6. Macroinvertbrates as indicators of acidification of high-altitude Alpine lakes

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Introduction

High-altitude lakes, due to climatic factors, shallow soil cover, little vegetation, modest dimension of the watershed, long iced surface and rapid flushing rates are known to be particularly sensitive to atmospheric pollution (Wathne et al. 1995). In response to decreased atmospheric acid deposition, lakes in the Western Alps showed signs of chemical recovery since the mid 1990s (Rogora et al. 2003; Steingruber and Colombo, 2010). Neverthless, examples of biological recovery are still rare (Marchetto et al. 2004). Moreover, using benthic macroinvertebrates to assess acidification, for high-altitude Alpine lakes a specific method has not yet been developed. Unfortunately, because of the small data set (macroinvertebrate data from only 5 lakes in Southern Switzerland) the development of such a method goes beyond our possibilities. Instead, the aim of this study was to apply different already existing metrics to macroinvertebrate samples from lakes with different pH (from acid sensitive to alkaline), with the purpose to find which reflects best differences in lake acidity in order to improve temporal assessment of acidification through benthic macroinvertebrates in high-altitude Alpine lakes in Southern Switzerland.

Study site

The study area is located in the Lepontine Alps in the northern part of Canton Ticino, Switzerland (Fig. 1). Annual mean values of the main chemical parameters are shown in Tab. 1.

Figure 1. Map showing the location of the sampling sites 1: Lago del Starlaresc da Sgiof, 2: Lago di Tomè, 3: Laghetto Superiore, 4: Laghetto Inferiore, 5: Lago Bianco

