 (The Buckeye Arborist, vol.51, no.2, March/April, 2020 Ohio chapter International Society of Arboriculture)

Spectral Reflectance & Tree Risk Analysis and Management

By Mark A. Webber BCMA, CPH, LTE, MArborA, OCMNT, TPAQ, TRAQ

K. N. Au, Geocarto International Centre Limited

When professionals inspect trees with preexisting defects for the potential of failure, one question an arborist should consider is if the tree is adequately healthy to produce carbohydrates necessary for its essential functions plus the needs for the management of decay through compartmentalization (Smith, 2015). Plants, including trees, face an existential dilemma in the allocation of internal resources for the individual tree's survival and reproductive effort. Trees must grow fast enough to compete for light, water, and essential mineral elements while providing defense against pests, decay, pathogens, and episodically or chronically adverse environments (Smith, 2015). Plants, including trees, depend upon radiant energy (sun) to carry on photosynthesis and other physiological processes (Gates et al., 1965).

When trees capture light and generate sugar, it becomes photosynthate and it is usually transported by the phloem from the foliage to where the energy is to be stored or used. In trees in the temperate zones (Ohio), energy is stored in the sapwood parenchyma, particularly in the wood rays (Savage et al., 2017). The other starch that is created by the tree after photosynthesis is then stored in the branches and roots to provide reserves for important life processes, including the compartmentalization of decay (CODIT) (Pallardy et al., 1991; Smith & Downer, 2019).

The energy stored in the parenchyma cells is critical for compartmentalization to be successful (Smith & Downer, 2019). Additionally, the newly formed wood for wall four in CODIT and other defense materials in trees need energy (Smith, 1997). The energy generated to produce cellulose, hemicellulose, and lignin is a direct biological product of photosynthesis (Smith & Downer, 2019). However, a key part of decay management in trees is if the trees will have the reserves to accomplish this successfully (Hirons & Thomas, 2015). Although trees can potentially produce large volumes of carbohydrates, research has shown that tree defense (managing decay) is the last priority in energy resource allocation for most trees (Hirons & Thomas, 2015; Smith & Downer, 2019).

How do we know if photosynthesis has accumulated enough carbohydrates for the defense of decay in trees?

As previously discussed, the sum of photosynthesis that is used in tree defense is the last priority in energy resource allocation for most trees (Hirons & Thomas, 2015; Pallardy, 2007). So as practicing arborists, how do we measure if a tree is producing carbohydrates at a high enough capacity to have enough energy for the management of decay and defend the plant? The starch test using iodine solutions has been used with some reliability as a measure of carbohydrates in trees (Webber, 2016). However, starch testing only shows what has accumulated and does not reflect if the photosynthetic process of the tree is fully functional. Trees have two-stage priorities of energy needs that are known as metabolisms (Hirons & Thomas, 2015). A fully functioning tree has both primary and secondary metabolisms (Hirons & Thomas, 2015). The first metabolism is the production of energy for primary metabolites for the basic functions of normal growth, reproduction, and energy storage for the trees primary needs but not for the defense of decay (Hirons & Thomas, 2015). The secondary accumulation of energy metabolism in trees provides the vital defenses to compartmentalize decay and defend the tree (Hirons & Thomas, 2015; Pallardy et al., 1991; Smith & Downer, 2019). However, unless the primary energy needs are not met, then the secondary energy reserves will be limited and or non-existent (Hirons & Thomas, 2015).

Spectral Reflectance in Plants

Green plants, including trees, have unique spectral features, mainly because of the chlorophyll, carotenoid, other pigments, and water content together constitute the spectral features of a plant (Chen, 2008) The leaf of a tree is the primary photosynthesizing organ with photosynthesis occurring in the chloroplasts where the chlorophyll pigment is located (Gates et al., 1965). The radiant energy (sun) interacts with the leaf structure by absorption and by scattering. The energy absorbed selectively at certain wavelengths by chlorophyll will be converted into heat or fluorescence and converted photochemically into stored energy in the form of organic compounds through photosynthesis (Gates et al., 1965).

