A PRELIMINARY STUDY IN MODELLING EVAPOTRANSPIRATION OF COMMON REED STANDS IN THE KIS-BALATON WETLAND

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Abstract

During the examination of the water balance of Kis-Balaton wetland, the direct measurement and determination of evaporation and evapotranspiration is difficult. Evapotranspiration - as outcome parameter - is essential for the operation of the Kis-Balaton Water Protection System (KBVR). The evapotranspiration of the common reed (*Phragmites australis*), which plays a decisive role in ecosystems of KBVR marshes is a significant factor due to the fact that the area of reed canopies exceeds 2,000 hectares. The actual evapotranspiration from the heat balance and the Bowen ratio can be modelled indirectly by using microclimate measurements. Modelling can be performed with resistances expressed by meteorological parameters, whose values are temporally variable. Examinations in a reed canopy of Ingói-berek was carried out with a Bowen mast from July to August 2019. The following meteorological parameters were measured every 10 minutes: surface water temperature, air temperature and air humidity in the canopy, air temperature and humidity and wind speed at two levels above the canopy. Our measurements were supplemented weekly with canopy heights and leaf surface measurements (LAI), which are important model inputs. Hourly and daily evapotranspiration data were counted from the 10-minute microclimate probes. Our goal was to examine how Bowen-ratio modelling can be used to estimate reed evapotranspiration.

Keywords: wetland, common reed, evapotranspiration, Bowen-ratio

Összefoglalás

A Kis-Balaton vizes élőhely vízháztartásának vizsgálata során a párolgás és az evapotranszspiráció mérése és meghatározása közvetlen méréssel nehezen megoldható. A párolgás - mint eredményparaméter - a Kis-Balaton Vízvédelmi Rendszer (KBVR) működéséhez elengedhetetlen. A KBVR mocsarak ökoszisztémájában meghatározó szerepet játszó közönséges nád (*Phragmites australis*) párolgása jelentős tényező, mivel a nádasok területe meghaladja a 2000 hektárt. A hőháztartási egyenletből és a Bowen-arányból származó tényleges evapotranszspiráció mikroklímamérésekkel közvetve modellezhető. A modellezés meteorológiai paraméterekkel kifejezett ellenállásokkal végezhető, amelyek értékei időben változóak. Az Ingói-berek nádállományában 2019 júliusától augusztusáig Bowen-oszloppal végeztünk vizsgálatokat. A meteorológiai paramétereket 10 percenként mértük az alábbiak szerint: felszíni vízhőmérséklet, az állományban a levegő hőmérséklete és páratartalma, az állomány feletti két szintben a levegő hőmérséklete és páratartalma, valamint a szélsebesség. Méréseinket hetente kiegészítettük az állomány magasság és a levélfelület (LAI) mérésével, amelyek fontos modellbemeneti adatok. Az óránkénti és napi evapotranszspirációs adatokat a 10 perces szenzoradatokból számoltuk. Célunk megvizsgálni, hogy a Bowen-aránnyal történő modellezés hogyan használható a nád párolgásának becslésére.

Kulcsszavak: vizes élőhely, nád, evapotranszspiráció, Bowen-arány

Introduction

Evapotranspiration (ET) is the main component of wetlands' water loss, the highest energy consumer of incoming solar radiation, considered latent heat flux as its energy equivalent (Priban & Ondok 1985). The reed (*Phragmites australis* L.) is the dominant macrophyte plant of the Kis-Balaton. The area of its contiguous stands in the Kis-Balaton Water Protection System (KBWPS) is estimated to be about 2,000 ha. The presence of small or large coherent reed stands are very common in wetland habitats in the whole world (Struyf et al., 2007). The main objective of our study was to estimate the in-situ evapotranspiration of reed beds. A domestic precedent on reed evaporation can be found in Walkowszky (1973), in which the study site was Lake Fertő. Walkowszky tried to keep the reeds alive in evapotranspirometers, which could not survive more than 1 month, so that permanent replanting was necessary. In the case of the Ingói-berek of KBWPS, there is no possibility to use site-installed evapotranspirometers, so as an indirect method we tried to model the actual evapotranspiration by microclimate measurements based on the heat balance equation and the Bowen ratio.