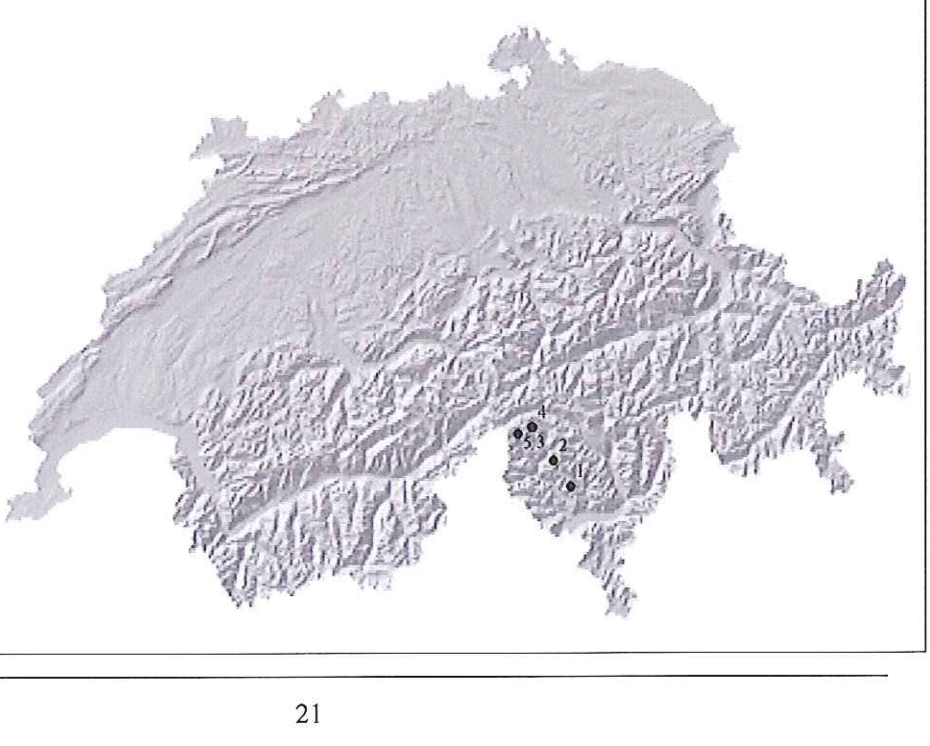

Table 1: *Water chemistry of the lakes: 2007 average values*

Lake name	Conductivity 20°C (µS cm^{-1})	pH	Alkalinity (meq m^{-3})	Ca^{2+} (meq m^{-3})	Mg^{2+} (meq m^{-3})	Na^{+} (meq m^{-3})	K^{+} (meq m^{-3})	NH_4^{+} (meq m^{-3})	SO_4^{2-} (meq m^{-3})	NO_3^{-} (meq m^{-3})	Cl^{-} (meq m^{-3})	DOC (mg C l^{-1})	SiO_2 (mg l^{-1})	$Al_{dissolved}$ (µg l^{-1})	Al_{tot} (µg l^{-1})	$Cu_{dissolved}$ (µg l^{-1})	Cu_{tot} (µg l^{-1})	$Zn_{dissolved}$ (µg l^{-1})	Zn_{total} (µg l^{-1})
Lago del Starlaresc da Sgiof	8.5	5.5	3	25	8	15	4	2	31	22	3	0.78	1.4	65	79	<0.2	<0.4	4.3	4.6
Lago di Tomè	8.6	5.7	5	42	6	14	4	1	32	28	3	0.28	1.8	26	33	<0.2	<0.2	1.7	1.8
Laghetto Superiore	8.8	6.7	33	51	8	12	8	0	28	16	2	0.42	1.2	6	15	<0.2	<0.2	2.0	1.4
Laghetto Inferiore	10.1	6.7	36	59	9	14	11	0	33	19	2	0.34	1.4	6	22	<0.2	<0.2	1.1	1.3
Lago Bianco	64.0	7.6	441	579	59	15	20	0	210	11	3	0.26	1.6	6	19	<0.2	<0.2	<0.3	<1.0

Methods

Macroinvertebrates have been collected by "kick sampling" the littoral and the outlet of each lake with a 250 µm mesh size net according to the ICP Waters Programme Centre Protocol (2010) usually 2 to 3 times a year during the ice free period. Samples have been preserved in 70% ethanol in the field, then sorted, identified to species and if not possible to higher taxa levels and then counted in the lab. Sampling occurred since 2000 but because up to date identification of chironomids and oligochaets was restricted to samples from 2007, we concentrated our first attempt of analysis on these year.

The applied acidification metrics can be divided in:

- general metrics (total number of taxa, number of taxa and relative abundance of Ephemeroptera, Plecoptera, Trichoptera, Diptera, Chironomidae, Oligochaeta and relative abundance of Predators),
- acidification specific metrics based on presence/absence or relative abundance of acid sensitive taxa (Raddum index (Raddum et al. 1988; Fjellheim and Raddum, 1990; Raddum, 1990), NIVA index (Bækken and Kjellberg, 2004), $AWIC_{fam}$ index (Davy-Bowker et al. 2003, 2005), $AWIC_{sp}$ index (Davy-Bowker et al. 2003), Braukmann index (Braukmann and Biss, 2004), LAMM index (McFarland et al. 2010), number and relative abundances of acid sensitive taxa, reported in literature)
- and classification systems based on both the previous type of metrics (MEDIN (Henrikson and Medin, 1986) and MILA indexes (Johnson and Goedkoop, 2007)).

Results

In the littoral samples a total of 14373 individuals were collected and 70 taxa were determined, while in the outlets the individuals and taxa where 20298 and 99, respectively. Twenty taxa were exclusive to the littoral, 44 to the outlets and 42 were common to both sampling zones. In general *Diptera* was the dominant order regarding both the abundance and the number of taxa. With exception of the littoral of Laghetto Inferiore and Laghetto Superiore, where *Simuliidae* were also abundant, chironomids prevailed in the samples. Oligochaetes were also highly abundant (mainly Naididae in the outlets), excluding the outlets of Lago di Tomè and Lago del Starlaresc da Sgiof and the littoral of the latter. In most littorals nematods were numerous, as well.

Application of acidification metrics to outlet macroinvertebrates

Results from the application of different metrics are shown in Tab. 2. The total number of taxa increased with pH. Also metrics related to Ephemeroptera (number of families, taxa and relative abundance) and to Oligochaeta (number of taxa and relative abundance) increased with pH. For Plecoptera only the number of taxa clearly increased with pH. A clear increase with pH can also be observed for the number of families and taxa of Ephemeroptera/Plecoptera/Trichoptera. The number of taxa of Diptera and Chironomidae also increased with pH. Furthermore as expected from literature (Johnson and Goedkoop, 2007) the relative abundance of Diptera and predators were higher in more acidic waters. Instead, for most of the specific acidification indexes tested differences among pH's could not be observed. Only the Raddum and the MILA index increased with increasing pH, although the first seems not to be very sensitive toward changes in pH. Finally, the number of acid sensitive species also increased in lakes with higher pH, while differences between the relative abundance of acid sensitive taxa can be observed only between acid sensitive lakes (Lago del Starlaresc da Sgiof, Lago di Tomè) and not acid sensitive lakes (Laghetto Superiore, Laghetto Inferiore, Lago Bianco).

