1 *Article*

2 Modelling wetland growing season rainfall
3 interception losses based on maximum canopy
4 storage measurements

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16   **Abstract:** This study estimates rainfall interception losses from natural wetland ecosystems based
17   on maximum canopy storage measurements. Rainfall interception losses play an important role in
18   water balance, which is crucial in wetlands, and has not yet been thoroughly studied in relation to
19   this type of ecosystem. Maximum canopy storage was measured using the weight method. Based
20   on these measurements, daily values of interception losses were estimated and then used to
21   calculate long term interception losses based on precipitation and potential evapotranspiration data
22   for the 1971–2015 period. Depending mainly on the number of days with precipitation, the results
23   show that total interception losses for the growing season as well as monthly interception losses are
24   around 13% of gross rainfall. This value is similar to the values observed for some forests. Hence,
25   interception losses should not be disregarded in hydrologic models of wetlands, especially because
26   data trends in meteorological conditions (mainly number of days with precipitation) show that
27   interception losses will increase in the future if those trends stay the same.

28   **Keywords:** interception losses; water balance; water storage capacity; wetland; sedges; Biebrza river
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30   1. Introduction

31   Rainfall interception is the process where ground surfaces, whether vegetated or sealed because of
32   human construction, catching and retaining water during precipitation [1]. It is of considerable
33   importance in water resource management [2], and in the context of climate change [3]. Phytoelement
34   wetness caused by rainfall interception also plays an important role in many areas such as the control
35   of plant disease [4,5], plant susceptibility to dry and wet acid deposition [6,7], in plant photosynthesis
36   and in plant yield [8,9]. However, the lack of knowledge about rainfall interception means that this
37   process has been disregarded or underestimated in rainfall-runoff analysis [10]. Some models
38   disregard it completely, e.g. the THALES model [11], the DBSIM model [12], the REW approach [13],
39   and the Topkapi model [14]. Other models simplify interception, and lump its value with
40   transpiration: Topmodel [15], SHE [16], Wetspa [17].
41   The rain that falls and hits plant surfaces is temporarily retained on the plant surface and,
42   ultimately, either evaporates or makes its way to the ground by throughfall or by flowing down
43   branches and stems [3]. Storage water can be divided into transistor storage (water that drips down
44   immediately), conditional storage (drip out by leaf movements caused, e.g., by wind) and residual
45   storage (water which can be removed only by evaporation) [18]. Residual storage is the most widely

examined and it can be represented as: canopy storage [18], water storage capacity [19], canopy rainfall capacity [20] and rainfall interception [1,21].

Most research on rainfall interception by plant canopies has focused on different kind of trees in different climatic zones, for instances tropical rain forests in Guyana [22], Brazil [23] and eastern Amazonia [24]; tropical montane cloud forest of Guatemala [25]; laurel forest in Canary Island [26]; lowland tropical rainforest in Brunei [27]; boreal forest in Sweden [28]; arid zone pine forest [29]; and deciduous Mediterranean forest in Slovenia [30]. The number of studies on rainfall interception by lower vegetation are inadequate with focusses mainly on: grasslands [19,21,31], drylands [1,20] shrublands [31,32], or croplands [33]. There are two reasons for this. The first is that interception losses from forest are generally greater in absolute volume than those from lower vegetation. However some studies [31] showed that interception of grasslands can reach approximately 30% of annual rainfall, which is similar to many forests [34]. The second reason is the difficulties in measuring rainfall interception in lower vegetation, especially in natural heterogeneous ecosystems.

Lately, a few studies on rainfall interception have been made in a natural wetland ecosystem in Biebrza Basin (NE Poland). Those studies focused on determining the spatial distribution of interception capacity based on ground truth measurements of maximum canopy storage and ALS (airborne laser scanning) [35], also ground truth data was used with Landsat 7 ETM+ image [36]. There have also been numerous studies conducted on estimation of interception using remote sensing techniques that have focused on forest [37,38], croplands [39] or grasslands [38]. Remote sensing techniques show great potential in estimating the spatial distribution of interception, but ground measurements are mandatory for studies on less well-recognised ecosystems such as wetlands. This study follows increasing interest in interception on wetlands ecosystems and on growing season interception in this area.

Studies on the hydrologic cycle has shown a rising interest in rainfall interception phenomena. Even in urban areas where rainfall interception losses seem to be insignificant has begun to be investigated for examination of its influence on water balance [40,41]. The main aim of this study is to investigate the influence of hydrological processes and meteorological conditions (precipitation, evapotranspiration, length of growing season, number of days with precipitation) on the amount of intercepted water for the typical land covers in the Biebrza Valley. The second aim is to estimate interception losses for long time series based on ground measurements of maximum canopy storage. The research focuses only on the growing season due to its length (perennial average 200 days) and the fact that the height and size of analysed plants outside the growing season is negligible. Relation with meteorological conditions together with investigations of the perennial trends of meteorological conditions in year 1971-2015 can show potential influence of climate change on rainfall interception in future. These results might improve hydrological modelling on wetlands and the understanding of wetland ecohydrological processes.

2. Materials and Methods

2.1. Study site

The maximum canopy storage measurements were taken in the Upper Biebrza Basin (NE Poland) (Figure 1). The study area is part of a river valley and is dominated by peat soils (mainly peat moss with the exception of areas near the river). The area is inundated due to irregular floods. The dominated plant community is *Carici canescentis-Agrostietum caninae*, creating a belt of up to 0.6 km wide on both banks along the river. The area is also covered by *Caricion lasiocarpae*, *Molinio-Arrhenatheretea*, as well as *Phragmitetum* communities which grows along the Biebrza river. In sections of the valley abandoned by agriculture, as it is typical of natural river valleys with wetland vegetation, sedges will form in hummock patterns. Research has been conducted on areas covered with phytocenoses of semi-natural plant communities created by a single, extensive, mechanical mowing followed by biomass removal, typically carried out after July 1st, depending on whether soil moisture conditions in the valley is allowing for the entry of field equipment or not. This type of usage is dominant in the study area of the Biebrza valley (Figure 2).

