

## **Aquatic Insect Larvae as Indicators of Limiting Minimal Contents of Dissolved Oxygen - Part II**

by

Udo JACOB, Hendrik WALTHER and Reinhard KLENKE

U. JACOB, H. WALTHER & R. KLENKE: Aquatic Insect Larvae as Indicators of Limiting Minimal Contents of Dissolved Oxygen - Part II.  
Aquatic Insects 6 (1984), No. 3, pp. 185-190.

The oxygen tolerance of aquatic insect larvae with tracheal gills or comparable respiratory mechanisms can be used for bioindication of limiting minimal contents of dissolved oxygen. An analysis of the community permits the retrospective evaluation of critical values. Specific lethal oxygen concentrations and their temperature dependence are given for 22 species. Above a critical temperature,  $T_c$ , the specific  $LC_{50}$  increases exponentially.  $T_c$  is considerably lower with cold-adapted than with warm-adapted species. The values of oxygen tolerance determined demonstrate that restriction of a species to running water is not determined by oxygen level, temperature and water flow only.

U. JACOB, H. WALTHER & R. KLENKE, Section Biosciences of the Karl-Marx-University Leipzig, Department Taxonomy and Ecology; Correspondence: U. JACOB, Limnologische Flusstation der MPG, Postfach 260, D-6407 Schlitz, Federal Republic of Germany.

### INTRODUCTION

“Every aquatic organism can be considered as indicator. Its participation in a community shows that it gets on well there... Its absence in localities where it normally should occur makes it a negative indicator, especially in the cases of toxic or physical effects” (Sládeček, 1982; present authors’ translation). It is now well accepted that insect larvae with tracheal gills or other underwater respiratory mechanisms are, apart from other ecological factors, strongly dependent on the effective oxygen content of the water. Nevertheless, in most cases the tolerance to decreasing oxygen content has been only roughly estimated and classified into few categories (e.g., polyoxybiont, euryoxybiont). In a previous report (Jacob & Walther, 1981) a simple and reproducible method was described to determine the oxygen tolerance of aquatic organisms. Furthermore, it was stated that this

tolerance can be used for the bioindication of limiting minimal contents of dissolved oxygen. Of course, the estimation by means of bioindicators is not as accurate as physico-chemical methods (v. Tümpling, 1975) but it is favoured for its convenience. A single analysis of the community permits the retrospective evaluation of these critical values with sufficient accuracy.

Usually, euryptent organisms are not very useful bioindicators (Klausnitzer, Jacob & Richter, 1978; Bick, 1982), but for the bioindication of critical oxygen levels all aquatic organisms which are dependent on dissolved oxygen are equally suited (e.g., most fishes, crustaceans, all aquatic insect larvae with tracheal gills, and a variety of other invertebrates).

Fig. 1 gives a hypothetical representation of the effect of limiting oxygen

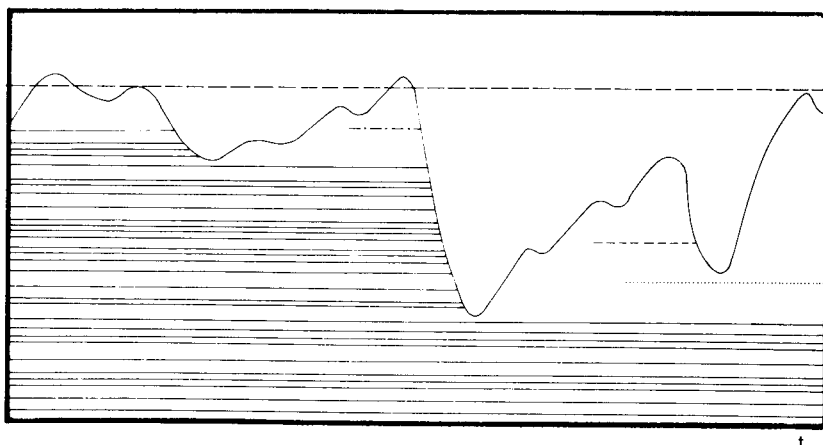


Fig. 1. Influence of varying actual oxygen content (curve) on the species composition of a hypothetical community of aquatic insects, compare text. Ordinate: oxygen content, from low values at bottom to 100% saturation (interrupted line at top) and over; abscissa: time axis. Horizontal lines indicate minimal oxygen demand of resident (continuous lines) and immigrant (interrupted and dotted lines) species.

