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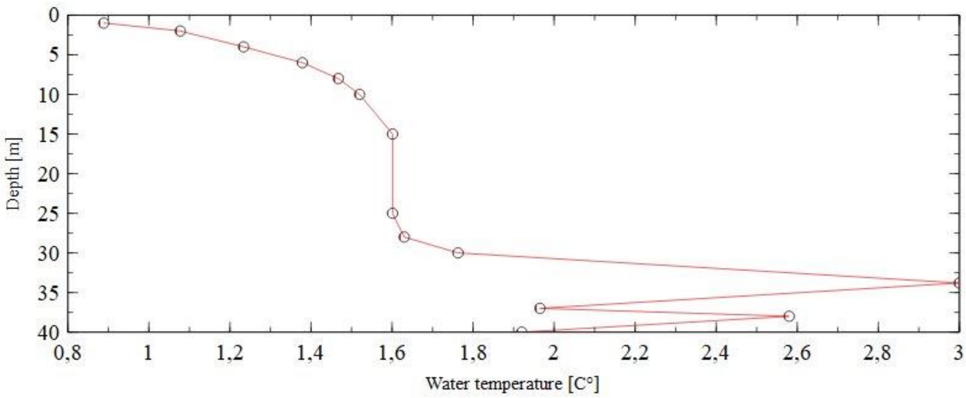
Long-term trend of surface and bottom water temperature of Swedish lakes during 1979-2016

– Changes in lake water stratification

Astrid Max



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Long-term trend analysis of surface and bottom water temperature of Swedish lakes during 1979–2016 – Changes in lake water stratification

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"The real voyage of discovery consists not in seeking new landscapes, but in having new eyes."
Marcel Proust

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Abbreviations

BS-ratio	Bottom-surface water temperature ratio
BWT	Bottom water temperature
Cat	Category (referring to depth category of water samples 1, 2, 4 and 6)
IVM	Institutionen för Vatten och Miljö (Institute for Water and Environment)
MK	Mann-Kendall
MLR	Multiple linear regression
MVM	Mark-Vatten Miljöcentrum (Environmental Center for Soil and Water)
n.a.	Not applicable
n.r.	No result
SLU	Sverige Landbruksuniversitet Uppsala (Swedish University of Agricultural Science)
SMHI	Swedish Meteorological and Hydrological Institute
SWT	Surface water temperature
SWEDAC	Styrelsen för ackreditering och teknisk kontroll (Swedish Board for Accreditation and Conformity Assessment)

Abstract

Long-term studies on lakes are of utmost importance to detect effects of climate change on lake ecosystems. As air temperatures are rising, the effect on lake water temperature, and therefore lake internal mixing processes is likely to alter the current state of the ecosystem.

In this thesis, water temperature changes in 145 Swedish lakes for the months February, April, August and September were investigated for the period of 1979-2016. Changes in temperature and chemical data in surface water, and bottom water were analyzed using seasonal Mann-Kendall trend test and Theil-Sen slopes. Moreover, trends on bottom-surface ratios were calculated to derive information on changes in stratification strength.

Based on the long-term observations of at least 10-year data coverage, water temperature trends for 83 lakes were detected. The results underlined the possibility of a prolonged stratification duration with an early onset in April and a shift of turnover events into the late autumn. Moreover, a correlation analyses with the calculated trends of water temperature and chemical parameters showed dependencies between absorbance, total organic carbon and water temperature. In addition, a multilinear regression highlighted the impact of air temperature, and absorbance on water surface temperature during April, August, and September.

To gain further insights into the inlake effects of temperature changes, it is recommended to intensify the sampling of temperature profiles and chemical parameters, and to also include more lakes of northern Sweden. Continuous monitoring throughout the year is important to verify the changes of temporal shifts of stratification occurrence, and to gain knowledge about the vertical extension of the mixolimnion. Future research should also include the effect of wind force to explain stratification strength, and turnover periods more accurately.

Popular Scientific Summary

In the past decades a global warming of air temperature has been detected. As temperature can define boundaries of livable space, our daily life is affected by changes in temperature; even life in lakes can be influenced by these changes. Therefore, in this thesis I focused on the temperature changes in Swedish lakes over the time period of 1979–2016 by calculating trends. Those can give an idea of future conditions, and thus make it possible to develop measurements to adapt.

In lakes a temperature gradient from shallow waters to deep waters is common. We can experience this when taking a bath in a lake during summer. While the water at the surface seems quite comfortable to swim, our feet already feel the colder water in the deeper water layer. Especially while diving the so called thermocline can be experienced. It is the layer in which the temperature drops from warm surface water, also called the epilimnion, to cold water close to the bottom of the lake. The latter is called the hypolimnion. The temperatures can also be equal or almost equal within the water column. In this case, chemicals within the lake like oxygen, or nutrients like phosphorus and nitrogen can mix easily within the water column. These mixing periods are common during the spring and the autumn, whereas the layers of warm and cold water, the so called stratification period, is common during winter and summer. If the warming of air temperature causes water temperature to rise, the pattern of mixing events and stratification can be altered. Consequently, the oxygen and nutrient distribution which is important for life under water would be changed. This could cause impossible living conditions for some organisms.

The data showed that in the Swedish lakes the stratification period was getting stronger in spring, summer, and early autumn. Therefore, a decline in oxygen in the deep water was likely to occur as it could have been consumed by the organisms living there without getting replenished through mixing of the water layers. Also, increasing temperatures were common during these season in surface waters, and in some cases the entire water column was warming. In February, which represents the winter season here, water temperatures were falling in surface water, whilst in some lakes bottom water was warming.

Water temperature and mixing processes depend on many factors, but this study focused on air temperature, and the effect of the colour of the water. As darker colour reflects less sunlight, the particles causing the colour might have increased the process of lake warming. Dependencies between these factors were seen in the datset by applying a correlation analysis. Yet, more studies need to be made to detect which other main factors were responsible for the temperature increase, and change in mixing processes; and which would be the resulting consequences for the ecosystems of these lakes specifically.

1 Introduction

Climate change is one of the most worrying environmental topics of our time. As changing climate patterns affect our environment, the stability of current systems is challenged (Hondzo and Stefan 1993)(IPCC 2014). Therefore, local and international decision makers need to plan ahead by using prediction models in order to start mitigation and adaptation plans. As the 5th IPCC report states: "*Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems*" (IPCC 2014). These impacts will also stress water resources, both oceanic and limnic systems.

Limnic systems (inland water systems) are essential to everyday life and are used for recreational activities, fish production, drinking water supply, and other ecological services. They are also important connectors between ecological zones (river deltas, wetlands) and can protect from flooding when managed correctly (Aladin et al. 2005). As with any other environmental system, they are affected by climate change through several pathways. Models and long term analysis of lakes around the world depict changes such as temporal ice-cover duration, mixing behavior, temperature within the lakes (Woolway and Merchant 2019; Coats et al. 2006; Peeters et al. 2002; O'Reilly et al. 2015), and runoff into rivers (Matti et al. 2017; Arheimer and Lindström 2015; Berghuijs, Woods, and Hrachowitz 2014; Olsson et al. 2016).

Climate change predictions for Sweden include a significant increase in air temperature during all seasons and in all RCP (representative concentration pathways) scenarios which were elaborated by the IPCC (Intergovernmental Panel on Climate Change) for future climate models. For the period 2071–2100 compared to 1971–2000, the highest increase in temperature of 6–7 °C is predicted to occur during the winter and in the northernmost regions of Sweden. For the summer period (mainly +3°C) and the south (+1–2°C) a relatively small change compared to other seasons is predicted (Fig. 1). It should be noted that the change in air temperature not only compared to preindustrial levels, but also to the comparativley higher air temperature mean over the years 1961–1990 is predicted to increase in Sweden by 2–4°C until the year 2100 (Fig. 2). This exemplifies the extreme air temperature rise over a geologically short period of time which has to be endured by environmental systems (SMHI n.d.; Allen et al. 2018).

Information about aquatic systems and their probable changes of ecological state is generally limited. Yet, the Millennium Ecosystem Assessment (Aladin et al. 2005) described inland aquatic systems as one of the most vulnerable ecosystems due to various factors, including climate change. Despite the diversity in findings of influencing factors, there is an agreement on the response of lake water temperature to meteorological conditions which in turn shows a strong influence on water quality and the internal ecosystem (Adrian et al. 2009; Woolway and Merchant 2019; Boehrer and Schultze 2008; Tanentzap et al. 2008; Hondzo and Stefan 1993). For example, dissolved gases in lake water depend upon particulate organic matter, biological activity and water temperature. Furthermore, the removal efficiency of dissolved organic material like phosphorus, nitrogen and carbon through microbial activity in the water is dependent on temperature next to the redox potential of the water (Jørgensen 2013). Lake´s temperature profiles from the epilimnion (surface waters) towards the hypolimnion (bottom water) vary throughout the year by providing mixing opportunities to distribute oxygen, nutrients and other chemicals within the lake. Changes can therefore alter the composition of species, induce chemical reactions at the water sediment layer and affect the productivity of a lake (Wu et al. 2014; Schwefel et al. 2019).

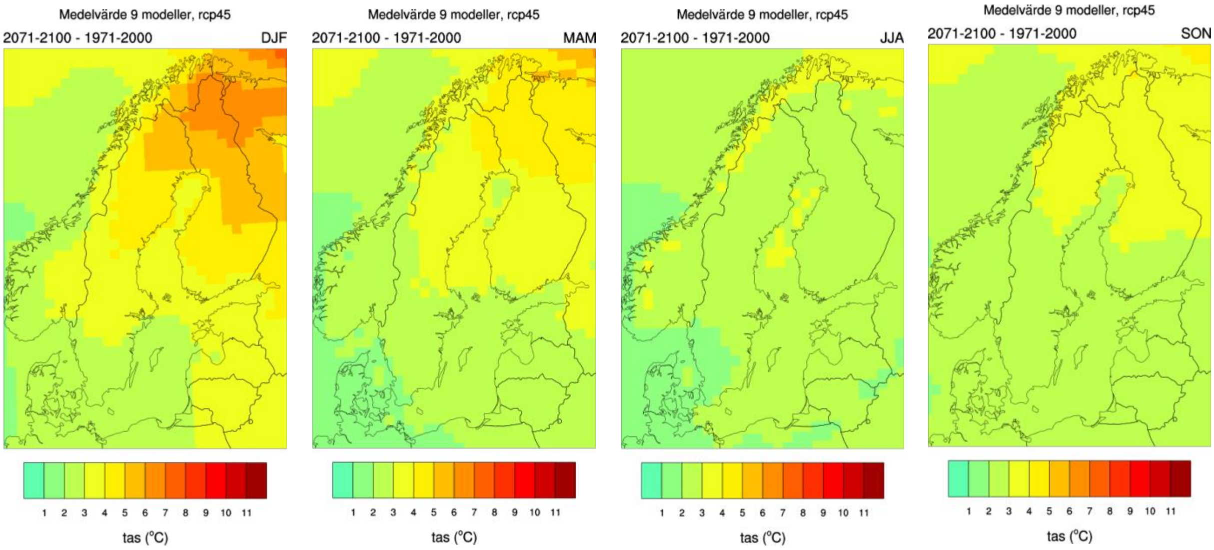


Figure 1: Calculated change in mean temperature (°C) for the period 2071-2100 compared with 1971-2000 for all seasons (left to right: winter, spring, summer, autumn) (SMHI (n.d.). Climate Scenarios. Accessed online at http://www.smhi.se/en/climate on 20.06.2019).

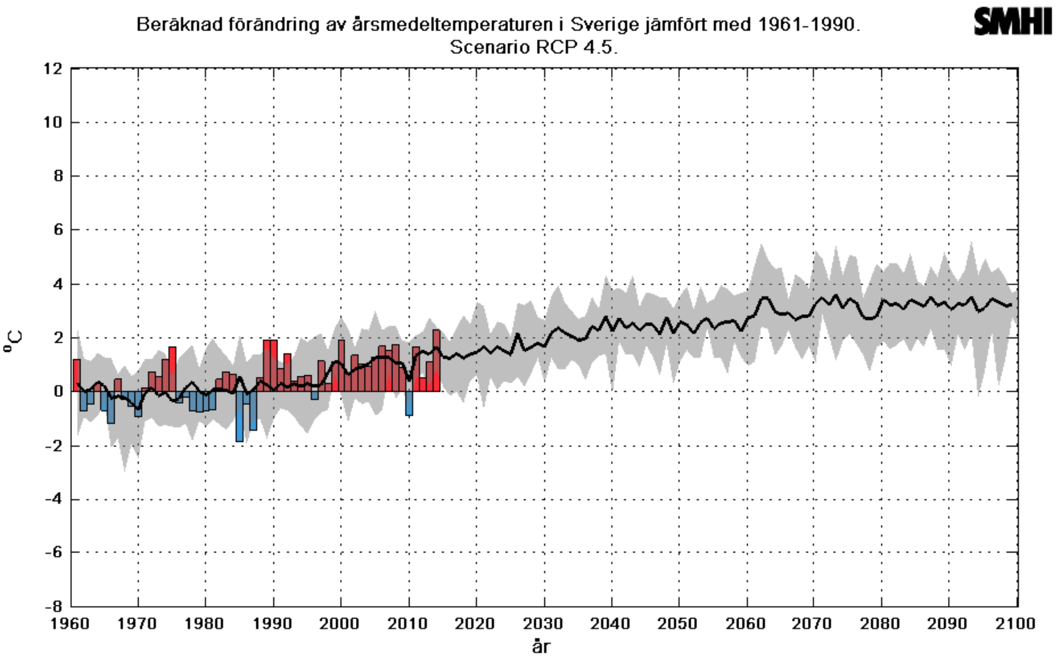


Figure 2: Calculated change with RCP 4.5 scenario for mean temperature in winter (°C) in Sweden during the years 1961-2100 compared to observed data (mean for 1961-1990), (red bars: temperatures above normal; blue bars: temperature below normal; x-axis indicates years), (SMHI (n.a.). Climate Scenarios. Accessed online at http://www.smhi.se/en/climateon 20.06.2019).

Due to the potential effects on chemistry and biota, the role of lake water warming is becoming more important every day. Projects are starting all over the world to analyze possible warming trends and their effects on lake ecosystems and subsequently the human environment. The Rensselaer Polytechnic Institute (RPI) in New York for example, started a grand project in 2015 on modelling the effects of climate change on lake water temperature and water chemistry, coupling it with the carbon cycle to predict future changes in carbon storage or release by lakes (Heathcote et al. 2015; Rensselaer Polytechnic Institute (RPI) 2016).

Several lakes throughout the northern hemisphere have shown warming trends in their surface water temperatures (SWT) through the use of validated simulations (Hondzo and Stefan 1993; Peeters et al. 2002). An increase in the mean SWT by 0.015 °C yr^{-1} was found in Lake Tahoe in the United States over a span of 32 years (1970–2002) (Coats et al. 2006). In nine Polish lakes, an increase of 0.39 °C dec^{-1} for the maximum water temperature was detected for the period 1971–2015. Of these nine lakes, those with larger depths and water transparency were warming up slightly faster (0.41 °C dec^{-1}) than the rest (Ptak, Sojka, and Kozłowski 2019). O'Reilly et al. (2015) found a global temperature increase of summer SWT by 0.34°C dec^{-1} based on 245 lakes (with in situ and satellite data) between 1985 and 2009.

Using 635 lakes worldwide, a modelled SWT for the period 2080–2100 predicted a warming of 1.1 ± 0.4 °C and 2.3 ± 0.6 °C under climate scenarios RCP 2.0 and 6.0, respectively. At the individual lake level, warming could be even higher, reaching up to 5.4 ± 1.1 °C under RCP 6.0. Of these studied lakes, 99% were projected to increase in mean SWT under RCP 2.6 (Woolway and Merchant 2019).

More time intensive sampling of whole lake water profiles or deep-water layers resulted in far less evidence for changing temperature within deeper water layers compared to surface waters. Still, some authors found or simulated temperature changes. Hondzo and Stefan (1993) modelled hypolimnetic water to warm by 3.1 °C in shallow lakes, to decrease by -1.1 °C in deep lakes and by -1.7 °C in lakes with medium depth and small surface area. Yet, in lakes with medium depth but large area they predicted a warming by 2.0 °C in a world of $2xCO_2$ according to the GISS climate model. The model was validated for 27 lake classes from Minnesota in the United States, and fits findings of other studies which also predict a cooling or a moderate warming of the hypolimnion in deep lakes (Stefan, Fang, and Hondzo 1998; Hostetler and Giorgi 1995; Müller 2010; Komatsu, Fukushima, and Harasawa 2007). Peeters et al. (2002), however, modelled an increase in the hypolimnion temperature of 1.4 °C at an air temperature increase of 4 °C in Lake Zürich in Switzerland over a 50 year time period (1948–1997). This increase was almost as large as the predicted increase for the epilimnion water.

These changes in temperatures of the epilimnion and hypolimnion layers will affect water stratification, which is predicted to shift its timing of development within a year and to intensify mainly during the summer (Stefan, Fang, and Hondzo 1998; Jankowski et al. 2006; Peeters et al. 2002; Coats et al. 2006; Woolway and Merchant 2019). Even for spring, hypolimnion water is likely influenced by the heat storage of the previous year which again will affect early year mixing processes (Peeters et al. 2002).

For an understanding of lake water temperature changes in Sweden this trend analysis on water temperature was carried out. To the current knowledge of the author this thesis study on lake water stratification is the first one in Sweden. Web of Science has not given even five results of publications on lake water temperature changes during the last century up to today (January 2000 – June 2019). So far, most studies of lake warming have been performed on surface measurements or on thermal structures in single lakes. Water temperature has been integrated in some studies which had other focal points; e.g. diatoms, nitrogen (N), phosphorus (P) compositions, or other nutrients, however, it has never been addressed in large scale studies and almost never by investigating the linkage between climate change and lake water stratification in particular. Lake Erken in Sweden, as the only lake, has been mentioned as an example for studies including lake water temperature/stratification and climate change (Blenckner, Omstedt, and Rummukainen 2002; Weyhenmeyer 1996).

This study addressed whether there are long-term temperature trends in 145 lakes across Sweden, with the hypotheses being that surface water temperature (SWT) will increase with increasing air temperature, but the temperature in deep water, close to the lake bottom, may decrease during sumer due to stronger stratification and less heat transfer to the bottom water. The lakes studied included lake basins of large Swedish lakes which were treated as individual systems and are referred to as lake basins in the following.

Changes detected for lake water temperature were then linked to external and internal drivers, where possible. These drivers included air temperature lake morphometry and selected chemical parameters for the period 1979–2016. Trend analysis using Mann-Kendall trend test and Theil-Sen slope estimator, bivariate correlations, and simple and multiple linear regression (MLR) were used to detect changes and relate them to potential drivers.

2 Lake water stratification and temperature changes

"A lake is a body of water located at a certain latitude, longitude, and altitude, occupying depressions in a watershed, or is a result of damming a river"(Jørgensen 2013). Lakes are in continuous exchange with their surrounding environment. Inflows of gases (oxygen, nitrogen, carbon dioxide, etc.) and heat/cold from the atmosphere, organic matter, sediment, and metals from the watershed system change the biochemical composition of lake water. Wind stress causes turbulences at the water surface and solar radiation enhances the photosynthesis of algea. The ecology of a lake is dependent on the meteorological conditions of the watershed, which impacts the lake environment in several ways; e.g. streamwater inflow, net input of nutrients from surface water flow, strength of wind development. Changes within a lake due to the influencing variables are detectable on a very small timescale (hourly/daily), however, those are superimposed by seasonal meteorological changes (Jørgensen 2013).

According to Adrian et al. (2009) lakes rapidly respond to changes and are sensitive to climate. They found significantly increasing epilimnion temperatures in twelve lakes they studied. Moreover, they summarized key response variables that indicate climate change:

- precipitation,
- air temperature,
- water temperature,
- wind speed,
- cloud cover,
- relative humidity,
- turbulent kinetic energy,
- dissolved organic carbon.

Factors playing a major role on lake water temperature are air temperature, wind speed, cloud cover, and relative humidity. To derive in depth information on temperature shifts in lakes, epilimnetic temperatures, the duration of summer stratification (temperature differences within a lake profile), and the depth of a thermocline are good indicators. For the latter two indicators, continuous sampling is necessary with a high time and space resolution to derive information on stratification as the onset, duration, and strength can vary (Adrian et al. 2009). In best case, data is collected at a daily basis and covering different areas of a lake; the amount of sample points depend on the lake size and morphology.

The mechanisms in internal lake structure that influence nutrient exchanges, and the possible affects of climate change on lakes and their ecosystems, especially in Sweden, are addressed in the following.

2.1 Lake water stratification

Stratification due to different densities within the water are common in many lakes, at least for some periods throughout the year. Some lakes, especially deep lakes, can be even permanently stratified. Otherwise, changes in density gradients throughout the year and meteorological forces break up stratification patterns and lead to mixing processes. Both physical and chemical influences can cause density gradients. The dominant system depends on each lake specifically (Boehrer and Schultze 2008). Additionally, complex physical processes within lakes influence partial stratification and variances in the location of stratification within the same lake. These internal seiches (standing internal waves) include Rossby waves, water intrusions from rivers and lake basins into another basin, and eddy currents (Imboden 1990). These factors have not been considered in detail in this work as they were not detectable in the available data. Despite large variations of stratification patterns in lakes, the prototype is described here to gain an understanding for mixing procedure within lakes.

2.1.1 Thermal stratification

Throughout a year, lake surface water shows a distinct cycle of temperature variations, mostly linked to solar radiation heating the surface layer; with the excpetion of tropical areas, where almost constant radiation and heat can decrease variation in temperature patterns. Additionally, in- and outflow of groundwater and surface water, precipitation, and thermal exchange at the sediment-water zone can influence water temperature.

The annual cycle of thermal stratification (example Fig. 3) starts with the ice-breaking (in high latitudes or altitudes) after winter. The common stratification of colder water at the surface and warmer temperatures in deeper water layers is slowly dissolved by equalizing the densities of the water layers. The spring sun then warms up the surface water, slowly distributing heat along the depth gradient via diffusive heat transfer. However, to transport heat over the distance of one meter in water takes approximately one month. Therefore, an important factor for mixing heat are wind forces at the water surface.

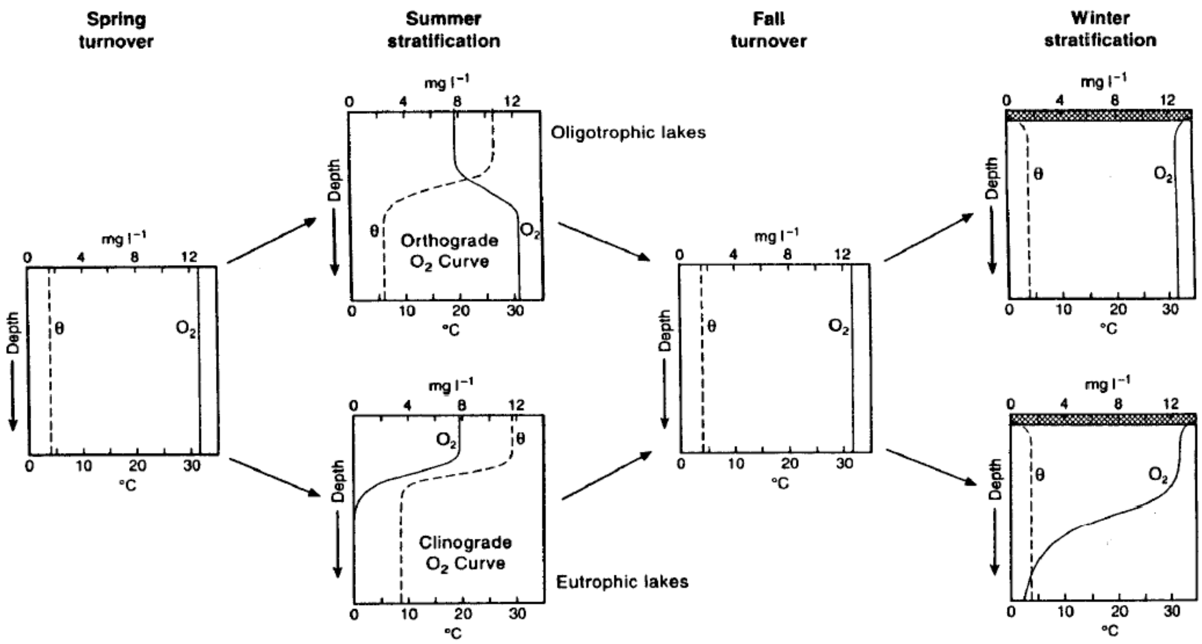


Figure 3: Idealized vertical distribution of oxygen concentration and temperature during the four main seasonal phases of an oligotrophic and a eutrophic dimictic lake (Imboden 1990).

The maximum water density is reached at 4°C. It is a common temperature in stratified deep lakes or generally during winter stratification within the hypolimnion, the deepest layer of a stratification structure. When surface water warms up to 4°C during the spring, the density gradient between the surface layer (epilimnion) and the hypolimnion can reach 0 at equal temperature distribution.

No stratification is present and the interchange of nutrients between water layers is facilitated. When solar radiation starts to get stronger, the surface water also begins warming up until it reaches more than 4°C. A reverse temperature gradient compared to winter stratification establishes until it reaches its maximum during summer stratification. In Sweden summer stratification is usually reached during August. As autumn starts and the radiation is decreasing, surface waters start to cool and the gradient decreases again until it reaches winter stratification. The warm layer during summer stratification, the epilimnion, is separated from the cooler hypolimnion by the metalimnion which is characterized by a sharp temperature decline (thermocline). All layers vary in their extension and can increase or reduce in depth throughout the year (Boehrer and Schultze 2008).

A characteristic difference between the epilimnion and the hypolimnion is their interaction with the atmosphere. Whilst the epilimnion is exchanging both heat and gases with the atmosphere, the hypolimnion remains mostly isolated from exchanges during stratification periods. Exchanges with its surrounding happen mostly at the sediment-water interface. However, chemical precipitation and sedimentation of particles can lead to some small exchanges between the surface water and hypolimnion, even during stratification periods. These exchanges are, however, rather small. Another characteristic is light penetration which in most cases only reaches the epilimnion and is lacking in the meta- and hypolimnion (Boehrer and Schultze 2008).

During the mixing states of lakes, nutrients from the hypolimnion can reach the epilimnion, as can metals and other substances from the sediment, while oxygen from the epilimnion reaches deeper water. A perfectly homogenized state with only one layer is called a mixolimnion.

According to their mixing pattern, lakes have been classified regarding their:

1) Extension of mixing process
   - Holomictic: Entire mixing of the lake water body at least once per year
   - Meromictic: Only part of the lake water body is mixing
   - Amictic: Permanent ice cover, therefore generally no mixing

2) Time recurrence of mixing processes in <u>holomictic lakes</u>:
   - Oligomictic: Mixing occurs irregularly, less than once per year, mainly due to extreme events
   - Monomictic: Mixing occurs once per year
   - Dimictic: Mixing occurs twice per year
   - Polymictic: Shallow lakes without a hypolimnion, mixing can occur several times a year/day

Further sub-classes have been discovered and can be found in the respective literature.

2.1.2 Chemical stratification

Beside the thermal stratification, salts, dissolved matter and other chemical substances can impact water density and thus cause stratification, and even superimpose thermal stratification. The higher the salt concentration, the higher the density. Therefore, salty water can reach lower temperatures than 4°C. A typical sign of lakes with chemically influenced stratification is the monimolimnion; a layer below the hypolimnion which does not mix and where water density is even higher than in the hypolimnion. Similar to the thermocline in case of thermal stratification, a chemocline develops and indicates separation of hypolimnion and monimolimnion (Fig. 4). In the latter anoxic conditions occur often as water does not get mixed throughout the whole water column. Lakes with chemically induced, or supported stratification, are often meromixis, thus parts with stabilized stratification will not mix compared to other areas within the lake (Boehrer and Schultze 2008).

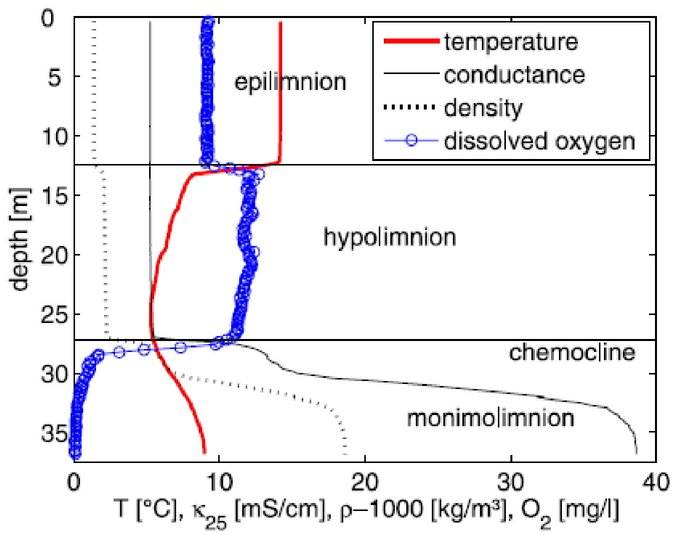


Figure 4: Profiles of temperature conductance, density, and dissolved oxygen from Rassnitzer See in former mining area Merseburg-Ost on 7th of October 2003 (adapted from Boehrer and Scuhltze [2005] with permission from ecomed). (Oxygen concentration numerically corrected for response time of 7.5 s of the sensor) in (Boehrer and Schultze 2008).

2.1.3 Lake colour and sunlight absorbance

Lake colour ist derived by measuring the absorbance of light in water samples (IVM 2018). The higher the load of suspended particles and dissolved substances, the darker the colour of the lake and hence the higher the absorption. As solar radiation is absorbed at the surface water layer, deeper layers are shielded from sunlight penetration. As a result, SWT warms up faster than underlying water levels, which again enhances a thermal separation between the two layers, and thus contributes to stratification. However, the effect on water temperatures due to absorbance is not as straight forward as it might appear. Persson and Jones (2008) argue that the epilimnion temperature does not vary much throughout a year between a dark and a clear lake. This is due to increased temperature loss in dark lakes through evaporation, and intrusions of cooler water from the hypolimnion during summer, compared to clear lakes. Whereas SWT in dark lakes compared to clear lakes warms up more during spring and early summer due to light absorption, it also cools down more during late summer. Nevertheless, the absorbance of sunlight can have an impact on stratification strength. However, physical forcing seems to be domninant in lakes larger than 5km^2 (King, Shuter, and Zimmerman 1999).

2.1.4 Shallow lakes versus deep lakes

The depth of a lake is variable throughout its basin and even an apparently shallow lake might have a large depression in some part. Also, the size of a lake´s surface area varies widely. Whilst a deep lake can have a small surface area a shallow lake can appear very large at its surface. Due to these strong variations in lake size and depth a classification in shallow and deep lakes has not been promoted in the field of limnology. Instead, an approach, considering both, surface area and depth has been proven to give good results when studying the occurrence of stratification. One of these approaches is the Osgood Index (OI), which measures the mean depth of a lake related to its surface area (Osgood 1988):

$$mean\ \ depth/\sqrt{surface\ area}\,[m\ km^{-1}]$$

According to OI, lakes can be classified into monomictic, dimitic and polymictic lakes. The larger the value for OI the more probable is the development of a stabilized stratification; the lower the value, the more often can a mixing state of the lake occur.

Despite the fact that a distinction into shallow and deep lakes is not a reliable indicator when analyzing the complex inlake processes, some distinction can still be made. Shallower lakes are less likely to develop a stable stratification because warmer surface water can reach deeper water faster. Moreover, the euphotic zone (zone of plant growth due to sunlight penetration) can extend throughout the whole bottom of a shallow lake, and nutrient recycling takes place at a faster rate (Wetzel 2001). During winter the ice-free layer, or layer with warmer conditions is smaller than in deep lakes, making survival more difficult for aquatic life (Scheffer 2004). Another distinction is the effect of light absorption on stratification strength. The latter might have stronger effects on water temperature in shallow lakes than in deep lakes. As its impact increases with smaller depth of the mixed layer (Persson and Jones 2008).

3 Methods

Data has been selected with a focus on water temperature samples of different depth layers. Additionally, air temperature, precipitation, and chemical data were included. Trend analyses via seasonal Mann-Kendall and Theil-Sen slope were performed on all variables. Then, correlations and multilinear regression were calculated with the trends of the analysis results.

3.1 Data collection and handling

The focus for data selection was laid on gathering as much data as was available. Therefore, data from different monitoring programs, received from SMHI and SLU were joined. These datasets from the MVM department at SLU consisted of the Swedish national monitoring program "Trend lakes" (110 lakes), the monitoring program on the application of lime within lakes "Integrerad kalkningseffekt-uppföljning" (IKEU), LIMS djupprofiler (including programs KAKLREF, KALKSPEC, and several IVM projects) (137 lakes), Sjöprofiler (115 lakes), and summer and winter temperature data from SMHI (96 lakes). Some of the lakes included in the datasets were overlapping. Figure 4 shows a summary overview of the data cleaning and selection procedure.

