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Ecological study of caddis larvae (Insecta: Trichoptera) in the brook system of the city of Salzburg

Robert STURM

A b s t r a c t : The present contribution investigates the distribution of the larvae of three caddisfly species (*Silo pallipes*, *Allogamus auricollis*, *Hydropsyche pellucidula*) in the brook system of the city of Salzburg. Further, the dependence of species occurrence on diverse physical and chemical factors is subjected to a detailed analysis. In order to obtain significant results, 50 locations were sampled for the animals and analyzed with regard to eight environmental factors (water temperature, pH, electric conductivity, water hardness, oxygen content, BOD_5, nitrogen content, current velocity). Ecological demands of single caddisfly species were modelled by application of the logistic regression method, where presence/absence data are plotted against single physical and chemical factors. With the help of the computer-generated regression curves ecological preferences as well as tolerance intervals of the animals could be predicted. According to the results received from the study, the three species exhibit rather similar demands on their aquatic habitats and may be regarded as generalists with regard to most analyzed physical and chemical factors. Lowest tolerance was predicted for high contents of nitrogen in the water and enhanced BOD_5, underlining the possible use of the species as bioindicators for water quality management.

K e y w o r d s : Caddisfly, brook system, distribution, logistic regression, city of Salzburg.

Introduction

In general, the aquatic larvae of caddisflies (Trichoptera) represent an essential component of the macrozoobenthos usually occurring in many flowing waters of Central Europe (MALICKY 1980, TOBIAS&TOBIAS 1981, SCHWOERBEL 1994, BAUR 1997, STURM 2009, 2010, 2013a). With regard to their abundance and species diversity they rank on the same level as the larvae of dipterans or fall only slightly back behind them in brooks and similar small water bodies (SCHWOERBEL 1994, STURM 2009). The number of caddisfly species commonly varies between 10 in poorly structured rivers of the lowlands and 50 in mountain brooks, but may amount to much more than 100 in sporadic riverine biotopes (PITSCH 1983, 1993). According to the present knowledge, due to their highly particular ecology numerous species are restricted to flowing waters in general or single sectors of brooks and rivers offering them respective living conditions (MALICKY 1980). Correspondingly, species being preferably specialized on springs and spring brooks (crenal) may be distinguished from those, which preferentially occur in brooks (rhithral) or rivers (potamal) (WICHARD 1988, KLAUSNITZER 1997, MEY 2000).

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In the past, the ecological value of caddis larvae was additionally expressed by their use as indicators for the biological measurement of water quality (e.g., SCHWOERBEL 1994, BAUR 1997, STURM 2009). Within the scope of these investigations, a preference of aquatic habitats with good or very good water quality (class I-II) could be determined for most species. There were also few Trichoptera, which exhibited increased tolerance for water pollution (class III-IV), and this circumstance finally resulted in their massive reproduction due to the absence of competing species (PITSCH 1993). Currently, the biological assessment of water quality again represents a target of increased criticism, because the high complexity of this analysis tool is successively brought to light by many new studies. Nevertheless, caddisflies exhibit a certain reliability with regard to bioindication, so that a complete rejection of the ecological method does not seem to be purposeful.

Fig. 1: Map of the city of Salzburg with its urban brook system. Sample points analyzed in this study are marked by black circles.

The main objective of the present contribution consists in the significant enlargement of or knowledge concerning the auto-ecology of three caddisfly species (*Silo pallipes*, *Allogamus auricollis*, *Hydropsyche pellucidula*). For fulfilling this ambitious aim 50 locations situated along the main flowing waters of the city of Salzburg (Fig. 1) were tested for the influence of several environmental factors on the presence or absence of the Trichoptera. The study generally holds the hypothesis that caddisfly species occur-

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ring in specific sectors of a water body are partly characterized by restricted ecological differentiation, whereas their ecological demands on the habitats may differ remarkably from those raised by other representatives of the macrozoobenthos.