96   The climate of the Biebrza River Valley is temperate transitional, with evident continental
97   influences. The mean annual air temperature in the basin was 6.6 °C in the years 1961–2000. However,
98   in individual years the mean values can vary between 4.8 °C and 8.3 °C. The mean annual
99   precipitation ranged from 536 mm to 610 mm, and the mean annual wind speed was 3.8 m·s^{-1} [42].
100 The diverse topography and morphology lead to variations in local and macro-scale climate
101 conditions and high biodiversity, which are the main cause of differences in temperature and
102 humidity in the warm part of the year [43].
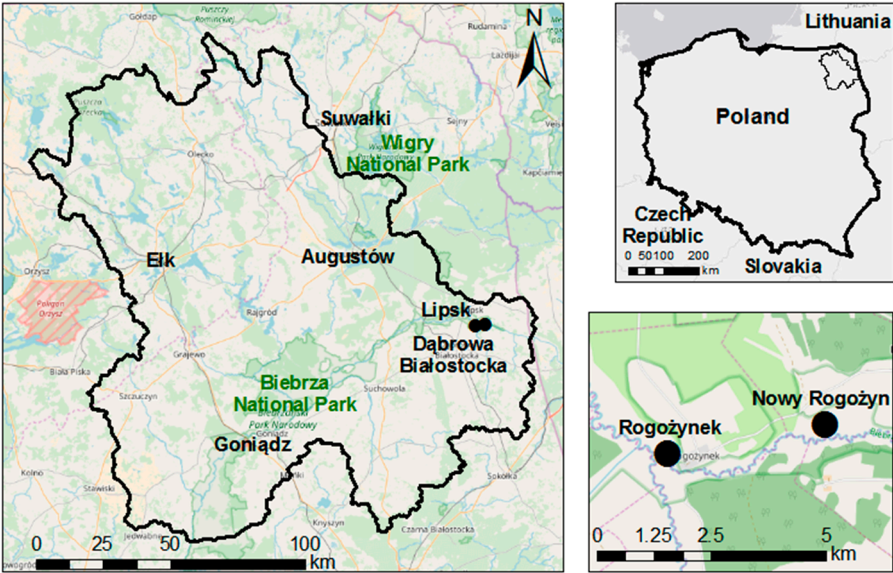
103

104   **Figure 1**. Study site area (location in the Biebrza River Basin – left).

Figure 2. Meadows under extensive agricultural use (in Summer – left; in Autumn –right).

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106 *2.2. Maximum canopy storage field measurements*

107 Field measurements focused on determining maximum canopy storage (I_{max} [mm]) were conducted
108 on two meadows (Figure 1). The two selected meadows (in Nowy Rogożyn and Rogożynek) are
109 mowed one time per year and are representative for the whole Upper Biebrza Basin wetland
110 meadows. Acquired phytosociological relevés from the selected meadows show high variability of
111 vegetation with up to 60 different plant species per meadow.
112   Measurements are made during three field campaigns in 2014: 26–29 June (1–2 months into the
113 growing season), 28–30 July (peak of growing season) and 4–5 September (plant weeding, 1–2 weeks
114 before the end of the growing season). The dates of field campaigns were chosen to represent changes
115 in plant phenology from the beginning of growth through to the state of full development and plant
116 weeding till the death of the plants. Field campaigns were organized on sunny days in hours when
117 dew was not present. First, in order to characterise plant communities presented in the research area,

118 phytosociological data were collected in relevés. Then samples were collected by cutting all the
119 above-ground vegetations within a 0.25m by 0.25m square. In total, 68 samples were collected, with
120 each sample consisting of 90–250 plants.
121   All collected plants were immediately transported to a laboratory, where further measurements
122 were conducted in a natural state. I_{max} was determined by weighting. I_{max} is calculated as the
123 difference between the freshly collected and the weight of a soaked plant . There are two methods of
124 soaking plants with water: spraying [21,31,32,44] and submerging [1,19,45]. In this study plants were
125 submerged because it is less ideal with spraying where the droplet size will cause variations [46].
126 Results obtained by submersion are less dependent on human factors and are more reproducible.
127   All plants from each square were weighed one by one to an accuracy of 0.01 g using a WPS2100/C
128 scale (RADWAG). Then, to avoid interactions between plants, the plants were submerged in a tank
129 of water one by one. After a few seconds after submersion (to allow the excess water to drip from the
130 leaves) each plant was weighed. The difference between the weight of plants before and after
131 submergence is a factor of I_{max} in grams per sampling area (0.0625 m^2). This value was recalculated
132 into mm of H_2O per unit area by dividing the volume of intercepted water (calculated assuming water
133 density equal to 1 g/cm^3) by the sampling area.

134 *2.3   Generating daily values of maximum canopy storage*

135 All measurements of maximum canopy storage were taken in three campaigns during a single
136 growing season, and the means of I_{max} for the three campaigns were tested for statistical significance
137 in their differences using the ANOVA test. We find the difference not statistically significant with
138 p=0.141 (section 3.1). Hence, to obtain perennial daily values of I_{max} the Monte Carlo method was
139 used. Based on the 2014 measurements (n=68), 100,000 repetitions of daily unbiased maximum
140 canopy storage samples were generated for the 1971–2015 period. Our measurements distribution
141 was fitted with gamma distribution using the maximum-likelihood estimation method. Gamma
142 distribution was chosen because it is often used to model maximum discharge or precipitation.
143 Maximum canopy storage values can be modelled using gamma distribution. Our tests with other
144 distributions, such as X^2, lognormal and normal, showed that gamma distribution fits better to the
145 data. The fitted gamma distribution parameters were: shape=4.704 and rate=6.386. The fitted
146 distribution is good according to the Kolmogorov–Smirnov test (D=0.0617, p=0.95). The generated
147 values were assigned to the mid-day of the 15th days of June, July, August and September. Other
148 values were linearly interpolated assuming that I_{max} is 0 at the beginning and end of the growing
149 season. Previous research on wetland meadow canopy storage in this area [35,36,45,47] also focused
150 only on the growing season. This is due to the negligible height of sedge communities before and
151 after the growing season in this area. Hence, this study focused on rainfall interception losses in the
152 growing season.
153   The results of measurements and the example of generated daily maximum canopy storage
154 values are show in Figure 3. For diurnal calculation, daily values of maximum canopy storage depend
155 on the beginning and end of the growing season, which was calculated based on air temperature
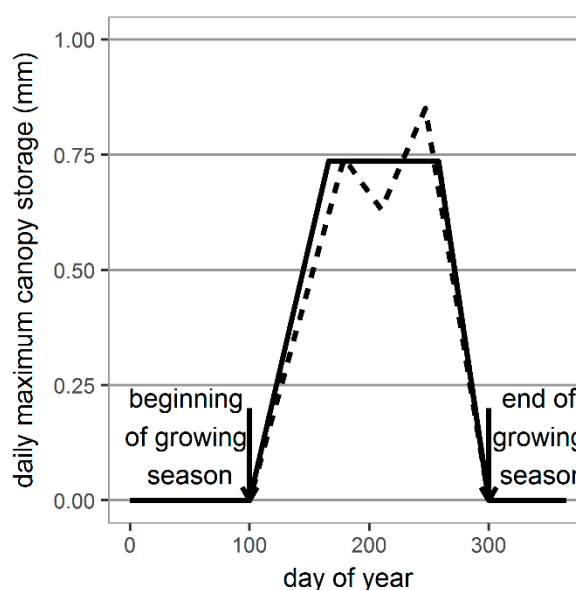156 (section 3.2).