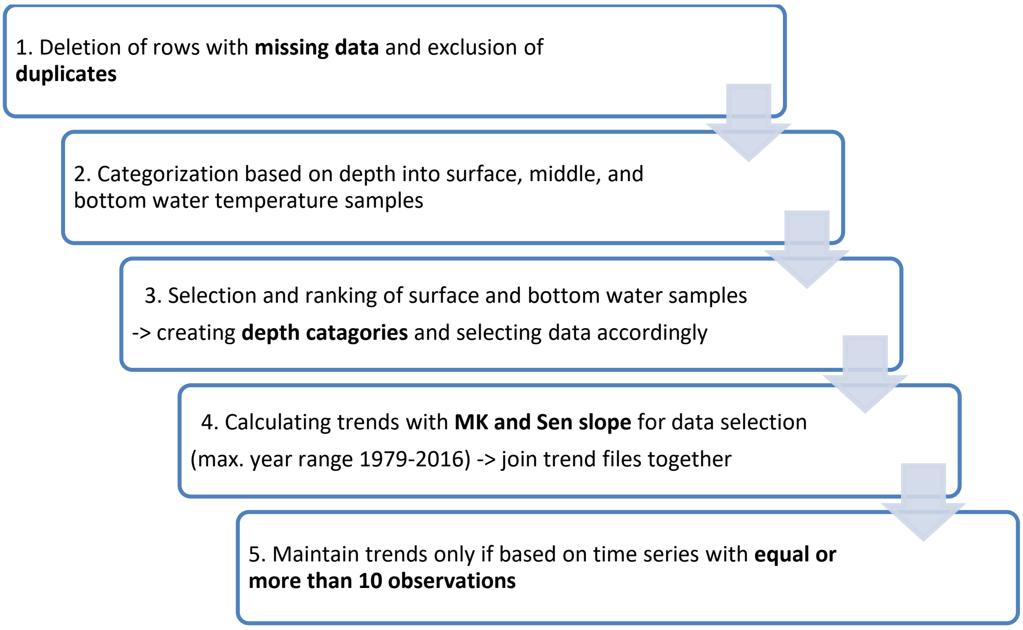


Figure 5: Data cleaning and selection steps (NOTE: Point 3 applies only to water temperature and chemical data).

Water temperature dataset

Long-term data from MVM were sampled closest to the midpoint of each month and for profile data at the deepest lake point. SMHI samples were taken at the lake´s deepest point and when water was approximately at its warmest and coolest temperatures, respectively. After joining, the dataset contained 117,641 rows with information on lake water temperature and sample depth per specific date for 233 Swedish lakes. As SMHI lake data did not contain EU identification numbers (EUids), these were created using the x and y coordinates of the RT90 coordinate system of the lake outflow location. This procedure has been adopted for all lakes lacking an EUid but containing information on coordinates. An additional effort was made to correct some EUids which were found of having been applied incorrectly (e.g. Skärgölen) or where the basin of a large lake had not been specified by its own Id but with the overall lake´s Id (e.g. Mälaren, Siljan, Vänern Vättern,[1]). Obvious spelling mistakes of the lake names or wrongly entered dates were also adjusted. A major error entry seems to have occurred for Långsjön, EUid: SE656590-164240. According to (SLU IKEU 2017), the maximum depth is 7.7m, however in the data file there are several entries above 8m depth. All profile information containing deeper data than the maximum depth was therefore excluded.

The dataset was examined for normal distributions and binomial correlations for a first impression with the software JMP14. This led to several attempts of sorting the data in a way that guaranteed a minimum loss of datapoints. First, rows with missing values and duplicates of monthly data were deleted. The selection criteria for duplicates was the closeness to the midpoint of the month in the respective years, with the following exceptions:

1) If several depth samples were available for one day in a month compared to only one depth sample for another day during the same month, the amount of available depth data was higher ranked than closeness to midpoint of month;
2) If a depth sampling sequence contained two or more samples (depths) than other sequences in the same month, the amount of samples is again higher ranked than closeness to midpoint of month.

As the aim of the study was to compare trends and the impact of climatic change between lakes and regions, the a cross-check of the sample depths per lake was performed in a second step. As the differences of sample depths between lakes were too large to use them for comparison, only surface and bottom water temperature (SWT and BWT) values were used. The deepest samples taken for water temperature were referred to as the "bottom water samples", even though they might not always have been taken close to the lake bottom; but they were generally located in the hypolimnion. The selection of all SWT and BWT values was then categorized according to a rank function. The highest number of samples per depth and lake over all years received a rank of 1. In case the same number of data was also found for other depths, either the lowest depths with the highest amount of datapoints for SWT or the deepest depth for BWT were ranked as 1. The categories were applied as follows (Table 1).

[1] Blacken, Ekoln Vreta Udd, Galten, Granfj. Djurgårds Udde, Görväln S, S. Björkfjärden SO, Skarven, Svinnegarnsviken, Ulvhällsfjärden is all part of **Mälaren**; Edeskvarnaån NV, Jungfrun NV is both part of **Vättern**; Dagskärsgrund N, Mariestadsviken M1, Mariestadsviken M2, Megrundet N, Tärnan SSO is parts of **Vänern**; Siljan (vert8) and Siljan (vert2) are part of **Siljan**

Table 1: Chosen depth categories for surface water temperature (SWT) and bottom water temperature (BWT).

Depth categories	SWT	BWT
Cat1	Depth with most data found (0,5m)	Deepest depth with most data found per lake (varies between lakes)
Cat2	Cat1 +/- 0,5 m	Cat1 +/- 1m
Cat3	Cat1 +/- 1m	Cat1 +/- 2m
Cat4	Cat1 +/- 1,5m	Cat1 +/- 3m
Cat5	n.a.	Cat1 +/- 4m
Cat6	n.a.	Cat1 +/- 5m
Cat7	n.a.	Cat1 +/- 6m

As a measure of temperature change and therefore stratification stability between SWT and BWT, a ratio was calculated (BWT/SWT) which is referred to as BS-ratio in the following sections. It was calculated using all SWT data up to 2m and their corresponding BWT value. Then it was selected according to BWT categories (see Table 3). Thus, it could be that SWT from different categories were included for one specific BWT category.

Due to a lack of samples, all years before 1979 were deleted. After cleanup, the dataset for water temperature contained 27,513 rows from the original 117,641. For BWT samples, there were in total 8,932 rows (77 lakes), whereas for SWT there were 18,581 rows (149 lakes).

Climate datasets

The dataset for climate (air temperature and precipitation) from the PTHBV database hosted by SMHI[2], was cleaned separately. This dataset is based on an interpolation of data derived from climate stations. The resolution of the climate grid is 4 x 4 km. For air temperature, means of daily values were used to calculate monthly mean values. Monthly mean values of precipitation were derived by the sum of daily values. Same as for water temperature data, any duplicates were deleted. As air temperature values differed amongst duplicates, those entries with more information, e.g. EUid, were maintained. Because the weather stations were stationed at different distances from each lake, a column showing the distance from the coordinates of the lake to the centroid coordinates of the climate grid was included in the dataset. Distances varied between 0.84 and 2.7 km.

As the specific heat of water is higher, it increases and decreases in temperatures more slowly than air. Month August is highly likely to show stratification occurrence and it had the largest amount of continuous sampling. Therefore, to check for a delayed air temperature impact on water temperature in August, monthly air temperature means were taken for April-May, April-May-June, April-May-June-July and April-May-June-July-August for southern Sweden and the same with a one-month delay (starting from May) for the northern region.

[2] Information can be found here: http://luftwebb.smhi.se/PTHBV_produktblad.PDF (Accessed on 24.04.2019)

This dataset contains no missing values and was adjusted to match the time range from 1979-2016.

Chemical dataset

Chemical data, which had been gathered within the IKEU, Kalkref, and Trendlakes projects, contained 32,140 rows and had already been checked for duplicates in previous work (Huser et al. 2018). It contained information on the chemical parameters TOC (total organic carbon), calcium (Ca), chlorine (Cl), fluorine (F), iron (Fe), sodium (Na), potasium (K), conductivity, magnesium (Mg), manganese (Mn), oxygen (O), phoshpor (P), phosphate (PO4-P), silicon (Si), sulfate (SO4), ammonium (NH4-N), nitrite (NO2-N), nitrite+nitrate (NO2+NO3-N), alkalinity/acidity, filtered and unfiltered absorbance, pH, and secchi depth over the time from 1983–2016. According to SS-EN ISO 7887:20012 the colour (mg $PT^{-1}l$) of lakes was calculated using filtered absorbance (median Abs420)*500 which again was the base for deriving the trophic status of the lakes.

As the file contained samples of water temperature as well, their possible addition as datapoints to the water temperature dataset was checked. However, the lakes and months per year that contained extra information did not contain enough datapoints to run a trend analysis in the next step and were therefore dismissed. As water sampling depths deviated too much between the chemical dataset and lake water temperature dataset, only SWT chemistry samples were included.

The chemical data was analysed by the accredited Geochemical laboratory at the Department of Aquatic Sciences and Assessment at SLU, using SWEDAC accredited methods. Further information can be found at the website of the Geochemical laboratory of SLU:

https://www.slu.se/en/departments/aquatic-sciences-assessment/laboratories/vattenlabb2/

Missing values and outliers

An analysis of missing values has been performed for each lake by calculating the percentage of missing years per month and year range:

$$N_{\text{missing years}}[\%] = \frac{n_{\text{missing years}} * 100}{n_{\text{year range}}}$$

For the months of February, April, August, and September, an additional analysis on data gaps between sample years was performed for each lake for surface water, and for April and September for bottom water and calculated BS-ratios. The focus on this selection was derived from the significance check of the results of the Mann-Kendall (MK) trend test. The length of gaps was counted over the entire available time series to detect differences between data series and the possible impact on trend analysis and comparison between lakes.

An outlier analysis of the data per lake using Mahalanobis distance and T^2 showed almost no outliers for air temperature and surface water temperature, and only a few outliers for the bottom water temperature. The BS-ratio calculated, however, showed some outliers as well as parameters from the dataset containing chemical data. As a sorting of outliers would have been too time intensive, in a next step all the datasets were analyzed for trends via the non-parametric, outlier robust seasonal Mann-Kendall (MK) test and Theil-Sen slope calculation. Water temperatures measured below 0 were excluded from the analysis because of a very large impact on the BS-ratio and possible wrong measurements.

Hypolimnion check

To check whether the BWT samples were in the hypolimnion, the difference between the maximum depth of a lake and the sample depth at depth categories 2 and 6 for BWT and BS-ratios was compared annex 1. All values were ≥ 1.5m deep as 0–2m depth was considered to be in the epilimnion. There were two very shallow lakes with a sample depth ≤ 2 m in the dataset and only Tångerdasjön showed significant trends. SWT samples for those lakes were always measured at a depth of 0.5m or less.

V. Skälsjön had been sampled at a slightly (0.3m) deeper depth than the maximum depth given. It was assumed that the maximum lake depth for this lake had been sampled in a year with a lower water level and/or at a slightly shallower site. As the divergence was as small as 30 cm this error was ignored.

The divergence for sample depths and maximum depths found for lakes with significant trends was -0.3–6m for BWT and -0.3–4m for BS-ratios. From this check it is assumed that temperature samples were taken in the bottom water where in case of stratification a hypolimnion layer could have developed.

Additional information on lakes

Additional information (Annex 2 (I-IV)) about lake coordinates, volume, height above sea level, maximum and mean depths, distance to the ocean, watershed size, land use types in percent within the watershed, and size of the lake area were added to these files. Lake area in this dataset described the water fluctuation zone of the lake outlining the lake and included islands within the lake. Additionally, an approximated Osgood index (OI) (Osgood 1988) was calculated based on the mean depth and lake surface area. Unfortunately, the mean depth was not available for all lakes. Based on the OI, the lakes were categorized into different mixing behaviors at a threshold of ≤ 5 = polymictic (mixed), > 5 < 7 = variable, ≥ 7 = dimictic (stratified) lakes. As not all lakes had sufficient data to calculate the OI an sites were separated into deep lakes (> 6m depth), shallow lakes (≦ 6m depth) and lake basins for a comparison of the trends found. The trophic state and brownification status were further calculated

Table 2: Mean and median of location variables of lake sites and watershed size distribution

Variable	Mean	Median
Watershed area [km²]	178.2	5.8
Distance to sea [m]	281.2	122.3
Altitude [m]	381.2	151.5
Lake area [km²]	5.9	0.6
Forest%	60.7	65.8
Wetland%	8.5	5.3
Water%	13.4	12.6
Urban%	0.3	0.0
Agriculture%	4.4	0.6
Wood felling%	7.4	6.9
Other vegetation%	3.6	0.0
Other%	1.7	0
Watershed Area Distribution		**N sites**
0-5km²		55
5-25km²		44
25-250km²		19
>250km²		8
Total Sites		**126**

based on methods of the Swedish Environmental Protection Agency (EPA 2000). Further information on the calculation can be found in annex 2 (II). Furthermore, information on the limed status of lakes was added to check whether those lakes might show different results compared to natural lakes.

Sweden is divided into a southern zone with an approximate continuous water flow during the year and a northern zone with a pronounced water accumulation in winter and a release in the spring with snowmelt (Huser et al. 2018). The two seasonal regions differ in the onset of spring and the duration of seasons. The division is located at a latitude of approximately 60° North. Therefore, additonal to respective ecoregions (Annex 3) the season type (1=Southern Sweden, 2=Northern Sweden) were linked to each lake.

Sites (excluding large lake basins) were minimally impacted by urban areas. Agriculture and forestry, including wood felling areas, occupied a larger proportion of the watershed area (Table 2).

3.2 Trend analysis

Seasonal Mann Kendall (seasonal MK), extended from the original MK trend test, and the Sen slope are common methods for monotonic trends in water quality monitoring. They were chosen due to partial nonlinearity and non-normal distribution of the studied time series. Basics of their mathematical function and their applicability for this study are explained in the following. Seasonal MK and Theil-Sen slope in this study were performed by using the Visual Basic Excel program developed by Grimvall (1998) and further extended and modified by Fölster and Seibert (2003), which show the sign of the trend and the calculated slope with respective p-values.

3.2.1 Seasonal Mann-Kendall test

To analyze long term data, trends over time are a useful tool to depict changes. MK (Mann 1945; Kendall 1975), a nonparametric method, provides the detection of monotonic trends, whether positive (> 0), no change (= 0) or negative (< 0) for time series. As MK is a well-tested statistical method in environmental science, and specifically for water quality measurements, it was chosen for the purpose of this study (e.g. Ptak, Sojka, and Kozłowski 2019; Huser et al. 2018). Because yearly analysis turned out to be statistically too weak, the seasonal MK (also called Hirsch-Slack test) was performed (Hirsch, Slack, and Smith 1982). It is a multivariate extension of the basic MK test and calculated for each month. Whilst it requires a constant spread of the distribution and no serial correlation, it is fit for missing values, robust against outliers and non-normal data distribution as its trend line is based on median values. Even compared to similar proposals of trend tests, the seasonal MK performs better at small and large sample sizes. However, it does not work well for sample sizes smaller than N = 10 (Hirsch and Slack 1984).

Seasonal MK is calculated on ranks of medians of all possible differences of the data series. In a first step Kendall´s S statistic is performed, correlating variables (y) to time (T) by sorting the data in an increasing order. A positive correlation exists when y is increasing more often than decreasing with increasing T and vice versa. No correlation exists if y shows no or nearly no difference in number of increasing versus decreasing values over T.

Then the two-sided S statistics, measuring the monotonic dependence of y on T, is calculated by:

$$S = P - M$$

Where:

M = discordant pairs (y decreases, T increases) – N of -

P = concordant pairs (y increases, T increases) – N of +

To calculate Kendall´s tau (τ) correlation coefficient:

$$\tau = \frac{S}{n(n-1)/2}$$

If:

$\tau = 0$ -> H0: No trend as there is no significant correlation between y and T

$\tau \neq 0$ -> H1: There is a monotonic trend as y is correlated to T

To test for significance with $n > 10$, S is compared to a critical value of a normal standard distribution at an exceedance level of $\alpha/2$ (Helsel and Hirsch 2002). In this study the commonly used $\alpha = 0.05$ was applied as the critical cutoff level. The selected significant trend data was then further analysed with correlations and multilinear regression.

3.2.2 Theil-Sen slope

The Theil-Sen slope, or Kendall slope estimator, is a method to calculate the magnitude in trend (unit yr^{-1}) detected by the Mann-Kendall test. It was developed by Theil (Theil 1950) and Sen (Sen 1968). As a nonparametric test it is more robust against outliers than a simple least square regression approach, especially in cases with skewed data. The calculation is based on the median of all differences in observations along the time series (Hirsch, Slack, and Smith 1982). While missing values do not affect accuracy of MK signs, it is highly likely that they increase the error of the slope estimate in cases with > 5% missing data. No information on the magnitude of error impact on Theil-Sen slope regarding the amount of missing values was found. Therefore, in this thesis, missing data of greater than 20% are assumed to increase uncertainty to a very high level. In addition to the missing values, the size of data gaps likely plays a role in increasing uncertainty. Yearly data gaps larger than two missing values in consecutive years and respective sampling month were therefore assumed to increase the error in Theil-Sen slope calculation.

Theil-Sen slope is calculated based on a comparison between all data pairs of a time series (y - T). Slopes are computed for each data pair ($\Delta y/\Delta T$). The median of all slopes constitutes the Theil-Sen slope. Whilst Theil uses a comparison between all data pairs, Sen adjusted the approach to using only pairs of data with distinct x coordinates, as is the case for all the analyzed data in this dataset (Helsel and Hirsch 2002). For better comparison, means of water temperature samples over the time series were used to calculate the relative annual changes per lake ($trend*mean^{-1}$).

3.2.3 Application of seasonal MK and Theil-Sen slope

Seasonal MK and Theil-Sen slope were calculated separately for:

1) SWT cat 1-4 (up to maximum 2m depth)
2) BWT cat 1-7
3) BS-ratio cat 1-7
4) Precipitation
5) Air temperature
6) Chemical data (up to max. 2m depth)
7) Degree month (monthly mean air temperature)

Due to missing values a yearly calculated MK could not be performed based on monthly values nor on seasonal values. Furthermore, the program was not able to calculate Theil-Sen slopes for cases with a high recurrence of the same sample value or when the measurement column started with a 0. Moreover, not all lakes per dataset contained enough information to calculate the Theil-Sen slope. Those lakes were dismissed for the respective dataset. However, in case the same lake showed results in another dataset, it would be still considered for further analysis in the final data compilation; a join of all results of the data files from 1-7 per category. Therefore, the final overview can be used to detect a lack in sampling data per lake.

A check on the amount of significant Theil-Sen slopes at p-values with $\alpha = 0.05$ for water temperature showed the best recurrence at the lowest sample depth divergence of water temperature data for cat 4 for SWTand cat 2 for BWT samples, and BS-ratios. Both categories were the best selection, also with a separation into including all lakes and excluding basin lakes (Table 2 a & b). Cat 1 instead, due to the same depth selection, ensures the highest quality of data. Therefore, cat 1 and 4 were chosen for SWT as the best with the least depth divergence and categories 2 and 6 for BWT and BS-ratios respectively for the highest amount of data found. Months for further analysis were selected according to the amount of data trends found (Tables 3a and b) and their likeliness to show changes in stratification patterns in the spring and early autumn:

1) Surface water: February, April, August and September
2) Bottom water: April and September (for consistency)
3) Bottom-surface ratios: April and September

Table 3: Number of significant Theil-Sen slopes for water temperature per month according to p-values (α ≦ 0.05), dark grey indicates months with more than 8 lakes and light grey indicates months with more than 4 lakes.

a) With lake basins

Depth layer	Depth category	N significant trends per month									Comparison cat 1 to others	
		2	3	4	5	6	7	8	9	10	Sum N	Dif. of N
SWT	Cat1	12	3	13	17	3	6	19	16	10	Σ99	baseline
	Cat2	13	4	16	18	3	6	20	16	10	Σ106	+7
	Cat3	14	5	16	18	3	6	20	16	11	Σ109	+10
	Cat4	30	8	14	19	7	6	30	16	12	Σ142	+43
BWT	Cat1	2	n.a.	3	11	7	3	7	3	2	Σ38	baseline
	Cat2	3	n.a.	7	14	7	5	6	7	5	Σ54	+16
	Cat3	3	n.a.	7	13	5	5	6	8	5	Σ52	+14
	Cat4	3	n.a.	7	14	5	6	6	8	5	Σ54	+16
	Cat5	4	n.a.	6	14	5	6	6	9	5	Σ55	+17
	Cat6	4	n.a.	6	14	5	6	6	10	5	Σ56	+18
	Cat7	4	n.a.	6	13	5	7	6	10	5	Σ56	+18
BS-ratio	Cat1	n.a.	n.a.	5	3	8	5	6	6	5	Σ38	baseline
	Cat2	2	n.a.	6	4	7	6	5	10	10	Σ50	+12
	Cat3	2	n.a.	6	5	5	5	5	10	10	Σ48	+10
	Cat4	2	n.a.	6	5	5	5	5	10	10	Σ48	+10
	Cat5	2	n.a.	6	5	5	5	5	10	10	Σ48	+10
	Cat6	2	n.a.	6	6	5	5	5	11	9	Σ49	+11
	Cat7	2	n.a.	6	6	5	5	5	11	9	Σ49	+11

a) Without lake basins

Depth layer	Depth category	Month									Comparison cat 1 to others	
		2	3	4	5	6	7	8	9	10	Sum N	Dif. of N
SWT	Cat1	12	3	11	4	1	1	9	14	6	Σ61	baseline
	Cat2	13	4	14	5	1	1	10	14	6	Σ68	+7
	Cat3	14	5	14	5	1	1	10	14	7	Σ71	+10
	Cat4	30	8	12	6	5	1	20	14	8	Σ104	+43
BWT	Cat1	n.a.	n.a.	2	n.a.	6	3	4	2	1	Σ18	baseline
	Cat2	3	n.a.	6	3	6	5	3	6	4	Σ36	+16
	Cat3	3	n.a.	6	2	4	5	3	7	4	Σ34	+14
	Cat4	4	n.a.	5	3	4	6	3	8	4	Σ37	+17
	Cat5	4	n.a.	5	3	4	6	3	8	4	Σ37	+17
	Cat6	4	n.a.	5	3	4	6	3	8	4	Σ37	+17
	Cat7	4	n.a.	5	2	4	7	3	8	4	Σ37	+17
BS-ratio	Cat1	n.a.	n.a.	5	n.a.	8	4	5	5	2	Σ29	baseline
	Cat2	2	n.a.	6	1	7	5	4	9	7	Σ41	+12
	Cat3	2	n.a.	6	2	5	4	4	9	7	Σ39	+10
	Cat4	2	n.a.	6	2	5	4	4	9	7	Σ39	+10
	Cat5	2	n.a.	6	2	5	4	4	9	7	Σ39	+10
	Cat6	2	n.a.	6	2	5	4	4	10	7	Σ40	+11
	Cat7	2	n.a.	6	2	5	4	4	10	7	Σ40	+11

The total number of lakes with water temperature data with at least one months with $n \geq 10$ (trends at $\alpha \leqq 0.05$), including lake basins, was 143 (62) and 143 (89) for SWT at cat 1 and cat 4; 56 (30) and 58 (31) for BWT and 56 (28) 58 (28) for BS-ratios at cat 2 and cat 6, respectively. Their location ranged from latitude 68-55°N within the Swedish boundaries.

3.3 Correlations and regressions

To analyze the relationships of different variables from the chemical and climate datasets with water temperature the calculated trends found were correlated to each other, and simple linear regressions were performed. From the results of the correlations a trial of model building with multilinear regression was done in addition.

3.3.1 Simple linear regression

A simple linear regression on all water trends for cat 4 and cat 6 was performed using x/y plots in JMP14. Water temperature was plotted against chemical data, air temperature, and precipitation, calculating a linear regression line for each pair. Results were then chosen according to significant p-values at 0.05 for parameter estimates.

3.3.2 Correlation and multilinear regression (MLR)

To detect the strength of linear relationships of climate and chemical variables with water temperature, a parametric correlation was calculated for different variable combinations of significant and non-significant trend data. As the trends were not normally distributed in all combinations, the results were affected by it. The Pearson Product-Moment Correlation Coefficient (r) was calculated with JMP14 and portrayed in a matrix showing the response of each pair of variables. The statistics was performed on data tables without data gaps. Therefore, a row-wise approach was chosen to be best. Additionally, a correlation probability based on p-values and a covariance analysis measuring the degree of change of variable pairs were calculated.

Combinations chosen for analysis were:

1) Significant lake water temperature, air temperature and degree months
2) Significant lake water temperature, filtered absorbance and TOC
3) Significant lake water temperature and Osgood index, trophic and brownification states

Using the results of selection 1) and 2), MLR was computed with the selected variables in JMP14. This selective approach was applied because not all variables with a likely impact on water temperature showed significant trends for the same months. In a further step, variables in the MLR were selected according to a p-value threshold of 0.05. Those selected variables were used for model creation. Then, the model estimates were again checked for significance at the same level. Additionally, a MLR test run on the sample values of SWT at cat 4 was done to compare the performance between sample values and trends for MLR calculation. R^2 results for MLR were adjusted for degrees of freedom.

4 Results

The results presented focus on the months of February, April, August, and September. These months had the highest amount of significant trends and were also the most interesting for stratification analysis because of the typical stratification circle during a year for lakes in mid-to high latitudes. In Swedish lakes stratification can occur during winter (e.g. February) due to cooling of surface waters and heat maintenance in deep water layers. During April, spring warmth heats up surface layers and the lake water turns over, or mixes as stratification breaks down during this month. August and September instead are prone to show a reverse stratification structure compared to winter. February and August are months where winter and summer stratification are generally most pronounced. The trend results on water temperature were compared to this general pattern by analyzing the strength of temperature change, and the trend direction; increasing or decreasing temperatures, and stronger or weaker stratification.

Detailed information for each lake on location, watershed description, lake characteristics, and time of sample periods can be found in annex 2 (IV). Some information, however, was lacking for lake basins; therefore the available information on those lake basins is summarized in annex 2 (V). Analysed datasets covered a range from 1979-2016. However, all trends found for lakes, excluding lake basins, cover a time range from 1983-2016.

The highest amount of missing values was found for trend calculations of BWT, and BS-ratios, particularly in February and April (Annex 7 (I-IV)). Interestingly, despite a high amount of trends found in February, September showed the lowest amount of missing values, especially for SWT with only 3 out of 22 lakes missing more than 20% of their values in the time series.

In most cases, the lakes showed data gaps of one year within a time series, but these were not considered to have a larger impact on trend calculation; though there could have been impacts, especially in cases of climatic extreme years. Alike the missing values, September showed the best overall result with the smallest amount and size of data gaps (Annex 7 (V)).

As a visual comparison between air temperature and lake water temperature suggested, air temperature means for all sites fitted with the development of water temperature means of lakes at the selected depth at cat 4 for SWT, and cat 6 for BWT, and BS-ratios (Annex 4). Water temperature curves showed slower declines, which was possibly due to the heat capacity of water and the therefore slower heat distribution. BS-ratios showed peaks during spring months, indicating expected weak stratification patterns. Interestingly, SWT means reached higher temperatures than the calculated mean air temperatures. BWT means, as expected, varied less in temperature than SWT means and seldomly exceeded 10°C.

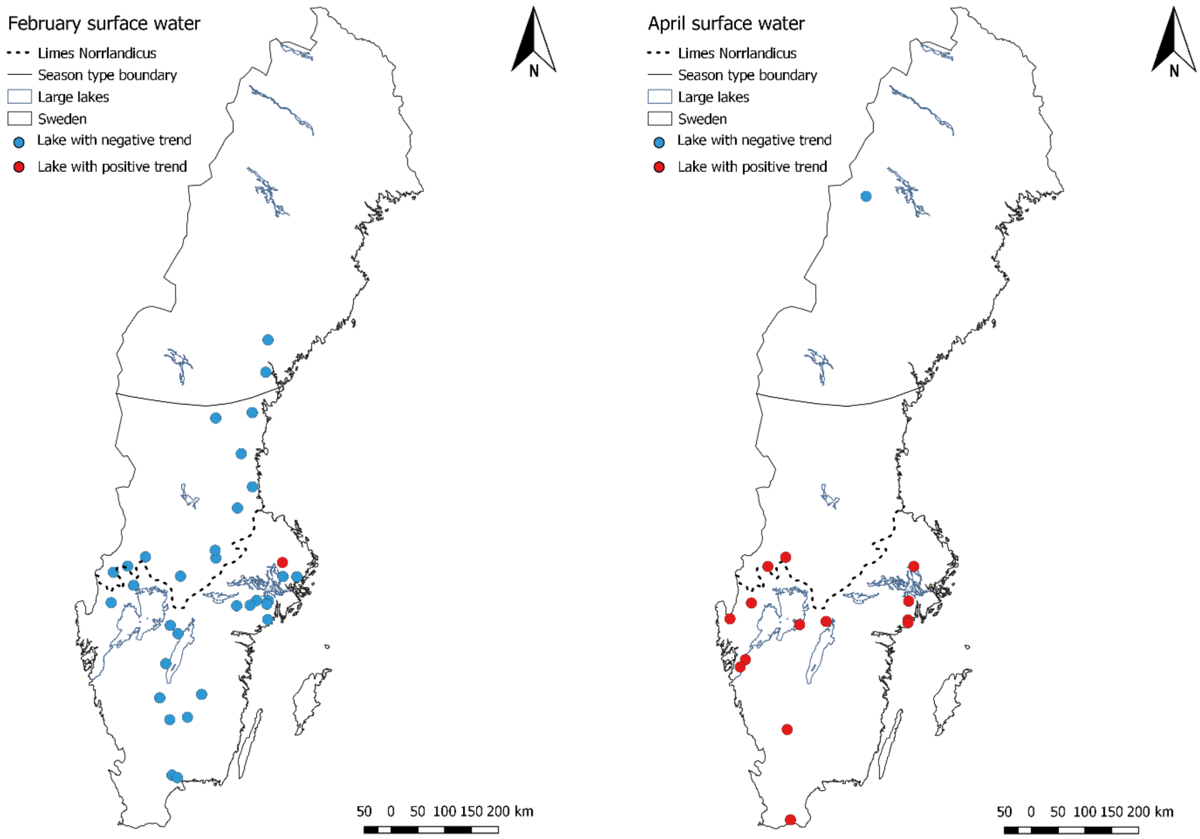
But is air temperature the driving force of water temperature change, or are other factors prevalent, or contributing? Correlation and regression analysis gave more insights to answer these questions.

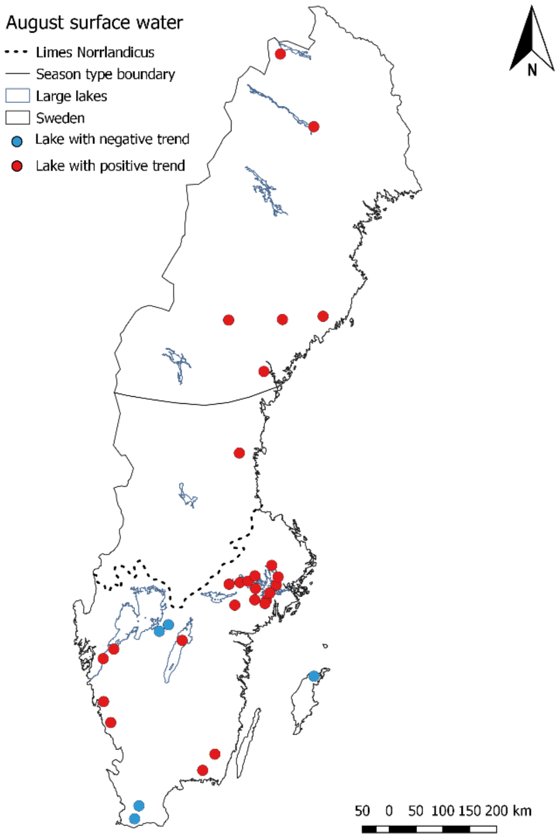
4.1 Significant trends

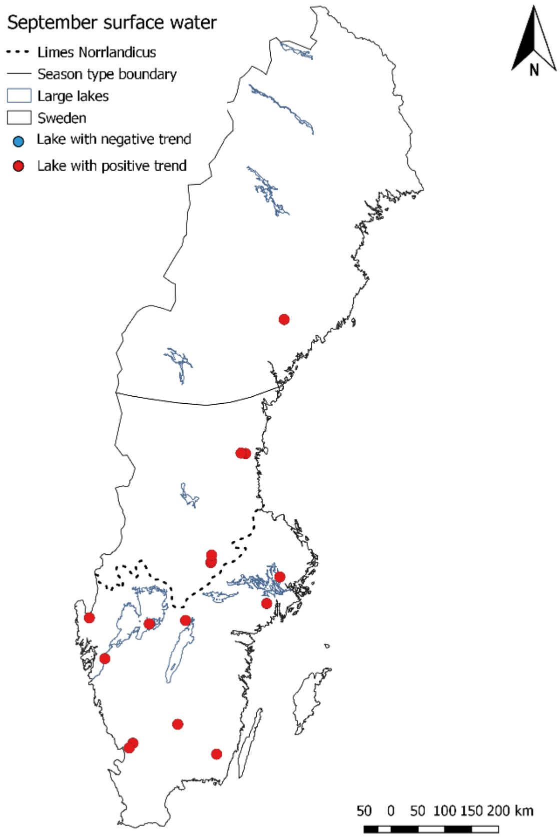
Of all lakes in the dataset, 83 lakes showed significant trends at α ≦ 0.05 for SWT, BWT, and/or BS-ratios. Figure 6 gives an overview of the location of those trends per selected month. They could either be positive, increasing temperature, or negative, decreasing temperature, for SWT and BWT. Positive and negative BS-ratios instead indicated the tendency towards less stratification strength, or stronger stratification, respectively.

