Agricultural and Forest Meteorology 192–193 (2014) 69–77

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Can the plant area index of a submerged vegetation canopy be estimated using digital hemispherical photography?

Dehua Zhao*, Meiting Lv, Penghe Wang, Tangwu Yang, Shuqing An*

State Key Laboratory of Pharmaceutical Biotechnology, Nanjing University, Nanjing 210093, PR China

ARTICLE INFO

Article history:
Received 1 December 2013
Received in revised form 17 February 2014
Accepted 7 March 2014
Available online 29 March 2014

Keywords:
Submerged vegetation
Leaf area index
Digital hemispherical photography
Exposure
Photographic distance

ABSTRACT

Digital hemispherical photography (DHP) has been widely used to estimate the plant area index (PAI, a surrogate for leaf area index, LAI) for terrestrial vegetation. However, DHP has not been applied in aquatic environment fields for submerged vegetation, where only a few methods are available for LAI measurement. The objective of this study was to identify whether DHP could be used to estimate the PAI of submerged vegetation (the total projected area of leaf and stem per unit of ground surface area) using the submerged plant species *Potamogeton malainus*. The results suggested that the exposure setting and photographic distance from the water surface significantly influenced the gap fraction derivation of upward photographs taken from beneath the water surface. To derive the gap fraction accurately from upward photographs, we recommend an exposure setting of 4–8 times the sky reference exposure and photographic distances of 60–90 cm from the water surface to take upward photographs. A simple model was developed to calculate the percentage of projected stem (or leaf) area deeper than the camera lens to the entire projected area of aquatic vegetation; the model was proven effective by field-truth data and could thus be used to compensate for the projected area that is undetected by the camera. Using our recommended exposure settings, photographic distance and adjusted model, a significant linear relationship was observed between the measured PAI and PAI estimated using DHP ($p < 0.001$), and only a 5.1% deviation was found between the measured and estimated PAI. Therefore, DHP can be used to estimate the PAI for certain submerged vegetation species, such as *Potamogeton malainus*, using our recommended optimum procedure.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Leaf area index (LAI) has become one of the most important parameters for characterizing plant canopy structure, processes and functions since it was first defined in 1947 (Bréda, 2003; Chen et al., 1997; Morisette et al., 2006; Watson, 1947). Similar to the LAI, the plant area index (PAI) was defined in the 1990s (Chen et al., 1991; Jonckheere et al., 2004) and has since been widely used; the PAI can act as a surrogate for the LAI in cases where obtaining the LAI directly is difficult (Jonckheere et al., 2004; Weiss et al., 2004) and estimate the aboveground biomass of certain communities (Ens et al., 2009; Hangs et al., 2011). Despite the significance of the PAI (or LAI, the PAI and LAI were later abbreviated to PAI) and the large effort involved in developing numerous methods for its estimation, obtaining accurate and reliable measurements of the PAI remains one of the most difficult tasks for certain canopies (Ryu et al., 2010).

Numerous methods have been developed to estimate the PAI, and they can be divided into two groups: destructive and non-destructive methods (Bréda, 2003; Jonckheere et al., 2004; Weiss et al., 2004). As a non-destructive method, digital photography has been used to measure the LAI and canopy light environment since the 1970s, and these methods have experienced a resurgence in recent years with the development of photographic and processing technology (Chen et al., 1997; Fuentes et al., 2008; Nfon et al., 2011). Compared with destructive and non-destructive PAI measurement approaches, digital hemispherical photography (DHP) has many advantages, such as low processing time and financial expenditures, ease of operation, and the establishment of a permanent record of canopy information. Thus, DHP has become one of the most widely used methods for PAI ground measurements (Chen et al., 1997; Gonsamo and Pellikka, 2009; Mason et al., 2012; Pueschel et al., 2012). DHP has been widely used for many canopy types, from tall trees to small shrubs and herbaceous canopies (Chianucci and Cutini, 2013; Garrigues et al., 2008; Gonsamo and Pellikka, 2009; Hangs et al., 2011; Liu and Pattey, 2010; Ryu et al.,

* Corresponding author. Tel.: +86 25 83592705; fax: +86 25 83592705.
E-mail addresses: wheatzd@sina.com.cn (D. Zhao), anshq@nju.edu.cn (S. An).

http://dx.doi.org/10.1016/j.agrformet.2014.03.008
0168-1923/© 2014 Elsevier B.V. All rights reserved.

2010). However, it remains difficult to answer whether DHP can be used to estimate the PAI for submerged vegetation wherein all of the stems and leaves are beneath the water.

For submerged vegetation, the PAI (the total projected area of leaf and stem per unit of ground surface area) is not only closely related to canopy photosynthesis but also affects ecological functions, such as providing habitat for other aquatic organisms by changing the light environment, stabilizing sediments by slowing water currents and purifying the water by regulating the nutrient cycle (Armitage et al., 2008; Franklin et al., 2008; van der Heide et al., 2011; Zhao et al., 2012a). Therefore, accurately and reliably measuring the PAI of aquatic vegetation also draws wide interest from researchers and managers in related fields. However, the currently used destructive sampling method, which is nearly the only documented approach for measuring aquatic vegetation (Armitage et al., 2008; Dierssen et al., 2003; Nfon et al., 2011; Yang et al., 2010; Yang and Yang, 2009), often cannot provide satisfactory data because it is time consuming and destructive, and it poorly represents the characteristics of similar terrestrial vegetation (Chianucci and Cutini, 2013). There are additional difficulties in obtaining an accurate quantitative sample to determine the PAI for aquatic vegetation (as opposed to terrestrial vegetation) that result from aquatic growth characteristics and the lack of specialized and reliable sampling tools (Zhao et al., 2012c). Therefore, developing accurate and reliable non-destructive methods for sampling aquatic vegetation is important scientifically and practically (Zhao et al., 2012c). However, because of aquatic disturbances, organic and inorganic particles in water, and the significant morphological differences between aquatic and terrestrial vegetation, the theory and methods for measuring the PAI using DHP that were developed for terrestrial vegetation likely cannot be directly applied to aquatic vegetation (Zhao et al., 2012c).

