nature portfolio

Peer Review File

A 150-year record of U.K. River Thames water quality shows reductions in phosphorus loads but not algal growth potential

Corresponding Author: Professor Helen Jarvie

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Version 0:

Decision Letter:

** Please ensure you delete the link to your author home page in this e-mail if you wish to forward it to your coauthors **

Dear Professor Jarvie,

First of all, please allow me to apologise for the delay in sending a decision on your manuscript titled "Tackling River Eutrophication: 150 years of challenges, successes and 'treading water' in a warming climate". It has now been seen by two reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment, provided you can fully address all the criticisms raised.

We therefore invite you to revise your paper to respond to the concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

Please note that we will need you to make the final compiled data set available in a publicly accessible repository.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Heike Langenberg, PhD
Chief Editor
Communications Earth & Environment

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

Tackling River Eutrophication: 150 years of challenges, successes and ‘treading water’ in a warming climate

This is a well written, easily understood manuscript using one of the world’s longer (longest?) water quality datasets to contextualise and explain land to water pollution patterns and frame within the reality of a changing climate.

The analyses and interpretations are clear and I have no doubt will be of wide interest to a broad audience both in the UK (where these issues are current) and worldwide in major river systems with human pressures. If published following revisions, my view is that this will be a benchmark paper in this field and highly cited.

The figures are well produced and all necessary to support the points made.

My recommendations for revision are minor:

Line 27. The two references cited are from 2003 and 2007. I suggest that the statement made requires more up to date references.

Lines 29-30. “…which we understand to be…” sounds unsure and framed within the authors’ understanding so can’t be quantified. I suggest being more assertive here. It should be possible to validate that this is indeed the longest water quality record.

Figure 1a and Figure 2. There seems to be an ambiguity between Fig. 1 (TRP time-series), Fig. 2 (1930 to 1939) and the statement on line 64. I see the switch to a dilution pattern in the 1940-49 chart (Fig. 2), but the data in Fig. 1 only seems to start just before 1940? Are data missing from Fig. 1? Or are the data for the 1930-39 period only for a short part of that decade? Some explanation required where needed (Figs. and/or text).

Lines 78 and 85. Use of 15th and 85th percentile flows for median base and high flows. Here and/or in SI (lines 447-450), a justification is needed for these as flow metrics. Is there a reference to support?

Line 86. Correct to “…increases in high-flow…”

Line 102. Correct to “…reduced organic matter…”

Lines 117-121. Justification needed on comparing unfiltered TRP magnitudes against threshold and standard P concentrations that are based on filtered SRP magnitudes.

Lines 117-118. Justification needed why mean annual P concentration, then median nitrate concentration as descriptive stats. Why not keep the same?

Line 132. Should the ‘but’ be ‘and’ instead?

Line 137. Correct to “Diatoms are the dominant phytoplankton…”

Line 151. Subscript 2 on SiO2.

Line 151. Change ‘fell’ to ‘falling’. Or just delete ‘fell’.

Line 242. Start sentence “As shown in this paper,…”

Line 430. After "…for each year" change full-stop to comma.

Reviewer #2 (Remarks to the Author):

Review of COMMSENV-24-2184-T "Tackling River Eutrophication: 150 years of challenges, successes and 'treading water' in a warming climate", by Jarvie and others.

The authors state that eutrophication in the River Thames has increased over the past 150 years and reduction of phosphorus concentration in the river may be the best lever to control harmful algal blooms. This paper provides a new historical benchmark for the River Thames eutrophication trajectory and offers a template for understanding anthropogenic pressures on rivers. This paper also offers a new dataset that dates back to the 1880s that are alone novel, and the authors provide insights into trends and connections to land use. For example, since 1880, phosphorus loads delivered to the river have been reduced by 82%, but concentrations have remaining high, well above some standards (0.25 mg P/L > 0.05 mg P/L). The findings are mostly convincing, but in the opinion of this reviewer, there are still some statements not fully backed with evidence or some statements that could mislead the reader, which the authors could improve with minor revision (see specific comments).

Will the authors provide the final compiled dataset? This reviewer could not tell where those would be made available. A reader would appreciate access to all data that were compiled rather than piecing together on their own.