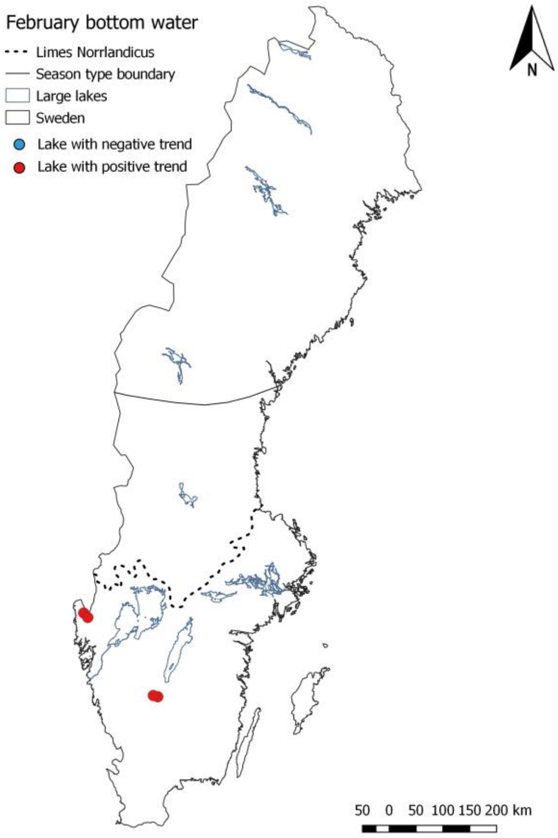
Significant trends were detected mainly for SWT and the southern seasonal type 1. In most cases, cat 4 and cat 6 showed a higher number of significant trends compared to cat 1 and cat 2. If both categories (cat 1 and cat 4, or cat 2 and cat 6) showed a trend for a lake, the direction of the trend was the same. Moreover, if BWT and BS-ratios had trends, both were negative. A few lakes had significant trends for more than one month.

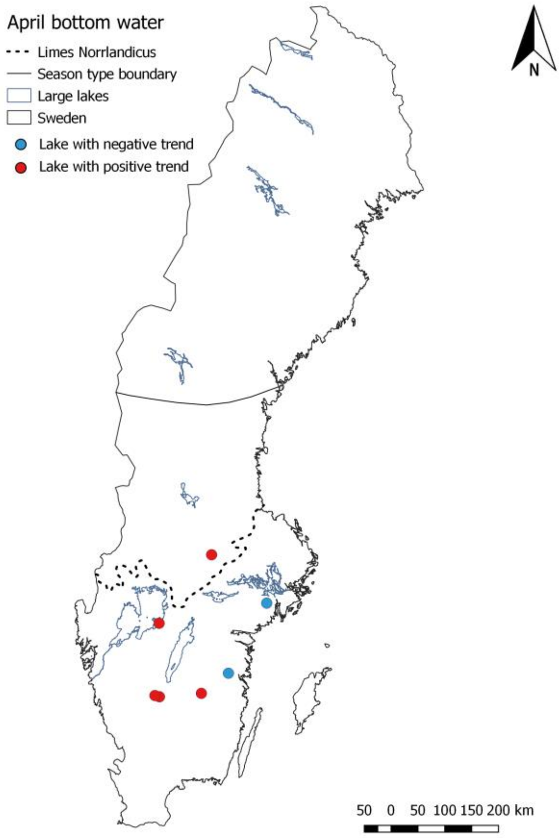
Significant trends for air temperature were found for 38 lakes for April, August, and September. Degree months, however, had significant trends for a total of 68 lakes, for at least one of the degree month categories (monthly combinations from May–August). These, however, could only have an effect on water temperature of August and September, leaving February with no information of air temperature impact. All variables for air temperature and precipitation showed positive trends in all results.

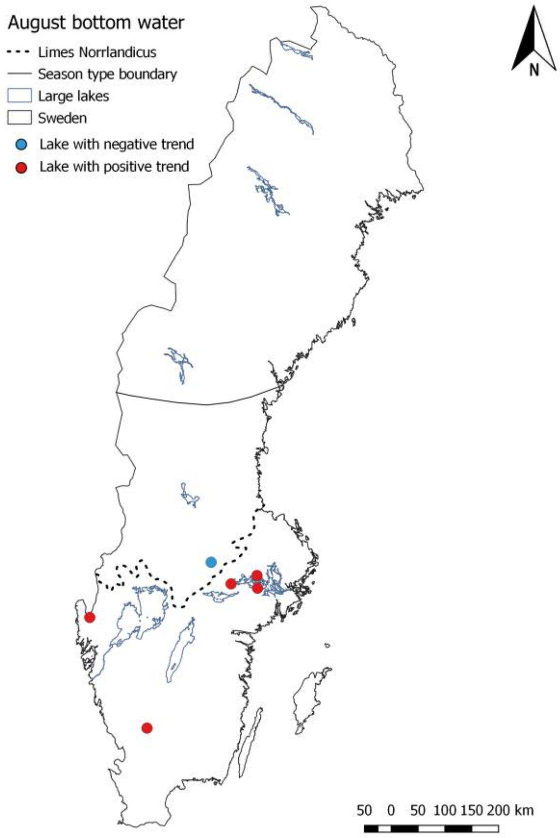


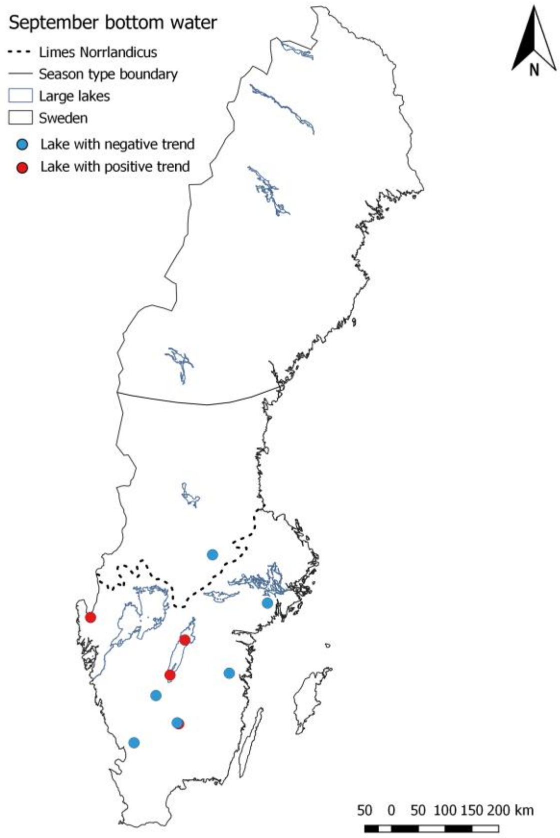

August surface water
Limes Norrlandicus
Season type boundary
Large lakes
Sweden
Lake with negative trend
Lake with positive trend
N
50 0 50 100 150 200 km

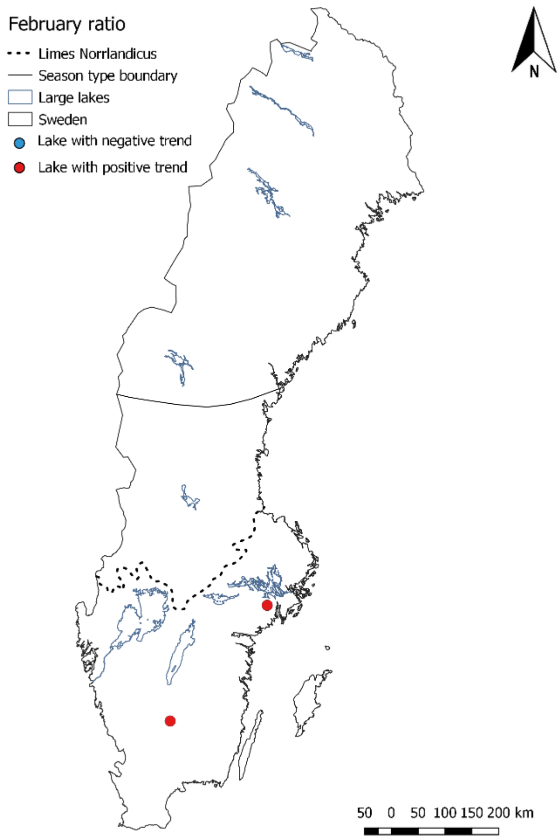

September surface water
Limes Norrlandicus
Season type boundary
Large lakes
Sweden
Lake with negative trend
Lake with positive trend
N
50 0 50 100 150 200 km

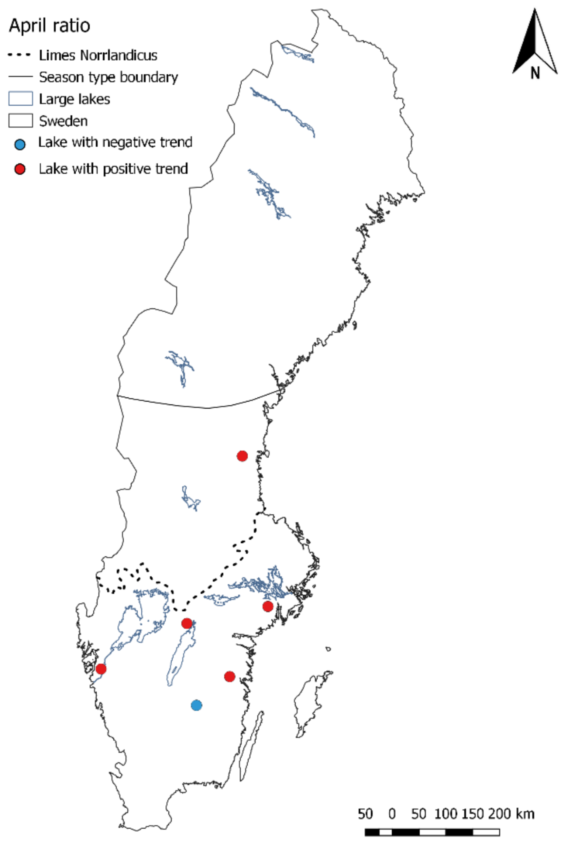

February bottom water
Limes Norrlandicus
Season type boundary
Large lakes
Sweden
Lake with negative trend
Lake with positive trend
N
50 0 50 100 150 200 km


April bottom water
Limes Norrlandicus
Season type boundary
Large lakes
Sweden
Lake with negative trend
Lake with positive trend
N
50 0 50 100 150 200 km


August bottom water
Limes Norrlandicus
Season type boundary
Large lakes
Sweden
Lake with negative trend
Lake with positive trend
N
50 0 50 100 150 200 km


September bottom water
Limes Norrlandicus
Season type boundary
Large lakes
Sweden
Lake with negative trend
Lake with positive trend
N
50 0 50 100 150 200 km


February ratio
Limes Norrlandicus
Season type boundary
Large lakes
Sweden
Lake with negative trend
Lake with positive trend
N
50 0 50 100 150 200 km


April ratio
Limes Norrlandicus
Season type boundary
Large lakes
Sweden
Lake with negative trend
Lake with positive trend
N
50 0 50 100 150 200 km

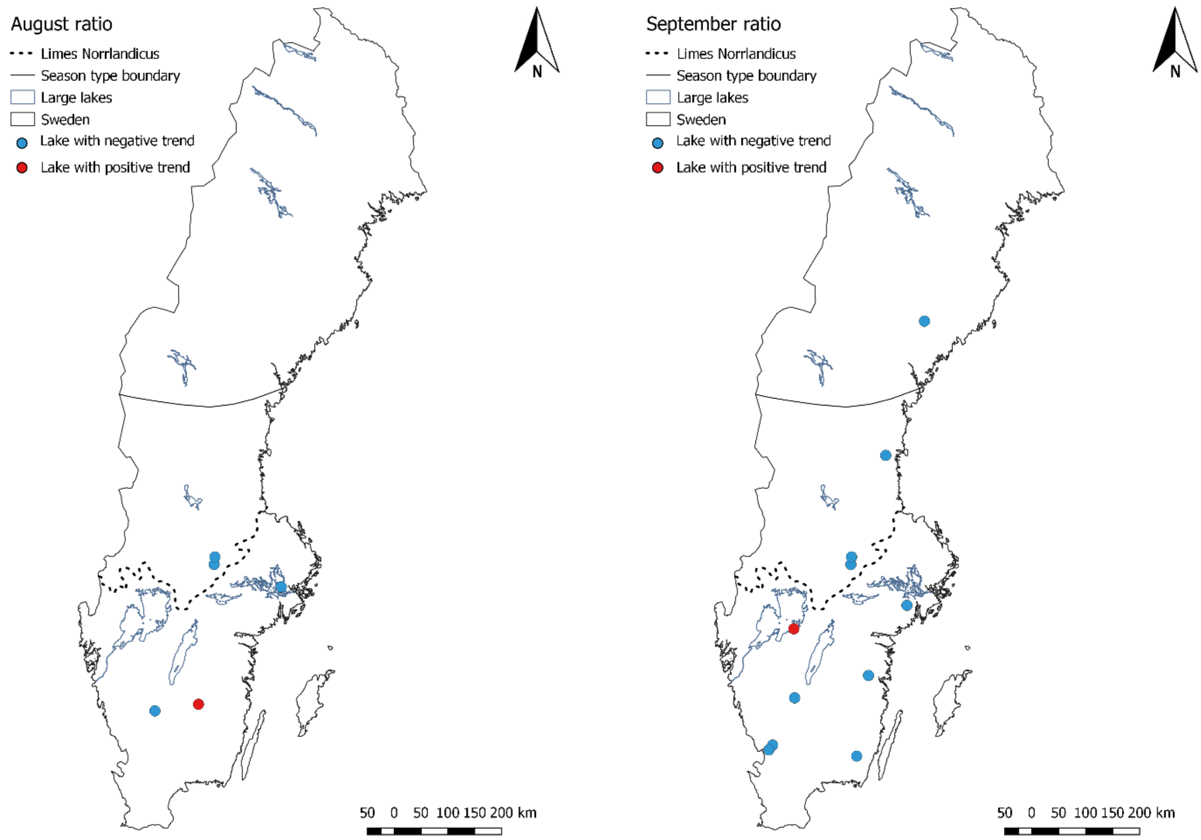


Figure 6: Location of lakes with significant trend directions (positive or negative) for surface water (SWT), bottom water (BWT) and bottom-surface ratios (BS-ratios). All categories chosen (1,4 & 2,6) are included in the maps.

In deep lakes, February showed only negative trends for SWT, and positive trends for BWT and BS-ratios. During April the trends changed to a more positive inclination, increasing temperatures and less stratification, however, positive and negative trends were common for SWT and BWT. Therefore, no overall pattern could be detected. BS-ratio trends were all negative during April, indicating a stronger stratification occurrence. In August and September only positive trends were detected for SWT, and negative trends for BS-ratios. BWT trends varied but tended to positive trends in August and negative trends in September.

The trends of the shallow lake selection were mostly negative for SWT in both February and August. BWT and BS-ratios were always positive, also during April. No trends were detected during September.

For lake basins yet another pattern was found. All trends for SWT and BWT for April, August, and September were positive. No February trends were found and BS-ratios were negative during August and positive during September. However, the latter were derived from only one lake per respective month.

Table 4: Overview of significant direction of trends for deep lakes (maximum depth > 6m); Grey background = trends differing from the common pattern; * = trends for 2 month; ** = trends for 3 months; *** = trends for 4 months.

Site	EUid	Month	limed	SWT Cat1	SWT Cat4	BWT Cat2	BWT Cat6	BS-ratio Cat2	BS-ratio Cat6	Air temperature	Mixing behavior	Season type
Björken*	SE652707-159032	2			-						dimictic	1
Djupa Holmsjön*	SE656263-156963	2			-						dimictic	1
Ejgdesjön	SE653737-125017	2	yes			+	+				dimictic	1
Fjärasjö*	SE638725-146677	2			-						dimictic	1
Humsjön	SE650061-142276	2		-	-						dimictic	1
Lillesjö	SE623161-142148	2			-						dimictic	1
Mäsen	SE665654-149206	2		-	-						dimictic	1
Örvattnet*	SE662682-132860	2			-						dimictic	1
Översjön*	SE664410-136192	2			-						dimictic	1
Rotehogstjärnen**	SE652902-125783	2				+	+				dimictic	1
Stora Envättern**	SE655587-158869	2			-			+	+		dimictic	1
Ulvsjön	SE661521-130182	2			-						dimictic	1
V. Rännöbodsjön	SE691365-156127	2			-						dimictic	1
Västra Solsjön*	SE655863-129783	2		-							dimictic	1
Älgarydssjön	SE633989-140731	2		-	-			+	+		polymictic	1
Älgsjön*	SE655275-153234	2			-						polymictic	1
Bäen	SE623624-141149	2			-						polymictic	1
Dagarn	SE664197-149337	2			-						polymictic	1
Hällvattnet	SE704955-159090	2		-	-						polymictic	2
Limmingsjön	SE660804-142742	2		-	-						polymictic	1
N. Yngern**	SE656206-159170	2		-							polymictic	1
Överudssjön	SE659105-133982	2			-						polymictic	1
Stengårdshultasjön**	SE638317-138010	2	yes				+				polymictic	1
Tärnan	SE660688-164478	2		-	-						polymictic	1
Tväringen	SE690345-149315	2			-						polymictic	1
Holmeshultasjön	SE634447-144024	2		-	-						variable	1

Lillsjön	SE655380-155738	2			-						variable	1
Stensjön_2***	SE683673-154083	2			-						variable	1
Valasjön*	SE698918-158665	2			-						variable	2
Allgjuttern*	SE642489-151724	4				-	-	-	-	+	dimictic	1
Björken*	SE652707-159032	4		+						+	dimictic	1
Fjärasjö*	SE638725-146677	4				+	+			+	dimictic	1
Fräcksjön*	SE645289-128665	4		+	+					+	dimictic	1
Härsvatten	SE643914-127698	4		+	+			-	-	+	dimictic	1
Örvattnet*	SE662682-132860	4		+	+					+	dimictic	1
Översjön*	SE664410-136192	4		+	+					+	dimictic	1
Rotehogstjärnen**	SE652902-125783	4			+					+	dimictic	1
Stora Envättern**	SE655587-158869	4				-	-	-	-	+	dimictic	1
Stor-Tjulträsket	SE731799-151196	4		-	-						dimictic	2
V. Skälsjön*	SE664620-148590	4	yes			+	+			+	dimictic	1
Västra Solsjön*	SE655863-129783	4		+	+					+	dimictic	1
Harasjön*	SE632231-136476	4		+	+					+	polymictic	1
Krageholmssjön	SE615375-137087	4			+					+	polymictic	1
N. Yngern**	SE656206-159170	4		+	+					+	polymictic	1
Stengårdshultasjön**	SE638317-138010	4	yes			+				+	polymictic	1
Långsjön_1*	SE652412-143738	4	yes	+	+			-	-	+	variable	1
Stensjön_2***	SE683673-154083	4						-	-	+	variable	1
Rundbosjön	SE652177-159038	4		+	+					+	n.a.	1
Alsjön	SE647050-130644	8			+						dimictic	1
Brunnsjön*	SE627443-149526	8			+					+	dimictic	1
Djupa Holmsjön*	SE656263-156963	8			+					+	dimictic	1
Fräcksjön*	SE645289-128665	8			+						dimictic	1
Hagasjön	SE635878-137392	8						-	-		dimictic	1
Rotehogstjärnen**	SE652902-125783	8				+	+				dimictic	1
Skärsjön_2	SE637260-128728	8			+						dimictic	1
Stora Envättern**	SE655587-158869	8			+					+	dimictic	1

V. Skälsjön*	SE664620-148590	8	yes					-	-		dimictic	1
Älgsjön*	SE655275-153234	8			+						polymictic	1
Harasjön*	SE632231-136476	8				+	+				polymictic	1
Jutsajaure	SE744629-167999	8		+						+	polymictic	2
N. Yngern**	SE656206-159170	8			+					+	polymictic	1
Remmarsjön*	SE708619-162132	8		+	+					+	polymictic	2
Sännen	SE624421-147234	8		+	+					+	polymictic	1
Abiskojaure	SE758208-161749	8		+	+					+	variable	2
Degervattnet	SE708512-152086	8			+					+	variable	2
Lien*	SE663216-148449	8	yes			-	-	-	-		variable	1
Skärsjön_1	SE633344-130068	8			+					+	variable	1
Stensjön_2***	SE683673-154083	8			+						variable	1
Valasjön*	SE698918-158665	8			+						variable	2
Allgjuttern*	SE642489-151724	9					-	-	-	+	dimictic	1
Brunnsjön*	SE627443-149526	9		+	+			-	-	+	dimictic	1
Fräcksjön*	SE645289-128665	9		+	+					+	dimictic	1
Gyltigesjön	SE629489-133906	9		+	+	-	-	-	-	+	dimictic	1
Källsjön	SE683582-154935	9	yes	+	+			-	-	+	dimictic	1
Rotehogstjärnen**	SE652902-125783	9		+	+	+	+			+	dimictic	1
Stora Envättern**	SE655587-158869	9		+	+	-	-	-	-	+	dimictic	1
V. Skälsjön*	SE664620-148590	9	yes	+	+	-	-	-	-	+	dimictic	1
Fiolen	SE633025-142267	9		+	+	+	+			+	polymictic	1
Övre Skärsjön	SE663532-148571	9		+	+					+	polymictic	1
Remmarsjön*	SE708619-162132	9		+	+			-	-	+	polymictic	2
Stengårdshultasjön**	SE638317-138010	9	yes				-		-	+	polymictic	1
Gyslättasjön	SE633209-141991	9	yes			-	-			+	variable	1
Långsjön_1*	SE652412-143738	9	yes	+	+					+	variable	1
Lien*	SE663216-148449	9	yes	+	+			-	-	+	variable	1
St Skärsjön	SE628606-133205	9		+	+			-	-	+	variable	1
Stensjön_2***	SE683673-154083	9		+	+					+	variable	1

Table 5: Overview of significant direction of trends for shallow lakes (maximum depth ≤ 6 m); Grey background = trends differing from the common pattern; * = trends for 2 months; ** = trends for 3 months; *** = trends for 4 months.

Site	EUid	Month	SWT Cat1	SWT Cat4	BWT Cat2	BWT Cat6	BS-ratio Cat2	BS-ratio Cat6	Air temperature	mixing behavior	Season type
Långsjön_3	SE673534-153381	2		-						dimictic	1
Svartsjön*	SE651609-140839	2	-	-						dimictic	1
Fysingen	SE660749-161885	2	-	-						polymictic	1
Gosjön	SE677506-156174	2		-						polymictic	1
Mossjön*	SE638085-138862	2		-	+	+				polymictic	1
Edasjön	SE663365-161779	2	+							variable	1
St. Lummersjön	SE644463-139986	2		-						variable	1
Mossjön*	SE638085-138862	4			+	+			+	polymictic	1
Tångerdasjön*	SE637120-145525	4					+	+	+	polymictic	1
Horsan	SE642008-168013	8	-						+	dimictic	1
Sidensjön	SE709218-169710	8		+					+	dimictic	2
Svartsjön*	SE651609-140839	8	-	-						dimictic	1
Havgårdssjön	SE615365-134524	8	-	-					+	polymictic	1
Krankesjön	SE617797-135339	8	-	-						polymictic	1
Tångerdasjön*	SE637120-145525	8					+	+		polymictic	1
Ymsen	SE650398-139136	8	-	-						polymictic	1

Table 6: Overview of significant direction of trends for lake basins with mostly unknown maximum depth; Grey background = trends differing from the common pattern; * = trends for 2 months; ** = trends for 3 months; *** = trends for 4 months.

Site	EUid	Month	lake basin of	SWT Cat1	SWT Cat4	BWT Cat2	BWT Cat6	BS-ratio Cat2	BS-ratio Cat6	Season type	Shallow/deep
Ekoln Vreta Udd*	SE658080-162871	4	Mälaren	+	+					1	Deep
Mariestadsviken M2	SE647666-129906	4	Vänern	+	+	+	+			1	
Blacken	SE658080-162871	8	Mälaren	+	+					1	
Ekoln Vreta Udd*	SE658080-162871	8	Mälaren	+	+					1	Deep
Galten	SE658080-162871	8	Mälaren	+	+	+	+			1	
Görväln S	SE658080-162871	8	Mälaren	+	+			-	-	1	
Granfj. Djurgårds Udde	SE658080-162871	8	Mälaren	+	+					1	
S. Björkfjärden SO	SE658080-162871	8	Mälaren	+	+					1	
Skarven	SE658080-162871	8	Mälaren	+	+					1	
Svinnegarnsviken	SE658080-162871	8	Mälaren	+	+	+	+			1	
Ulvhällsfjärden	SE658080-162871	8	Mälaren	+	+	+	+			1	
Vättern	SE649029-145550	8	Vättern	+	+					1	Deep
Dagskärsgrund N	SE647666-129906	9	Vänern	+	+					1	
Edeskvarnaån NV	SE649029-145550	9	Vättern				+			1	
Jungfrun NV	SE649029-145550	9	Vättern			+	+			1	
Mariestadsviken M1	SE647666-129906	9	Vänern					+	+	1	
Skarven	SE658080-162871	9	Mälaren	+	+					1	

The results (Tables 4–6) for significant trends were structured by paragraphs describing SWT, BWT, and BS-ratios, which were listed according to deep lakes (> 6m deep), shallow lakes (≤ 6m deep), and lake basins; they were organized by months. Total amount of trends found using cat 1 and cat 4 for SWT, and cat 2 and cat 6 for BWT and BS-ratios, were denoted in parenthesis after each month. If not indicated otherwise, the lakes were part of seasonal type 1 (southern Sweden).

When comparing deep lakes, shallow lakes, and lake basins, different trend patterns were recognizable. However, no patterns were detected regarding the mixing type (Osgood Index).

4.1.1 Surface water temperature (SWT)

Deep lakes

In **February** (N=26) all trends showed decreasing temperatures. Representative for the spring period, all **April** (N=13) trends, with the exception of Stor-Tjulträsket, showed increasing temperatures. Stor-Tjulträsket lake is part of northern Sweden (season type 2) with longer winter periods than in southern Sweden; therefore, the decreasing trend might have been a result of extended winter periods in the dataset. No trend was found for air temperature for this specific lake for comparison. Analysis of data from **August** (N=16) and **September** (N=14) resulted in positive trends only. No differences were found in lakes that were part of the liming project.

Shallow lakes

All trends found for **February** (N=7), with the exception of Edasjön at cat 1, showed decreasing temperatures. Edasjön is categorized as a lake that varies between polymictic and dimictic mixing patterns, according to the Osgood Index. However, this trend has not been found again at cat 4 and must therefore depend on the specific sample years used for the calculation. No trends were found for **April** (N=0) or **September (N=0)**. For **August** (N=6) five negative trends and one positive trend, for lake Sidensjön at cat 4, were found. Sidensjön is located in northern Sweden (season type 2) and was categorized as a dimicic lake. Again, the positive trend has not been detected when considering the data from cat 1; therefore, it is mainly influenced by the sample years used for the calculation, and moreover, it might have been influenced by the depth of the samples as cat 4 contained seven values at 2m depth additionally. The lake itself has a maximum depth of 5m.

Large Lake basins

All lake basins showed increasing water temperature trends for April (N=2), August (N=10), and September (N=2). The trends were detected at both categories 1 and 4.

4.1.2 Bottom water temperature (BWT)

Deep lakes

All trends found for **February** (N=3) showed positive trends. In **April** (N=5) three lakes showed increasing and two decreasing water temperature (Allgjuttern and Stora Envättern). For both decreasing trends an increase in air temperature and in stratification strength were detected leading to the assumption of an increase in SWT and less heat diversion into deeper layers. For **August** (N=3) lakes showed two positive trends and one negative trend (lake Lien). No air temperature trends could be linked, however, all trends of degree months for two of the lakes, including lake Lien, were increasing. Additionally, lake Lien with a variable mixing pattern between poly- and dimitic turnovers, also had trends showing an increase in stratification strength. Like in April an increase in stratification might have let to less mixing and therefore the maintenance of cooler BWT. In **September** (N=8) six negative and two positive trends were found. Mixing patterns approximated through the Osgood Index for the lakes with positive trends were dimictic and polymictic. For five negative trends an indication for stronger stratification (negative BS-ratio) was detected; like in April and August. The positive trends instead had not corresponding BS-ratio trends to compare to.

Shallow lakes

The only trends found were positive for **February** (N=1) and **April** (N=1). Lake Mossjön showed not only an increase in BWT during February but also a decrease in SWT, which is likely an indication of an increase in strength of temperature difference between the epilimnion and the hypolimnion. The negative trend for SWT, however, was only detected at depth cat 4. Additionally, no trends for BS-ratios were found; therefore, no indication for an increase in stratification strength was found.

For the April trend a positive air temperature trend was detected for lake Mossjön; this led to the question whether higher spring temperature and early breaking of the stratification influenced the distribution of warm surface water into deeper layers in this polymictic lake. However, as there was a negative trend in February for SWT, it is also likely that less mixing kept the warmth in BWT.

Large Lake basins

All trends found were positive for **April** (N=1), **August** (N=3) and **September** (N=2). Trends found for April and August were also positive for SWT leading to the assumption of 1) a reduction or 2) a maintenance of the temperature ratio between the layers and therefore an overall warming of the lake. However, no trends for BS-ratios were found, hence suggesting assumption 2) to be more valid.

4.1.3 Bottom-surface ratios (BS-ratios)

Deep lakes

For **February** **(N=2)**, two positive trends were found for BS-ratios in deep lakes indicating a decrease in stratification strength. Both lakes differed in their mixing pattern (polymictic and dimictic). Corresponding SWT trends were negative, indicating a possible higher impact from SWT than BWT on the BS-ratio. In **April** **(N=5)**, all lakes had negative trends, thus showing an increase in stratification strength; corresponding air temperature trends increased. For two of these lakes, SWT increased, thus possibly being the main driver for a stronger stratification. Therefore, an earlier onset of stratification due to SWT warming seemed likely for those two (Härsvatten & Långsjön_1). Two other lakes (Allgjuttern & Stora Envättern) which had no trends for SWT, instead had negative trends for BWT. In these cases changes in the bottom water might be the driving force for changes in stratification strength. For **August** **(N=3)**, all lakes had negative trends with no corresponding air temperature. One corresponds to declining bottom water trends.

In **September** (N=9) all trends indicated an increase in stratification. However, one trend was not detected at cat 2. Thus, the change in the temperature gradient was likely dependent on the additional sample years at cat 6.

When BWT trends were found for respective BS-ratios, they were negative; lakes with corresponding SWT trends were always positive. Thus, they indicated either a stronger influence on BS-ratios from BWT or SWT in the respective cases. Three lakes (Gyltigesjön, Stora Envättern, V. Skälsjön) with negative BS-ratios (increasing stratification strength) during September had both, negative trends for BWT, and positive trends for SWT. Therefore, those seemed to show the strongest change in stratification strength towards an increased stratification. Those three lakes were part of the southern seasonal type 1 and dimictic according to the Osgood Index.

Shallow lakes

Only positive trends, a decrease in stratification strength, were detected for **April** (N=1) and **August** (N=1) for polymicitic lake Tångerdasjön. In April, a corresponding positive trend for air temperature was also present. No trends were found for SWT and BWT, thus a shift of stratification onset to a previous month seemed likely. In case the time of sampling collided in most year with times of mixing, this might have also influenced the result.

Large Lake basins

Only two trends were found for BS-ratios. In **August** (N=1), an increasing stratification, was calculated for Görvaln S. (Mälaren); this corresponded to an increase of SWT. A tendency to an increased strength of temperature difference between epilimnion and hypolimnion due to surface water warming seems likely therefore. For **September** (N=1), a decreasing stratification was detected for Mariestadsviken M1. No corresponding trends of different water layers were found.

4.2 Magnitude of trends – temperature rates over time

Theil-Sen slopes for trends of SWT at cat 1 and cat 4, BWT and BS-ratios at cat 2 and 6 were compared for their annual changes in temperature (°C yr^{-1}). A monthly comparison of the results showed smaller changes in SWT for February compared to April, August, and September (Fig. 7). For slopes of BWT this pattern was also present when comparing February to April and September (Fig. 8).

When comparing the Theil-Sen slopes calculated from SWT of shallow lakes, deep lakes, and lake basins, the shallow lakes had temperature changes opposing the common trend pattern in February and August. The one change towards warmer SWT in February and all decreasing temperatures in August belonged to shallow lakes.

