Reviewer comments

Author responses

RC1

MAJOR COMMENTS

Long-term patterns of CO2 levels and emissions in rivers have been reported by several studies (Jones et al. 2003; Ran et al. 2015; 2021; Nydahl et al. 2017; Marescaux et al. 2018) (non-exhaustive list). Findings from these studies could be used to contextualize the present study (Introduction) and to discuss differences or convergences by comparison (Discussion).

Reply:

Thank you for the references.

In the introduction, we will include a paragraph reviewing the literature on long-term CO_2 emission patterns. In the discussion, we will draw on previous studies to compare with our findings and examine time-dependent variations in region-specific attributes.

L 30: « water pollution » is extremely vague. This should be broken down into several human impacts on riverine systems that do not necessarily lead to the same change in CO2 emissions. Eutrophication (increase of nutrient inputs) can potentially lead to enhanced primary production and a CO2 sink in impounded large rivers such as the Mississippi (Crawford et al. 2016). Conversely, croplands seem to also lead to enhanced organic carbon inputs from soils enhancing CO2 emissions compared to more natural land cover such as forests (Borges et al. 2018; Mwanake et al. 2023) Wastewater inputs lead to CO2 production in the river, although this impact seems very local, in the near vicinity of the emissary (Marescaux et al. 2018).

Reply:

Thank you. We agree with you that “water pollution” is indeed a broad term, and it is important to consider its impacts on riverine CO_2 emissions from various perspectives.

Accordingly, we will expand our description to encompass different viewpoints, including the effects of organic carbon from agricultural runoff and domestic sewage (Borges et al., 2018; Marescaux et al., 2018; Mwanake et al., 2023), as well as the carbon sink impact attributable to eutrophication caused by increased nutrient levels (Crawford et al., 2016).

L 30 “this percentage continues to increase because the unprecedented anthropogenic stresses on riverine systems have led to many negative issues such as water pollution”. I’m not sure this statement applies assertively to all climate zones (Crawford et al., 2016). According to Liu et al. (2022), tropical rivers are responsible for 57% of the riverine CO2 global emission, followed by temperate (30%) and Arctic regions (13%). The most direct anthropogenic impacts expected to affect riverine CO2 emissions should occur at temperate latitudes (North America, Europe and parts of Asia) that account for less than a third of total emissions. Note that this percentage was lower in earlier estimates for which tropical rivers accounted for 80% of riverine CO2 emissions (Raymond et al. 2013; Laueward et al. 2015).

Reply:
Thank you. We agree that the impacts of river pollution and restoration efforts on riverine CO_2 emissions, which result from human activities, should be concentrated in regions with high population density.

We will revise the sentence to offer a more accurate depiction that incorporates the suggestions you have provided.

L 34: Rivers do not have “ecosystem's natural carbon absorption and storage capabilities”. Rivers do not store carbon in sediments and do not “absorb” carbon on contrary tend to emit CO2 to the atmosphere. High CO2 over-saturation in rivers occurs ubiquitously even in pristine (or near pristine) river basins such as the Amazon and Congo.

Reply:
Thank you very much for the correction. We agree that most rivers consistently serve as a source of carbon.

We will revise the text from this perspective.

L 37: It has been argued that CO2 emissions from lowland rivers in particular in the tropics are related to inputs from wetlands (Abril et al. 2014; Borges et al. 2015) that are conceptually different (Abril and Borges 2019) from “terrestrial organic carbon (OC)» (as stated).

Reply:
Thank you for the correction. We will add the reference and the information.

L38: Can you please clarify the role of «nutrient availability” in this context?

Reply:
We will delete the term "Nutrient availability" here, as it is misleading in this context.

L44-46: This argument is awkward. DOM produced by phytoplankton should indeed sustain microbial respiration but phytoplankton also photosynthesized prior to DOM release, so both effects should cancel each other in terms of net carbon fluxes.

Reply:
Thank you. The sentence will be deleted.

L 44: reference to “lakes and reservoirs » seems to be out of context here.

Reply:
Will be rephrased.

L49-50: statement “trophic status related to nutrient availability significantly impacts the levels of CO2 in rivers” is contradicted by the fact that CO2 emissions in rivers are in majority related to lateral inputs of carbon from soils and ground-waters (Hotchkiss et al. 2015) or from wetlands (Abril and Borges 2019), and are not related to in-stream CO2 production from metabolism (Hotchkiss et al. 2015; Abril et al. 2014; Borges et al. 2019).

Reply:
In this study, Figures 3c and 3d demonstrate the significant and negative correlation between RUE (the ratio of Chl-a to nutrient concentrations) and pCO_2.

The sentence will be rephrased deleting the terms ‘trophic status related nutrient availability’ and replaced by ‘nutrient concentration’.

L 51: reference to “biodiversity” seems out of context here.

Reply:
Will be rephrased.

L 55: The authors should cite the “existing studies” they critique rather than stating this in a vague way.

Reply:
Thank you. Related studies will be cited (like Nydahl et al. (2017); Marescaux et al. (2018) etc.)