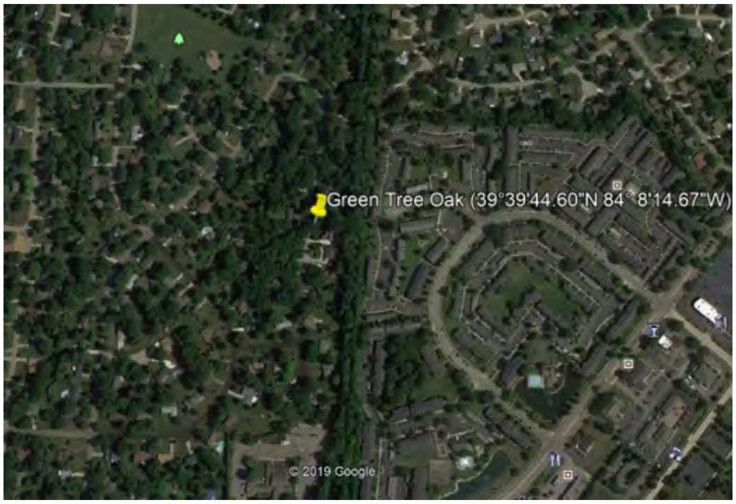
Electromagnetic radiation (EMR) produced by the sun has different wavelengths that make up the electromagnetic spectrum. Important wavelengths of the spectrum are ultraviolet, visible (VIBGYOR), which is violet, indigo, blue, green, yellow, orange, and red, and other types (Roy, 1989). The research results confirmed by Horler et al., (1983) show a direct correlation between spectral reflectance color and chlorophyll content in plants. The spectral reflectance color can be used to estimate the chlorophyll content of a plants leaves. Plants with less chlorophyll will generate fewer leaves, less carbohydrate accumulation, and less spectral reflectance color (Humbolt.edu, 2020). Wavelength is a measure known by the symbol of µm. Chlorophyll strongly absorbs light at wavelengths around 0.45 µm (blue) and 0.67 µm (red) and reflects strongly in the green light; thus, our eyes perceive healthy vegetation as green. Healthy plants have a high reflectance in the near infrared between 0.7 µm and 1.3 µm. This is primarily due to the healthy internal structure of plant leaves, and there is an internal structure that varies amongst different plant species (Roy, 1989).

Methods and Means

Geocarto International Centre Ltd. and Mark A. Webber worked in collaboration in this exercise. Neither party knew of each other's work or methods as well as each other's independent findings until the final report was compiled and written collaboratively. The purpose of this experiment was to determine if there was any correlation between tree structural condition concerns and management of trees inspected utilizing an ANSI A300 Part 9 level two tree risk assessment. Mark Webber's data would then be compared and analyzed to the Geocarto spectral reflectance data collected from the same trees. Also, if the spectral reflectance data provided by Geocarto can provide information as to if structurally troubled trees are indeed functioning inadequately in the production of carbohydrates to manage decay. More so, if the data provided by spectral reflectance analysis would provide additional information on how to better advise the trees owner on how to manage the tree in the long-term.

Four deciduous trees were chosen by Mr. Webber for this study and were designated as the Woodland swamp white oak (Quercus bicolor), Green Tree chestnut oak (Quercus montana), Jefferson silver maple (Acer saccharinum), and the School Yard sycamore (Platanus occidentalis). (See Photographs 1-4)

Photograph 1. Woodland swamp white oak
(Source Google Earth)



Photograph 2. Green Tree chestnut oak
(Source Google Earth)

Photograph 3. Jefferson silver maple
(Source Google Earth)

Photograph 4. School Yard sycamore
(Source Google Earth)

