Т. 87, № 1 **ЖУРНАЛ ПРИКЛАДНОЙ СПЕКТРОСКОПИИ** ЯНВАРЬ — ФЕВРАЛЬ 2020
V. 87, N 1 **JOURNAL OF APPLIED SPECTROSCOPY** JANUARY — FEBRUARY 2020

CANOPY SPECTRAL CHARACTERISTICS UNDER DIFFERENT BACKGROUNDS OF WETLAND AQUATIC VEGETATION

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This paper presents wetland aquatic vegetation remote sensing data using laboratory experiments on irises (Iris tectorum Maxim) and a simulation of the wetland aquatic vegetation growth environment. The spectral reflectance of the iris canopy under the background of different substrates was monitored. Experimental results show that under different backgrounds of wetland aquatic vegetation, the canopy spectral characteristics are different and present a certain regularity.
Keywords: *aquatic vegetation backgrounds of wetland, remote sensing, spectral reflection.*

СПЕКТРАЛЬНЫЕ ХАРАКТЕРИСТИКИ ПОЛОГА ВОДНОЙ РАСТИТЕЛЬНОСТИ ВОДНО-БОЛОТНЫХ УГОДИЙ ПОД РАЗЛИЧНЫМИ ФОНАМИ

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УДК 543.42:581.526.33

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(Поступила 22 ноября 2018)

Измерены спектральные зависимости коэффициента отражения полога ириса, выросшего на различных грунтах. Экспериментальные результаты показывают, что при разных грунтах водно-болотной растительности спектральные характеристики ее полога различаются и обнаруживают определенную закономерность.
Ключевые слова: *водная растительность, фон водно-болотных угодий, дистанционное зондирование, спектральное отражение.*

Introduction. Wetlands mark the transition between land and water areas. These locations contain abundant terrestrial and aquatic animals and plant resources and play an important role in maintaining the global ecological balance [1]. Wetland aquatic vegetation is an integral part of the wetland ecosystem. The particularity of aquatic vegetation is that it only grows in water environments. In these environments, the substrate controls numerous processes and is the main provider for wetland material cycles. Although aquatic vegetation can promote ground settlement and reduce the amount of suspended solids, the type of sediment determines, to a certain extent, the type of aquatic plants that will grow.

Remote sensing technology can generate multiband, long-phase information from large, repeated areas [2]. This technique has been widely used in wetland survey, mapping, and remote sensing monitoring. Remote sensing technology in the field of aquatic vegetation research, however, still possesses some limitations such as a poorer classification effect and inversion of low precision [3]. This is because of the unique growth environment of wetland aquatic vegetation. Indeed, the canopy spectrum of aquatic vegetation is affected by water background elements, including air, water-water interface, transparency, plankton, sediment content (either in the water column or deposited at the bottom), water depth, and the influence of other optical active components [4]. Wetland substrates are composed of rock, sand, clay, silt, etc. The spectral response varies following the different types of sediment. Furthermore, since wetland aquatic vegetation is usually found on the shores of shallow water and marshes, the depth of the water column is limited, and thus the vegetation canopy spectra is more significantly affected by the composition of the bottom than in deeper aqueous environments.

Numerous studies have focused on the spectral characteristics of the bottom and on their relationship with water depth, the two main factors controlling the physical properties of water in the vegetation growth environment. For example, Xu et al. analyzed the spectral characteristics of humic acid in natural bodies of water to distinguish the differences made by various sediment compositions in the structural properties of the spectra [5]. Shi Yingni et al. showed that differential spectrum technology can be very useful for several applications such as sediment type recognition [6]. Based on the different substrate used to obtain hyperspectral data, an algorithm is proposed to classify bottom sediments by studying the relationship between the spectral reflectance of the different sediments and water depth. In particular, the reflectivity correlation coefficients of the different substrates are analyzed and correlated with the depth of the water. Through the spectral characteristics of the substrates obtained from the remote sensing images, the substrates are divided into different types. Comparative analyses with different types of bottom sediments and the water nitrogen and phosphorus contents may also be considered [7].