Table 2. *Application of existing metrics regarding macroinvertebrates and acidity. For each classification system the possible classes are indicated in brackets from the less acidic toward the most acidic sites.*

METRICS	OUTLET					LITTORAL				
	STA	TOM	SUP	INF	BIA	STA	TOM	SUP	INF	BIA
Total number of taxa	35	40	41	46	55	27	28	41	38	31
Rel. Abundance Ephemeroptera %	0	0	0.3	0.9	1.3	0	0	0	0	0
Number of families Ephemeroptera	0	0	1	1	2	0	0	0	0	0
Number of taxa Ephemeroptera	0	0	1	2	2	0	0	0	0	0
Rel. Abundance Plecoptera %	14.2	36.0	5.9	6.0	10.7	0	0.4	4.1	1.1	0.1
Number of families Plecoptera	2	3	3	3	3	0	1	1	1	1
Number of taxa Plecoptera	1	3	5	6	6	0	1	1	1	1
Rel. Abundance Trichoptera %	1.5	1.1	1.2	0.4	0.6	0.6	6.7	4.9	2.4	0
Number of families Trichoptera	3	3	3	3	4	1	2	2	2	0
Number of taxa Trichoptera	4	4	4	3	5	1	2	3	2	0
Rel. Abundance Ephemeroptera/Plecoptera/Trichoptera %	15.7	37.2	7.3	7.2	12.6	0.6	7.1	9.0	3.5	0.1
Number of families Ephemeroptera/Plecoptera/Trichoptera	5	6	7	7	9	1	3	3	3	1
Number of taxa Ephemeroptera/Plecoptera/Trichoptera	5	7	10	11	13	1	3	4	3	1
Rel. Abundance Diptera %	76.7	60.7	47.5	55.6	40.4	88.5	61.6	45.1	74.5	55.1
Number of taxa Diptera	19	23	23	27	30	15	13	22	21	17
Rel. Abundance Chironomidae %	67.7	52.1	27.9	35.0	39.8	72.3	61.6	44.2	73.0	55.0
Number of taxa Chironomidae	16	21	21	24	27	13	12	19	19	15
Rel. Abundance Oligochaeta %	0.7	0.3	40.7	31.5	45.8	3.0	21.4	8.2	12.3	29.6
Number of taxa Oligochaeta	3	3	4	4	7	4	7	10	9	10
Rel. Abundance Predators%	11.3	10.5	6.1	7.5	2.7	13.8	52.7	21.5	30.3	9.9
Braukmann index (1-5)	4	5	5	5	5	4	4	4	4	4
Raddum index (1-0)	0	0.5	0.5	0.5	1	0	0	0.5	0.25	0
NIVA index (1-4)	4	4	4	4	4	4	4	3	3	4
AWICfam index (6-0)	3.9	4.0	3.5	3.5	3.8	5.5	3.7	4.0	4.0	3.7
AWICsp index (10-0)	5.7	5.3	5.2	5.2	5.3	6.0	5.1	5.5	5.4	5.0
MEDIN index (1-5)	5	5	5	5	5	5	5	4	5	5
MILA index (100-1)	15	21	28	29	33	25	7	13	3	23
LAMM index (6-0)	4	4	4	4	4	6	2	4	3	4
Relative abundance of acid taxa species according to Table 5 %	0.0	0.3	5.6	9.1	3.6	0.1	0.0	0.1	0.0	6.7
Number of acid taxa species according to Table 5	0	3	4	7	8	1	0	2	0	2

Application of acidification metrics to littoral macroinvertebrates

Interestingly, most of the existing metrics applied to littoral samples seemed not to correlate with pH. Considering that the number of taxa in Lago Bianco is probably reduced compared to the other two not acid sensitive lakes (Laghetto Superiore and Laghetto Inferiore), because of its more monotone substrate consisting mainly of silt, only the number of total taxa, Diptera, Chironomidae and Oligochaeta seemed to slightly increase with pH. All other general metrics concerning relative abundances, the specific acid indexes and the number of acid sensitive taxa did not seem to correlate with lake acidity.