Specific comments:
What is the connection between water use and BOD. Why is BOD an issue? You state "harmful" algal bloom. BOD can be considered harmful if waters go hypoxic or if drinking water treatment are affected?
Main title: this reviewer does not follow "treading water." Is that a metaphor for something? You later imply that managers are only treading water. This reviewer does not follow the message nor really backed by any type of evidence. Throughout the manuscript, you provide a history that over 80% of TRP have been reduced. That is amazing progress yet the authors imply we are only treading waters. The opinion of this review is it only adds confusion for the reader; however, that is only honest feedback and this reviewer encourages the authors to use whichever writing style they prefer.
33: why is N left off the list here? Because nitrate is its own record already published? Ah I see.
33: Suggest to also state here reconstruction of water temperature. And what about records regarding amount of treated wastewater instead of population proxy?
41: What is the current crisis explicitly? This statement is not convincing nor backed with evidence. Reference 5 in an opinion piece—this reviewer does not view that as a viable citation.
44: "troubled waters". So, these are not also murky? What is troubled? These words add confusion.
67: "this" refers to what? This "decadal lag in response" indicates…?
67: perhaps another helpful reference: https://doi.org/10.1016/j.scitotenv.2023.169361
99: "Murky waters" So, these are not also troubled? Are they always murky? So, if murky they are no longer troubled? This reviewer does not find theses word helpful and actually cause the sub-title to be less clear. The picture of successes is murky. The metaphors are adding confusion.
123: Nice, it is helpful to also include nitrate. Thank you.
123: Careful. Yes, this reviewer is also certain that the nutrients are important, but you started your story with a warming climate too. Would HABs still be increasing in frequency in the climate was not warming? Meaning, a key driver, in addition to nutrients, is the increase in heat energy stored within surface waters. The connection between nutrients and temperature is not altogether clear—it is fine to state that.
130: this reviewer is not sure this is true, "which approximates to the ratio of N:P needed by algae." It is useful to compare to the 16:1 ratio, but did that reference from 1958 conclude that for algae in rivers?
135: Perhaps useful here: https://www.science.org/doi/10.1126/science.1245279. Is increased nitrate as a result not a concern? Is there a way to also promote denitrification or is that a lost cause?
137: Confusing sentence, this review does not follow "Diatoms (phytoplankton)"? Diatoms are one type of many types of phytoplankton. Are diatoms the dominant form of phytoplankton algal blooms in the River Thames? Are diatoms an issue, the main issue? Is BOD the concern there? Cyanotoxins are less of a concern? So, chlorophyll-a paired with SiO_2 is used as a proxy for diatoms? A concise statement that connects diatom blooms to BOD issues seems missing, even though that is shown in Fig 5d.
145: Are you sure it is water temperature? This reviewer thought that diatoms tended to bloom in nutrient rich, less turbid waters, and could bloom when temperatures were cooler. Warmer temperatures tend to give opportunity to cyanobacteria.
156: 100 ug/L is high, especially for rivers. It seems that threshold (4.5 mg/L) identifies the clear cases of growth of blooms dominated by diatoms, but there seems to still be a lot of activity between 40 and 100 ug/L. In rivers, this reviewer has assumed that a 40 ug/L threshold of chlorophyll-a is an indicator of a bloom. Where do cyanobacteria fit into this picture?
161: What does this density look like with chlorophyll-a? Could it be that 15 degrees C is just the temperature that diatoms like? If the dominant phytoplankton are diatoms, this statement with temperature would make sense, but only if there are not many other types of algae contributing to that chlorophyll-a signal.
166-176: this reviewer gets lost with the many uses of "optimal". Plus, a temperature range of 9.6 to 18.25 seems quite cool. This reviewer thought that diatoms tended to favor cooler waters and do not do as well during the hottest temperatures. So, a water temperature of 9.6 C is quite cool to this reviewer, and tracks with that assumption. However, the title is "Warming waters" as increasing algae and the authors say diatoms decrease in warm June. This reviewer is not convinced that the