Regarding the study of water body remote sensing, the composition of the deposited bottom sediment greatly affects the change of reflectivity and thus the surface spectral reflectance (due to variations in the composition of the water and of water and sediment), especially in the case of shallow waters in the coastal inshore. Therefore, investigating the relationship between the substrate and the surface spectral reflectance is of great significance to the precision of remote sensing inversion study [2]. Different types of bottom sediments induce great differences in the spectrum characteristics, thus influencing the spectra of the aquatic vegetation canopy. Applied to wetland aquatic vegetation canopy spectral research, remote sensing technology should provide a concrete analysis of various bottom sediments corresponding to different aquatic vegetation growth environments.

The main purpose of this study is to establish a water plant canopy spectral library and to provide the corresponding technical support for image interpretation and classification of hyperspectral remote sensing image. We used a spectrometer to collect spectral reflectance data of the canopy of the water plant iris under different types of bottom sediments. We monitored the spatial and temporal variations of growth and distribution of the irises in order to develop real-time monitoring of the wetland ecological environment. This study should provide a scientific base for large-scale remote sensing monitoring of the distribution of water plants and their dynamic changes.

Experimental. This study used *Iris tectorum* Maxim. for the aquatic vegetation material. These water plants grow in swamp soil or in shallow water. They require moderate moisture, good drainage, and a cohesive soil rich in humus and possibly slightly alkaline. However, irises are mainly distributed in north temperate regions such as Europe, Asia, and North America. In particular, they grow in the southwest, northwest and northeast of China, where the climate is perfectly suitable for water plant development [8]. Four kinds of substrate were selected to simulate wetland common types of sediments: yellow sand from coastal estuary wetland, black sand, clays from river wetland, and silts from marshes.

Experimental measurement of the vegetation canopy spectra was carried out using the ASD Field Spec 4 portable object spectrometer that has a 350–2500 nm wavelength range, a wavelength accuracy of ±0.5 nm, and a spectral resolution of less than 3 nm for the 700 nm band, 1400, 2100 nm less than 8 nm. We chose an angle of view (FOV) of 25 for the lenses. Experiments on irises were made in six basins. requiring basic consistent, robust growth and no symptoms or the leaves (plant height of about 25 cm, 45–50 blades). The length, width, and height of the tanks used are 1 m. It is important to note that plastic water tanks and flower pot require the use of extinction cloths ($F < 0.03$) with a complete coverage in order to avoid the influence of the diffuse reflection of these materials on the vegetation canopy spectra. We fixed the spectrometer probe by means of a tripod and used the camera viewing angle to adjust the relative height and angle between the vegetation canopy and the probe. Before starting the measurements, the instrument is preheated for at least 30 min to ensure the accuracy of the measurement. Irises are arranged in the tank in the form of concentric circles. The spectrometer probe is fixed 1 m vertically above the iris canopy. We used a reference white board to calibrate the spectrometer measurements and then measure the reflectance of the iris canopy under the background of different substrates. Measurement times were chosen depending on the type of sediment and on the water depth gradient. Overall, this experiment comprises five different types of substrate (yellow sand, black sand, pure vegetation, silt, and clay) and five different water depths (0, 5, 10, 15, and 20 cm), thus resulting in a total of 25 different circumstances for measurement of the reflectance of the iris canopy.

During this experiment, we measured and displayed in real time the reflectance of the iris canopy, using the ASD RS3 software packages. Data export and simple processing are made using Field Spec ®-4 Hi Res feature spectrometer matching View Spec Pro6 software. Origin Pro8.5 and Microsoft Office Excel 2013 are used for data visualization and relevant analysis. The spectrometer intrinsic noise can affect the authenticity of the spectral data. This influence is significant in particular at both ends of the band ranges. In order to guarantee the accuracy of the experimental results, we selected specific effective spectrum data bands for analysis within the scope of the 400–2400 nm.

Vegetation has a characteristic spectral reflection, which differs from that of soil, water, and other natural features. Indeed, variations can be found within each band of vegetation reflection spectra following: (i) pigment absorption, which influences visible light band spectral reflectance, (ii) cellular structure, associated with the spectral reflectance of the near-infrared band, and (iii) water vapor absorption related to short-wave infrared spectral reflectance. In order to specifically analyze the relationship between the aquatic vegetation canopy spectra within each band and the vegetation coverage, data analysis was divided into three spectral zones: the visible spectrum wavelengths (400–700 nm), near-infrared wavelengths (700–1000 nm), and short-wave infrared wavelengths (1000–1800, 1800–2400 nm).