The GPS (Global Positioning System) location of each tree was collected during site inspection by Mark Webber, and that data was reconfirmed via Google Earth Pro GPS tools. Geocarto was supplied the GPS location, and the Google Earth photographs by Mr. Webber as shown in **Photographs 1-4.** Geocarto procedures then precisely selected a few pixels (each of about 30cm x 30cm to 50cm x 50cm, depending on the resolution used) from the foliage at the top canopy of the subject trees to compute the spectral reflectance value. The pixels are selected from the adaxial (upper) surface of the leaves. The spectral reflectance value provided information of leaf cellular structure and chlorophyll content of each of the subject trees. The Geocarto procedure for this analysis precludes the air space and ground data. Geocarto's spectral reflectance technology for tree health monitoring is based on subtle changes in chlorophyll content and leaf cellular structure generated from the three spectral bands of (1) near-infrared, (2) red edge and (3) red, collected by high-resolution WorldView-2 and WorldView-3 satellites. Global case studies have verified this new approach. It is an early detecting approach revealing internal warning indicators before the emergence of discernible external symptoms. Details are presented in two articles in Arborist News, April 2017 and August 2018 issues published by the International Society of Arboriculture and in a white paper published by DigitalGlobe in June 2017. All are available online at www.geocarto.hk.

Geocarto's interpretation is based on a comparison of the spectral reflectance of the same tree on different dates in the same season and sensor azimuth. According to Geocarto, it can be performed for different trees regardless of the species. Interference of light reflection from nearby buildings will not affect the result, because such reflection will occur in all the images for that tree. With data collected on at least three dates, this technology can identify four categories of tree health, namely, (a) improving, (b) stable, (c) fluctuating, and (d) declining.

Geocarto research has found that biotic (living) and abiotic (non-living) factors affecting chlorophyll content and leaf cellular structure will be

CEUs at Home Cont. on page 22

revealed in spectral reflectance changes. It is similar or analogous to the use of X-ray, CT scan (CATSCAN), and MRI (magnetic resonance imaging) in medical examinations that reveal hidden warning indicators not observable externally. Geocarto states that this technology provides objective and early information to assist arborists and tree management teams in carrying out remedial measures expeditiously. This monitoring technology can be undertaken remotely without a field visit. Being computer-based, it is non-invasive, time-saving, and cost-effective.

In fact, the technology of monitoring urban tree health from space is very new. Prior to the launch of the two satellites, WorldView-2 on October 8, 2009 and WorldView-3 on August 13, 2014, it was not feasible to implement this technique, because the data provided by other commercial satellites only included four multispectral bands of blue, green, red, and near-infrared, without the red edge band which is a good indicator of chlorophyll content. Moreover, the resolution of the data collected by other satellites is not high enough for monitoring an individual tree. For analysis, Geocarto uses AComp (atmospheric compensation) data, which is then pan-sharpened with a "lossless" program to retain the spectral information content from each pixel.

Mark Webber Level 2 Inspection Data

In the autumn of 2019 Mark Webber inspected the four subject trees. A level two risk assessment was conducted by following the protocols of the ANSI A300 Part 9. That inspection included tree identification, measurement of trunk diameter at 4.5 feet above the ground, possible targets, a complete 360-degree ground based visual inspection of the roots, root flare, trunk, large scaffold limbs, secondary limbs, and overall canopy for defects. Mr. Webber also performed an analysis of the most likely parts of each tree to fail and the likelihood of failure of those known defects. The other portions of this risk assessment were precluded in this study. The time period for the assessment was 18-months before the next inspection. Mark Webber's findings are listed below in Table A for each of the four subject trees.

Table A. Mark Webber Level 2 Inspection Data (Fall of 2019)

