Recovery of macroinvertebrates from acidification in Swedish national reference lakes

av

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Förord

Följande rapport utgör redovisningen av projektet ”Återhämtning av Bottenfauna” finansierat av Naturvårdsverket (Överenskommelse Nr 501 0605). Syftet med projektet är att med hjälp av data från den Nationella Miljöövervakningen undersöka om den kemiska återhämtning från försurning som tidigare uppmätts, nu följs av en återhämtning även av sjöarnas litoralfauna. Rapporten kommer att utgöra underlag för den fördjupade utvärderingen av Miljömålet ”Bara naturlig försurning” 2007. Motsvarande undersökningar på fisk i sjöar och vattendrag genomförs samtidigt av Fiskeriverket.

Uppsala i oktober 2006

Sonja Stendera
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Svensk Sammanfattning

Internationala överenskommelser för att minska utsläpp av försurande ämnen har lett till kraftigt minskad deposition av svavel och – i mindre omfattning – kväve. Detta har lett till minskade sulfathalter i sjöar i hela Sverige med de största förändringarna i de södra delarna där den antropogena belastningen är störst. I många sjöar har sulfatminskningen även följts av en ökning av pH och syraneutraliserande förmåga (ANC). Eftersom vattenkemin i hög grad styr artförekomsten i sjöar, förväntas att den kemiska återhämtningen ska följas av en biologisk återhämtning.

I denna studie har 89 nationella referenssjöar med provtagning av vattenkemin och bottenfauna sedan 1995, undersöktes med avseende på trender i kemi och litoralfauna. Sjöarna indelades inom 4 grupper beroende på försurningsgrad och trender med antingen ANC eller pH som kriterium för kemisk återhämtning. Försurade sjöar indelades i 2 grupper, grupp 1 omfattade sjöar som visade en positiv trend i ANC eller pH, grupp 2 omfattade sjöar som visade inga trender i de två parametrar. Ej försurade sjöar indelades också i två grupper, antingen om de visade positiva trender i ANC eller pH (grupp3) eller inte (grupp 4). Biologisk återhämtning definierades som positiv trend i olika försurnings- och diversitetsindex.

Ungefär hälften av de försurade sjöarna visade positiva trender i ANC eller pH (grupp 1) och därmed tecken på kemisk återhämtning. Ungefär hälften av sjöarna i denna grupp visade också tecken på biologisk återhämtning i form av positiva trender i flera index. Till exempel visade flera sjöar ett förändrat bottenfaunasamhälle och ökad diversitet med etablering av försurningsintoleranter arter vilket återspeglades i signifikanta positiva trender i både diversitetsmått (bl.a. Simpsons diversity, artantal) och försurningsindex (Medins). Däremot fanns de många försurade sjöar som visade negativa trender i flera bottenfaunaindex och ej försurade sjöar som visade positiva trender i både kemin (ANC och pH) och biologin. Till exempel förekom både positiva och negativa trender i litoralfaunan hos försurade sjöar utan kemisk återhämtning (grupp 2). Resultaten visar att litoralfaunan inte bara påverkas av surhetstillståndet utan även av andra faktorer som klimat och biotiska faktorer.

Background

As a result of concerted international efforts to protect and restore natural resources threatened by acidification, both the emission and deposition of acidifying compounds have decreased markedly and widespread increases in surface water pH have been attributed to these ameliorative measures (e.g. Stoddard et al. 1999; Skjelkvåle et al. 2003). Since surface water chemistry exerts a major control on aquatic biodiversity (e.g. Resh & Rosenberg 1993), it is anticipated that improvement in surface water quality (e.g. raised pH and ANC) should result in biological recovery, albeit with inherent time lag responses (Evans et al. 2001). Thus far, however, records of biological recovery are scarce and results equivocal (Skjelkvåle et al. 2003; Alewell et al. 2001), and acidification is still considered one of the foremost problems affecting the biodiversity of inland surface waters in northern Europe (e.g. Johnson et al. 2003).

However, a recent study of 10 lakes from the Swedish long-term national monitoring program noted a significant increase in diversity of macroinvertebrate littoral fauna and phytoplankton in some lakes with increased pH (Stendera 2006). Chemical recovery of acidified lakes, within the national reference lakes program, has occurred mainly since the mid 1990's. The sampling of littoral macroinvertebrates which started in 1995 and 1996 provides an excellent opportunity to study macroinvertebrate recovery from acidification with a more encompassing data material than the study mentioned above. Stendera (2006) showed that despite signs of recovery in the littoral habitats, macroinvertebrate communities of sublittoral and profundal habitats showed negative trends, i.e. diversity and taxa richness decreased over the 16 year study period. These changes in community compositions were related to climatic factors (like increased water color) and suggest that trends in community composition and diversity might not be due to changes in acidification stress, but could rather entirely or partly due to natural variation. To gain better insight into the factors driving biological recovery, this study compared lakes showing chemical recovery with lakes showing no recovery and lakes that have not been impacted by acidification.

In the present study, this comparison is done with 89 lakes sampled for chemistry and biota for 10 years. The lakes were subdivided into four groups depending on their acidity status and recovery trends in either ANC or pH. Lakes showing signs of chemical recovery were then analyzed for signs of biological recovery with respect to littoral macroinvertebrate fauna.

Methods

The data set used in this study consists of 89 lakes having different acidity status sampled for littoral macroinvertebrates from 1995-2005 (Table 1). All lakes are relatively small (mean lake area 1.65 km^2), shallow (mean depth 5.3 m), nutrient poor and clear-water lakes (Table 2 & 3). Distribution of catchment land use and cover is shown in Figure 1. More information on these lakes is available on http://www.ma.slu.se.

Table 1: Ranges of pH class within different lake groups belonging to two different monitoring programs.

Program	**pH < 5.6**	**pH > 5.6 – 6.2**	**pH > 6.2**	**Σ**
Intensive	4	0	10	14
National reference	13	10	52	75
Total	17	10	62	89

Surface water samples (0-2 m) were collected six to eight times a year by taking a mid lake water sample and analyzed for water chemistry within 48 hours at the Department of Environmental Assessment following international (ISO) or European (EN) standards when available (Wilander et al. 2003). The analyzed parameters included pH, Ca, Mg, Na, K, SO4, Cl, NO2+NO3, Total phosphorus, absorbance of filtered water at 420 nm, and TOC. Sum of non-marine base cations (BC*) was calculated as Ca + Mg + Na + K – 1.111*Cl and non-marine SO4 as SO4 – 0.103*Cl with Al concentrations as meq/l (Umweltbundesamt 1996). ANC was calculated as (Ca + Mg + Na + K) – (SO4 +Cl + NO3) (see Table 2 for mean values).

Trends in pH and ANC, as criterion for chemical recovery, were calculated with Seasonal-Kendall tests (Loftis et al. 1991). Impact of acidification was assessed according to the Swedish Environmental Quality Criteria on data from the period 1990 – 1995. For some lakes where the time series started 1995 or later, data from the period 1995 to 1999 was used for the acidification assessment.

Littoral macroinvertebrates were collected in late autumn (October – November) each year using standardized kick-sampling (European Committee for Standardization 1994) with a handnet (0.5 mm mesh size). A composite sample consisting of five kick-samples (20 sec x 1 m ca 0.5 m depth) was taken from hard bottom, vegetation-free sites of each lake. Macroinvertebrate samples were preserved in 70% ethanol in the field, and in the laboratory the samples were processed by sorting with 10 x magnifications, identified and counted using dissecting and light microscopy. Organisms were identified to the lowest taxonomic unit possible, generally to species level.

Several metrics were used to analyse for changes in benthic macroinvertebrate communities. Taxon richness was selected as a qualitative measure of changes in community composition and community diversity was calculated as Simpson diversity, Simpson's dominance (Simpson 1949) and Shannon diversity (Shannon 1948). Numbers of EPT taxa (EPT(T)) and EPT individuals (EPT(N)) were taken as a general indicator of the ecological status. The acidity indices, Medin's index (Henrikson & Medin 1986) and MILA index (Multimetric Index of Lake Acidity, Johnson & Goedkoop 2006) were used as indicators for acidification. These metrics were analyzed on trends for 1995-2005 with Kendall's tau *b*, a nonparametric measure of association.

In order to test for differences between acidified lakes showing chemical recovery or no recovery as well as biological recovery and non-acidified lakes showing chemical and/or biological trends, the whole data set was divided into four groups.

- Group 1: acidified lakes showing a positive chemical recovery trend
- Group 2: acidified lakes showing no chemical recovery trend
- Group 3: non-acidified lakes showing a positive chemical recovery trend
- Group 4: non-acidified lakes showing no chemical recovery trend

Differences between groups were tested with one-way ANOVA for each criterion (ANC/pH) in JMP (SAS 1994).

