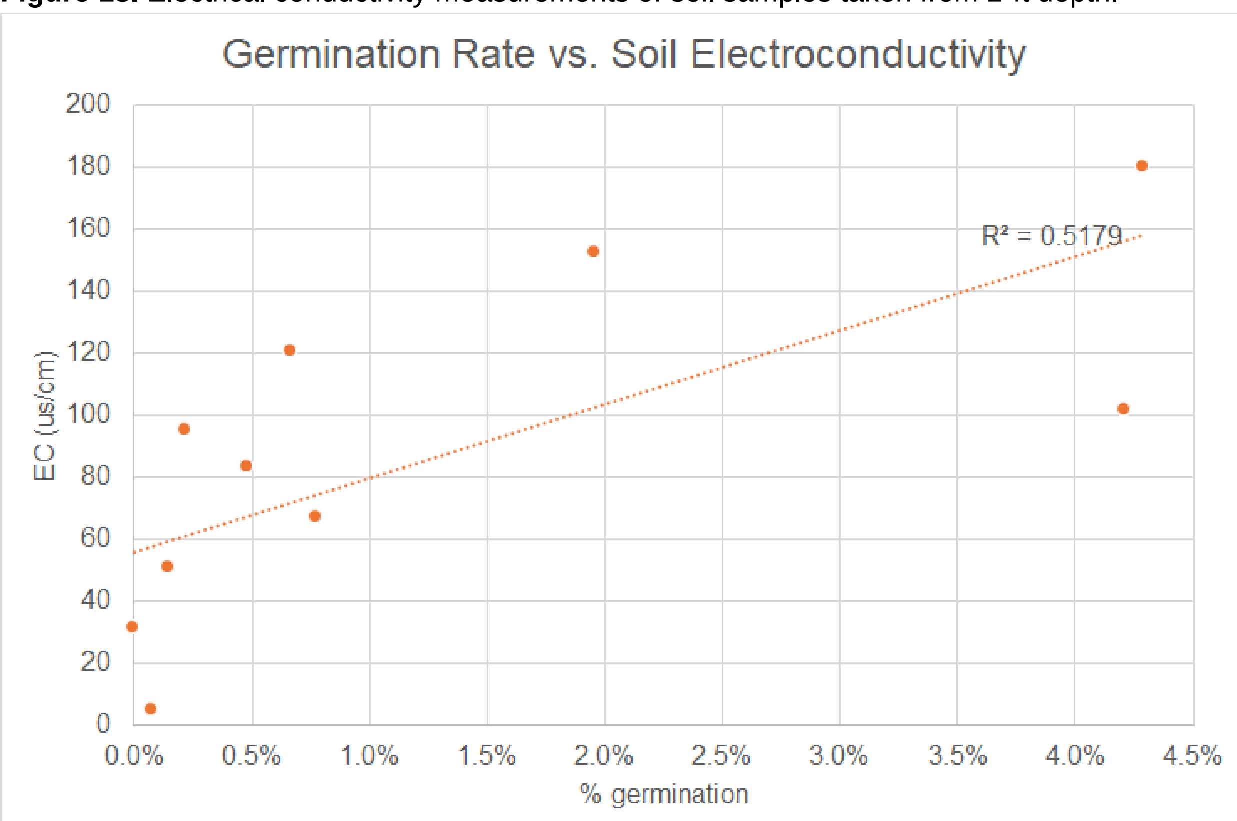

Figure 14. Scatter plot of germination rate vs soil electrical conductivity from 2-ft depth samples.

Most sites had slightly acidic soil (Figure 15). Only 7 Dune Pond, 9 East Main Channel, and 11 Lagoon South had an average soil pH greater than 7. Soil pH was weakly correlated with germination rate (r = 0.0959), but it had a moderate positive correlation with population density (r = 0.4105) and a strong positive correlation with survivorship (r = 0.5999). This seems to suggest that soil acidity has little effect on milk-vetch germination, but that it performs better in neutral to slightly alkaline soils.

Due to the predominantly sandy soils, % moisture content was low at most sites, the exception being 10 Lagoon North with an average of 48.82% (Figure 16). By contrast, this site had compact clay soils. The poor performance of this site resulted in a weak negative correlation between soil moisture and all milk-vetch performance metrics. When the outlier was excluded, there was little correlation between population density (r = -0.0113) and survivorship (r = 0.0361), but a moderate positive correlation with % germination (r = 0.2377). It may be that the soil moisture at a depth of 2 feet has little effect on young milk-vetch within their first year, as their roots have yet to grow that deep.

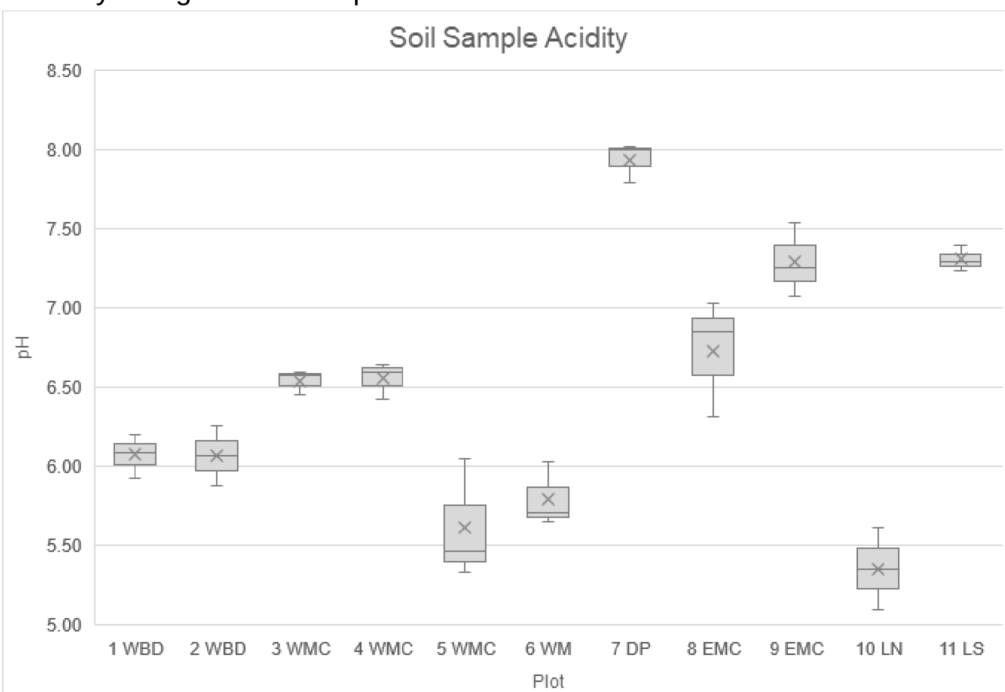

Figure 15. Acidity measurements of soil samples taken from 2-ft depth.

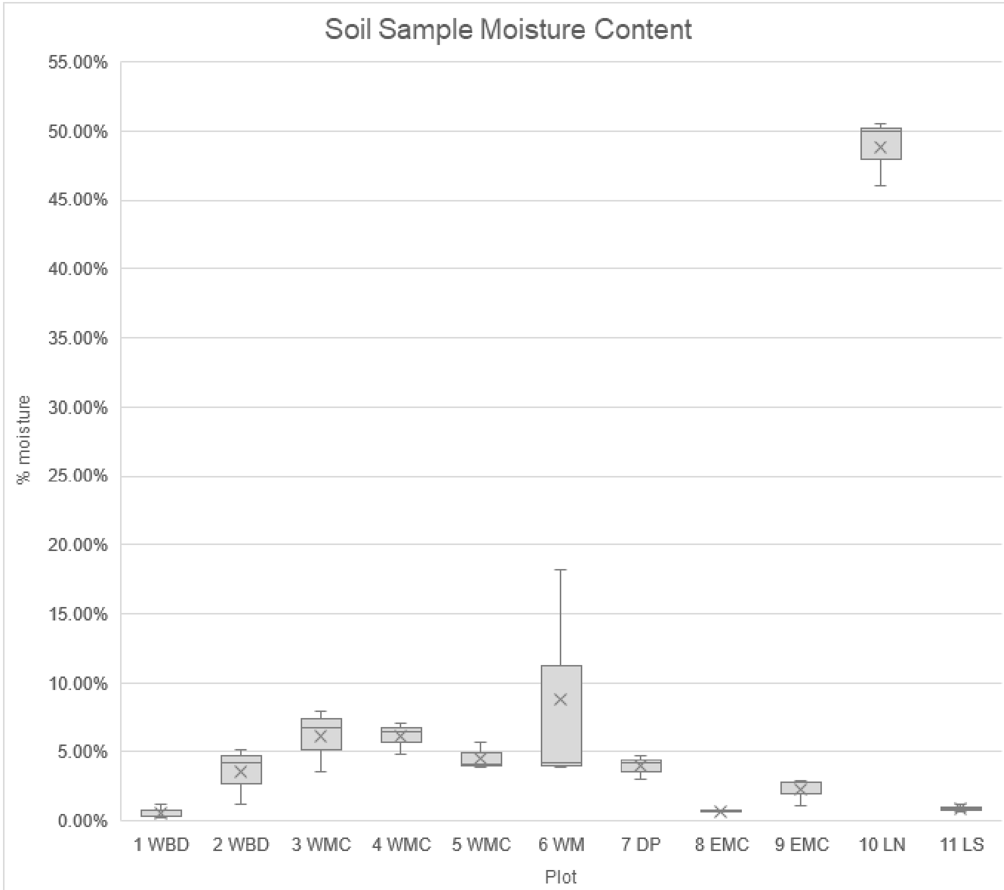

Figure 14. Soil moisture measurements of soil samples taken from 2-ft depth.

