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Introduction

Lichens are generally known to be indicators of air quality and the presence of pollutants in an ecosystem. *Cladonia portentosa* subsp. pacifica, known commonly as reindeer lichen, or grey lichen, is a fungal composite symbiont that is composed of a mycobiont, or fungal partner, and a photobiont, in the form of a green algal partner [1]. *C. portentosa* subsp. pacifica is a light-colored fruticose lichen whose habitat range is limited to within several kilometers of the ocean and spans from Southeast Alaska to California. [2, 10]. The preferred substrate of *C. portentosa* subsp. pacifica includes sandy soils, humus, and moss over sand. In California, the habitat range of *C. portentosa* subsp. pacifica is limited to within a few kilometers of the ocean. *C. rangiferina* is another fruticose reindeer lichen in the same genus as *Cladonia portentosa* subsp. pacifica. These two lichens are macroscopically nearly identical to each other, excepting a few features which make them distinguishable. These features include different, subtle branching patterns, UV light reactivity in *C. portentosa* subsp. pacifica, and most notably their different habitat ranges. Although *C. portentosa* subsp. pacifica is limited to the coastal ranges, *C. rangiferina* grows in both hot and cold climates and thrives in areas of low disturbance, with low levels of moisture, as well as within areas that have well-drained, shallow soil and open canopies [3]. Both species are found in California, but *C. rangiferina* is most

Figure 1 - Lanphere Dunes survey site, top, and Ma-le'l Dunes survey site, bottom.

commonly prevalent in the arctic tundra regions of the northern hemisphere and in alpine regions and is believed to be a possible glacial refugia of the Pleistocene era [10]. Another documented difference between the two common taxa are the noted variability in the chemicals produced by them. *C. portentosa* subsp. pacifica, an exclusively coastal taxon, has been known to produce both usnic acid-containing and usnic acid-deficient chemotypes, whereas *C. rangiferina* has only been documented as an usnic acid-containing chemotype in its inland habitat range. This may suggest that selective pressures are less stringent in oceanic regions than in inland regions [10]. Due to the ability of *C. portentosa* subsp. pacifica and *C. rangiferina* to fix nitrogen, it would not be uncommon for both lichen species to develop in areas that experience fire as a natural regime, as this gives it the advantage of existing in habitats with low or non-existent levels of nitrogen [1]. *C. rangiferina* has a few commonly associated, fire-regime adapted, plant species that also share its ability to thrive in deficient soil conditions. Such areas that are occupied by the lichen, which also experience this natural fire regime, are predominantly lodgepole pine (*Pinus contorta*) forests with Kinnikinnick (*Arctostaphylos uva-ursi)* as a commonly associated species.

Although fire is infrequent in coastal regions, the shifting sand substrates and wind-borne salt spray act as a way to discourage competition and provide suitable conditions for stand formation of *Pinus contorta* [10]. Kinnikinnick is also tolerant of fire and is often indicative of sites that are moisture deficient due to rapid drainage [2, 4]. In the Pacific Northwest of Humboldt County, California, there are a few dense stands of pygmy lodgepole pines that exist in the swales of the coastal dunes ranging along the coastline within the unique dune habitat of the North Ma-le'l and Lanphere Dunes areas. Among these particular nutrient-deficient, well-draining, and sandy pygmy forests, kinnikinnick is also commonly present. Lodgepole pine and Kinnikinnick both exhibit fire, drought, and low-nutrient tolerance, and *Cladonia portentosa* subsp. pacifica tends to develop in undisturbed areas that have often experienced similar environmental coastal conditions [7]. The dune habitat where this lichen was found during this study appeared to be very limited to a small section of the coastal regions that harbored roughly the same necessary conditions for *C. rangiferina* to thrive. This suggests that there may be some aspect of specific areas of the coastal dune ecosystem that is allowing the subspecies of *C. portentosa* subsp. pacifica to exist and thrive, where its nearly identical relative, *C. rangiferina*, cannot.