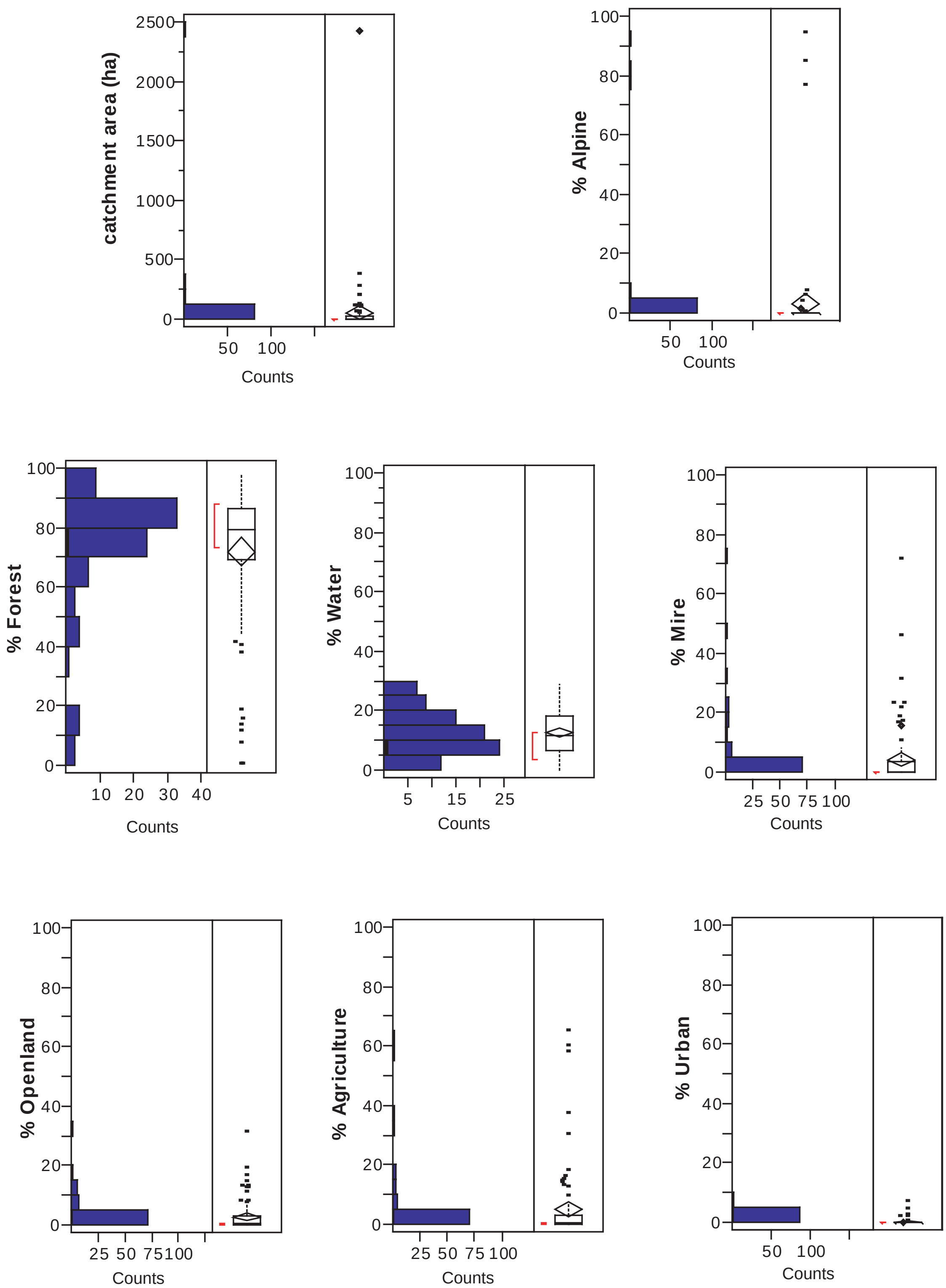

Figure 1: Catchment area and distribution of land cover and land use of the 89 lakes studied here for chemcial and biological recovery trends

Table 2: Location and physical parameters of the lakes and catchments (n = 89) analyzed on chemical and biological trends of recovery after acidification.

Lake	**X**	**Y**	**Lake altitude [m.a.s.l.]**	**Lake area [km^2]**	**Temp. [°C]**	**Runoff [mm]**	**Precipitation [mm]**
Abiskojaure	758208	161749	489	2.98	-2.2	785	1041
Allgjuttern	642489	151724	130	0.16	7.0	250	650
Alsjön	647050	130644	113	0.06	7.0	250	850
Bjännsjön	713404	172465	180	0.41	2.1	450	750
Björken	652707	159032	33	1.35	6.0	250	650
Brunnsjön	627443	149526	98	0.11	7.0	250	750
Brännträsket	728095	175926	82	0.81	1.0	350	650
Bysjön	658086	130264	126	1.18	5.4	350	850
Bäen	623624	141149	95	0.53	7.0	250	750
Bästeträsk	642555	168553	6	6.52	7.0	234	0
Dagarn	664197	149337	No data	1.72	No data	No data	No data
Dagstorpssjön	620953	135500	109	0.45	7.1	450	850
Degervattnet	708512	152086	213	1.60	2.0	350	722
Djupa Holmsjön	656263	156963	59	0.14	6.0	229	671
Dunnervattnet	713131	144608	455	2.67	1.0	551	1016
Edasjön	663365	161779	14	0.19	6.0	250	650
Ekholmssjön	663907	156927	62	0.57	6.0	250	650
Fagertärn	651558	143620	162	0.17	6.0	250	750
Fiolen	633025	142267	226	1.55	6.0	250	850
Fjärasjö	638725	146677	237	0.32	6.0	250	650
Fräcksjön	645289	128665	63	0.27	7.0	460	950
Fyrsjön	704082	148125	299	18.90	1.9	413	771
Fysingen	660749	161885	5	4.76	6.0	225	650
Gipsjön	672729	138082	382	0.75	3.0	450	850
Gosjön	677506	156174	63	0.39	5.0	350	750
Granvattnet	646293	126302	57	0.20	7.0	450	0
Grissjön	651578	146163	136	0.24	6.0	250	789
Gryten	652840	151589	47	1.06	6.0	150	650
Hagasjön	635878	137392	170	0.11	6.0	450	950
Harasjön	632231	136476	164	0.57	6.0	450	950
Havgårdssjön	615365	134524	53	0.50	8.0	250	750
Hinnasjön	630605	144655	172	0.26	6.0	250	750
Hjärtsjön	632515	146675	276	1.28	6.0	250	750
Humsjön	650061	142276	129	0.21	6.0	150	750
Hällsjön	667151	149602	168	0.21	4.0	350	750
Hällvattnet	704955	159090	216	6.58	2.7	350	717
Härsvatten	643914	127698	126	0.24	7.0	550	1050
Hökesjön	639047	149701	147	0.51	6.0	150	650
Jutsajaure	744629	167999	421	1.11	-1.0	350	717
Krageholmssjön	615375	137087	43	2.05	8.0	250	774
Krankesjön	617797	135339	20	3.31	8.0	287	750
Lilla Öresjön	638665	129243	107	0.64	7.0	550	1050
Lillesjö	623161	142148	88	0.04	7.0	213	750