The additional soil samples processed by Fruit Growers' Lab, Inc. were collected from plots 5 West Main Channel, 6 West Mouth, 7 Dune Pond, and 8 East Main Channel, as well as the NCOS main population, sandy zone, and tule site. In contrast to the previous samples, these were taken from a shallower depth between 2 to 4 inches. An NMDS analysis grouping the samples by site showed that NCOS sites had distinctly different soil characteristics, average vigor, and population densities than the samples from the Lagoon and COPR (Figure 15).

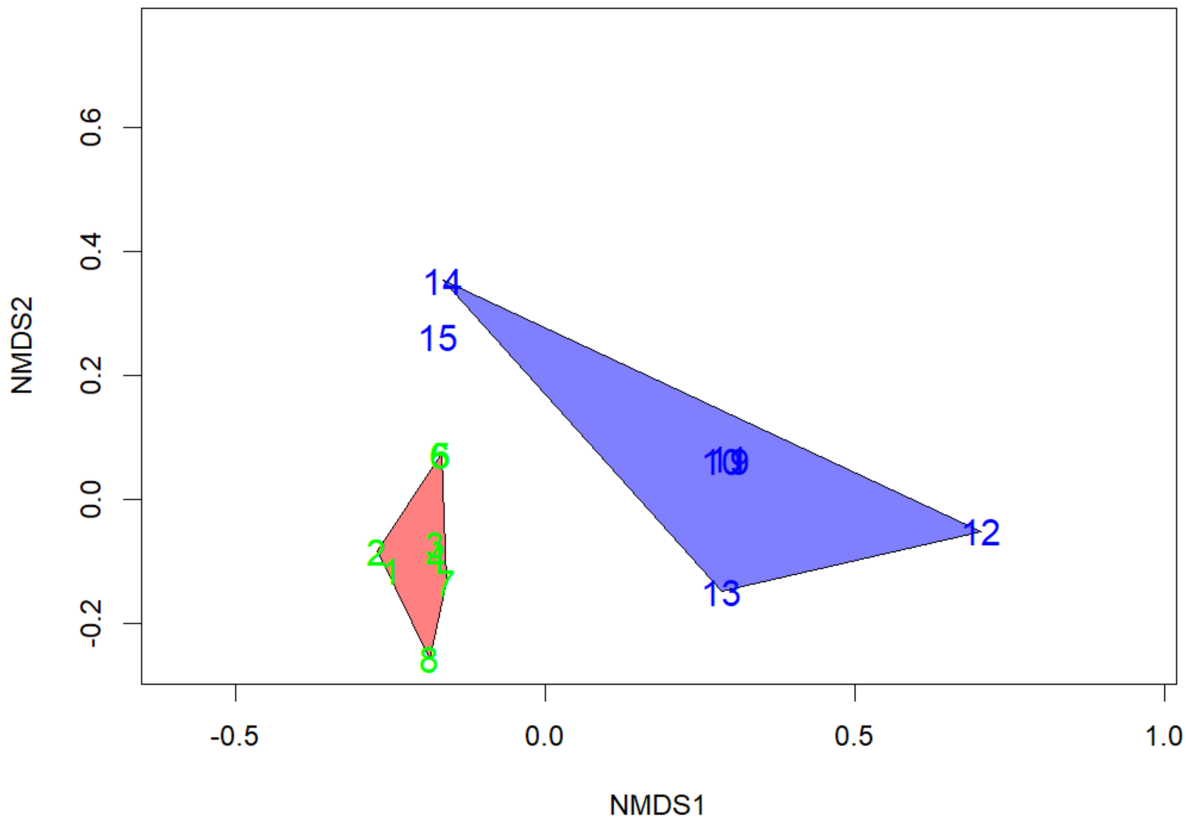

Figure 15. NMDS analysis of the soil samples grouped by site, where NCOS sites are in red and COPR/Lagoon sites are in blue.

Due to the large number of variables in the dataset (27 soil characteristics), a principal component analysis was performed to determine which characteristics accounted for the majority of variability within the dataset. Each variable was scaled to a unitless standard linearly combined into a smaller set of summary indices called principal components. Each principal component represents a larger amount of dataset variance than the next. In the case of these soil characteristics, Principal Component 1, or PC1, contains 31.32% of the original dataset's variance, PC2 contains 28.57% of its variance, and PC3 contains 12.37% (Figure 16). Thus, together the first three principal components represent the majority of the dataset's variance (72.26%).

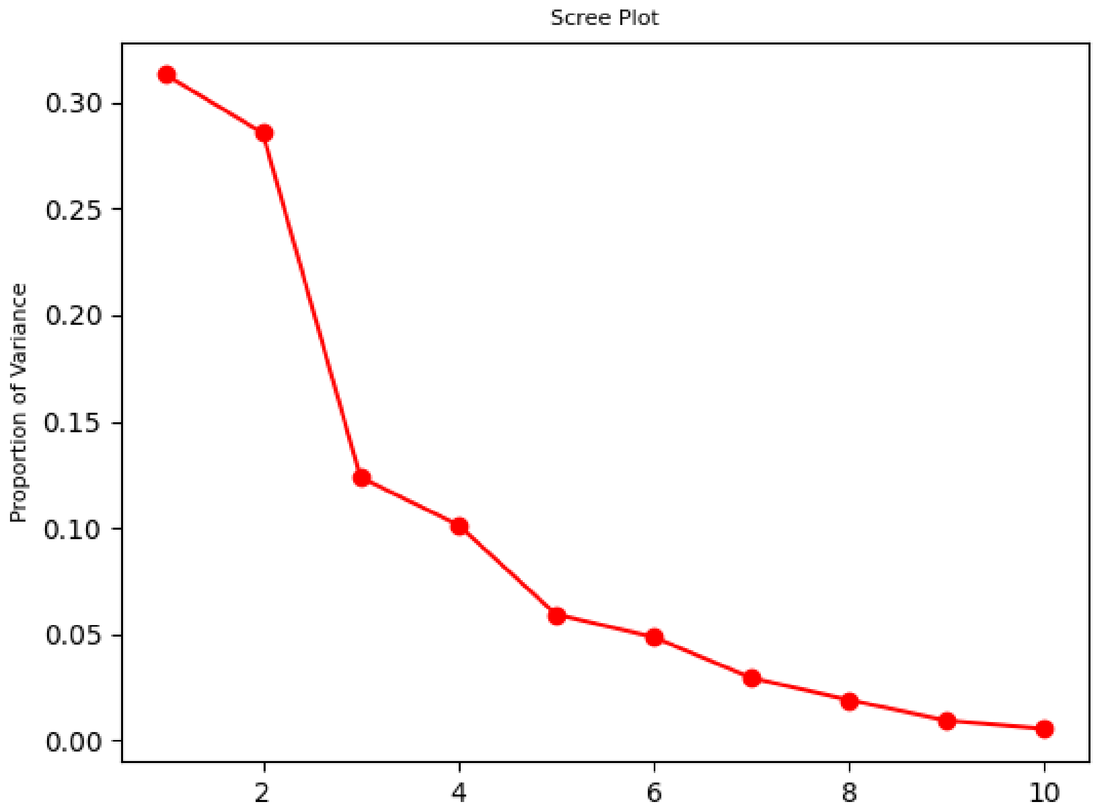

Figure 16. Scree plot of the proportion of the dataset's variance explained by each principal component.

