Responses to the reviewers in bold, manuscript text in red, manuscript changes in red and italics.

<u>Reviewer 1</u>

Although many papers have been published about changes in lake characteristics depending on climate warming, eutrophication, oligotrophication and other (anthropogenic) drivers, the majority has focussed either on single lakes with long records or on – mostly iconic – large lakes with established data collections. In many cases, the focus was on temperature, ice cover and overturn events. Here, the authors have undertaken a huge work, first by scrolling through unpublished (handwritten?) records of Swiss commissions, cantonal offices and monitoring programs. Secondly, as different as the sources of these data are, considering sampling intervals, depth profiles and measured parameters (with their potential analytical errors) as helpful is the careful selection of parameters: which one is useful, how reliable are the measurements, how significant is the measured or calculated value (Schmidt stability, heat content, hypolimnetic volume …) to infer shifts in the lake's characteristics. And, eventually, which common trends can be extracted from this comparison, and which ones are either counterintuitive or in contrast with observed trends.

We thank the reviewer for the kind assessment of our manuscript.

Not surprisingly, surface temperatures are increasing in almost all lakes, and the inflection point in lakes with long-term records is around 1980, coinciding with almost all air and water temperature measurements in the Alps. It could be interesting for the authors to have a look at the paper of Niedrist et al. 2018 (Climate warming increases vertical and seasonal water temperature differences and inter-annual variability in a mountain lake. Climate change https://doi.org/10.1007/s10584-018-2328-6) who found warming trends only in certain months or seasons, a reversing of warming around 1995 and an unexplained increase in variability of temperatures and Schmidt stability. I imagine that it could be helpful to have a second look at their data.

We agree that it could be interesting to have a closer look at seasonal temperature changes using our data set as well. However, we had to restrict our analysis to a limited set of parameters and seasons/yearly averages to not overcrowd the manuscript. Because the data of this paper is publicly available, such seasonal temperature analysis could be done by any interested scientist, though.

I found Figure 4 (Theil-Sen regression slopes) quite interesting for it shows how differently the studied 21 lakes behave with respect to to surface and bottom temperatures. The values of heat content (Fig. 5) are normalized for the year 2000 in order to compare the curves of lakes of shorter time records, a clever idea for it allows to show also the changes in heat content of Lower Lake Zurich, Lake Zug, Lake Sempach and Greifensee going back to the 1950s, similarly also the shifts in Schmidt stability (Fig. 6). The summer thermocline depth (Fig. 7), although showing a slight trend to greater depths in some lakes, seems to oscillate in other lakes, thus indicating that there are individual drivers, obviously depending on air temperature, precipitation, inflow and wind.

We are happy to hear that the selected parameters are interesting for the reviewer. Depending on the feedback we receive in the coming years, we might adjust the parameters for future versions of this data publication.

The majority of lakes shows an increase in Secchi depth (Fig. 8) during the last ten years or so, others show and up and down or rather stable values, especially those lakes with already low transparency on the long run. The mean summer oxygen concentrations (Fig. 9) reflect – in my view – the wax and vane of eutrophication with increase until around the 1980s an a decrease thereafter. In contrast to these trends, the hypolimnetic oxygen concentration in autumn (Fig. 10) is more erratic, i.e., with little change over time, but with big differences (from 0 to 10 mg/L) between lakes.

Part of the observed variability (or up and down) is probably due to limited temporal resolution (usually around monthly). Especially for temperature, numerical modelling (based on high-frequency meteorological data) could be a useful interpolation tool to improve the trend calculations from monthly observations.

I had some problems to understand Fig. 11, although the basic idea (projected oxygen recharge upon mixing) is clear. The authors might consider to use a different way to show the – positive and negative – excursions from the expected outcomes. Fig. 12 is more easy to understand and it shows the enormous difference between the 21 lakes, but here it might be advisable to use 4 colours instead of a combination of blue-red and plus-minus to present the results.

We improved the readability of Figure 11 by adjusting the legend to make it clearer what the different colors mean. Concerning Figure 12, our intent was to emphasize the relation between mixing and oxygen recharge (minuses associated with red, pluses with blue). As this association would be harder to detect using four colors, we suggest keeping this figure as it is.

In the **Conclusions** the authors talk about decreasing phosphorus concentrations and their potential effect on water clarity. The re-oligotrophication, observed (or inferred) from oxygen concentrations and thermocline depths reminds me of a paper of Weniger & Sommaruga 2025 (Fifty-Year Trends Reveal Reversal from Recovery to Re-eutrophication and Reinforced Anoxia in a Managed Mountain Lake. Ecosystems https://doi.org/10.1007/s10021-025-01003-5) who found, on the contrary, a consistent re-eutrophication around 1995 – notwithstanding a continuous decrease in phosphorus inputs. Weniger & Sommaruga attributed this to warming, so it might be interesting to consider this also for the 21 Swiss lakes.

