ADVANCEMENT IN NIR REFLECTANCE MEASUREMENTS OF SMALL LEAVES AND PINE NEEDLES AND ANALYSIS OF DIFFERING SPECTRAL RESOLUTION

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ABSTRACT

With rapidly changing environmental conditions due to climate change, novel and accurate UV-VIS-NIR remote sensing techniques for vegetation are critical to observe environmental metrics. Capturing reflectance data of small vegetation samples such as pine needles, blades of grass, and tiny leaves is a technical challenge to overcome. The very small field of view needed for the measurement, as well as the required high sensitivity of the spectrometer can be an obstacle in obtaining high quality data. To combat this challenge, researchers have taken to measuring the combined spectrum of many small samples bunched together. Arranging mats or needle holders, in turn, enhance mutual shading of adjacent needles, multiple scattering, or re-absorption. (Rajewicz et al. 2019) There is also difficulty in repeatability that should be avoided. The resulting measurements represent an average of the spectral features of all samples, not necessarily of the individual sample. Advancements in field and laboratory vegetation spectral methods are needed to study small leaves. To address this problem, we deployed Spectral Evolution's novel leaf clip reflectance probe and small leaf adapter using both standard and high-resolution spectroradiometers. This method allows for reflectance measurements of individual needles and more control on the target. 4 types of small vegetation samples were measured with this method including small leaves and two species of pine needles. The enhanced spectral resolution combined with the ability to control the field of view targeting individual needles, allows for more accurate measurements of small vegetation samples.

Key words **—** UV-VIS-NIR, VEGETATION, HYPERSPECTRAL, SPECTROMETER, REFLECTANCE

1. INTRODUCTION

With the growing influence of climate change it is critical to have effective tools to monitor environmental health. Climate change and land use change are affecting ecosystems drastically and vegetation is often the first to show symptoms. Stress factors can come in the form of invasive species, reduced water availability, and temperature. Increasing economic activities and growing populations, as well as changes in temperature and precipitation regimes, pose major threats to freshwater ecosystems and biodiversity in many catchments (Ramoelo et al 2014). Climate change will compound the threat of alien plants on water resources, and it is predicted to accelerate the rate of invasive plant spread. Pine trees are among the most important invasive taxa in South Africa and are particularly important invaders of the high yielding montane catchment areas. (Dzikiti et al. 2012). Instances like this make it critical to have a spectrometer attached to a leaf clip that can target small or needle like leaves. Remote sensing research using a leaf clip is a growing field and the application of pine needle adapters is a new and exciting development. There are countless studies that can be conducted using a leaf clip adapter. Remote sensing using a leaf clip can give a robust analysis of the overall health of plants by analyzing indices like NDWI, NDVI, leaf water potential, leaf nitrogen, and moisture stress index.

For this study we will be showing the capabilities of a pine needle adapted spectroradiometer as well as the differences between two different resolution instruments. Through this study we aim to better understand the relationship of resolution, signal to noise ratio and pine needle reflectance because it is critical to understanding potential applications. We present this methodology as an alternate to the common procedures of bundling pine needles for reflectance measurements. We will analyze the spectral differences in four small samples including 3 species of pine needles, and a small leaf. A measurement will be taken with these samples bunched up on the regular leaf clip as well to show the differences from self-shading and repeatability using previous methods. By targeting some of the impact in resolutions on the instrument and with the needle adapter it will allow for scientists to have a more robust understanding of their data and the limitations.

2. MATERIAL AND METHODS

Standard vs. high resolution and bundles vs. single needle measurement

The reflection of small leaf, and 3 species of pine needle were analyzed using Spectral Evolution's standard resolution spectroradiometer RS-3500 and the high-resolution NaturaSpec. Each leaf species had 15 measurements taken on both resolution spectroradiometers. The average spectra for each sample were calculated and compared. Bunches of each leaf sample were measured on the NaturaSpec to show the differences between individual leaves and a bunching method. This yielded 4 average measurements on the RS-3500, 4 average measurements on the NaturaSpec, and 4 average measurements of bundles on the NaturaSpec. A graph showing the reflectance measurements on both sides of the same small leaf was taken showing the difference in absorption and exemplify the ability to target small parts of a needle. There was also a comparison of a single needle to a stem and bundle to show the influence of the stem within bundled spectra. We also measured the reflectance of a fresh leaf compared to a dried leaf.