By plotting the first two principal components against each other we can visualize how closely each soil characteristic is associated with the principal components (Figure 17). The abstraction of PCA makes the results difficult to interpret, but generally, the characteristics that are lumped together are more strongly correlated with each other. Variables with a higher value on the x-axis contribute more towards PC1, and therefore have more of an effect on the overall variance of the dataset. These include cation exchange capacity, copper, manganese, available magnesium, and available calcium, and exchangeable potassium. Variables high on the y-axis contribute more to PC2, such as pH, salinity, chlorides, boron, SAR, and soluble sodium. Factors such as sulfates, moisture, and exchangeable sodium contribute to both PC1 and PC2 and are thus responsible for nearly half of the dataset's variance.

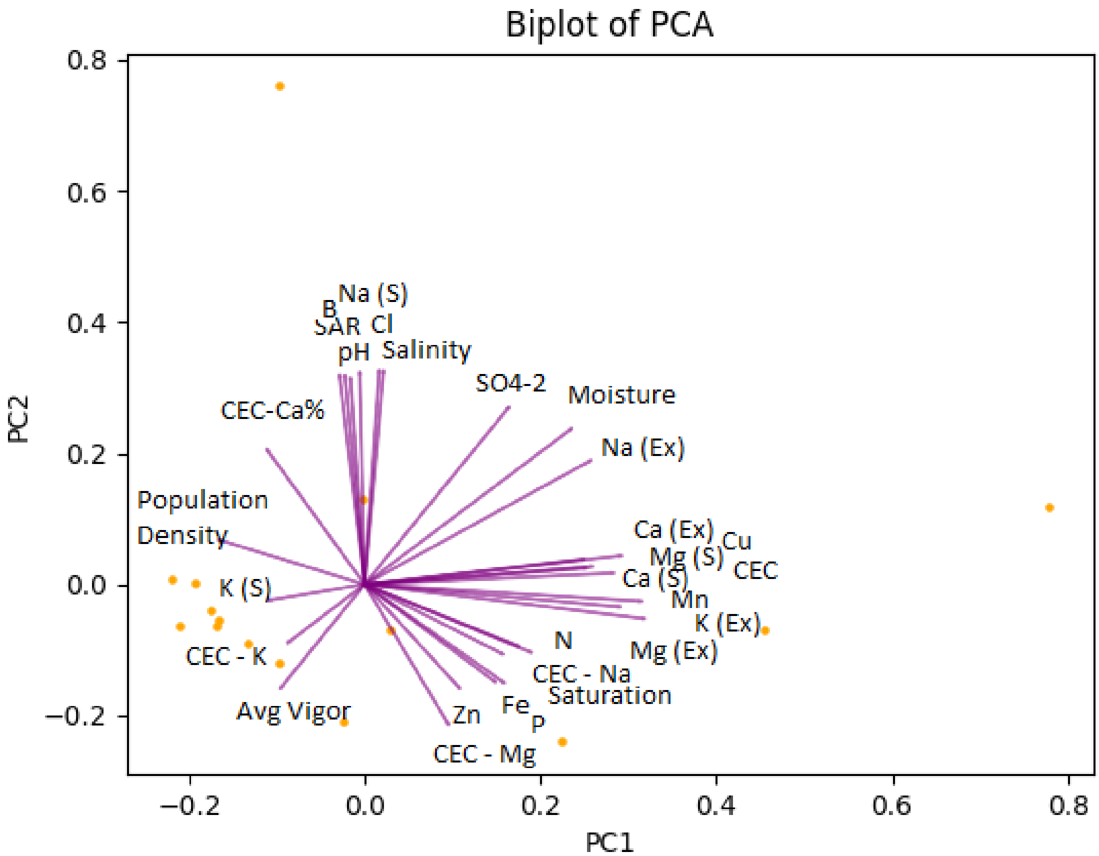

Figure 17. Scatter plot of visualizing the first two principal components of the dataset.

Some soil characteristics in the results of the FGL analysis contained significant outliers. Values outside of 1.5 times the interquartile range were removed from the dataset and Pearson's r coefficient was calculated to measure the correlation of each soil characteristic with milk-vetch average vigor or population density (Table 5). One should note once again that plant vigor is evaluated on a scale from 1 (healthy) to 4 (dead). Thus, a greater average vigor score indicates worse health. Any positive correlations with soil characteristics infer poor milk-vetch health, whereas negative correlations with soil characteristics infer better health. The average vigor, area, and population density of each plot is listed in Table 6. The NCOS main population had the highest population density, but a moderately unhealthy population with an average vigor of 2.24. The NCOS tule site had the healthiest milk-vetch population with an average vigor of 1.00, and a relatively low population density of 1.15 vetch/m^2**.**

Table 5: R-values measuring correlation between soil characteristics and milk-vetch properties. Moderate correlations are highlighted in yellow and strong correlations are highlighted in green.

Soil Characteristic	Average Vigor	Population Density
Primary Nutrients		
Nitrate-Nitrogen	0.4564104968	-0.17023722
Phosphorus (P_2O_5)	-0.5357967367	-0.3466596454
Potassium (K_2O, Exchangeable)	0.6488216676	-0.1144539547

Potassium (K_2O, Soluble)	-0.1906882022	0.03868721281
Secondary Nutrients		
Calcium (Exchangeable)	-0.2251217142	-0.1621503825
Calcium (Soluble)	0.2177790904	0.1593920577
Magnesium (Exchangeable)	0.4044546293	0.03233719316
Magnesium (Soluble)	0.3426003006	-0.2237786125
Sodium (Exchangeable)	-0.1249471711	-0.4417232999
Sodium (Soluble)	0.2501906359	-0.5765281715
Sulfate	-0.2666913897	-0.6102913059
Micronutrients		
Zinc	0.3100771716	-0.6667275532
Manganese	0.6820247134	-0.2545272211
Iron	-0.452425842	-0.8076530295
Copper	0.01953951066	0.07722668453
Boron	-0.05169866972	-0.4968509676
Chloride	-0.46069164	-0.1791367317
Cation Exchange Capacity		
CEC	-0.2346732766	-0.2427544899
Calcium Base Saturation	-0.05494427489	0.507453318
Magnesium Base Saturation	0.1339173637	-0.4884870194
Potassium Base Saturation	0.02242299516	0.2007809291
Sodium Base Saturation	-0.2766657816	-0.4703466552
Other		
pH	-0.5566323424	0.3569720394
Salinity	-0.0002507618595	-0.2773256058
SAR	0.313807135	-0.5651047864
% Moisture	-0.1527831245	-0.2307325126
% Saturation	-0.1207838461	-0.4926336577

Table 6

Plot ID	Plot Area	Average Vigor	Population Density (vetch/m^2)
COPR_5_West Main Channel	21.26	3.25	1.22
COPR_6_West Mouth	80.89	1.53	2.87
COPR_7_Dune Pond	95.08	1.08	1.11
COPR_8_East Main Channel	40.80	2.75	5.59
NCOS Main Population	1146.16	2.24	13.16
NCOS Sandy Zone	2951.48	1.38	6.12
NCOS Tule	13.91	1.00	1.15

The primary nutrients nitrogen and phosphorus tended to be found in low concentrations in milk-vetch plots, typical of sandy soils, while potassium was found in more optimum concentrations (Figure 18). Plot 7 Dune Pond had relatively low nitrogen concentrations (mean = 1.785 ppm). Plot 5 West Main Channel had much higher phosphorus concentrations than any other site (mean = 55 ppm), and the second highest potassium concentrations (mean = 93.2495 ppm). Soils from the NCOS tule site had relatively high nitrogen (mean = 15.64 ppm) and potassium concentrations (mean = 176.725 ppm). Both nitrates and potassium were positively correlated with average vigor. Therefore, soils with higher nitrate and potassium content were linked with lower milk-vetch health. However, phosphorus content had a strong negative correlation with average vigor, so K_2O may contribute to healthier milk-vetch populations. By contrast, phosphorus had a moderate negative correlation with population density.