Figure 3. Measured (dashed line) and mean of generated (solid line) daily maximum canopy storage.

2.4   Interception losses model

Daily rainfall interception losses (I_{day}), meaning water that was retained by plants during a given period, were calculated with equation (1) based on daily precipitation (P), potential evapotranspiration (ET_0) (calculated according to [48]) and maximum canopy storage (I_{max}):

$$I_{day} = \begin{cases} I_{max} \; if \; P - ET_0 > I_{max} \\ P - ET_0 if \; P - ET_0 \leq I_{max} \end{cases} \tag{1}$$

Calculations of I_{day} were performed for data from the nearest non-urban meteorological station located in the Biebrza Valley (in Pieńczykówek) for the years 1971 to 2015. Then, it is repeated for all 100,000 simulated values of maximum canopy storage. The meteorological data for Pieńczykowek station were made available by the Institute of Meteorology and Water Management: National Research Institute (IMGW-PIB) in Poland.

This model of rainfall interception is a simple one as there are no well-defined physically-based interception model of wetland vegetation in the study area. The most common physically-based models are Gash [49] and Rutter [34], which were developed for forest ecosystems, and applying them to the ecosystems of our research area was difficult due to the issue of distinguishing certain model parameters (such as trunk storage capacity or free throughfall coefficient, which are technically difficult to define for low vegetation). For this reason, rainfall interception models for grasslands or wetland meadows have not been properly configured. And of the nearly 70 applications we found in the literatures, only 4 were agricultural [3], and these models are difficult to implement due to issues with parametrisation and measurements of rainfall interception. Because of similar reasons, and adding the diversity in natural heterogeneous wetland ecosystems, it is even more difficult to model their rainfall interception.

3. Results

3.1.   Field measurements results

The results of the three field campaigns are compared in Table 1 and Figure 4. The numbers of samples per campaign varies from 19 in July to 29 in June, but the ANOVA test show no statistically significant relation between the means of maximum canopy storage for these campaigns (p=0.141). In all months the standard deviation was about 50% of the mean value, which is caused by high biodiversity (phytosociological relevés were recorded from 24 to 39 different species; in the same sampling areas the number of species was constant during the growing season). The highest (1.61

188 mm) and the lowest (0.19 mm) values of I_{max} were measured in September. Other than high
189 biodiversity which is causing the large variation in values of I_{max}, plants in September are also going
190 through different stages of their life cycle (some were still growing, while others had already dried
191 out) which is another reason for the big range of observed values in this month. In June and July all
192 plants are in the same phenological phase. From all campaigns, the mean values of I_{max} are the same
193 at 0.75 mm.

194 **Table 1**. Maximum canopy storage in mm H_2O per unit area and in g H_2O per sampling area
195 measured in 3 field campaigns

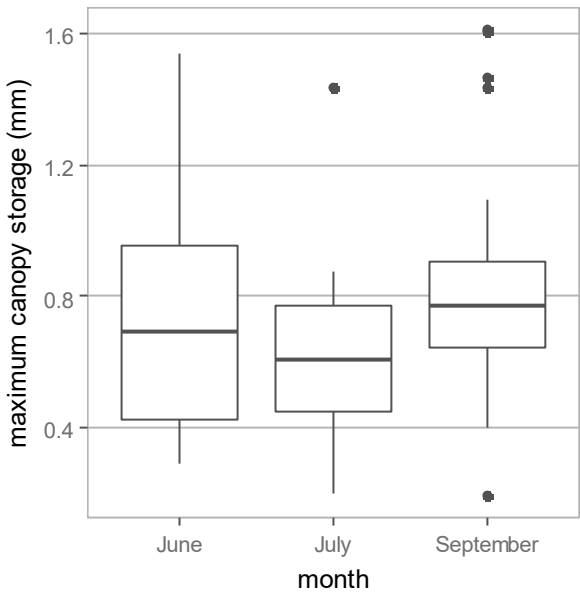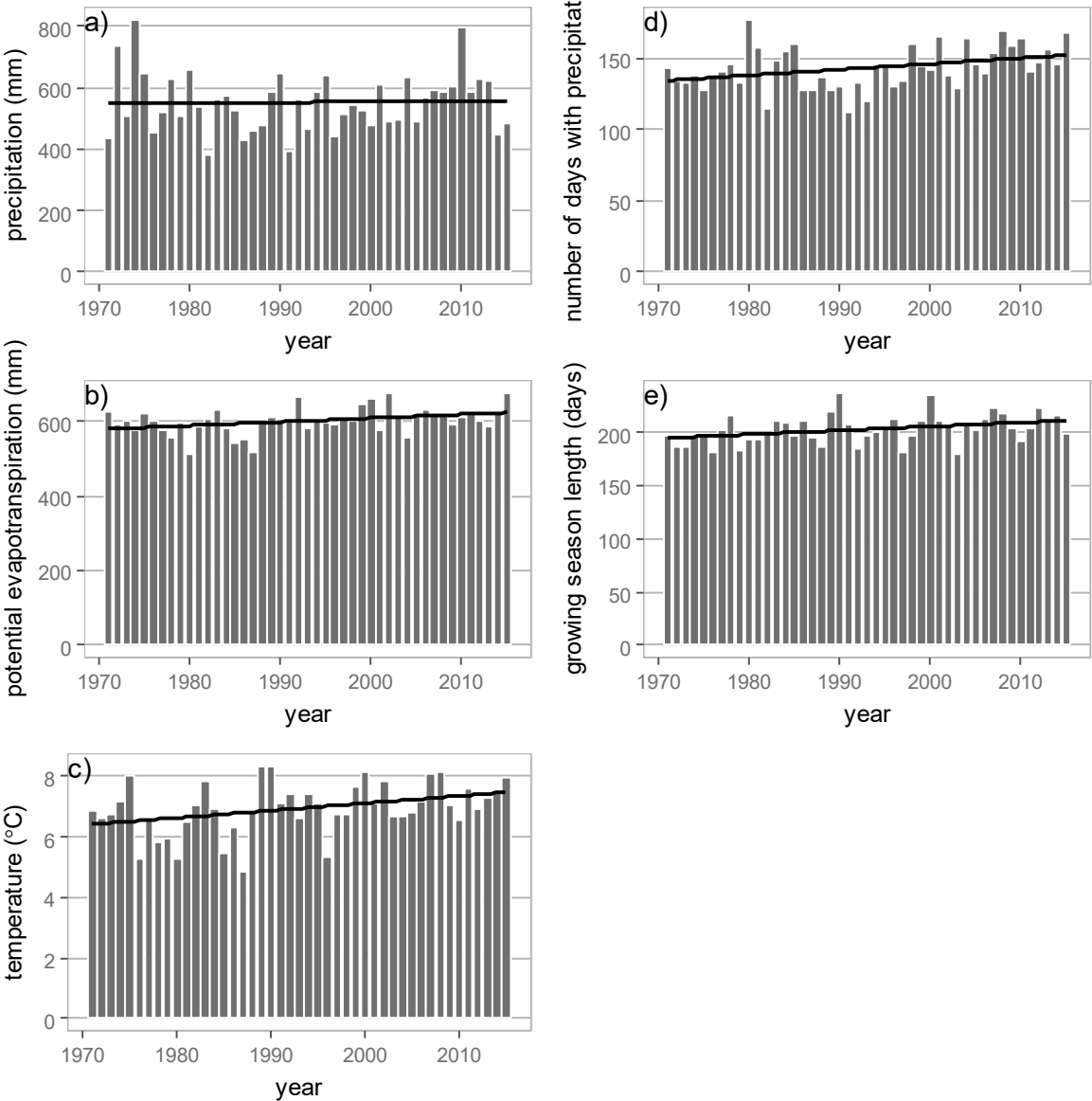| date	number of samples	maximum canopy storage					
		mm H_2O per unit area			g H_2O per sampling area		
		mean ± SD	min	max	mean ± SD	min	max
26-29.06	28	0.74 ± 0.35	0.29	1.54	46.4 ± 21.9	17.9	96.2
28-30.07	19	0.63 ± 0.27	0.20	1.44	39.5 ± 16.9	12.2	89.7
3-5.09	21	0.85 ± 0.39	0.19	1.61	53.2 ± 24.4	12.1	100.6