contents on the corresponding part of the aquatic community depending on dissolved oxygen. In the figure, specific lethal concentrations (LC) of oxygen for several different indicator organisms are shown as horizontal lines. Oxygen levels were plotted over an extended time range (days, months, even years). Depending on minimal values attained, those species whose oxygen demand has not been fulfilled (full lines) would disappear. As time proceeds, this loss of species will successively be compensated by drift and active immigration (dotted and interrupted lines) of organisms, and their survival would then be determined by the oxygen levels that follow thereafter. In a sufficiently diverse biocoenosis where all specific oxygen tolerances are known, such immigrant species should initially be recognizable by their low abundances and the fact that their LC is higher than that of most other species, which have survived previous stress situations.

Except for *Ephemera vulgata* L. the oxygen tolerance values of all the taxa investigated so far exhibit a marked temperature dependence. Furthermore, Nagell & Fagerström (1978) found that a long term acclimatisation to low temperatures induces, in *Cloeon dipterum* (L.) (in marked contrast to *Nemoura cinerea* (Retzius)), a high degree of resistance to anoxia at temperatures close to 0°C. This hampers the use of this method, particularly in waters with marked changes of temperature. This limitation can partly be overcome by a reference system based on absolute, instead of relative, oxygen concentrations. Organisms whose oxygen tolerance is little dependent on temperature, at least within a given limited temperature range, are particularly suitable as indicators of levels of dissolved oxygen.

One has to discriminate between long and short term reactions to changes of natural or experimental conditions (Besch, 1983). So far, we have performed only short-time experiments (2...5 hours) with nearly grown nymphs adapted to spring, summer, or autumn water temperatures. Under natural conditions, similarly rapid depletions of oxygen may only occur in running waters because of, e.g., a surge of strong organic pollution, or also in warm eutrophic waters during darkness. The lethal concentrations determined under such conditions are certainly lower than oxygen levels that can be tolerated over long periods. During the experiments most of the species tried to escape at oxygen levels considerably above their specific lethal concentrations. With decreasing oxygen, displacement is achieved by alternating periods of active movement followed by drifting. This supports our assumption that in actual streams the oxygen level suggested by bioindication has in fact never fallen below this indicator level during the life span of the specimens found (up to several years; e.g., 2 years for *Ephemera* and several Aeshnidae, 3 years for *Palingenia* and several Gomphidae, even 5 years for *Cordulegaster*).

Available oxygen depends not only on the oxygen dissolved but also on the flow of water (Ambühl, 1959; Knight & Gaufin, 1962; Franke, 1977). Because the oxygen electrode used in our investigations gives correct readings only in flowing waters, the lenitic species were also studied under moderate flow. Also for this reason, the lethal concentrations determined will probably be lower than the actual tolerances. To prevent non-physiological damage during transport and in captivity, polyoxybiont species in particular were tested with a transportable test-set immediately after they had been collected.

It was not always possible to collect the number of specimens required for a statistical evaluation at the same time and at the same stage of development. That is why in some cases we had to perform our tests with fewer specimens, but thus obtained at least an indication of the range of the tolerance limits.

In Table 1 the LC<sub>50</sub> of different species is indicated in relation to temperature. As expected, above a critical temperature the specific LC<sub>50</sub> increases exponentially. This critical temperature is considerably lower with cold-adapted than with warm-adapted species, where the point at which exponential increase occurs was not reached in the temperature range investigated.