Material and method

The site of our investigations was the Ingói-berek of the Lake Fenéki of the KBWPS Phase II, where the Bowen station was installed (N 46° 38' 8.6", E 17° 11' 57.6") (Figure 1). The station measures the following meteorological parameters at 10-minute resolution: surface water temperature and mean water temperature, canopy air temperature and humidity, above-stand air temperature and humidity at height of 1 and 2 m, above-stand wind speed at height of 2 m and sun radiation.

Figure 1. Measuring site in the Ingói-berek of Lake Kis-Balaton and the reference Agrometeorological Station in Keszthely (Google Earth)

Boreas type wind sensor at 2 m above the canopy were installed. Radiance was measured with Delta Ohm HD 2102.2 and Delta Ohm HD 2302.0 RAD sensors (Figure 2).

Figure 2: Bowen station in the Ingói-berek (July 23, 2019, photo bí Gábor Soós)

The hourly evapotranspiration was modelled using the Massman and Burba method (Massman, 1992; Burba et al.,1999). The basis is the net energy balance, R_n (the difference between shortwave and longwave radiation), which is the source of the energy-intensive processes in the reed stand. From the energy balance equation:

$$R_n - G - \lambda E - H \approx 0 \qquad (1)$$

where: H: sensible heat flux, λE: latent heat flux, G: ground heat flux.

Bowen ratio: expressed as the ratio of sensible (H) to latent heat fluxes (λE):

$$\beta = H/\lambda E \qquad (2)$$

The Bowen ratio can be calculated from the vertical change in air temperature and vapour pressure:

$$\beta = \gamma \frac{\Delta T}{\Delta e} \qquad (3)$$

The latent heat flux:

$$\lambda E = \frac{R_n - G}{1 + \beta} \qquad (4)$$

In our case, G is calculated from the change in water temperature:

$$G = c_w d \left(\frac{dT}{dt}\right) \qquad (5)$$

where c_w is the specific heat of water, d is the water depth, dT is the change in temperature with respect to dt.

The sensible heat flux (H):

$$H = \beta \frac{R_n - G}{1 + \beta} \qquad (6)$$

The surface energy budget is (R_{ns}):

$$R_{ns} - G - \lambda E_s - H_s \approx 0 \qquad (7)$$

where: λE_s: surface latent heat flux, H_s: surface sensible heat flux.

The energy budget of a given thickness of vegetation (R_{nv}):

$$R_{nv} - \lambda E_v - H_v \approx 0 \qquad (8)$$

where: λE_v: vegetation latent heat flux, H_v: vegetation sensible heat flux.

The net radiation is the combined energy of the surface and the stand:

$$R_n = R_{ns} + R_{nv} \qquad (9)$$

The sums of latent and sensible heat:

$$\lambda E = \lambda E_s + \lambda E_v \qquad (10)$$

and

$$H = H_v + H_s \quad (11)$$

The surface net radiation is calculated from the Monsi-Saeki (1953) formula. The extinction coefficient (k) is determined using digital image processing by weighing the incident radiation by the area ratio of sunlit and shadowed spots:

$$R_{ns} = (R_n)\exp(-kLAI) \quad (12)$$

Surface Bowen ratio, (β_s) latent heat flux, and sensible heat flux are approximated as follows:

$$\beta_s = \frac{H_s}{\lambda E_s} \quad (13)$$

$$\lambda E_s = \frac{R_{ns} - G}{1 + \beta_s} \quad (14)$$

$$H_s = R_{ns} - G - \lambda E_s \quad (15)$$

β_s is needed to calculate λEs, Hs, λEv and Hv. derived by Massman (1992), taking into account that in our case the resistance to surface water vapor transport is zero.

$$\beta_s = \frac{\rho_a C_p (T_{ws} - T_a) - Hr_a}{\left[(\lambda\gamma\rho_a / P)(e_{*Tws} - e_a) - \lambda E r_a\right]} \quad (16)$$

Where: ρ_a: wet air density, C_p: air heat capacity, T_{ws}: water surface temperature (measured), T_a: air temperature (measured), r_a: aerodynamic resistance,

λ: latent heat capacity of vapour, γ: psychrometric constant, P: atmospheric pressure, e_{Tws}: surface vapour pressure (measured), e_a: above-canopy vapour pressure (measured).