Table 2: continued

Lake	X	Y	Lake altitude [m.a.s.l.]	Lake area [km^2]	Temp. [°C]	Runoff [mm]	Precipitation [mm]
Lillsjön	655380	155738	22	0.32	6.0	250	650
Limmingsjön	660804	142742	234	1.08	5.0	350	850
Louvvajaure	736804	160569	459	0.82	-1.0	450	650
Långsjön	673534	153381	239	0.07	4.0	350	750
Mäsen	665654	149206	106	0.42	5.0	350	750
N. Yngern	656206	159170	39	14.01	6.0	249	650
Njalakjaure	741340	153576	850	0.33	-2.0	650	949
Pahajärvi	742829	183168	249	1.21	1.0	350	650
Rammsjön	629570	135470	160	0.34	6.0	550	1150
Remmarsjön	708619	162132	234	1.29	1.9	350	750
Rotehogstjärnen	652902	125783	121	0.16	6.0	650	950
Rundbosjön	652177	159038	4	0.91	6.0	250	650
Sangen	686849	145214	444	1.44	3.0	350	750
Siggeforasjön	665175	157559	74	0.70	5.0	250	650
Skärgölen	651573	152481	73	0.18	6.0	150	650
Skärsjön1	633344	130068	49	2.98	7.0	544	1000
Spjutsjön	672467	148031	182	0.40	4.0	350	745
Stensjön	683673	154083	269	0.53	4.0	350	750
Stor-Arasjön	716717	158596	544	7.13	1.0	350	750
Stor-Backsjön	695220	143383	427	2.09	2.0	302	650
Stor-Björsjön	706083	132287	568	0.43	1.0	950	1000
Stor-Tjulträsket	731799	151196	544	5.25	-1.1	760	944
Stora Envättern	655587	158869	65	0.38	6.0	250	650
Stora Lummersjön	644463	139986	240	0.06	6.0	250	850
Stora Skärsjön	628606	133205	55	0.33	7.0	550	1149
Stora Tresticklan	655209	126937	207	1.29	6.0	550	950
Storasjö	631360	146750	253	0.35	6.0	250	750
Svinarydsjön	622803	144609	28	0.18	7.0	250	650
Sännen	624421	147234	63	0.99	7.0	250	750
Tomeshultagölen	629026	147562	179	0.09	7.0	250	750
Tväringen	690345	149315	308	1.61	3.0	350	650
Täftesträsket	711365	171748	140	2.22	3.0	350	750
Tängersjö	637121	151366	114	0.09	7.0	150	650
Tärnan	660688	164478	41	1.06	6.0	250	650
Tångerdasjön	637120	145525	217	0.14	6.0	250	650
Ulvsjön	661521	130182	211	0.55	5.0	350	850
V. Rännöbodsjön	691365	156127	47	0.46	3.0	353	701
Valasjön	698918	158665	101	1.98	3.0	350	687
Vuolgamjaure	728744	162653	437	2.03	0.0	350	650
Västra Solsjön	655863	129783	148	1.85	6.0	450	850
Älgarydssjön	633989	140731	201	0.32	6.0	350	825
Älgsjön	655275	153234	50	0.36	6.0	216	650
Öljaren	655974	150853	24	17.91	6.0	150	640
Örsjön	624038	143063	89	0.19	7.0	250	750
Örvattnet	662682	132860	278	0.80	5.0	350	850
Övre Skärsjön	663532	148571	222	1.70	5.0	350	850

Table 3: Chemical parameters (mean of 10 years 1995-2005) of the lakes (n = 89) analyzed on chemical and biological trends of recovery after acidification.

Lake	**pH**	**Alkalinity [meq/l]**	**SO4* [meq/l]**	**NO2+NO3-N [µg/l]**	**TP [µg/l]**	**absorbance [420nm/5]**	**TOC [mg/l]**	**ANC [meq/l]**	**BC* [meq/l]**
Abiskojaure	7.02	0.19	0.07	24.92	5.61	0.01	1.74	0.20	0.27
Allgjuttern	6.58	0.07	0.18	39.17	8.37	0.05	7.25	0.14	0.32
Alsjön	5.22	-0.01	0.11	45.71	12.42	0.27	13.40	0.08	0.19
Bjännsjön	6.29	0.07	0.07	32.64	13.60	0.16	8.27	0.13	0.20
Björken	7.04	0.22	0.22	83.65	9.93	0.06	7.61	0.32	0.54
Brunnsjön	5.46	0.00	0.25	112.54	13.39	0.37	17.84	0.13	0.39
Brännträsket	6.60	0.13	0.07	23.79	10.61	0.13	9.36	0.21	0.28
Bysjön	6.49	0.09	0.11	43.74	11.19	0.06	7.16	0.13	0.24
Bäen	5.72	0.02	0.27	99.39	13.53	0.14	8.25	0.07	0.34
Bästeträsk	8.20	2.21	0.16	50.79	6.50	0.03	11.14	2.40	2.56
Dagarn	6.66	0.11	0.09	43.94	9.02	0.06	6.46	0.18	0.27
Dagstorpssjön	7.14	0.38	0.24	225.54	32.68	0.11	9.64	0.51	0.77
Degervattnet	6.95	0.19	0.04	20.92	7.25	0.09	8.01	0.27	0.31
Djupa Holmsjön	5.89	0.02	0.10	61.84	10.23	0.18	12.37	0.12	0.22
Dunnervattnet	6.80	0.09	0.03	13.57	5.29	0.08	6.21	0.13	0.16
Edasjön	7.16	0.95	0.16	94.48	38.48	0.14	13.31	1.14	1.31
Ekholmssjön	6.99	0.37	0.17	59.61	18.44	0.08	9.60	0.47	0.65
Fagertärn	5.91	0.03	0.10	49.06	13.48	0.17	9.94	0.10	0.20
Fiolen	6.49	0.05	0.17	72.60	12.18	0.05	6.63	0.10	0.27
Fjärasjö	6.80	0.14	0.20	40.67	10.75	0.07	9.23	0.24	0.43
Fräcksjön	6.38	0.06	0.13	82.79	10.38	0.11	8.85	0.14	0.27
Fyrsjön	7.37	0.74	0.06	37.04	7.35	0.09	7.06	0.83	0.89
Fysingen	7.71	1.86	2.07	876.59	28.05	0.04	8.57	2.01	4.14
Gipsjön	5.38	0.00	0.04	32.36	12.97	0.28	12.65	0.07	0.11
Gosjön	6.21	0.06	0.06	31.81	15.92	0.24	13.38	0.16	0.23
Granvattnet	6.36	0.08	0.10	45.25	16.14	0.07	8.45	0.14	0.24
Grissjön	5.51	0.00	0.13	51.65	9.86	0.12	9.54	0.06	0.20
Gryten	6.61	0.16	0.21	76.02	14.51	0.19	16.66	0.33	0.54
Hagasjön	6.23	0.05	0.12	57.02	11.15	0.10	7.82	0.11	0.23
Harasjön	5.22	-0.01	0.12	87.23	18.05	0.32	12.74	0.06	0.19
Havgårdssjön	8.16	2.24	0.22	299.41	52.83	0.04	8.75	2.45	2.69
Hinnasjön	5.98	0.04	0.21	56.17	13.92	0.15	11.21	0.13	0.34
Hjärtsjön	5.17	-0.01	0.17	62.22	6.64	0.03	3.99	0.00	0.18
Humsjön	6.79	0.15	0.09	26.45	11.83	0.05	6.52	0.19	0.29
Hällsjön	6.19	0.04	0.09	27.67	7.57	0.08	8.03	0.10	0.20
Hällvattnet	6.50	0.06	0.04	57.89	7.68	0.13	8.49	0.13	0.18
Härsvatten	4.61	-0.03	0.10	121.48	5.11	0.01	2.70	-0.05	0.06
Hökesjön	6.88	0.14	0.14	17.11	7.97	0.02	5.30	0.19	0.32
Jutsajaure	6.57	0.10	0.02	16.87	9.33	0.08	6.06	0.14	0.17
Krageholmssjön	8.31	2.44	0.51	429.75	76.73	0.04	8.31	2.68	3.21
Krankesjön	8.12	2.17	0.79	383.23	31.95	0.06	10.77	2.45	3.26
Lilla Öresjön	5.05	-0.02	0.10	258.14	7.45	0.06	5.34	0.01	0.13
Lillesjö	4.75	-0.05	0.26	97.66	6.39	0.01	2.26	-0.07	0.20
Lillsjön	7.01	0.46	0.19	200.54	63.39	0.20	15.84	0.65	0.85
Limmingsjön	6.66	0.09	0.08	38.88	8.23	0.06	6.31	0.14	0.23