L 55: Please clarify what is meant by “short term effects »? “effects” of what on what? Do you mean short-term time-series? Some studies have reported relatively long time series (Jones et al. 2003; Ran et al. 2015; 2021; Nydahl et al. 2017; Marescaux et al. 2018). It is not necessary to downplay existing literature to put forward your own study.

Reply:
Thank you. In our study, "Short-term effects" is a relative term compared with continuous long term time series, refers to the analysis of F_{CO2} or CO_2 efflux below 10 years (decadal). Will be clarified.

For the research you provided, While Ran et al. (2015) provided extensive data on long-term pCO_2, they did not conduct analyses related to F_{CO2}. After that, Ran et al. (2021) compared CO_2 efflux from the average of two periods (1980s to the 2010s) but did not offer an exhaustive continuous time series analysis. Similarly, the work of Nydahl et al. (2017)

and Marescaux et al. (2018) was primarily directed towards understanding pCO_2 dynamics, with less emphasis on F_{CO2}. As a result, there is a research gap in continuous and long-term analyses of F_{CO2} and CO_2 efflux, which our research questions aim to address. Will be rephrased and related studies will be included.

L 55: What do you mean by «hydrological conditions»? CO2 emissions from rivers depend on CO2 concentration between water and air, and on the gas transfer velocity. Both are more or less indirectly linked to "hydrological conditions" but this should be clarified, especially when criticizing "existing studies".

Reply:
Thank you. In this research, we are using estimates of both the flow discharge and flow velocity for the estimation of the gas transfer velocity and water surface area. The parameters represent hydrological conditions.

This aspect will be clarified in the text.

L61: Please provide a reference to back this statement, and clarify compared to which other rivers was it the most polluted? At European level? Globally? It could be also useful to take into account size effects. A very small stream can be extremely impacted by wastewater from a small village, while very large rivers are unaffected by large cities because all inputs are diluted by high discharge.

Reply:
Thank you. Before 1990, the Elbe River was one of the most polluted rivers in European scale. Related references will be added (ICPER, 2023; Kempe, 1982).

L 163: the equation relating river width and Q given by Raymond et al. (2012) was derived for small streams. Can you comment on its applicability to large rivers? Also this relation is probably affected by channelization and probably does not apply to highly engineered rivers such as the Elbe.

Reply:
Most of the Elbe River's flow, categorized with Strahler orders from 1 to 6, matches the flow discharge range used to create the equation by Raymond et al. (2012) (Figure R1).

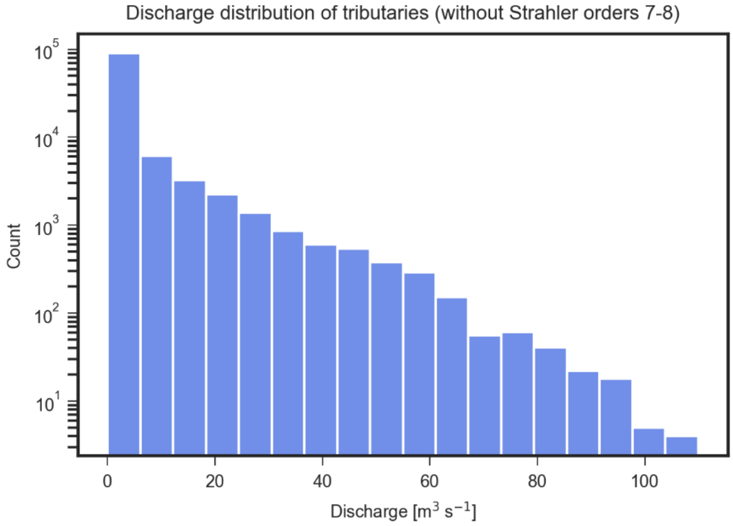

Figure R1. Flow discharge distribution of tributaries of the Elbe River. Discharge data obtained and resampled from GRADES (The Global Reach-scale A priori Discharge Estimates for SWOT) (Lin et al., 2019; Yang et al., 2019).

For the larger segments of the river, classified as Strahler orders 7 and 8, primarily the mainstem, we compared our estimated river widths with the research of Mallast et al. (2020). Their measurements were derived from satellite imagery. The average river width we estimated showed good agreement with their findings (this research: 177 m for Strahler order 7&8 (Figure R2), versus Mallast et al. (2020): 183 m, with an area of 107 km^2 divided by a length of 594 km).

Therefore, we believe the error introduced by our method in this research should be minor. An additional discussion of uncertainties will be added.