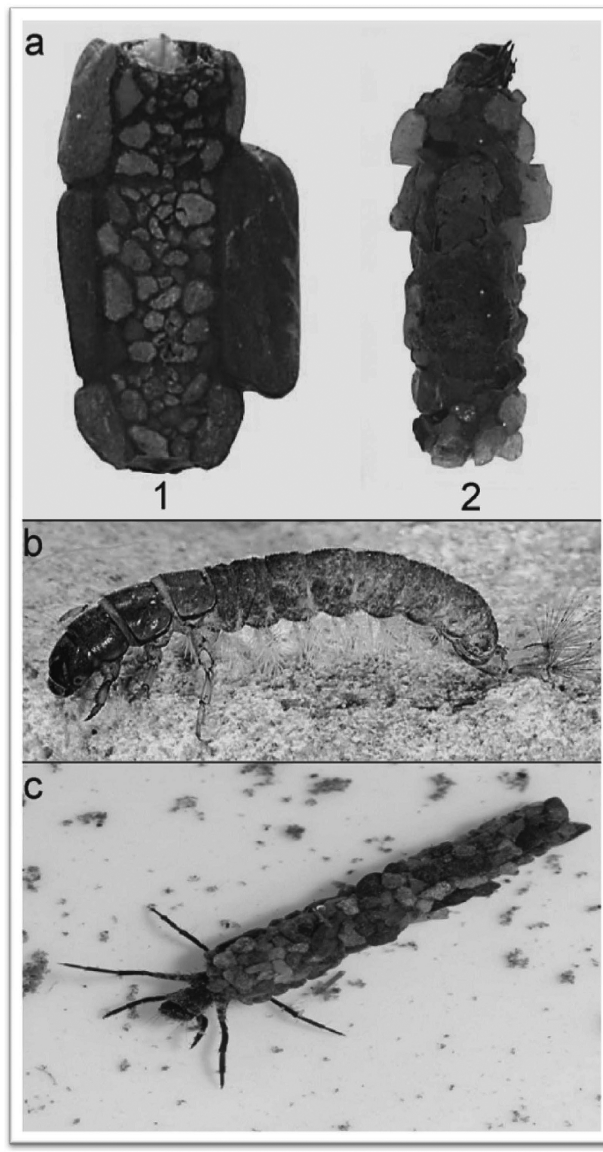

Fig. 2: Larvae of caddisfly species investigated in the present contribution: (**a**)*Silo pallipes* (1: view from above, 2: side view), (**b**) *Hydropsyche pellucidula*, (**c**)*Allogamus auricollis* (STURM 2013a).

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Materials and Methods

Brief characterization of the studied caddis larvae

Larvae of the caddisfly species *Silo pallipes* (FABRICIUS, 1781; Goëridae) are distinguished by their characteristic case consisting of fine central and coarser lateral sediment components (Fig. 2a). Detailed information on the ecology of this organism was among other outlined by KANTER (1966) and BOTOSANEANU & MALICKY (1978). Larval representatives of *Hydropsyche pellucidula* (CURTIS, 1834; Hydropsychidae) are among other marked by their renunciation of a case and their yellowish coloring with bright spots. Ecological specificities of this Trichoptera may be drawn from the studies of BENZ (1986) or MALICKY (1986). The third caddisfly species included in the investigation is *Allogamus auricollis* (PICTET, 1834; Limnephilidae), whose larval case is commonly characterized by its composition of nearly equally sized sediment particles. Prevailing ecological findings with regard to this insect have been among other summarized by KIAUTA & KIAUTA (1979) as well as WALLACE et al. (1990).

Sampling of the caddisflies and water analysis

At each sample point marked in Fig. 1, the sediment was investigated for the three caddisfly species by using a large sieve (mesh distance: 0.4 mm) for the separation of sediment particles and animals. Additionally, larger stones were visually inspected for the insect larvae, and, in the case of a find, the Trichoptera were removed from the stony surface by using feather tweezers. All sampled larvae were subjected to a taxonomic determination on the spot and were afterwards released into the water. For documentary purposes, some representatives were fixed in formalin and stored in the laboratory for further investigations (STURM 2003, 2004, 2007, 2009, 2012, 2013b).

Analysis of the sample points also included the measurement of essential physical and chemical water parameters. Besides water temperature (°C), pH, electric conductivity (µS/cm), and content of oxygen (mg/L), also aquatic nitrogen concentration (mg/L), biological oxygen demand after five days (BOD_5; mg/L), total water hardness (°dH) and current velocity were determined (STURM 2009). Temperature and diverse concentration factors were analyzed on the spot by application of electronic measuring instruments. For determination of the BOD_5 a water sample was taken, analyzed for its O_2 content, stored in a dark box for five days, and finally analyzed again for its oxygen concentration (STURM 2012, 2016). Current velocity of the brooks was estimated by observation of the distance mastered by floating leaves and wooden pieces within a given time period.