Results and discussion. Spectral experiments were divided into two stages. First, we analyzed the influence of different types of bottom sediment at different water environment depths; then we analyzed the wetland aquatic vegetation canopy under different backgrounds of bottom sediments [9]. Analysis of the results was divided into two parts as well.

The wetland substrate types are different depending on the wetland area. The wetlands of Hang Zhou Bay, for example, belong to the coastal wetland types and include large tidal flats, reeds, and weeds. In particular, sediment samples were collected from the sandy bottom deposition of the Qian Tang River. Hangzhou Xi wetland belongs to the urban wetland type. In this region, the water flow velocity is slow, the update cycle of biological metabolism is short, and the substrate type is muddy. The other part of the river comprises rice paddies and presents a clay sediment distribution. To reflect the influence of the bottom sediments on the spectral characteristics of different habitat types of wetland aquatic vegetation canopy, the black sand, yellow sand, silt, and clay sediments are selected in this experiment as experimental objects.

Under natural conditions, the reflectance characteristics of soil surfaces show no significant peak value. Generally speaking, a fine quality of the soil will lead to a high reflectivity. Also, the higher the organic matter and water contents, the lower the reflectivity. Although water background features such as water depth and water turbidity may have some effects, the spectral characteristics of aquatic vegetation sediments are similar to the reflectance features of natural soil. Under different types of bottom sediments and at various depths of water, the reflectivity obtained from the experimental results show that yellow sand, black sand, silt, and clay sediments exhibit different spectral curve features for the same water depth. Figure 1 shows the reflectivity spectrum curves of the black sand, yellow sand, silt, and clay sediments in a dry environment and at water depths of 0, 5, 10, and 15 cm.

Figure 1a indicates that the overall trend of reflectivity of the four types of substrate is reduced with increasing water depth. In a dry environment (red curves), the reflectivity of the four types of substrate is relatively high compared to the measurements made in water. In particular, within the 800–2400 nm band, the reflectivity of the yellow sand substrate is higher than 0.4. As the depth of water increases to 15 cm, the reflectivity of the four sediment types falls below 0.1. At depths of 5, 10, and 15 cm, the differences observed among the reflectivity of the four types of sediment are meager. Within the 400–2400 nm band, the bottom reflectivity of the yellow sand remains higher than that of the three other types of substrate. In the visible light band, the bottom reflectivity of black sand, silt, and clay exhibits an irregular arrangement. In near infrared and short-wave infrared wavelengths, the substrate ground reflectance is arranged regularly from the highest to the lowest: black sand, silt, and clay.

Figure 1b shows the reflectivity curves of the yellow sand, black sand, silt, and clay sediments in a dry environment and at water depths of 0, 5, 10, and 15 cm. We can see that the reflectivity of the four bottom sediment types decreases with increase in water depth. In addition, at the same water depth, the reflectivity of the four sediment types shows no significant differences. Overall, horizontal and vertical analyses show that the bottom reflectivity of sediments exhibiting various composition and colors does not show significant variations. Indeed, in dry conditions or at the same water depth, sediments with smooth surfaces and consisting of fine particles exhibit a high reflectivity, while sediment types with coarse surfaces and coarse particles have a relatively lower reflectivity. Bottom sediments with light color show a high reflectivity, while the darker grounds show lower reflectivity. This is the case for yellow sand and black sand. Furthermore, the sediment humus content also significantly affects the reflectivity. High contents of humus results in low reflectivity, and thus in a lower spectral curve.