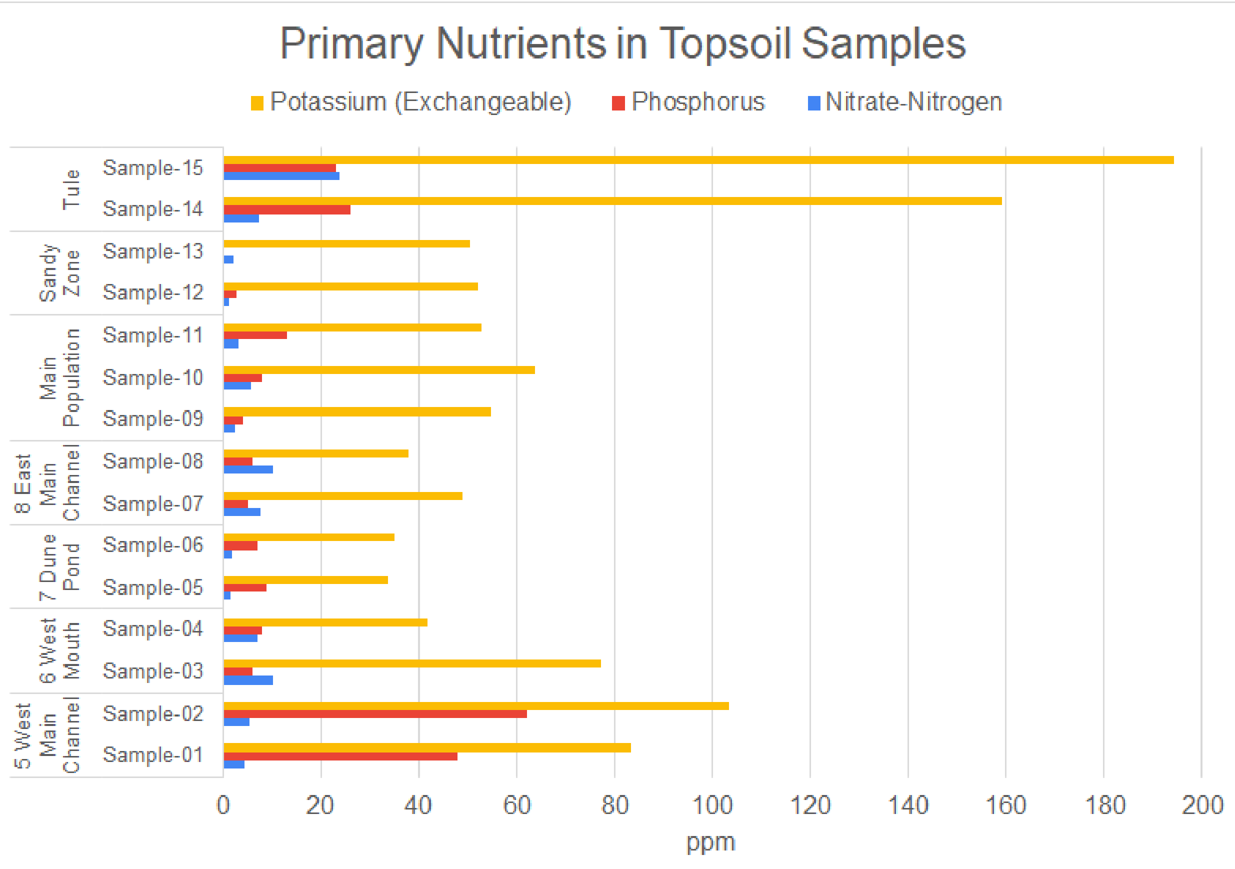

Figure 18. Primary soil nutrient measurements of soil samples taken from 2-4 inch depth.

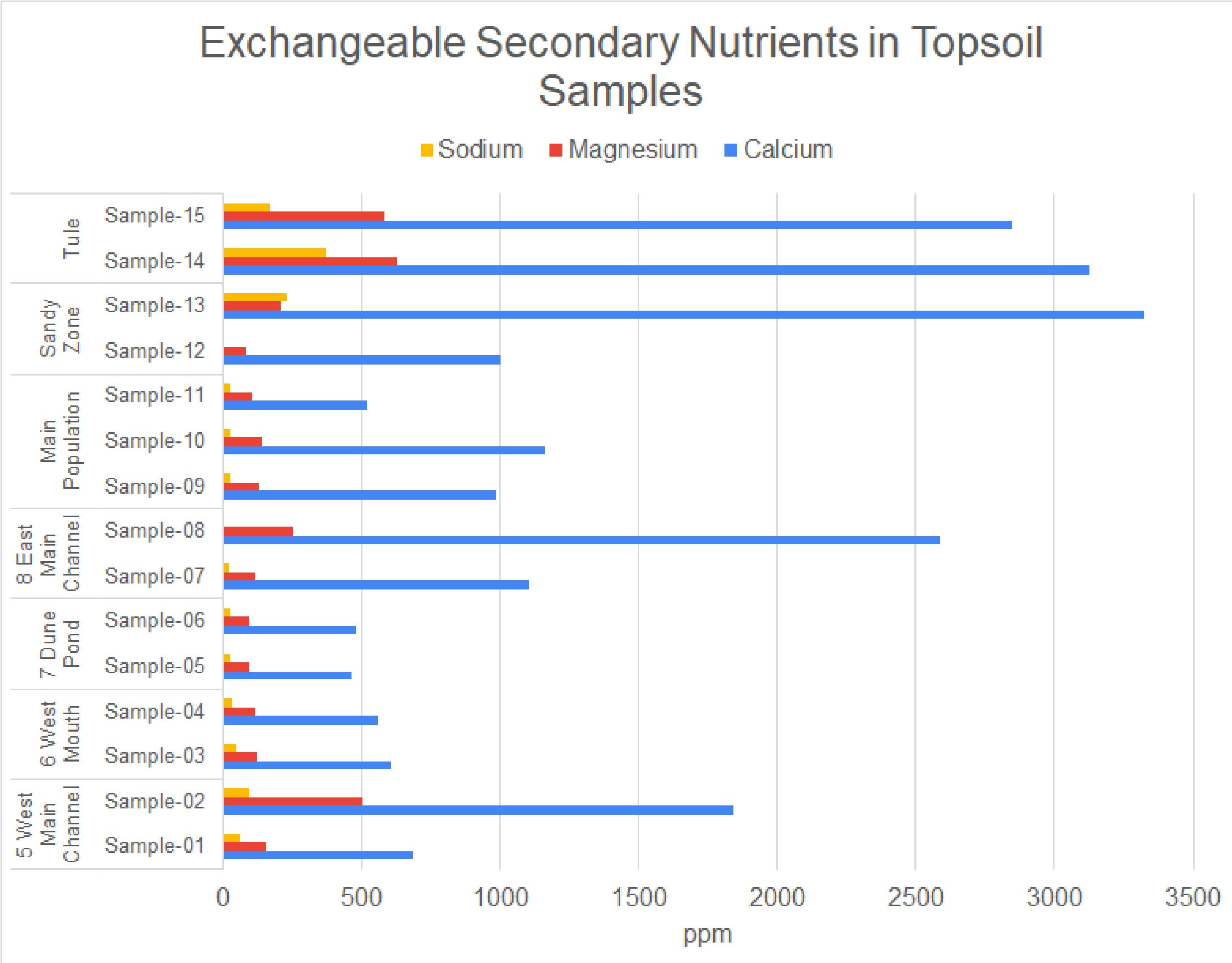

Figure 19. Exchangeable secondary soil nutrient measurements of soil samples taken from 2-4 inch depth.

Secondary soil nutrients (sodium (Na), magnesium (Mg), calcium (Ca), and sulfates) were measured in their available forms, either exchangeable or soluble. Sodium in both forms was relatively high at the NCOS sandy zone and tule site (Figures 19 & 20). It was weakly correlated with average vigor, but both exchangeable Na and soluble Na had stronger negative correlations with population density ($r = -0.4417$ and $r = -0.5765$ respectively). Exchangeable Mg was found at higher concentrations at plot 5 West Main Channel and the NCOS tule site. Soluble Mg was also very high at the tule site and NCOS sandy zone. Both forms of Mg were positively correlated with average vigor. Ca varied more widely across all sites. The tule site had relatively high soluble Ca. No strong correlation was found between Ca concentration and either average vigor or population density. Sulfates were found in relatively high concentrations in the NCOS sandy zone and tule site. Sulfates were strongly negatively correlated with population density ($r = -0.6101$).

