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Biomass determination of aquatic invertebrates in the Northern German lowland using the relationship between body length and dry mass

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Zusammenfassung

Biomassebestimmung aquatischer Wirbelloser des norddeutschen Tieflandes durch Relationen zwischen Körperlängen-Parametern und Trockengewichten

Die Biomasse aquatischer Wirbelloser stellt einen wichtigen Parameter für das Verständnis von Entwicklungszyklen, saisonalen Verläufen, Sekundärproduktion und biologischen Wechselwirkungen einschließlich den trophischen Verhältnissen zwischen funktionalen Ernährungstypen und trophischen Nährstoff- oder Energiebudgets von Nahrungsnetzen und ihren Kompartimenten dar.

Für die Berechnung der Biomasse (DM) von Wirbellosen werden im folgenden Ergebnisse der Trockengewichtsbestimmung als Abhängigkeit des Individualgewichtes von Körperlängen-Parametern wie Kopfkapselbreite (HW) oder Körperlänge (BL) aufgezeigt. Für einzelne Arten wurden andere Parameter gemessen, wie z.B. die Strecke vom Vorderbis Hinterrand der letzten halben Schalenwindung (WL), die Pleotelson-Länge (PL) oder die Länge des ersten Thorakalsegmentes (TL). Die Beschreibung des Verhältnisses zwischen der Länge und der Trockenmasse erfolgt mittels der Funktion $DM = a * L^b$. Aufgezeigt wird dieses Verhältnis für 31 Taxa aquatischer Makroinvertebraten und – ermittelt aus den Einzelerhebungen – für einzelne taxonomische Ordnungen, um eine Abschätzung der Größenordnung ihrer Biomasse zu ermöglichen. Die in der vorliegenden Studie aufgezeigten Gleichungen sind anwendbar für Arten aus karbonatreichen Fließgewässern des zentralen europäischen Tieflandes.

Introduction

Biomass of aquatic invertebrates is an important parameter for the understanding of life histories, seasonal patterns, secondary production, and biological interactions including trophic relationships between functional feeding groups and trophic nutrient or energy budgets of food webs and their compartments. Therefore, various methods of direct and indirect biomass determination were proposed in the literature (DERMOTT & PATERSON 1974, MCCAULEY 1984, MEYER 1989, SCHWEDER 1985, SCHWOERBEL 1986, SMOCK 1980, STANFORD 1973). The direct determination of wet or dry mass of preserved specimens often produce inaccurate results, a change can be noticed in the preservative and in preservation time (HOWMILLER 1972, DERMOTT & PATERSON 1974, STANFORD 1973). This direct determination take up a great deal of time whereas the indirect method of using the biovolume often underestimates the mass of larger animals (BURGHERR & MEYER 1997). Fundamental relationships exist between linear body measurements and the biomass of organisms (SMOCK 1980) and have been used for terrestrial arthropods since the beginning of the 20th century (WENZEL et al. 1990). The method of length dry mass relationship is fast and more precise than the two previous ones (BURGHERR & MEYER 1997).

Only few equations developed to estimate dry mass from linear body length parameters are available for macrozoobenthos (comp. WENZEL et al. 1990). Equations are restricted to distinct stream types or geographic regions. SMOCK (1980) presents results for invertebrates of North America and TOWERS et al. (1994) of New Zealand. MEYER (1989) and WENZEL et al. (1990) developed equations for silicate and BURGHERR & MEYER (1997) for carbonate mountain stream of Central Europe. In this study length dry mass relationships are recorded for carbonate stream invertebrates of the Central European lowland, area 14 in the faunistic catalogue of IILLIES (1978).

Material and methods

Macroinvertebrates were collected at several sampling sites in the outlet of Lake Belau, situated 30 km south of Kiel at the outer margin of the Weichselian glaciation. These sites partially differ in the composition of the substrate, the presence of submerged macrophytes, and the vegetation (woody plants) at the banks. The stream flows through cultivated farmland and has very little of a buffer zone at its banks. After a distance of 1.9 km the stream flows into Lake Stolpe.