Table 3: continued

Lake	pH	Alkalinity [meq/l]	SO4* [meq/l]	NO2+NO3-N [µg/l]	TP [µg/l]	absorbance [420nm/5]	TOC [mg/l]	ANC [meq/l]	BC* [meq/l]
Louvvajaure	6.99	0.16	0.03	8.02	5.90	0.02	3.76	0.20	0.23
Långsjön	6.04	0.05	0.07	31.37	11.19	0.21	10.66	0.13	0.20
Mäsen	6.83	0.17	0.14	25.26	12.22	0.05	7.61	0.24	0.39
N. Yngern	7.15	0.25	0.23	27.42	12.61	0.03	6.18	0.32	0.55
Njalakjaure	6.41	0.03	0.02	12.00	5.31	0.01	1.91	0.03	0.05
Pahajärvi	6.82	0.14	0.04	16.61	10.02	0.04	5.21	0.18	0.22
Rammsjön	4.83	-0.03	0.04	175.14	28.03	0.52	13.38	0.02	0.08
Remmarsjön	6.30	0.06	0.03	20.46	11.03	0.18	9.34	0.14	0.17
Rotehogstjärnen	5.44	0.00	0.10	49.45	14.38	0.22	11.45	0.08	0.18
Rundbosjön	7.09	0.37	0.40	206.44	44.66	0.11	10.36	0.53	0.94
Sangen	6.67	0.11	0.03	22.87	10.40	0.10	6.89	0.17	0.20
Siggeforasjön	6.67	0.15	0.11	84.48	11.88	0.21	14.96	0.29	0.41
Skärgölen	6.76	0.15	0.18	26.06	10.33	0.06	7.39	0.22	0.41
Skärsjön1	6.79	0.09	0.20	118.58	10.47	0.02	4.04	0.13	0.34
Spjutsjön	6.59	0.09	0.13	30.08	6.78	0.03	4.32	0.12	0.25
Stensjön	6.32	0.04	0.04	19.36	8.18	0.10	6.51	0.09	0.14
Stor-Arasjön	6.58	0.06	0.02	10.11	6.72	0.09	7.17	0.11	0.14
Stor-Backsjön	6.75	0.22	0.05	30.64	12.82	0.19	12.28	0.33	0.39
Stor-Björsjön	6.90	0.19	0.02	16.21	5.92	0.09	4.89	0.22	0.23
Stor-Tjulträsket	7.20	0.30	0.04	37.66	7.01	0.02	2.31	0.31	0.36
Stora Envättern	6.53	0.06	0.14	20.74	9.47	0.06	8.98	0.13	0.27
Stora Lummersjön	6.38	0.14	0.07	30.64	15.07	0.23	7.57	0.18	0.26
Stora Skärsjön	6.77	0.11	0.16	75.88	9.67	0.04	4.48	0.15	0.31
Stora Tresticklan	4.74	-0.03	0.07	102.08	7.40	0.05	5.08	-0.02	0.05
Storasjö	5.43	0.00	0.10	30.64	14.60	0.16	9.43	0.06	0.16
Svinarydsjön	5.80	0.02	0.24	79.03	18.41	0.07	9.03	0.08	0.33
Sännen	5.92	0.02	0.29	66.33	13.12	0.06	7.24	0.08	0.37
Tomeshultagölen	5.14	-0.02	0.16	32.11	22.32	0.48	18.80	0.11	0.27
Tväringen	6.64	0.12	0.05	17.56	9.81	0.10	7.60	0.18	0.22
Täftesträsket	6.44	0.07	0.06	40.08	10.55	0.13	9.65	0.15	0.22
Tängersjö	6.54	0.10	0.12	35.38	10.29	0.06	10.49	0.17	0.29
Tärnan	7.06	0.32	0.16	49.00	12.89	0.08	9.76	0.42	0.58
Tångerdasjön	7.05	0.36	0.13	64.67	56.10	0.09	11.17	0.46	0.59
Ulvsjön	6.01	0.03	0.09	85.69	8.09	0.10	8.56	0.08	0.18
V. Rännöbodsjön	6.81	0.26	0.08	66.67	13.64	0.11	7.79	0.32	0.41
Valasjön	6.50	0.09	0.06	58.28	12.00	0.18	10.61	0.18	0.25
Vuolgamjaure	6.80	0.12	0.03	9.48	6.83	0.06	5.80	0.17	0.19
Västra Solsjön	6.85	0.12	0.11	46.63	6.02	0.03	4.84	0.15	0.26
Älgarydssjön	5.52	0.01	0.14	49.57	17.09	0.19	11.67	0.07	0.21
Älgsjön	6.74	0.22	0.14	42.29	21.29	0.27	17.72	0.40	0.55
Öljaren	8.03	1.40	0.44	270.63	83.10	0.06	9.61	1.61	2.07
Örsjön	5.95	0.03	0.17	59.29	11.25	0.07	7.30	0.08	0.25
Örvattnet	5.29	0.00	0.08	50.40	6.11	0.03	4.28	0.01	0.09
Övre Skärsjön	5.59	0.00	0.12	125.10	7.43	0.13	7.24	0.05	0.18

Results

ANC trend as criterion for recovery

Taking ANC as criterion to assess chemical recovery from acidification resulted in 31 acidified lakes showing chemical recovery (Group 1, Table 4 & Table A1). Only two acidified lakes (L. Bäen and L. Rotehogstjärnen) lacked a positive trend in ANC. 36 non-acidified lakes in group 3 showed positive trends in ANC during 1995-2005 and 20 non-acidified lakes in group 4 showed no trends in ANC.

Of the 31 lakes in group 1, about half showed significant trends in one or several metrics of ecological status or acidification (e.g. Fig. 2). In 11 of these 15 lakes, positive trends, mainly in macroinvertebrate diversity, were noted. For instance, four lakes (Lake Storasjö, L. Lilla Öresjön, L. Tomeshultagölen, and L. Övre Skärsjön) showed positive trends in Medin's Index (Fig. 3) and two lakes showed an increase in total diversity. However, in four other lakes (L. Fagertärn, L. Grissjön, L. Hjärtsjön, and L. Ulvsjön), decreasing numbers of individuals and taxa of EPT families as well as a negative trend in the multimetric acidification index MILA were noted. Moreover, the two lakes in group 2 showed negative trends in both acidification (MILA) and ecological status (EPT(N)).

Table 4: Total numbers of lakes classified to different groups depending on the variable (ANC/pH) used to define lake acid status, and numbers of positive (+) or negative (-) trends of lakes showing trends and numbers of lakes in groups showing no trends.

Group/criterion	**ANC**			**pH**		
	Total	Trend	No trend	Total	Trend	No trend
1 (acidified & pos. trend)	31	+11/-4 (15)	17	20	+7/-3 (10)	10
2 (acidified & no trend)	2	-2 (2)	0	13	+4/-3 (7)	6
3 (non-acidified & pos. trend)	36	+13/-9 (22)	14	17	+6/-3 (9)	8
4 (non-acidified & no trend)	20	+4/-5 (9)	11	39	+10/-10 (20)	19

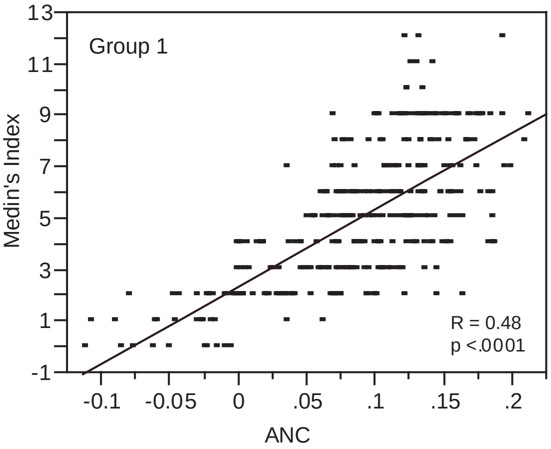

Figure 2: Medin's index versus ANC in lakes of group 1.

Of the 36 lakes assigned to group 3 (non-acidified lakes with positive trends in ANC), only 13 revealed positive trends in one or more biological metrics. For instance, both in L. Hällvattnet and L. Täfteträsket, macroinvertebrate diversity as well as the number of acid intolerant taxa increased during the 10-year period reflected by positive trends in Medin's index and diversity indices. In L. Täfteträsket, there was also a strong increase of taxa richness, whereas the littoral community in L. Hällvattnet shifted from an acidophil to a more circumneutral composition. Nine lakes in group 3 showed strong negative trends, mainly in diversity indices, but also in MILA, indicating a shift in littoral fauna composition towards more acidophilic taxa. Lake Rammsjön revealed a similar pattern with a negative trend in Medin's index.

Of the 20 lakes in group 4, four showed positive and five negative trends in macroinvertebrate diversity and acidification indices, even though these non-acidified lakes showed no positive trends in chemical recovery. For instance, in L. Lillsjön, L. Remmarsjön and L. Rundbosjön, the number of EPT taxa and the total number of benthic taxa strongly increased from 1995 to 2005, whereas in L. Siggeforasjön a strong decrease in littoral diversity occurred. In L. Öljaren, the total number of taxa decreased accompanied by a shift in community composition towards acid tolerant taxa. One lake, L. Älgsjön showed a positive trend in taxa richness but a negative trend in Medin's index.

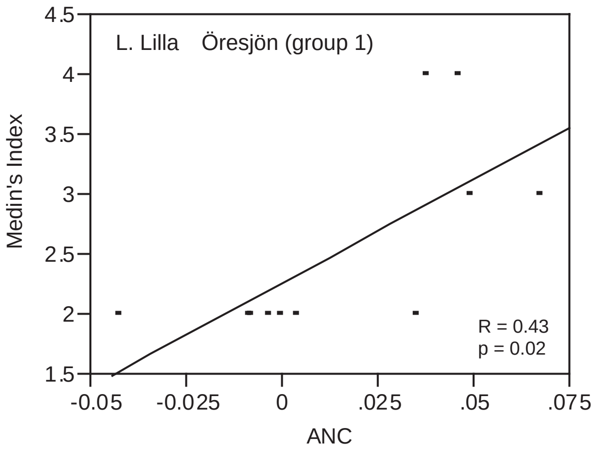

Figure 3: Medin's Index versus ANC in a group 1 lake.