The paper by Weniger and Sommaruga is a striking example of improved lake conditions between 1990 and 1995 followed by worse conditions since then. We did not observe anything as drastic among our lakes.

<u>Reviewer 2</u>

The presented data are quite valuable for understanding the changing environmental conditions in Swiss temperate lakes and future research on their dynamics. Further, the applied analyses seem reasonable and adequately examined. Thus, I think that it is worthy to be published in ESSD. However, there are a few points still to be revised or explained carefully before acceptance of the publication.

We thank the reviewer for the positive general feedback.

A. Questions and/or comments

1. The reason(s) for not including the data on Lake Lucern. Probably, much data are accumulated in this lake.

We only included lakes with at least around 8 profiles per year down to the maximum depth. Lake Lucerne has several basins, of which, since around 2000, only the "Vitznauerbecken" is monitored to its maximum depth (but only twice a year) and the "Luzernersee" close to Seeburg 5-6 times a year, but only down to 50 m (maximum depth of all major basins is 150 to 200m). As a result, we would not be able to calculate most of the seasonal and yearly averages of Lake Lucerne, unfortunately.

2. Table 1: "Yearly" means monomictic or dimictic?

Both monomictic and dimictic were considered as "yearly". With the inclusion of ice cover in Table 1 (see comment further below), it becomes clear which lakes can be dimictic and which ones are usually monomictic. The main reason why we prefer to not differentiate monomictic and dimictic lakes is that we lack the observations to do so. With only monthly profiles, we cannot assess whether a slight inverse stratification develops or not.

3. Eq. (2): Check the dimensions (divided by A_0?).

Yes, the division by A_0 was missing. We thank the reviewer for spotting this mistake.

4. Eq. (3): the layer thickness was calculated using the depth: 5 m below the mean long-term late summer thermocline depth (line 174) vs. mean autumn hypolimnetic oxygen concentration in Fig. 10: Why are used different seasons?

This is a typo. We did use the mean long-term autumn thermocline depth. We corrected the typo in the updated manuscript. In addition, we noticed that the thermocline depth was not correctly assigned for some lakes, and we thus further revised Fig. 10 to address this issue.. However, the interpretation of the results is not affected.

5. Fig. 11: Do you recommend density threshold = 0.005 (kg/m^3) and with salinity because the agreement rate is the highest (89%)? More explanation is needed for the meaning of this agreement.

Yes, we would recommend a threshold close to 0.005 kg/m3 and with salinity based on our analysis. However, one could still test more thresholds to get the best possible agreement.

We changed a few details in this paragraph and updated the caption of Fig. 11 to improve the clarity of our explanations. The caption now reads:

Prediction success of various density thresholds for the full recharge of deepwater oxygen for 21 Swiss lakes and lake basins. Oxygen recharge is defined as the occurrence of surface and bottom oxygen saturation within 10% between January and March. A mixing event is defined as the occurrence of surface and bottom density within a certain threshold between January and March. Inverse stratification is counted as mixing event. Agreements are years when a predicted mixing event coincides with an oxygen recharge event (green); disagreements include years when mixing is *predicted but no oxygen recharge is observed (yellow), and years when oxygen is recharged but no mixing predicted (red hatched).*

6. Fig. 12 and Fig. 13: Show the reason(s) using 2006. Specially cold winter? Explanation is needed.

Yes, 2006 was an especially cold (and windy) winter that caused a mixing event in all Swiss lakes. We added this information in the updated manuscript in the caption of Fig. 13: *2006 was the last winter when all major Swiss lakes experienced a deep mixing event.*

7. Fig. 13: anomaly? Difficult to understand the sentence in line 436-438. Show the period which the tendencies are clarified.

Anomaly compared to the year 2006 as specified in the caption. We revised this sentence to mention which period we mean (i.e., since 2006/2012) with change in italics.

Among Swiss lakes, Upper Lake Lugano seems to be most prone to future long-term meromixis because of less strong decrease of bottom density compared to other deep lakes *since the last mixing events in 2006 and 2012 (Fig. 13),* respectively. Lake Maggiore seems least prone to meromixis because it exhibits almost no solute accumulation.

B. Requests

1. Table 1: Indicate the presence or absence of winter ice cover.

Most included lakes never freeze except for very extreme conditions like in 2006. Ice cover data is usually only available through visual observations (for example Franssen and Scherrer, 2007) or more recently satellite observation. Ice cover observations are not part of this work, but we agree that giving some qualitative information can be helpful. As a consequence, we added a column about ice cover to Table 1 indicating "yes" with an asterisk, meaning that these lakes freeze, but only occasionally. We added this sentence to the caption: *Information about mixing and ice cover is derived from the data of this publication and records from cantonal observations. For ice cover, the asterisk means that winter ice cover only occurs occasionally.*

2. Fig. 9: Separate the lakes by the condition with or without aeration.

We agree that it can be important to know which lakes are or were aerated. We changed all Figures about hypolimnetic/bottom oxygen by:

- **Adding an asterisk to lakes that were or are aerated**
- **Adding the period of lake aeration to the caption:** *Lakes with asterisk are or were artificially aerated: BAL since 1982, SEM since 1984, HAL since 1986, GRE since 2009 (only a small aeration system) and PFA between 1992 and 2010.*

3. Showing the seasonal DO decreasing patterns because DO minimum months might change in the respective lakes and year by year. How are this problem (seasonal DO decreasing pattern) solved to analyze the long-term change in lake DO depletion?