196

197
198 **Figure 4**. Measured values of maximum canopy storage for the 3 field campaigns

199 *3.2   Meteorological element trends, 1971–2015*

200 Based on daily values of air temperature (mean, minimum and maximum), relative humidity and
201 wind speed, potential evapotranspiration was calculated using the Penman–Monteith equation with
202 the FAO modification [47]. Potential evapotranspiration and daily precipitation are used to
203 investigate perennial trends of precipitation sum, potential evapotranspiration sum, mean
204 temperature and days with precipitation in the whole year and during the growing season. The
205 length of the growing season was also investigated. The growing period in Poland is closely related
206 to the dates on which the +5°C daily mean air temperature threshold value is permanently crossed.
207 Because the ecological factor which affects the rate of plant life processes is thermal conditions, the
208 duration of the growing period is approximately equal to the thermal growing season [50]. Results
209 for perennial trends are showed in Figure 5. Mean perennial values of meteorological elements and
210 slope of the trend (for whole year and for only growing season) were calculated, and the results are
211 summarized in Table 2. Apart from precipitation and number of days with precipitation in the
212 growing season, all elements show slightly growing trends which are significant (p-value<=0.05). The

213   non-parametric Mann–Kendall trend test was also performed, using the Kendall R package [51].
214   Results are compared in Table 2 and it shows the same trends as the linear trends.

215

Figure 5. Perennial trends of a) precipitation, b) potential evapotranspiration, c) temperature, d)
number of days with precipitation, e) length of growing season

Table 2. Annual and growing season means of measured meteorological elements, and slope of their
trends

meteorological parameter	annual mean	trend slope	growing season mean	trend slope	annual M-K tau
precipitation (mm)	552**	+0.15 mm/year	383**	-0.02 mm/year	0.062**
potential evapotranspiration (mm)	600*	+1 mm/year	530*	+1.76 mm/year	0.259*
temperature (°C)	6.9*	+0.02 °C/year	13.1*	+0.02 °C/year	0.259*
number of days with precipitation (-)	143*	+0.4 day/year	78**	+0.18 day/year	0.274*
growing season length (-)	204*	+0.37 day/year			0.272*

220   * p-value ≤0.05

221   **p-value >0.05

222   *3.3.   Relations between interception losses and meteorological elements*

223   The daily interception losses calculated in Section 2.4 was used to compute the growing season and
224   monthly sums of interceptions, hereinafter referred to as 'absolute growing season' (AI_{gs}) and
225   'monthly' interception (AI_{month}) expressed in mm. Absolute interception was also divided by growing
226   season or monthly sum of precipitation, which hereinafter are referred to as 'relative growing season
227   interception' (RI_{gs}) and 'relative monthly interception' losses (RI_{month}), and are both expressed as
228   percentage of precipitation. Additionally, for both RI_{gs} and RI_{month} the relationship with
229   meteorological elements was investigated in the monthly and growing season timescales.