Tests of differences between trends of all metric slopes between groups with ANOVA and Tukey's HSD are shown in Table 4. Only slopes of the EPT(N) index in group 2 were significantly different from all other groups (Table 4, Fig. 4), whereas slopes of the acidity index Medin in group 2 were significantly different from group 1 and group 3.

Table 4: One-way ANOVA of slopes of acidity and diversity indices of the four groups (see text) with ANC as the criterion for acid status. Differences were tested with Tukey's HSD. Significant results are shown in bold. MILA = Multimetric Index of Lake Acidity (for calculation, see Johnson & Goedkoop 2006), EPT (N) = # individuals of Ephemeroptera, Plecoptera and Trichoptera), EPT (T) = # taxa of Ephemeroptera, Plecoptera and Trichoptera).

Effect	**DF**	**SS**	**MS**	**F Ratio**	***P***
MILA Index					
group	3	0.351	0.117	1.418	0.243
Error	85	7.013	0.083		
C. Total	88	7.364			
EPT(N)					
group	3	1.377	0.459	5.026	**0.003***
Error	85	7.766	0.091		
C. Total	88	9.144			
EPT(T)					
group	3	0.185	0.062	0.640	0.591
Error	84	8.205	0.097		
C. Total	87	8.390			
Medin's Index					
group	3	1.436	0.479	4.055	**0.010****
Error	83	10.033	0.118		
C. Total	86	11.468			
		0.002	-0.222	-0.900	
Shannon Diversity					
group	3	0.298	0.099	1.210	0.311
Error	84	6.986	0.082		
C. Total	87	7.284			
Simpson Diversity					
group	3	0.307	0.102	1.233	0.303
Error	84	7.064	0.083		
C. Total	87	7.372			
Simpson's Dominance					
group	3	0.308	0.103	1.244	0.299
Error	84	7.023	0.083		
C. Total	87	7.331			
No. of taxa					
group	3	0.500	0.167	1.570	0.203
Error	80	9.018	0.106		
C. Total	83	9.518			

* Group 2 was different from all other groups, ** group2 was different from group 1and 3

pH trends as criterion for recovery

With pH as criterion to assess chemical recovery from acidification, 20 acidified lakes showed signs of chemical recovery (group 1, Table 5). Thirteen acidified lakes lacked a positive trend in pH (group 2). Seventeen non-acidified lakes showed positive trends in pH during 1995-2005 (group 3), whereas 31 non-acidified lakes showed no trends in pH.

From the 20 lakes of group 1, six lakes showed positive trends in several metrics. For instance, L. Lilla Öresjön and L. Övre Skärsjön showed both positive trends in acidification and diversity indicators, whereas L. Skärsjön and L. Storasjö only revealed an increase of macroinvertebrate diversity. In contrast, the improved water quality (raised pH) in L. Stora Tresticklan was solely reflected by one acidity index, the Medin's index, which showed a strong trend towards a community composition typical for circumneutral conditions. Negative trends were found in two lakes, L. Grissjön (MILA) and L. Hjärtsjön, which showed a decrease of EPT abundances over the ten years.

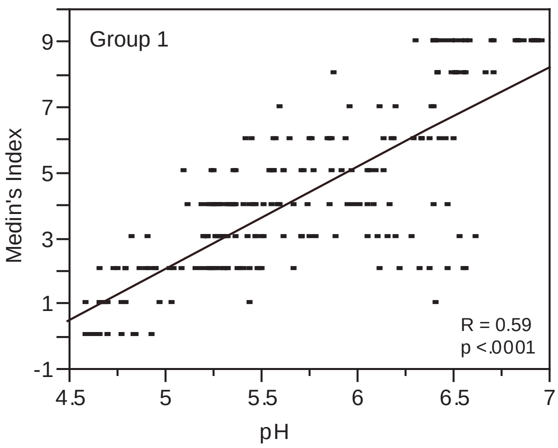

Figure 4: Medin's index versus pH in lakes of group 1.

In group 2, four lakes had positive trends, mostly in diversity indices. For instance, a strong increase in macroinvertebrate diversity was noted from 1995-2005 in L. Tomeshultagården. In contrast, three lakes showed negative trends, mainly in acidification parameters. In L. Bäen, the littoral community showed a strong decrease in number of individuals of EPT taxa and a shift towards a more acid tolerant community composition.

From the non-acidified subset of lakes studied here, 17 lakes were classified to group 3 (non-acidified showing positive pH trends) and 39 to group 4 (non-acidified lakes showing no trends in pH). Of the six lakes showing positive trends in macroinvertebrate indices, three (L. Bjännsjön, L. Stor-Björsjön, L. Täfteträsket) showed a shift in community composition towards a more circumneutral adapted assemblage, as indicated by strong positive trends in Medin's index. In L. Täfteträsket, there was also a strong increase in general number of taxa, number of EPT taxa and individuals as well as in general diversity. Three lakes showed negative trends, mainly indicated by a strong decrease of EPT taxa and total number of taxa, which was partly reflected as a decrease in overall diversity (e.g. L. Gryten).

Of the 39 lakes classified to group 4, 11 showed positive and 11 showed negative trends in several metrics. For instance, in L. Hällvattnet, the total number of littoral taxa and diversity increased accompanied by a community composition shift from acidophilic to acidophobic taxa. A similar pattern was noted in L. Valasjön, L. Remmarsjön, L. Rundbosjön and L. Ekholmssjön. Furthermore, this pattern, albeit inverse, could be found in some of the 11 lakes showing negative trends in both acidification and diversity metrics. For instance, in L. Allgjuttern and L. Siggeforasjön, community composition changes were only reflected by decreasing diversity, whereas changes in L. Humsjön and L. Långsjön were only reflected by negative trends in the MILA index. Lake Älgsjön was the only lake which showed simultaneous negative (Medin's index) and positive (no. of taxa) trends.

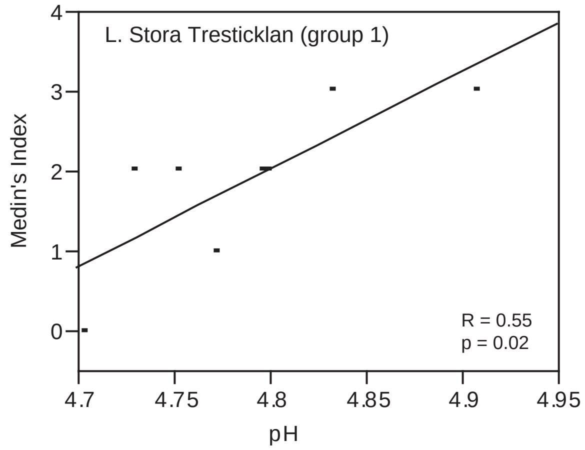

Figure 5: Medin's index versus pH in a group 1 lake.

Tests of differences between trends of all metrics with ANOVA and Tukey's HSD were all insignificant (Table 5).

Table 5: One-way ANOVA of slopes of acidity and diversity indices of the four groups (see text) with pH as the criterion for acid status. Differences were tested with Tukey's HSD. Significant results are shown in bold. MILA = Multimetric Index of Lake Acidity (for calculation, see Johnson & Goedkoop 2006), EPT (N) = # individuals of Ephemeroptera, Plecoptera and Trichoptera), EPT (T) = # taxa of Ephemeroptera, Plecoptera and Trichoptera).

Effect	**DF**	**SS**	**MS**	**F Ratio**	***P***
MILA Index	3	0.215	0.072	0.851	0.470
group	85	7.149	0.084		
Error	88	7.364			
C. Total					
EPT(N)	3	0.537	0.179	1.769	0.159
group	85	8.606	0.101		
Error	88	9.144			
C. Total					
EPT(T)	3	0.200	0.067	0.693	0.559
group	85	8.190	0.096		
Error	88	8.390			
C. Total					
Medin's Index	3	0.687	0.229	1.804	0.153
group	84	10.782	0.127		
Error	87	11.468			
C. Total					
Shannon Diversity	3	0.394	0.131	1.619	0.191
group	85	6.891	0.081		
Error	88	7.284			
C. Total					
Simpson Diversity	3	0.241	0.080	0.958	0.417
group	85	7.130	0.084		
Error	88	7.372			
C. Total					
Simpson's Dominance	3	0.241	0.080	0.963	0.414
group (pH)	85	7.090	0.083		
Error	88	7.331			
C. Total					
No. of taxa	3	0.115	0.038	0.346	0.792
group	85	9.403	0.111		
Error	88	9.518			
C. Total					

Discussion

The present study of chemical and biological recovery in 89 national reference lakes distributed across Sweden shows that chemical as well as biological recovery has begun or is in progress in some of these lakes. However, the majority of these lakes still lack clear positive trends in acid status towards circumneutral water quality and thus biological recovery has not yet occurred.