relationship stated by the authors is altogether accurate. Is warming water temperature really the main driver? The changing nutrient conditions, yes, but temperature seems less clear.
179: Ah, it would help the reader to state this upfront when diatoms and phytoplankton are introduced. As this reviewer read above, this statement was missing.
189: this gets lost down here. Suggest opening this section with this. A concise statement that says temperatures were more favorable to diatoms, but lately have shifted to favor more cyanobacteria blooms. Then, your temperature story makes sense. You found a range in which diatoms exist, great, that is not necessarily “optimum,” but an ecological range where they can grow, optimum would imply peak growth (that is more like 15 C), but any more than that, other species will dominate.
212: “there has been no corresponding improvement in the eutrophication status.” Is that true? And it seems the eutrophication status has simply shifted to a new status. Is shifting back to levels 150 years ago even possible? There seems to be a clear reduction in BOD following a reduction in TRP. Suggest a revision here as that could be misleading to the reader. Suggest trying and write in a more positive tone. What if there were no reductions in P, or no management? The problem would be much worse. By those standards, one could argue that there has been a lot of improvement. Sure, we need to do much more. Also, this reviewer would not necessarily classify management action as “treading water.” Treading water doesn’t even happen in most of the world. Having data in the River Thames itself is a huge accomplishment. It is helpful to state for the reader what the authors recommend need to be done, but “treading water” reads as a bias opinion and is of course up to the authors if they want to keep that tone. This reviewer is supportive of the authors, but that was my reaction.
222: “in a major world river system” suggest to just state River Thames. The reader will follow.
224: diffuse not needed, redundant
230: Are there any turbidity records? That could be useful for estimating shading effects as light penetration is an important control.
269: But what happens if more nitrate gets delivered to estuaries? Could reducing the occurrence of algal blooms by starving them of P cause unintended consequences in the N delivery to marine waters? Could that just shift the BOD issue downstream, causing more frequent hypoxic zones?
Fig 3: What about streamflow? Has that changed from 1880?
Fig 5d: the reader needs to work too hard to figure out the blue line is BOD. And it would be helpful to add the 4.5 SiO2 threshold. Add BOD 5 mg/L threshold perhaps.

Reponses to Reviewer's Comments

Reviewer #1 (Remarks to the Author):

Tackling River Eutrophication: 150 years of challenges, successes and 'treading water' in a warming climate

This is a well written, easily understood manuscript using one of the world's longer (longest?) water quality datasets to contextualise and explain land to water pollution patterns and frame within the reality of a changing climate.

The analyses and interpretations are clear and I have no doubt will be of wide interest to a broad audience both in the UK (where these issues are current) and worldwide in major river systems with human pressures. If published following revisions, my view is that this will be a benchmark paper in this field and highly cited.

The figures are well produced and all necessary to support the points made.

My recommendations for revision are minor:

We thank Reviewer 1 for this very positive review and we have responded to each of the minor revisions below:

Line 27. The two references cited are from 2003 and 2007. I suggest that the statement made requires more up to date references.

We have updated these references to the following:

- **Bouwman A.F. et al. Impact of lifestyle, human diet and nutrient use efficiency in food production on eutrophication of global aquifers and surface waters. Global Environmental Change 87, 102874 (2024).**
- **Feng L. et al. Harmful algal blooms in inland waters. Nature Reviews Earth & Environment 5, 631-644 (2024).**

Lines 29-30. "…which we understand to be…" sounds unsure and framed within the authors' understanding so can't be quantified. I suggest being more assertive here. It should be possible to validate that this is indeed the longest water quality record.

The Thames river water quality record was verified as the longest continuous water quality record in the world in the Howden et al. (2010) paper (cited reference #3). The Hamlin (1990) book: "The Science of Impurity" (cited in Methods, #74) also provides a definitive guide to the water chemistry techniques used, and these were implemented in London and Oxford, U.K., as a result of Bazalgette's engineering works (see Supplementary Information Notes), and the first verified water quality measurement outputs were in 1867-1868 for the Thames. We have therefore reworded this to be more assertive and it now reads: "Here, we provide a new perspective on historical eutrophication trajectories, by analysing a hitherto unpublished 150-year dataset of monthly water-quality measurements for the River Thames at Teddington (West London, United Kingdom, U.K): the world's longest continuous water-quality record[3]."

