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Preliminary Study on Water Bodies' Effects on the Decomposition Rate of Goldenrod Litter

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Abstract: Leaf-litter input constitutes a major load in natural waters; therefore, to achieve and maintain high water quality, it is important to thoroughly examine and understand the litter decomposition process. The widespread *Solidago canadensis* exerts a negative effect on the composition of the ecosystem, causes extinction of species, and modifies the function of the system. In Hungary, goldenrod constantly spreads to newer areas, which can also be observed around Lake Balaton and at the bank of the Hévíz canal. In our investigation, we examined the decomposition rate of the leaves and stems of the goldenrod with the commonly applied method of leaf litter bags. As water temperature, ranging from 24.0 °C to 13.7 °C, decreases in Hévíz canal away from Lake Hévíz (−0.32 °C/100 m), we chose three different sampling sites with different water temperatures along the canal to determine how water temperature influences the rate of decomposition. For both leaves and stems, the fastest decomposition rate was observed at the first site, closest to the lake. At further sites with lower water temperatures, leaf litter decomposition rates decreased. Results observed through Hévíz canal demonstrated that higher water temperature accelerated the goldenrod decomposition dynamics, while the drift also impacted its efficiency.

Keywords: leaf litter decomposition; *Solidago canadensis*; Lake Hévíz; Hévíz canal

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1. Introduction

Water is one of the main natural resources of the world and a prime constituent of the biosphere. Fresh water sources are primarily present in forms of lakes, rivers, precipitation, and underground water. In the past century, the increased nutrient load of the wetland due to anthropogenic intervention highly deteriorated the water quality of Lake Balaton. Water coming from Lake Hévíz (LH) through the 10–12 m wide and 13 km long Hévíz canal (Hc) enters Zala River, after nutrients are retained within the natural wetland of Ingói berek.

The Balaton's largest tributary, the River Zala, which enters the lake through its westernmost and smallest basin, the Keszthely Basin, supplies ~50% of the lake's total water input and accounts for 35–40% of the lake's nutrient input [1]. The Hc, as a part of the Kis-Balaton Water Protection System—designed on the lower part of River Zala, contributes to the nutrition cycle of the wetland's ecosystem. The Kis-Balaton Water Protection System (KBWPS) is a wetland restoration project whose purpose is the water quality protection of Lake Balaton [2] retaining elements through a reservoir food chain. Based on local measurements, the nutrient retention of KBWPS at the mouth of River Zala is functioning well.

Water quality parameters are commonly determined in the months between spring and autumn in the case of non-thermal waters [3]; however, the water temperature (T_w) of LH and its canals are also increased in the winter months, as compared to other water sources. LH is the deepest thermal water in Europe originating from two crater springs with different temperatures: 26 °C and 41 °C. The water of the two springs becomes blended in the cave and flows into the lake. The T_w of LH is evenly distributed as a result of a mist layer over its surface which functions as a cover thus preventing heat loss from its surface. The average summer and winter temperatures are about 33–35 °C and 24–28 °C, respectively. As water moves away from the source through the canal, its temperature constantly decreases.

Leaf litter falling into water includes leaves, leaves fragments, stems, twigs, harvest, and other plant components [4]. Depending on the location of the vegetation, the composition of leaf litter may vary to a certain extent; however, usually leaves constitute the biggest proportion of leaf litter with 41–98% [5]. Leaf-litter input is responsible for a major proportion of the background load in natural waters. Allochthon sources deriving from plants in the water or at the banks contributes to the inner nutrient load of water bodies [6]. After a leaf falls into water, it loses one quarter of its original dry leaf mass through the dissolution of its water-soluble components already within the first 24 h [7]. It is followed by microbial decomposition, which causes the most significant change in leaf structure. The next phase is the macroinvertebrate and finally the physical shredding of leaves. These decomposition dynamics are significantly influenced by ecological and chemical parameters and the temperatures; thus, these parameters should be examined. In addition to plant biological characteristics the response of decomposition to other changes in nutrients availability [8], temperatures [9], and vegetation under water (watershed one) [10] may also modify the process [11].