Eleven of 89 lakes showed positive trends in macroinvertebrate diversity and acidification indices when ANC taken as the criterion for acidification, and six of 89 lakes showed positive trends in group 1 with pH, indicating that due to improved water quality, biological recovery of littoral communities in terms of increasing diversity and number of acid intolerant taxa is in progress or might be completed in some lakes. Thereby, Medin's index was a better indicator for recovery trends of the littoral community than the family-based, MILA index.

However, negative trends were also noted in four (ANC) and two (pH) lakes, respectively, mainly a decrease of EPT individual numbers. These negative changes in community composition indicate that other mechanisms than changes in acidity might also be important in structuring littoral communities. For instance, the decrease of EPT abundances might be due to abiotic factors such as physico-chemical factors (changes in TOC, temperature, oxygen regime) or due to biotic factors (intraspecific competition, lack of food).

Surprisingly, several lakes in group 2 and group 4 showed significant positive (pH) or negative (ANC) trends in acidification and diversity metrics, although no changes in water acidity were noted. For acidified lakes, negative trends in macroinvertebrate diversity and acidification indices indicated clearly the lack of chemical recovery, whereas positive trends in group 2 with pH as the criterion for acidification indicated that pH is a less powerful indicator of changes in acidification status, since these lakes were attributed to group 1 when ANC taken as a discriminator. For non-acidified lakes showing no trends in acidity metrics (ANC/pH), both positive as well as negative trends in biological indices (e.g. L. Hällvattnet and L. Valasjön with positive trends in Medin's index) clearly indicated that other factors might be responsible for the observed changes in diversity or acidification.

The allocation of all lakes into distinct groups reliant on either acidification or non-acidification showing positive trends or no trends in chemical recovery seems to be a good approach for detecting biological recovery. Delineation in only two groups distinguishing acidified/non-acidified lakes without considering separation of chemical trends in the acidified lake population followed by groupwise analyses of biological trends may imply the risk of missing important patterns and underlying processes. In other words, the higher 'resolution' of the whole data set into finer groups provided a higher accuracy. For instance, lakes of groups 2 and 4 showed positive as well as negative trends, although water chemistry changes did not occur during the studied time period at least according to the definition of chemical recovery used here. Here, further investigation of these lakes is needed to find explanations and patterns generating these trends.

Furthermore, testing two acidity parameters simultaneously, namely ANC and pH, showed the importance of choosing the "right" indicator to detect biological recovery. Here, ANC trends seemed to be a more sensitive indicator of the acidification status of the lake population since it grouped more lakes into group 1 and separated the groups more distinctively avoiding misinterpretation. For instance, when taking pH as a criterion, Lake Rotehogtjärnen was classified to group 1, i.e. showing a positive trend in chemical recovery. However, with ANC as a criterion, this lake was defined as not showing chemical recovery, which might explain the negative trends in biological metrics. The conjecture that ANC might be more powerful indicator than pH was also supported by the results of the redundancy analysis of the whole data set prior to all analyses, where ANC trends was the best predictor in explaining variation in the macroinvertebrate data set (not shown here).

These results contrast somewhat to comparisons between sites where pH was shown to be a better predictor than ANC for littoral fauna (Johnson & Goedkoop 2006). However, a change in pH can depend on many factors, such us TOC and carbon dioxide pressure, whereas a change in ANC is more directly linked to decreases in water sulfate concentration due to decreased S deposition. Therefore, ANC might be a better indicator for detecting biological recovery as a direct result of decreased deposition pressure and thus improved water quality. On the other hand, linkages between changes in pH and changes in TOC might qualify pH as a good indicator of changes in water quality due to changes in regional climate patterns.

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Appendix

Table A1: Positive and negative trends (Kendall's tau) of acidity and diversity indices of all lakes (n = 89), divided into four groups (for clarification see text) with ANC trends as a criterion for recovery for the years 1995 until 2005. Significant trends are shown in bold. MILA = Multimetric Index of Lake Acidity (for calculation, see Johnson & Goedkoop 2006), EPT (N) = # individuals of Ephemeroptera, Plecoptera and Trichoptera), EPT (T) = # taxa of Ephemeroptera, Plecoptera and Trichoptera). * = $p< 0.05$, ** = $p< 0.01$.

Lake/group	MILA Index	EPT(N)	EPT(T)	Medin's Index	Shannon diversity	Simpson Diversity	Simpson's Dominance	No. of taxa
Group 1								
Alsjön	0.02	-0.09	-0.11	-0.11	0.20	0.27	0.27	-0.19
Brunnsjön	0.02	0.05	0.20	0.46	**0.53***	0.42	0.42	0.33
Bysjön	0.16	-0.31	-0.04	-0.13	-0.45	-0.35	-0.35	-0.28
Dagarn	0.13	0.13	**0.60***	0.32	-0.16	-0.31	-0.31	**0.59***
Djupa Holmsjön	-0.31	0.35	0.13	-0.08	0.05	0.05	0.07	0.20
Fagertärn	0.38	**-0.49***	0.00	0.31	0.05	0.09	0.09	0.28
Fiolen	-0.42	-0.09	0.11	0.20	-0.20	-0.31	-0.31	0.09
Fräcksjön	-0.05	-0.13	-0.29	-0.18	0.24	0.13	0.13	-0.21
Granvattnet	0.02	-0.11	-0.44	-0.30	-0.16	-0.20	-0.20	-0.48
Grissjön	**-0.53***	-0.38	-0.17	0.20	0.05	0.18	0.18	0.29
Hagasjön	-0.16	-0.09	-0.15	-0.31	0.02	0.11	0.11	-0.09
Harasjön	-0.45	-0.24	-0.17	0.26	0.16	0.27	0.27	0.09
Hinnasjön	0.16	0.38	**0.51***	0.31	0.02	-0.02	-0.02	0.41
Hjärtsjön	-0.35	**-0.49***	0.33	-0.26	0.02	0.05	0.05	0.11
Härsvatten	0.07	-0.04	0.07	-0.03	0.42	0.45	0.45	-0.21
Lilla Öresjön	0.35	-0.20	**0.66****	**0.57***	0.02	-0.11	-0.09	**0.60***
Lillesjö	0.24	**0.53***	0.16	0.13	0.13	0.27	0.27	0.22
Njalakjaure	0.38	0.13	-0.10	-0.26	-0.11	-0.20	-0.20	0.00
Skärsjön1	-0.42	0.09	0.19	0.43	0.60*	**0.56***	**0.56***	0.33
Stora Envättern	-0.27	-0.13	0.24	-0.30	-0.16	-0.31	-0.31	0.26
Stora Skärsjön	-0.02	0.38	-0.13	0.13	-0.20	-0.20	-0.20	0.17
Stora Tresticklan	-0.14	0.07	0.54	**0.87****	0.07	0.00	0.00	**0.74***
Storasjö	-0.16	-0.35	0.19	0.46	**0.67****	**0.60***	**0.60***	**0.50***
Svinarydsjön	-0.05	-0.22	0.04	0.46	-0.20	-0.24	-0.24	-0.16
Sännen	0.31	**0.64****	0.44	0.38	0.05	0.05	0.05	0.34
Tomeshultagölen	-0.47	-0.29	0.49	**0.60***	**0.64****	**0.64****	**0.64****	**0.54***
Ulvsjön	0.27	**-0.55***	-0.38	-0.29	-0.13	-0.24	-0.24	-0.40
Älgarydssjön	0.20	0.24	-0.23	-0.47	-0.38	-0.24	-0.24	-0.15
Örsjön	0.09	0.24	0.39	0.37	0.09	0.02	0.02	0.41
Örvattnet	-0.35	-0.20	0.06	0.38	0.09	0.05	0.05	-0.06
Övre Skärsjön	-0.38	-0.02	**0.64****	**0.65****	0.13	-0.20	-0.20	**0.65****
Group 2								
Bäen	**-0.53***	**-0.64****	-0.22	**-0.62***	0.24	0.31	0.31	-0.46
Rotehogstjärnen	-0.11	**-0.60****	0.44	-0.39	0.33	0.38	0.38	0.26
Group 3								
Abiskojaure	-0.09	0.04	0.09	0.20	**-0.34***	-0.33	-0.33	-0.01
Allgjuttern	-0.38	0.26	0.30	-0.20	**-0.33***	**-0.40***	**-0.39***	0.21
Bjännsjön	0.16	0.45	0.38	**0.58***	-0.24	-0.27	-0.27	**0.50***
Björken	0.05	0.45	**0.49***	0.11	-0.20	-0.05	-0.05	0.40
Brännträsket	-0.33	0.16	0.02	0.53	-0.20	-0.07	-0.07	0.14
Degervattnet	-0.39	**-0.56***	-0.51	-0.45	-0.17	0.11	0.11	**-0.59***
Dunnervattnet	0.07	-0.20	0.02	-0.02	0.16	0.11	0.11	-0.05
Edasjön	0.11	0.27	-0.26	0.27	-0.29	-0.42	-0.42	0.48
Ekholmssjön	0.20	0.42	**0.51***	0.11	-0.26	-0.31	-0.31	**0.55***
Fjärasjö	-0.20	-0.31	**0.47***	-0.08	0.26	0.20	0.20	0.23
Gipsjön	-0.02	0.42	**0.75****	0.43	0.13	0.09	0.09	**0.62****
Gosjön	-0.20	0.07	0.02	0.34	-0.07	-0.18	-0.20	-0.09