The discharge of 0.08 to 0.6 $m^3 s^{-1}$ is mainly regulated by a water-mill. Current velocity ranged from 0.05 to 0.6 m s^{-1}. The water level of the stream shows a variation of up to 0.4 m, the stream has a constant width of 6 m. Over the year the water temperature varied from -1.4 °C to 24.9 °C. The stream can be regarded as a temperate summerwarm stream (SCHWOERBEL 1987). The chemical characterization shows the stream to be calcareous and rich in nutrients (POEPPERL 1996, 1998). High amplitudes in conductivity, pH, N- and P-concentration are caused mainly by the biological activities of the plankton in the eutrophic Lake Belau. The conductivity varies between 279 and 425 μS_{25} cm^{-1}, pH between 7.0 and 9.1. The concentrations of the different N- and P-fractions show the intensive agricultural activities in the catchment-area of the stream. The oxygen content varies between 5.1 and 14.3 mg l^{-1} corresponding to 51 and 162% saturation. During the summer the saturation shows considerably high daily amplitudes with over-saturation in the early afternoon.

Samples were taken with a box sampler with a square area of 500 cm^2 (POEPPERL 1992) mainly from October 1988 to March 1990. The substrate and the organisms were extracted using a hand net. Additionally, quantitative samples were taken of larger organisms that were unable to escape. The macroinvertebrate colonization of the lake outlet was studied by collecting benthic animals at stream sections which are characteristic of the course of the stream. These sections partially differ in the composition of the substrate, the presence of submerged macrophytes and the vegetation (woody plants) at the banks. So, the samples represented the macroinvertebrates in different stream sections and their population dynamics over the year.

After the transport to the laboratory the samples were stored in a temperature-controlled and aerated aquarium. All macroinvertebrates were sorted out from the samples within 2 – 4 days. To facilitate this process the samples were carefully separated into different size classes by sieving. A minimal mesh size of 0.5 mm was chosen (comp. BARBER & KEVERN 1974).

For the development of a length-mass relationship the length of the whole body or certain parts of it were measured for the most frequent species. In many taxa the head capsule width was chosen because the head of many species is heavily sclerotized and helps characterize larval instar better than body length (DUMONT & BALVAY 1979, comp. BURGHERR & MEYER 1997). Head capsule width (HW) always was measured across the widest part of the head. Body length (BL) was measured as the distance between the anterior of the head to the posterior of the last abdominal segment. In addition, for a few species other linear body dimensions were used: In *Theodoxus fluviatilis* L. the distance between the anterior and posterior margin of the last half whorl of the shell (WL) was measured, in *Asellus aquaticus* L. the length of the pleotelson (PL), and in *Gammarus pulex* L. the length of the first thoracic segment (TL). Whereas large individuals (i.e. *Dreissena polymorpha*) were measured directly, the size parameters of smaller species were determined under a binocular microscope (Fa. Leitz) with an ocular micrometer allowing a measurement of 0.05 mm.

After the determination of linear body dimension the individuals were transferred into preweighed aluminium dishes (between 3 and 13 dishes for each species). The animals were dried at 60 °C for at least 48 h. After cooling in a desiccator the dry mass (DM) was measured to the nearest 0.01 mg with a Satorius R 160P scales. The low temperature and the long drying time was preferred after several preliminary experiments to avoid a loss of biomass by volatization of organic compounds which may occur at higher temperatures (DOWNING & RIGLER 1984).

Results

Overall 126 macroinvertebrate taxa were identified in the outlet of Lake Belau (POEPPERL 1992, POEPPERL & MARTIN 1995). Many animals could be identified to the species level or the size class of the species. When the determination of the macroinvertebrate species was not possible (e.g. larvae of Diptera), a higher taxonomic level was used.

For 31 of the most frequent species the relationship between the length of the whole body or certain parts of it (in most cases head capsule width) and the mass was established. This relationship can be described by the general power equation

$$DM = a * L^b$$

where a, b = regressions constants
DM = dry matter
L = length parameter (HW, BL, WL, PL, TL).

The determination of a and b took place after the transformation of the mean length and the mean dry mass of each size class by the common logarithm followed by a linear regression:

$$\log_{10}(DM) = \log_{10} a + b * \log_{10}(L).$$

Values of a and b are presented in Table 1 obtained by regression of dry mass on body length for 31 species of aquatic invertebrates of a northern German lowland stream. High correlation coefficients (near 1) calculated for most of the species, indicate that the number of mass determinations produce sufficiently precise results.