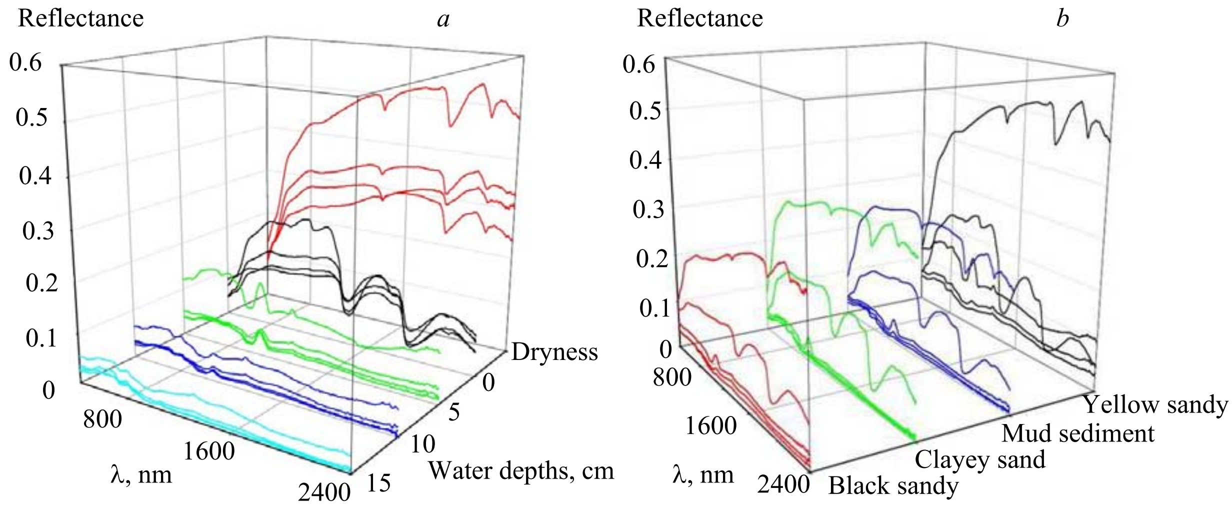

Fig. 1. Substratum spectral curves under different depths of water lateral comparison (a) and vertical comparison (b).

As reported above, different types of bottom sediment yield different spectral characteristics. Based on this observation, we carried out iris canopy spectral experiments under different substrate backgrounds. Experimental results show that for the same depth of water, the reflectance spectrum curve of irises exhibits the typical spectral characteristics of plants, independently of variations in the type of substrate. However, at varying depths and in different wavelength ranges, the influence of bottom background on iris canopy reflectance is significant. Therefore, results are divided into two parts for analysis: the same water depth and different bottom substrates, and different water depths and the same bottom substrate.

The spectral reflectance of aquatic vegetation canopy is inversely proportional to water depth. With increasing depth, the spectral reflectance of the vegetation canopy decreases. Indeed, the canopy reflectance constantly decreases with increase in depth, independently of the type of aquatic vegetation on bottom sediments. Figure 2a shows the canopy spectral curves for irises in yellow sand, black sand, silt, and clay in dry conditions and at water depths of 0, 5, 10, 15, and 20 cm.

In the visible spectrum (400—760 nm), the plant spectrum is mainly controlled by various pigments located in the blades, among which chlorophyll plays a leading role. Due to the strong absorption of the pigments, the reflectivity and transmissivity of the blade are very low. This spectral band is not significantly affected by the depth of water. Indeed, with increasing depths, the spectral curve of the iris canopy still significantly exhibits the characteristic peaks of green plants near 540 nm. In the near-infrared spectrum (760–1200 nm), the spectral characteristics of the plants depend mainly on the cellular structure of the blade. Normally, leaf reflectance and transmittance are similar, with low energy absorption (<5%). Around 730 nm, the spectral reflectance curves of the vegetation canopy rise sharply and approximate a linear form.

In the spectral interval, water depth is the most significant factor influencing the reflectance of the vegetation canopy. Indeed, with increasing water depth, the reflectance of the iris canopy decreases from ~30 to ~10%, independently of the four types of substrate. Within the shortwave infrared spectrum (1200–2400 nm), the incident energy is poorly reflected or is absorbed by the plants, resulting in a limited transmission. The spectral characteristics of plants are mostly controlled by the total water content of the leaf. Hence, the reflectivity of the blade is negatively correlated with the total water content of the leaves.

As shown in Fig. 2a, two significant reflection troughs can be seen at 1400 and 1900 nm, caused by water absorption bands. However, two peaks are observed in the water absorption bands between 1600 and 2200 nm. Because the water content in the leaf of aquatic vegetation is high, low reflectance is shown at the water absorption bands. Thus, with increase in depth, the reflectance of the vegetation canopy does not change significantly, and this observation is true for the four types of bottom sediments.