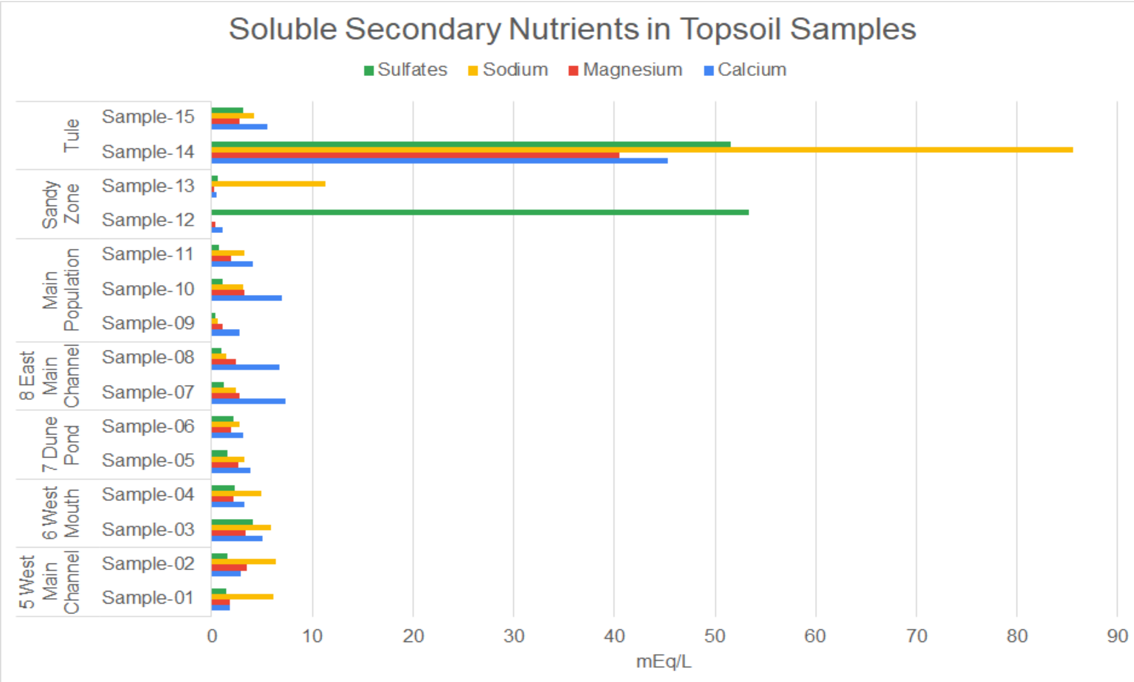

Figure 20. Soluble secondary soil nutrient measurements of soil samples taken from 2-4 inch depth. The sodium result of Sample-12 was excluded as an outlier (826 mEq).

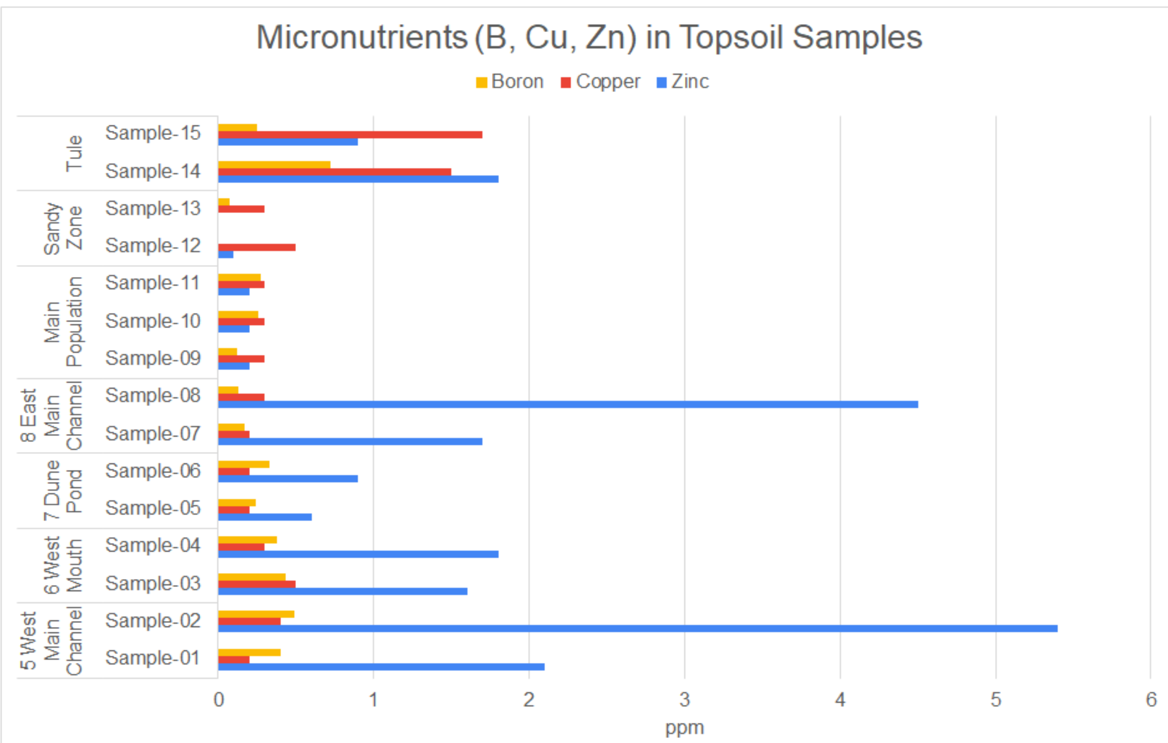

Figure 21. Micronutrient measurements of soil samples taken from 2-4 inch depth. The boron result of Sample-12 was excluded as an outlier (8.65 ppm).

Micronutrients boron (B), copper (Cu) and iron (Fe) concentrations were similar across most sites, though the tule site had relatively high concentrations and one of the sandy zones had an abnormally high boron concentration (8.65 ppm) (Figure 22). Zn was found in higher concentrations in the COPR plots 5 West Main Channel and 8 East Main Channel, and was relatively low at the NCOS main population. 5 West Main Channel also had relatively high concentrations of Fe (Figure 21). Mn was found in higher concentrations at the tule site. The tule site and the sandy zone each had one sample with abnormally high chloride concentrations (108 mEq/L and 556 mEq/L, respectively). Chloride levels were relatively similar across all other sites (Figure 23).

Zn and Fe both had strong negative correlations with population density (r = -0.6667, r = -0.8077). However, Fe had a moderate negative correlation with average vigor (r = -0.4524), indicating better health in iron-rich soils. Chlorides also had a moderate negative correlation with average vigor (r = -0.4607).

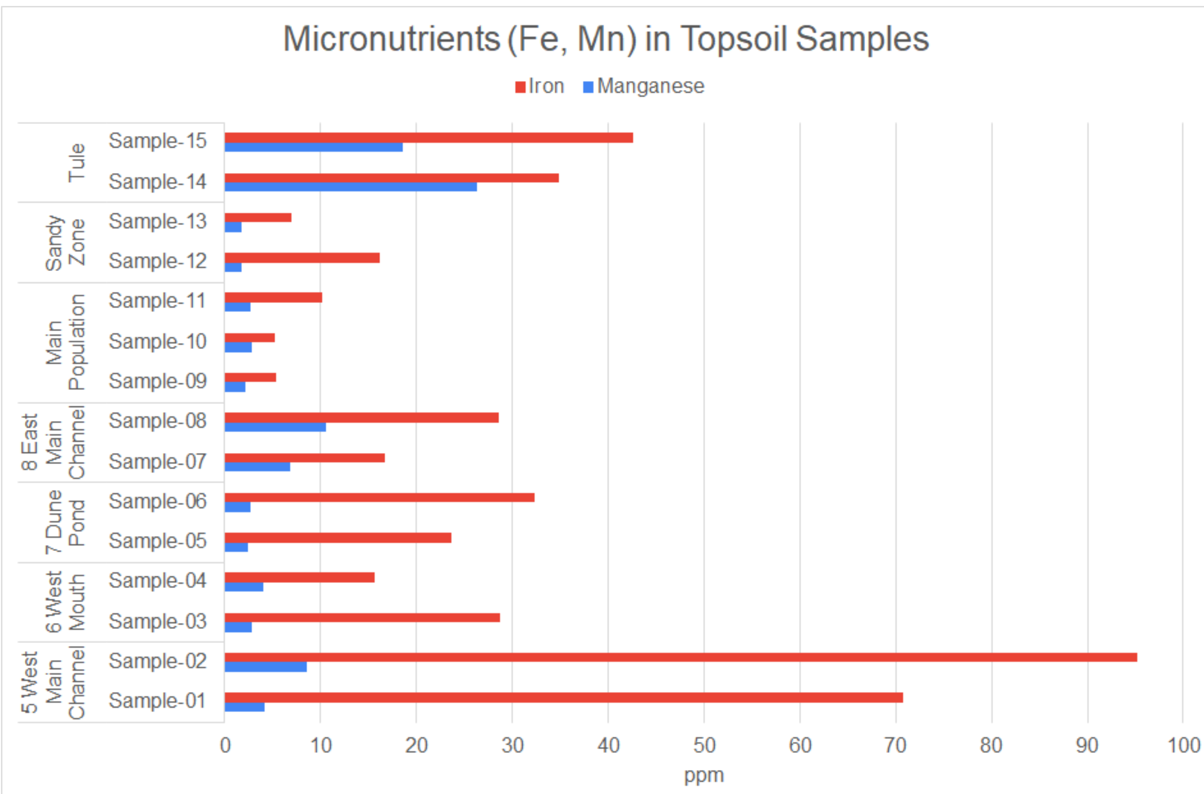

Figure 22. Micronutrient measurements of soil samples taken from 2-4 inch depth.