The dune habitats observed in this study are currently wrapping up an extensive 15 year res-

toration process, and during that time the pygmy forest was left mostly undisturbed by human activity [5]. This restoration process was fueled by the desire to eradicate the invasive fore dune species of European beach grass, *Ammophila*, and the ice plant, *Carpobrotus*, using controlled burns on the dunes. These invasive plants work to trap most of the sand that blows off of the beach on the seaward slope rather than allowing the sand to flow naturally over the fore dune and into the semi-stable dunes behind it [5]. This effectively creates a protected area of habitat beyond the fore dune within the lower dune swales where other plant species, such as the ones observed in this study, have been established. It is the lack of disturbance within the pygmy forest from the invasive plants, the long term restoration projects currently underway, and the shared similar associated species of *C. ranigferina* that have led us to question what allows *C. portentosa* subsp. pacifica to reside in the dunes, but not its nearly identical relative. We hypothesized that if the presence of *Arctostaphylos uva-ursi* and *Pinus contorta* positively correlate with the presence of *C. portentosa* subsp. pacifica in areas near the ocean that have experienced relatively low disturbance, then the probability of *C. portentosa* subsp. pacifica being absent when *Arctostaphylos uva-ursi* and *Pinus contorta* are present in that range will be zero. Essentially, if we can find *P. contorta* and *A. uva-ursi* in a particular undisturbed oceanic area, then *C. portentosa* subsp. pacifica should also be present, if indeed the presence of the lichen subspecies is influenced by the presence of its nearly identical relative's commonly associated species.

Methods

To determine if there is a correlation between the three species of interest, we surveyed two large areas within a habitat that were known to contain the desired species (FIG 1). These sites were selected using inaturalist, an app that allows anyone who chooses to post a geo-tag of a specific species' location. We searched the app for areas where both the *Arctostaphylos* and the *Pinus* species were observed. We then surveyed twenty-two total sites at random within those two larger pre-determined areas of a similar habitat, and at each larger area we sampled eleven sites. The first large area was located in North Ma-le'l Dunes restoration habitat, and the second larger area was located North of Ma-le'l at the Lanphere Dunes Unit, both located in Arcata, California (FIG 2, 3).

At each location the sites were chosen at random by picking points sporadically on and off the trails, and each of us took turns choosing which direction to venture. The sites were predominantly nestled within the hind dunes, between the coastline, and Humboldt Bay, which were all located at lowland dune elevations within two kilometers of the ocean. At each site, the elevation, Longitude (N), and Latitude (W) was recorded using a GPS device, with precision and accuracy of 0.5-2 me-

Table 1. Candidate Models for Presence of Cladonia in Northern California

Candidate Models	AIC Value
Lichen~ elevation in feet + longitude + latitude + manzanita + lodgepole	31.63
Lichen~ elevation in feet + longitude + manzanita + lodgepole	29.69
Lichen~ elevation in feet + longitude + manzanita	27.96
Lichen~ elevation in feet	27.58
	27.31

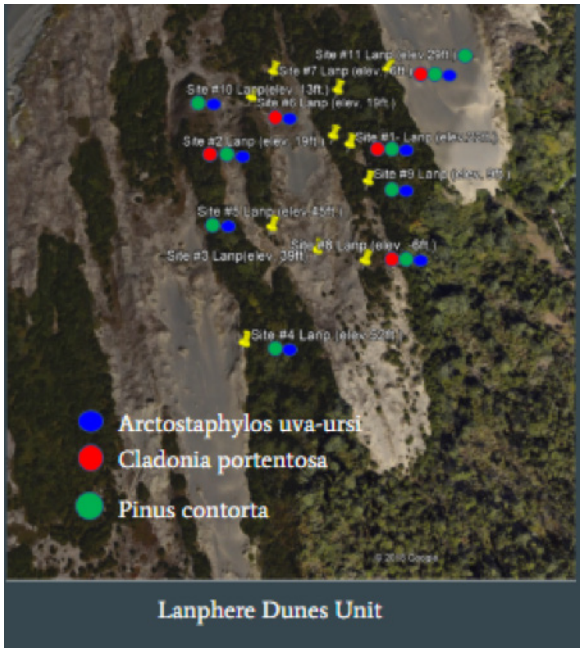

Figure 2 - Lanphere Dunes Survey Site. Yellow pins mark the location of sample taken, a blue dot represents presence of *A. uva-ursi*, a red dot represents presence of *C. portentosa subsp. pacifica*, and a green dot represents the presence of *P. contorta*. Each colored dot on the figure is representative of the species found at the site of the closest corresponding yellow pin.