Generally, mean temperature changes over all months and lakes ranged between -0.3–0.4°C yr^{-1} for SWT at cat 4, and -0.11–0.24°C yr^{-1} for BWT cat 6 (see annex 5 (I-III)). In shallow lakes, the changes were highest around -0.30–0.18°C yr^{-1} for SWT and 0.05–0.24°C yr^{-1} for BWT. Followed by deep lakes with changes ranging between -0.14–0.21°C yr^{-1} for SWT, and -0.11–0.17°C yr^{-1} for BWT. In lake basins, the mean temperature changes were smallest and ranged between 0.04–0.39°C yr^{-1} for SWT and 0.06–0.17°C yr^{-1} for BWT. The changes found with samples of cat 1 and cat 2 were similar to the listed values of cat 4 and cat 6, respectively.

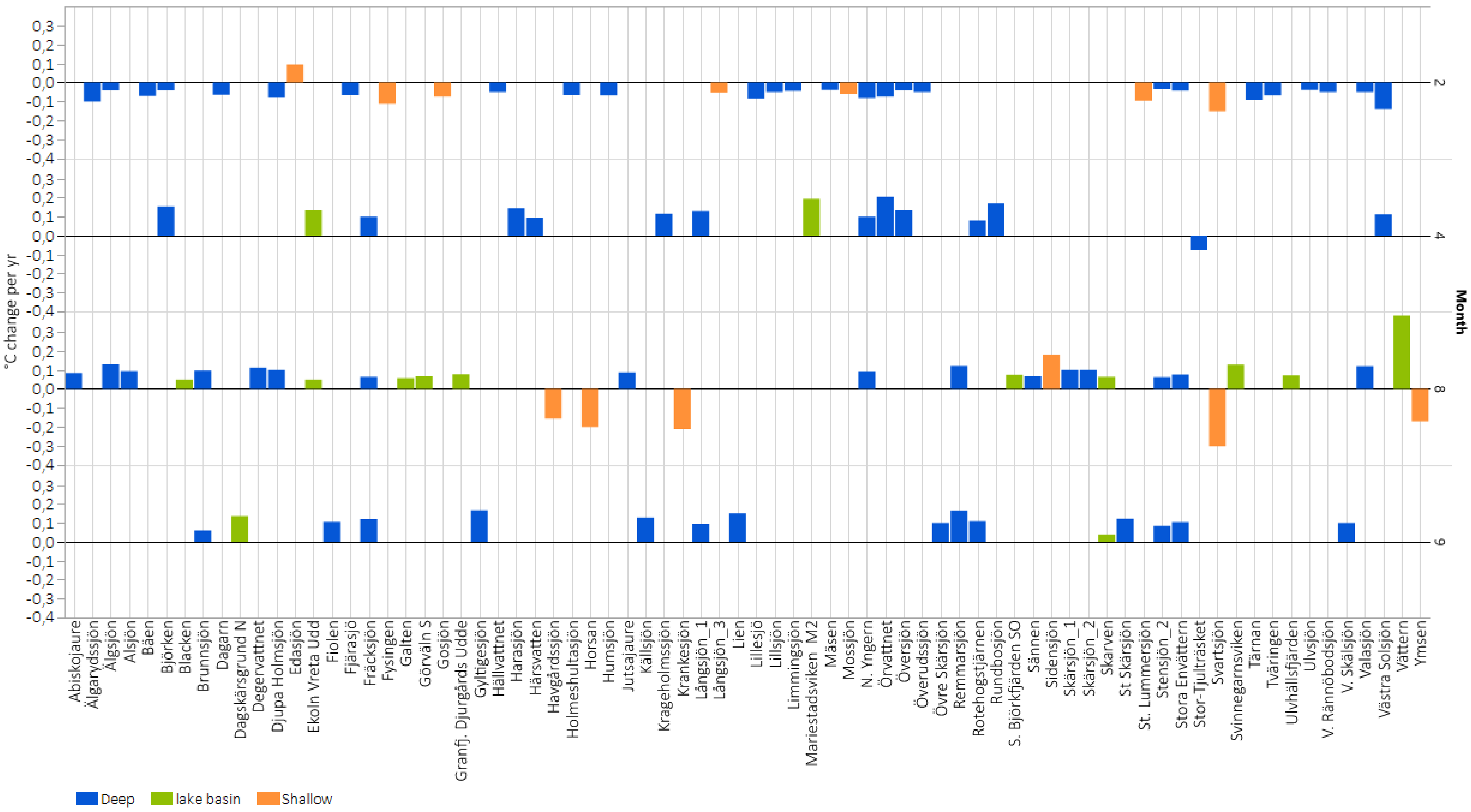


Figure 7: Theil-Sen slope (°C change per year) of significant lakes for SWT during February, April, August and September. Selection shown includes lakes at depth cat 4 and lakes Edasjön, N. Yngern and Västra Solsjön at depth cat 1.

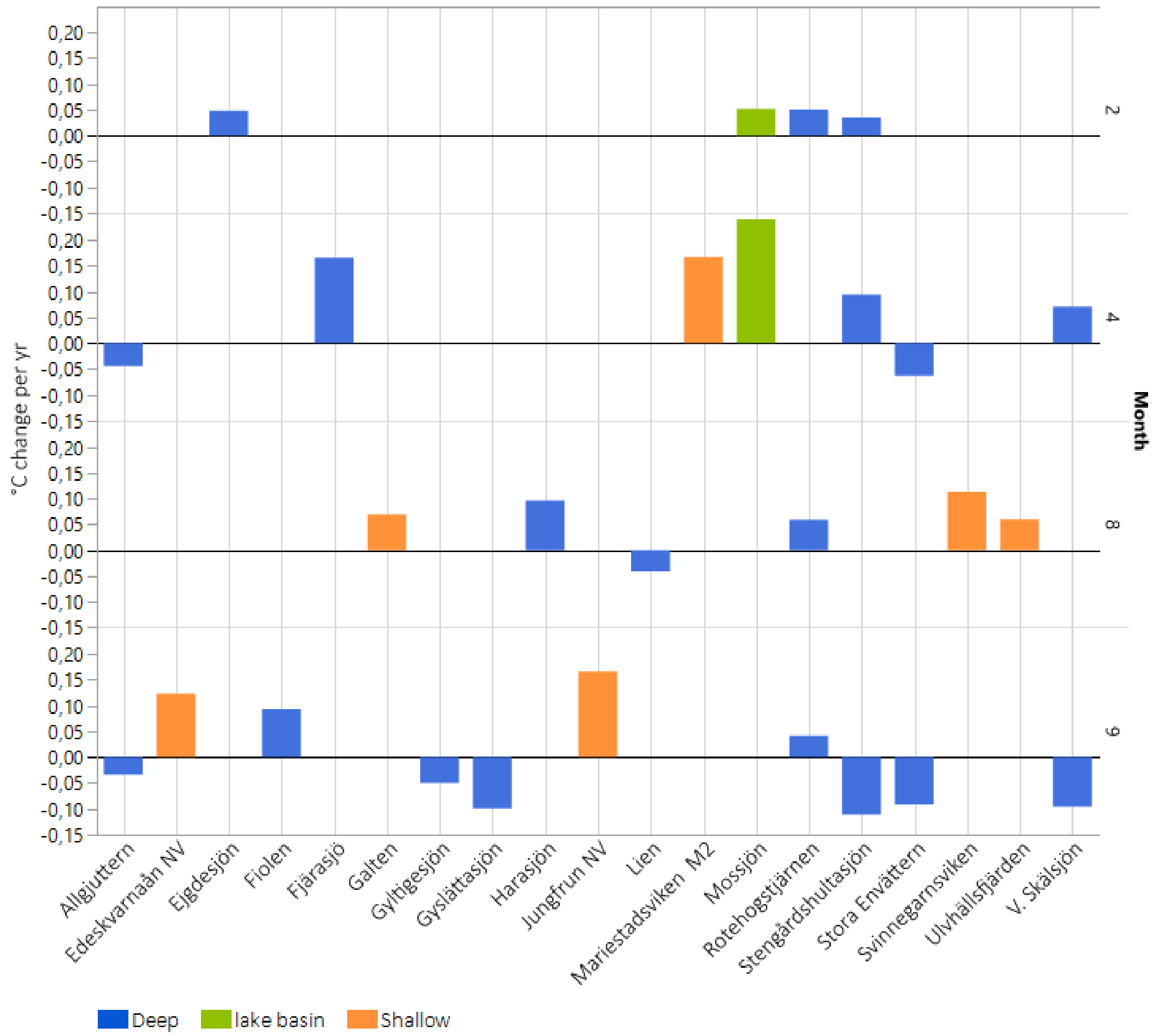


Figure 8: Theil-Sen slope (°C change per year) of significant trends for BWT during February, April, August and September. Selection shown includes lakes at depth cat 6 and lake Stengårdshultasjön in April at depth cat 2.

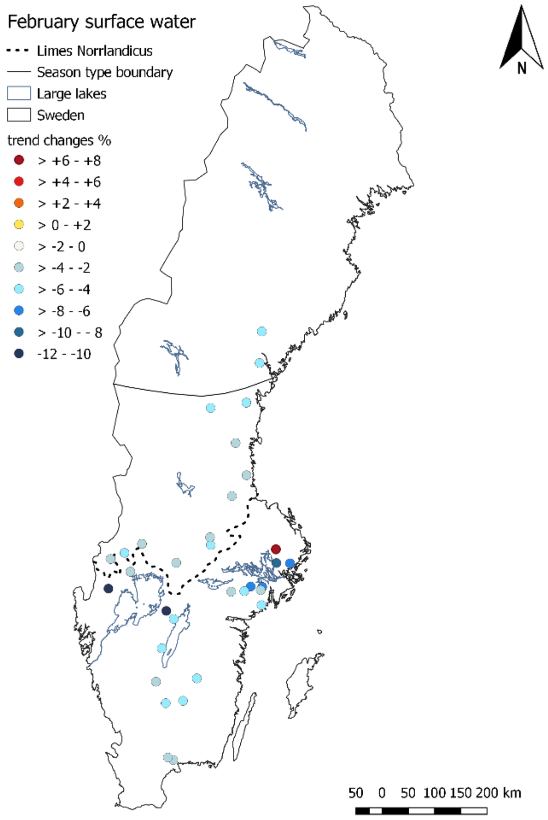
Monthly percent trend changes

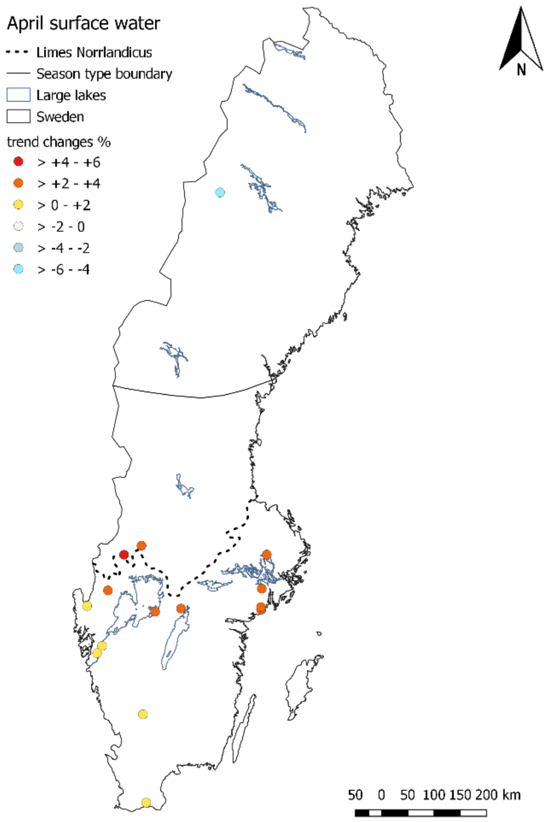
Percent changes of °C per year and month were calculated based on the Theil-Sen slope and corresponding monthly water temperature means for SWT (cat 1, cat 4), BWT and BS-ratios (cat 2, cat 6) per lake (trend/mean*100). Based on the calculated percent trend changes, no comparison between the monthly data could be made. This is due to the fact that the higher the mean water temperatures sampled, the lower the percent trend change. Therefore, changes during summer months would always appear relatively small.

Patterns for magnitudes of change regarding a location factor, e.g. the impact of continental versus maritime air, were neither detectable for data in February, August, and September for SWT trends, nor generally for BWT, and BS-ratio trends. For SWT trends in April, however, an accumulation of lakes with small changes of 0–2% was found at the south-west coast of Sweden (Fig. 9). This was, however, not linked to a maritime air influence when checking the relationship using a correlation analysis. Close to the *limes norrlandicus* and in northern Sweden, SWT changes ranged between >2–6% yr^{-1}.

It should be noted that the maps display SWT changes in percent of the monthly means for depth cat 4. When trends were not found at this level but at cat 1, the latter were used for the maps. This applied to lakes Edasjön, N. Yngern, Björken, Ekoln Vreta Udd, Horsan, and Jutsajaure. Trends found in both depth categories did not differ

Figure 9: Maps with significant trends found for surface water temperature at cat 4 and cat 1 (magnitude of temperature change per lake and year in percent compared to the monthly mean of each lake).



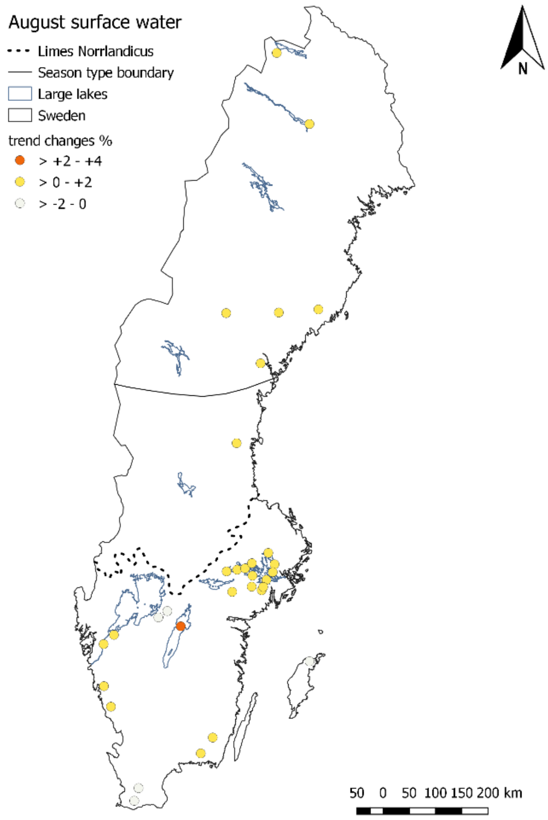


much overall. For SWT in 49 lakes out of 53 lakes, percent trend changes showed discrepancies from 0–0.6% yr^{-1} between cat 1, and cat 4. However, four trends differed by 1.0–3.4% yr^{-1} with larger temperature changes per year at cat 1 (Hällvattnet, Holmeshultasjön, Tärnan, Limmingsjön).

For BWT, the maximum divergence between calculated percent trend changes for cat 2 and cat 6 was 0.2% yr^{-1} for 22 lakes, and of those 16 had the same change rate. Also, 22 lakes for BS-ratios showed a divergence between 0–0.4% yr^{-1} between cat 2 and cat 6. One trend showed a difference of almost 2 % (Långsjön_1).

Generally, means of percent trend changes for different water layers and ratios at their specific depth categories were greater for SWT than BWT or BS-ratios for deep lakes, shallow lakes, and lake basins (Tables 7–9). For the selection of deep lakes, a tendency to stronger changes in SWT at cat 1 and in BWT at cat 6 compared to categories 4 and 2, was apparent. No patterns regarding the temperature change could be found when comparing percent trend change regarding mixing type, brownification, and trophic state.

In tables 8 and 9, temperature changes in shallow and deep lakes were summarized. Some of the values shown were not based on means but on the only one trend found at the respective category. Those values can be detected due to the missing standard deviation. The specific percent trend change for each lake can be seen in Annex 6 (I-III).



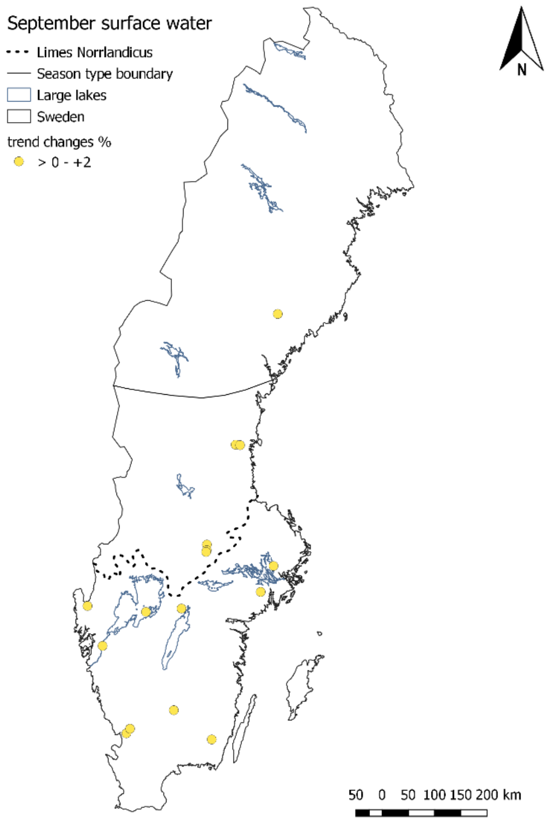


Table 7: Deep lakes – Mean percent trend change and standard deviation per year and month.

Depth selection	Month							
	2		4		8		9	
	Mean%	Std. dev.	Mean%	Std. dev.	Mean %	Std. dev.	Mean%	Std. dev.
SWT Cat1	-5.94	3.00	1.61	2.46	0.59	0.14	0.81	0.24
SWT Cat4	-4.11	1.27	1.51	2.32	0.52	0.14	0.81	0.24
BWT Cat2	1.39	0.04	0.91	1.98	0.29	1.01	-0.60	0.95
BWT Cat6	1.55	0.14	0.68	2.21	0.32	0.95	-0.73	0.86
SB-ratio Cat2	2.29	0.49	-2.62	1.05	-0.96	0.20	-1.50	0.69
SB-ratio Cat6	2.22	0.40	-2.13	1.00	-0.96	0.20	-1.51	0.65

n.a. = not applicable

Table 8: Shallow lakes – Mean percent trend change and standard deviation per year and month.

Depth selection	Month							
	2		4		8		9	
	Mean%	Std. dev.	Mean%	Std. dev.	Mean%	Std. dev.	Mean %	Std. dev.
SWT Cat1	-4.34	10.45	n.a.	n.a.	-1.20	0.28	n.a.	n.a.
SWT Cat4	-5.86	3.46	n.a.	n.a.	-0.66	1.00	n.a.	n.a.
BWT Cat2	1.47	n.a.	3.82	n.a.	n.a.	n.a.	n.a.	n.a.
BWT Cat6	1.47	n.a.	3.82	n.a.	n.a.	n.a.	n.a.	n.a.
SB-ratio Cat2	n.a.	n.a.	0.19	n.a.	0.24	n.a.	n.a.	n.a.
SB-ratio Cat6	n.a.	n.a.	0.19	n.a.	0.24	n.a.	n.a.	n.a.

n.a. = not applicable

Table 9: Lake basins – Mean percent trend change and standard deviation per year and month.

Depth selection	Month					
	4		8		9	
	Mean%	Std. dev.	Mean%	Std. dev.	Mean%	Std. dev.
SWT Cat1	3.37	0.61	0.38	0.13	0.63	0.52
SWT Cat4	3.37	0.61	0.60	0.69	0.63	0.52
BWT Cat2	3.55	n.a.	0.48	0.21	2.72	n.a.
BWT Cat6	3.55	n.a.	0.48	0.21	2.59	0.51
SB-ratio Cat2	n.a.	n.a.	-0.49	n.a.	0.18	n.a.
SB-ratio Cat6	n.a.	n.a.	-0.49	n.a.	0.18	n.a.

n.a. = not applicable

4.3 Simple linear regression – plotting chemical data and water temperature

To find relationships between water temperature, climatic, and chemical variables, simple linear regressions were performed. Trends of SWT, BWT, and BS-ratios for cat 4 and 6 were plotted against corresponding air temperature, precipitation, and chemical trends; the latter corresponded to depth levels between 0–2m. A selection of significant relationships was chosen based on a p-value ≤ 0.05 for variable estimates (Table 10).

In general, no relationships were found for April and no other results than those shown here were found when considering cat 1 and cat 2, with one exception. BS-ratios in cat 2 related with calcium in three lakes during April. No linear relations existed between air temperature, or precipitation, and water temperature.

Table 10: Significant results of simple linear regression between SWT, BWT and BS-ratios with chemical data, air temperature and precipitation; (-) = negative relationship.

Month	SWT (cat4)	BWT (cat6)	BS-ratio (cat6)
2	(-) filtered absorbance, (-) TOC, P, alk/acid, conductivity, NH4-N, F and Ca	(-) Na*	n.r.
8	(-) P, alk/acid, (-) pH, Ca	n.r.	n.a.
9	(-) F, (-), Si, (-) Cl	n.r.	(-) alk/acid*

n.r. = no results
* = based on only three lakes.

Whilst organic compounds (filtered absorbance and TOC) were negatively related to SWT in February, total phosphorus (P), alkalinity (alk/acid), conductivity, ammonium (NH4-N), fluorine (F), and calcium (Ca) were positively related. BWT in three lakes showed one negative relation with sodium (Na) which could not be found in any other months or water layer.

In August, the previously positive relation between SWT and total phosphorus turned negative. Alkalinity stayed positive, however, pH, which is closely related, had a negative relation with SWT in August. Calcium did maintain its positive relation.

Negative relations of silicon (Si) and chlorine (Cl) with SWT were found only in September. The positive relation between fluorine and SWT during February turned negative during September. Additionally, a negative relation between BS-ratio and alkalinity was detected for September. Thus, a stronger stratification was accompanied by a decrease in alcalinity and vice versa.

4.4 Correlation Analysis

Correlations were calculated between water temperature, and air temperature, degree month air temperature, organic matter (filtered absorbance, and TOC), Osgood index (OI), trophic, and brownification states, using significant trends. Large lake basins were not included in this analysis due to a lack of corresponding trends of the listed variables. The Pearson-Product-Moment correlation coefficient (r) was used to determine the strength of a linear correlation between the variables using $r \geq 0.7$ as a threshold for considering a correlation to be strong. Anything smaller than $r \leq 0.5$ was considered a weak correlation. The correlations were furthermore checked for true linear relationships using a cut-off level of p-values at 0.5 and 0.1.

Air temperature and degree months

In a first step correlations analysis was performed on significant trends. Differentiations between season types 1 and 2 (southern and northern Sweden) were not possible due to too low numbers of trends to further separate into groups.

The highest correlation strengths found for the variable combinations according to Pearson-Product-Moment correlation coefficient (r) were summarized (Table 11). No results were found for February because of the lack of trends in air temperature. Three values were significant with average strength ($5 < r < 7$) when compared for non-linearity under the H_0 hypothesis at a cutoff p-value of 0.05 for SWT. For BWT and BS-ratios a total of three correlations at $\alpha \leq 0.1$ were detected. Those had strong correlations ($r \geq 0.7$) for BWT.

April did not contain any significant correlations according to p-value thresholds. BWT correlated strongest and positively with air temperature ($r \approx 0.7$) when compared to the other selections in April. Thus, a mixing state of the lake seemed likely. The strength of positive BS-ratio correlations with air temperature ranged between $0.55 \leq r \leq 0.60$; thus, higher air temperature likely weakened stratification in April.

For August, significant correlations differed regarding the variables with strongest influence. The combinations found for all water layers and categories were dgm 4, dgm 4–6. Whereas dgm 4 (April air temperatures) correlated with water temperature and BS-ratios negatively, dgm 4–6 (air temperature mean of April-June) had positive, strong correlations with BWT and BS-ratios and a negative correlation with SWT; suggesting an increase in mixing which brought warm surface water into deeper water layers and cooler bottom water to the surface layers in case of warming mean air temperatures.

During September, no correlation pattern could be found. SWT, BWT and BS-ratios correlated with different variables. SWT was positively correlated with dgm 5–8 (air temperature mean of May–August) at a strength around $r \approx 0.62$ and a significant linear relationship of p-value ≤ 0.05. Thus, a delayed heating effect of previous monthly air temperature seemed likely for SWT in September. For BWT correlations with air temperature or degree months no conclusion could be derived as the results varied largely per category, correlating variable, and even direction of correlation. Therefore, the state of the particular lakes, wether mixing or stratified or in between, might have varied largely; thus the results given. For BS-ratios, a pattern was present. The combination of a positive correlation with dgm 4–6 (air temperature mean of April–June) and a negative correlation with air temperature of September suggested a weakening of the stratification during this month. If exclusively the impact of air temperature would be considered, a strengthening of the stratification would be expected; the higher air temperature, the stronger the stratification.

Table 11: Correlation between air temperature (Air temp), degree months (Dgm), and water temperature and BS-ratios with r ≥ 0.35 (dark grey = significant p-value ≤ 0.05; light grey = p-value ≤ 0.1; N = number of trends correlated).

Month	SWT cat1	SWT cat4	BWT cat2	BWT cat6	BS-ratio cat2	BS-ratio cat6
February	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
April	Air temp: -0.39 (N=10)	Air temp: -0.38 (N=11)	Air temp: +0.69 (N=6)	Air temp: +0.71 (N=5)	Air temp +0.55 (N=6)	Air temp: +0.60 (N=6)
August	Dgm4: -0.67 Dmg5: +0.6749 (N=7)	Dgm4-6: -0.61 (N=16)	Dgm4: -0.99 Dgm4-6: +0.99 (N=3)	Dgm4: -0.10 Dgm4-6: +0.99 (N=3)	Dgm4: -0.77 Dgm4-6: +0.78 (N=4)	Dgm4-6: +0.78 (N=4)
September	Dgm5-8: +0.63 (N=11)	Dgm5-8: +0.62 (N=11)	Dgm5: +0.52 (N=6)	Dmg4-8: -0.41 (N=8)	Dgm4-6: +0.60 Air temp: -0.52 (N=7)	Dgm4-6: +0.40 Air temp : -0.56 (N=8)

n.r. = no result (either N < 3 or r ≤ 0.4)

TOC versus filtered absorbance

For organic material, represented by total organic carbon (TOC), or filtered absorbance (Abs-F), most correlations were found for SWT with TOC in February and April, and Abs-F in August and September (Table 12). No correlations were present with BWT, or during February, April and August with BS-ratios. However, BS-ratios had one correlation with Abs-F in September, which added to the tendency of Abs-F correlating with water temperature in August and September.

TOC correlated negatively with SWT in February and August but positively in April. Furthermore, SWT correlated positively but weakly (r ≤ 0.5) with Abs-F in August and positively, strong in September. For BWT, no correlations with r ≥ 0.4 were found; other, weaker correlations were not displayed here. The correlations between BS-ratio and Abs-F in September differs with the results for SWT in so far as it was a negative correlation; thus, it is likely that an increase in Abs-F led to warmer SWT and therefore an increase in stratification.

Table 12: Correlation between organic material, and water temperature and BS-ratios with r ≥ 0.4 (dark grey = significant p-value ≤ 0.05; light grey = p-value ≤ 0.1; N = number of trends correlated).

Month	SWT cat1	SWT cat4	BWT cat2	BWT cat6	BS-ratio cat2	BS-ratio cat6
February	n.r.	TOC: -0.63 (N=18)	n.r.	n.r.	n.r.	n.r.
April	TOC: +0.46 (N=5)	TOC: +0.77 (N=5)	n.r.	n.r.	n.r.	n.r.
August	n.r.	Abs-F: +0.46 TOC: -0.4310 (N=7)	n.r.	n.r.	n.r.	n.r.
September	Abs-F: +0.71 (N=8)	Abs-F: +0.70 (N=8)	n.r.	n.r.	n.r.	Abs-F: -0.46 (N=4)

n.r. = no result (either N < 4 or r ≤ 0.4)

Osgood index (OI), colour (brownification status), and trophic state (mean total phosphorus (mTP))

The selection of OI, colour (based on filtered absorbance), and trophic state had some strong correlations with trends of BS-ratios ($r \geq 0.7$), and significant correlations with BS-ratios, and SWT (p-value cutoff level at $\alpha \leq 0.05$) (Table 13). For further understanding, the greater OI, the greater the likelihood of a strong temperature gradient and therefore stratification. The greater the mean TP (base for trophic state), the greater the load of nutrients, and the greater the colour, the greater the load of humic substances. Colour and mTP were derived from surface water measurements between 0–2 m depth.

Table 13: Correlations between Osgood Index (OI), colour, mean total phosphorus (mTP), and water temperature and BS-ratios with $r \geq 0.4$ on significant trends (dark grey = significant p-value ≤ 0.05; N = number of trends correlated).

Month	SWT cat1	SWT cat4	BWT cat2	BWT cat6	BS-ratio cat2	BS-ratio cat6
February	mTP: +0.52 (N=11)	Colour: -0.49 (N=28)	n.r.	n.r.	n.r.	n.r.
April	n.r.	n.r.	mTP: +0.59 (N=5)	mTP: +0.56 OI: -0.45 (N=4)	n.r.	n.r.
August	mTP: -0.52 (N=9)	mTP: -0.64 (N=19)	n.r	n.r	mTP: +1.0 OI: -0.79 (N=4)	mTP: +1.0 OI: -0.78 (N=4)
September	n.r.	n.r.	mTP: +0.62 (N=6)	mTP: +0.55 (N=8)	OI: +0.51 (N=9)	OI): +0.50 (N=10)

n.r. = no result (either N < 4 or r ≤ 0.4)

Generally, correlations between trophic state (mTP) and water temperature were predominant compared to colour and OI. The four significant correlations found were between trophic state (mTP) and SWT, or BS-ratios. Furthermore, while mTP correlated positively with BWT in April and September, and with BS-ratios during August and September, a positive correlation with SWT was present in February. This indicated either an increase in SWT and a higher load of nutrients; or a decrease in SWT (as previously found) with decreasing nutrient load. In August, however, a negative correlation between MTP and SWT was found; it could be an indication for a mixing event bringing nutrients up to the surface layer and warmer surface water to deeper layers. Thus, on the one hand an increase in nutrients correlated with a decrease SWT. On the other hand, lower nutrient loads in the surface layer and an increase in SWT as suggested by previous findings in the trend analysis would be likely the result of a mixing event without a cooling effect of the surface water layer.

The overall picture of mTP and water temperature correlations with exception of the negative correlation of SWT and mTP during August suggested a nutrient decrease whith cooling water or vice versa for BWT correla tions with mTP. Though, April had more increasing BWT trends than decreasing ones, and September had shown more decreasing BWT than increasing in the previous trend analysis.

The strong correlation of trophic state and BS-ratios during August seemed logical, if nutrients would increase at the surface water layer due to mixing events in the selected lakes. Moreover, the correlations of BS-ratios and OI during August were logical. The smaller OI, the more likely mixing event occur, and thus the larger the BS-ratio, which indicated a weak stratification. However, the positive correlation of the same combination during September was less intuitive; increasing stratification correlated with large probability of mixing events.

4.4 Multilinear regression (MLR)

MLR did not lead to any significant model calculation by considering selected trend variables according to the findings in the correlation analysis (air temperature, degree months (dgm 4–6 and dgm 5–8), TOC or Abs-F) and SWT, BWT, or BS-ratios. Large lake basins were not considered as no trends for air temperature were available. Generally, resulting R^2 adjusted were 0 or close to 0.

A MLR analysis on sample values, linked monthly and yearly to climate and chemical parameters, resulted in finding significant predictor variables for explaining variation in SWT (depth cat 4); those variables were air temperature (airt) and filtered absorbance (Abs-F). A combination of air temperature and absorbance resulted in a R^2 of 0.46 adjusted for degrees of freedom (46 % of variation explained) in April (Table 14). For August and September, air temperature was a significant predictor variable for SWT with slightly hogher R^2 values of 0.58 and 0.61, respectivley. For February no predictor variables were significant enough to explain changes in SWT.

Table 14: R^2 adjusted, and prediction formula for surface water temperature (SWT) per months.

Month	$R^2_{adjusted}$	Prediction formula
4	0.46	Swt = airt *1,0178096950539 + Abs-F *2,33854196635998 + 0,860668647193903
8	0.58	Swt = airt* 0,916755162976468 + 4,84295635744429
9	0.61	Swt = airt*0,814422498758786 + 5,31227726286864

5 Discussion

Projections of lake water temperature changes are prognosing a change towards stronger stratification and reduced mixing between surface and bottom water mainly during the summer and autumn for the northern hemisphere in mid latitutes and high latitudes (Woolway and Merchant 2019; Coats et al. 2006; Lee et al. 2012; Peeters et al. 2002). The temperature changes in two Swiss lakes due to the heat wave of 2003 in Europe also resulted in stronger summer stratification compared to other years in a 50 year time period (Jankowski et al. 2006). The results of the current trend analysis of Swedish lakes indicated similar tendencies towards stronger stratification and less mixing.