The reference evapotranspiration (ET_0) is calculated from data of the nearby (distance from measuring site: 7 km) Agrometeorological Station in Keszthely (N 46°44'; E 17°14') (Figure 1). The FAO-56 Penman-Monteith ET_0 [mm day^{-1}] equation (Allen et al., 1998) is as follows:

$$ET_0 = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \quad (17)$$

where T is mean daily air temperature at 2 m height, u_2 is wind speed at 2 m height, e_s is saturation vapour pressure, (e_s-e_a) is saturation vapour pressure deficit, Δ is slope vapour pressure curve, 0.408 is a conversion factor.

The calculation of the new daily crop coefficients as a dimensionless indicators using reference evapotranspiration (Eq. 17) and the modelled actual evapotranspiration λE (Eq. 10):

$$K_c = \frac{ET_c}{ET_0} \quad (18)$$

The monthly weather of 2019 July and August were characterized by the Thorthwaite Index (TI) based on the World Meteorological Organisation (WMO) Report (1975):

$$TI = 1.65\left(P / T_a + 12.2\right)^{10/9} \quad (19)$$

where P and T_a are the monthly sum of precipitation and the monthly mean of air temperatures, respectively.

Anda et al. (2014) suggested the next categories after calculating TI for monthly climate norms (1971-2000), and assuming 20% deviation:

Hot (dry) month (h): $TI_{month} > TI_{norm} \times 0.8$,

Cool (wet) month (c): $TI_{month} > TI_{norm} \times 1.2$,

Month with normal weather (n): $TI_{norm} \times 0.8 \leq TI_{month} \leq TI_{norm} \times 1.2$.

Anda et al. (2014) published the K_c values (Table 1) due to TI for *P. australis*.

Table 1 Values of reed crop coefficients (K_c) for July and August with different weather (Anda et al., 2014).

Season	July	Aug.
Cool	0.77	0.8
Normal	1.51	0.99
Hot	1.62	1.39
Average	1.46	1.22

Results and discussion

Characterizing the investigated period with the TI, July (Ta: 22.8 °C P: 92.1 mm) was 19% higher and August (Ta: 22.6 °C P: 25.9 mm) was with 67% lower than TI_{norm} of 1971-2000. At the same time, 1,51 and 1.39 K_c values were computed for “Normal” July and “Hot” August, with respectively. Due to weather conditions in summer 2019, high monthly mean ET_0 of 4.55 mm day^{-1}were computed in July, while somewhat lower monthly mean ET_0 of 3.98 mm day^{-1} for August were detected. With these counted K_c values, the $ET_{a\text{-}Kc}$ for reed was calculated using equation 18 and ET_0. The modelled data series $ET_{a\text{-}Bowen}$ were compared with these $ET_{a\text{-}Kc}$ data series.

For the modelled data the measured LAI was between 3.9 and 4.4 and the weighing average extinction coefficient (k) was 0.4. Hourly and then daily total evapotranspiration ($ET_{a\text{-}Bowen}$) was produced from the ten minutes of measurements. The model allows the calculation of evaporation and transpiration, separately. The daily values of mature vegetation in July and August 2019 are shown in Figure 3.