230   3.3.1.   Growing season interception

231   Calculated absolute interception in the growing season ranged from 27.6 mm to 55.0 mm, with a
232   mean of 39.3 mm. The part of the rain that was intercepted (relative interception) ranged from 9.0%
233   to 16.3%, with a mean of 12.6%. Extreme values were observed in different months for both type of
234   interception.
235   The relation between absolute interception in the growing season and hydrological and climatic
236   variables is presented in Figure 6. The relation between the number of days with rain in the growing
237   season and the length of the growing season is positive, while, the relation between potential
238   evapotranspiration and temperature is conversely negative. This relation is observed because in
239   years with high potential evapotranspiration, the sum of precipitation is low, and the total amount
240   of water which can be intercepted by plants understandably drops. Correlation coefficients (R) are
241   compared in Table 3. The highest correlation was obtained for number of days with rain in the
242   growing season (R=0.88), while a weak but significant correlation was also obtained for precipitation
243   (R=0.72). The quadratic relation with precipitation shows that in wet years (precipitation above 550
244   mm), intercepted water cannot evaporate between rain episodes (because of high humidity which
245   leads to slow evaporation) and interception rates start to drop after the threshold precipitation value
246   is exceeded. Other meteorological variables (potential evapotranspiration, temperature and the
247   length of the growing season) were not significantly correlated with the absolute rainfall interception
248   in the growing season.
249   The relationship of relative interception in the growing season to hydrological and climatic
250   variables is showed in Figure 7. All relations are negative. Coefficients of correlation (R) are compared
251   in Table 3. The highest correlation was obtained for precipitation (R=0.75). Other meteorological
252   variables (potential evapotranspiration, temperature, number of days with precipitation in the
253   growing season, and length of growing season) were not significantly correlated with the relative
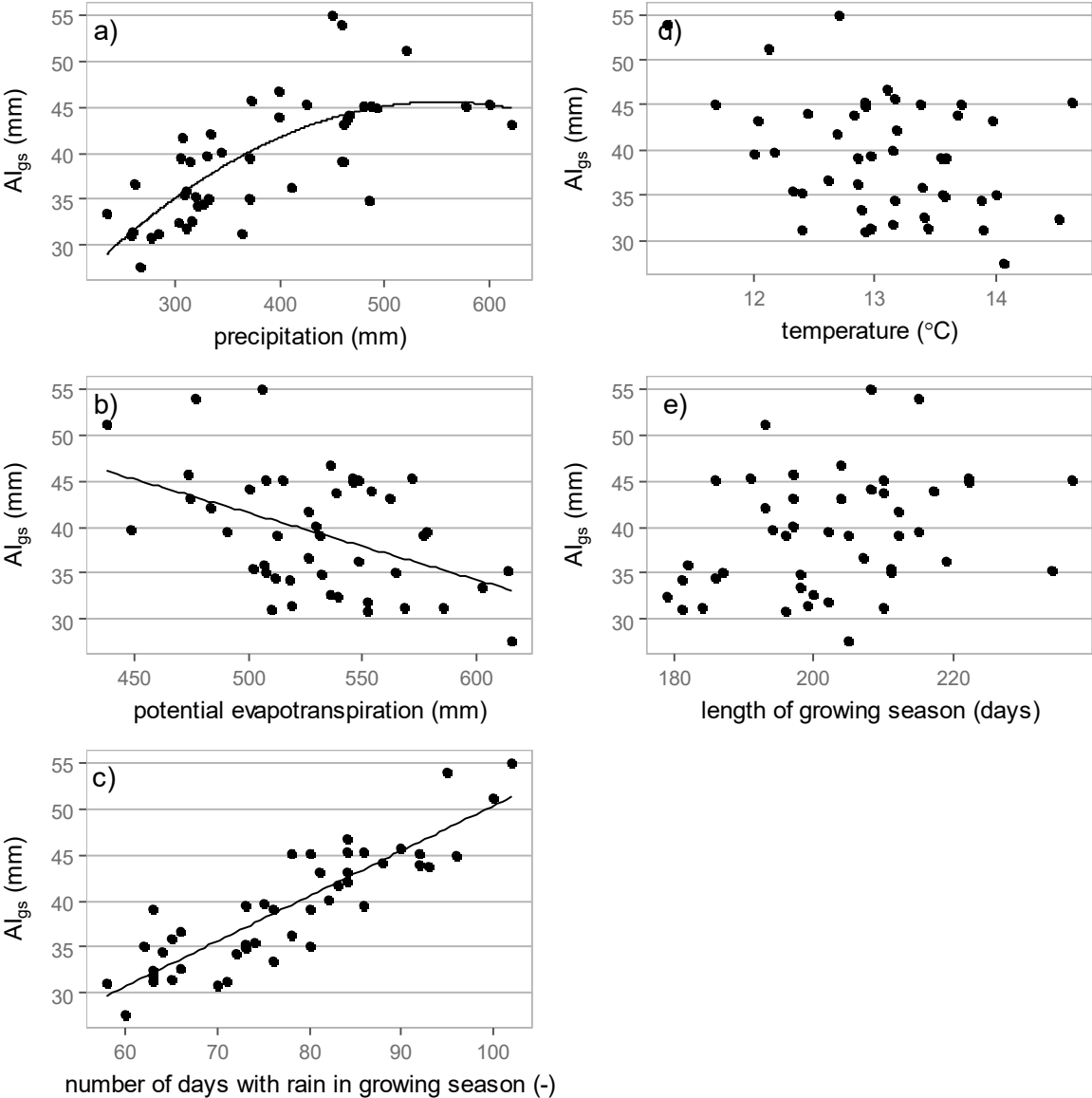254   interception in the growing season.

Figure 6. Relationship between absolute growing season interception (AIgs) and: a) sum of precipitation, b) sum of potential evapotranspiration, c) number of days with rain, d) mean temperature, e) length of the growing season

Figure 7. Relationship between relative growing season interception and: a) sum of precipitation, b) sum of potential evapotranspiration, c) number of days with rain, d) mean temperature, e) length of the growing season
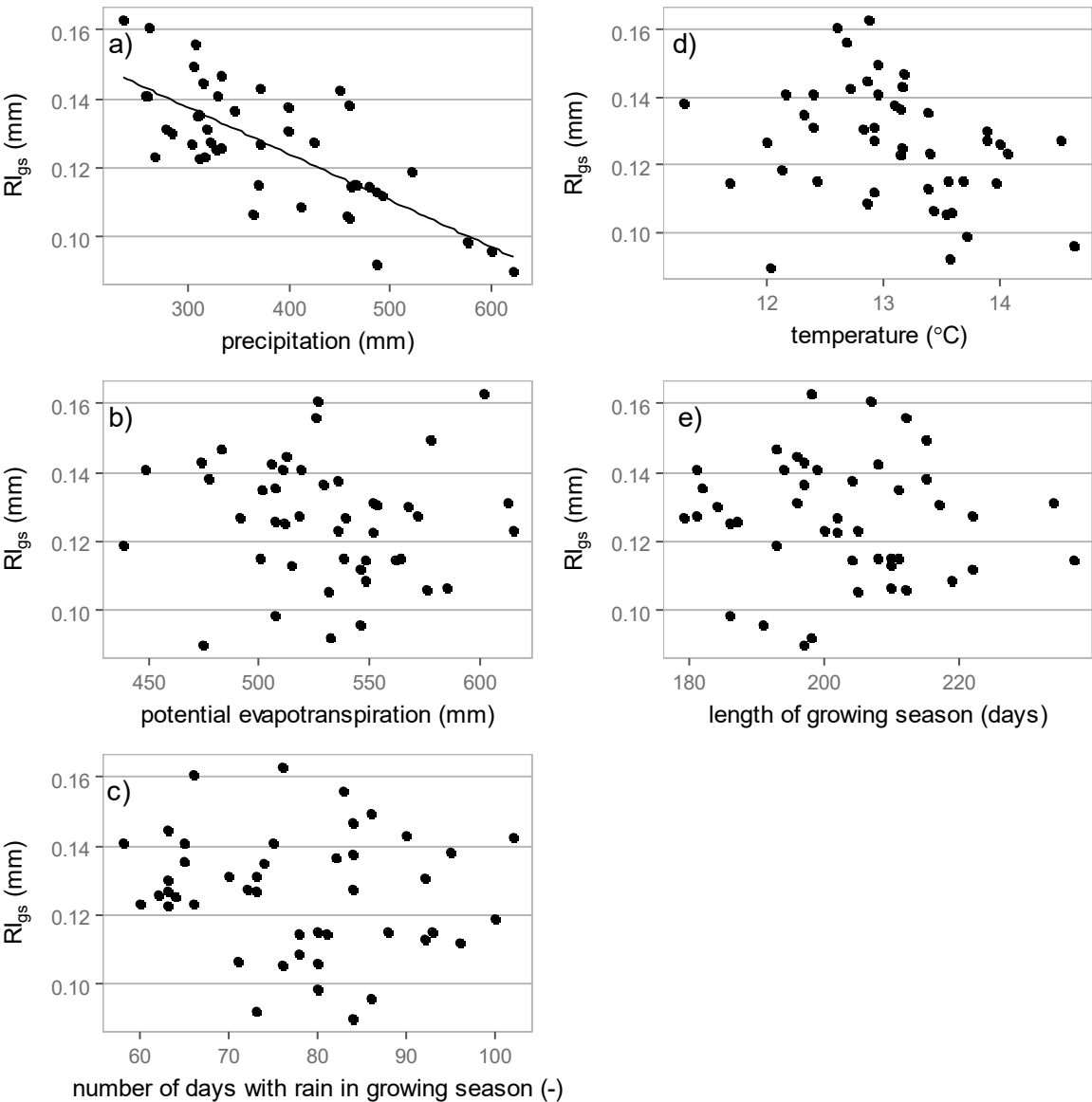
Table 3. Correlation coefficients for relation between growing season interception (absolute and relative) and meteorological elements