The findings of the trend analysis, correlation and linear regression are discussed in this chapter according to the season of the year represented by the studied month February, April, August and September. Moreover, the limitations of this study regarding the sample set and the approach are presented. It should be kept in mind that air temperature trends were showing increasing temperatures when present throughout all months; the same applied to total organic carbon (TOC) trends, and in general to filtered absorbance.

5.1 Winter – February

The large majority of lakes studied showed decreasing SWT trends during February and increasing BWT trends in all detectable cases. The decreases of SWT ranged between -0.03– -0.15 °C yr^{-1} and the increases for BWT 0.04–0.05 °C yr^{-1}. Also, BS-ratios showed increasing trends which indicated a reduction in stratification strength despite the fact that decreasing SWT and increasing BWT would lead to the assumption of a trend towards stronger stratification. However, in most cases either trend was present, thus no assumption on stratification strength could be verified. Nevertheless, decreasing SWT trends likely contribute to stronger stratification as BWT are generally warmer during winter. In comparison Ptak, Sojka, and Kozłowski (2019) generally detected increasing trends in maximum water temperature over the time period of 1971–2015 during February with 0.03–0.04 °C yr^{-1} (derived from decadal data).

A trend to decreasing temperatures during winter was not intuitive. Especially, with the background that several studies found a reduction of ice-cover and length of ice-cover duration due to warmer air temperature (Sharma et al. 2019; Magnuson et al. 2000). However, losses in ice-cover which could sustain an insulating layer of snow during winter and/or less snow which could lead to a reduction of the insulation effect could be possible explanations for a stronger impact of cold air temperature on the lake water. Also, the selection of SWT at cat4 with samples at 0.5–2m depth resulted in more significant trends than for the samples at 0.5m depth only. Generally, water temperature is increasing with depth during winter. Therefore, this might be an indication of either an effect of very cold winters that have not been included in the cat1 selection, or internal mixing processes that could not be detected with this dataset. However, the first assumption seemed more plausible as colder winters might have led to thicker ice-cover and therefore samples would have been collected at higher depth.

Moreover, Sharma et al. (2019) also found the lakes that did not build up an ice cover through some years to have higher SWT and a higher biomass production. Thus, less ice-cover strength and insulation might not be the only possible factors leading to a temperature reduction. They also found a dependency of ice-cover reduction and lake depth. Deep lakes would therefore lose their ice cover with increasing air temperature and shorter winters sooner than shallow lakes (around 12m deep). This finding could not be verified with the dataset used in this study, as lakes, no matter their depth, showed declining temperatures during February. Regarding the biomass production, the analyzed dataset showed a negative correlation between filtered absorbance and total organic carbon (TOC) with SWT. Therefore, a decreasing SWT could be a possible influencing factor for a higher biomass production. If less snow would lead to less insulation and more sunlight penetration through the ice, this could activate photosynthesis processes while at the same time causing decreasing temperatures.

Additionally, Woolway et al. (2019) found an increase in the annual minimum temperatures of eight European lakes which were ice-free. In their study, some lakes showed even larger changes for SWT compared to changes in air temperature. Due to lack of trends for air temperature during February, such a comparison could not be made with the current dataset.

As studies found lakes without ice cover to show increasing SWT and the investigated Swedish lakes were probably frozen at least during parts of the winter season, the ice cover seemed to be the main driver of SWT changes. A verification would however, require further investigations.

5.2 Spring – April

During April most lakes of the dataset showed increasing SWT, or BWT trends. An increase in stratification strength was present for warming SWT, or cooling BWT. This was likely an indication of which water layer influenced the change in stratification strength the most; the cases varied. The one lake with a decreasing trend in SWT was located in northern Sweden. This might indicate a delay in warming in northern Swedish lakes due to longer winter periods. However, this tendency is unexpected, as climate models suggest a faster warming in northern Swedish territories, especially during winter months.

Other studies also detected a general increase of SWT in lakes worldwide using simulation models, or the Mann-Kendall trend test (Ptak, Sojka, and Kozłowski 2019; Hondzo and Stefan 1993; Woolway and Merchant 2019). In comparison Ptak, Sojka, and Kozłowski (2019) detected trends of 0.08–0.12 °C yr^{-1} (based on decadal data) of maximum lake water temperature during April over the time range 1971–2015. In the Swedish lakes the warming of SWT ranged between 0.09–0.21 °C yr^{-1}, and for BWT between 0.07–0.24 °C yr^{-1}. Decreasing BWT trends ranged between -0.04– -0.07 °C yr^{-1}.

Decreasing trends in BWT tended to stronger stratification. This led to the assumption that an increase in SWT, which was not discovered in the trend analysis, reduced heat diversion into deep layers. These cases could be explained with an early onset of spring stratification, which is supported by the findings of Hondzo and Stefan (1993) who detected cooler summer hypolimnetic water due to an early and fast onset of spring stratification.

Increasing BWT with no trend for SWT could be explained through a general warming of the hypolimnion which is maintaining the heat throughout the winter until the spring mixing period, or an early heating of SWT and therefore breaking of the winter stratification led to a mixing of warm surface water into deeper water layers (Peeters et al. 2002).

Both were plausible explanations. First, warmer temperatures during winter as explained in the previous section, might lead to a decrease in SWT and therefore a stronger statification. Thus, warmer hypolimnion temperatures might have been stored until spring instead of mixing with surface waters; therefore an increase of BWT could be detected. On the other hand as BWT and BS-ratios correlated positively with air temperature during April, this indicated a mixing state.

Faster increases in SWT per year than for air temperature were present for deep lakes over the time span of 1979–2016. This contradicted the findings of Hondzo and Stefan (1993). They discovered a smaller increase in SWT compared to air temperature over the period of 1955–1979 for lakes in north-central US. As the trends of this study did not contain exact matching air temperature and water temperature samples, the result might have been influenced by a longer time period taken into consideration for simulated air temperature than for water temperature. However, larger increases in SWT might have depended on heat storage from previous summer months, e.g. in the sediment, and a faster ice-out and therefore earlier warming of lake surface waters. If hypolimnetic water was generally getting warmer it might have enhanced warming of SWT when mixing occured in spring; thus the already warmer water might have risen to the surface and thus added to the heating through sunlight. The extension of the vegetation period due to shorter winters, or an earlier onset of biomass production due to sunlight penetration through the thinner ice, might have furthermore contributed with more material for light aborption; this could have led to an enhanced heat uptake. This hypothesis matched the trends found for filtered aborbance and total organic carbon (TOC) which were increasing in all cases with increasing SWT. However, filtered absorbance were weakly correlated. Thus, a higher biomass production could have been the result of warmer temperatures but without having an effect on lake warming in spring. As the study period is more recent than the one of Hondzo and Stefan (1993) the warming trends might be even enhanced by the storage of higher temperatures from previous years; thus, an intensifying increase in temperature might have been possible.

A slower increase in BWT per year compared to air temperature changes was detected in deep-lakes during April. Low temperature changes or even decreasing temperatures within the hypolimnion of seasonally stratified, dimictic lakes were also found by Hondzo and Stefan (1993).

5.3 Summer – August

During August lake water temperatures mainly increased at the surface, and in the bottom layers. The warming during summer months was also predicted by other studies (Stefan, Fang, and Hondzo 1998; Jankowski et al. 2006; Peeters et al. 2002; Coats et al. 2006; Woolway and Merchant 2019). However, the group of shallow lakes generally had decreasing SWT trends. SWT trends ranged between 0.05–0.39°C yr^{-1}, BWT trends between -0.04–0.11°C yr^{-1}. The decreasing trends in SWT within shallow lakes ranged between -0.16– -0.30°C yr^{-1}. Increases of maximum water temperature in August during a similar time range (1971–

2015) found by Ptak, Sojka, and Kozłowski (2019) in Polish lakes ranged between 0.04–0.08°C yr^{-1} (based on decadal data).

Increasing water temperatures were expected during August with increasing air temperature during summer. Higher SWT could cause an increase in stratification strength which was also detected in some lakes (Hondzo and Stefan 1993; Stefan, Fang, and Hondzo 1998; Jankowski et al. 2006; Peeters et al. 2002; Coats et al. 2006; Woolway and Merchant 2019). In other cases both, the epi- and the hypolimnion were warming up. Thus, the whole lake seemed to have warmed up. This was especially the case in the large lakes` basins.

Decreasing temperatures in the epilimnion of a lake, however, could be caused either due to mixing processes that brought colder hypolimnetic water to the surface; thus an earlier onset of autumn mixing in shallow lakes could be possible. Or the lakes were simply sampled during a mixing period, or during years and dates of cooler August air temperatures and/or strong winds that could initiate mixing of water layers. An in-depth analysis of the conditions around the sampling day would be required to gain further insights.

Alike April, faster increases in SWT per year than for air temperature were also present for deep lakes in August. The same discussion applied for these findings. However, a possible impact of stored heat from previous months by comparing degree month air temperature means to SWT showed smaller changes for air temperature means of May to August. However, SWT again had larger change rates than degree months based on means from April to August. Therefore, SWT warming in August seemed to depend upon temperature rises during the spring /summer period May–August. Turn-over events during April might have inhibited a trend recognition. Thus, it is likely, that since May a stratification was developing without mixing events that could interefere in the process.

Unlike the trend of water temperature which suggested a tendency towards stronger stratification during August, the correlation analysis with degree months indicated otherwise. However, the correlations included shallow lakes with their decreasing SWT trends. Therefore, mixing processes within shallow lakes seemed likely, whereas the rest tended towards stronger stratification. Furthermore, absorbance might slightly contribute to higher SWT during August, and even to lower BWT due to shading effects (Thrane, Hessen, and Andersen 2014). It seemed, however, that other, unknown factors were more impacful for the increase in temeperature.

Interestingly, phosphorus declined in the epilimnion with increasing temperatures. It would have been expected to increase in case of stronger stratification. On the one hand side this would have led to an oxygen depletion in the hypolimnion and therefore it would have induced P release from the sediment. On the other hand, the stratification might have caused P to precipitate as mixing processes were unlikely. Thus, it would be interesting to analyze hypolimnetic phosphorus content during August to understand the process.

5.4 Autumn – September

September was expected to show mixing processes between epi- and hypolimnion. However it showed the strongest tendency towards intensified stratification. Other studies also detected a trend to later autumn turnovers (e.g. Ptak, Sojka, and Kozłowski 2019; Magee et al. 2016).

Whilst all lakes had increasing epilimnion temperatures, most also had declining hypolimnion temperatures and even intensifying stratification strength depicted in their trends. The lakes with the probably highest intensification of stratification were Gyltigesjön, Stora Envättern and V. Skälsjön. Those lakes had increasing SWT, decreasing BWT and decreasing BS-ratios. All three lakes belonged to the dimictic mixing category. However, no negative but warming trends were detected in August. Thus, it seemed likely that the decrease in BWT depended on specific inlake or climatic conditions.

The increase in SWT ranged between 0.04–0.17°C yr^{-1}, and the decrease in BWT ranged between -0.03– -0.11°C yr^{-1}. In comparison Ptak, Sojka, and Kozłowski (2019) found trends of 0.02–0.06°C yr^{-1} (based on decadal data) for maximum water temperatures for the time period 1971-2015.

Alike April and August, faster increases in SWT per year than for air temperature were also present for deep lakes in September. The same discussion applied for these findings, and similar to August, degree month calculated as means from May to August had higher change rates, and degree months based on months April to August had smaller change rates than SWT. Therefore, also in September, SWT warming seemed to depend upon temperature rises during the spring/summer period May–August. This assumption was supported by the correlation outcome of mean air temperatures of May–August correlating significantly with SWT.

Furthermore, a strong correlation with absorbance indicated a possible influence from biomass production towards increased SWT. This finding was even supported by the dependency between stratification strength and absorbance in some lakes. Thus, it could be possible that the higher the load of absorbance, the stronger the stratification. This again, would likely be the cause of intensified epilimnion warming.

In general

Overall, rates of change for increasing temperature at the surface and bottom water levels suggested a stronger temperature increase within the epilimnion compared to the hypolimnion. Peeters et al. (2002) argued these findings that were also found in several previous studies (Hondzo and Stefan 1993; Stefan, Fang, and Hondzo 1998; Robertson and Ragotzkie 1990) because their simulations of lake Zürich suggested an increase of almost the same rate for the hypolimnion temperatures compared with the epilimnion temperature increases.

Furthermore, they found changes in temperature within surface waters to be similar throughout the seasons. The previously mentioned studies, however, suggested higher temperature increases during summer than in winter, or early spring. Results from the Swedish lakes also indicated generally slightly higher temperature changing rates in the epilimnion during summer compared to winter, however, also the spring had higher rates than winter in this case.

5.5 Factors influencing lake water temperature

The results of the multilinear regression showed an inclination towards air temperature being the predominant factor, with in-lake organic matter being considered as an additional driver for the samples of SWT at cat 4. However, the unexplained part remained high with 54% for April, 42% for August, and 39% for September. Light absorption has been found to be increasing in lake Constance, in Europe (Fink et al. 2014). Yet, the absorption is not explained due to more absorbance within the water but by higher radiation rates in the atmosphere. As Woolway and Merchant (2019) pointed out *"the responses of lake mixing regimes to climate change are complex and may not be associated closely with change in any one climatic variable. The mixing regime of a lake will instead depend on changes in a combination of climatic factors that contribute to the lake heat budget (such as air temperature, solar and thermal radiation, cloud cover, wind speed, humidity)"*. This statement seemed to be true, also for the time series covered in this study. Air temperature explained more than 50% of the changes in SWT for August and September and 46% during April. These results were based on no further distinction between deep and shallow lakes or lake basins. Thus, R^2 might have been even larger and should be investigated further by considering different groups. The same applied to the impact of degree months. Those might explain an even larger percentage of water temperature changes for August and September and should be investigated; especially for bottom waters, when heat from previous months reached deeper layers. In conclusion, it can be said that, though air temperature had a large influence on SWT (Ptak, Sojka, and Kozłowski 2019), other factors not included in this dataset must be considered to explain the entirety of water temperature changes.

Moreover, MLR with calculated trends did not present any significant results which was likely due to the small number of trends. Different trials and selections showed that the lakes might be too diverse to be used as a batch for MLR. For example, a division according to brownification status gave slightly better results for MLR. However, most likely more significant trends would have been needed to run a successful MLR.

5.6 Limitations

This study was limited by various factors. First, not every lake had been sufficiently sampled in its water profile. Therefore, not all lakes could be taken into consideration for stratification analysis. Only 58 out of the 77 lakes had sufficient data for epilimnion and hypolimnion water ($N \geq 10$). Unfortunately, due to the different measurement levels within lakes, even within the same lake between different sample dates, it was impossible to create trends for the metalimnion, let alone to organize the data in a way to make it comparable between lakes. The focus was therefore shifted towards surface (epilimnion) and deep (most likely hypolimnion) water layers. Due to a lack of morphological and water temperature information, the sample depths could not be identified with exactitude as being part of either epi-, meta- or hypolimnion. However, all SWT samples up to 2m depths were considered as belonging to the epilimnion and all BWT samples as belonging to the hypolimnion. In addition, samples have been taken starting from the water surface. As the water level varies between dry and wet years and even seasons, the depth measurement must not necessarily correspond to the exact same depth in another year, despite the same depth notified. The samples should therefore be taken starting from the bottom onwards or if possible be corrected with water gauge data. Moreover, it should be kept in mind that some lakes have been part of liming projects for lake restauration, which might have had an indirect effect on stratification and water warming, or cooling.

Additionally, the timepoint of sampling varied slightly between the samples of IVM and SMHI, and at a yearly and monthly basis. Furthermore, the samples have been taken as a maximum, only once per month, thus containing a high probability of not detecting the onset or offset of stratification periods within a year. The chemistry samples used have again been sampled in some cases on somewhat different dates than water temperature samples. Consequently, assumptions about stratification development were based on a combination of the trends in this study and temperature patterns found in other studies. Overall, trends needed to be interpreted with caution due to the amount of missing values and also data gaps in the dataset; Theil-Sen slope calculation is influenced by an amount of 5% missing values, which most lakes surpassed. Moreover, BWT trends were more unreliable than SWT trends. Even though temperature around 4°C would have been expected as the minimum hypolimnetic temperatues during stratification periods, the data still contained trends of decreasing temperatures. Those might have belonged to samples that have not been sampled in a hypolimnion but in the metalimnion. Or, internal mixing processes could have obscured the results.

The distance between lake and climate stations ranged between 0.84–2.7 km distance. As the data has been interpolated, inaccuracies might have occurred. Furthermore, the distance towards the ocean is calculated by joining the nearest river sample points. Despite small distance differences towards the respective lake sides from a maximum of 3.8km and a majority within a 500m distance, the impact change of oceanic versus continental location would still be highly accurate.

The studied lakes have not been monitored constantly over the study period from 1979-2016. For example, from the final established dataset of SWT samples, only 15 lakes have been sampled back until 1979, by 1984 the number rises to 72 lakes. Therefore, a reduced selection of the sampling period with starting in 1987, or 1988 might have produced more reliable results for a comparison of trends between lakes.

Important factors that influence the occurrence of lake water mixing include ice-out dates, wind strength and direction, wind coverage due to e.g. trees, and the amount of solar radiation and cloud coverage. Data on the chemical composition of different water layers would also be important to detect influences on stratification. Additionally, morphological data about the width to length ratio of the lakes and in lake turbulences contain significant information. However, the listed factors were missing or too scarce in this study, and therefore limited the research to a rough approach on detecting trends in air and water temperature. Thus, possible conclusions about stratification were considering solely thermally induced stratification.

Morphological data on lakes was also missing for some lakes, e.g. volume or mean depth values. This inhibted the calculation of the Osgood Index (OI) for some sites. Therefore, a grouping according to mixing type was replaced by a grouping according to deep lakes, shallow lakes and lake basins. As the depth of a lake alone is not indicative for stratification occurrence and mixing processes, a further study could investigate lakes grouped according to their mixing behavior. Especially a correlation analysis might give further insights into stratification occurrence when such a grouping is applied. However, trend results could also cause more confusion considering the proposed grouping, as trends found in the current groups did not show a pattern regarding their corresponding mixing type. For the final dataset of significant trends in this study, a separation into deep and shallow lakes could have been rejected in favor of a grouping according to OI because the calculation was missing for one lake only. Moreover, it should be noted that the separation into deep and shallow lakes not necessarily coincided with dimictic or polymictic mixing behavior, respectively. Though it is more common to find stratifications in deep lakes than in shallow ones. A deep lake could therefore be polymictic if its square root of the surface area was larger than its mean depth. And a comparatively shallow lake could be dimitic if the square root of its surface area is smaller than its mean depth.

6 Conclusion

The study of lake water temperature in Swedish lakes over the period 1979–2016 revealed increasing temperatures mainly in April, August and September, within the epilimnion. Most decreasing temperature trends were detected in February in the epilimnion, and in September in the hypolimnion. Positive and negative trends in bottom-surface ratios indicated a decrease in stratification strength during February, and an increase in stratification during April, August, and September, respectively. Generally, basins of the large Swedish lakes were warming within the entire water column.

Despite the declining temperatures during February, some lakes tended towards less stratification during this month. This supported the theory of a shift of spring turnover to an earlier onset within the year due to shorter winters and earlier ice-out. At the same time, strong stratification tendencies in September could be an indicator for a later onset of autumn turnover. As August was the common months of stratification in Sweden, and April should concur with mixing events, it seemed as if the stratification period had extended.

Stratification can lead to oxygen depletion in hypolimnetic water. This furthermore, can cause anoxic conditions which enhances phosphor release from sediments. As the lakes Gyltigesjön, Stora Envättern and V. Skälsjön showed particularly strong trends towards stratification increases during September, it would be interesting to further investigate the oxygen content of these lakes.

Air temperature was warming according to all calculated trends, and it was found to have a large impact on water temperature, explaining around 50% of the epilimnion temperature changes. As the north in Sweden is predicted to encounter larger air temperature changes than the south it is recommended to increase sampling in lakes located in northern Sweden. In the current dataset no distinction between trends in lake water temperpture in northern and southern Swedish lakes could be detected due to a too small dataset for the northern territory.

In addition, no differentiated patterns regarding mixing types, or whether a lake had been part of a liming programme, were detected. Yet, the categorization into deep and shallow lakes revealed a distinct pattern during August, with decreasing epilimnion temperatures within shallow lakes, compared to deep lakes. Thus, a differentiation according to the possibility of turn-over occurrence seemed still appropriate and should be kept or improved in further studies.

The effects of these findings could be a possible decline of oxygen supply within deep water layers due to stronger, and longer stratification periods. Less turn-overs, furthermore, would lead to less mixing of nutrients. This could have detrimental effects on the ecosystem in the long run. It is therefore recommended to extend the research on long-term studies in lakes by intensifying sampling throughout the year and the water depth. Moreover, to guarantee a more precise depth sampling it is recommended to change the procedure of top-to-bottom sampling towards a bottom-to-top approach, especially for the analysis of deeper water layers.

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Annex 1

I. Maximum and mean depth for each lake with significant trends for bottom water temperature (BWT), and/or bottom-surface water temperature ratios (BS-ratios). Grey cells = high difference between sample and maximum depth; * = very shallow lake; ** = maximum sample depth deeper than measured maximum lake depth.

Site	EUid	lake basin of	Month	Lake depth		Sample depth BWT (cat 2 & cat 6)		Sample depth BS-ratio cat 2		Sample depth BS-ratio cat 6	
				Mean depth	Max depth	Min depth	Max depth	Min depth	Max depth	Min depth	Max depth
Älgarydssjön	SE633989-140731		2	1.4	8	n.a.	n.a.	6	6.5	6	6.5
Stora Envättern	SE655587-158869		2	5	11.2	n.a.	n.a.	9	11	8	11
Ejgdesjön	SE653737-125017		2	7	28.6	25	26	n.a.	n.a.	n.a.	n.a.
Mossjön	SE638085-138862		2	1.8	5.2	4	5	n.a.	n.a.	n.a.	n.a.
Rotehogstjärnen	SE652902-125783		2	3.6	10	8	9	n.a.	n.a.	n.a.	n.a.
Härsvatten	SE643914-127698		4	5.7	26	n.a.	n.a.	24	24	22	24
Långsjön_1	SE652412-143738		4	4.2	17.8	n.a.	n.a.	14	14	14	17
Stensjön_2	SE683673-154083		4	4.3	11	n.a.	n.a.	7	8	7	8
Tångerdasjön*	SE637120-145525		4	1.4	3	n.a.	n.a.	1.5	2	1.5	2
Allgjuttern	SE642489-151724		4	11.7	40	33	36	33	36	33	36
Fjärasjö	SE638725-146677		4	4.3	15	12	13	n.a.	n.a.	n.a.	n.a.
Mariestadsviken M2	SE647666-129906	Vänern	4	n.a.	n.a.	10	10	n.a.	n.a.	n.a.	n.a.
Mossjön	SE638085-138862		4	1.8	5.2	4	5	n.a.	n.a.	n.a.	n.a.
Stengårdshultasjön	SE638317-138010		4	7.1	26.8	24	25	n.a.	n.a.	n.a.	n.a.
Stora Envättern	SE655587-158869		4	5	11.2	9	11	9	11	8	11
V. Skälsjön	SE664620-148590		4	7.4	18.7	18	18	n.a.	n.a.	n.a.	n.a.
Görväln S	SE658080-162871	Mälaren	8	n.a.	n.a.	n.a.	n.a.	40	40	40	40
Hagasjön	SE635878-137392		8	3.7	11	n.a.	n.a.	8	9	8	9
Tångerdasjön*	SE637120-145525		8	1.4	3	n.a.	n.a.	1.5	2	1.5	2
V. Skälsjön	SE664620-148590		8	7.4	18.7	n.a.	n.a.	18	19	18	19
Galten	SE658080-162871	Mälaren	8	n.a.	n.a.	10	10	n.a.	n.a.	n.a.	n.a.
Harasjön	SE632231-136476		8	2.3	10	8	9	n.a.	n.a.	n.a.	n.a.
Lien	SE663216-148449		8	7.8	29.2	25	26	25	26	24	26
Rotehogstjärnen	SE652902-125783		8	3.6	10	8	9	n.a.	n.a.	n.a.	n.a.
Svinnegarnsviken	SE658080-162871	Mälaren	8	n.a.	n.a.	10	10	n.a.	n.a.	n.a.	n.a.

Ulvhällsfjärden	SE658080-162871	Mälaren	8	n.a.	n.a.	10	10	n.a.	n.a.	n.a.	n.a.
Stengårdshultasjön	SE638317-138010		9	7.1	26.8	n.a.	n.a.	n.a.	n.a.	20	25
Allgjuttern	SE642489-151724		9	11.7	40	n.a.	n.a.	33	36	33	36
Brunnsjön	SE627443-149526		9	5.3	13	n.a.	n.a.	9	11	9	11
Källsjön	SE683582-154935		9	7.1	17.4	n.a.	n.a.	15	16	15	16
Lien	SE663216-148449		9	7.8	29.2	n.a.	n.a.	25	26	24	26
Mariestadsviken M1	SE647666-129906	Vänern	9	n.a.	n.a.	n.a.	n.a.	10	10	10	10
Remmarsjön	SE708619-162132		9	5.2	15	n.a.	n.a.	12	14	10	14
St Skärsjön	SE628606-133205		9	3.9	12	n.a.	n.a.	10	11	10	11
Fiolen	SE633025-142267		9	3.9	15	8	9	n.a.	n.a.	n.a.	n.a.
Gyltigesjön	SE629489-133906		9	9.1	20	18	20	18	20	18	20
Gyslättasjön	SE633209-141991		9	2.8	9.8	7	8	n.a.	n.a.	n.a.	n.a.
Jungfrun NV	SE649029-145550	Vättern	9	n.a.	n.a.	75	75	n.a.	n.a.	n.a.	n.a.
Rotehogstjärnen	SE652902-125783		9	3.6	10	8	9	n.a.	n.a.	n.a.	n.a.
Stora Envättern	SE655587-158869		9	5	11.2	9	11	9	11	8	11
V. Skälsjön**	SE664620-148590		9	7.4	18.7	18	19	18	19	18	19

Annex 2

I-IV: General information on all lakes analyzed with seasonal MK and Theil-Sen slope on water temperature:

NOTE! For I.-IV. lake basins are excluded as no specific information on watershed and lake characteristics were available, all information for the latter are displayed in table V..

n.a.=not available

n.s.= not sampled

+ = lakes with significant trends ($\alpha \leq 0.05$) for water in the months February, April, August, or September

++ = lakes with significant trends ($\alpha \leq 0.05$) for water and air temperature in the months February, April, August, or September

+++ = lakes with significant trends ($\alpha \leq 0.05$) for water, air temperature and filtered absorbents in the months February, April, August, or September

Cursive letters = lake was part of a liming project

I. Watershed characteristics

Site	EUid	Forest %	Wetland %	Water %	Urban %	Agriculture %	Wood felling %	Other vegetation %	Other %	Watershed area [km2]
Abiskojaure++	SE758208-161749	8	0	4	0	0	0	56	32	370.00
Älgarydssjön+	SE633989-140731	77	3	10	0	4	5	0	0	3.46
Älgsjön+	SE655275-153234	63	5	6	0	4	21	0	0	5.04
Allgjuttern+++	SE642489-151724	68	1	15	0	0	16	0	0	1.13
Alsjön+	SE647050-130644	76	17	7	0	0	1	0	0	0.95
Åsunden	SE639683-134896	50	6	7	2	16	9	9	0	644.94
Bäen+	SE623624-141149	81	2	7	0	6	4	0	0	9.49
Bästeträsk	SE642555-168553	65	6	18	0	5	1	0	5	41.04
Båtkåjaure	SE742442-153530	1	0	13	0	0	0	85	0	4.87
Bergträsket	SE733110-182955	68	9	20	0	0	4	0	0	1.46
Bjännsjön	SE713404-172465	71	12	6	0	2	10	0	0	9.40
Björken+++	SE652707-159032	78	0	17	0	0	5	0	0	7.96
Bösjön	SE680235-141799	72	14	13	0	0	1	0	0	8.86
Brännträsket	SE728095-175926	76	8	10	0	1	5	0	0	12.48
Brunnsjön+++	SE627443-149526	75	4	3	0	1	17	0	0	3.42
Bysjön	SE658086-130264	65	3	13	0	11	8	0	0	10.59
Dagarn+	SE664197-149337	70	2	14	0	3	11	0	0	15.97
Degervattnet++	SE708512-152086	64	9	11	0	1	15	0	0	199.58

Djupa Holmsjön+++	SE656263-156963	72	6	13	0	0	9	0	0	1.61
Dunnervattnet	SE713131-144608	64	13	7	0	0	6	9	0	101.26
Edasjön+	SE663365-161779	64	5	4	0	5	18	3	0	4.20
Ejgdesjön+	SE653737-125017	55	8	26	0	1	10	1	0	4.34
Ekholmssjön	SE663907-156927	66	4	14	0	3	13	0	0	7.33
Fagertärn	SE651558-143620	73	6	12	0	0	9	0	0	1.82
Fiolen+++	SE633025-142267	42	5	29	0	18	6	0	0	5.45
Fjärasjö++	SE638725-146677	73	2	14	0	1	10	0	0	2.58
Försjön	SE641603-144848	68	3	16	0	2	12	0	0	10.69
Fräcksjön+++	SE645289-128665	73	4	6	2	1	15	0	0	4.59
Fyrsjön	SE704082-148125	51	25	6	0	2	12	4	0	2428.98
Fysingen+	SE660749-161885	33	2	4	3	44	9	4	0	112.74
Gipsjön	SE672729-138082	59	19	7	1	0	15	0	0	10.75
Glimmingen	SE642122-148744	74	1	13	0	2	9	0	0	28.10
Gosjön+	SE677506-156174	55	7	27	0	0	11	0	0	1.54
Granvattnet	SE646293-126302	75	1	15	0	4	5	0	0	1.26
Grissjön	SE651578-146163	84	2	13	0	0	1	0	0	1.61
Gyltigesjön+++	SE629489-133906	58	24	6	0	4	6	2	0	172.06
Gyslättasjön+++	SE633209-141991	66	13	10	0	2	9	1	0	3.29
Hagasjön+	SE635878-137392	47	15	18	0	6	14	0	0	0.71
Hällsjön	SE667151-149602	70	3	13	0	1	13	0	0	1.50
Hällvattnet+	SE704955-159090	69	12	8	0	0	10	0	0	108.69
Harasjön+++	SE632231-136476	59	18	10	0	1	11	0	0	5.61
Härsvatten+++	SE643914-127698	75	6	19	0	0	0	0	0	1.94
Havgårdssjön+++	SE615365-134524	14	0	24	0	62	0	0	0	2.15
Helgasjön	SE630764-143570	60	5	14	1	6	9	4	0	1224.70
Hinnasjön	SE630605-144655	75	3	9	4	0	9	0	0	3.81
Hjärtsjön	SE632515-146675	64	10	19	0	3	3	0	0	6.58
Hökesjön	SE639047-149701	64	4	30	0	1	2	0	0	1.98
Holmeshultasjön+	SE634447-144024	56	5	12	0	16	11	0	0	5.74
Horsan++	SE642008-168013	76	1	20	0	0	1	0	1	2.73
Humsjön+	SE650061-142276	67	5	22	0	0	6	0	0	1.14
Ivösjön	SE621669-141629	61	4	13	2	9	5	5	0	994.08
Jutsajaure++	SE744629-167999	67	22	6	0	1	2	1	0	18.99

Källsjön++	SE683582-154935	76	16	3	0	0	5	0	0	16.40
Krageholmssjön++	SE615375-137087	22	0	18	0	59	1	0	0	11.45
Krankesjön+	SE617797-135339	20	3	6	2	64	1	4	0	52.95
Långsjön_1+++	SE652412-143738	76	7	11	0	1	5	0	0	6.77
Långsjön_2	SE656590-164240	71	10	7	0	0	0	0	0	1.75
Långsjön_3+	SE673534-153381	69	0	16	0	0	16	0	0	0.45
Latnjajaure	SE758677-161050	0	0	7	0	0	0	37	56	10.55
Lien+++	SE663216-148449	50	17	21	0	1	11	1	0	3.48
Lilla Öresjön	SE638665-129243	60	11	14	0	7	8	0	0	4.41
Lillesjö+	SE623161-142148	91	0	4	0	0	5	0	0	0.99
Lillsjön+	SE655380-155738	71	6	6	0	14	3	0	0	5.81
Limmingsjön+	SE660804-142742	50	8	18	0	0	23	0	0	9.62
Louvvajaure	SE736804-160569	68	2	19	0	0	11	0	0	4.06
Mäsen+	SE665654-149206	73	3	12	0	2	9	2	0	3.42
Mossjön++	SE638085-138862	41	38	15	0	0	6	0	0	3.22
N. Yngern++	SE656206-159170	62	3	26	0	4	5	0	0	60.19
Njalakjaure	SE741340-153576	0	0	6	0	0	0	43	50	5.84
Ögerträsket	SE712246-170866	89	4	5	0	1	1	0	0	2.52
Öjsjön	SE644987-152393	69	0	26	0	1	4	0	0	8.33
Örsjön	SE624038-143063	77	0	22	0	1	0	0	0	0.87
Örvattnet+++	SE662682-132860	69	4	26	0	0	1	0	0	2.97
Översjön+++	SE664410-136192	65	0	19	0	0	16	0	0	2.07
Överudssjön+	SE659105-133982	57	5	14	0	13	11	0	0	15.68
Övre Fjätsjön	SE690617-134197	22	8	5	0	0	0	65	1	44.70
Övre Skärsjön+++	SE663532-148571	66	8	20	0	1	5	0	0	8.76
Pahajärvi	SE742829-183168	66	14	17	0	0	3	0	0	7.33
Rammsjön	SE629570-135470	7	65	28	0	0	0	0	0	1.18
Remmarsjön++	SE708619-162132	66	14	4	0	1	16	0	0	125.72
Rotehogstjärnen+++	SE652902-125783	65	16	5	0	1	13	0	0	3.58
Rundbosjön+++	SE652177-159038	69	1	12	0	15	4	0	0	20.07
Sangen	SE686849-145214	71	17	12	0	0	0	0	0	12.23
Sännen++	SE624421-147234	69	2	20	0	2	7	0	0	5.02
Sidensjön++	SE709218-169710	89	0	9	0	0	2	0	0	0.85
Siggeforasjön	SE665175-157559	67	13	7	0	2	10	0	0	21.51