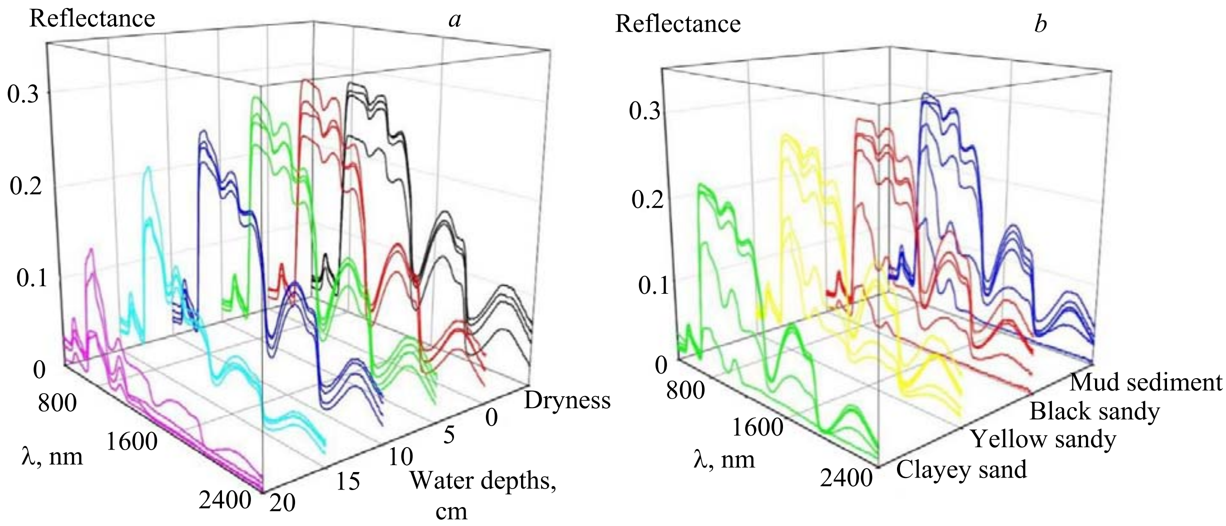

Fig. 2. Spectral curves of the irises at different depths of water lateral comparison (a) and vertical comparison (b).

The spectral curves of the iris canopy for four types of bottom sediment and in transverse comparison show that for the same water depth but with different soil types, the spectral reflectance of the iris vegetation canopy exhibits significant high and low points. For instance, the spectral reflectance of the canopy grown in clay sediment is generally lower than that of irises grown in silt sand, yellow sand, and black sand, and for various depths.

Conclusion. Research on the spectral characteristics of terrestrial vegetation canopy shows that vegetation communities exhibit different canopy spectral characteristics depending on different soil backgrounds. In this study, iris also showed significant spectral differences when grown among various sediment substrates. By measuring the reflectivity of different types of bottom sediment at various water depths and under dry conditions, we conclude that the composition of the sedimentological material, color, grain size, humus content, etc. are all relevant factors that influence the spectral characteristics of the bottom sediment. Thus, measuring the reflectance of iris aquatic vegetation canopy under different types of bottom sediment (in this study silt and clay, yellow sand, and black sand) is also relevant. The spectral characteristics of aquatic vegetation canopy under different types of ground sediment are consistent with the above-mentioned research results. In addition, we state that the spectral reflectance of aquatic vegetation canopy is also significantly influenced by water depth and water turbidity.

In this study, indoor controlled experiments revealed that differences in the type of substrate (mainly related to the composition, color, grain size, and humus content) significantly influence the canopy spectral characteristics of aquatic vegetation. Therefore, not unlike terrestrial vegetation remote sensing, aquatic vegetation canopy spectral acquisition needs to take into account the influence of the bottom sediment background. Failing to do so could lead to inaccuracy of the data collected from aquatic vegetation canopy spectral field measurements, and to an increase in the inversion error. We conducted an investigation regarding the influence of water depth and vegetation coverage on the water plant canopy spectral reflectance. The aim was to obtain a quantitative relationship between the background signal of the water depth and that of the vegetation coverage. Our experiment also controlled other factors that interfere with the spectral characteristics of vegetation, such as water turbidity and the presence of suspended solids in water. Future research should involve the in-depth analysis of the influence of water turbidity on aquatic vegetation canopy spectra, and on the spectral differences created by three types of aquatic vegetation canopy. Combined with the present study, further research should thus improve our understanding of aquatic vegetation canopy spectra and provide full support for the concrete applications of aquatic vegetation studies in the field of remote sensing.

Acknowledgment. This work is financially supported by the Zhejiang Provincial Natural Science Foundation of China (Grant No. LY16D010007) and the Foundation of Hangzhou City Science and Technology Bureau (Grant No. 20170533B01).

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