For each kind of small leaf, we collected 15 measurements that were then averaged together and then normalized for comparison. All leaves of each species were taken from the same tree. We will be applying a calibration set by subtracting the reflectance of the plastic to ensure the best representation of the pine needle reflectance. This is done by scanning the empty pine needle adapter and subtracting this from the adapter with the pine needle to subtract off any influence from the non-reflective plastic surface of the adapter. Measurements were taken using the same leaf clip attachment and pine needle adapter on both instruments. An RS-3500 full range (350nm-2500nm) spectroradiometer was used to collect standard resolution reflection measurements. The RS-3500 spectroradiometer has a resolution of 2.8nm in the vis, 8nm in swir 1, and 6 nm in swir 2. The NaturaSpec spectroradiometer was used to collect high-resolution reflection measurements. The spectral resolution of the NaturaSpec is 2.7nm in the VIS, 5.5nm in SWIR 1 and 5.8nm in SWIR 2. Although the small leaf adapter is made of low reflectance plastic, a calibration is calculated for each instrument to reduce the influence of the pine needle adapter material in the field of view. This was done by collecting spectra of the leaf clip without a leaf and subtracting that from the leaf measurements.

3. RESULTS

When comparing the needle spectra to the bundles few differences were observed in the spectral shapes. The starkest differences can be accounted for by water absorption. This is likely the difference between a single needle and the average of many. For instance, one needle may be more hydrated than an average of them. Issues with repeatability of the bundles with the more difficult shaped needles were observed and the influence of the stem is characterized in figure 4.

Figure 1 is images of the pine needles and small leaves used in the experiment.

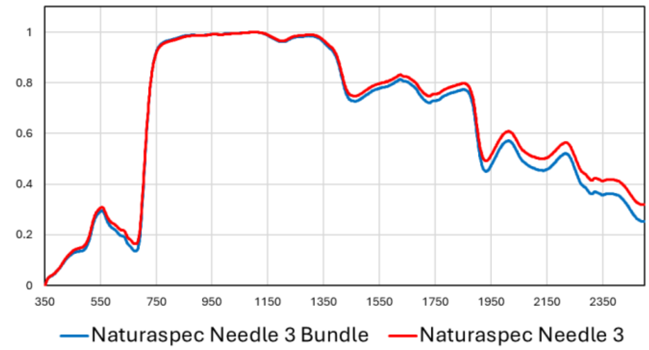

Figure 2 represents the comparison of individual needle 3 compared to a bundle of them. The spectra is nearly identical showing no loss of spectral features using the adapter.

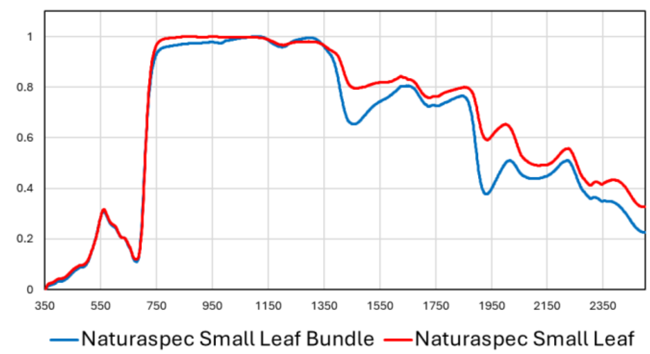

Figure 3 is the comparison of the small leaf spectra compared to a bundle. Showing the primary differences in the spectral features are the water bands at 1400 and 1900nm.

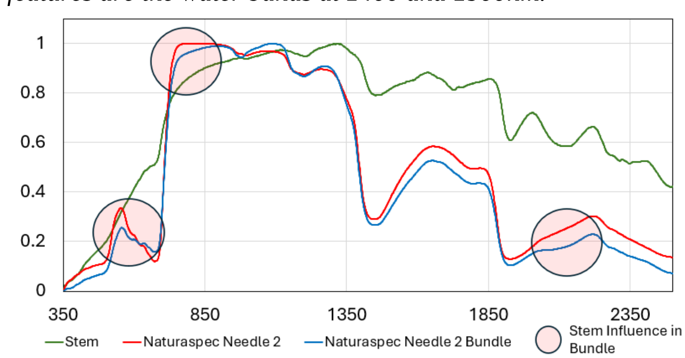

Figure 4 shows the comparison of the spectra of a stem, individual needle 2, and a bundle of needle 2. This unmixes the components effecting the signal in a bundled spectra.

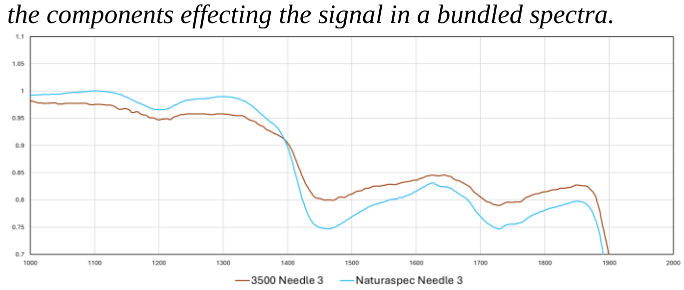

Figure 5 Represents the comparison of the standard resolution RS-3500 and the high resolution NaturaSpec on needle 3.