Skärgölen_1	SE651573-152481	67	0	22	0	0	11	0	0	0.74
Skärsjön_1^{+++}	SE633344-130068	60	4	26	0	6	4	1	0	14.03
Skärsjön_2^{+}	SE637260-128728	66	2	30	0	1	1	0	0	5.09
Sommen	SE644727-145497	57	3	13	1	8	10	7	0	1904.96
Spjutsjön	SE672467-148031	74	3	11	0	0	12	0	0	3.99
St Skärsjön^{++}	SE628606-133205	71	9	16	0	0	5	0	0	2.64
St. Lummersjön^{+}	SE644463-139986	62	22	2	0	0	14	0	0	1.98
Stengårdshultasjön^{+++}	SE638317-138010	56	18	13	0	3	6	3	0	83.54
Stensjön_1	SE656419-164404	49	5	10	0	0	0	0	0	7.07
Stensjön_2^{++}	SE683673-154083	60	16	18	0	0	6	0	0	3.09
Stora Envättern^{+++}	SE655587-158869	59	14	27	0	0	0	0	0	1.43
Stora Gryten	SE652840-151589	61	9	10	4	5	11	0	0	19.12
Stora Härsjön	SE640364-129240	59	6	24	2	1	7	1	0	23.67
Stora Skärsjön	SE633738-142203	69	8	5	0	7	12	0	0	7.07
Stora Tresticklan	SE655209-126937	81	5	14	0	0	0	0	0	7.86
Stor-Arasjön	SE716717-158596	52	26	21	0	0	0	0	0	33.81
Storasjö	SE631360-146750	68	12	17	0	0	3	0	0	2.13
Stor-Backsjön	SE695220-143383	55	30	7	0	0	8	0	0	55.29
Stor-Björsjön	SE706083-132287	21	33	5	0	0	0	26	16	22.92
Stor-Tjulträsket^{+}	SE731799-151196	16	5	5	0	0	0	66	8	274.78
Svartesjön	SE630558-134327	41	47	7	0	0	5	0	0	0.38
Svartsjön^{+}	SE651609-140839	49	21	21	0	0	8	0	0	1.34
Svartvattnet	SE706672-167201	70	7	2	0	0	21	0	0	5.59
Svinarydsjön	SE622803-144609	75	2	10	2	6	5	0	0	1.83
Täftesträsket	SE711365-171748	56	13	13	0	8	8	1	0	20.26
Tångerdasjön^{++}	SE637120-145525	42	1	26	0	18	13	0	0	0.67
Tängersjö	SE637121-151366	59	0	26	0	7	7	0	0	0.44
Tärnan^{+}	SE660688-164478	75	2	11	0	1	11	0	0	13.48
Tomeshultagölen	SE629026-147562	76	13	2	0	0	8	0	0	3.91
Tryssjön	SE670275-146052	61	12	3	0	0	24	0	0	12.26
Tväringen^{+}	SE690345-149315	67	8	8	0	1	16	0	0	36.25
Ulvsjön^{+}	SE661521-130182	70	5	13	1	0	12	0	0	3.98
V. Rännöbodsjön^{+}	SE691365-156127	79	2	4	0	5	10	0	0	50.34
V. Skälsjön^{++}	SE664620-148590	57	0	31	0	0	12	0	0	1.31

Valasjön[+]	SE698918-158665	73	4	4	0	2	17	0	0	99.85
Valkeajärvi	SE751252-175433	67	9	24	0	0	0	0	0	2.73
Västra Solsjön[++]	SE655863-129783	67	1	24	0	3	6	0	0	9.15
Vidöstern	SE631841-138929	56	15	6	2	7	9	4	0	1375.21
Vuolgamjaure	SE728744-162653	63	17	6	0	0	10	3	0	37.33
Ymsen[+]	SE650398-139136	35	5	29	0	25	5	0	0	45.33

II. Lake characteristics

Brownification status is stated as: UO = ultra-oligotrophic, O = oligotrophic, M = mesotrophic, E = eutrophic and H= hypertrophic
Trophic status: H = humic and C = clear

Site	EUid	Lake area [km2]	Altitude [m]	Maximum depth [m]	Volume [Mm3]	Colour	Browni-fication status*	Trophic status**	Depth category	Mixing behavior***
Abiskojaure[++]	SE758208-161749	2.79	488	38	31.22	6	C	O	deep	variable
Älgarydssjön[+]	SE633989-140731	0.32	202	8	0.48	98	H	M	deep	polymictic
Älgsjön[+]	SE655275-153234	0.36	50	7	1.67	134	H	E	deep	polymictic
Allgjuttern[+++]	SE642489-151724	0.16	132	40	2.09	26	C	UO	deep	dimictic
Alsjön[+]	SE647050-130644	0.06	113	10	n.a.	143	H	M	deep	dimictic
Åsunden	SE639683-134896	32.75	165	40	n.a.	n.s.	n.a.	n.a.	deep	polymictic
Bäen[+]	SE623624-141149	0.53	97	10	1.98	81	H	M	deep	polymictic
Bästeträsk	SE642555-168553	6.52	6	6	n.a.	12	C	UO	shallow	polymictic
Båtkåjaure	SE742442-153530	0.63	633	28	n.a.	10	C	UO	deep	variable
Bergträsket	SE733110-182955	0.17	40	7	n.a.	98	H	M	deep	unknown
Bjännsjön	SE713404-172465	0.41	180	4	0.72	78	H	O	shallow	polymictic
Björken[+++]	SE652707-159032	1.35	32	23	n.a.	31	H	O	deep	dimictic
Bösjön	SE680235-141799	1.18	581	17	4.80	53	H	UO	deep	polymictic
Brännträsket	SE728095-175926	0.81	81	8	1.87	68	H	O	deep	polymictic
Brunnsjön[+++]	SE627443-149526	0.11	99	13	0.57	190	H	M	deep	dimictic
Bysjön	SE658086-130264	1.18	125	12	8.25	26	C	M	deep	variable
Dagarn[+]	SE664197-149337	1.67	135	13	8.80	28	C	O	deep	polymictic
Degervattnet[++]	SE708512-152086	1.60	214	19	n.a.	44	H	UO	deep	variable
Djupa Holmsjön[+++]	SE656263-156963	0.14	61	24	1.67	99	H	O	deep	dimictic
Dunnervattnet	SE713131-144608	2.67	449	35	n.a.	38	H	UO	deep	variable

Edasjön+	SE663365-161779	0.19	18	5	0.48	64	H	E	shallow	variable
Ejgdesjön+	SE653737-125017	0.85	143	29	6.03	27	C	UO	deep	dimictic
Ekholmssjön	SE663907-156927	0.57	63	7	1.75	40	H	M	deep	polymictic
Fagertärn	SE651558-143620	0.17	169	11	0.68	82	H	M	deep	dimictic
Fiolen+++	SE633025-142267	1.55	226	15	7.03	27	C	M	deep	polymictic
Fjärasjö++	SE638725-146677	0.32	236	15	1.49	44	H	O	deep	dimictic
Försjön	SE641603-144848	1.56	267	22	9.35	n.s.	n.a.	n.a.	deep	polymictic
Fräcksjön+++	SE645289-128665	0.27	69	15	1.16	57	H	O	deep	dimictic
Fyrsjön	SE704082-148125	13.17	299	23	n.a.	41	H	UO	deep	polymictic
Fysingen+	SE660749-161885	4.76	5	6	10.00	18	C	E	shallow	polymictic
Gipsjön	SE672729-138082	0.75	382	15	3.28	143	H	O	deep	variable
Glimmingen	SE642122-148744	1.62	152	32	18.20	21	C	UO	deep	dimictic
Gosjön+	SE677506-156174	0.39	63	5	n.a.	114	H	M	shallow	polymictic
Granvattnet	SE646293-126302	0.20	58	3	0.29	37	H	M	shallow	polymictic
Grissjön	SE651578-146163	0.24	140	16	1.03	64	H	O	deep	dimictic
Gyltigesjön+++	SE629489-133906	0.39	77	20	3.59	135	H	M	deep	dimictic
Gyslättasjön+++	SE633209-141991	0.29	226	10	0.91	86	H	M	deep	variable
Hagasjön+	SE635878-137392	0.11	167	11	0.42	52	H	O	deep	dimictic
Hällsjön	SE667151-149602	0.21	169	18	n.a.	44	H	O	deep	dimictic
Hällvattnet+	SE704955-159090	6.58	217	48	85.30	69	H	UO	deep	polymictic
Harasjön+++	SE632231-136476	0.57	164	10	1.38	169	H	E	deep	polymictic
Härsvatten+++	SE643914-127698	0.24	127	26	1.01	7	C	UO	deep	dimictic
Havgårdssjön+++	SE615365-134524	0.50	52	6	1.67	15	C	E	shallow	polymictic
Helgasjön	SE630764-143570	48.54	163	25	n.a.	n.s.	n.a.	n.a.	deep	polymictic
Hinnasjön	SE630605-144655	0.26	172	5	0.36	88	H	M	shallow	polymictic
Hjärtsjön	SE632515-146675	1.28	275	7	4.64	12	C	UO	deep	polymictic
Hökesjön	SE639047-149701	0.51	150	22	4.09	11	C	UO	deep	dimictic
Holmeshultasjön+	SE634447-144024	0.64	211	17	3.07	n.s.	n.a.	n.a.	deep	variable
Horsan++	SE642008-168013	0.56	5	1	n.a.	13	C	O	shallow	dimictic
Humsjön+	SE650061-142276	0.21	130	13	n.a.	29	H	O	deep	dimictic
Ivösjön	SE621669-141629	50.12	6	50	n.a.	n.s.	n.a.	n.a.	deep	polymictic
Jutsajaure++	SE744629-167999	1.11	421	10	2.40	41	H	O	deep	polymictic
Källsjön++	SE683582-154935	0.24	232	17	1.75	148	H	O	deep	dimictic
Krageholmssjön++	SE615375-137087	2.05	41	9	10.62	20	C	H	deep	polymictic

Krankesjön^{+}	SE617797-135339	3.31	20	4	3.49	28	C	E	shallow	polymictic
Långsjön_1^{+++}	SE652412-143738	0.67	142	18	n.a.	99	H	O	deep	variable
Långsjön_2	SE656590-164240	0.11	52	8	n.a.	83	H	O	deep	dimictic
Långsjön_3^{+}	SE673534-153381	0.07	240	6	0.12	113	H	M	shallow	dimictic
Latnjajaure	SE758677-161050	0.74	969	43	n.a.	2	C	UO	deep	dimictic
Lien^{+++}	SE663216-148449	1.40	156	29	11.70	54	H	UO	deep	variable
Lilla Öresjön	SE638665-129243	0.64	109	17	2.50	30	H	O	deep	variable
Lillesjö$^{+}$	SE623161-142148	0.04	88	13	0.19	6	C	UO	deep	dimictic
Lillsjön^{+}	SE655380-155738	0.32	22	7	n.a.	95	H	E	deep	variable
Limmingsjön^{+}	SE660804-142742	1.08	236	26	n.a.	32	H	UO	deep	polymictic
Louvvajaure	SE736804-160569	0.82	458	15	n.a.	10	C	UO	deep	unknown
Mäsen^{+}	SE665654-149206	0.42	107	24	4.11	26	C	O	deep	dimictic
Mossjön^{++}	SE638085-138862	0.48	279	5	0.90	95	H	n.a.	shallow	polymictic
N. Yngern^{++}	SE656206-159170	14.03	39	29	119.00	15	C	O	deep	polymictic
Njalakjaure	SE741340-153576	0.33	850	20	n.a.	5	C	UO	deep	dimictic
Ögerträsket	SE712246-170866	0.08	213	10	n.a.	168	H	M	deep	dimictic
Öjsjön	SE644987-152393	1.97	99	25	n.a.	19	C	UO	deep	dimictic
Örsjön	SE624038-143063	0.19	89	11	n.a.	38	H	O	deep	dimictic
Örvattnet^{+++}	SE662682-132860	0.80	280	38	n.a.	18	C	UO	deep	dimictic
Översjön^{+++}	SE664410-136192	0.37	220	38	n.a.	35	H	UO	deep	dimictic
Överudssjön^{+}	SE659105-133982	2.24	57	8	6.21	45	H	E	deep	polymictic
Övre Fjätsjön	SE690617-134197	0.91	745	18	n.a.	36	H	O	deep	variable
Övre Skärsjön^{+++}	SE663532-148571	1.70	223	32	10.10	73	H	O	deep	polymictic
Pahajärvi	SE742829-183168	1.21	249	14	n.a.	23	C	M	deep	polymictic
Rammsjön	SE629570-135470	0.34	160	2	n.a.	242	H	E	shallow	polymictic
Remmarsjön^{++}	SE708619-162132	1.29	235	15	6.96	86	H	O	deep	polymictic
Rotehogstjärnen^{+++}	SE652902-125783	0.16	123	10	0.59	111	H	M	deep	dimictic
Rundbosjön^{+++}	SE652177-159038	0.91	5	11	n.a.	57	H	E	deep	unknown
Sangen	SE686849-145214	1.44	445	14	n.a.	51	H	O	deep	polymictic
Sännen^{++}	SE624421-147234	0.99	63	15	3.98	28	C	M	deep	polymictic
Sidensjön^{++}	SE709218-169710	0.09	135	5	n.a.	110	H	E	shallow	dimictic
Siggeforasjön	SE665175-157559	0.70	74	11	3.20	120	H	M	deep	variable
Skärgölen_1	SE651573-152481	0.18	73	13	1.08	27	C	O	deep	dimictic
Skärsjön_1^{+++}	SE633344-130068	2.98	50	23	28.01	11	C	O	deep	variable

Skärsjön_2[+]	SE637260-128728	1.23	74	23	15.00	n.s.	n.a.	n.a.	deep	dimictic
Sommen	SE644727-145497	37.71	147	53	n.a.	n.s.	n.a.	n.a.	deep	polymictic
Spjutsjön	SE672467-148031	0.40	182	23	2.11	15	C	UO	deep	dimictic
St Skärsjön[++]	SE628606-133205	0.33	55	12	1.24	21	C	O	deep	variable
St. Lummersjön[+]	SE644463-139986	0.06	240	6	n.a.	123	H	O	shallow	variable
Stengårdshultasjön[+++]	SE638317-138010	4.73	224	27	34.60	89	H	O	deep	polymictic
Stensjön_1	SE656419-164404	0.39	36	21	3.22	43	H	O	deep	dimictic
Stensjön_2[++]	SE683673-154083	0.53	269	11	2.55	54	H	UO	deep	variable
Stora Envättern[+++]	SE655587-158869	0.38	65	11	1.89	35	H	O	deep	dimictic
Stora Gryten	SE652840-151589	1.06	48	7	n.a.	86	H	M	deep	unknown
Stora Härsjön	SE640364-129240	2.61	90	42	36.20	25	C	UO	deep	dimictic
Stora Skärsjön	SE633738-142203	0.28	206	14	1.20	173	H	M	deep	dimictic
Stora Tresticklan	SE655209-126937	1.29	208	21	n.a.	30	C	UO	deep	unknown
Stor-Arasjön	SE716717-158596	7.13	544	27	n.a.	46	H	UO	deep	polymictic
Storasjö	SE631360-146750	0.35	253	6	0.66	89	H	M	shallow	polymictic
Stor-Backsjön	SE695220-143383	2.09	428	13	3.28	87	H	O	deep	polymictic
Stor-Björsjön	SE706083-132287	0.43	567	15	n.a.	43	H	UO	deep	dimictic
Stor-Tjulträsket[+]	SE731799-151196	5.25	543	39	114.00	13	C	UO	deep	dimictic
Svartesjön	SE630558-134327	0.03	158	6	n.a.	220	H	M	shallow	dimictic
Svartsjön[+]	SE651609-140839	0.07	126	4	n.a.	237	H	E	shallow	dimictic
Svartvattnet	SE706672-167201	0.04	173	18	n.a.	136	H	M	deep	unknown
Svinarydsjön	SE622803-144609	0.18	28	2	n.a.	32	H	M	shallow	polymictic
Täftesträsket	SE711365-171748	2.22	141	18	10.33	66	H	O	deep	polymictic
Tångerdasjön[++]	SE637120-145525	0.14	218	3	0.28	46	H	E	shallow	polymictic
Tängersjö	SE637121-151366	0.09	116	12	0.22	30	C	O	deep	dimictic
Tärnan[+]	SE660688-164478	1.06	42	12	5.11	39	H	M	deep	polymictic
Tomeshultagölen	SE629026-147562	0.09	179	3	n.a.	225	H	E	shallow	unknown
Tryssjön	SE670275-146052	0.29	345	20	n.a.	120	H	O	deep	dimictic
Tväringen[+]	SE690345-149315	1.61	308	19	7.87	50	H	UO	deep	polymictic
Ulvsjön[+]	SE661521-130182	0.55	211	31	n.a.	55	H	O	deep	dimictic
V. Rännöbodsjön[+]	SE691365-156127	0.46	50	78	2.95	56	H	O	deep	dimictic
V. Skälsjön[++]	SE664620-148590	0.39	233	19	3.00	9	C	UO	deep	dimictic
Valasjön[+]	SE698918-158665	1.98	102	26	n.a.	89	H	O	deep	variable
Valkeajärvi	SE751252-175433	0.62	315	11	n.a.	10	C	UO	deep	variable

Västra Solsjön++	SE655863-129783	1.85	151	40	23.02	17	C	UO	deep	dimictic
Vidöstern	SE631841-138929	42.61	144	44	n.a.	n.s.	n.a.	n.a.	deep	polymictic
Vuolgamjaure	SE728744-162653	2.03	436	15	n.a.	29	C	UO	deep	polymictic
Ymsen+	SE650398-139136	13.10	72	4	32.32	26	C	H	shallow	polymictic

*Based on August total phosphor concentrations in lake surface waters 2014–2016 with exception of Granvattnet, Hagasjön, Härsvatten, Lillesjö, Louvvajaure, Översjön, Övre Fjätsjön, Pahajärvi, Stora Gryten, Stora Gryten, Stor-Backsjön, Stor-Björsjön (2012-2014) and Gyltigesjön and Lien (2007-2009): ≤ 6 µg l^{-1} = UO, > 6 ≤ 12.5 µg l^{-1} = O, TP between > 12.5 – 25 µg l^{-1} = M, TP between > 25 – 100 µg l^{-1} = E and > 100 µg l^{-1}= H (EPA 2000).
** Based on mean absorbance (filtered, 420 nm/5 cm) in lake surface waters from May to October 2014-2016 with exception of Gyltigesjön, Härsvatten, Lien, Mossjön, Stora Gryten (2006-2008): Absorbance ≤ 0.06 = clear, absorbance > 0.06 humic (EPA 2000).
***Based on approximated Osgood Index with mean depth and lake surface area: ≤ 5 = polymictic, > 5-7 = variable, ≥ 7 = dimictic

III. Site location

Site	EUid	Distance to the Sea [km]	Eco-region	Season type*	Station coordinate_North	Station coordinate_East	X RT90	Y RT90
Abiskojaure++	SE758208-161749	489	2	2	7581424	650600	7582080	1617490
Älgarydssjön+	SE633989-140731	171	7	1	6337178	456028	6339890	1407310
Älgsjön+	SE655275-153234	73	4	1	6551428	578455	6552750	1532340
Allgjuttern+++	SE642489-151724	60	4	1	6423441	564895	6424890	1517240
Alsjön+	SE647050-130644	100	6	1	6466507	353666	6470500	1306440
Åsunden	SE639683-134896	149	6	1	6396633	401434	6400020	1353397
Bäen+	SE623624-141149	56	5	1	6233634	461425	6236240	1411490
Bästeträsk	SE642555-168553	0	4	1	6426108	733122	6425550	1685530
Båtkåjaure	SE742442-153530	380	2	2	7422760	570495	7424420	1535300
Bergträsket	SE733110-182955	11	3	2	7333268	865858	7331100	1829550
Bjännsjön	SE713404-172465	40	3	2	7134909	763500	7134040	1724650
Björken+++	SE652707-159032	9	4	1	6526457	636722	6527070	1590320
Bösjön	SE680235-141799	360	2	1	6799512	461113	6802350	1417990
Brännträsket	SE728095-175926	19	3	2	7282225	796227	7280950	1759260
Brunnsjön+++	SE627443-149526	45	4	1	6272787	544705	6274430	1495260
Bysjön	SE658086-130264	254	6	1	6576747	348540	6580860	1302640
Dagarn+	SE664197-149337	207	3	1	6640136	538420	6641970	1493370
Degervattnet++	SE708512-152086	157	3	2	7083426	560401	7085120	1520860

Djupa Holmsjön+++	SE656263-156963	66	4	1	6561754	615611	6562630	1569630
Dunnervattnet	SE713131-144608	280	2	2	7128648	485073	7131310	1446080
Edasjön+	SE663365-161779	108	4	1	6633334	662893	6633650	1617790
Ejgdesjön+	SE653737-125017	28	6	1	6532654	296633	6537370	1250170
Ekholmssjön	SE663907-156927	123	4	1	6638162	614324	6639070	1569270
Fagertärn	SE651558-143620	164	4	1	6513117	482808	6515580	1436200
Fiolen+++	SE633025-142267	131	7	1	6327724	471494	6330250	1422670
Fjärasjö++	SE638725-146677	168	7	1	6385218	514896	6387250	1466770
Försjön	SE641603-144848	202	7	1	6413766	496273	6416030	1448480
Fräcksjön+++	SE645289-128665	58	6	1	6448672	334101	6452890	1286650
Fyrsjön	SE704082-148125	183	2	2	7038648	521368	7040820	1481250
Fysingen+	SE660749-161885	50	4	1	6607195	664270	6607490	1618850
Gipsjön	SE672729-138082	429	2	1	6724037	424887	6727290	1380820
Glimmingen	SE642122-148744	159	4	1	6421980	533782	6421220	1487440
Gosjön+	SE677506-156174	17	3	1	6774007	605132	6775060	1561740
Granvattnet	SE646293-126302	6	6	1	6458422	310367	6462930	1263020
Grissjön	SE651578-146163	95	4	1	6513623	508222	6515780	1461630
Gyltigesjön+++	SE629489-133906	31	6	1	6291400	388350	6294890	1339060
Gyslättasjön+++	SE633209-141991	133	7	1	6329531	468714	6332090	1419910
Hagasjön+	SE635878-137392	130	6	1	6355662	422434	6358780	1373920
Hällsjön	SE667151-149602	250	3	1	6669695	540709	6671510	1496020
Hällvattnet+	SE704955-159090	82	3	2	7048754	630861	7049550	1590900
Harasjön+++	SE632231-136476	150	6	1	6319106	413711	6322310	1364760
Härsvatten+++	SE643914-127698	17	6	1	6434816	324602	6439140	1276980
Havgårdssjön+++	SE615365-134524	48	5	1	6150322	396176	6153650	1345240
Helgasjön	SE630764-143570	121	4	1	6313450	486413	6315794	1437427
Hinnasjön	SE630605-144655	104	4	1	6303819	495647	6306050	1446550
Hjärtsjön	SE632515-146675	121	7	1	6323148	515611	6325150	1466750
Hökesjön	SE639047-149701	222	4	1	6388795	545084	6390470	1497010
Holmeshultasjön+	SE634447-144024	152	7	1	6342145	488886	6344470	1440240
Horsan++	SE642008-168013	1	4	1	6420575	727788	6420080	1680130
Humsjön+	SE650061-142276	182	4	1	6497994	469555	6500610	1422760
Ivösjön	SE621669-141629	5	5	1	6214151	466450	6216690	1416290
Jutsajaure++	SE744629-167999	228	2	2	7446496	714847	7446290	1679990

Källsjön++	SE683582-154935	23	3	1	6834590	591996	6835820	1549350
Krageholmssjön++	SE615375-137087	6	5	1	6150719	421789	6153750	1370870
Krankesjön+	SE617797-135339	44	5	1	6174721	404038	6177970	1353390
Långsjön_1+++	SE652412-143738	175	4	1	6521667	483884	6524120	1437380
Långsjön_2	SE656590-164240	5	4	1	6565903	688317	6565900	1642400
Långsjön_3+	SE673534-153381	79	2	1	6733960	577702	6735340	1533810
Latnjajaure	SE758677-161050	494	1	2	7586022	643552	7586770	1610500
Lien+++	SE663216-148449	235	3	1	6630223	529664	6632160	1484490
Lilla Öresjön	SE638665-129243	29	6	1	6382547	340666	6386650	1292430
Lillesjö+	SE623161-142148	28	5	1	6229124	471463	6231610	1421480
Lillsjön+	SE655380-155738	72	4	1	6552780	603472	6553800	1557380
Limmingsjön+	SE660804-142742	329	2	1	6605422	472916	6608040	1427420
Louvvajaure	SE736804-160569	272	2	2	7367313	641584	7368040	1605690
Mäsen+	SE665654-149206	220	3	1	6654684	536934	6656540	1492060
Mossjön++	SE638085-138862	237	7	1	6377893	436864	6380850	1388620
N. Yngern++	SE656206-159170	79	4	1	6561452	637680	6562060	1591700
Njalakjaure	SE741340-153576	379	1	2	7411751	571098	7413400	1535760
Ögerträsket	SE712246-170866	56	3	2	7123130	747661	7122460	1708660
Öjsjön	SE644987-152393	44	4	1	6448490	571284	6449870	1523930
Örsjön	SE624038-143063	16	5	1	6237996	480506	6240380	1430630
Örvattnet+++	SE662682-132860	319	2	1	6622992	373926	6626820	1328600
Översjön+++	SE664410-136192	320	2	1	6640666	407015	6644100	1361920
Överudssjön+	SE659105-133982	272	6	1	6587380	385573	6591050	1339820
Övre Fjätsjön	SE690617-134197	514	2	1	6902328	383850	6906170	1341970
Övre Skärsjön+++	SE663532-148571	204	2	1	6633396	530845	6635320	1485710
Pahajärvi	SE742829-183168	178	2	2	7430468	866731	7428290	1831680
Rammsjön	SE629570-135470	75	6	1	6292542	403889	6295700	1354700
Remmarsjön++	SE708619-162132	95	3	2	7085765	660807	7086190	1621320
Rotehogstjärnen+++	SE652902-125783	25	6	1	6524402	304388	6529020	1257830
Rundbosjön+++	SE652177-159038	3	4	1	6521160	636846	6521770	1590380
Sangen	SE686849-145214	204	2	1	6866040	494426	6868490	1452140
Sännen++	SE624421-147234	20	4	1	6242312	522150	6244210	1472340
Sidensjön++	SE709218-169710	46	3	2	7092712	736488	7092180	1697100
Siggeforasjön	SE665175-157559	127	4	1	6650914	620487	6651750	1575590

Skärgölen_1	SE651573-152481	22	4	1	6514333	571374	6515730	1524810
Skärsjön_1+++	SE633344-130068	18	6	1	6329472	349541	6333440	1300680
Skärsjön_2+	SE637260-128728	25	6	1	6368446	335686	6372600	1287280
Sommen	SE644727-145497	159	4	1	6434212	503262	6436400	1455715
Spjutsjön	SE672467-148031	227	3	1	6722638	524356	6724670	1480310
St Skärsjön++	SE628606-133205	20	6	1	6282493	381448	6286060	1332050
St. Lummersjön+	SE644463-139986	193	7	1	6441770	447338	6444630	1399860
Stengårdshultasjön+++	SE638317-138010	168	7	1	6380110	428321	6383170	1380100
Stensjön_1	SE656419-164404	2	4	1	6564214	689977	6564190	1644040
Stensjön_2++	SE683673-154083	102	2	1	6835394	583469	6836730	1540830
Stora Envättern+++	SE655587-158869	35	4	1	6555227	634745	6555870	1588690
Stora Gryten	SE652840-151589	104	4	1	6526890	562305	6528400	1515890
Stora Härsjön	SE640364-129240	39	6	1	6399525	340434	6403640	1292400
Stora Skärsjön	SE633738-142203	129	7	1	6334843	470770	6337380	1422030
Stora Tresticklan	SE655209-126937	291	6	1	6547594	315641	6552090	1269370
Stor-Arasjön	SE716717-158596	231	2	2	7166268	624434	7167170	1585960
Storasjö	SE631360-146750	132	7	1	6311612	516497	6313600	1467500
Stor-Backsjön	SE695220-143383	303	2	2	6949478	475083	6952200	1433830
Stor-Björsjön	SE706083-132287	376	2	2	7056652	362825	7060830	1322870
Stor-Tjulträsket+	SE731799-151196	412	2	2	7316078	548538	7317990	1511960
Svartesjön	SE630558-134327	50	6	1	6302132	392431	6305580	1343270
Svartsjön+	SE651609-140839	273	6	1	6513292	455007	6516090	1408390
Svartvattnet	SE706672-167201	17	3	2	7066942	711727	7066720	1672010
Svinarydsjön	SE622803-144609	0	5	1	6225833	496102	6228030	1446090
Täftesträsket	SE711365-171748	38	3	2	7114434	756591	7113650	1717480
Tångerdasjön++	SE637120-145525	165	7	1	6369038	503572	6371200	1455250
Tängersjö	SE637121-151366	54	4	1	6369742	561955	6371210	1513660
Tärnan+	SE660688-164478	15	4	1	6606900	690200	6606880	1644780
Tomeshultagölen	SE629026-147562	92	4	1	6288378	524888	6290260	1475620
Tryssjön	SE670275-146052	239	2	1	6700486	504845	6702750	1460520
Tväringen+	SE690345-149315	185	2	1	6901492	534982	6903450	1493150
Ulvsjön+	SE661521-130182	294	2	1	6611064	347304	6615210	1301820
V. Rännöbodsjön+	SE691365-156127	30	3	1	6912536	602945	6913650	1561270
V. Skälsjön++	SE664620-148590	219	3	1	6644274	530902	6646200	1485900

Valasjön+	SE698918-158665	12	3	2	6988354	627371	6989180	1586650
Valkeajärvi	SE751252-175433	325	2	2	7513674	788304	7512520	1754330
Västra Solsjön++	SE655863-129783	209	6	1	6554474	344002	6558630	1297830
Vidöstern	SE631841-138929	139	6	1	6325358	439979	6328255	1391114
Vuolgamjaure	SE728744-162653	234	2	2	7287010	663453	7287440	1626530
Ymsen+	SE650398-139136	230	6	1	6500984	438132	6503980	1391360

*Southern Sweden=1; Northern Sweden=2

IV. Information on deep sample layer and sampled time period

Lake	EUid	Sample depth [m]	Mean depth [m]	Difference max depth - sample depth [m]**	Difference mean depth - sample depth [m]***	From year	To year	Year range
Abiskojaure++	SE758208-161749	15	11	23	-4	1987	2016	30
Älgarydssjön+	SE633989-140731	6	1.4	2	-4.6	1983	2016	34
Älgsjön+	SE655275-153234	7	2.5	0	-4.5	1984	2016	33
Allgjuttern+++	SE642489-151724	36	11.7	4	-24.3	1983	2016	34
Alsjön+	SE647050-130644	8	6	2	-2	1984	2016	33
Åsunden	SE639683-134896	n.s.	12.7	n.a.	n.a.	1980	1998	19
Bäen+	SE623624-141149	8	3.4	2	-4.6	1988	2016	29
Bästeträsk	SE642555-168553	n.s.	0.7	n.a.	n.a.	1995	2016	22
Båtkåjaure	SE742442-153530	n.s.	4.2	n.a.	n.a.	1997	2016	20
Bergträsket	SE733110-182955	n.s.	n.a.	n.a.	n.a.	1988	2016	29
Bjännsjön	SE713404-172465	n.s.	1.4	n.a.	n.a.	1988	2016	29
Björken+++	SE652707-159032	n.s.	12.5	n.a.	n.a.	1988	2016	29
Bösjön	SE680235-141799	16	4.2	1	-11.8	1989	2016	28
Brännträsket	SE728095-175926	5	2.2	3	-2.8	1983	2016	34
Brunnsjön+++	SE627443-149526	10	5.3	3	-4.7	1983	2016	34
Bysjön	SE658086-130264	9	7	3	-2	1983	2016	34
Dagarn+	SE664197-149337	n.s.	5.1	n.a.	n.a.	1988	2016	29
Degervattnet++	SE708512-152086	n.s.	6.7	n.a.	n.a.	1984	2016	33
Djupa Holmsjön+++	SE656263-156963	n.s.	8.5	n.a.	n.a.	1988	2016	29
Dunnervattnet	SE713131-144608	n.s.	10.9	n.a.	n.a.	1995	2016	22
Edasjön+	SE663365-161779	n.s.	3	n.a.	n.a.	1988	2016	29