Tab. 1: Parameter estimation of the regression $\log (DM) = \log a + b * \log (L)$, valid for the relationship between head capsule width HW or body length BL (independent variables, in mm), respectively, and dry mass DM (dependent variable, in mg) of various taxa of macroinvertebrates. WL = distance between the anterior and posterior margin of the last half whorl of the shell, PL = length of pleotelson, TL = length of the first thoracic segment. SE = standard error of the estimate, r^2 = coefficient of determination, obs. = number of dry mass determinations, range = range of values of the independent variables, n = number of individuals.

	conversion	a [mg]	log a ± SE	b ± SE	r^2	obs.	range	n
Ephemeroptera								
Baetis sp.	HW→DM	0.6302	-0.2005 ± 0.0728	3.0098 ± 0.1994	0.9870	5	0.25-0.75	18
Caenis sp.	HW→DM	0.3256	-0.4873 ± 0.0397	2.8496 ± 0.0753	0.9958	8	0.25-0.95	338
Centroptilum luteolum Müll.	HW→DM	0.3727	-0.4286 ± 0.0564	1.7023 ± 0.1720	0.9703	5	0.35-0.95	13
Ephemera danica Müll.	HW→DM	0.6445	-0.1908 ± 0.0481	3.3883 ± 0.0740	0.9962	10	0.50-2.30	222
Trichoptera								
Atripsodes sp.	HW→DM	4.1892	0.6221 ± 0.1169	4.0212 ± 0.4472	0.9642	5	0.35-0.75	80
Cyrnus trimaculatus Curtis	HW→DM	0.4157	-0.3812 ± 0.0587	3.2250 ± 0.1080	0.9922	9	0.35-1.25	116
Goera pilosa Fabr.	HW→DM	7.8205	0.8932 ± 0.1214	5.6484 ± 0.5561	0.9717	5	0.45-0.85	69
Hydropsyche angustipennis Curtis	HW→DM	0.7320	-0.1355 ± 0.0777	3.1032 ± 0.0997	0.9898	12	0.35-1.75	1,096
Hydropsyche pellucidula Curtis	HW→DM	0.8887	-0.0512 ± 0.0883	3.1084 ± 0.1438	0.9791	12	0.35-1.65	1,50
Lype phaeopa Stephens	HW→DM	0.5599	-0.2519 ± 0.0295	1.8162 ± 0.0687	0.9943	6	0.25-0.85	30
Molanna angustata Curtis	HW→DM	4.0924	0.6120 ± 0.3593	5.1315 ± 0.8976	0.9159	5	0.15-1.15	89
Mystacides sp.	HW→DM	3.7059	0.5689 ± 0.1920	3.5539 ± 0.7503	0.9182	4	0.15-0.65	60
Neureclipsis bimaculata L.	HW→DM	0.6312	-0.1998 ± 0.0482	2.8056 ± 0.0588	0.9952	13	0.25-1.45	2,264
Polycentropus flavomaculatus Pictet	HW→DM	0.3109	-0.5074 ± 0.0726	4.0763 ± 0.1561	0.9870	11	0.55-1.55	75
Silo nigricornis Pictet	HW→DM	3.2215	0.5081 ± 0.0943	3.2584 ± 0.2699	0.9798	5	0.25-0.95	122
Tinodes waeneri L.	HW→DM	0.6929	-0.1593 ± 0.0989	5.4712 ± 0.5274	0.9729	5	0.55-0.95	19
Megaloptera								
Sialis lutaria L.	HW→DM	0.5119	-0.2908 ± 0.0293	2.9758 ± 0.0968	0.9958	6	1.0- 2.8	65
Coleoptera								
Oulimnius tuberculatus Ph.Müll	BL→DM	0.0138	-1.8607 ± 0.0257	2.5548 ± 0.1178	0.9937	5	1.6- 3.6	99
Diptera								
Limoniidae	BL→DM	0.0039	-2.4070 ± 0.0400	2.4403 ± 0.1530	0.9883	5	6.0-16.0	22
Ceratopogonidae	BL→DM	0.0020	-2.7052 ± 0.0533	2.4387 ± 0.4715	0.9640	3	4.0- 7.0	19
Tabanidae	BL→DM	0.0001	-3.8656 ± 0.1257	4.2208 ± 0.6941	0.9737	3	5.0-15.0	19
Crustacea								
Asellus aquaticus L.	PL→DM	0.3792	-0.4211 ± 0.0522	2.4870 ± 0.0767	0.9943	8	0.45-2.55	1,641
Gammarus pulex L.	TL→DM	6.6646	0.8238 ± 0.0395	2.9642 ± 0.0832	0,9969	6	0.2- 1.2	58
Hirudinea								
Erpobdella octoculata L.	BL→DM	0.0058	-2.2356 ± 0.0845	2.2255 ± 0.1190	0.9776	10	2.0-32.0	42
Helobdella stagnalis L.	BL→DM	0.0294	-1.5310 ± 0.0223	1.7525 ± 0.1230	0.9951	3	4.0-10.0	31
Glossiphonia complanata L.	BL→DM	0.0198	-1.7040 ± 0.0474	2.2123 ± 0.1194	0.9885	6	4.0-16.0	30
Mollusca								
Theodoxus fluviatilis L.	WL→DM	0.0884	-1.0535 ± 0.0453	3.1247 ± 0.0551	0.9966	13	1.0- 7.5	211
Potamopyrgus antipodarum Gray	BL→DM	0.1526	-0.8166 ± 0.0411	2.3761 ± 0.0435	0.9967	12	0.6- 5.2	703
Sphaerium corneum L.	BL→DM	0.0288	-1.5407 ± 0.0773	3.4024 ± 0.0876	0.9941	11	1.0-12.0	1,071
Pisidium sp.	BL→DM	0.1066	-0.9722 ± 0.0224	2.9132 ± 0.0564	0.9985	6	1.0- 4.0	1,078
Dreissena polymorpha Pallas	BL→DM	0.2222	-0.6533 ± 0.1597	2.4683 ± 0.1261	0.9770	11	1.0-33.0	463