meteorological element	absolute interception (mm)	relative interception (-)
precipitation	0.72*	0.75*
potential evapotranspiration	0.45*	0.05**
numbers of days with rain	0.88*	0.13**
temperature	0.36*	0.28*
growing season length	0.30*	0.08**

* p-value ≤0.05

**p-value >0.05

3.3.2. Monthly interception

268 Calculated monthly absolute interception in the growing season ranged from 1.32 mm to 15.07 mm
269 with a mean of 7.25 mm. The part of the rain that was intercepted (relative interception) ranged from
270 3.8 % to 38.2 % with a mean of 13.0 %.
271   The relation between monthly absolute interception and observed meteorological elements is
272 shown in Figure 8. Correlation coefficients (R) are compared in Table 4, separately for single months
273 and overall for all months together. A high correlation was observed for the number of days with
274 precipitation per month. Overall R was 0.88, but for single months, R is higher with figures ranging
275 from 0.92 in May to 0.98 in August. Also significant, but much weaker, was the correlation of monthly
276 AI_{month} with monthly sum of precipitation (R=0.69). In September and July, R is 0.71 and 0.74,
277 respectively, while for other months the R values are slightly lower. The overall correlation with
278 potential evapotranspiration is irrelevant, but for single months the trend is significant and is up to
279 0.73 in July.
280   The relation between relative interception and observed meteorological elements is shown in
281 Figure 9. Correlation coefficients (R) are compared in Table 4, separately for single months and
282 overall for all available data. A significant correlation of relative interception was observed only for
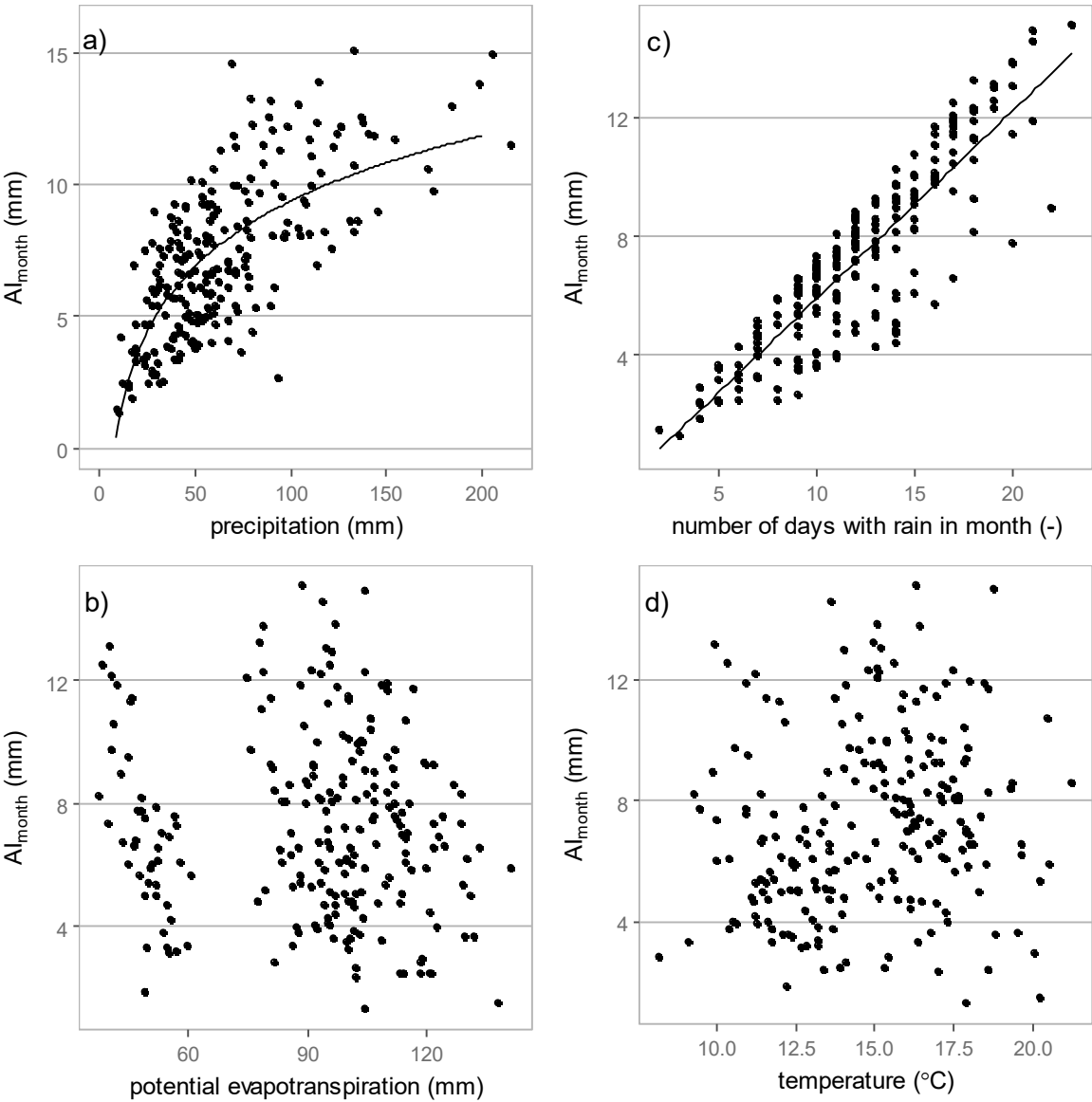283 precipitation, but overall R is only 0.62, with a maximum of 0.77 in June.