Table A1: continued

Lake/group	MILA Index	EPT(N)	EPT(T)	Medin's Index	Shannon diversity	Simpson Diversity	Simpson's Dominance	No. of taxa
Gryten	-0.24	0.29	0.33	0.19	-0.42	-0.51	**-0.51***	0.18
Humsjön	**-0.69****	0.20	-0.16	0.12	-0.20	-0.24	-0.24	-0.02
Hällsjön	-0.20	0.33	0.39	-0.36	-0.29	-0.42	-0.40	0.28
Hällvattnet	0.38	0.16	0.46	**0.74****	0.45	**0.49***	**0.49***	**0.55***
Hökesjön	0.24	-0.05	0.22	0.22	-0.05	-0.13	-0.13	0.26
Limmingsjön	0.09	-0.13	0.35	-0.25	**-0.56***	-0.45	-0.45	0.28
Louvvajaure	-0.29	0.13	0.29	0.03	0.33	0.31	0.29	0.26
Långsjön	**-0.64****	-0.33	0.35	0.08	-0.38	-0.18	-0.18	0.38
Mäsen	0.02	0.42	0.37	0.53	-0.24	-0.11	-0.11	0.22
N. Yngern	-0.20	0.13	**0.65****	0.08	-0.16	-0.24	-0.22	0.40
Rammsjön	-0.02	**-0.53***	-0.27	**-0.57***	-0.16	-0.09	-0.09	**-0.51***
Skärgölen	**-0.53***	**-0.56***	0.19	0.15	-0.13	-0.31	-0.31	0.23
Spjutsjön	0.20	0.16	0.38	0.31	0.42	0.42	0.42	0.34
Stensjön	-0.20	-0.16	-0.06	-0.31	-0.13	0.09	0.09	-0.28
Stor-Arasjön	0.31	0.45	0.46	**0.60***	0.05	-0.02	-0.02	**0.52***
Stor-Björsjön	0.07	0.14	-0.07	**0.70***	0.43	0.43	0.43	0.00
Stor-Tjulträsket	0.17	0.06	0.09	0.03	-0.17	-0.11	-0.08	0.08
Tväringen	0.07	0.09	-0.02	-0.06	-0.29	-0.29	-0.29	-0.07
Täftesträsket	0.27	**0.56***	**0.71****	**0.53***	**0.56***	0.38	0.40	**0.70****
Tängersjö	-0.27	0.42	0.31	-0.16	-0.05	-0.13	-0.13	0.41
Tärnan	-0.38	0.13	0.13	-0.04	0.04	0.20	0.20	-0.07
V. Rännöbodsjön	0.20	**0.56***	0.32	0.48	0.42	0.45	0.44	**0.55***
Valasjön	0.27	**0.53***	0.29	**0.65****	**0.64****	**0.56***	**0.56***	0.45
Västra Solsjön	0.44	0.28	-0.18	0.15	0.39	**0.56***	**0.56***	0.00
Group 4								
Bästeträsk	-0.02	-0.20	-0.42	**-0.55***	-0.02	0.16	0.16	-0.29
Dagstorpssjön	0.09	**0.49***	0.39	0.14	0.02	0.05	0.05	0.22
Fyrsjön	0.11	-0.17	0.03	0.06	0.00	0.03	0.03	0.00
Fysingen	0.35	0.20	0.42	0.26	0.27	0.13	0.13	0.20
Havgårdssjön	0.02	0.02	0.08	0.00	0.31	0.27	0.27	-0.13
Jutsajaure	0.09	0.16	0.46	0.34	0.27	0.16	0.16	0.30
Krageholmssjön	-0.33	-0.42	-0.37	-0.36	0.20	0.24	0.24	0.00
Krankesjön	0.45	-0.27	0.16	0.19	0.38	0.27	0.27	0.13
Lillsjön	**0.53***	0.45	**0.61***	0.40	-0.24	-0.20	-0.20	**0.50***
Pahajärvi	0.24	-0.07	-0.28	-0.07	-0.07	0.11	0.11	-0.37
Remmarsjön	0.38	0.22	**0.61***	**0.50***	0.02	-0.05	-0.05	**0.62****
Rundbosjön	-0.09	0.42	**0.71****	0.37	-0.02	-0.16	-0.16	**0.69****
Sangen	0.20	0.02	-0.07	0.08	0.29	0.42	0.42	-0.11
Siggeforasjön	-0.16	-0.02	0.09	-0.12	**-0.56***	**-0.56***	**-0.56***	0.16
Stora Lummersjön	0.29	-0.16	-0.15	-0.02	0.24	0.20	0.20	-0.21
Stor-Backsjön	-0.52	-0.43	-0.15	-0.58	-0.43	-0.24	-0.24	-0.45
Tångerdasjön	-0.42	-0.05	0.23	-0.42	-0.31	-0.27	-0.27	-0.22
Vuolgamjaure	0.07	**-0.56***	-0.18	-0.23	0.20	0.38	0.38	-0.13
Älgsjön	0.20	0.16	0.47	**-0.58***	0.09	0.05	0.07	**0.49***
Öljaren	-0.38	0.20	-0.07	**-0.59***	-0.20	-0.07	-0.04	**-0.60***

Table A2: Positive and negative trends (Kendall's tau) of acidity and diversity indices of all lakes (n = 89), divided into four groups (for clarification see text) with pH trends as a criterion for recovery for the years 1995 until 2005. Significant trends are shown in bold. MILA = Multimetric Index of Lake Acidity (for calculation, see Johnson & Goedkoop 2006), EPT (N) = # individuals of Ephemeroptera, Plecoptera and Trichoptera), EPT (T) = # taxa of Ephemeroptera, Plecoptera and Trichoptera). * = p< 0.05, ** = p< 0.01.