Modeling ecological demands of single caddisfly species

For studying possible effects of the environmental factors noted above on the occurrence of the three caddis larvae logistic regression analysis formerly developed by TER BRAAK & LOOMAN(1986) was applied. This rather simple method was used in numerous ecological investigations (e.g., HOSMER & LEMESHOW 1989, HASTIE & TIBSHIRANII 1990, PEETERS & GARDENIERS 1998, HEEGAARD 2002, STURM 2005, 2006, 2013b) and turned out to be a reliable tool for the solution of specific scientific problems. In general, logistic regression enables the analysis of the relationship between a binary response variable and one or more independent parameters. In the case of the so-called

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'presence/absence curve' introduced by TER BRAAK & LOOMAN (1986), the probability of a species occurring at a given sample point, $p(x)$, is expressed as function of an environmental parameter x as follows:

$$p(x) = \exp(\beta_0 + \beta_1 x + \beta_2 x^2)/[1 + \exp(\beta_0 + \beta_1 x + \beta_2 x^2)]. \quad (1)$$

In the equation noted above, β_0, β_1, and β_2 denote the regression coefficients with β_0 as constant term. If β_2 assumes a non-zero value, the function generates a symmetrical and bell-shaped curve ('Gaussian logit curve'). In the case of β_2 assuming the zero value, $p(x)$ performs a sigmoid increase or decrease. The species-associated optimum range of an environmental parameter may be expressed by the two factors u and t (JONGMAN et al. 1987), with

$$u = \beta_1/(-2\beta_2)^{0.5} \quad (2)$$

and

$$t = 1/(-2\beta_2)^{0.5}. \quad (3)$$

Whilst the factor u marks the position of the maximum of the probability curve (p_{max}), the factor t may be interpreted as a measure of tolerance and describes the range of the independent parameter between the turning points of the function with $p(x)'' = 0$. Within this interval the quotient $p(x)/p_{max}$ is usually characterized by values $\geqq 0.75$ (PEETERS & GARDENIERS 1998). Statistical significance (R^2) of the regression coefficients β_1 and β_2 was tested with the help of a likelihood ratio test (HOSMER & LEMESHOW 1989, TREXLER & TRAVIS 1993), where the predictive power between regular regression model and related null model (β_1 and $\beta_2 = 0$) is subject to a comparison. Parameters are excluded, if no discrepancies are available.

Results

Physical and chemical parameters measured at the sample locations

Results of environmental parameter analysis are summarized in Tab. 1. Therefore, mean temperature computed for all 50 sample points amounts to 9.39 $\pm$ 1.62°C and indicates rather low temperatures in the urban brooks. The pH value measured at the locations ranges from 6.20 to 7.80 with a mean of 6.86 $\pm$ 0.63. These values evidently exhibit pH neutrality in the observed water bodies. Electric conductivity assumes a mean value of 324.18 $\pm$ 48.32 µS/cm. This rather high value may be associated with limestone-dominated geology of the city and the partly exhaustive supply of spring waters with Ca^{2+} and Mg^{2+} ions. The content of oxygen in the water amounts to 11.52 $\pm$ 0.67 mg/L, whereas that of nitrogen may be numbered with 2.43 $\pm$ 2.19 mg/L. Based upon the latter value, the mean BOD_5 was estimated with 2.87 $\pm$ 2.33 mg/L and showed rather high fluctuations among the flowing waters included in the study. Total hardness was determined with 11.44 $\pm$ 3.32°dH and stood in good correspondence with the values of electric conductivity noted above. Current velocity measured in the flowing waters adopted an average value of 1.24 $\pm$ 0.37 m/s and thus presented as quite low.

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Tab. 1: Statistical analysis of the physical and chemical parameters measured at the sample sites (Abbreviations: EC = electric conductivity, BOD_5 = biological oxygen demand after five days, TH = total hardness, CV = current velocity).