Tab. 2: Parameter estimation of the regression log (DM) = log a + b * log (L), valid for the relationship between head capsule width HW or body length BL (independent variables, in mm) and dry mass DM (dependent variable, in mg) of various taxonomic orders. All species of Ephemeroptera are Non-Heptageniidae. SE = standard error of the estimate, r^2 = coefficient of determination, n = number of individuals.

	conversion	log a ± SE	b ± SE	r^2	n
Ephemeroptera	HW→DM	-0.1999 ± 0.1240	3.1980 ± 0.1096	0.9816	591
Trichoptera	HW→DM	-0.1250 ± 0.3479	2.6979 ± 0.1762	0.7226	5,156
Hirudinea	BL→DM	-1.5979 ± 0.2599	1.8413 ± 0.2733	0.7276	93
Mollusca	BL→DM	-0.8459 ± 0.3765	2.1181 ± 0.1416	0.8483	3,315

Predictive equations for single taxonomic orders were calculated from pooled data for individuals in that particular order. The regression constants for dry mass versus a linear length parameter are given in Table 2 and the regression lines are illustrated in Figure 1.

Discussion

The predictive equations presented in this paper may be used for biomass determination of aquatic macroinvertebrates of the Central European lowland to facilitate the determination of benthic standing crop and secondary production.

The degree of chitinization of the exoskeleton is one of the factors which greatly influence body mass – thereby greatly increasing of the body mass of *Oulimnius tuberculatus* per given body length and hence explaining the steepness of the curve relative to the curves of other insect families (SMOCK 1980). At the other extreme, the Diptera have a very elongated, tubular, relatively smoothly surfaced body shape providing a low surface to length ration. This body shape and the relatively small amount of chitinized area on these larvae explain the observed small increase in mass versus body length. As in other studies b yielded values around 3.0 for insect orders (comp. SMOCK 1980).

To get an estimation of the orders magnitude of standing crop values SMOCK (1980) as well as the present study give predictive equations not only for single species but also for the order levels. But, as also shown by MEIER (1989), in many cases the equation at lower taxonomic levels explain a higher proportion of dry mass (or body length) variation than do those at order level. Therefore, predictive equations for the lowest possible taxonomic level should be used when a high precision is needed (comp. MEIER 1989, SMOCK 1980).

Predictive equations were developed to estimate dry mass from linear body length parameters for 31 taxa of stream invertebrates of the Northern German lowland. SMOCK (1980) also presents regression constants for North American aquatic insects derived from power equations. This was also done for most of the taxa presented by MEIER (1989) for Central European running water invertebrates. Only slight differences could be observed between the length-dry mass relationships of specimens or populations of different stream systems of the same stream type (SMOCK 1980, WENZEL et al. 1990). But comparing the same species for different stream types, the results become more differentiated and the length-dry mass relationships of both populations are not comparable (SCHRÖDER 1987). WENZEL et al. (1990) also conclude significantly different relationships between a species living in carbonate and silicate streams. Therefore, the results of the present study are valid to species from Central European lowland carbonate streams.