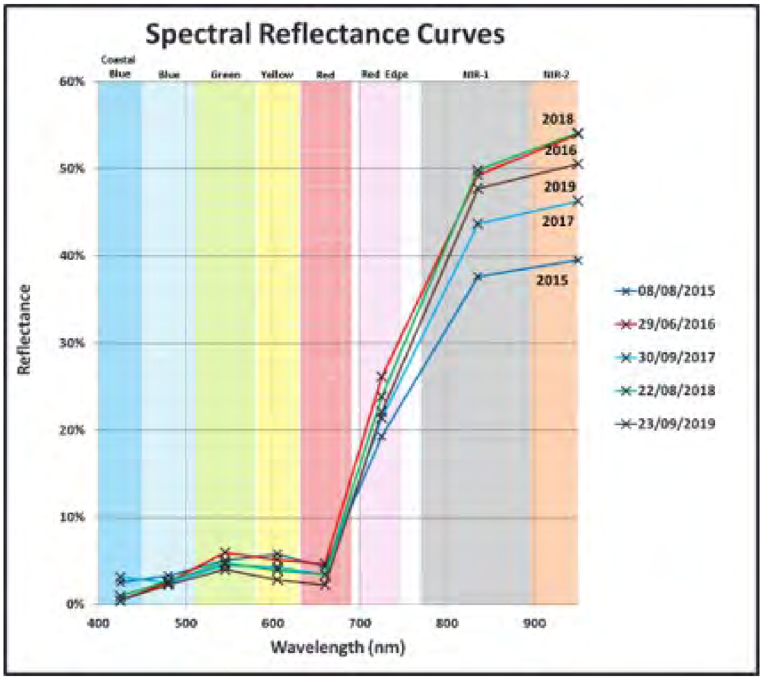
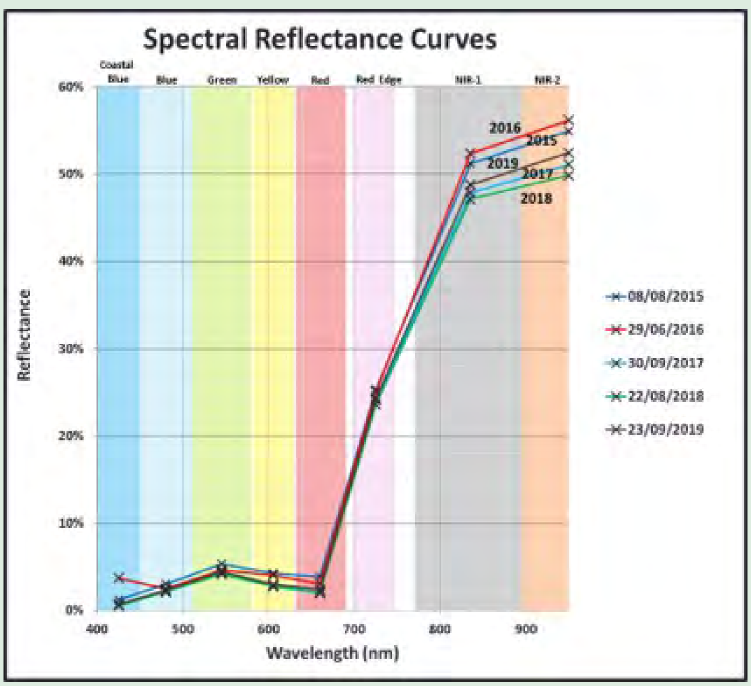
Tree Name	Species	DBH	Targets	Defects	Likelihood of failure
Woodland swamp white oak	Quercus bicolor	55"	Gravestones Infrequent pedestrian occupancy	The tree has a corrected lean. The lower trunk has three pockets of decay with no visible fungal bodies. At 25 feet from the ground, a 36" long by 6.0" wide opening with 8.0" outer wall and the upper trunk is hollow. Numerous old dead branches with proper wound closure around dead branches. A full canopy of leaves.	Probable failure of dead branches and possible failure of the upper trunk.
Green Tree chestnut oak	Quercus montana	42"	Dwelling, roadway, and frequent pedestrians	The lower trunk has a 40" long by 10" wide opening. The outer shell of the cavity is 15-18" with no visible buckling cracks. In 2017 a level three assessment found one (1) dried fungal body of Ganoderma species. The upper canopy is full, and the client was concerned about its leaf color in the summer of 2018.	Possible lower trunk failure.
Jefferson silver maple	Acer saccharinum	38"	Dwelling, roadway, passing vehicles, and occasional pedestrians.	Large tree branch (14") was removed 8 years ago after a storm. Wound wood has formed around the wound and is closing. The tree had little to no visible defects. The tree was affected by an herbicide drift event in 2016.	Possible failure of smaller scaffold limbs during an intense thunderstorm event.
School Yard sycamore	Platanus occidentalis	32"	School yard sidewalk is connecting the entrance of a school and a public sidewalk.	2 of 6 anchorage roots are decayed. The trunk is open and hollow. Wall of sound wood is approximately 3-6" thick. Opposite the large opening on the trunk, there is an open longitudinal crack that likely occurred due to partial trunk collapse. 2 of 9 large scaffold limbs are dead, and the canopy is in overall decline.	The probable – imminent failure of the trunk. Probable – imminent failure of two large dead scaffold limbs and or small branches.