The Solidago genus includes more than one hundred different species, most of which originate from North America, eight species are present in Mexico, four in South America and six–ten species are native species in Europe [12]. In Europe, *Solidago canadensis*—Goldenrod—is the most examined species. The goldenrod—as a widespread species—exerts a negative effect on other native plant species disturbing the ecosystem. In Hungary, the goldenrod constantly spreads to newer areas, and it can also be observed around Lake Balaton and alongside the bank of the Hc. Investigating the natural background load as a vital part of maintaining water quality, our aim was to examine the decomposition rate for both the stem and leaf material of the goldenrod. To date, there have been no studies concerning goldenrod decomposition in water, even of the two plant organs separately. As the River Zala strongly impacts the water quality of Lake Balaton, the watercourses flowing in tributary also determine the water quality of the Lake. The novelty of the investigation was also the study area, with different sampling places connecting Lake Hévíz, the deepest thermal lake in Europe, to Lake Balaton, the largest freshwater lake in Central Europe. The impact of T_w on leaf litter decomposition in such a complex ecosystem was not investigated until now, even in wintertime. This was the reason for our investigation at three sampling sites in the Hc (Hc1–Hc3) and one in the LH with different T_w. This study highlights the importance of considering different T_w aspects of litter decomposition in order to predict the decomposition process in warming environments, including rising T_w.

2. Materials and Methods

The investigation was conducted in the winter period at four different sampling sites (LH, and three sites at the Hc as Hc1, Hc2 and Hc3) with different T_w to determine the decomposition rate for both the stem and leaf material of the goldenrod (*Solidago canadensis*). Four sampling points were designated, one of them in the LH, and three other points from the LH as follows:

- Hc1: 400 m from the LH,
- Hc2: 1562 m from the LH,
- Hc3: 4280 m from the LH.

In the course of our investigation, we applied the commonly used and accepted method of leaf litter bags. Samples were collected at the time of litter fall, then were dried until they reached constant dry weight and finally 10 g of each were placed into 15 cm × 15 cm polyethylene bags with 3 mm mesh sizes. The mesh size ensured access for the macroinvertebrate species to leaf litter. 120 litter bags were used in the study (i.e., 2 plant part, 4 sampling points, 5 temporal sampling events, 3 replicates each). The bags were randomly attached to a plastic compartment with bricks placed in the center of the compartment. Bags were randomized and separated to avoid spatial confounds.

The filled leaf litter bags were placed into the water at about 1 m below the surface in the littoral zone to ensure that the bags will constantly remain under water. Three parallel samples of each plant component—the stem and leaves—were retrieved 7, 21, 42, 70 and 98 days after placing the leaf litter bags into the water. The litter bags were transferred to the laboratory where the foreign material was carefully removed, then samples were air dried until reaching constant weight, and finally the weight of the remaining litter mass was measured. Leaf litter mass (stem and leaf) breakdown rates, k was calculated applying an exponential model of the percent mass, W_t mass loss over time (t) as follows:

$$W_t = W_0 \times e^{-kt} \quad (1)$$

where W_0 was the initial weight [13].

T_w measurements were in situ recorded at 10-min intervals and integrated to daily intervals (Delta Ohm HD-226-1).

Conductivity and pH were measured in situ, using Adwa AD111 and AD310 field equipment. ammonium (NH_4^+) and phosphate (PO_4^{3-}) were determined in the laboratory, using a Lovibond MultiDirect (type 0913462) spectrophotometer. Biological oxygen demand (BOD_5) was measured after the procedure of the following standard: MSZ ISO 5813.

The composition in microorganisms was excluded from the study. There was no significant difference in the density of macroinvertebrate shredders between the sampling points.

The remaining mass was analyzed through a two-way repeated ANOVA in SPSS 25.0 [14] for five sampling dates at four different places in LH and Hc1-3.

3. Results

A gradual decrease in mean T_w of the warmer LH from 24.0 °C to cooler Lake Balaton to 13.7 °C (Hc3) was measured. With the exception for LH and Hc1 ($p = 0.566$), T_w of every other sampling place differed significantly ($p < 0.001$). The average T_w was lower by 22.0 and 29.5% in relation Hc1 to Hc2, and in Hc2 to Hc3, respectively. The farther the distance from LH, the lower the mean T_w was measured in the Hc between December 2019 and March 2020. The largest difference in T_w, above 10 °C, was observed in the case of Hc3. The length of the sampling area is at about 3.2 km from the LH. The highest mean T_w from December to March was measured in the LH. Declines in mean T_w were 1.3, 5.0 and 10.3 °C in Hc1, Hc2 and Hc3, respectively (Table 1).

