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| **Hyperspectral Remote Sensing for Monitoring Radiata Pine Health: Nutrient Status and Disease Detection** |
| Radiata pine (Pinus radiata D. Don) is a crucially planted species that requires vigilant monitoring to ensure optimal growth and mitigate pathogenic risks. Nutrient deficiencies and over-fertilization pose significant growth limitations, highlighting the importance of continuous monitoring. Specifically, the assessment of Nitrogen (N) levels, traditionally monitored through the link with chlorophyll *a*+*b* (Ca+b) content, emerges as pivotal for determining overall plant health. Moreover, diseases like Dothistroma needle blight (DNB), caused by Dothistroma septosporum and D. pini, induce chlorophyll concentration decreases via the synthesis of the dothistromin toxin, further emphasizing monitoring imperatives.  Remote sensing techniques employing hyperspectral imagery offer promising avenues for quantifying key biochemical indicators such as Ca+b, facilitating leaf Nitrogen quantification, and early DNB infection detection on a large scale. However, the structural complexity of pine crowns, compounded by clumped leaves/needles and background effects, presents challenges for accurately quantifying physiological parameters.  This study investigates the impact of scene components and segmentation strategies on chlorophyll concentration quantification through Radiative Transfer Models (RTM) inversion techniques. Results reveal varying accuracies between pure-vegetation pixels and full-crown spectra, with PRO4SAIL2 model exhibiting superior performance than other standard RT models in predicting needle Ca+b concentration. Furthermore, the study explores utilizing plant traits derived from remote sensing data to enhance DNB detection accuracy. Models incorporating pure vegetation traits outperform those reliant solely on hyperspectral indices, with early-stage disease detection benefiting from parameters describing photosynthesis and chlorophyll degradation. Conversely, severe disease stages are best characterized by traits reflecting extreme reductions in carotenoid content and foliage loss.  The predictions of needle Ca+b were more accurate from PRO4SAIL2 than from PRO4SAIL, using both full-crown (R2=0.82; 3.35 µg/cm2 vs R2=0.51; 4.88 µg/cm2) and pure-tree-crown spectra (R2=0.69; 4.03 µg/cm2 vs R2=0.7; 4.17 µg/cm2). Interestingly, for PRO4SAIL the accuracy of predictions was higher for pure-vegetation pixels than for full-crown spectra, while the reverse was true for PRO4SAIL2, with its highest accuracy being for predictions using full-crown data (RMSE = 3.35 µg/cm2).  For disease detection, models using plant traits obtained from pure vegetation as inputs showed an accuracy of R2 of 0.85, compared with R*2*= 0.52 when using only narrow-band hyperspectral indices. Early stages of the disease were most readily distinguished from asymptomatic trees using variables that predominantly describe changes in photosynthesis (Photochemical Reflectance Index), chlorophyll degradation (Normalized Phaeophytinization Index), and chlorophyll content. In contrast, the more severe impacts of the disease were most well characterized by traits associated with an extreme reduction in carotenoid content and loss of foliage (through LAI and LIDFa).  Overall, these findings underscore the potential of remote sensing for monitoring nutrient status and DNB in radiata pine plantations. By integrating leaf trait estimation with disease detection, forest managers can access valuable insights into tree health, optimize fertilization practices, and implement targeted disease control measures for enhanced forest productivity and sustainability. |