284

285 **Figure 8.** Relationship between absolute month interception (AI_{month}) and: a) sum of precipitation, b)
286   sum of potential evapotranspiration, c) number of days with rain, d) mean temperature

287

Figure 9. Relationship between relative month interception (RI$_{month}$) and: a) sum of precipitation, b) sum of potential evapotranspiration, c) number of days with rain, d) mean temperature
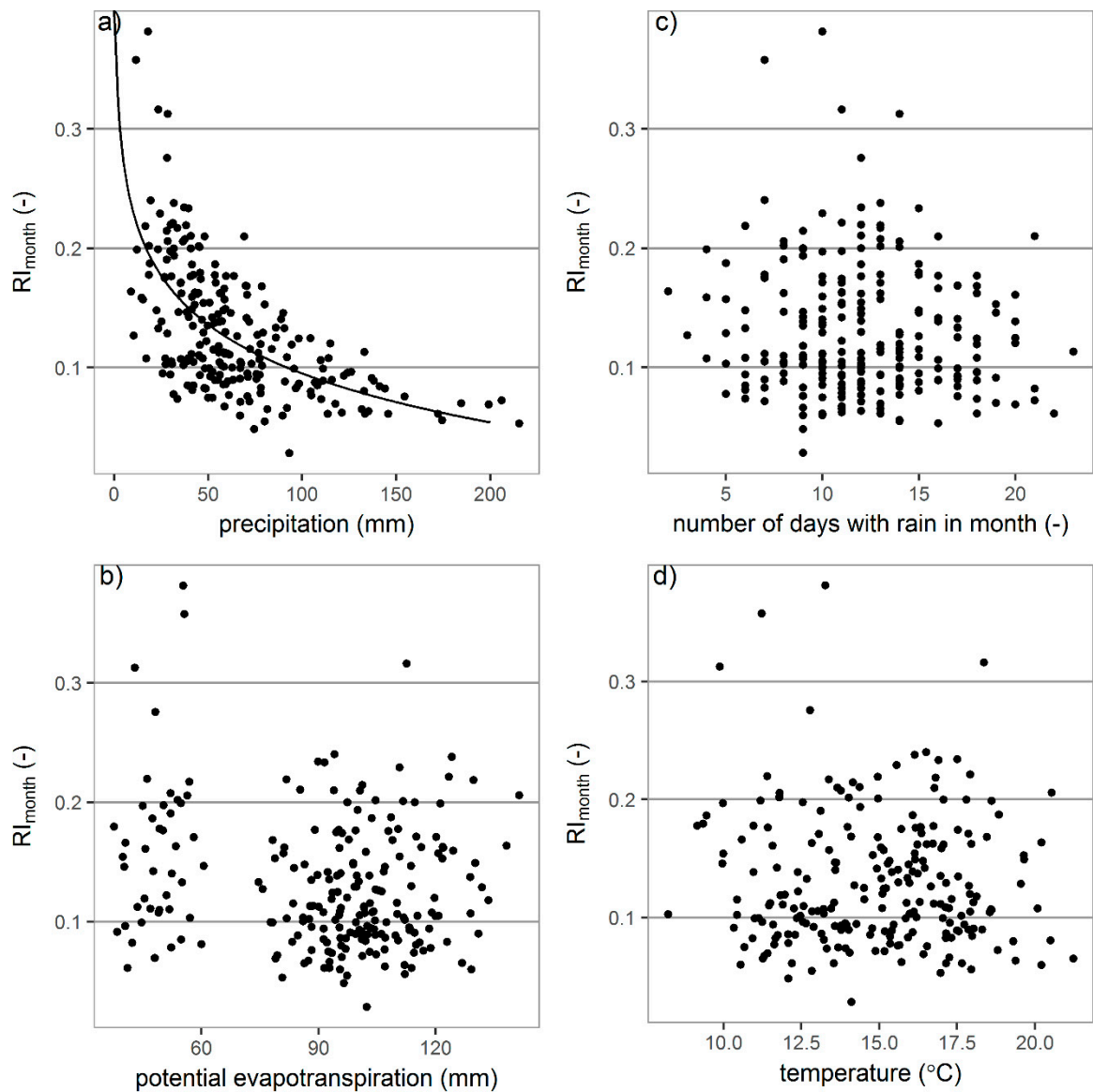
290　**Table 4.** Statistically significant (p-value<0.05) correlation coefficients for relation between growing
291　season absolute interception (AI), relative interception (RI) and meteorological elements

292

		May	June	July	August	September	All data
precipitation	AI	0.68	0.62	0.74	0.67	0.71	0.69
	RI	0.60	0.77	0.70	0.65	0.59	0.62
potential evapotranspiration	AI	0.40	0.59	0.73	0.64	0.69	*
	RI	*	*	*	0.37	*	*
numbers of days with rain	AI	0.92	0.98	0.97	0.98	0.97	0.88
	RI	*	*	*	*	*	*
temperature	AI	*	0.35	0.50	0.38	0.31	*
	RI	*	*	*	*	*	*

293　　　　　　　　　　　　*statistically insignificant relation (p-value >0.5)

294

4. Discussion

4.1   Maximum canopy storage

Investigation of maximum canopy storage on wetlands is not common. Based on what was observed in the literature, values between 0.2 mm and 1 mm are used, for example in the WetSpa model [17]. In this research the smallest value of maximum canopy storage is 0.19 mm, but the upper limit of the result is higher than 1 mm, reaching 1.61 mm (Table 1). Another research conducted in the Lower Biebrza Valley (to the south of the study site) shows that for selected species maximum canopy storage can range from 0.87 mm to 7.37 mm [45]. When compared with our work, results presented in [42] seems to be overestimated. This large variability is caused by the high biodiversity in the natural wetland ecosystem. We also would like to note that the sampling sizes and submerging techniques for the other study are different. In this study, each plant sample of 25 cm ×25 cm grid has been split for individuals plants and measurement taken one by one, but in [45] the whole plant sample in the 10 cm ×10 cm square has been submerged, which leads to a better generalisation of results in this study.