Table 1. Water temperature (°C) measured in Lake Hévíz (LH) and Hévíz canal (sample sites Hc1, Hc2 and Hc3) from December 2019 to March 2020.

Header	Min	Average	Max
LH	22.2	24.0	25.8
Hc1	18.4	22.7	25.7
Hc2	14.5	19.0	22.4
Hc3	9.8	13.7	16.9

Based on previous study, the conductivity in the water samples ranged from 715 to 867 µS cm^{-1} (Table 2). Conductivity of Hc3 and the other sampling points, moreover LH and Hc2 also differed significantly ($p < 0.001$) in the investigated period [15]. The pH of the study sites occurred in the range of 7.37–8.05, indicating slightly alkaline nature of the water quality. The pH of different sampling sites of the study varied significantly ($p < 0.001$). BOD_5 ranged from 0.2 to 1.7 mg L^{-1} in the studied period. LH differed with 20.9% ($p < 0.001$), 32.9% ($p < 0.001$) and 53.5% ($p < 0.001$) in Hc1, Hc2 and Hc3, respectively. There were no significant differences between the sampling points regarding ammonium.

In case of PO_4^{2-}, Hc3 differed with 34.8% (p = 0.049) and 25.0% (p = 0.026) from LH and Hc2, respectively.

Table 2. The conductivity, pH, BOD_5, NH_4^+ and PO_4^{2-} concentration values of the four sampling points in the studied period.

Sampling Place	Conductivity (μS cm^{-1})	pH	BOD_5 (mg L^{-1})	NH_4^+ (mg L^{-1})	PO_4^{2-} (mg L^{-1})
LH	750.0 ± 45.4	7.5 ± 0.2	0.5 ± 0.2	0.3 ± 0.1	0.5 ± 0.2
Hc1	763.8 ± 19.2	7.6 ± 0.2	0.7 ± 0.4	0.3 ± 0.1	0.5 ± 0.2
Hc2	775.8 ± 27.1	7.8 ± 0.2	0.8 ± 0.4	0.3 ± 0.1	0.6 ± 0.2
Hc3	821.7 ± 25.8	7.9 ± 0.1	1.1 ± 0.3	0.3 ± 0.1	0.7 ± 0.3

The passage time and the sample place significantly influenced the decomposition of both leaf and stem (Figure 1). The highest decomposition rate was observed in Hc1 resulting in the least amount of litter mass at the end of investigation. The farther the distance from LH, the more intense the litter decomposition was. Although, the T_w in the LH and Hc1 was similar, the fall was more intense in Hc1 as compared to LH. At Hc1, the remaining mass increased by 27.6–34.7% in leaf and 5.1–12.1% in stem in comparison to other sampling places. The lowest remaining mass was measured in the coolest Hc3.