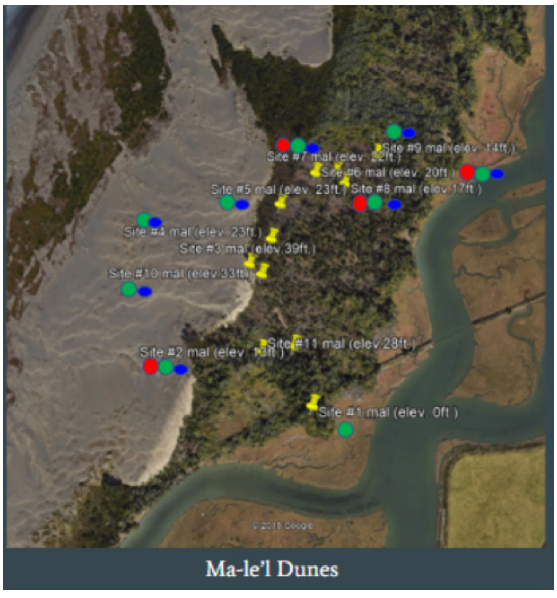

Figure 3 - Ma-le'l Dunes Survey Site. See caption for FIG 2 for key.

ters. Afterwards, the presence or absence of the desired species were determined by a visual survey of a 3-5 meter perimeter around the site. The data were analyzed using excel and r studio to perform a chi-square analysis and a stepwise regression of the candidate logistical models that we created to determine which variables had a significant effect.

Results

Pinus contorta and *Arctostaphylos uva-ursi* did not significantly influence presence of *Cladonia portentosa* subsp. pacifica, χ statistic= 24.84, p-value= 0.254, df=21. The presence of *Cladonia portentosa* subsp. pacifica was better explained by elevation, *p-value=0.0418*, *standard error=0.05021*. See Table 1 and Figure 4. Low Akike information criterion, or AIC values, show strongest correlation by using the data to estimate the quality of each model relative to the other models, see Table 1.

Discussion

Our data revealed that, although there was weak correlation between the presence of *A. uva-ursi* and *P. contorta*, and the presence of *C. portentosa* subsp. pacifica in areas where the data was collected, the correlation was not statistically significant. The patterns we observed after the chi-squared analysis led us to reject our hypothesis, and were more suggestive of a direct relationship between the presence of *C. portentosa* subsp. pacifica and elevation. This was based on the AIC values determined by a stepwise regression of all of the models we proposed in Table 1. This follows along with our research, which suggested that, within the dune ecosystems observed, the lichen might be less disturbed overall and thus more easily able to thrive in the lower-elevation protected swales of the dunes. Of the twenty-two sites that we surveyed, *C. portentosa* subsp. pacifica was more frequently present at relatively low elevations. Interestingly, our data concluded that for every one-foot increase of elevation the probability of the presence of *C. portentosa* subsp. pacifica decreased by 10%. Through our time-restricted research, we did not find any information regarding, specifically, how the lichen subspecies

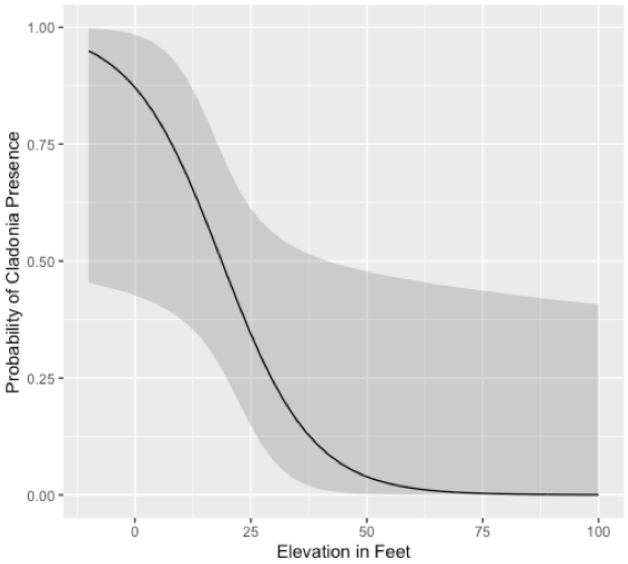

Figure 4 - Probability of *Cladonia portentosa subsp. pacifica* as Elevation (in ft.) increases. Shaded areas represent confidence intervals.

was introduced or naturalized into the dunes, if it is salt-tolerant, or what aspect of the dunes restricts its proliferation to some areas over others, even when environmental conditions and associated species remained constant. However, since our survey suggests that there may be a correlation between elevation and the presence of the lichen, this may hypothetically imply that, within the protected dune ecosystem that we observed, there is some specific factor(s) that may explicitly allow for this lichen subspecies to thrive. Ultimately, determining what dictates the presence or absence of *C. portentosa* subsp. pacifica in these surveyed areas may be worth investigating in future surveys to help scientists, stewards, and conservationists to better understand the sensitive dynamics of the dune ecosystems of Arcata, California. If we were to repeat this study, our future observations could greatly benefit from taking elevation and other associated factors, such as variation in chemotypes and the implications of that, into consideration when collecting and analyzing data.

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