CEUs at Home Cont. from page 22

Geocarto Data Analysis

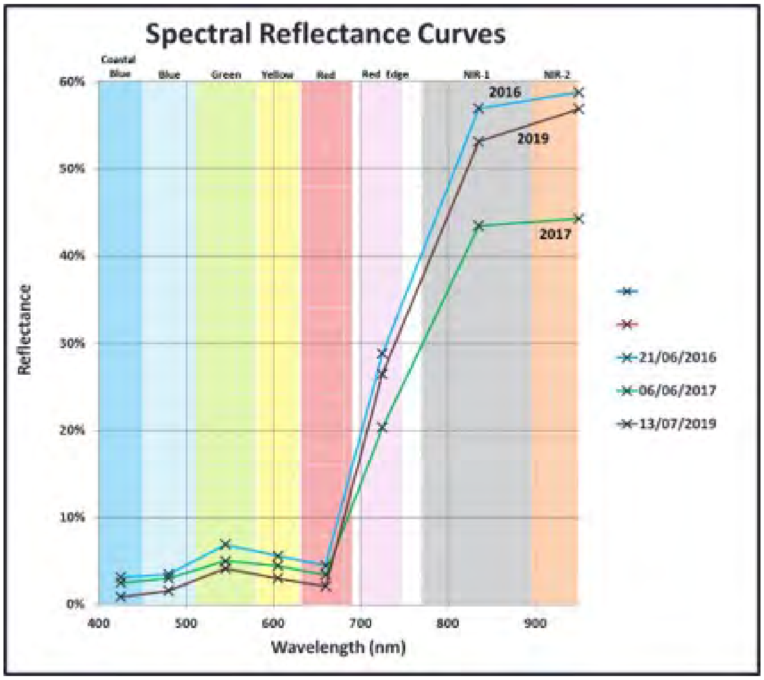
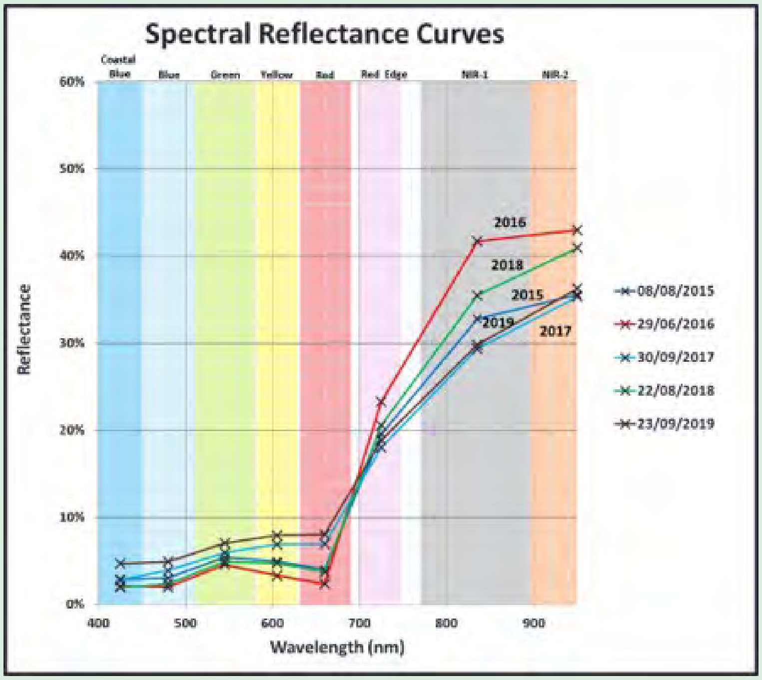
The Geocarto spectral reflective data analysis of the four subject trees can be found in Table B.