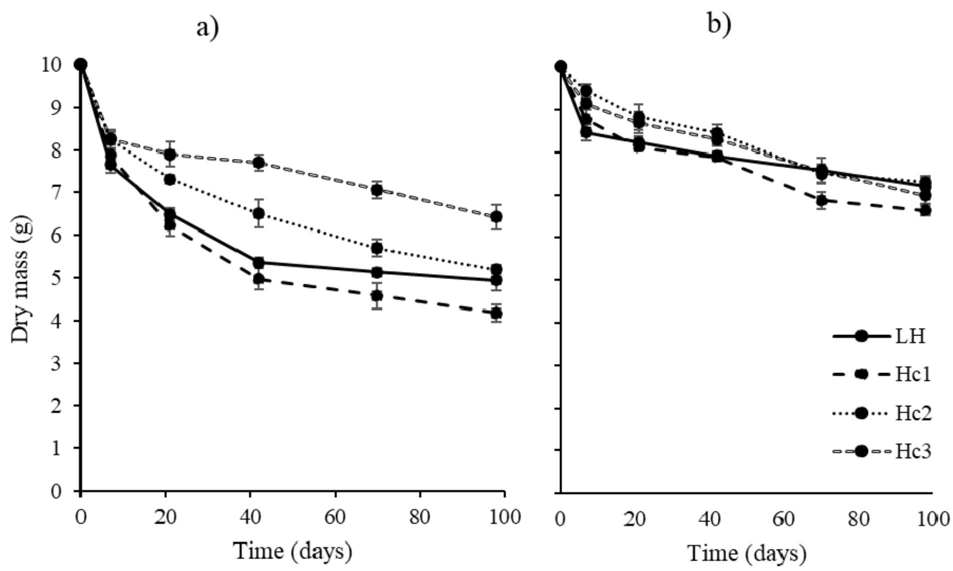

Figure 1. Changes in mean (± SE) leaf (**a**) and stem (**b**) mass loss (g) of goldenrod in Lake Hévíz (LH) and its canal (Hc1–3), n = 3.

The mass loss of leaf litter as a function of time was long ago approximated by an exponential decay model [9]. Exponential decay coefficients (k) were determined according to Bärlocher et al. [16]. In the LH, mean k varied from 0.009 to 0.038 and from 0.003 to 0.024 in leaf and stem (Figure 2), respectively. Somewhat lower values were observed in the canal ranging from 0.034 (leaf, Hc1) to 0.003 (stem, Hc3). Portillo-Estrada et al. [17] also revealed that the decomposition k rates were higher in warmer sites than in colder ones.

As Mauchly's Test of Sphericity was significant, the Greenhouse–Geisser test, one of the alternative univariate tests, was applied. There were significant main effects of place (p = 0.013) and of passage time (p = 0.001) on stem mass decay. In contrast, there was no significant interaction between place x time (p = 0.065) in case of stem mass loss (Table 3).

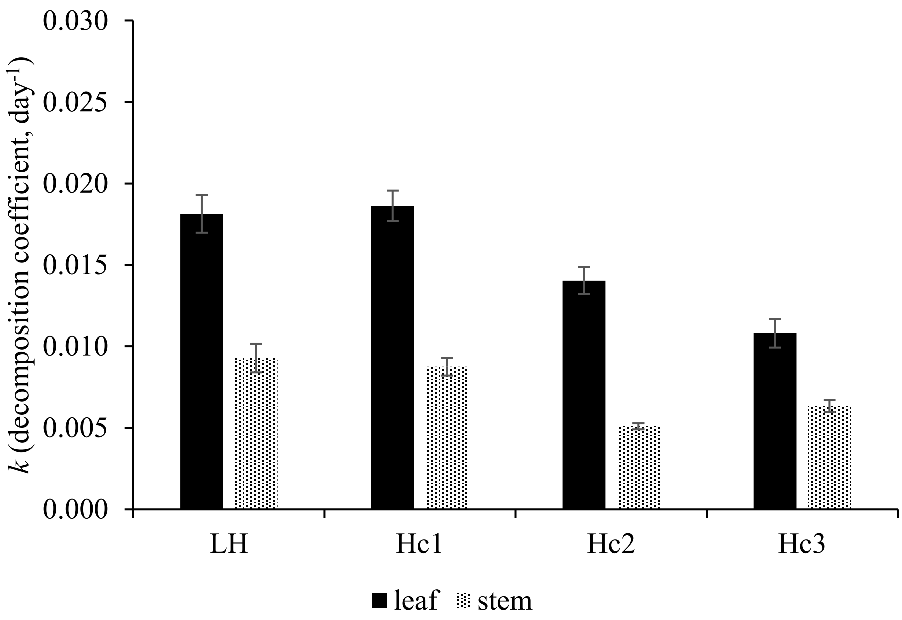

Figure 2. Decomposition coefficients (k) of goldenrod leaf and stem in Lake Hévíz and its canal (Hc1-3) (mean ± SD).

Table 3. Tests of within-subjects effects of goldenrod stem mass loss (g) in Lake Hévíz and through Hévíz canal.

Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2
Place	3.075	1.013	3.036	74.3	0.013	0.974
Error (Place)	0.083	2.026	0.041	-	-	-
Time	69.646	1.025	67.954	983.9	0.001	0.998
Error (Time)	0.142	2.05	0.069	-	-	-
Place X Time	2.754	1.039	2.65	13	0.065	0.867
Error (Place X Time)	0.423	2.078	0.203	-	-	-

Similarly, there were significant main effects of place ($p = 0.000$) and of passage time ($p = 0.000$) on leaf (Table 3).