   Most of the related works have been focused on grasslands and meadows, where plants are similar in morphology. For 27 alpine plant species found in the Glacier Lakes in Wyoming the maximum canopy storage was maximally 0.05 mm [52]. On the other hand, for 9 herbaceous species in the Alps the observed values ranged from 0.13 mm to 3.14 [19]. In the Bodega Marine Reserve (California) for 18 clover species the maximum canopy storage ranged from 0.13 mm to 0.36 mm [5]. In comparison, the results for wetland vegetation in this study fall in the middle.

   Maximum canopy storage is in general lower for wetland plants than for forest. For example in [53], the maximum canopy storage for a Douglas-fir forest (>450 years old) located within the Gifford Pinchot National Forest (southern Washington) equals 3.32 mm, but in the same study for a young Douglas-fir forest (20–25 years old) the value was much smaller at 1.4 mm, which is comparable to the extreme values shown in this study. In [54] a Douglas-fir forest in Speulderbos in the centre of the Netherlands has obtained higher values, such as 2.4 mm. However, some researchers have reported similar results of wetland vegetation for *P. sitchensis* in Great Britain (0.75 mm [55]) or even smaller for *Pinus sp.* in the Bray forest located 20 km southwest of Bordeaux, with a range of 0.50 to 0.55 mm [56]. Hence, this study shows that maximum canopy storage for wetland plants communities is smaller than for forests, but for some specific wetland sites it intercepts more water than forest.

4.2   Interception losses

Maximum canopy storage provides information on the maximum amount of water that can be held by plants during a rainfall event. To investigate the influence of interception on water balance we need the meteorological information about precipitation and evapotranspiration. With these values it is possible to estimate interception losses in a given period of time.

   Most research on interception losses is focused on forests [57]. Generally, interception losses in tree canopies represent 9% to 36% of the gross rainfall [58,59]. It has been estimated the rainfall interception losses is up to 48% of gross rainfall for the Corsican pine stands [34]. For upland forests in England the interception losses amount to 35% in areas with an annual rainfall of more than 1000 mm, but it is reported that the loss is higher in areas with lower rainfall with 500–600 mm, amounting to about 40–50% [60]. For the mountainous areas in Poland, interception losses amount to 30% for both coniferous and deciduous forests where the annual rainfall ranged from 560 mm to 740 mm [61]. For wetland plants investigated in this study the amount of interception losses is lower than values for forests (mean equal to 12.6% of rainfall) but as with trees, higher gross rainfall was associated with lower interception losses. In the wettest growing season (sum of precipitation 621 mm) interception losses amount to only 9% of gross rainfall, while in the driest growing season (sum of precipitation 235 mm) interception losses are almost twice as high and amount to 16.3% of the gross rainfall.

There are fewer studies conducted on interception losses for grass or other herbaceous plants, and with those few studies, their results show very high variability. In one study conducted in Texas, the interception losses for *Curlymesquite* grass were estimated as 10.8% of annual rainfall, while interception losses for *Sideoats grama* grass were estimated at 18.1% of annual rainfall [21]. In another study conducted in Australia, higher values were observed for *Curly Mitchell* grass at 32% of annual rainfall [31]. The study area in [21] has a mean annual precipitation of 609 mm, while in [31], it is 255 mm. In our study for interception losses values of wetland plants, that area has a mean annual precipitation of 552 mm, lies between values of the two previously mentioned studies. These suggest that annual rainfall is an important factor and can lead to big variations in estimation of interception losses.

Our study confirmed that there are different driving factors of maximum canopy storage and interception losses. Maximum canopy storage depends on plant morphology and is highly varied across the same plant types, which can be seen by high standard deviation of field measurements and it is confirmed by different studies carried out in Biebrza Valley [36,45]. In addition, when maximum canopy storage was calculated for the entire plant communities (in the measuring squares) for the selected times of growing season, high variability is still observed where the mean values do not differ significantly. Meanwhile, interception losses are driven by hydrological and climatic variables, not just plant morphology and phenology (expressed by maximum canopy storage).

Interception losses was calculated with daily time step, based on precipitation, potential evapotranspiration and maximum canopy storage. So the obtained values of interception losses must be affected by those processes. However, daily values were then used to calculate relationship of interception losses in growing season and month time scales. For these two time scales, more factors were taken into account and this factor: maximum storage capacity and precipitation distribution over time play an important role in values of monthly or growing season interception losses. Our results show there is a high correlation between growing season and monthly interception losses and the number of days with precipitation in a given period, also precipitation is highly correlated with interception losses.

Based on the data from 1971-2015, we observe a trend of increasing number of days with precipitation, at a rate of 0.4 days/year. The R of days of raining and absolute interception losses is very high at 0.88. Therefore, it is reasonable to expect the interception losses will be higher in the future. Our projection is it will be increased by 7.2 mm till 2050 and by 17.4 mm till 2100.

If the trends in our collected meteorological data remain the same in the future, a great impact on interception is anticipated. Potential huge increase in interception losses will in turn affects water balance. In our study area, there is no significant increase in precipitation over the years. However, for study areas where change in precipitation is significant, then this change needs to be considered in the projection/estimation of interception.

5. Conclusions

Based on one year's measurements of maximum canopy storage for wetland plant communities, interception losses for the 1971–2015 period were estimated using meteorological elements. For both months and growing seasons, the mean value was around 13% gross precipitation, which shows that interception cannot be neglected in such areas and should be taken into account with more care in hydrological modelling.

One essential process in interception losses estimation is precipitation. The total sum of precipitation in the investigated period highly affected the estimation of interception. However, more important is the time distribution of precipitation, and the results show that the number of days with precipitation in the growing seasons is most strongly correlated with annual absolute rainfall interception. Even higher correlations are observed for monthly absolute interception. The fact that precipitation characteristics are driven by climate change makes rainfall interception an important parameter to consider in water-balance studies.

Because interception losses are calculated based on daily values of climate and hydrological variables, its dependence on the latter is natural. However, relation between interception losses with

parameters is made in different time scales (in months and growing season) and we should look at all other processes such as distribution of rainfall over time and changes in maximum storage capacity. These observations enable us to project future trend of rainfall interception.

For annual and monthly relative interception, no strong correlations with meteorological elements were observed. Nonetheless, interception is a complex phenomenon which depends not only on meteorological conditions, but also on plant morphology. Hence, still more comprehensive research should be performed to fully understand the interception process itself and its influence on the whole ecosystem.

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