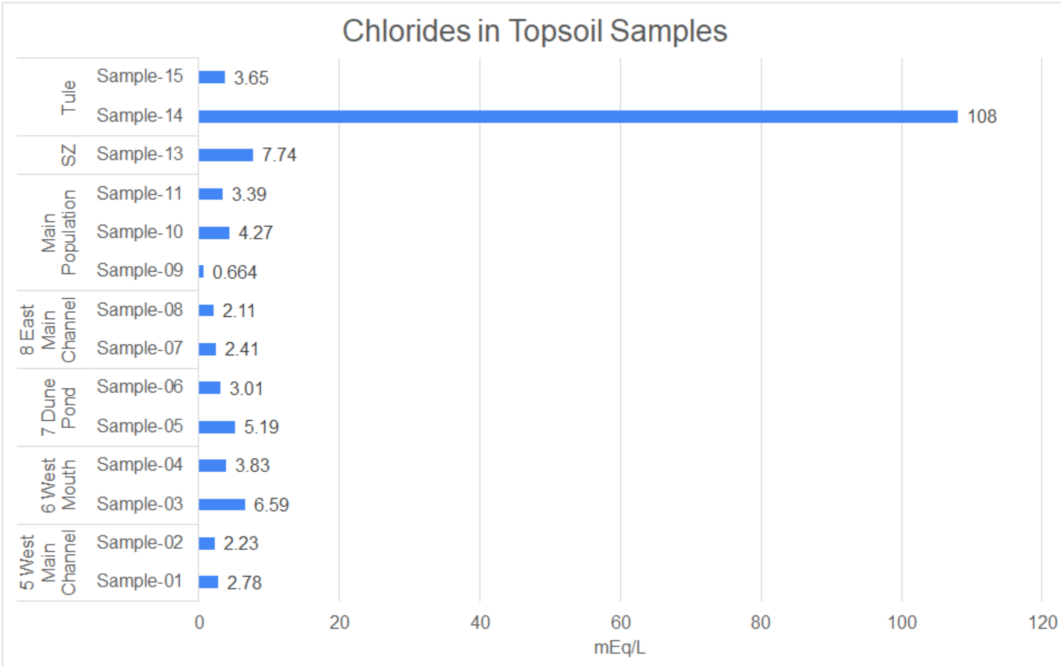

Figure 23. Chloride measurements of soil samples taken from 2-4 inch depth. Sample 12 excluded as an outlier (556 mEq/L)

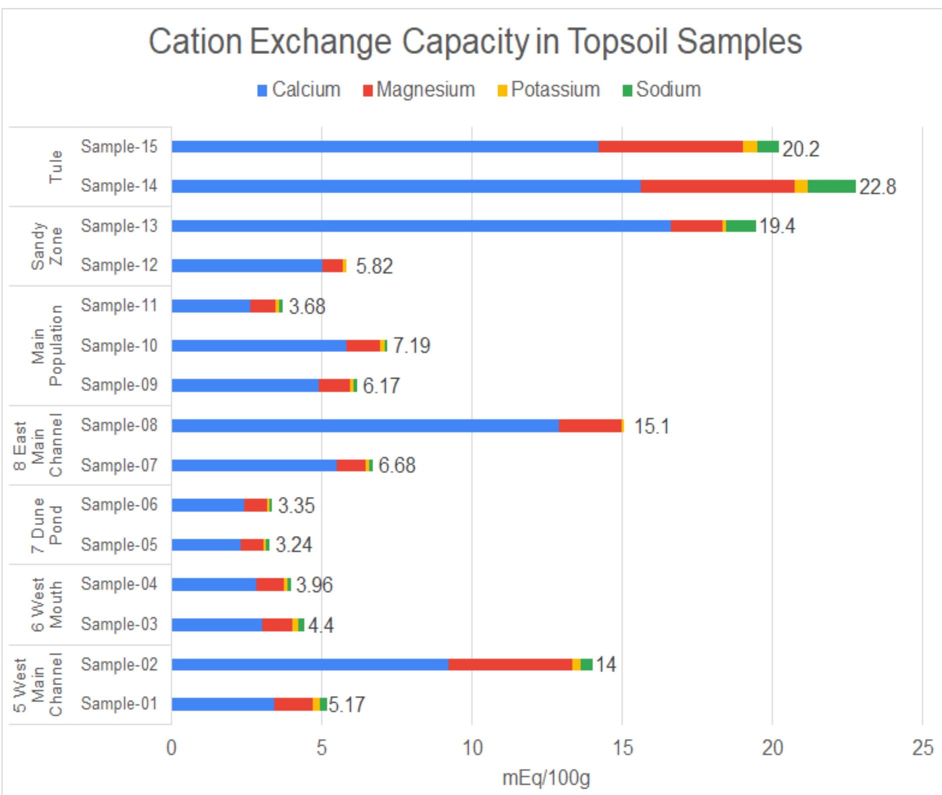

Figure 24. Bar chart of cation exchange capacity of soil samples taken from 2-4 inch depth. % base saturation of Ca, Mg, K, and Na cations shown proportionally.

Cation exchange capacity was higher in the NCOS tule site and sandy zone soils (Figure 24). It was also slightly higher at plots 8 East Main Channel and 5 West Main Channel. It was moderately negatively correlated with average vigor (r = -0.2346) and with population density (-0.2428). There was little correlation between average vigor and base saturation % of any particular cation. However, calcium saturation % was strongly positively correlated with population density (r = 0.5074). In turn, Mg and Na saturation % were moderately negatively correlated with population density.

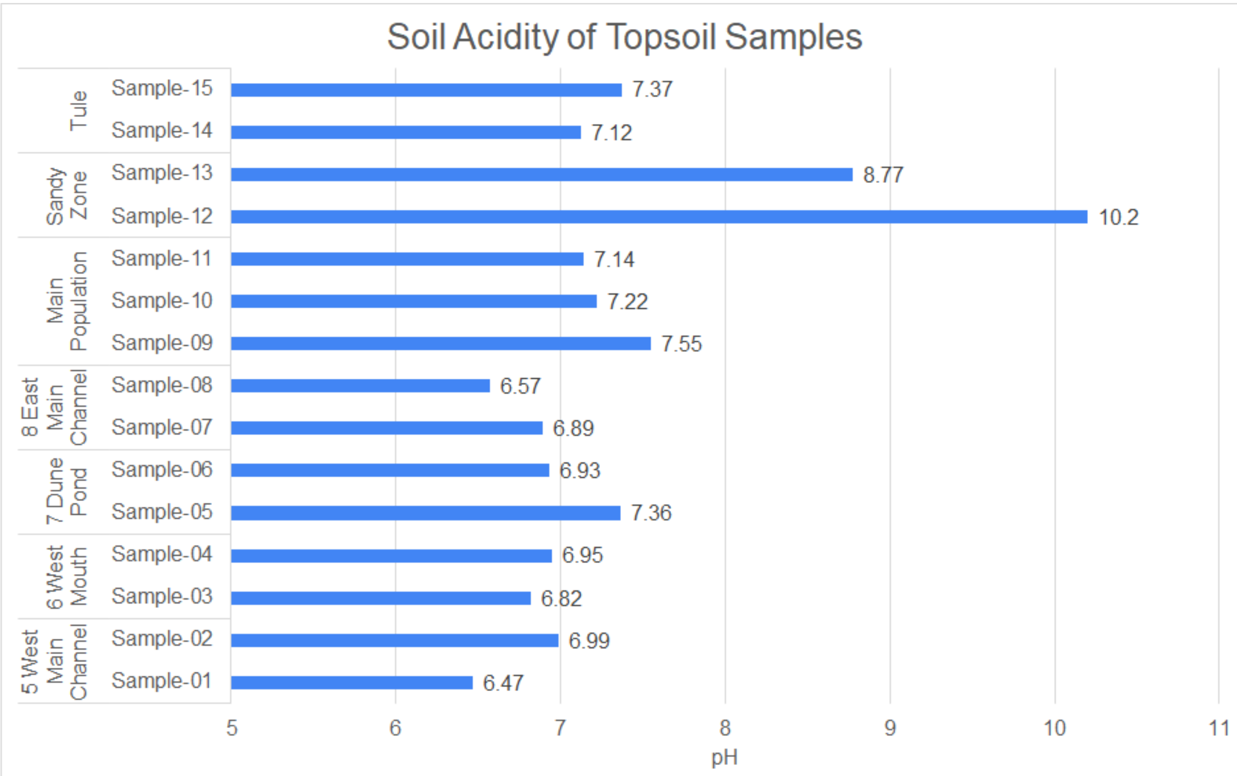

Figure 25. Bar chart of pH of soil samples taken from 2-4 inch depth.