Table B. Geocarto Spectral Reflective Data Analysis

Woodland swamp white oak	 Tree Location (39°44'35.89"N, 84°10'40.80"W)	The spectral reflectance analysis shows that this tree showed much fluctuation over the period from 2015 to 2019. It revealed marked improvement from 2015 to 2016 and then declined significantly from 2016 to 2017, but improved again from 2017 to 2018. Then it became quite stable from 2018 to 2019. Over the 5-year period, the spectral reflectance was highest in 2016 but lowest in 2015, with the minor difference between 2018 and 2019. Such major changes imply marked fluctuation in health conditions.
Green Tree chestnut oak	 Tree Location (39°39'44.39"N, 84°8'14.57"W)	The spectral reflectance analysis shows that this tree indicated a quite stable condition over the period from 2015 to 2019. The spectral reflectance from 2015 to 2016 differed mildly, and from 2016 to 2017, it varied slightly more, but from 2017 to 2018, the difference was reduced, and then from 2018 to 2019, it showed a minor difference. These small changes in spectral reflectance imply a fairly stable health condition

CEUs at Home Cont. on page 24

Table B. Geocarto Spectral Reflective Data Analysis Cont.

Jefferson silver maple	 Tree Location (39°41'14.39"N, 84°19'47.59"W)	The spectral reflectance analysis shows significant declining condition from 2016 to 2017 and then marked improvement from 2017 to 2019. It, therefore, indicates fluctuating conditions over the period from 2016 to 2019. For this tree, we only have satellite data for three dates for our analysis and interpretation.
School Yard sycamore	 Tree Location (39°39'58.22"N, 84°14'56.18"W)	The Spectral reflectance analysis shows a highly fluctuating condition from 2015 to 2019. There was a marked improvement from 2015 to 2016 and significant deterioration from 2016 to 2017, followed by amelioration from 2017 to 2018, but declining condition from 2018 to 2019. Therefore, the health condition over that period was fluctuating and unstable.

Discussion and Analysis

A review of the data and visual evidence showed that the use of spectral reflectance data of trees can provide arborists, tree managers, and owners important objective and quantitative information regarding photosynthetic production capacity of individual trees and the carbohydrates available for decay management. Spectral reflectance data combined with visual ground inspection data from a trained arborist can provide meaningful information to the tree owner on how to best manage a tree long-term. However, the spectral reflectance interpretation of the data alone may produce a finding that masks the structural deficiency of the tree and create findings not rooted in reliable facts and data. Another important consideration is if spectral reflectance data is plentiful enough (number of years) to produce a valid finding that can be relied upon. The spectral reflectance data of the four subject trees in this case study underpins this analysis and findings.

Woodland Swamp White Oak

The Woodland swamp white oak in this study is an example of a tree with structural defects that may cause the owner or arborist to remove it, however the spectral reflectance data demonstrates that it is still functioning at a very-high photosynthetic capacity (Pallardy, 2007). Trees can be structurally sound, but not green and healthy. Conversely, a tree can be structurally deficient but green and healthy (Dunster, 2013). It has been published that oaks (Quercus) can manage decay well (Gilman, 2002). The Woodland swamp white oak, in this case, contains a large pocket of decay. The spectral reflectance data, in this case, does provide an adequate factual indicator of the structural defects by the fluctuation in health condition as the tree is likely attempting to manage decay (Smith & Downer, 2019). The inspection by Mr. Webber of the location and severity of the defect determined it is not likely to fail under normal weather conditions. The low likelihood of failure from the visual inspection combined with the spectral reflectance data shows that the tree can likely be retained if the trees owner accepts the risk. Thus, the Woodland swamp white oak is likely producing enough extra carbohydrates for secondary tree needs for the defense of decay (Smith & Downer, 2019; Dunster, 2013).