Ejgdesjön+	SE653737-125017	26	7	3	-19	1989	2016	28
Ekholmssjön	SE663907-156927	n.s.	2.9	n.a.	n.a.	1995	2016	22
Fagertärn	SE651558-143620	n.s.	3.2	n.a.	n.a.	1985	2016	32
Fiolen+++	SE633025-142267	8	3.9	7	-4.1	1983	2016	34
Fjärasjö++	SE638725-146677	12	4.3	3	-7.7	1984	2016	33
Försjön	SE641603-144848	21	5.7	1	-15.3	1995	2016	22
Fräcksjön+++	SE645289-128665	13	4.1	2	-8.9	1983	2016	34
Fyrsjön	SE704082-148125	n.s.	10.9	n.a.	n.a.	1984	2016	33
Fysingen+	SE660749-161885	n.s.	2	n.a.	n.a.	1995	2016	22
Gipsjön	SE672729-138082	15	4.9	0	-10.1	1983	2016	34
Glimmingen	SE642122-148744	n.s.	10.4	n.a.	n.a.	1996	2016	21
Gosjön+	SE677506-156174	n.s.	2	n.a.	n.a.	1985	2016	32
Granvattnet	SE646293-126302	n.s.	1.6	n.a.	n.a.	1983	2016	34
Grissjön	SE651578-146163	14	4.6	2	-9.4	1984	2016	33
Gyltigesjön+++	SE629489-133906	19	9.1	1	-9.9	1989	2009	21
Gyslättasjön+++	SE633209-141991	8	2.8	2	-5.2	1989	2016	28
Hagasjön+	SE635878-137392	9	3.7	2	-5.3	1985	2016	32
Hällsjön	SE667151-149602	17	5.3	1	-11.7	1983	2016	34
Hällvattnet+	SE704955-159090	n.s.	12.7	n.a.	n.a.	1988	2016	29
Harasjön+++	SE632231-136476	9	2.3	1	-6.7	1983	2016	34
Härsvatten+++	SE643914-127698	24	5.7	2	-18.3	1988	2016	29
Havgårdssjön+++	SE615365-134524	n.s.	3.1	n.a.	n.a.	1995	2016	22
Helgasjön	SE630764-143570	n.s.	6.1	n.a.	n.a.	1980	1998	19
Hinnasjön	SE630605-144655	n.s.	1.4	n.a.	n.a.	1988	2016	29
Hjärtsjön	SE632515-146675	n.s.	3.4	n.a.	n.a.	1983	2016	34
Hökesjön	SE639047-149701	n.s.	7.4	n.a.	n.a.	1983	2016	34
Holmeshultasjön+	SE634447-144024	12	4.4	5	-7.6	1983	2016	34
Horsan++	SE642008-168013	n.s.	5.8	n.a.	n.a.	1997	2016	20
Humsjön+	SE650061-142276	10	4	3	-6	1983	2016	34
Ivösjön	SE621669-141629	n.s.	11	n.a.	n.a.	1984	1998	15
Jutsajaure++	SE744629-167999	7	2	3	-5	1984	2016	33
Källsjön++	SE683582-154935	16	7.1	1	-8.9	1989	2016	28
Krageholmssjön++	SE615375-137087	8	5	1	-3	1995	2016	22
Krankesjön+	SE617797-135339	n.s.	1	n.a.	n.a.	1995	2016	22

Långsjön_1+++	SE652412-143738	14	4.2	4	-9.8	1989	2016	28
Långsjön_2	SE656590-164240	7	3.8	1	-3.2	1999	2016	18
Långsjön_3+	SE673534-153381	n.s.	2	n.a.	n.a.	1984	2016	33
Latnjajaure	SE758677-161050	n.s.	16.5	n.a.	n.a.	1988	2016	29
Lien+++	SE663216-148449	26	7.8	3	-18.2	1989	2009	21
Lilla Öresjön	SE638665-129243	n.s.	4.1	n.a.	n.a.	1983	2016	34
Lillesjö+	SE623161-142148	12	5	1	-7	1988	2016	29
Lillsjön+	SE655380-155738	n.s.	3.6	n.a.	n.a.	1995	2016	22
Limmingsjön+	SE660804-142742	n.s.	4.71	n.a.	n.a.	1983	2016	34
Louvvajaure	SE736804-160569	n.s.	n.a.	n.a.	n.a.	1988	2016	29
Mäsen+	SE665654-149206	20	9.6	4	-10.4	1983	2016	34
Mossjön++	SE638085-138862	4	1.8	1	-2.2	1983	2016	34
N. Yngern++	SE656206-159170	n.s.	8.4	n.a.	n.a.	1988	2016	29
Njalakjaure	SE741340-153576	n.s.	5.8	n.a.	n.a.	1988	2016	29
Ögerträsket	SE712246-170866	n.s.	3.6	n.a.	n.a.	1996	2016	21
Öjsjön	SE644987-152393	n.s.	10	n.a.	n.a.	1988	2016	29
Örsjön	SE624038-143063	n.s.	3.5	n.a.	n.a.	1988	2016	29
Örvattnet+++	SE662682-132860	36	9	2	-27	1988	2016	29
Översjön+++	SE664410-136192	35	11.4	3	-23.6	1988	2016	29
Överudssjön+	SE659105-133982	n.s.	2.7	n.a.	n.a.	1988	2016	29
Övre Fjätsjön	SE690617-134197	n.s.	5.1	n.a.	n.a.	1986	2016	31
Övre Skärsjön+++	SE663532-148571	31	6.1	1	-24.9	1983	2016	34
Pahajärvi	SE742829-183168	n.s.	3.9	n.a.	n.a.	1988	2016	29
Rammsjön	SE629570-135470	n.s.	0.8	n.a.	n.a.	1983	2016	34
Remmarsjön++	SE708619-162132	13	5.2	2	-7.8	1984	2016	33
Rotehogstjärnen+++	SE652902-125783	8	3.6	2	-4.4	1983	2016	34
Rundbosjön+++	SE652177-159038	n.s.	n.a.	n.a.	n.a.	1995	2016	22
Sangen	SE686849-145214	n.s.	5.3	n.a.	n.a.	1984	2016	33
Sännen++	SE624421-147234	11	3.6	4	-7.4	1983	2016	34
Sidensjön++	SE709218-169710	n.s.	2.6	n.a.	n.a.	1988	2016	29
Siggeforasjön	SE665175-157559	n.s.	4.2	n.a.	n.a.	1988	2016	29
Skärgölen_1	SE651573-152481	11	7	2	-4	1984	2016	33
Skärsjön_1+++	SE633344-130068	n.s.	9.3	n.a.	n.a.	1983	2016	34
Skärsjön_2+	SE637260-128728	n.s.	12	n.a.	n.a.	1984	2016	33

Sommen	SE644727-145497	n.s.	16.7	n.a.	n.a.	1980	1998	19
Spjutsjön	SE672467-148031	21	5.9	2	-15.1	1983	2016	34
St Skärsjön++	SE628606-133205	11	3.9	1	-7.1	1983	2016	34
St. Lummersjön+	SE644463-139986	n.s.	1.5	n.a.	n.a.	1984	2016	33
Stengårdshultasjön+++	SE638317-138010	25	7.1	2	-17.9	1989	2016	28
Stensjön_1	SE656419-164404	20	9.1	1	-10.9	1989	2016	28
Stensjön_2++	SE683673-154083	7	4.3	4	-2.7	1985	2016	32
Stora Envättern+++	SE655587-158869	10	5	1	-5	1983	2016	34
Stora Gryten	SE652840-151589	n.s.	n.a.	n.a.	n.a.	1984	2012	29
Stora Härsjön	SE640364-129240	39	14.1	3	-24.9	1989	2016	28
Stora Skärsjön	SE633738-142203	n.s.	4	n.a.	n.a.	1983	2016	34
Stora Tresticklan	SE655209-126937	n.s.	n.a.	n.a.	n.a.	1988	2016	29
Stor-Arasjön	SE716717-158596	n.s.	7.3	n.a.	n.a.	1988	2016	29
Storasjö	SE631360-146750	4	1.8	2	-2.2	1983	2016	34
Stor-Backsjön	SE695220-143383	n.s.	1.6	n.a.	n.a.	1984	2016	33
Stor-Björsjön	SE706083-132287	n.s.	4.7	n.a.	n.a.	1986	2016	31
Stor-Tjulträsket+	SE731799-151196	35	21.2	4	-13.8	1988	2016	29
Svartesjön	SE630558-134327	4	3	2	-1	1983	2016	34
Svartsjön+	SE651609-140839	n.s.	2.14	n.a.	n.a.	1997	2016	20
Svartvattnet	SE706672-167201	n.s.	n.a.	n.a.	n.a.	1997	2016	20
Svinarydsjön	SE622803-144609	n.s.	1.2	n.a.	n.a.	1988	2016	29
Täftesträsket	SE711365-171748	n.s.	4.3	n.a.	n.a.	1988	2016	29
Tångerdasjön++	SE637120-145525	2	1.4	1	-0.6	1995	2016	22
Tängersjö	SE637121-151366	9	2.2	3	-6.8	1984	2016	33
Tärnan+	SE660688-164478	n.s.	4.3	n.a.	n.a.	1988	2016	29
Tomeshultagölen	SE629026-147562	2	n.a.	1	n.a.	1983	2016	34
Tryssjön	SE670275-146052	18	7.2	2	-10.8	1989	2016	28
Tväringen+	SE690345-149315	17	4.5	2	-12.5	1984	2016	33
Ulvsjön+	SE661521-130182	28	10	3	-18	1988	2016	29
V. Rännöbodsjön+	SE691365-156127	n.s.	6.2	n.a.	n.a.	1988	2016	29
V. Skälsjön++	SE664620-148590	18	7.4	1	-10.6	1989	2016	28
Valasjön+	SE698918-158665	n.s.	9	n.a.	n.a.	1988	2016	29
Valkeajärvi	SE751252-175433	n.s.	4.8	n.a.	n.a.	1988	2016	29
Västra Solsjön++	SE655863-129783	n.s.	12.3	n.a.	n.a.	1988	2016	29

Vidöstern	SE631841-138929	n.s.	4.6	n.a.	n.a.	1980	1998	19
Vuolgamjaure	SE728744-162653	n.s.	4.1	n.a.	n.a.	1988	2016	29
Ymsen+	SE650398-139136	n.s.	2.4	n.a.	n.a.	1995	2016	22

**the larger and positive the lower the sample depth compared to maximum depth

***the larger and negative, the deeper the sample depth compared to the mean depth; positive values = lower sample depth than mean dept

V. Available information on large lake basins

Site	EUid	part of lake	Lake basin area [km^2]	app. Altitude [m]	Eco-region	Season type*	Station coordinate_North	Station coordinate_East	X RT90	Y RT90	From year	To year	N of years
Blacken+	SE658080-162871	Mälaren	87.01	0.6	4	1	6593806	587499	6595030	1541900	1979	2012	34
Ekoln Vreta Udd+	SE658080-162871	Mälaren	21.54	0.6	4	1	6626576	646548	6627090	1601360	1979	2016	38
Galten+	SE658080-162871	Mälaren	54.50	0.6	4	1	6590333	567347	6591800	1521700	1979	2012	34
Görväln S+	SE658080-162871	Mälaren	73.10	0.6	4	1	6589962	655471	6590361	1609840	1979	2012	34
Granfj. Djurgårds Udde+	SE658080-162871	Mälaren	77.38	0.6	4	1	6596508	602533	6597550	1556970	1979	2012	34
S. Björkfjärden SO+	SE658080-162871	Mälaren	320.54	0.6	4	1	6575080	643534	6575620	1597721	1979	2012	34
Skarven+	SE658080-162871	Mälaren	25.88	0.6	4	1	6605058	658667	6605421	1613220	1979	2012	34
Svinnegarnsviken+	SE658080-162871	Mälaren	99.11	0.6	4	1	6606543	615498	6607430	1570060	1979	2012	34
Ulvhällsfjärden+	SE658080-162871	Mälaren	44.65	0.6	4	1	6582814	616796	6583680	1571071	1979	2012	34
Siljan (Vert2)	SE673490-145597	Siljan	n.a.	161.6	3	1	n.a.	n.a.	n.a.	n.a.	1980	1998	19
Siljan (vert8)	SE673490-145597	Siljan	n.a.	161.6	3	1	n.a.	n.a.	n.a.	n.a.	1980	1998	19
Dagskärsgrund N+	SE647666-129906	Vänern	n.a.	44.4	6	1	6514464	416159	6517730	1369540	1979	2016	38
Mariestadsviken M1+	SE651196-137852	Vänern	n.a.	44.4	6	1	6508806	425203	6511960	1378520	1982	2016	35
Mariestadsviken M2+	SE647666-129906	Vänern	n.a.	44.4	6	1	6515126	434583	6518170	1387980	1982	2016	35
Megrundet N	SE647666-129906	Vänern	n.a.	44.4	6	1	6524990	373863	6528770	1327350	1979	2016	38
Tärnan SSO	SE647666-129906	Vänern	n.a.	44.4	6	1	6551217	411988	6554550	1365810	1979	2016	38
Edeskvarnaån NV+	SE649029-145550	Vättern	n.a.	88.5	4	1	6418632	454151	6421401	1406400	1979	2003	25
Jungfrun NV+	SE649029-145550	Vättern	n.a.	88.5	4	1	n.a.	n.a.	n.a.	n.a.	1979	2003	25
Vättern+	SE649029-145550	Vättern	n.a.	88.5	4	1	n.a.	n.a.	n.a.	n.a.	1982	1998	17

*Southern Sweden=1; Northern Sweden=2

Annex 3

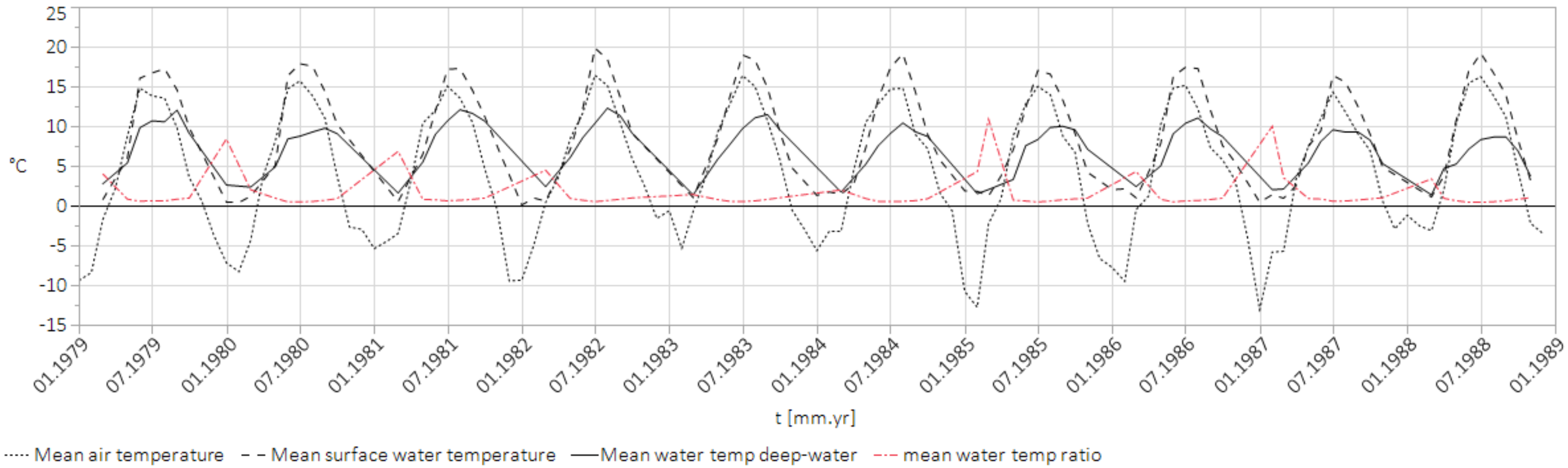
I. Overview of the classification of lakes in ecoregions in Sweden.

Ecoregion	Description
1	Mountains above tree line
2	Norrland´s inland, below tree line, above över highest coast line
3	Norrland´s coast, below highest coast line
4	Southeast, south of limit to Norrland, within the watershed of the Baltic Sea, below 200 m a.s.l.
5	Southern Sweden, Skåne, Blekinge´s coast and part of Öland
6	Southwest, south of limit o Norrland, within the watershed of the North Sea, below 200 m a.s.l.
7	Southern Swedish highlands, south of limit to Norrland, above 200 m a.s.l.

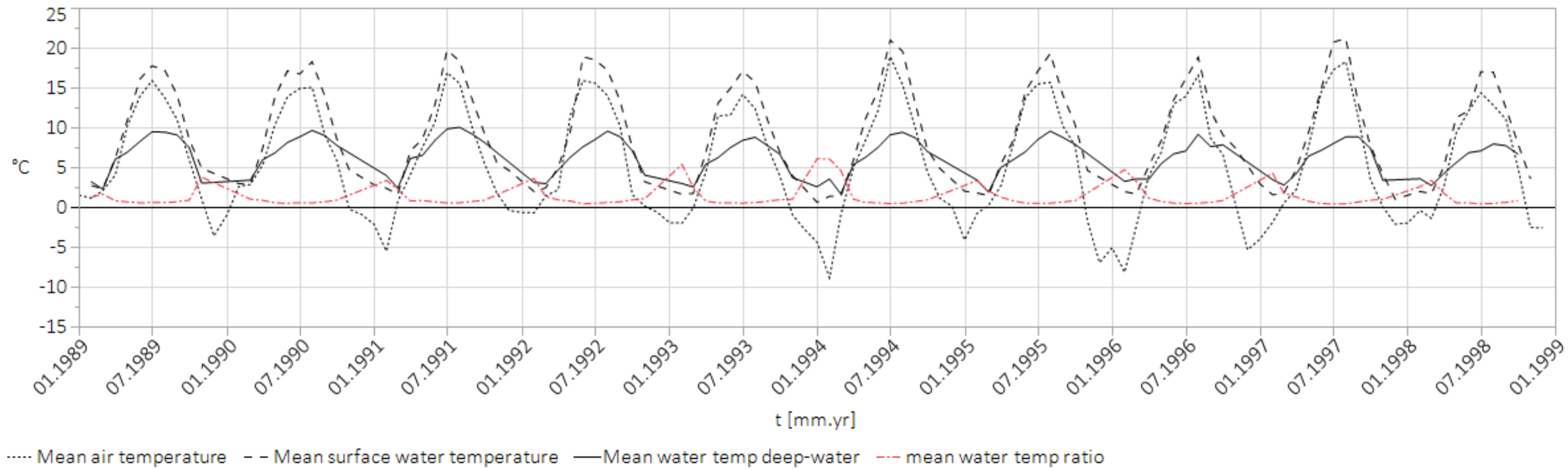
Annex 4

Air temperature, surface water temperature (SWT) (cat4), bottom water temepratures (BWT) (cat6) and bottom-surface water temperature ratios (BS-ratio) (cat6) at a °C scale over 10yr time ranges. Means calculated on significant and non-significant lakes from 1979-2016, air temperature 1979-2017.

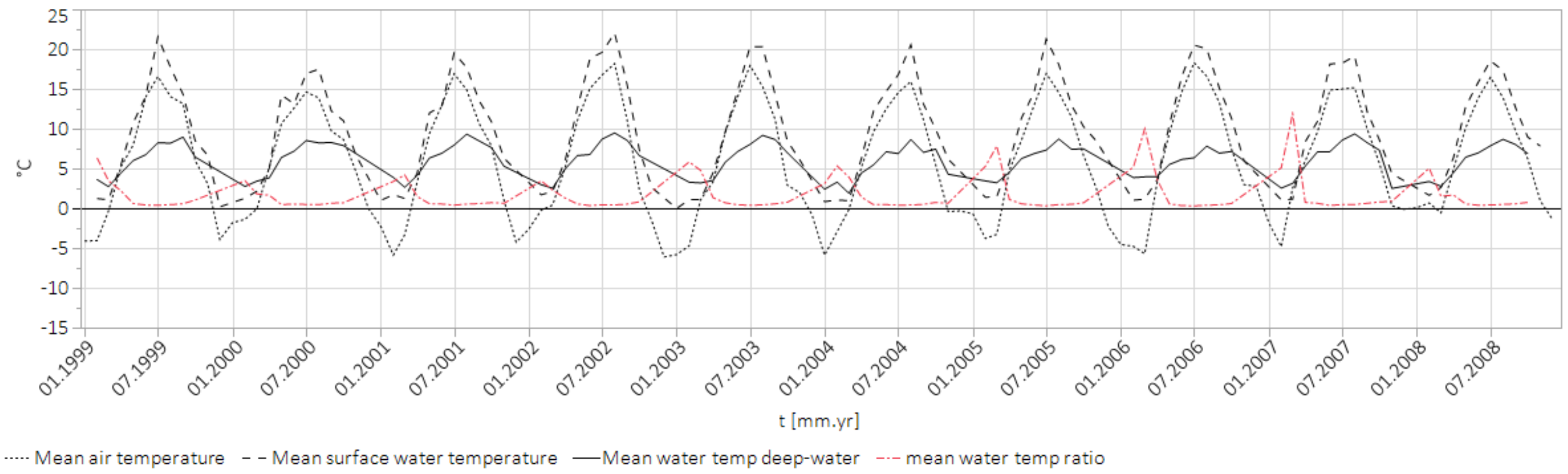
1979-1988



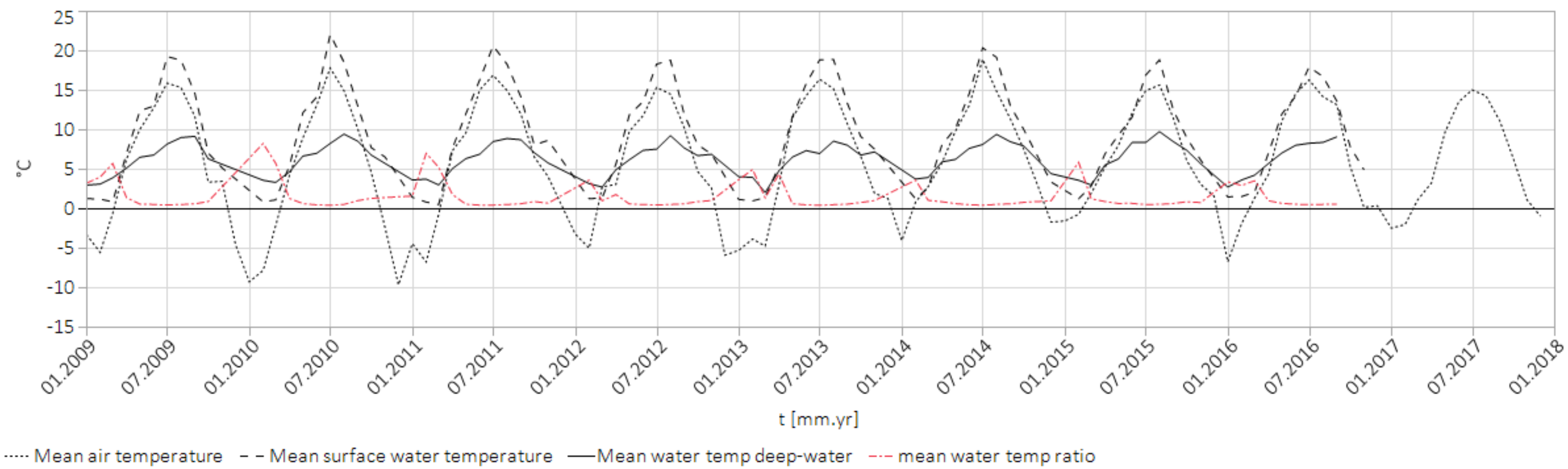
1989-1998



1999-2008



2008-2016



Annex 5

I-III: Theil-Sen slopes for each significant trend found per month for surface watere temperature (SWT), bottom water temperature (BWT), and botton-surface water temperature ratios (BS-ratio).

I. Deep lakes

Site	EUid	Month	Limed	Change in °C yr-1						Air temperature	Brownification status	Trophic status	Mixing behavior	Season type
				SWT Cat1	SWT Cat4	BWT Cat2	BWT Cat6	BS-ratio Cat2	BS-ratio Cat6					
Älgarydssjön	SE633989-140731	2		-0.07	-0.10			0.08	0.08		H	M	polymictic	1
Älgsjön	SE655275-153234	2			-0.04						H	E	polymictic	1
Bäen	SE623624-141149	2			-0.07						H	M	polymictic	1
Björken	SE652707-159032	2			-0.04						H	O	dimictic	1
Dagarn	SE664197-149337	2			-0.06						C	O	polymictic	1
Djupa Holmsjön	SE656263-156963	2			-0.08						H	O	dimictic	1
Ejgdesjön	SE653737-125017	2	yes			0.04	0.05				C	UO	dimictic	1
Fjärasjö	SE638725-146677	2			-0.07						H	O	dimictic	1
Hällvattnet	SE704955-159090	2		-0.03	-0.05						H	UO	polymictic	2
Holmeshultasjön	SE634447-144024	2		-0.04	-0.06						n.a.	n.a.	variable	1
Humsjön	SE650061-142276	2		-0.07	-0.07						H	O	dimictic	1
Lillesjö	SE623161-142148	2			-0.09						C	UO	dimictic	1
Lillsjön	SE655380-155738	2			-0.05						H	E	variable	1
Limmingsjön	SE660804-142742	2		-0.07	-0.04						H	UO	polymictic	1
Mäsen	SE665654-149206	2		-0.04	-0.04						C	O	dimictic	1
N. Yngern	SE656206-159170	2		-0.08							C	O	polymictic	1
Örvattnet	SE662682-132860	2			-0.07						C	UO	dimictic	1
Översjön	SE664410-136192	2			-0.04						H	UO	dimictic	1
Överudssjön	SE659105-133982	2			-0.05						H	E	polymictic	1
Rotehogstjärnen	SE652902-125783	2				0.05	0.05				H	M	dimictic	1
Stengårdshultasjön	SE638317-138010	2	yes				0.04				H	O	polymictic	1
Stensjön_2	SE683673-154083	2			-0.03						H	UO	variable	1
Stora Envättern	SE655587-158869	2			-0.04			0.09	0.09		H	O	dimictic	1
Tärnan	SE660688-164478	2		-0.10	-0.09						H	M	polymictic	1

Tväringen	SE690345-149315	2			-0.07						H	UO	polymictic	1
Ulvsjön	SE661521-130182	2			-0.04						H	O	dimictic	1
V. Rännöbodsjön	SE691365-156127	2			-0.05						H	O	dimictic	1
Valasjön	SE698918-158665	2			-0.05						H	O	variable	2
Västra Solsjön	SE655863-129783	2		-0.14							C	UO	dimictic	1
Allgjuttern	SE642489-151724	4				-0.04	-0.04	-0.01	-0.01	0.06	C	UO	dimictic	1
Björken	SE652707-159032	4		0.15						0.07	H	O	dimictic	1
Fjärasjö	SE638725-146677	4				0.17	0.17			0.07	H	O	dimictic	1
Fräcksjön	SE645289-128665	4		0.09	0.10					0.07	H	O	dimictic	1
Harasjön	SE632231-136476	4		0.11	0.14					0.07	H	E	polymictic	1
Härsvatten	SE643914-127698	4		0.10	0.10			-0.02	-0.02	0.07	C	UO	dimictic	1
Krageholmssjön	SE615375-137087	4			0.12					0.06	C	H	polymictic	1
Långsjön_1	SE652412-143738	4	yes	0.13	0.13			-0.03	-0.01	0.08	H	O	variable	1
N. Yngern	SE656206-159170	4		0.10	0.10					0.06	C	O	polymictic	1
Örvattnet	SE662682-132860	4		0.21	0.21					0.06	C	UO	dimictic	1
Översjön	SE664410-136192	4		0.13	0.13					0.06	H	UO	dimictic	1
Rotehogstjärnen	SE652902-125783	4			0.08					0.07	H	M	dimictic	1
Rundbosjön	SE652177-159038	4		0.17	0.17					0.07	H	E	n.a.	1
Stengårdshultasjön	SE638317-138010	4	yes			0.10				0.07	H	O	polymictic	1
Stensjön_2	SE683673-154083	4						-0.21	-0.21	0.06	H	UO	variable	1
Stora Envättern	SE655587-158869	4				-0.07	-0.06	-0.01	-0.01	0.06	H	O	dimictic	1
Stor-Tjulträsket	SE731799-151196	4		-0.07	-0.07						C	UO	dimictic	2
V. Skälsjön	SE664620-148590	4	yes			0.07	0.07			0.08	C	UO	dimictic	1
Västra Solsjön	SE655863-129783	4		0.11	0.11					0.07	C	UO	dimictic	1
Abiskojaure	SE758208-161749	8		0.08	0.08					0.06	C	O	variable	2
Älgsjön	SE655275-153234	8			0.13						H	E	polymictic	1
Alsjön	SE647050-130644	8			0.09						H	M	dimictic	1
Brunnsjön	SE627443-149526	8			0.10					0.04	H	M	dimictic	1
Degervattnet	SE708512-152086	8			0.11					0.05	H	UO	variable	2
Djupa Holmsjön	SE656263-156963	8			0.10					0.04	H	O	dimictic	1
Fräcksjön	SE645289-128665	8			0.06						H	O	dimictic	1
Hagasjön	SE635878-137392	8									H	O	dimictic	1
Harasjön	SE632231-136476	8				0.10	0.10				H	E	polymictic	1
Jutsajaure	SE744629-167999	8		0.09						0.05	H	O	polymictic	2

Lien	SE663216-148449	8	yes			-0.05	-0.04				H	UO	variable	1
N. Yngern	SE656206-159170	8			0.09					0.04	C	O	polymictic	1
Remmarsjön	SE708619-162132	8		0.11	0.12					0.03	H	O	polymictic	2
Rotehogstjärnen	SE652902-125783	8				0.06	0.06				H	M	dimictic	1
Sännen	SE624421-147234	8		0.08	0.07					0.04	C	M	polymictic	1
Skärsjön_1	SE633344-130068	8			0.10					0.03	C	O	variable	1
Skärsjön_2	SE637260-128728	8			0.10						n.a.	n.a.	dimictic	1
Stensjön_2	SE683673-154083	8			0.06						H	UO	variable	1
Stora Envättern	SE655587-158869	8			0.08					0.04	H	O	dimictic	1
V. Skälsjön	SE664620-148590	8	yes								C	UO	dimictic	1
Valasjön	SE698918-158665	8			0.12						H	O	variable	2
Allgjuttern	SE642489-151724	9					-0.03			0.03	C	UO	dimictic	1
Brunnsjön	SE627443-149526	9		0.06	0.06					0.05	H	M	dimictic	1
Fiolen	SE633025-142267	9		0.11	0.11	0.09	0.09			0.04	C	M	polymictic	1
Fräcksjön	SE645289-128665	9		0.12	0.12					0.05	H	O	dimictic	1
Gyltigesjön	SE629489-133906	9		0.17	0.17	-0.05	-0.05	-0.01	-0.01	0.04	H	M	dimictic	1
Gyslättasjön	SE633209-141991	9	yes			-0.10	-0.10			0.04	H	M	variable	1
Källsjön	SE683582-154935	9	yes	0.13	0.13			-0.01	-0.01	0.05	H	O	dimictic	1
Långsjön_1	SE652412-143738	9	yes	0.10	0.10					0.05	H	O	variable	1
Lien	SE663216-148449	9	yes	0.15	0.15			-0.01	-0.01	0.05	H	UO	variable	1
Övre Skärsjön	SE663532-148571	9		0.10	0.10					0.05	H	O	polymictic	1
Remmarsjön	SE708619-162132	9		0.16	0.17			-0.01	-0.01	0.06	H	O	polymictic	2
Rotehogstjärnen	SE652902-125783	9		0.11	0.11	0.04	0.04			0.05	H	M	dimictic	1
St Skärsjön	SE628606-133205	9		0.12	0.12			0.00	0.00	0.04	C	O	variable	1
Stengårdshultasjön	SE638317-138010	9	yes				-0.11		-0.01	0.05	H	O	polymictic	1
Stensjön_2	SE683673-154083	9		0.08	0.08					0.05	H	UO	variable	1
Stora Envättern	SE655587-158869	9		0.10	0.10	-0.10	-0.09	-0.01	-0.01	0.05	H	O	dimictic	1
V. Skälsjön	SE664620-148590	9	yes	0.10	0.10	-0.10	-0.10	-0.01	-0.01	0.05	C	UO	dimictic	1
Min				**-0.14**	**-0.10**	**-0.10**	**-0.11**	**-0.21**	**-0.21**	**0.03**				
Max				**0.21**	**0.21**	**0.17**	**0.17**	**0.09**	**0.09**	**0.08**				

II. Shallow lakes

Site	EUid	Month	Change in °C yr-1				Air temperature	Brownification status	Trophic status	Mixing behavior	Season type
			SWT Cat1	SWT Cat4	BWT Cat2	BWT Cat6					
Edasjön	SE663365-161779	2	0.09					H	E	variable	1
Fysingen	SE660749-161885	2	-0.11	-0.11				C	E	polymictic	1
Gosjön	SE677506-156174	2		-0.07				H	M	polymictic	1
Långsjön_3	SE673534-153381	2		-0.05				H	M	dimictic	1
Mossjön	SE638085-138862	2		-0.06	0.05	0.05		H	n.a.	polymictic	1
St. Lummersjön	SE644463-139986	2		-0.10				H	O	variable	1
Svartsjön	SE651609-140839	2	-0.15	-0.15				H	E	dimictic	1
Mossjön	SE638085-138862	4			0.24	0.24	0.07	H	n.a.	polymictic	1
Tångerdasjön	SE637120-145525	4					0.07	H	E	polymictic	1
Havgårdssjön	SE615365-134524	8	-0.21	-0.16			0.04	C	E	polymictic	1
Horsan	SE642008-168013	8	-0.20				0.05	C	O	dimictic	1
Krankesjön	SE617797-135339	8	-0.27	-0.21				C	E	polymictic	1
Sidensjön	SE709218-169710	8		0.18			0.04	H	E	dimictic	2
Svartsjön	SE651609-140839	8	-0.30	-0.30				H	E	dimictic	1
Tångerdasjön	SE637120-145525	8						H	E	polymictic	1
Ymsen	SE650398-139136	8	-0.18	-0.17				C	H	polymictic	1
Min			**-0.30**	**-0.30**	**0.05**	**0.05**	**0.04**				
Max			**0.09**	**0.18**	**0.24**	**0.24**	**0.07**				

III. Lake basins

Site	EUid	Month	Change in °C yr-1				Lake basin of	Season type	Shallow/Deep
			SWT Cat1	SWT Cat4	BWT Cat2	BWT Cat6			
Ekoln Vreta Udd	SE658080-162871	4	0.13	0.13			Mälaren	1	Deep
Mariestadsviken M2	SE647666-129906	4	0.19	0.19	0.17	0.17	Vänern	1	
Blacken	SE658080-162871	8	0.05	0.05			Mälaren	1	
Ekoln Vreta Udd	SE658080-162871	8	0.05	0.05			Mälaren	1	Deep
Galten	SE658080-162871	8	0.06	0.06	0.07	0.07	Mälaren	1	
Görväln S	SE658080-162871	8	0.07	0.07			Mälaren	1	
Granfj. Djurgårds Udde	SE658080-162871	8	0.08	0.08			Mälaren	1	
S. Björkfjärden SO	SE658080-162871	8	0.08	0.08			Mälaren	1	
Skarven	SE658080-162871	8	0.06	0.06			Mälaren	1	
Svinnegarnsviken	SE658080-162871	8	0.13	0.13	0.11	0.11	Mälaren	1	
Ulvhällsfjärden	SE658080-162871	8	0.07	0.07	0.06	0.06	Mälaren	1	
Vättern	SE649029-145550	8	0.39	0.39			Vättern	1	Deep
Dagskärsgrund N	SE647666-129906	9	0.14	0.14			Vänern	1	
Edeskvarnaån NV	SE649029-145550	9				0.12	Vättern	1	
Jungfrun NV	SE649029-145550	9			0.15	0.17	Vättern	1	
Mariestadsviken M1	SE647666-129906	9					Vänern	1	
Skarven	SE658080-162871	9	0.04	0.04			Mälaren	1	
Min			**0.04**	**0.04**	**0.06**	**0.06**			
Max			**0.39**	**0.39**	**0.17**	**0.17**			

Annex 6

I-III: Percent of Theil-Sen slopes for each significant trend found per month for surface watere temperature (SWT), bottom water temperature (BWT), and botton-surface water temperature ratios (BS-ratio); calculated on means for each time series (grey = February ≥ +/- 5.0 %; April ≥ +/- 3.0 %, August ≥ +/-0.7 %; September ≥ +/- 1.5 %).

