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Spectral phenology features of *Platycladus orientalis* (L.) Franco

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Abstract. Spectral plant phenology, based on time series of vegetation indices, is a useful tool for monitoring vegetation condition and climatic changes. The chlorophyll/carotenoid index (CCI) and photochemical reflectance index (PRI) show promise for spectral phenology of coniferous plants. This study evaluates the potential of using CCI, PRI, and the normalised difference vegetation index (NDVI) as phenological metrics for *Platycladus orientalis*. The study found a strong correlation between the annual dynamics of the chlorophyll/carotenoid ratio (Chl/Car) and the time series of CCI ($R^2 = 0.89$, $p < 0.001$) and PRI ($R^2 = 0.85$, $p < 0.001$). The CCI time series was used to determine the beginning and end of the phenological vegetation period (PVP) of *P. orientalis* through a double logistic regression model. The PRI model had an error of approximately two weeks in predicting the beginning and end of the PVP, with a tendency to overestimate the duration of the PVP. The use of NDVI as a model is unsuitable for describing the *P. orientalis* 2023 PVP.

1 Introduction

Spectral plant phenology (SPP) utilises annual time series of their spectral characteristics, which can be obtained remotely or proximally. The main metrics used in the SPP are vegetation indices (VI). Compared to "classical phenology" it is less detailed, but more operational and large-scale (both in terms of area and objects). This makes SPP a useful tool for monitoring vegetation condition and climate change. The phenology of deciduous woody plants is well described by chlorophyll-sensitive VI, among which the most commonly used are the normalised difference vegetation index (NDVI) and enhanced vegetation index (EVI) [1, 2]. Describing the phenology of coniferous plants using time series of such VI is more challenging due to the minimal changes in chlorophyll concentration and leaf area throughout the seasons. During the annual cycle of conifers, the concentrations of xanthophyll cycle pigments change more. In this regard, the vegetation indices responsive to carotenoids – photochemical reflectance index (PRI) and chlorophyll/carotenoid index (CCI) – are of great interest as phenological metrics [3-6]. Furthermore, the use of CCI and PRI allows the diagnosis of vegetation and winter dormancy states in conifers [7]. The study aimed to

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compare the time series of photosynthetic pigments with the time series of CCI, PRI, and NDVI, and to evaluate these VI as metrics of P. orientalis phenology.

2 Objects, materials, and methods

The study focused on the coniferous plant *Platycladus orientalis* (L.) Franco. Photosynthetic pigments and spectral characteristics of P. orientalis shoots were measured every 7-10 days from 14 February 2023 to 14 February 2024. Pigment concentrations were determined using a spectrometric method. Pigments were extracted in 96% ethanol [8]. Spectral imaging of shoots was performed under laboratory conditions using a Cubert UHD-185 hyperspectral camera. The formulas used to calculate the VI are as follows:

$$\mathrm{NDVI} = \frac{R_{900} - R_{680}}{R_{900} + R_{680}} \quad (1)$$

$$\mathrm{PRI} = \frac{R_{528} - R_{570}}{R_{528} + R_{570}} \quad (2)$$

$$\mathrm{CCI} = \frac{R_{528} - R_{645}}{R_{528} + R_{645}} \quad (3)$$

The double logistic model was built using the 'greenbrown' package (v2.5.0) [9]. Calendar dates were converted to an uninterrupted numerical sequence beginning on 14 February 2023.

3 Results and discussion

The time series of the chlorophyll to carotenoid ratio (Ch *a* + Ch *b* / Car, Ch/Car) had a well-defined seasonal character – a rapid increase in spring, reaching a maximum in June, and a rapid decrease from August (Fig. 1). The time series of chlorophyll *a* + *b* concentrations (Ch *a* + Ch *b*, Ch) did not have a seasonal character – a peak in concentration was followed by a decline in early June, which was again replaced by a rise in September, followed by a slow decline. This can be explained by the high sensitivity of Ch to weather conditions. The character of the Ch concentration curve is a consequence of the drought in August, the atypical warm and wet autumn and the winter of 2023.

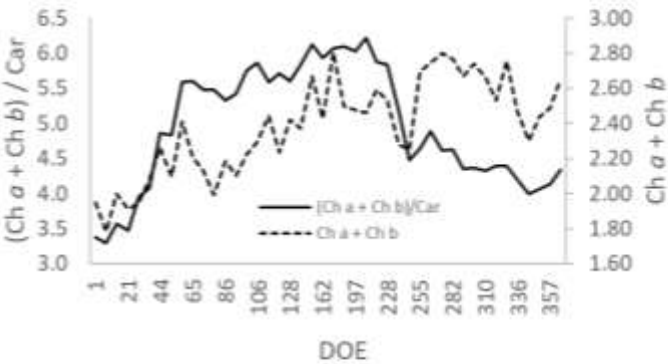

Fig. 1. Time series of Ch concentrations and Ch/Car values in *P. orientalis*.

The linear regressions of PRI and CCI values on Ch/Car values show a strong relationship between VI and Ch/Car, as indicated by the high coefficient of determination (Fig. 2a, 2b). The linear regression of the dependence of NDVI values on Ch has a mean value of the coefficient of determination (Fig. 2c). Generally, PRI and CCI accurately describe the seasonal dynamics of Ch/Car, while NDVI satisfactorily captures the seasonal dynamics of

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Ch.