In our previous research, we initially and primarily proved the significant correlation of the vertical gap fraction to the PAI (Zhao et al., 2012c). However, the estimation of PAI using a vertical gap fraction photograph is sensitive to leaf inclination and plant structure, and its application is therefore limited (Jonckheere et al., 2004; Liu and Pattey, 2010). Moreover, the method using vertical gap fraction photographs generally requires numerous photographs to improve the representation because of the relatively small coverage of each photograph. The need for several photographs might add uncertainty to the aquatic vegetation PAI estimation because of the probable disturbance of the canopy structure when taking upward photographs from beneath the water. DHP with multiple viewing angles can mitigate these limitations (Chen et al., 1997; Liu and Pattey, 2010).

The aim of this study was to identify whether DHP could be used to measure the PAI for submerged vegetation using the species *Potamogeton malainus*, which is one of the most widely distributed species of submerged vegetation in China (Cheng and Li, 2006; Liu et al., 2007; Zhao et al., 2012a, 2012b). For terrestrial vegetation, a rigorous procedure has been recommended to improve the stability of using DHP, which includes decreasing potential errors in two ways: deriving the gap fraction from photographs and obtaining the PAI from the gap fraction (Pueschel et al., 2012; Weiss et al., 2004). For submerged vegetation, water disturbances and canopy structure differences between terrestrial and aquatic vegetation are two of the most important factors that determine the applicability of DHP and influence the accuracy of the above two aspects (Zhao et al., 2012c). Therefore, our specific objectives in accomplishing our goal were to (1) quantify the effects of the photographic exposure settings and photographic distance from the water surface, which are two of the most important factors that influence the identification of a plant from the background in hemispherical photographs, (2) develop a simple model to compensate for the projected area of stems (or leaves) that are undetected by the camera because they are positioned deeper than the camera lens when taking upward photographs, and (3) examine the possibility of obtaining the PAI from the gap fraction for aquatic vegetation by comparing the PAI obtained using destructive measurements and mathematical models developed for terrestrial vegetation.

2. Materials and methods

2.1. Site description and experimental design

Our study was conducted in 22 fiber reinforced plastic (FRP) incubators of two sizes: 18 were cuboids (length = 1.7 m, width = 1.25 m, and height = 1.0 m), and the other 4 were cylinders (diameter = 1.5 m and height = 2.0 m), which are referred to hereafter as 100-cm and 200-cm incubators, respectively. *Potamogeton malainus* was transplanted from the eastern coastal areas of Taihu Lake in China to the incubators on August 24–25, 2013. To avoid variation of canopy structure because of varying water depth, we sampled the *Potamogeton malainus* plants at the sites with water depths from 80 cm to 100 cm and 180 cm to 200 cm for the 100-cm and 200-cm incubators, respectively. Before transplantation, we salvaged sediment from Taihu Lake and placed it in the incubators to form a 5 cm silt layer. To maintain a clear status and avoid the suspension of sediments when taking a photograph or filling the incubator with water, a 5 cm sandy layer was added above the silt layer. In different incubators, *Potamogeton malainus* plants were transplanted with densities varying from 20 to 200 plants/m^2 to form canopies with high PAI variability in the incubators.

2.2. Field photography

One month after transplanting the *Potamogeton malainus*, we took upward-directed digital hemispherical photographs with a resolution of 4912×3264 using a digital camera (Sony nex-5N) fitted with a 180° hemispherical lens (MADOKA 180) installed in a diving shell. To ensure that the camera was in the horizontal position required to obtain the vertical upward photographs, we attached bubble-levels to the lens-side camera surface and the opposite end of a pole-pod (Zhao et al., 2012c). Before taking photographs, we leveled the bubbles simultaneously. When taking photographs, we adjusted the pole-pod using the bubble level at the non-camera end to ensure that the camera was horizontal. All upward photographs were taken under uniform sky conditions without direct sunlight (i.e., either on overcast days or during twilight periods before sunrise and after sunset).

To examine the effects of exposure on the identification of plant pixels from photographs, we first took photographs of the sky with the aperture-priority mode (F5.6) to obtain the sky reference exposure and then took upward photographs in the manual mode with a series of exposures starting with the sky reference exposure (F5.6). For example, if we determined the sky reference exposure to be 1/2000 s, a series of nine photographs would be taken with the aperture fixed at F5.6 and shutter speeds of 1/2000 s, 1/1000 s, 1/500 s, 1/250 s, 1/125 s, 1/60 s, 1/30 s, 1/15 s and 1/8 s, which was similar to the process of Zhang et al. (2005). Photographs were taken at a depth of 70 cm in the 100-cm incubators. At least five photographs were taken in 9 of the 18 100-cm incubators. Before taking photographs, we measured the turbidity of each incubator using a multi-parameter water quality checker (HORIBA, U-52) and determined that the turbidity ranged from 0 to 1.36 NTU with an average of 0.32 NTU (a turbidity of 0 indicates that the water is too clear to be measured using the quality checker). To determine the optimum exposure for water with different turbidities, we artificially stirred the water in the other nine 100-cm incubators to produce a slightly turbid status near 8.0 NTU (the actual measured turbidity

Download English Version:

https://daneshyari.com/en/article/81749

Download Persian Version:

https://daneshyari.com/article/81749

Daneshyari.com