The results also revealed that there was a significant interaction between place and time ($p = 0.000$) in case of the leaf mass decay (Table 4).

Table 4. Tests of within-subjects effects of leaf mass decay (g) in Lake Hévíz and through Hévíz canal.

Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2
Place	26.464	1.081	24.485	71,003.5	0	1
Error (Place)	0.001	2.162	0	-	-	-
Time	187.715	1.787	105.017	57,642.1	0	1
Error (Time)	0.007	3.575	0.002	-	-	-
Place X Time	15.133	1.799	8.41	2463.5	0	0.999
Error (Place X Time)	0.012	3.599	0.003	-	-	-

The statistical investigation showed that the decomposition rate of stem did not depend significantly on time and place interaction. The probable explanation is that the stem with higher lignin content requires more time for breakdown, and the decomposition rate is less determined by temperature (also by place). The dense nature, hydrophobicity, and nonspecific structure of lignin make it difficult for enzymes to attack [18].

4. Discussion

Previous works demonstrated that T_w modulates litter decomposition by driving activity of decomposers [19–22]. Many other authors investigated synergistic influences with T_ws and dissolved nutrients [23–25]. As there was minimal difference in flow velocity between sampling sites (data not shown), we assumed that the variation in their decomposition rate might be the changed T_w.

In accordance with the results of this study, Geraldes et al. [22] found faster leaf decomposition under increased T_w (from 16 to 24 °C) in alder (*Alnus glutinosa*) using a microcosmos experiment. The used temperature range of Geraldes et al. [22] was close to the applied T_ws of this study. Temperature determines organism activity, with increased temperatures stimulating biological processes at least within physiological limits [22,26]. Faster decomposition of the goldenrod leaf litter was probably due to low lignin and polyphenolics and high nutrient concentrations compared to the stem, that might be preferred by microorganisms and invertebrates [27]. In addition to the internal properties of the decomposition, the T_w is also an important factor, with higher temperatures stimulating biological activities [22,26]. Although the higher decomposition dynamics measured in Hc1 as compared to warmer LH was probably due to more intense litter drift in Hc1 [16].

The quality of water should be impaired by processes within the catchment area. The effect of small canals on lake health could be clarified by assessing litter decomposition due to water quality that may be limited [28]. Pressures exerted by a diversity of human activities (application of fertilizers, pesticides, removal of vegetation, ploughing, soil surface sealing) are transmitted, and their effects can potentially accumulate in the water bodies. On the other hand, vegetation cover can modify these processes, adding to or alleviating the pressures [29]. The study of the decomposition of goldenrod on the embankment of Hc and LH is of primary importance as it may impact the water quality of Lake Balaton as well. Migliorini and Romero [30] projected that future temperature rise might accelerate decomposition rates in aquatic systems by stimulating the leaf litter decomposition. This study can be one such example.

5. Conclusions

Temperature is an important factor in litter decomposition and biological processes. Future climate change scenarios predict that rising temperature, mainly in winter, will modify the nutrient cycle, including decomposition processes. In the winter period, we carried out a three-month investigation to examine the decomposition rate of the stem and leaf material of the widespread goldenrod. Except for LH, covered by water lily species, the dominant vegetation of the remaining three sampling points is close to each other; the common surrounding area is herbaceous vegetation, with dominant goldenrod.

In LH and Hc, we selected three sampling sites with different mean T_w ranging from 24.0 to 13.7 °C with the hottest T_w in the lake. On account of the distance from the LH, the T_w of the canal continuously decreased. The T_w gradient was −0.32 °C/100 m on the site of the study. Such an experiment has not been previously conducted at these sampling sites; thus, it can be considered a new, innovative investigation. Furthermore, in contrast to previous studies, the sampling sites were selected in thermal water, which is connected to non-thermal water, thus it can contribute to a more complete and in-depth understanding of the background load of the Keszthely Bay.

The study site was a natural "microcosm", in which litter decomposition rate increased, as the main driver of the process, the T_w rose, regardless of the similarity in water quality parameters and the absence of difference in invertebrates' colonization. The highest decay rate could be observed at the sampling site, which was nearest to LH. Due to possible impacts of climate changes, any modification in decomposition processes will affect the strictly protected Balaton's water quality. Results in this study could help in preparing mitigation of these future challenges.

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