Lake/group	**MILA Index**	**EPT(N)**	**EPT(T)**	**Medin's Index**	**Shannon Diversity**	**Simpson Diversity**	**Simpson's Dominance**	**No. of taxa**
Group 1								
Alsjön	0.02	-0.09	-0.11	-0.11	0.20	0.27	0.27	-0.19
Fiolen	-0.42	-0.09	0.11	0.20	-0.20	-0.31	-0.31	0.09
Fräcksjön	-0.05	-0.13	-0.29	-0.18	0.24	0.13	0.13	-0.21
Grissjön	**-0.53***	-0.38	-0.17	0.20	0.05	0.18	0.18	0.29
Hagasjön	-0.16	-0.09	-0.15	-0.31	0.02	0.11	0.11	-0.09
Harasjön	-0.45	-0.24	-0.17	0.26	0.16	0.27	0.27	0.09
Hjärtsjön	-0.35	**-0.49***	0.33	-0.26	0.02	0.05	0.05	0.11
Härsvatten	0.07	-0.04	0.07	-0.03	0.42	0.45	0.45	-0.21
Lilla Öresjön	0.35	-0.20	**0.66****	**0.57***	0.02	-0.11	-0.09	**0.60***
Lillesjö	0.24	**0.53***	0.16	0.13	0.13	0.27	0.27	0.22
Njalakjaure	0.38	0.13	-0.10	-0.26	-0.11	-0.20	-0.20	0.00
Rotehogstjärnen	-0.11	**-0.60***	0.44	-0.39	0.33	0.38	0.38	0.26
Skärsjön1	-0.42	0.09	0.19	0.43	**0.60***	**0.56***	**0.56***	0.33
Stora Tresticklan	-0.14	0.07	0.54	**0.87****	0.07	0.00	0.00	**0.74***
Storasjö	-0.16	-0.35	0.19	0.46	**0.67****	**0.60***	**0.60***	**0.50***
Svinarydsjön	-0.05	-0.22	0.04	0.46	-0.20	-0.24	-0.24	-0.16
Sännen	0.31	**0.64***	0.44	0.38	0.05	0.05	0.05	0.34
Örsjön	0.09	0.24	0.39	0.37	0.09	0.02	0.02	0.41
Örvattnet	-0.35	-0.20	0.06	0.38	0.09	0.05	0.05	-0.06
Övre Skärsjön	-0.38	-0.02	**0.64****	**0.65****	0.13	-0.20	-0.20	**0.65****
Group 2								
Brunnsjön	0.02	0.05	0.20	0.46	**0.53***	0.42	0.42	0.33
Bysjön	0.16	-0.31	-0.04	-0.13	-0.45	-0.35	-0.35	-0.28
Bäen	**-0.53***	**-0.64***	-0.22	**-0.62***	0.24	0.31	0.31	-0.46
Dagarn	0.13	0.13	**0.60***	0.32	-0.16	-0.31	-0.31	**0.59***
Djupa Holmsjön	-0.31	0.35	0.13	-0.08	0.05	0.05	0.07	0.20
Fagertärn	0.38	**-0.49***	0.00	0.31	0.05	0.09	0.09	0.28
Granvattnet	0.02	-0.11	-0.44	-0.30	-0.16	-0.20	-0.20	-0.48
Hinnasjön	0.16	0.38	**0.51***	0.31	0.02	-0.02	-0.02	0.41
Stora Envättern	-0.27	-0.13	0.24	-0.30	-0.16	-0.31	-0.31	0.26
Stora Skärsjön	-0.02	0.38	-0.13	0.13	-0.20	-0.20	-0.20	0.17
Tomeshultagölen	-0.47	-0.29	0.49	**0.60***	**0.64****	**0.64****	**0.64****	**0.54***
Ulvsjön	0.27	**-0.55***	-0.38	-0.29	-0.13	-0.24	-0.24	-0.40
Älgarydssjön	0.20	0.24	-0.23	-0.47	-0.38	-0.24	-0.24	-0.15
Group 3								
Bjännsjön	0.16	0.45	0.38	**0.58***	-0.24	-0.27	-0.27	**0.50***
Brännträsket	-0.33	0.16	0.02	0.53	-0.20	-0.07	-0.07	0.14
Gipsjön	-0.02	0.42	**0.75****	0.43	0.13	0.09	0.09	**0.62****
Gosjön	-0.20	0.07	0.02	0.34	-0.07	-0.18	-0.20	-0.09
Gryten	-0.24	0.29	0.33	0.19	-0.42	**-0.51***	**-0.51***	0.18
Hällsjön	-0.20	0.33	0.39	-0.36	-0.29	-0.42	-0.40	0.28
Hökesjön	0.24	-0.05	0.22	0.22	-0.05	-0.13	-0.13	0.26
Jutsajaure	0.09	0.16	0.46	0.34	0.27	0.16	0.16	0.30
Krankesjön	0.45	-0.27	0.16	0.19	0.38	0.27	0.27	0.13
N. Yngern	-0.20	0.13	**0.65****	0.08	-0.16	-0.24	-0.22	0.40
Pahajärvi	0.24	-0.07	-0.28	-0.07	-0.07	0.11	0.11	-0.37
Rammsjön	-0.02	**-0.53***	-0.27	**-0.57***	-0.16	-0.09	-0.09	**-0.51***
Stor-Björsjön	0.07	0.14	-0.07	**0.70***	0.43	0.43	0.43	0.00
Stor-Tjulträsket	0.17	0.06	0.09	0.03	-0.17	-0.11	-0.08	0.08
Täftesträsket	0.27	**0.56***	**0.71****	**0.53***	**0.56***	0.38	0.40	**0.70****
V. Rännöbodsjön	0.20	**0.56***	0.32	0.48	0.42	0.45	0.44	**0.55***
Vuolgamjaure	0.07	**-0.56***	-0.18	-0.23	0.20	0.38	0.38	-0.13

Table A2: continued

Lake/group	MILA Index	EPT(N)	EPT(T)	Medin's Index	Shannon Diversity	Simpson Diversity	Simpson's Dominance	No. of taxa
Group 4								
Abiskojaure	-0.09	0.04	0.09	0.20	**-0.34***	-0.33	-0.33	-0.01
Allgjuttern	-0.38	0.26	0.30	-0.20	**-0.33***	**-0.40***	**-0.39***	0.21
Björken	0.05	0.45	**0.49***	0.11	-0.20	-0.05	-0.05	0.40
Bästeträsk	-0.02	-0.20	-0.42	**-0.55***	-0.02	0.16	0.16	-0.29
Dagstorpssjön	0.09	**0.49***	0.39	0.14	0.02	0.05	0.05	0.22
Degervattnet	-0.39	**-0.56***	-0.51	-0.45	-0.17	0.11	0.11	**-0.59***
Dunnervattnet	0.07	-0.20	0.02	-0.02	0.16	0.11	0.11	-0.05
Edasjön	0.11	0.27	-0.26	0.27	-0.29	-0.42	-0.42	0.48
Ekholmssjön	0.20	0.42	**0.51***	0.11	-0.26	-0.31	-0.31	**0.55***
Fjärasjö	-0.20	-0.31	**0.47***	-0.08	0.26	0.20	0.20	0.23
Fyrsjön	0.11	-0.17	0.03	0.06	0.00	0.03	0.03	0.00
Fysingen	0.35	0.20	0.42	0.26	0.27	0.13	0.13	0.20
Havgårdssjön	0.02	0.02	0.08	0.00	0.31	0.27	0.27	-0.13
Humsjön	**-0.69***	0.20	-0.16	0.12	-0.20	-0.24	-0.24	-0.02
Hällvattnet	0.38	0.16	0.46	**0.74****	0.45	**0.49***	**0.49***	**0.55***
Krageholmssjön	-0.33	-0.42	-0.37	-0.36	0.20	0.24	0.24	0.00
Lillsjön	**0.53***	0.45	**0.61***	0.40	-0.24	-0.20	-0.20	**0.50***
Limmingsjön	0.09	-0.13	0.35	-0.25	**-0.56***	-0.45	-0.45	0.28
Louvvajaure	-0.29	0.13	0.29	0.03	0.33	0.31	0.29	0.26
Långsjön	**-0.64***	-0.33	0.35	0.08	-0.38	-0.18	-0.18	0.38
Mäsen	0.02	0.42	0.37	0.53	-0.24	-0.11	-0.11	0.22
Remmarsjön	0.38	0.22	**0.61***	**0.50***	0.02	-0.05	-0.05	**0.62****
Rundbosjön	-0.09	0.42	**0.71****	0.37	-0.02	-0.16	-0.16	**0.69****
Sangen	0.20	0.02	-0.07	0.08	0.29	0.42	0.42	-0.11
Siggeforasjön	-0.16	-0.02	0.09	-0.12	**-0.56***	**-0.56***	**-0.56***	0.16
Skärgölen	**-0.53***	**-0.56***	0.19	0.07	-0.13	-0.31	-0.31	0.23
Spjutsjön	0.20	0.16	0.38	0.31	0.42	0.42	0.42	0.34
Stensjön	-0.20	-0.16	-0.06	-0.31	-0.13	0.09	0.09	-0.28
Stora Lummersjön	0.29	-0.16	-0.15	-0.02	0.24	0.20	0.20	-0.21
Stor-Arasjön	0.31	0.45	0.46	**0.60***	0.05	-0.02	-0.02	**0.52***
Stor-Backsjön	-0.52	-0.43	-0.15	-0.58	-0.43	-0.24	-0.24	-0.45
Tväringen	0.07	0.09	-0.02	-0.06	-0.29	-0.29	-0.29	-0.07
Tångerdasjön	-0.42	-0.05	0.23	-0.42	-0.31	-0.27	-0.27	-0.22
Tängersjö	-0.27	0.42	0.31	-0.16	-0.05	-0.13	-0.13	0.41
Tärnan	-0.38	0.13	0.13	-0.04	0.04	0.20	0.20	-0.07
Valasjön	0.27	**0.53***	0.29	**0.65****	**0.64****	**0.56***	**0.56***	0.45
Västra Solsjön	0.44	0.28	-0.18	0.15	0.39	**0.56***	**0.56***	0.00
Älgsjön	0.20	0.16	0.47	**-0.58***	0.09	0.05	0.07	**0.49***
Öljaren	-0.38	0.20	-0.07	**-0.59***	-0.20	-0.07	-0.04	**-0.60***