Green Tree Chestnut Oak

The Green Tree chestnut oak, another example of a tree with structural defects, where the spectral reflectance data demonstrates that it is still functioning at a very-high photosynthetic capacity and is likely managing decay. The visual inspection found that the Green Tree chestnut oak's lower trunk cavity has no visible buckling cracks and in 2017 a level three assessment found one (1) dried fungal body of Ganoderma. The visual inspections found that the upper canopy was full of leaves, and the client was concerned about its leaf color in the summer of 2018. The spectral reflectance data from 2018 to 2019 showed a minor difference in photosynthesis in the same period as the tree's owner had concerns about the subject tree. These small changes in spectral reflectance imply a relatively stable health condition whereas Mr. Webber's long-term prognosis after inspection found the Green Tree chestnut oak in a stable condition (Dunster, 2013; Smith & Downer, 2019). The combinations of the arborist inspections and the spectral reflectance data show the Green Tree chestnut oak has decay, but it is likely being managed well by the tree (Dunster, 2013 & Smith & Downer, 2019). Thus, the Green Tree chestnut oak is likely producing enough extra carbohydrates for secondary tree needs for the defense of decay.

Jefferson Silver Maple

In the case of the Jefferson silver maple, fluctuating spectral reflectance data revealed a drop in its photosynthetic values correlated to when it was exposed to an herbicide drift event in 2016, but the data shows that the tree then quickly recovered and is still functioning at a high capacity. Mr. Webber's visual inspection found very few defects with the tree and when combined with the spectral reflectance data shows that the tree is likely producing enough extra carbohydrates for secondary tree needs in managing decay (Dunster, 2013; Smith & Downer, 2019).

School Yard Sycamore

In the case of the School Yard sycamore, the spectral reflectance data showed that the photosynthetic values over that period were fluctuating and unstable. Mr. Webber's visual inspection determined that the sycamore was a probable – imminent candidate for trunk failure and likely probable – imminent failure of two large dead scaffold limbs and or small branches. The fluctuating and unstable spectral reflectance data is likely showing the trees struggles and attempts to generate enough photosynthetic capacity to take care of its primary needs and little to no allocation for defense against decay. The spectral reflectance data combined with Mr. Webber's assessment underpins the probable – imminent likelihood of failure and the risk to targets below in the next 18-months.

Other Research

Research conducted by Hovi et al., (2017) has shown that tree species and leaf side (adaxial (lower) vs. abaxial (upper)) were important factors in explaining spectral variation, whereas canopy position had a minor role. These findings were consistent in both broadleaved and coniferous trees, which suggests that the results can be generalized to a large variety of species, and also confirms that the measurements were carefully conducted. Other studies show high near-infrared (NIR) and particularly the high short-wave infrared (SWIR) light transmission in broadleaved tree species across genera and species. However, other research shows that conifer tree species differ dramatically in readings between genera and species. The differences in conifer species may be related to needle age and density as well as seasonal influences.

Research by (Möttus et al., 2014) found that seasonal trends in broadleaved tree species were similar as observed by other research and reflect changes in biochemical composition and thickness of the leaves. These changes in biochemical composition and thickness of the leaves can produce findings that are not reliable. This research demonstrates that arborists should work with spectral reflectance data that produces a mean average of several years of a tree's photosynthetic capacity. Research conducted by (AU, 2018) shows that trees that have had a prolonged period of decline, as seen in spectral reflectance data analysis, are likely candidates for imminent failure. Conversely, this same research by (AU, 2018) shows that trees that were in decline but were treated by arboricultural services reflected improvements in spectral reflectance data.

The following two case studies demonstrate positively the practical application of spectral reflectance technology to detect declining or improving health conditions of trees. The first example was a heritage Tembusu tree (Fagraea fragrans), of more than 270 years old, collapsed on February 11, 2017 causing the death of one person and injuring four others. According to the press report, this tree was inspected twice a year and was found to be healthy in September 2016. However, spectral reflectance analysis has detected progressive deterioration since 2010.

The second was a Chinese banyan tree (Ficus microcarpa), that is approximately 400 years old, diagnosed with brown root rot disease (Phellinus noxius) in 2009 and was marked for removal by September 2013. As that tree was regarded as an old and valuable tree of high historical value, the removal decision was later withdrawn, and that tree was treated with a new method of applying Trichoderma to the soil around the root zone to suppress the fungus that caused the disease. This tree recovered markedly, and the improvement was indicated by the consistent rise of spectral reflectance in recent years.