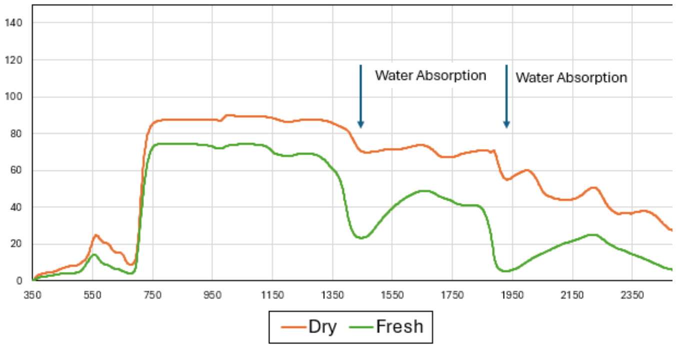

Figure 6 represents the spectral differences between a dry leaf and a fresh leaf

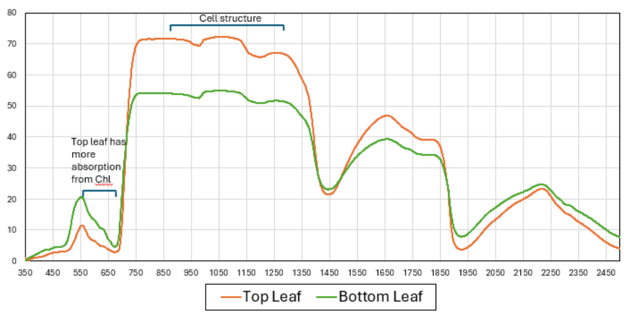

Figure 7 plots the reflectance spectrum of a top of a leaf and the bottom of the same leaf

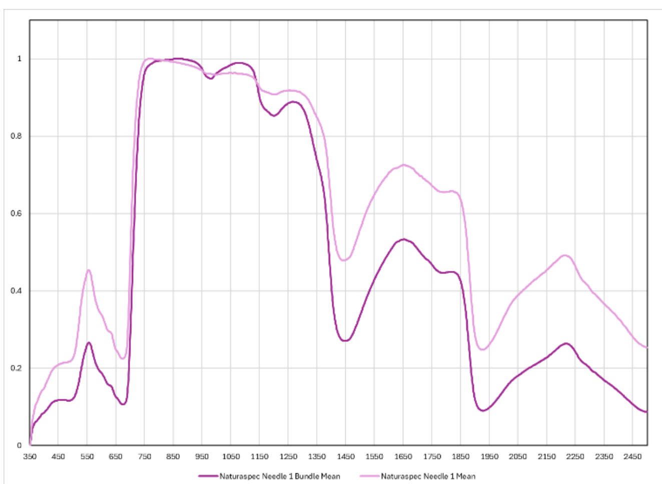

Figure 8 represents needle 1 bundled compared to the individual pine needle reflectance. The feature at 960nm is shallower in the pine needle adapter reflectance compared to the bundle.

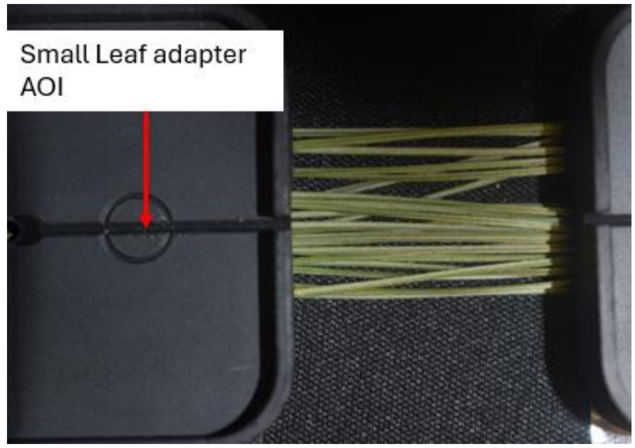

Figure 9 on the left is the pine needle adapter with the red arrow pointing to the area of interest. On the right is a typical bundle of pine needles.

Figure 10 Image of the small leaf adapter attached to the leaf clip taking a scan of a pine needle.

4. DISCUSSION

These tests yielded results showing the ability of the small leaf adapter to collect accurate leaf spectra. The goal was to explore the utility of a pine needle adapter for a leaf clip reflectance probe and how that relates to current methods. The primary methods of collecting pine needle reflectance data are done by bundling in a leaf clip or integrating sphere which involves an unavoidable gap fraction (Daughtry et al. 1989). The pine needle adapter compared to any method involving bundling eliminates any of the uncertainty in calculating a gap fraction. In Olascoaga et al. 2014 they used a bundle of needles to measure leaf surface reflectance and when arranging the needles in the clips some manipulation was unavoidable, and note a certain degree of measurement noise due to this.

