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Supplementary Information of

Lake eutrophication dynamics and indicators in the boreal zone: case examples from Finland

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Table S1.

Approaches and assessment methods used in studied Finnish lakes

Approach	Assessment method	Reference
Water Quality Monitoring & Chemical Analyses	• Nutrient Concentration Measurements, • Monitoring Nutrient Inputs, • Secchi Depth Measurement • Benthic Flux Measurements • Spectrophotometry for Nutrient Concentration Analysis • Chlorophyll-Phosphorus Relationship • Biogeochemical Analyses • Benthic Flux Measurements • Temporal Analysis of Nutrients in Ice-Free Period	Zhao et al. 2024b; Kauppila et al. 2012; Partanen et al. 2009; Mäkinen et al. 2010; Meriläinen et al. 2000; Jyväsjärvi et al. 2013; Ventela et al. 2007; Rissanen et al. 2023; Laakso et al. 2023; Leppäranta et al. 2018; Ruuhijärvi et al. 2010; Jilbert et al. 2020; Hynynen et al. 2004 ; Silvonen et al. 2021; Malve et al. 2007; Ekholm *et al.* 1997; Niinioja et al. 2003; Sarvala and Helminen 2023; Silvonen et al. 2023; Ekholm and Mitikka 2006; Ventelä et al. 2016
Paleolimnological Analysis	• Diatom-Inferred Total Phosphorus (DI-TP) Models • Chironomid-Inferred Total Phosphorus (TP) models • Tracking of Ephippia Production in Cladocera Populations as a Stress Response • Sediment Water Content Analysis • Sediment Chemistry Analysis • Analysis of Fossil Assemblages • Analysis of Sedimentary Aluminum Accumulation • Sediment Trap Experiments • Benthic Quality Index (BQI) • Transfer Function Models • Midge-Based Hypolimnetic Oxygen Transfer Functions	Zhao et al. 2024a; Kauppila et al. 2012; Mäkinen et al. 2010; Meriläinen et al. 2000; Kauppila and Valpola 2003; Meriläinen et al. 2003; Kauppila et al. 2002; Nevalainen and Luoto 2013; Valpola et al. 2007; Rissanen et al. 2023; Laakso et al. 2023; Jilbert et al. 2020; Sarvala et al. 2020; Shala et al. 2014; Tammelin et al. 2019; Luoto et al. 2017; Silvonen et al. 2021; Luoto et al. 2019; Turkia and Lepistö 1999; Nevalainen et al. 2011; Niinioja et al. 2003; Weckström et al. 2015; Nevalainen and Luoto 2017; Ventelä et al. 2016; Zhao et al. 2024b; Miettinen et al. 2005; Luoto and Ojala 2014; Luoto and Nevalainen 2011; Kauppila et al. 2016
Biological and Ecological Assessments	• Microscopic Analysis • Gill Netting and Electrofishing Surveys • Biodiversity Surveys • Monitoring and sampling of Submerged Plants, Phytoplankton, Chl-a, Zooplankton, and Fish • Community Composition Analysis • Functional and Phenotypic Indices • Analyzing Zooplankton Biomass and Fish Population Impacts on Nutrient Cycles • Microbial Community Analysis • Denaturing Gradient Gel Electrophoresis (DGGE) • Canonical Correspondence Analysis (CCA)	Zhao et al. 2024a; Voutilainen and Huuskonen 2010; Sarvala et al. 2020; Hynynen et al. 2004; Karels and Niemi 2002; Malve et al. 2007; Nevalainen et al. 2011; Niinioja et al. 2003; Rask et al. 2003; Haukka et al. 2006; Ptacnik et al. 2008; Zhao et al. 2024b; Luoto and Nevalainen 2011; Zhao et al. 2024b; Kauppila et al. 2012; Mäkinen et al. 2010; Valpola 2003; Meriläinen et al. 2003

Table S2.