The soil samples from the COPR plots were mostly slightly acidic, with the exception of one slightly alkaline sample from the Dune Pond. In contrast, the NCOS main population, tule site, and especially the sandy zone all had alkaline soils (Figure 25). There was strong negative correlation between pH and average vigor (r = -0.5566) as well as a moderate positive correlation with population density (r = 0.3570). This holds true to the finding from the deeper soil samples that milk-vetch prefers neutral to slightly alkaline soil.

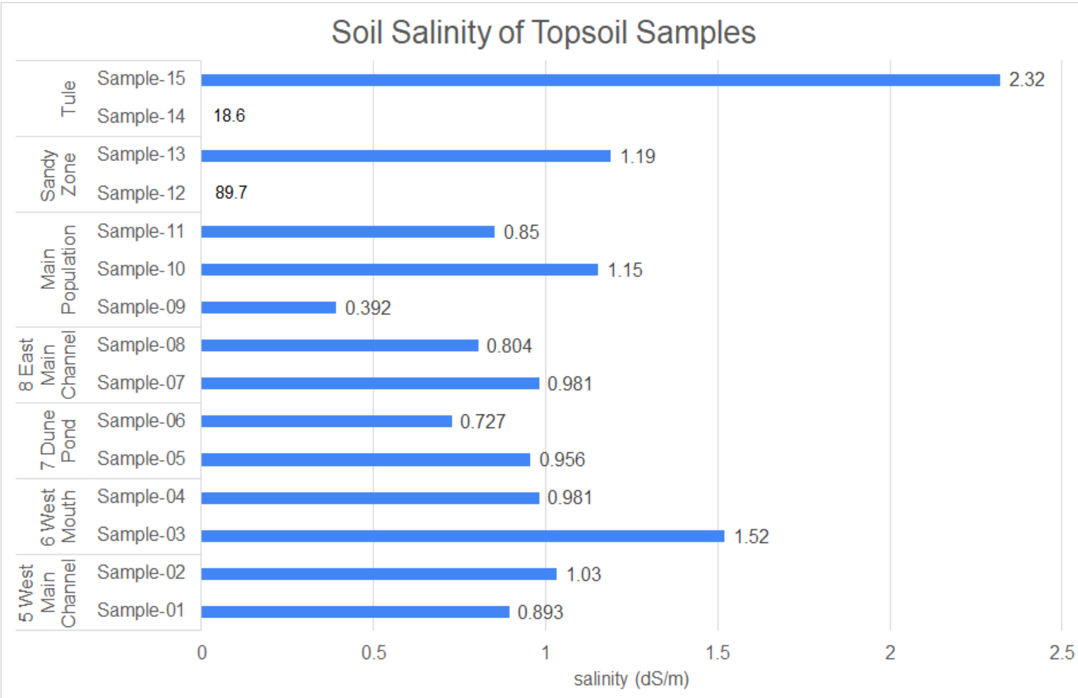

Figure 26. Bar chart of soil salinity of soil samples taken from 2-4 inch depth. Bars for samples 12 and 14 were omitted as outliers.

Soil salinity was similar across most COPR sites and the NCOS main population, but notably higher at the sandy zone and tule site (Figure 26). There was very little correlation between salinity and average vigor or population density.

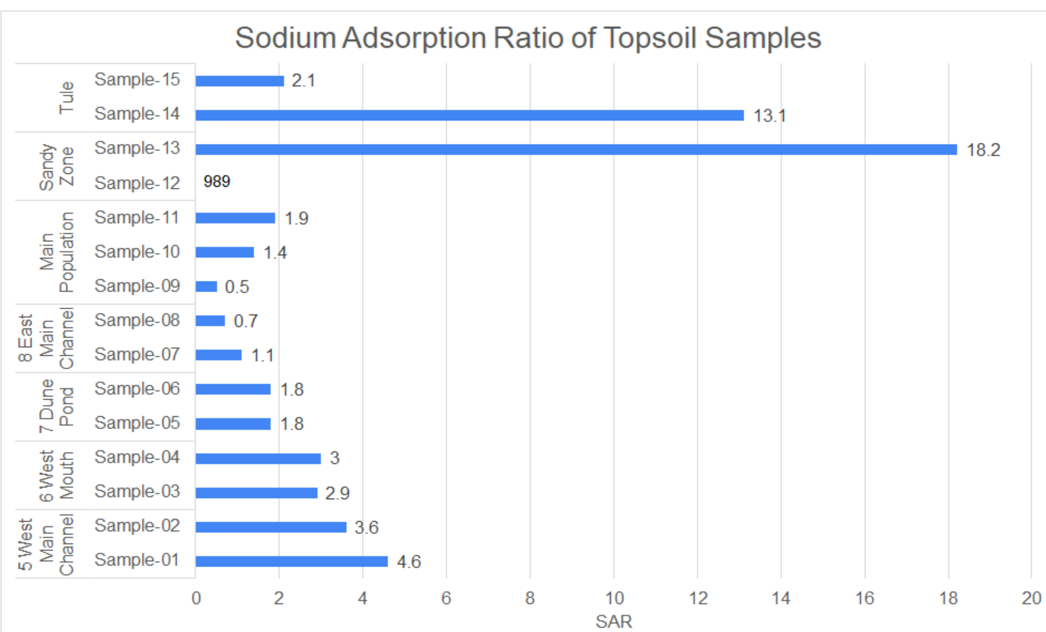

Figure 27. Bar chart of SAR of soil samples taken from 2-4 inch depth. Bar for samples 12 omitted as an outlier.

Sodium adsorption ratio is a measure of the soil sample's sodium content relative to its calcium and magnesium content. High SAR may decrease a soil's infiltration rate and the availability of water. SAR was generally low in the COPR plots and the main population, but extremely high at the sandy zone and one of the tule site samples (Figure 27). SAR had a moderate positive correlation with average vigor (r = 0.3138) and a strong negative correlation with population density (r = -0.5651). High SAR values may have a negative effect on the milk-vetch health and population density.

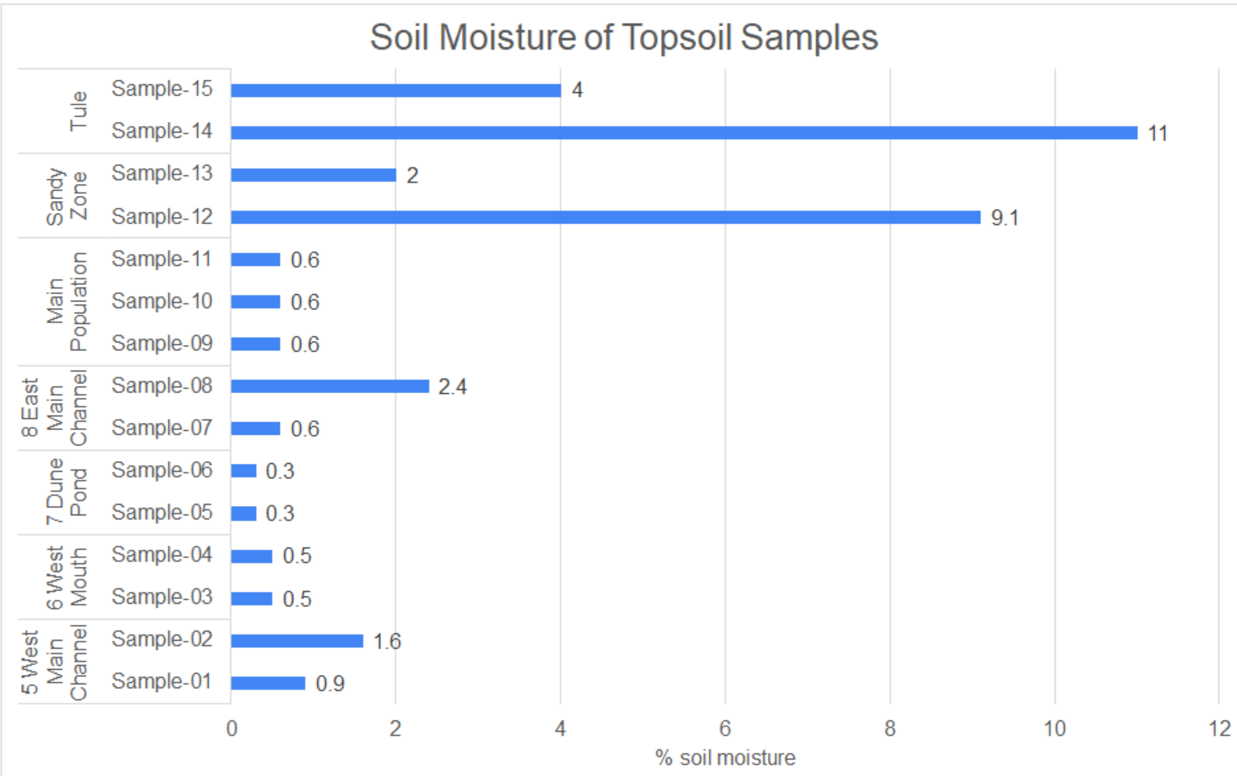

Figure 28. Bar chart of moisture of soil samples taken from 2-4 inch depth.