Discussion

Results showed that many general metrics gave a good description of differences in pH in outlet samples. The number of total identified taxa (often used to compare community diversity), and the number of EPT taxa (recognized as being the most sensitive to pollution, Weber, 1973), are known to decrease with water quality. In fact, both metrics seem to increase with lake pH. Not surprisingly, in the two acid sensitive lakes no Ephemeroptera were found. Ephemeroptera are known to be the most sensitive order for acidification (Raddum et al., 1988),. The number of EPT families was also higher in lakes with higher pH but was a less sensitive metric. The relative abundance of Diptera (mainly Chironomidae) and of predators that are known to increase with acidification (Johnson and Goedkoop. 2007), effectively follow this trend. Interestingly, the number of taxa of the numerically important chironomids and oligochaetes, increased with pH, suggesting that an improvement of lake pH is also reflected in their taxa richness. Although chironomids have not generally been regarded as sensitive indicators for acidity (Wiederholm and Eriksson, 1977; Mossberg and Nyber, 1979; Meriläinen and Hynynen, 1990; Schnell, 2001; Olander, 2002), results from other studies were consistent to ours (Raddum and S± ther, 1981; Allard and Moreau, 1987; Schnell and Raddum, 1993; Halvorsen et al., 2001). With regard to oligochaetes, taxa richness and relative abundance increased with lake pH. Oligochaetes are generally known to be tolerant to acidification (Wathne et al. 1997), or even prefer acidified environments (Rota, 1995). However, some studies observed that although the diversity of oligochaetes does not change significantly with pH, their total abundance may decrease with decreasing pH (Keller et al. 1990; Lonergan and Rasmussen, 1996; Sommer and Horwith, 2001). Regarding the acidification metrics. only the number of sensitive taxa and the MILA index correlated with lake pH, which is not surprising. In fact, the number of acid sensitive taxa is based on a list of species occurring at the study site and the MILA index is a multimetric index based on general metrics, most of them just shown to correlate positively with lake pH in this study (relative abundance of Ephemeroptera, Diptera and Predator, number of taxa of Ephemeroptera and Gastropoda, $AWIC_{fam}$ index). The negative results of the other metrics also could be expected: the Raddum and the NIVA indexes are based on the presence/absence of acid sensitive species in Norway, the $AWIC_{fam}$ and $AWIC_{sp}$ indexes on the average sensitivity score of families or species from the UK. Both the MILA and the LAMM index were developed specifically for lake ecosystems. However, the first is based on the presence/absence of many taxonomic groups that are rare or absent in high-altitude Alpine lakes even at high pH (Amphipoda, Hirudinea, Elmididae, Gastropoda, Bivalvia) and on the presence/absence of acid sensitive species from Sweden. The second is based on the relative abundance of acid sensitive species common in the UK and their sensitivity score. Finally, the Braukmann index, although developed for German river ecosystems, is based on a list of acid indicator taxa, were most of species identified in this study (except chironomids and oligochaets) are considered. However, results from the application of these metrics are negative, as well, because it considers also the relative abundances of sensitive indicator taxa, that are higher in river ecosystems compared to high-altitude Alpine lake outlets.

Regarding lake littoral samples, results from the application of general and specific metrics gave much less encouraging results. One of the reasons is that many taxa known to be acid sensitive are rhephil or rheobiont and prefer or need flowing waters (many Ephemeroptera, Plecoptera and Trichoptera) and are therefore absent in the littorals. Another reason may be the fact that other environmental factors than lake acidity may vary significantly among lakes (especially substrate) hiding a little the effect of different acidity on macroinvertebrate population. From this study the only metrics that can be tried to use to determine effects on littoral macroinvertebrates as a result of variations in lake acidity may be the total number of taxa, the relative abundance and number of taxa of Diptera, Chironomidae and Oligochaeta.

Conclusion

In general macroinvertebrates from lake outlets are better indicators of acidity than from lake littorals. Moreover, because of the high relative abundance and taxa richness of especially chironomids but also oligochaetes and their responding to some extent to changes in pH and the poorness of other taxonomic groups, in high-altitude Alpine lakes determination to species of these 2 taxonomic groups, especially the first, should be recommended. Finally, more studies on the acid sensitivity of chironomids and oligochaetes species are necessary.

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