I. Deep lakes

Site	EUid	Month	Limed	% Trend change						Brownification status	Trophic status	Mixing behavior	Season type
				SWT Cat1	SWT Cat4	BWT Cat2	BWT Cat6	BS-ratio Cat2	BS-ratio Cat6				
Björken*	SE652707-159032	2			-4.06					H	O	dimictic	1
Djupa Holmsjön*	SE656263-156963	2			-7.02					H	O	dimictic	1
Ejgdesjön	SE653737-125017	2	yes			1.36	1.55			C	UO	dimictic	1
Fjärasjö*	SE638725-146677	2			-4.25					H	O	dimictic	1
Humsjön	SE650061-142276	2		-5.08	-4.56					H	O	dimictic	1
Lillesjö	SE623161-142148	2			-3.42					C	UO	dimictic	1
Mäsen	SE665654-149206	2		-2.71	-2.71					C	O	dimictic	1
Örvattnet*	SE662682-132860	2			-4.47					C	UO	dimictic	1
Översjön*	SE664410-136192	2			-2.07					H	UO	dimictic	1
Rotehogstjärnen**	SE652902-125783	2				1.42	1.42			H	M	dimictic	1
Stora Envättern**	SE655587-158869	2			-2.78			2.63	2.51	H	O	dimictic	1
Ulvsjön	SE661521-130182	2			-2.37					H	O	dimictic	1
V. Rännöbodsjön	SE691365-156127	2			-4.90					H	O	dimictic	1
Västra Solsjön*	SE655863-129783	2		-11.20						C	UO	dimictic	1
Älgarydssjön	SE633989-140731	2		-4.05	-4.45			1.94	1.94	H	M	polymictic	1
Älgsjön*	SE655275-153234	2			-3.04					H	E	polymictic	1
Bäen	SE623624-141149	2			-3.11					H	M	polymictic	1
Dagarn	SE664197-149337	2			-5.03					C	O	polymictic	1
Hällvattnet	SE704955-159090	2		-3.69	-5.14					H	UO	polymictic	2
Limmingsjön	SE660804-142742	2		-7.18	-3.75					H	UO	polymictic	1
N. Yngern**	SE656206-159170	2		-6.81						C	O	polymictic	1
Överudssjön	SE659105-133982	2			-2.46					H	E	polymictic	1
Stengårdshultasjön**	SE638317-138010	2	yes				1.69			H	O	polymictic	1
Tärnan	SE660688-164478	2		-9.67	-6.37					H	M	polymictic	1

Tväringen	SE690345-149315	2			-4.57					H	UO	polymictic	1
Holmeshultasjön	SE634447-144024	2		-3.07	-4.08					n.a.	n.a.	variable	1
Lillsjön	SE655380-155738	2			-5.78					H	E	variable	1
Stensjön_2***	SE683673-154083	2			-3.35					H	UO	variable	1
Valasjön*	SE698918-158665	2			-4.98					H	O	variable	2
Allgjuttern*	SE652177-159038	4		2.73	2.73					H	E	n.a.	1
Björken*	SE642489-151724	4				-1.06	-1.09	-1.64	-1.48	C	UO	dimictic	1
Fjärasjö*	SE652707-159032	4		2.76						H	O	dimictic	1
Fräcksjön*	SE638725-146677	4				3.35	3.35			H	O	dimictic	1
Härsvatten	SE645289-128665	4		1.30	1.42					H	O	dimictic	1
Örvattnet*	SE643914-127698	4		1.55	1.55			-2.33	-1.92	C	UO	dimictic	1
Översjön*	SE662682-132860	4		4.73	4.73					C	UO	dimictic	1
Rotehogstjärnen**	SE664410-136192	4		2.52	2.52					H	UO	dimictic	1
Stora Envättern**	SE652902-125783	4			1.04					H	M	dimictic	1
Stor-Tjulträsket	SE655587-158869	4				-1.21	-1.17	-1.68	-1.77	H	O	dimictic	1
V. Skälsjön*	SE731799-151196	4		-5.21	-5.21					C	UO	dimictic	2
Västra Solsjön*	SE664620-148590	4	yes			1.62	1.62			C	UO	dimictic	1
Harasjön*	SE655863-129783	4		2.21	2.21					C	UO	dimictic	1
Krageholmssjön	SE632231-136476	4		1.16	1.54					H	E	polymictic	1
N. Yngern**	SE615375-137087	4			1.41					C	H	polymictic	1
Stengårdshultasjön**	SE656206-159170	4		1.91	2.16					C	O	polymictic	1
Långsjön_1*	SE638317-138010	4	yes			1.84				H	O	polymictic	1
Stensjön_2***	SE652412-143738	4	yes	2.01	2.01			-3.54	-1.58	H	O	variable	1
Rundbosjön	SE683673-154083	4						-3.89	-3.89	H	UO	variable	1
Alsjön	SE647050-130644	8			0.50					H	M	dimictic	1
Brunnsjön*	SE627443-149526	8			0.51					H	M	dimictic	1
Djupa Holmsjön*	SE656263-156963	8			0.48					H	O	dimictic	1
Fräcksjön*	SE645289-128665	8			0.33					H	O	dimictic	1
Hagasjön	SE635878-137392	8						-0.74	-0.74	H	O	dimictic	1
Rotehogstjärnen**	SE652902-125783	8				0.87	0.87			H	M	dimictic	1
Skärsjön_2	SE637260-128728	8			0.51					n.a.	n.a.	dimictic	1
Stora Envättern**	SE655587-158869	8			0.38					H	O	dimictic	1
V. Skälsjön*	SE664620-148590	8	yes					-1.00	-1.00	C	UO	dimictic	1
Älgsjön*	SE655275-153234	8			0.66					H	E	polymictic	1

Harasjön*	SE632231-136476	8				0.87	0.87			H	E	polymictic	1
Jutsajaure	SE744629-167999	8		0.60						H	O	polymictic	2
N. Yngern**	SE656206-159170	8			0.46					C	O	polymictic	1
Remmarsjön*	SE708619-162132	8		0.66	0.72					H	O	polymictic	2
Sännen	SE624421-147234	8		0.38	0.32					C	M	polymictic	1
Abiskojaure	SE758208-161749	8		0.71	0.71					C	O	variable	2
Degervattnet	SE708512-152086	8			0.65					H	UO	variable	2
Lien*	SE663216-148449	8	yes			-0.88	-0.78	-1.13	-1.13	H	UO	variable	1
Skärsjön_1	SE633344-130068	8			0.51					C	O	variable	1
Stensjön_2***	SE683673-154083	8			0.34					H	UO	variable	1
Valasjön*	SE698918-158665	8			0.64					H	O	variable	2
Allgjuttern*	SE642489-151724	9					-0.77	-0.95	-0.94	C	UO	dimictic	1
Brunnsjön*	SE627443-149526	9		0.42	0.42			-0.82	-0.82	H	M	dimictic	1
Fräcksjön*	SE645289-128665	9		0.79	0.80					H	O	dimictic	1
Gyltigesjön	SE629489-133906	9		1.16	1.16	-1.00	-1.00	-2.52	-2.52	H	M	dimictic	1
Källsjön	SE683582-154935	9	yes	1.01	1.01			-1.82	-1.82	H	O	dimictic	1
Rotehogstjärnen**	SE652902-125783	9		0.80	0.80	0.60	0.60			H	M	dimictic	1
Stora Envättern**	SE655587-158869	9		0.70	0.70	-1.24	-1.13	-0.97	-0.94	H	O	dimictic	1
V. Skälsjön*	SE664620-148590	9	yes	0.67	0.67	-1.34	-1.34	-2.10	-2.10	C	UO	dimictic	1
Fiolen	SE633025-142267	9		0.71	0.71	0.63	0.63			C	M	polymictic	1
Övre Skärsjön	SE663532-148571	9		0.69	0.69					H	O	polymictic	1
Remmarsjön*	SE708619-162132	9		1.32	1.36			-1.45	-1.50	H	O	polymictic	2
Stengårdshultasjön**	SE638317-138010	9	yes				-1.53		-1.56	H	O	polymictic	1
Gyslättasjön	SE633209-141991	9	yes			-1.28	-1.28			H	M	variable	1
Långsjön_1*	SE652412-143738	9	yes	0.62	0.62					H	O	variable	1
Lien*	SE663216-148449	9	yes	1.02	1.02			-2.21	-2.23	H	UO	variable	1
St Skärsjön	SE628606-133205	9		0.79	0.79			-0.65	-0.65	C	O	variable	1
Stensjön_2***	SE683673-154083	9		0.64	0.64					H	UO	variable	1

II. Shallow lakes

Site	EUid	Month	% Trend change						Brownification status	Trophic status	Mixing behavior	Season type
			SWT Cat1	SWT Cat4	BWT Cat2	BWT Cat6	BS-ratio Cat2	BS-ratio Cat6				
Långsjön_3	SE673534-153381	2		-2.76					H	M	dimictic	1
Svartsjön*	SE651609-140839	2	-11.73	-11.73					H	E	dimictic	1
Fysingen	SE660749-161885	2	-8.89	-8.30					C	E	polymictic	1
Gosjön	SE677506-156174	2		-3.66					H	M	polymictic	1
Mossjön*	SE638085-138862	2		-3.96	1.47	1.47			H	n.a.	polymictic	1
Edasjön	SE663365-161779	2	7.61						H	E	variable	1
St. Lummersjön	SE644463-139986	2		-4.74					H	O	variable	1
Mossjön*	SE638085-138862	4			3.82	3.82			H	n.a.	polymictic	1
Tångerdasjön*	SE637120-145525	4					0.19	0.19	H	E	polymictic	1
Horsan	SE642008-168013	8	-1.01						C	O	dimictic	1
Sidensjön	SE709218-169710	8		1.02					H	E	dimictic	2
Svartsjön*	SE651609-140839	8	-1.61	-1.61					H	E	dimictic	1
Havgårdssjön	SE615365-134524	8	-1.03	-0.78					C	E	polymictic	1
Krankesjön	SE617797-135339	8	-1.37	-1.05					C	E	polymictic	1
Tångerdasjön*	SE637120-145525	8					0.24	0.24	H	E	polymictic	1
Ymsen	SE650398-139136	8	-0.96	-0.91					C	H	polymictic	1

III. Lake basins

Site	EUid	Month	lake basin of	% Trend change						Season type
				SWT Cat1	SWT Cat4	BWT Cat2	BWT Cat6	BS-ratio Cat2	BS-ratio Cat6	
Ekoln Vreta Udd*	SE658080-162871	4	Mälaren	2.94	2.94					1
Mariestadsviken M2	SE647666-129906	4	Vänern	3.80	3.80	3.55	3.55			1
Blacken	SE658080-162871	8	Mälaren	0.27	0.27					1
Galten	SE658080-162871	8	Mälaren	0.31	0.31	0.39	0.39			1
Görväln S	SE658080-162871	8	Mälaren	0.36	0.36			-0.49	-0.49	1
Granfj. Djurgårds Udde	SE658080-162871	8	Mälaren	0.41	0.41					1
S. Björkfjärden SO	SE658080-162871	8	Mälaren	0.41	0.41					1
Skarven	SE658080-162871	8	Mälaren	0.34	0.34					1
Svinnegarnsviken	SE658080-162871	8	Mälaren	0.69	0.69	0.72	0.72			1
Ulvhällsfjärden	SE658080-162871	8	Mälaren	0.37	0.37	0.33	0.33			1
Ekoln Vreta Udd*	SE658080-162871	8	Mälaren	0.26	0.26					1
Vättern	SE649029-145550	8	Vättern		2.54					1
Dagskärsgrund N	SE647666-129906	9	Vänern	1.00	1.00					1
Edeskvarnaån NV	SE649029-145550	9	Vättern				2.23			1
Jungfrun NV	SE649029-145550	9	Vättern			2.72	2.95			1
Mariestadsviken M1	SE647666-129906	9	Vänern					0.18	0.18	1
Skarven	SE658080-162871	9	Mälaren	0.26	0.26					1

Annex 7

I-IV: Missing values in % of the data range (starting sample year to finishing year) for surface watere temperature (SWT), bottom water temperature (BWT), and botton-surface water temperature ratios (BS-ratio). The grey scale indicates: light grey = > 5–10 %; middle grey = > 10–20 %; dark grey = >20–30 % and darkest grey = > 30 % missing values.

I. Missing values in % of data range - February

Site	EUid	SWT cat1 %	SWT cat4 %	BWT cat2 %	BWT cat6 %	BS-ratio cat2 %	BS-ratio cat6 %
Älgarydssjön	SE633989-140731	33	22	56	56	56	56
Älgsjön	SE655275-153234	15	23	26	26	26	26
Bäen	SE623624-141149	27	22	0	0	0	0
Björken	SE652707-159032	5	14	n.a.	n.a.	n.a.	n.a.
Dagarn	SE664197-149337	15	14	n.a.	n.a.	n.a.	n.a.
Djupa Holmsjön	SE656263-156963	5	8	n.a.	n.a.	n.a.	n.a.
Edasjön	SE663365-161779	10	25	n.a.	n.a.	n.a.	n.a.
Ejgdesjön	SE653737-125017	32	28	54	46	54	46
Fjärasjö	SE638725-146677	37	25	43	43	48	52
Fysingen	SE660749-161885	20	14	n.a.	n.a.	n.a.	n.a.
Gosjön	SE677506-156174	13	24	n.a.	n.a.	n.a.	n.a.
Hällvattnet	SE704955-159090	11	12	n.a.	n.a.	n.a.	n.a.
Holmeshultasjön	SE634447-144024	37	28	69	70	69	70
Humsjön	SE650061-142276	26	16	0	0	0	0
Långsjön_3	SE673534-153381	13	28	n.a.	n.a.	n.a.	n.a.
Lillesjö	SE623161-142148	17	19	58	58	58	58
Lillsjön	SE655380-155738	5	5	n.a.	n.a.	n.a.	n.a.
Limmingsjön	SE660804-142742	50	38	n.a.	n.a.	n.a.	n.a.
Mäsen	SE665654-149206	43	43	50	75	50	75
Mossjön	SE638085-138862	42	38	50	50	54	54
N. Yngern	SE656206-159170	20	21	n.a.	n.a.	n.a.	n.a.
Örvattnet	SE662682-132860	5	4	67	21	67	21
Översjön	SE664410-136192	0	7	38	38	38	38
Överudssjön	SE659105-133982	5	7	n.a.	n.a.	n.a.	n.a.
Rotehogstjärnen	SE652902-125783	32	36	32	32	32	32
St. Lummersjön	SE644463-139986	16	19	n.a.	n.a.	n.a.	n.a.
Stengårdshultasjön	SE638317-138010	29	29	57	39	57	39
Stensjön_2	SE683673-154083	25	21	23	23	27	27
Stora Envättern	SE655587-158869	29	25	32	29	32	29
Svartsjön	SE651609-140839	18	18	n.a.	n.a.	n.a.	n.a.
Tärnan	SE660688-164478	20	21	n.a.	n.a.	n.a.	n.a.
Tväringen	SE690345-149315	64	17	0	0	0	0
Ulvsjön	SE661521-130182	0	0	63	63	63	63
V. Rännöbodsjön	SE691365-156127	26	24	n.a.	n.a.	n.a.	n.a.
Valasjön	SE698918-158665	16	15	n.a.	n.a.	n.a.	n.a.
Västra Solsjön	SE655863-129783	50	48	n.a.	n.a.	n.a.	n.a.

II. Missing values in % of data range - April

Site	EUid	SWT cat1 %	SWT cat4 %	BWT cat2 %	BWT cat6 %	BS-ratio cat2 %	BS-ratio cat6 %
Allgjuttern	SE642489-151724	10	15	17	14	17	14
Björken	SE652707-159032	0	11	n.a.	n.a.	n.a.	n.a.
Ekoln Vreta Udd	SE658080-162871	37	37	33	33	33	33
Fjärasjö	SE638725-146677	30	30	50	50	50	50
Fräcksjön	SE645289-128665	7	3	17	17	17	17
Harasjön	SE632231-136476	36	41	67	67	67	67
Härsvatten	SE643914-127698	3	3	18	13	18	13
Krageholmssjön	SE615375-137087	19	0	64	64	64	64
Långsjön_1	SE652412-143738	7	7	0	11	0	11
Mariestadsviken M2	SE647666-129906	14	14	6	6	6	6
Mossjön	SE638085-138862	20	20	47	47	47	47
N. Yngern	SE656206-159170	24	24	n.a.	n.a.	n.a.	n.a.
Örvattnet	SE662682-132860	30	30	0	55	0	55
Översjön	SE664410-136192	33	33	n.a.	n.a.	n.a.	n.a.
Rotehogstjärnen	SE652902-125783	3	3	4	4	4	4
Rundbosjön	SE652177-159038	0	0	n.a.	n.a.	n.a.	n.a.
Stengårdshultasjön	SE638317-138010	11	11	32	19	32	19
Stensjön_2	SE683673-154083	0	0	0	0	0	0
Stora Envättern	SE655587-158869	0	0	25	18	25	18
Stor-Tjulträsket	SE731799-151196	38	38	0	0	0	0
Tångerdasjön	SE637120-145525	30	30	45	45	45	45
V. Skälsjön	SE664620-148590	26	26	52	52	52	52
Västra Solsjön	SE655863-129783	29	29	n.a.	n.a.	n.a.	n.a.

III. Missing values in % of data range - August

Site	EUid	SWT cat1 %	SWT cat4 %	BWT cat2 %	BWT cat6 %	BS-ratio cat2 %	BS-ratio cat6 %
Abiskojaure	SE758208-161749	14	14	46	14	46	14
Älgsjön	SE655275-153234	0	6	20	20	20	20
Alsjön	SE647050-130644	28	9	0	0	0	0
Blacken	SE658080-162871	24	24	24	24	24	24
Brunnsjön	SE627443-149526	3	3	4	4	4	4
Degervattnet	SE708512-152086	10	13	n.a.	n.a.	n.a.	n.a.
Djupa Holmsjön	SE656263-156963	10	14	n.a.	n.a.	n.a.	n.a.
Ekoln Vreta Udd	SE658080-162871	9	9	21	21	21	21
Fräcksjön	SE645289-128665	3	0	7	7	7	7
Galten	SE658080-162871	15	15	24	24	24	24
Görväln S	SE658080-162871	18	18	24	24	24	24
Granfj. Djurgårds Udde	SE658080-162871	15	15	25	24	25	24
Hagasjön	SE635878-137392	7	6	22	22	22	22
Harasjön	SE632231-136476	28	18	57	57	57	57
Havgårdssjön	SE615365-134524	19	0	n.a.	n.a.	n.a.	n.a.
Horsan	SE642008-168013	50	5	n.a.	n.a.	n.a.	n.a.
Jutsajaure	SE744629-167999	3	0	33	28	33	28
Krankesjön	SE617797-135339	19	0	n.a.	n.a.	n.a.	n.a.
Lien	SE663216-148449	0	0	19	5	19	5

N. Yngern	SE656206-159170	5	0	n.a.	n.a.	n.a.	n.a.
Remmarsjön	SE708619-162132	3	3	7	3	7	3
Rotehogstjärnen	SE652902-125783	3	6	7	7	7	7
S. Björkfjärden SO	SE658080-162871	15	15	24	24	24	24
Sännen	SE624421-147234	10	6	14	14	14	14
Sidensjön	SE709218-169710	10	10	n.a.	n.a.	n.a.	n.a.
Skärsjön_1	SE633344-130068	29	12	n.a.	n.a.	n.a.	n.a.
Skärsjön_2	SE637260-128728	38	19	n.a.	n.a.	n.a.	n.a.
Skarven	SE658080-162871	15	15	24	24	24	24
Stensjön_2	SE683673-154083	3	3	4	4	4	4
Stora Envättern	SE655587-158869	0	0	10	3	10	3
Svartsjön	SE651609-140839	5	5	n.a.	n.a.	n.a.	n.a.
Svinnegarnsviken	SE658080-162871	15	15	24	24	24	24
Tångerdasjön	SE637120-145525	5	0	15	15	15	15
Ulvhällsfjärden	SE658080-162871	15	15	25	25	25	25
V. Skälsjön	SE664620-148590	0	0	11	11	11	11
Valasjön	SE698918-158665	25	3	n.a.	n.a.	n.a.	n.a.
Vättern	SE649029-145550	21	21	n.a.	n.a.	n.a.	n.a.
Ymsen	SE650398-139136	5	5	n.a.	n.a.	n.a.	n.a.

IV. Missing values in % of data range - September

Site	EUid	SWT cat1 %	SWT cat4 %	BWT cat2 %	BWT cat6 %	BS-ratio cat2 %	BS-ratio cat6 %
Allgjuttern	SE642489-151724	0	0	7	0	7	0
Brunnsjön	SE627443-149526	0	0	0	0	0	0
Dagskärsgrund N	SE647666-129906	26	26	30	30	30	30
Edeskvarnaån NV	SE649029-145550	33	33	56	38	56	38
Fiolen	SE633025-142267	3	3	7	7	7	7
Fräcksjön	SE645289-128665	4	0	4	4	4	4
Gyltigesjön	SE629489-133906	0	0	5	5	5	5
Gyslättasjön	SE633209-141991	0	0	0	0	0	0
Jungfrun NV	SE649029-145550	28	28	39	33	39	33
Källsjön	SE683582-154935	0	0	7	7	7	7
Långsjön_1	SE652412-143738	0	0	0	0	0	0
Lien	SE663216-148449	0	0	10	5	10	5
Mariestadsviken M1	SE647666-129906	18	18	15	15	15	15
Övre Skärsjön	SE663532-148571	3	3	11	11	11	11
Remmarsjön	SE708619-162132	10	7	15	4	15	4
Rotehogstjärnen	SE652902-125783	3	3	3	3	3	3
Skarven	SE658080-162871	15	15	15	15	15	15
St Skärsjön	SE628606-133205	0	0	10	10	10	10
Stengårdshultasjön	SE638317-138010	4	4	33	9	33	9
Stensjön_2	SE683673-154083	0	0	0	0	0	0
Stora Envättern	SE655587-158869	0	0	13	3	13	3
V. Skälsjön	SE664620-148590	5	5	5	5	5	5

V. Data gaps per lake, month and category. Only gap sizes of at least 2 years in a row are shown. Numbers in columns indicate the amount of recurrence of the size of a gap of missing values. For bottom water temperature (BWT), and botton-surface water temperature ratios (BS-ratio), only April and September have been considered.

Site	EUid	Month	Category	Gap size					
				2 yr	3 yr	4 yr	5yr	6 yr	7 yr
Stora Envättern	SE655587-158869	4	bottom2	1		1			
Mossjön	SE638085-138862	4	bottom2				1		
Fjärasjö	SE638725-146677	4	bottom2		1		1		
V. Skälsjön	SE664620-148590	4	bottom2		2		1		
Stora Envättern	SE655587-158869	9	bottom2	1					
Jungfrun NV	SE649029-145550	9	bottom2				1		
Allgjuttern	SE642489-151724	4	bottom6	1					
Stora Envättern	SE655587-158869	4	bottom6			1			
Mossjön	SE638085-138862	4	bottom6				1		
Fjärasjö	SE638725-146677	4	bottom6		1		1		
V. Skälsjön	SE664620-148590	4	bottom6		2		1		
Edeskvarnaån NV	SE649029-145550	9	bottom6				1		
Jungfrun NV	SE649029-145550	9	bottom6				1		
Allgjuttern	SE642489-151724	4	ratio2	2					
Härsvatten	SE643914-127698	4	ratio2		1				
Stora Envättern	SE655587-158869	4	ratio2	1		1			
Tångerdasjön	SE637120-145525	4	ratio2	1			1		
Allgjuttern	SE642489-151724	9	ratio2	1					
Mariestadsviken M1	SE647666-129906	9	ratio2	1					
Stora Envättern	SE655587-158869	9	ratio2	1					
Remmarsjön	SE708619-162132	9	ratio2		1				
Allgjuttern	SE642489-151724	4	ratio6	1					
Härsvatten	SE643914-127698	4	ratio6	1					
Stora Envättern	SE655587-158869	4	ratio6			1			
Tångerdasjön	SE637120-145525	4	ratio6	1			1		
Mariestadsviken M1	SE647666-129906	9	ratio6	1					
Älgarydssjön	SE633989-140731	2	sur1	2					
Holmeshultasjön	SE634447-144024	2	sur1	2					
Västra Solsjön	SE655863-129783	2	sur1	1	2				
Mäsen	SE665654-149206	2	sur1	2				1	
Limmingsjön	SE660804-142742	2	sur1	2					1
Mariestadsviken M2	SE647666-129906	4	sur1	1					
Västra Solsjön	SE655863-129783	4	sur1	1					
N. Yngern	SE656206-159170	4	sur1	2					
Stor-Tjulträsket	SE731799-151196	4	sur1	1		1			
Harasjön	SE632231-136476	4	sur1	2		1			
Ekoln Vreta Udd	SE658080-162871	4	sur1		1	1			
Örvattnet	SE662682-132860	4	sur1				1		
Översjön	SE664410-136192	4	sur1				1		
Krankesjön	SE617797-135339	8	sur1	1					
Abiskojaure	SE758208-161749	8	sur1		1				
Ekoln Vreta Udd	SE658080-162871	8	sur1		1				
Galten	SE658080-162871	8	sur1		1				
Granfj. Djurgårds Udde	SE658080-162871	8	sur1		1				
Havgårdssjön	SE615365-134524	8	sur1		1				
S. Björkfjärden SO	SE658080-162871	8	sur1		1				

Skarven	SE658080-162871	8	sur1		1			
Svinnegarnsviken	SE658080-162871	8	sur1		1			
Ulvhällsfjärden	SE658080-162871	8	sur1		1			
Görväln S	SE658080-162871	8	sur1		2			
Horsan	SE642008-168013	8	sur1	1	1	1		
Blacken	SE658080-162871	8	sur1		1		1	
Remmarsjön	SE708619-162132	9	sur1	1				
Skarven	SE658080-162871	9	sur1		1			
Dagskärsgrund N	SE647666-129906	9	sur1	1	1			
Älgarydssjön	SE633989-140731	2	surf4	1				
Bäen	SE623624-141149	2	surf4	1				
Björken	SE652707-159032	2	surf4	1				
Dagarn	SE664197-149337	2	surf4	1				
Hällvattnet	SE704955-159090	2	surf4	1				
Lillesjö	SE623161-142148	2	surf4	1				
St. Lummersjön	SE644463-139986	2	surf4	1				
Fjärasjö	SE638725-146677	2	surf4	2				
Holmeshultasjön	SE634447-144024	2	surf4	2				
Limmingsjön	SE660804-142742	2	surf4	4				
Älgsjön	SE655275-153234	2	surf4		1			
Stora Envättern	SE655587-158869	2	surf4		1			
Stensjön_2	SE683673-154083	2	surf4	1	1			
Tväringen	SE690345-149315	2	surf4	1	1			
Mossjön	SE638085-138862	2	surf4	4	1			
Gosjön	SE677506-156174	2	surf4	1		1		
Långsjön_3	SE673534-153381	2	surf4	2		1		
Mäsen	SE665654-149206	2	surf4	2				1
Mariestadsviken M2	SE647666-129906	4	surf4	1				
Västra Solsjön	SE655863-129783	4	surf4	1				
N. Yngern	SE656206-159170	4	surf4	2				
Stor-Tjulträsket	SE731799-151196	4	surf4	1		1		
Ekoln Vreta Udd	SE658080-162871	4	surf4		1	1		
Harasjön	SE632231-136476	4	surf4	2	1	1		
Örvattnet	SE662682-132860	4	surf4				1	
Översjön	SE664410-136192	4	surf4				1	
Alsjön	SE647050-130644	8	surf4	1				
Skärsjön_2	SE637260-128728	8	surf4	2				
Abiskojaure	SE758208-161749	8	surf4		1			
Ekoln Vreta Udd	SE658080-162871	8	surf4		1			
Galten	SE658080-162871	8	surf4		1			
Granfj. Djurgårds Udde	SE658080-162871	8	surf4		1			
S. Björkfjärden SO	SE658080-162871	8	surf4		1			
Skarven	SE658080-162871	8	surf4		1			
Svinnegarnsviken	SE658080-162871	8	surf4		1			
Ulvhällsfjärden	SE658080-162871	8	surf4		1			
Görväln S	SE658080-162871	8	surf4		2			
Blacken	SE658080-162871	8	surf4		1		1	
Remmarsjön	SE708619-162132	9	surf4	1				
Skarven	SE658080-162871	9	surf4		1			
Dagskärsgrund N	SE647666-129906	9	surf4	1	1			