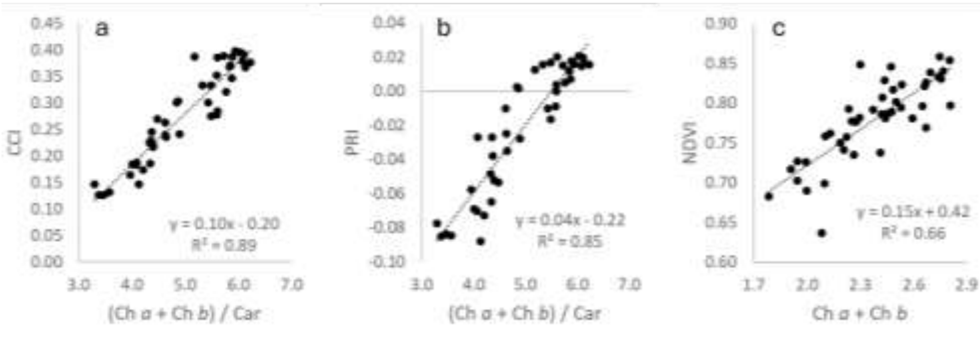

Fig. 2. Linear regressions of the dependence of CCI (a), PRI (b) and NDVI (c) values on photosynthetic pigment concentrations for *P. orientalis*.

The first and final phases of the phenological vegetation period (PVP) of *P. orientalis*, recorded visually, are opening of male strobili and autumn browning of needles. In 2023, they occurred on 1 April and 20 November respectively. The beginning of shoot growth was recorded on 19 April, its peak on 30 May, and its completion on 25 June (it should be noted that these phases are recorded with error). The CCI time series double logistic model accurately predicts the start of PVP (SOS), but determines the end of PVP (EOS) 7 days later (Fig. 3). The POP date is closer to the end of shoot growth than to its peak. The PRI model proved to be less accurate. The error in predicting SOS and EOS was about two weeks in the direction of increasing LOS. The NDVI model based on 2023 data had a very large error in determining the EOS date (more than two months). This is natural, as the time series of chlorophyll concentration in 2023 did not have a pronounced seasonal character.

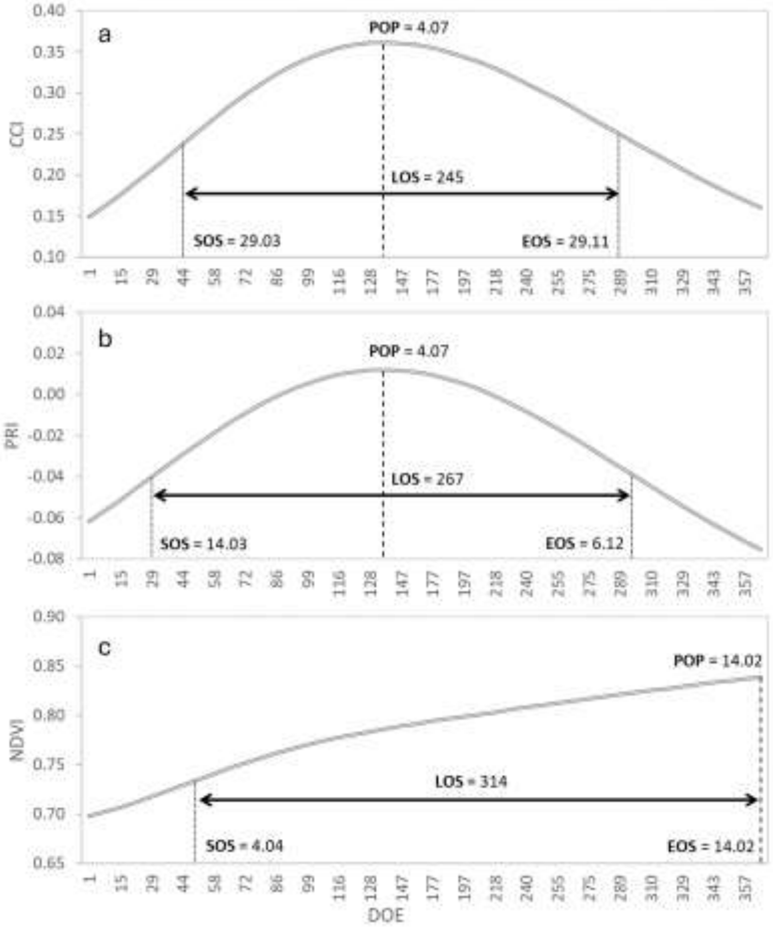

Fig. 3. Double logistic models of CCI (a), PRI (b) and NDVI (c) time series for *P. orientalis*.

Conclusion

Thus, the time series of CCI and PRI accurately reflect the dynamics of Ch/Car. The double logistic CCI model allows predicting the start of PVP without error, the end of PVP with weekly error. The PRI model had an error of approximately two weeks when predicting SOS and EOS, in the direction of increasing PVP. These VI [4], are thought to reflect the productive season of plants. For evergreens, the productive season can extend well beyond PVP because these plants become photosynthetically active long before visible development begins [10]. NDVI time series correlate with chlorophyll concentration time series. However, both of these metrics were not suitable for describing the PVP of P. orientalis 2023. Further development of spectral phenology technology will make it possible to remotely assess the status of conifers without showing visible signs of development.

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