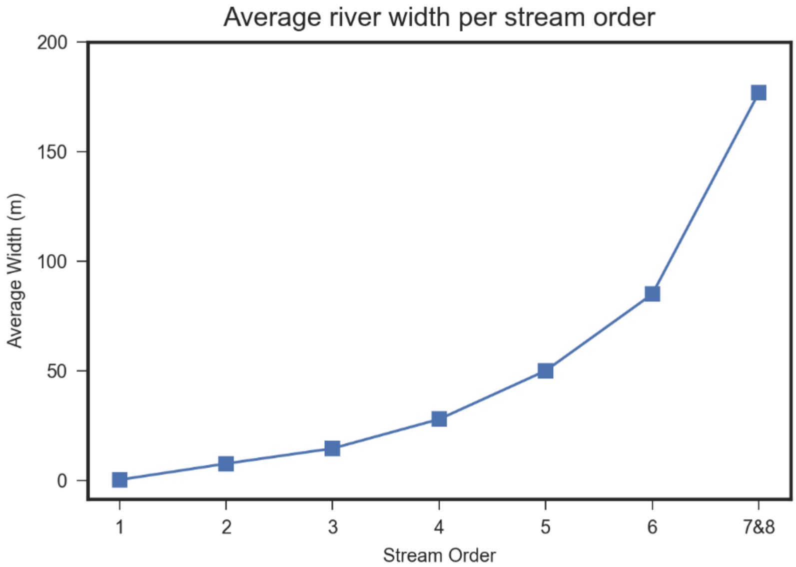

Figure R2: Estimated River width across different Strahler orders.

L 300: can you please provide a numerical comparison and a reference for the data for the 1954–1977 period?

Reply:
The modeled pCO_2 and the corresponding data and plot will be added.

Can you please explain somewhere in text why the analysis was not extended back to 1954 and only started in 1984?

Reply:
Since our study conducted a temporal and spatial analysis. In this process, we integrated a range of environmental indicators along with carbon. On the other hand, the data from 1954 was restricted to just one site (sample location of the local water works company Hamburg Wasser) and did not provide any environmental indicators (Kempe, 1982).

Consequently, we employed this data merely as a background reference value. A short explanation will be added.

L341-344: This statement does not seem relevant. Indeed, it is conceivable that light absorption by CDOM limits photosynthesis from aquatic primary producers, but in rivers CDOM mostly originates from soils. Also, DOM from phytoplankton is usually very labile and is quickly consumed by micro-organisms. CDOM is usually related to highly refractory substances, typically from soils.

Reply:
The sentence will be deleted.

L 370-373: Please clarify the text of the two hypothesis and also provide extra arguments and references to back them.

Reply:
The two main arguments are as follows:

Firstly, the treatment of municipal wastewater has resulted in a decrease in the amount of labile organic carbon being directly introduced into the river, thereby reducing the potential for its degradation into CO_2 (Lasaki et al., 2023). Secondly, the reduced discharge of heavy metals, along with reductions in nitrogen and phosphorus concentrations, has promoted a healthier aquatic ecosystem (Qasem et al., 2021). Although photosynthesis and respiration processes may balance each other, the net growth of aquatic plants contributes to the overall reduction of CO_2 in the river if the rate of plant growth exceeds the rate of decomposition of plant residues (Demars et al., 2016).

Will be clarified with extra arguments and references.

What do you mean by “biomass amount » and why should it not increase in « restored aquatic system”?

Reply:
The most important factor affecting biomass quantity is the toxicity from heavy metals, which impedes biomass growth. As environmental conditions shift from polluted to non-polluted states, the quantity of biomass is expected to change, subsequently influencing CO_2 levels. However, heavy metals primarily originate from industrial inputs, and the closure of factories along with advanced wastewater treatment technologies has significantly improved water quality (Amann et al., 2012). Since trace elements do not exceed the thresholds that limit phytoplankton growth, biomass remains relatively stable.

Will be rephrased. And a plot of temporal biomass amount variations will also be provided.

What do you mean by “challenging through water quality treatments.”

Reply:
The challenge could be that CO_2 emissions from sewage water discharge may be avoided at the cost of CO_2 emission of wastewater treatment plants through biological treatment process and electricity consumption.

According to global estimates, the degradation of OC during wastewater treatment in 2010 contributed to approximately 770 Tg CO_2-equivalent GHG emissions, representing nearly 1.57% of the total global GHG emissions of 49,000 Tg CO_2 (Edenhofer, 2015).

On the other hand, the oxidized and anaerobic digestion of the organic carbon of wastewater is converted mainly to CO_2 and CH_4 (Campos et al., 2016), thus offsetting the reduction in CO_2 in wastewater treatment.

MINOR COMMENTS
Text contains numerous awkward phrasing or typos or redundancies. The senior co-authors should spend some time looking through the text and make the necessary improvements; this is not the reviewer’s job. Nevertheless, some are listed hereafter (not an exhaustive list):

Reply:
We apologize for this oversight. We will do our utmost to significantly improve the language quality of the text.

L40 + L 337: Labile instead of “liable”?

Reply:
Will be replaced.

L 55: context instead of « contest” ?

Reply:
Will be replaced.

L42: “phytoplankton behaviors » is awkward, please rephrase.

Reply:
Will be rephrased.

L61: most instead of “highest”

Reply:
Will be replaced.

L66: “FCO2 efflux » is redundant sinc "F" of "FCO2" abbreviates the word flux.

Reply:
Will be replaced.

L68: "high-resolution" is self-evaluation, please simply state instead the actual time step of the data.

Reply:
Extra descriptions will be added.

L 368: “CO2 drawdown ratio by water quality management” is awkward, please rephrase.

Reply:
Will be rephrased.

References

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