Soil moisture content in the topsoil samples ranged between 0.3 and 2.4% in the COPR plots and the main population, but was generally higher at the tule site and the sandy zone (Figure 28). Soil moisture was weakly correlated with both average vigor (r = -0.1528) and population density (r = -0.2307).

Soil saturation was in the 30-40% range for most of the samples, though it was higher at 5 West Main Channel, the tule site, and one sample at 8 East Main Channel (Figure 29). Soil saturation is often used as a proxy for soil texture classification, where the 20-40% range would correspond with loam, 40-50% with silty loam, 50-60% with clay loam, and 60-70% with clay. The correlation between soil saturation and soil texture is not perfect however, and may be skewed by extreme salinity or the higher organic material content in topsoil samples. In this case, by hand-testing alone, most samples were closer to sand than clay. Soil saturation was weakly negatively correlated with average vigor (r = -0.1208) and moderately negatively correlated with population density (r = -0.4926), suggesting that population density increases in sandier soils that retain less water.

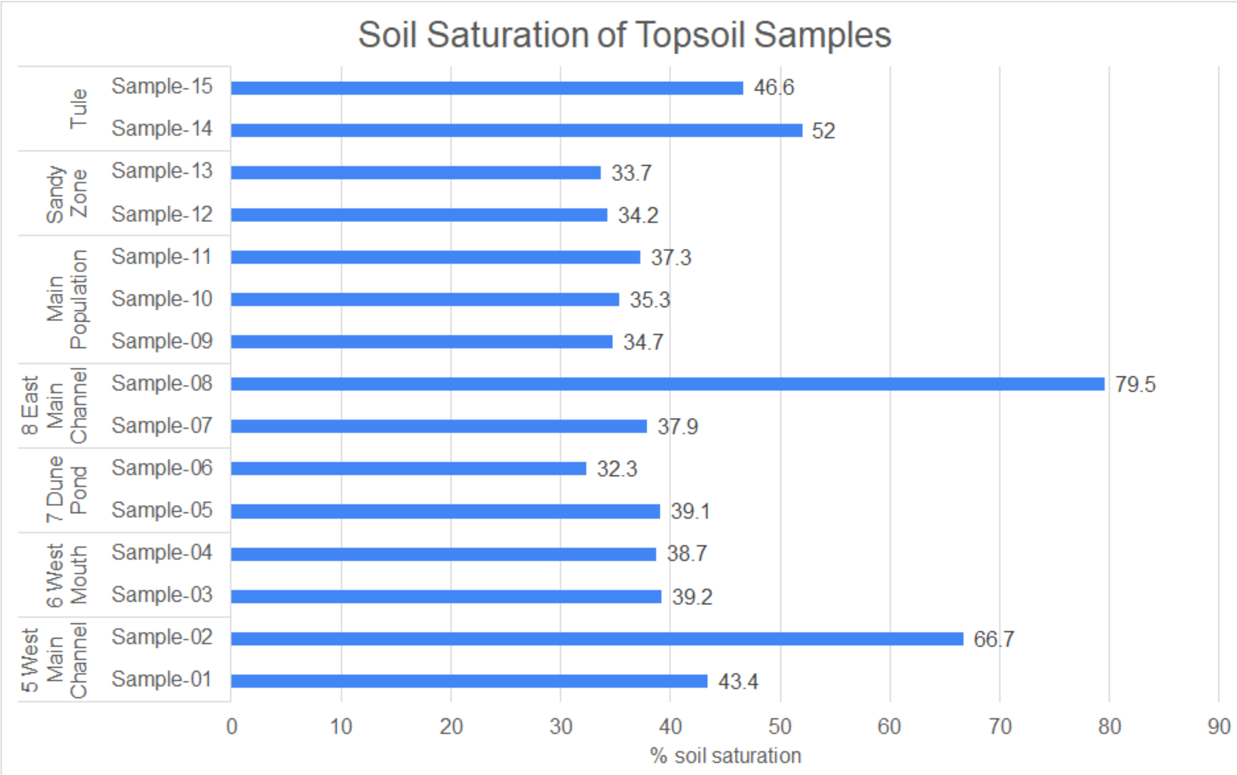

Figure 29. Bar chart of soil saturation of soil samples taken from 2-4 inch depth.

Further Considerations

Findings are consistent with previous conceptions of the milk-vetch's life history. Successful seeding sites were largely dependent on a high water table throughout the year. Milk-vetch seemed to prefer saltier groundwater, low soil SAR, and sandy, well-drained, nutrient-poor soils. Further soil data collection may provide clearer relationships between milk-vetch success and a variety of nutrients.

Previous attempts to establish a population of Ventura marsh milk-vetch on COPR's Devereux Slough have been unsuccessful in the long-term. A site near the slough at Venoco bridge was seeded in 2003 and experienced fluctuations in population until extirpation in 2010. A site near the Dune Pond was planted in 1999, with subsequent plantings in 2001, 2004, 2013, and 2014 and seed spreading in 2003, before extirpation in 2019. There are records of the Dune Pond flooding in 2001, 2005, and 2006, which inundated the milk-vetch, resulting in high mortality and impeding establishment (Lemein et al., 2020). While the flood event in 2023 seems to have encouraged germination at this site and at 6 West Mouth, yearly flooding may kill young adults before they have the chance to produce seed. Ideally, these stochastic disturbances would occur once every few years when the oldest generation of milk-vetch has had multiple reproductive seasons and replenished the seed bank.

Management challenges included encroachment from invasive plants, such as *Bromus diandrus, Polypogon monspeliensis,* and *Plantago lanceolata.* For example, the initial flush of milk-vetch seedlings in plot 8 East Main Channel was limited by subsequent germination of *B. diandrus*. In 2024, more time will be allotted towards hand-weeding around milk-vetch to reduce competition. Besides non-native plants, poison oak *(Toxicodendron diversilobum)* is spreading in the back dunes of COPR, which may impede access to plots 1-5.

Access to plot 6 West Mouth was also made more difficult during the breeding season of the endangered snowy plover *(Charadrius nivosus)*, which nests on the beach. The seeding site was placed above the plover's designated breeding zone and it is partially visible from the bird's point of view. Getting too close to the snowy plovers during the summer is discouraged as it is easy to spook the birds into leaving their nests unattended and vulnerable. Access to this site is possible coming from the Dune Pond trail, but caution should be taken by staying quiet and remaining out of sight as much as possible.

Coastal goosefoot *(Chenopodium littoreum)* was found in several of the COPR plots. This plant is considered threatened in California, with a CA Rare Plant Rank of 1B.2. In this case, protection of the milk-vetch may also protect the coastal goosefoot by proxy. Milk-vetch monitors should be familiar with this species in order to avoid trampling while managing the milk-vetch plots.

The Cheadle Center funding to continue monitoring COPR and the Lagoon will only last until March 2024. We hope to find funding to monitor the survivorship and flowering in the summer 2024. It would be helpful to have funding for the full spring and summer as the population dynamics of the second generation of milk-vetch will provide a better understanding of the long-term viability at these sites.

References

Lemein, T., Niessen, K., Darst, C., & Erickson, B. (2020). Species Status Assessment for Ventura Marsh Milk-Vetch. In *U.S. Fish & Wildlife Service*. US. Fish & Wildlife Service. Retrieved February 1, 2024, from https://www.fws.gov/node/70330

Stratton, L., Chapman, W., & Calderon, C. (2021). Status of Ventura marsh milk-vetch at North Campus Open Space. *UC Santa Barbara: Cheadle Center for Biodiversity and Ecological Restoration*. Retrieved from https://escholarship.org/uc/item/91f243kg