Characteristics and coordinates of the case studies

Number	lake Name	Longitude	Latitude	Depth (m)	Area (km^2)	Summer mixing regime
1	Littoistenjärvi	22.39	60.45	2.2	0.44	Polymictic
2	Hiidenvesi	24.19	60.37	6.4	29.3	Stratified
3	Kytäjärvi	24.64	60.61	3.8	0.8	Polymictic
4	Kirmanjärvi	27.31	63.48	5–10	NA	Polymictic
5	Näsijärvi	23.75	61.70	14.1	256	Stratified
6	Pyhäjärvi	23.58	61.47	5.5	155	Stratified
7	Nuasjärvi	28.09	64.15	8.5	96	Stratified
8	Jormasjärvi	28.16	64.06	5.8	21	NA
9	Kolmisoppi	27.61	62.87	8	2	Stratified
10	Lappajärvi	23.64	63.14	7.5	149	Stratified
11	Kaljasjärvi	21.63	61.03	4.5	2.5	NA
12	Jyväsjärvi	25.78	62.24	5.8	3.4	Stratified
13	Valkjärvi	25.44	60.48	<10	1.5	Polymictic
14	Mallusjärvi	25.59	60.75	<8	5.4	Polymictic
15	Hormajärvi	28.06	62.78	8.7	3.5	Stratified
16	Pyhäselkä	25.65	61.65	10	361	Stratified
17	Pääjärvi	25.13	61.07	13	13.4	Stratified
18	Vähäjärvi	23.65	61.46	6.8	108	Polymictic
19	Vanajanselkä	24.25	61.16	7.7	103	Stratified
20	Äimäjärvi NB[a]	24.15	61.06	2	8.5	Polymictic
21	Äimäjärvi SB[b]	24.15	61.05	3	8.5	Stratified
22	Enonselkä	24.52	61.54	6.8	26.8	Stratified
23	Tiiläänjärvi	25.70	60.54	<10.5	2.1	Polymictic
24	Lievestuoreenjärvi	26.13	62.31	7.6	18.3	Stratified
25	Loitsana	29.28	67.80	NA	6.2	Stratified
26	Saarisjärvi	26.88	63.67	2.6	0.88	Polymictic
27	Näläntöjärvi	26.48	63.82	0.7	12.9	Polymictic
28	Porovesi	27.12	63.55	8.6	22	Stratified
29	Haapajärvi	26.97	63.57	<8.5	5–25	Polymictic
30	Kuortaneenjärvi	23.47	62.82	3.3	5–25	Stratified
31	Tuusulanjärvi	25.06	60.44	3.2	5–25	Polymictic
32	Kymijärvi	25.81	60.97	2.8	6.5	Stratified
33	Aneriojärvi	23.57	60.37	<4.12	1.24	Polymictic
34	Rusutjärvi	24.97	60.43	<3.5	5	Polymictic
35	Lapinjärvi	25.28	62.05	1.96	5.16	Polymictic
36	Enäjärvi	24.38	60.35	3.2	4.9	Polymictic
37	Kirkkojärvi	22.55	60.62	2.9	1.5	Polymictic

Number	lake Name	Longitude	Latitude	Depth (m)	Area (km^2)	Summer mixing regime
38	Köyliönjärvi	22.35	61.09	2.6	5–25	Polymictic
39	Martinjärvi	24.40	62.40	1.6	1.07	Polymictic
40	Iso Kivijärvi	24.50	62.41	1	1.5	Polymictic
41	Vesijärvi	25.59	61.03	6.8	26	Stratified
42	Hampträsk	25.25	60.28	<2.5	0.038	Polymictic
43	Pieni Majaslampi	24.58	60.32	6.6	0.011	Polymictic
44	Lehmälampi	24.60	60.33	8.1	0.051	NA
45	Lappajärvi	23.50	63.00	<36	145	Stratified

[a] Northern basin (NB)
[b] Southern basin (SB)