CEUs at Home Cont. on page 26

Apart from the application of this technology in monitoring a single tree to identify the four categories of tree health, a new procedure has now been developed by Geocarto to provide preliminary screening of a large number of trees to detect declining health. Utilizing this new procedure, Geocarto was able to identify 20,884 trees in an AOI (Area of Interest) of 3km x 3km with WorldView -2 satellite data for the period from 2014-02-17 to 2018-02-28. This AOI falls in the termite belt area of tree decline. The trees in this study have been weakened due to termite infestation. The preliminary screening result reveals that there are 3,148 trees with declining values for all the three internal warning indicators from 2016 to 2018. This number represents about 15% of all the 20,884 trees identified.

Research by (AU, 2019) found that 25 trees out of the top 500 in the list of the 3,148 declining trees from the preliminary screening were removed during the period from 2018-02-28 to 2019-07-15. This was confirmed through the latest date of satellite data for study by the use of Google Earth images available on the internet.

Conclusions

Spectral reflectance technology constitutes a likely breakthrough in tree health monitoring because it will reveal internal warnings before external symptoms are discernible. Spectral reflectance curves indicate the change in tree health. A rise in near-infrared and red edge, and a drop in red band reflectance imply amelioration; while a drop in the former two bands and a rise in the red band indicate deterioration. Minimal variation denotes stable conditions. Fluctuation signifies unstable conditions.

When this technology is integrated with onsite professional arborist inspections, diagnosis, and treatment, it will significantly enhance tree management, maintenance, and reduce the likelihood of risk to nearby targets.

References

AU. K.N. An Integrated Approach to Tree Stress. Arborist News. August 2018

AU. K.N. Monitoring Urban Tree Health from Space A New Remote Sensing Technology Using High Sensing Resolution WorldView-2/3 Satellite Data for Preliminary Screening of a Large Number of Trees.2019

Chen. 2008. "CORRELATION ANALYSIS BETWEEN INDICES OF TREE LEAF SPECTRAL REFLECTANCE AND CHLOROPHYLL CONTENT ." The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B7.

Dunster et al. Tree Risk Assessment Study Guide.2013

Gates, David M.; Keegan, Harry, J.; Schleter, John C.; Weidner, Victor R. 1965. Spectral Properties of Plants. APPLIED OPTICS

Gilman, Edward. An Illustrated Guide to Pruning.2002

Hirons, Andrew; Thomas, Peter. Applied Tree Biology 2015

Horler, D. N. H., Dockray, M., Barber, J., 1983. " The red edge of plant leaf reflectance." International Journal of Remote 4, pp. 273-288.

Hovi A., Raitio P., Rautiainen M. 2017. " A spectral analysis of 25 boreal tree species. ." Silva Fennica Vol. 51 no. 4 article id 7753. 16 p.

http://gsp.humboldt.edu/OLM/Courses/GSP_216_Online/lesson2-1/reflectance.html (Collected January 1, 2020)

Pallardy, Stephen G. Kramer, Paul Jackson, Kozlowski, Theodore T. The physiological ecology of woody plants. 1991

Pallardy, Stephen. Physiology of Woody Plants - 3rd Edition. 2007

Mõttus M., Sulev M., Hallik L. (2014). Seasonal course of the spectral properties of alder and birch leaves. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 7(6): 2496–2505.

Roy. 1989. Spectral reflectance characteristics of vegetation and their use in estimating productive potential. Indian Acad. Sci. (Plant Sci.), Vol. 99, No. 1, February 1989, pp. 59-81.

Savage, Jessica A. et al. Maintenance of carbohydrate transport in tall trees, Nature Plants (2017). DOI: 10.1038/s41477-017-0064-y

Smith, K.T. Curr Forestry Rep (2015) 1: 8. https://doi.org/10.1007/s40725-014-0002-4

Smith, Kevin T. 1997. Phenolics and compartmentalization in the sapwood of broad-leaved trees. In: Dashek, W.V., ed. Methods in plant biochemistry and molecular biology. Boca Raton, FL: CRC Press: 189-198.

Smith. Downer. Botany for Arborist: Energy and Trees. Western Arborist. Fall 2019

Webber, Mark. How Healthy is my Tree? A Measure of Carbohydrate Storage, Buckeye Arborist, January/February 2016