Besides the possible application of such investigations for bioindication, the data obtained can be discussed with respect to the normal habitat restrictions of

Table 1. Specific lethal oxygen concentrations ( $LC_{50}$ ) of various aquatic insects at different temperatures, compare text. n = number of specimen tested;  $x \pm LC_{50} \pm$  standard error; oxygen saturation in per cent.

	12°	15°	20°	25°	30°
<b>Ephemeroptera</b>					
<i>Baetis</i>					
<i>alpinus</i> (Pictet)	n = 10 x = 75,55 ± 5,02	n = 10 x = 82,5 ± 5,02	—	—	—
<i>Baetis</i>	—	—	n = 10 x = 42,7 ± 3,28	—	—
<i>niger</i> (L.)	—	—	—	—	—
<i>Baetis</i>	n = 10 x = 27,8 ± 3,28	—	—	—	—
<i>vernus</i> Curtis	—	—	—	—	—
<i>Cloeon</i>	—	n = 10 x = 11,15 ± 3,79	n = 24 x = 23,5 ± 3,74	n = 10 x = 32,05 ± 4,41	n = 10 x = 45,6 ± 5,68
<i>simile</i> Eaton	—	n = 10	n = 10	n = 10	—
<i>Epeorus</i>	n = 10 x = 75,0 ± 2,11	x = 80,2 ± 4,03	x = 96,5 ± 1,29	(at 100 p.c. no survival)	—
<i>Ephemera</i>	—	n = 10	n = 10	—	—
<i>danica</i> Müller	—	x = 0,56 ± 0,28	x = 3,7 ± 0,69	—	—
<i>Ephemera</i>	—	n = 10	n = 10	n = 10	—
<i>vulgata</i> L.	—	x = 0,3 ± 0,1	x = 0,37 ± 0,13	x = 0,45 ± 0,1	—
<i>Ephemerella</i>	—	n = 10	n = 10	n = 10	—
<i>macronata</i> (Bengtsson)	—	x = 12,2 ± 6,54	x = 19,2 ± 7,32	x = 49,5 ± 8,4	—
<i>Leptophlebia</i>	—	n = 10	n = 10	n = 10	n = 10
<i>marginata</i> (L.)	—	x = 1,38 ± 0,52	x = 1,63 ± 0,27	x = 11,1 ± 4,05	x = 25,5 ± 3,69
<i>Rithrogena</i>	n = 10 x = 49,9 ± 6,78	—	—	—	—
<i>iridina</i> (Kolenati)	—	—	—	—	—
<i>Siphonurus</i>	—	—	n = 10	n = 10	—
<i>aestivialis</i> (Eaton)	—	—	x = 5,25 ± 1,39	x = 6,6 ± 2,8	—
<i>Siphonurus</i>	—	n = 10	n = 10	n = 10	—
<i>lacustris</i> (Eaton)	—	x = 28,15 ± 6,88	x = 35,0 ± 6,68	x = 41,1 ± 3,32	—
<b>Odonata</b>					
<i>Brachytron</i>	—	—	—	—	n = 10
<i>hafniense</i> (Müller)	—	—	—	—	x = 26,4 ± 0,47
<i>Lesia</i>	—	—	n = 10	—	—
<i>sponsa</i> Hansemann	—	—	x = 10,18 ± 1,60	—	—
<i>Onychogomphus</i>	—	—	—	n = 3	n = 3
<i>forcipatus</i> (L.)	—	—	—	x = 14,3 ± 1,73	x = 15,17 ± 4,04