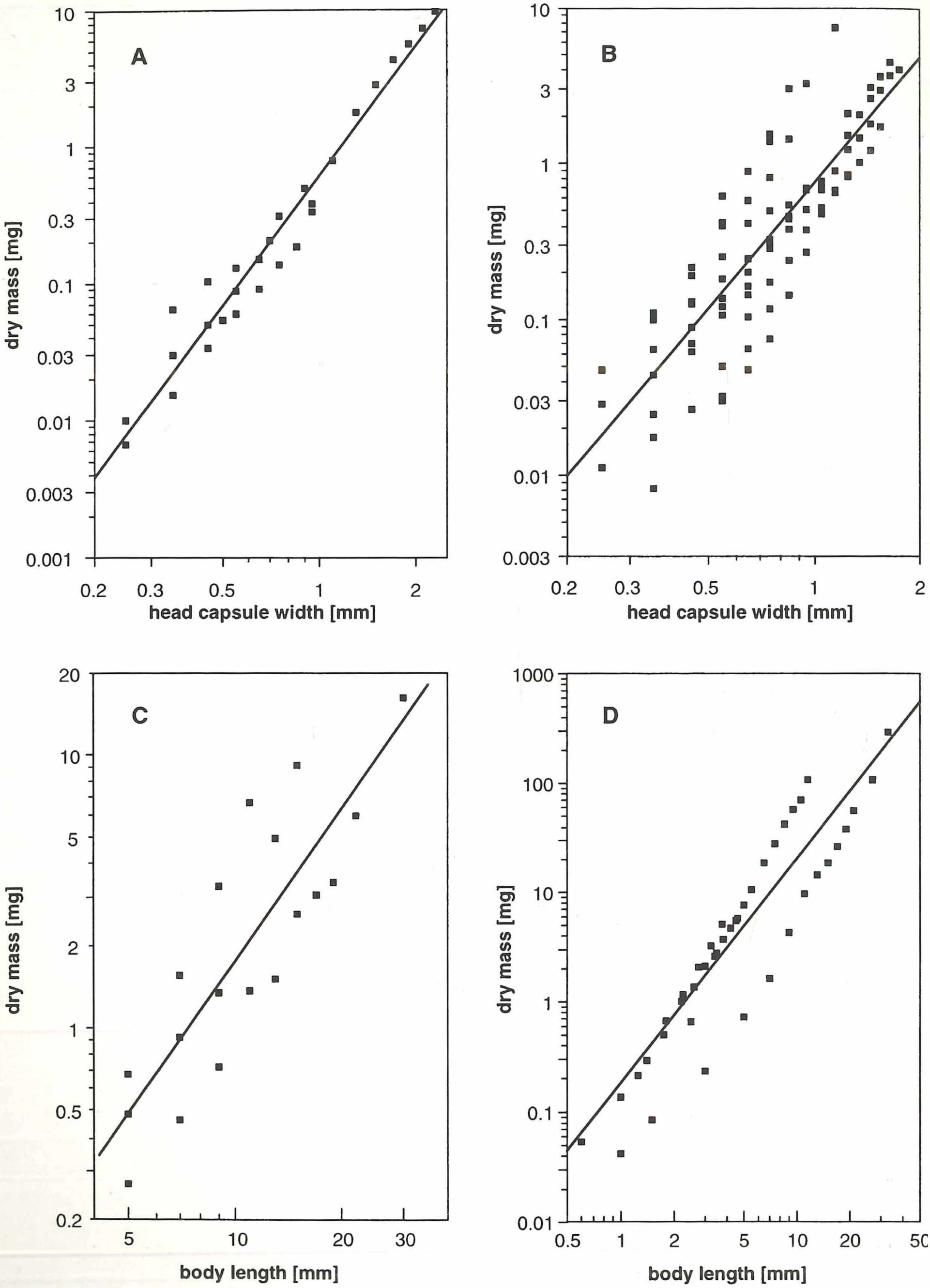

Fig. 1: Regression lines of dry mass versus body length parameters according to taxonomic orders. A: Ephemeroptera, B: Trichoptera, C: Hirudinea, and D: Mollusca.

Summary

Predictive equations were developed to estimate dry mass of macroinvertebrates from linear body length parameters like head capsule width (HW) or body length (BL). For a few species other linear body dimensions like the distance between the anterior and posterior margin of the last half whorl of the shell (WL), the length of the pleotelson (PL), or the length of the first thoracic segment (TL) were measured. For the description of the relationship between length and dry mass the power function $DM = a * L^b$ is used. These relationships were developed for thirty-one taxa of aquatic macroinvertebrates and for single taxonomic orders, calculated from pooled data to get an estimation of the orders magnitude of standing crop values. The equations presented in this study are valid for species from Central European lowland carbonate streams.

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