	T (°C)	pH	EC (µS/cm)	O_2(mg/L)	N_2(mg/L)	BOD_5(mg/L)	TH (°dH)	CV (m/s)
MEAN	9.39	6.86	324.18	11.52	2.43	2.87	11.44	1.24
SD	1.62	0.63	48.32	0.67	2.19	2.33	3.32	0.37
MIN	6.90	6.20	250.00	10.40	1.20	0.80	7.80	0.76
MAX	13.60	7.80	375.00	13.40	8.20	9.50	14.20	1.62
RANGE	6.70	1.60	125.00	3.00	7.00	8.70	6.40	0.86

Ecology of the caddis larvae

Results of the ecological modeling procedure described above can be drawn from Tab. 2. However, it has to be mentioned before that ecological demands of the caddisfly species included in this study are characterized by partly negligible discrepancies. Regarding water temperature highest probability of occurrence may be diagnosed at values of 9.10°C in the case of *Silo pallipes*, 9.02°C in the case of *Hydropsache pellucidula*, and 9.25°C in the case of *Allogamus auricollis*. Tolerance with $p(x)/p_{max}$ adopting values ≧ 0.75 is rather similar among the species and therefore ranges from 1.90 to 2.10°C. Highest individual occurrence takes place at pH values of 6.93, 6.98, and 6.90, and also here tolerance intervals only exhibit negligible differences between the species. A nearly identical diagnosis can be made for electric conductivity (u: 284.60 - 298.50 µS/cm, t: 44.50 - 50.40 µS/cm) and total hardness (u: 11.37 - 11.98 mg/L, t: 2.98 - 3.40°dH) standing in a chemically close relationship with this environmental factor.

Tab. 2: Results of logistic regression analysis summarizing all those parameters, which are essential for the ecological categorization of the larvae of single caddisfly species.

Silo pallipes	T (°C)	pH	EC (µS/cm)	O_2(mg/L)	N_2(mg/L)	BOD_5(mg/L)	TH (°dH)	CV (m/s)
p(max)	0.56	0.64	0.43	0.64	0.63	0.65	0.44	0.23
u	9.10	6.93	284.60	11.65	2.49	3.14	11.37	1.43
t	2.10	0.84	46.20	1.78	0.54	0.80	2.89	0.76
R^2	12.60	8.60	13.60	8.90	12.13	8.50	13.20	11.52
Hydropsyche pellucidula	**T (°C)**	**pH**	**EC (µS/cm)**	**O_2(mg/L)**	**N_2(mg/L)**	**BOD_5(mg/L)**	**TH (°dH)**	**CV (m/s)**
p(max)	0.48	0.65	0.45	0.62	0.67	0.63	0.41	0.28
u	9.02	6.98	292.80	11.87	2.48	3.04	11.65	1.23
t	1.92	0.76	44.50	1.97	0.65	0.68	2.91	0.36
R^2	15.10	9.10	16.70	12.10	13.89	9.50	11.87	13.52

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Allogamus auricollis	T (°C)	pH	EC (µS/cm)	O_2(mg/L)	N_2(mg/L)	BOD_5(mg/L)	TH (°dH)	CV (m/s)
p(max)	0.53	0.58	0.38	0.57	0.61	0.56	0.36	0.30
u	9.25	6.90	298.50	11.28	2.59	3.08	11.98	1.34
t	1.90	0.84	50.40	2.67	0.78	0.87	3.40	0.58
R^2	8.60	8.23	12.90	10.32	16.20	7.09	15.20	10.52

With regard to the oxygen content, nitrogen concentration, and BOD_5 differences between the investigated species become more obvious. Therefore, *Silo pallipes* exhibits highest probability of occurrence at theoretical values of 11.65 mg/L, 2.49 mg/L, and 3.14 mg/L, respectively, with associated tolerance intervals ranging from 0.54 to 1.78 mg/L. In the case of *Hydropsyche pellucidula* the parameter u indicating the position of p_{max} assumes values of 11.87 mg/L, 2.48 mg/L, and 3.04 mg/L, respectively. Here, tolerance for the concentration values ranges from 0.65 to 1.97 mg/L. The ultimately studied species *Allogamus auricollis* is distinguished by values for p_{max}, which can be numbered with 11.28 mg/L, 2.59 mg/L, and 3.08 mg/L, respectively. Associated tolerance intervals range from 0.78 to 2.67 mg/L. In the case of current velocity, the demands of the single species claimed for their aquatic habitats are also subject by larger discrepancies. Concretely speaking, probability of highest occurrence appears at values of 1.43 m/s, 1.23 m/s, and 1.34 m/s, respectively. Associated tolerance with regard to this physical parameter ranges from 0.36 to 0.76 m/s.