<i>Symplocma fusca</i> (Vanderlinden)	—	—	n = 10 x = 8,75 ± 1,11	n = 10 x = 15,45 ± 0,37	n = 10 x = 22,63 ± 2,69
<i>Sympetrum flaveolum</i> (L.)	—	—	—	n = 10 x = 3,96 ± 1,15	—
<b>Plecoptera</b>					
<i>Nemoura cinerea</i> (Retzius)	n = 10 x = 10,5 ± 3,23	—	—	n = 10 x = 32,57 ± 7,44	—
<b>Megaloptera</b>					
<i>Sialis lutaria</i> (L.)	—	—	n = 10 x = 10,6 ± 1,64	n = 10 x = 10,8 ± 5,29	n = 10 x = 12,65 ± 1,93
<b>Trichoptera</b>					
<i>Anabolia nervosa</i> (Leach)	—	—	—	n = 10 x = 7,95 ± 1,25	—
<i>Rhyacophila obliterata</i> McLachlan	—	n = 6 x = 70,17 ± 1,81	—	—	—
<i>Silo pallipes</i> (Fabricius)	n = 5 x = 73,2 ± 5,22	n = 3 x = 79,3 ± 3,75	—	—	—

species. For instance, it is generally accepted that mainly oxygen content, temperature and water flow tie lotic species to running waters. This is in good agreement with our findings on *Epeorus*, *Baetis alpinus* (Pictet) and other rhithrobiont species. But the values obtained for other species pose questions like the following: why are the  $LC_{50}$  of some lenitic species considerably higher than those of several lotic species? Why does *E. danica* inhabit lotic waters only, while its sister species, *E. vulgata*, inhabits also standing waters, despite the fact that both have an extremely low  $LC_{50}$ , as is necessary for the burrowing habits of their larvae. Phenomena like these suggest that inhabitants of running waters have not necessarily a higher demand for oxygen than lenitic species, as is usually assumed.

Dr. P. ZWICK is sincerely thanked for help with the English manuscript.

#### REFERENCES

- AMBÜHL, H. (1959): Die Bedeutung der Strömung als ökologischer Faktor. - Schweiz. Z. Hydrol. 21: 133-264.
- BESCH, W. K. (1982): Kritische Bewertung der Rolle von toxikologischen Tests bei der Gewässerüberwachung. - Decheniana, Beiheft 26: 67-77.
- BICK, H. (1982): Bioindikatoren und Umweltschutz. - Decheniana, Beiheft 26: 2-5.
- FRANKE, U. (1977): Experimentelle Untersuchungen zur Respiration von *Gammarus fossarum* Koch 1835 in Abhängigkeit von Temperatur, Sauerstoffkonzentration und Wasserbewegung. - Arch. Hydrobiol., Suppl. 48 (3/4): 369-411.
- JACOB, U. & H. WALTHER (1981): Aquatic Insect Larvae as Indicators of Limiting Minimal Contents of Dissolved Oxygen. - Aquatic Ins. 3 (4): 219-224.
- KLAUSNITZER, B., U. JACOB & K. RICHTER (1978): Insekten als Bioindikatoren. - Ent. Ber. 1978 (2): 89-96.
- KNIGHT, A. W. & A. R. GAUFIN (1963): The effect of water flow, temperature and oxygen concentration on the Plecoptera nymph, *Acro-neuria pacifica* Banks. - Proc. Utah Ac. Sci., Arts, Letters 40, 2: 175-184.
- (1964): Relative importance of varying oxygen concentration, temperature, and water flow on the mechanical activity and survival of the Plecoptera nymph, *Pteronarcys californica* Newport. - Proc. Utah Ac. Sci., Arts, Letters 41, 1: 14-28.
- NAGELL, B. (1974): The Basic Picture and the Ecological Implications of the Oxygen Consumption/Oxygen Concentration Curve of Some Aquatic Insect Larvae. - Ent. Tidskr. 95, Suppl.: 182-187.
- & T. FAGERSTRÖM (1978): Adaptations and resistance to anoxia in *Cloeon dipterum* (Ephemeroptera) and *Nemoura cinerea* (Plecoptera). - Oikos 30: 95-99.
- SLÁDEČEK, V. (1982): Kenntnisstand und aktuelle Probleme bei der Beurteilung der Wassergüte mittels Bioindikatoren. - Decheniana, Beih. 26: 99-104.
- TÜMPLING, W. v. (1975): Biologische Wasseruntersuchung. - Ausg. Meth. Wasserunters. 2, Jena.