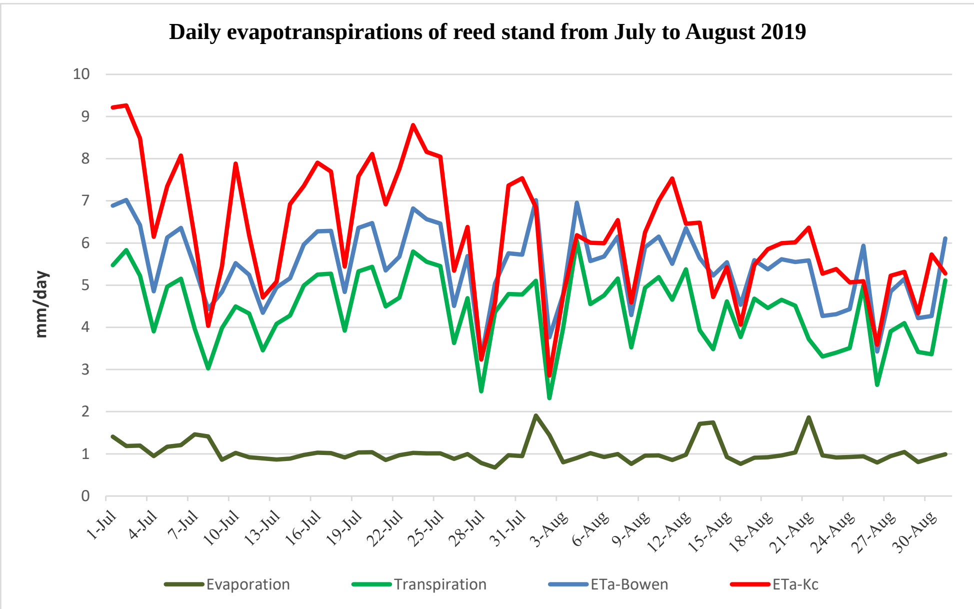

Figure 3 Daily evapotranspiration of reed stand ($ET_{a\text{-}Bowen}$) in the Ingói-berek and $ET_{a\text{-}Kc}$. $ET_{a\text{-}Kc}$ for reed was calculated using equation 18 and ET0.

The daily ET_{a-Kc} ranged from 3.24 to 9.26 mm in July and from 2.86 to 7.53 mm in August. The daily $ET_{a-Bowen}$ values ranged from 3.27 to 7.02 mm in July and from 3.43 to 7.01 in August. The ET_{a-Kc} values were 13.7% higher than that of the modelled $ET_{a-Bowen}$. The pattern of evapotranspiration curves was similar in the two ET assumptions, although, with smoother distribution in $ET_{a-Bowen}$.

The average portion of Evaporation and Transpiration to Evapotranspiration ($ET_{a-Bowen}$) are 0.19 (19%) and 0.81 (81%), respectively. The time series, with a normal data distribution, a paired-sample t-test was applied to compare differences between $ET_{a-Bowen}$ and ET_{a-Kc} from ET_0 and Kc counted by Anda et al. (2014). The difference between daily modelled $ET_{a-Bowen}$ and ET_{a-Kc} with average values of 5.46 and 6.21 mm respectively, was significant: $P(T<=t) = 0.000$. The average deviation was 0.75 mm.

We also counted new daily Kc values using the modelled reed evapotranspiration ($ET_{a-Bowen}$) and ET_0 from the Agrometeorological Station in Keszthely (Figure 4). The average values for July and August were 1.26 and 1.34 respectively. The August K_c value was closer to 1.39 suggested by Anda et al. (2014) than the July's to the extreme 1.51. So the wetland microclimate could be more balanced as it was thought earlier. The explanation could be the large water table characterized with the high value of specific heat of water. This could result in smoothing the original K_c curve, suggested by Anda et al. (2014).

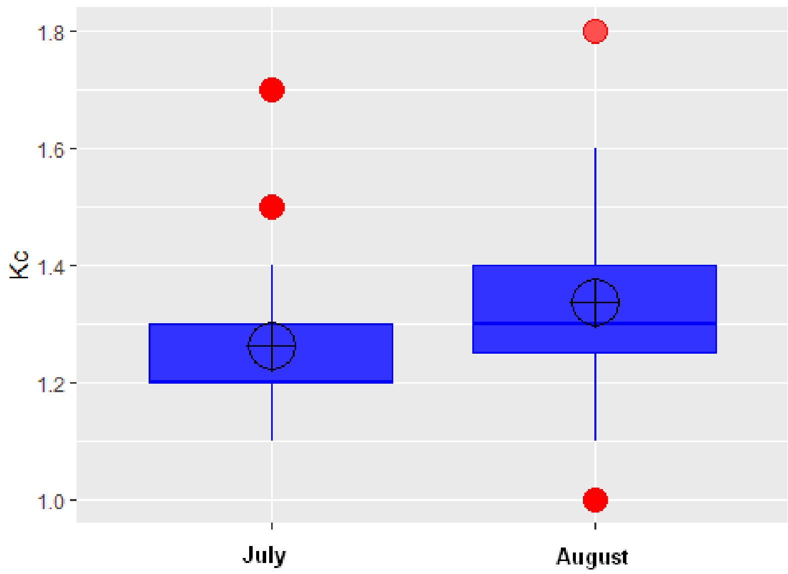

Figure 4 Boxplot of the new crop coefficient values for July and August with outliers. The crosshairs represent the mean

Conclusion

The crop coefficient values (K_c) were a good estimator of the reed water demand as published by Anda et al. (2014) through evapotranspirometer installed at the Agrometeorological Station in Keszthely. The method is also suitable for estimating the evapotranspiration of the large reed beds of Lake Kis-Balaton. We also should take into consideration the new discussion to get more precise outcome. Using this assumption, the largest outcome of the water balance, the ET can be determined more accurately.

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