In figure 1 we have a picture of the pine needles and small leaves that were selected for the study. These were selected due to their diversity in shape and size. Figure 10 shows an image of the leaf clip with the small leaf adapter attached taking a scan of an individual pine needle.

The analysis of individual needles vs. the bundled spectrum was shown in figure 2 and figure 3. Figure 2 shows the spectral features between the bundled spectrum and the individual needle and that there is little loss of information in the reflectance in the smaller field of view scanning with the pine needle adapter. Nearly all comparisons of bundle to individual needle showed similar reflectance spectra. The primary difference shown in Figure 3 is mostly only in the water absorption features. This shows that we are getting more information from the more targeted pine needle reflectance measurements that are being generalized by the bundling method. This also shows that the individual pine needle was drier than the more generalized scan from the bundle. This needed to be explored due to the significant decrease in signals in a smaller field of view.

Figure 4 compares a scan of the stem, a scan of the bundle, and a scan of the individual pine needle. This shows that the bundle is influenced by the stem and the targeted pine needle adapter eliminates this influence. The primary stem influence areas are highlighted in red.

Figure 6 shows the reflectance spectra of a fresh leaf compared to the same leaf days later and dryer. The spectral differences are primarily caused by the reduction in moisture within the leaf and the degradation of the chlorophyl. This is used as an example of potential research that can be conducted using the smaller field of view.

Through this study our goal was to give a better understanding of the instrumentation and how they respond to the pine needle adapter's lower reflectance signal and field of view. This is critical to identifying the potential limitations of these instruments in relation to the pine needle adapter. Through the analysis of the bundle vs. the pine needle adapter we showed that there was very little loss of absorption features in the spectra across the different pine needles. Where we did see absorption differences was in the water absorption which is to be expected with different leaves being more or less hydrated. In figure 5 we compared the RS-3500 performance to the NaturaSpec with the same field of view and needle. The NaturaSpec spectra eliminated noise influence showing that the NaturaSpec holds up well to the reduction in signal that is inherent to the measuring small samples.

There are some limitations due to the reduced signal when measuring singular leaves shown in figure 8. When targeting the singular pine needle 1 the reflectance curve had a reduction in depth on a feature at 960nm. This could be due to the geometry of the needle itself, the reduced signal not allowing the light to penetrate the leaf, or the influence of mutual shading and scattering. This is shown in figure 8 of a typical bundling compared to the more targeted pine needle area of interest. More research should be conducted on more pine needle geometries to identify any limitations in more detail.

Despite small discrepancies we have shown reliable reflectance measurements in significantly smaller fields of view, showing that this methodology can be used as an alternative to current methodologies for more targeted studies of leaf reflectance measurements both in the field and in the lab.

5. CONCLUSIONS

The small leaf adapter provides entirely new and different means of collecting small vegetation data. We were able to target different parts of a small leaf and show little loss of valuable information while taking more targeted measurements. By doing this we have compared standards methods like bundling to a new methodology using an individual needle. Through this experiment we show an alternative and accurate methodology to collecting pine needle reflectance data. We explore the limitations of bundling methods with their generalization, repeatability, and mutual shading. We also demonstrate some of the added benefits of higher spectral resolution and sensitivity when collecting spectra using the pine needle adapter. The ability to target an individual leaf is a new development and adds significant utility for a wide range of applications both in the field and in the lab.

8. REFERENCES

[1] Daughtry, C.S.T., Biehl, L.L., Ranson, K.J., 1989. A new technique to measure the spectral properties of conifer needles. Remote Sensing of Environment 27, 81–91.

[2] Dzikiti, S., Schachtschneider, K., Naiken, V., Gush, M., Le Maitre, D., 2013. Comparison of water-use by alien invasive pine trees growing in riparian and non-riparian zones in the Western Cape Province, South Africa. Forest Ecology and Management 293, 92–102.

[3] Olascoaga, B., Juurola, E., Pinho, P., Lukeš, P., Halonen, L., Nikinmaa, E., Bäck, J., Porcar-Castell, A., n.d. 2014 Seasonal variation in the reflectance of photosynthetically active radiation from epicuticular waxes of Scots pine (Pinus sylvestris) needles Vol.19.

[4] Rajewicz, P.A., Atherton, J., Alonso, L., Porcar-Castell, A., 2019. Leaf-Level Spectral Fluorescence Measurements: Comparing Methodologies for Broadleaves and Needles. Remote Sensing 11, 532.

[5] Ramoelo, A., Dzikiti, S., van Deventer, H., Maherry, A., Cho, M.A., Gush, M., 2015. Potential to monitor plant stress using remote sensing tools. Journal of Arid Environments 113, 134–144.