Table A.3

Symptoms of eutrophication in studied Finnish lakes

Symptom of eutrophication	Reference
Cyanobacterial bloom	Kauppila et al. 2012; Meriläinen et al. 2000; Laakso et al. 2023; Leppäranta et al. 2018; Ruuhijärvi et al. 2010; Jilbert et al. 2020; Sarvala et al. 2020; Tammelin et al. 2019; Maeda et al. 2019; Silvonen et al. 2021; Malve et al. 2007; Ekholm et al. 1997; Rask et al. 2003; Sarvala and Helminen 2023; Haukka et al. 2006; Ptacnik et al. 2008; Ekholm and Mitikka 2006; Ventelä et al. 2011; Ventelä et al. 2016; Taipale et al. 2020; Luoto and Nevalainen 2011
Diatom community change	Zhao et al. 2024b; Kauppila et al. 2012; Mäkinen et al. 2010; Meriläinen et al. 2000; Kauppila and Valpola 2003; Meriläinen et al. 2003; Kauppila et al. 2002; Valpola et al. 2007; Hynynen et al. 2004; Shala et al. 2014; Tammelin et al. 2019; Luoto et al. 2017; Malve et al. 2007; Turkia and Lepistö 1999; Niinioja et al. 2003; Weckström et al. 2015; Nevalainen and Luoto 2017; Ptacnik et al. 2008; Ventelä et al. 2016; Tammelin et al. 2017; Miettinen et al. 2005; Kauppila et al. 2016
Fish community change	Kauppila et al. 2012; Jyväsjärvi et al. 2013; Voutilainen and Huuskonen, 2010; Ruuhijärvi et al. 2010; Jilbert et al. 2020; Karels and Niemi 2002; Malve et al. 2007; Niinioja et al. 2003; Rask et al. 2003; Sarvala and Helminen 2023; Nürnberg et al. 2012; Ventelä et al. 2016; Taipale et al. 2020
Macrophyte Change	Zhao et al. 2024b; Kauppila and Valpola 2003; Voutilainen and Huuskonen 2010; Ruuhijärvi et al. 2010; Jilbert et al. 2020; Sarvala et al. 2020; Suhonen 2021; Ventelä et al. 2016
Zooplancton community change	Nevalainen and Luoto 2013; Ruuhijärvi et al. 2010; Jilbert et al. 2020; Luoto et al. 2019; Malve et al. 2007; Nevalainen et al. 2011; Rask et al. 2003; Nevalainen and Luoto 2017; Ventelä et al. 2011; Ventelä et al. 2016; Taipale et al. 2020
Chironomid community change	Zhao et al. 2024b; Meriläinen et al. 2000; Meriläinen et al. 2003; Luoto 2013; Jyväsjärvi et al. 2013; Leppäranta et al. 2018; Hynynen et al. 2004; Shala et al. 2014; Luoto et al. 2017; Luoto et al. 2019; Turkia and Lepistö 1999; Nevalainen et al. 2011; Nevalainen and Luoto 2017; Luoto and Ojala 2014; Luoto and Nevalainen 2011; Kauppila et al. 2016

Symptom of eutrophication	Reference
Increased chlorophyll a	Zhao et al. 2024a; Leppäranta et al. 2018; Ruuhijärvi et al. 2010; Luoto et al. 2017; Maeda et al. 2019; Silvonen et al. 2021; Malve et al. 2007; Turkia and Lepistö 1999; Niinioja et al. 2003; Rask et al. 2003; Weckström et al. 2015; Sarvala and Helminen 2023; Nürnberg et al. 2012; Seip et al. 2000; Haukka et al. 2006; Silvonen et al. 2023; Ptacnik et al. 2008; Ekholm and Mitikka 2006; Ventelä et al. 2011; Ventelä et al. 2016; Tammelin et al. 2017; Taipale et al. 2020; Luoto and Ojala 2014; Luoto and Nevalainen 2011
Increased P release from sediment	Zhao et al. 2024a; Zhao et al. 2024b; Partanen et al. 2009; Mäkinen et al. 2010; Kauppila et al. 2002; Laakso et al. 2023; Ruuhijärvi et al. 2010; Jilbert et al. 2020; Sarvala et al. 2020; Tammelin et al. 2019; Luoto et al. 2017; Silvonen et al. 2021; Karels and Niemi, 2002; Nevalainen et al. 2011; Ekholm et al. 1997; Niinioja et al. 2003; Silvonen et al. 2023; Miettinen et al. 2005; Luoto and Nevalainen 2011
Decreased clarity	Mäkinen et al. 2010; Nevalainen and Luoto 2013; Jyväsjärvi et al. 2013; Ruuhijärvi et al. 2010; Sarvala et al. 2020; Hynynen et al. 2004; Tammelin et al. 2019; Maeda et al. 2019; Silvonen et al. 2021; Karels and Niemi 2002; Malve et al. 2007; Niinioja et al. 2003; Rask et al. 2003; Nevalainen and Luoto 2017; Sarvala and Helminen 2023; Ekholm and Mitikka 2006; Ventelä et al. 2011; Ventelä et al. 2016; Tammelin et al. 2017; Luoto and Ojala 2014; Luoto and Nevalainen 2011; Kauppila et al. 2016
Oxygen depletion	Zhao et al. 2024a; Meriläinen et al. 2000; Meriläinen et al. 2003; Leppäranta et al. 2018; Ruuhijärvi *et al.* 2010; Jilbert et al. 2020; Sarvala et al. 2020; Hynynen et al. 2004; Luoto et al. 2017; Silvonen et al. 2021; Luoto et al. 2019; Malve et al. 2007; Nevalainen et al. 2011; Ekholm et al. 1997; Nevalainen and Luoto 2017; Sarvala and Helminen 2023; Nürnberg et al. 2012; Silvonen et al. 2023; Ekholm and Mitikka 2006; Luoto and Ojala 2014; Luoto and Nevalainen 2011; Kauppila et al. 2016

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