We agree that this is clearly a question that arises with monthly to bi-weekly sampling as is the case here. We decided to keep seasons constant (i.e. Sept-Oct-Nov for autumn) because it is not straightforward to come up with a rationale of how to adjust them as a function of time and progressing climate change. Another option would be to compare minimum observed oxygen concentration every year. The disadvantage of this method is that individual measurements can be error-prone and thus trends could be more easily influenced by individual bad measurements.

We added one more sentence to make this clearer (starting line 356; change in italics): Another potential reason is the earlier start of summer stratification due to climate change (e.g. Woolway et al., 2021), extending the time available for oxygen consumption until the observations in autumn. *Note that autumn trends (Fig. 10) are influenced by an earlier onset of stratification but not by delayed winter overturn.*

While reviewing this part, we also decided to expand the discussion by including the role of legacy effects of lake sediments on hypolimnetic oxygen concentrations. To include it, we replaced lines 354 – 359 ("In most other lakes…) with:

In most other lakes, there is no significant trend despite efforts to reduce phosphorus loading. There are several processes that could contribute to this observation: i) sediment legacy effects leading to oxygen consumption (Müller et al., 2012), ii) hypolimnetic oxygen consumption only decreasing significantly below a threshold of phosphorus input (Müller et al., 2019), and iii) increased water clarity leading to deeper primary production, therefore accessing additional phosphorus resources (e.g. the arrival of Planktothrix spp. in a number of lakes) leading to additional export of organic matter to the hypolimnion.

Reviewer 3

1. Figure 1 is informative but its visual quality could be improved. It's recommended to add the color scheme for DEM information and adding latitude–longitude gridlines to improve geographic context and readability. Meanwhile, please mark the sampling point for each lake as points on the map.

This is a hillshade map, therefore there is no quantitative information about elevation. We added this information to the caption of the map. We also added the sampling points and one main gridline for geographic context.

2. Lines 150: Please provide the formulas for salinity and density directly to improve readability.

We now provide the salinity formula as equation (1), and we added the Chen & Millero (1986) density polynomial function to supplement S4.

3. Lines 207-208: The threshold for trend calculation appears potentially confusing. Since only lakes with at least 20 years of data were included, the requirement of a minimum of 10 years for trend analysis seems vague. This point should be clarified to improve readability.

We agree that this is potentially confusing, and it is true that these thresholds are chosen in an arbitrary way to some extent. We included lakes with at least 20 years of data to the paper. However, some lakes don't have data for every parameter every month of every year, e.g. some have no or few measurements for particular months. For example, there are very few winter profiles for Lake Pfäffikon and Lac de Joux because they tended to freeze often in the past. And because we only calculate annual averages if at least 10 months are covered and at least one of January/February, there are only few data points for mean annual surface/bottom temperature for these lakes and we do not calculate the trend because it would be based on a few data points only. We start calculating trends though if at least 10 data points are present. Both, the threshold of 20 years of total data and the threshold of 10 data points to calculate trends are choices, but they are not linked.

To make it clearer we updated this paragraph as follows:

For both trend calculation methods, we decided to set the minimum required number of data points (i.e., years with seasonal or annual mean) to 10, which was considered the minimum required for robust trend calculation. This means for example that no trends of annual means are calculated for Lake Pfäffikon and Lac de Joux because very often there is no data available for both January and February and thus no annual mean can be calculated for most years (see section 2.4).

4. Isn't the label "Mean annual surface temperature (bottom 10 % of depth)" in Figure 2 incorrect? "Surface" shouldn't be labeled with "bottom. In addition, there are two lakes here whose data isn't shown. I don't think it's appropriate to have the phrase "of 21 Swiss lakes" in the caption for this chart; the same applies to the subsequent captions.

Indeed, we thank the reviewer for spotting this and we corrected this mistake in the revised version. We updated the captions to "of 19 Swiss lakes" of the concerned plots.

References

Franssen, H. H., & Scherrer, S. C. (2008). Freezing of lakes on the Swiss plateau in the period 1901–2006. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *28*(4), 421-433. https://doi.org/10.1002/joc.1553

Moosmann, L., Gächter, R., Müller, B., and Wüest, A. (2006). Is phosphorus retention in autochthonous lake sediments controlled by oxygen or phosphorus?, Limnology and Oceanography, *51*(1part2), 763-771. https://doi.org/10.4319/lo.2006.51.1_part_2.0763