Discussion

The ecological value of caddisflies and particularly their aquatic larvae is founded on the circumstance that these organisms partly represent reliable indicators with regard to the estimation of water quality in diverse habitats (PITSCH 1993, BAUR 1997, STURM 2009, 2013a). This specificity, however, is mostly underlined by the results presented in this contribution. The application of innovative mathematical techniques additionally allows the making of advanced statements concerning the potential of species distribution (PITSCH 1983, 1993, WICHARD 1988, KLAUSNITZER 1997). In association with this fundamental problem, two essential questions have to be posed: (1) Does a given species possess the ability of being distributed over wide distances? (2) Has the species the ability to become sessile in a newly colonized habitat. As demonstrated in the studies of STURM(2009, 2013), all three caddis larvae considered here are largely in the possession of both abilities, which gives them a certain role of pioneer organisms in running waters of the alpine foreland.

As proposed by the results of this study, larvae of *Silo pallipes* are characterized by maximum probabilities of occurrence, if the environmental factors measured at a specific sample site fairly correspond with the mean values determined for all locations (Tab. 1, 2). An interesting result concerns the low tolerance of the species for higher deviations from these mean values. According to this investigation and previous studies (STURM 2009, 2013a), *Silo pallipes* may be classified as organism with significant local nature in

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ecological respects. An exception of this observation is given for the current velocity, where single larvae also tolerate values differing remarkably from the mean. These characteristics, however, predestinate the species to colonize upper reaches of brooks with constant water quality. In the case of *Hydropsyche pellucidula* similar observations as those stated for *Silo pallipes* can be made, which means that larvae of this species are marked by rather low tolerance regarding noticeable fluctuations of environmental factors. Contrary to the first species *Hydropsyche* may not be found in waters with high current velocity, but, on the other hand, seems to prefer habitats with increased water depth (STURM 2009, 2013). Therefore, also this species disposes of a valuable local nature, which enhances its value as bioindicator (PITSCH 1993). Based upon the results summarized in Fig. 3 and Tab. 2, aquatic larvae of *Allogamus auricollis* seem to show a slightly higher tolerance for most environmental factors than the other two species, due to which this caddisfly bears the highest potential to act in a more generalistic fashion and colonize a wider spectrum of habitats. This diagnosis corresponds rather well with ecological findings stated in previous publications (WALLACE et al. 1990, PITSCH 1993, STURM 2013a).

The present study yielded evidence that mathematical modelling may represent an appropriate tool for the determination of specific ecological demands made by a given organism. The technique may be also used for the identification of pioneer species disposing of the potential for colonizing ecological niches. Despite of the valuable results presented here it has to be concluded that the accuracy of a statement highly depends on the amount of collected data, so that many further studies will be necessary to obtain a complete picture of caddis larvae ecology.

Zusammenfassung

Ökologische Studie von Köcherfliegenlarven (Insecta: Trichoptera) im Bachsystem der Stadt Salzburg.Der vorliegende Beitrag untersucht die Verbreitung der Larven von drei Köcherfliegenarten (*Silo pallipes*, *Allogamus auricollis*, *Hydropsyche pellucidula*) im Bachsystem der Stadt Salzburg. Zudem wird die Abhängigkeit des Auftretens einzelner Spezies von diversen physikalischen und chemischen Faktoren einer detaillierten Analyse unterzogen. Um aussagekräftige Ergebnisse zu erhalten, wurden 50 Örtlichkeiten in Bezug auf das Vorhandensein der Tiere beprobt und hinsichtlich acht verschiedener Umweltfaktoren (Wassertemperatur, pH, elektrische Leitfähigkeit, Wasserhärte, Sauerstoffgehalt, BSB_5, Stickstoffgehalt, Fließgeschwindigkeit) analysiert. Ökologische Ansprüche der einzelnen Köcherfliegenarten wurden unter Anwendung der logistischen Regressionsmethode modelliert, bei welcher Präsenz-/Absenzdaten gegen jeweilige physikalische und chemische Faktoren grafisch aufgetragen werden. Mithilfe der computergenerierten Regressionskurven konnten ökologische Präferenzen sowie entsprechende Toleranzbereiche der Tiere vorhergesagt werden. Gemäß den aus der Studie erhaltenen Resultaten zeigen die drei Arten recht ähnliche Ansprüche an ihre aquatischen Habitate und können insgesamt als Generalisten in Bezug auf die meisten physikalischen unf chemischen Faktoren betrachtet werden. Die niedrigste Toleranz konnte gegenüber hohen Gehalten an Stickstoff im Wasser und erhöhten BSB_5-Werten prädiziert werden, was die mögliche Verwendung der Arten als Bioindikatoren für das Gewässergütemanagement unterstreicht.

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