Figure 1a and Figure 2. There seems to be an ambiguity between Fig. 1 (TRP time-series), Fig. 2 (1930 to 1939) and the statement on line 64. I see the switch to a dilution pattern in the 1940-49 chart (Fig. 2), but the data in Fig. 1 only seems to start just before 1940? Are data missing from Fig. 1? Or are the data for the 1930-39 period only for a short part of that decade? Some explanation required where needed (Figs. and/or text).

TRP measurements began in 1936. And, although this is stated in the legend for Figure 1, we have also amended the text to make that clearer; it now states: "TRP measurements began in 1936, but it was not until the 1940s that the TRP-flow relationship switched to a dilution pattern….". Moreover, we have also now added an annotation to Figure 2 to show that, under the heading "1930-1939", the TRP-flow relationships are for 1936 through 1939.

Lines 78 and 85. Use of 15th and 85th percentile flows for median base and high flows. Here and/or in SI (lines 447-450), a justification is needed for these as flow metrics. Is there a reference to support?

These percentiles simply provide a means of comparing chemical concentrations, for this dataset, at low flows versus high flows. However, we agree with the reviewer that the 15th percentile is not a recognized definition of "baseflow" (as defined as the groundwater component to flow). Accordingly, throughout the manuscript, we have changed "base flow" to "low flow". And we have amended the wording to "Median low-flow TRP concentrations (the 'low-flow' threshold was defined here as the 15th percentile of monthly flows for the 150-year series)." And "Median high-flow TRP concentrations (where the 'high-flow' threshold was taken defined here as the 85th percentile of monthly flows for the 150 year series)."

Line 86. Correct to "…increases in high-flow…"

This has been corrected.

Line 102. Correct to "…reduced organic matter…"

This has been corrected.

Lines 117-121. Justification needed on comparing unfiltered TRP magnitudes against threshold and standard P concentrations that are based on filtered SRP magnitudes.

The water quality standards in the U.K. are defined as unfiltered "reactive phosphorus" (TRP), not filtered SRP. This is because P measurements by U.K. agencies are of molybdate reactive phosphorus on unfiltered water samples. We have now added a reference (#23) to the UK Technical Advisory Group on the Water Framework Directive Report which supports this and states that U.K. P standards are as unfiltered reactive phosphorus.

Lines 117-118. Justification needed why mean annual P concentration, then median nitrate concentration as descriptive stats. Why not keep the same?

This was a typographic error and should have been median; we have now corrected this.

Line 132. Should the 'but' be 'and' instead?

Yes, we have changed ‘but’ to ‘and’

Line 137. Correct to “Diatoms are the dominant phytoplankton…”

This has been corrected.

Line 151. Subscript 2 on SiO2.

This has been corrected

Line 151. Change ‘fell’ to ‘falling’. Or just delete ‘fell’.

We deleted ‘fell’

Line 242. Start sentence “As shown in this paper,…”

We have started the sentence as recommended.

Line 430. After “…for each year” change full-stop to comma.

We have changed this full-stop to a comma.

Reviewer #2 (Remarks to the Author):

Review of COMMSENV-24-2184-T “Tackling River Eutrophication: 150 years of challenges, successes and ‘treading water’ in a warming climate”, by Jarvie and others.

The authors state that eutrophication in the River Thames has increased over the past 150 years and reduction of phosphorus concentration in the river may be the best lever to control harmful algal blooms. This paper provides a new historical benchmark for the River Thames eutrophication trajectory and offers a template for understanding anthropogenic pressures on rivers. This paper also offers a new dataset that dates back to the 1880s that are alone novel, and the authors provide insights into trends and connections to land use. For example, since 1880, phosphorus loads delivered to the river have been reduced by 82%, but concentrations have remaining high, well above some standards (0.25 mg P/L > 0.05 mg P/L). The findings are mostly convincing, but in the opinion of this reviewer, there are still some statements not fully backed with evidence or some statements that could mislead the reader, which the authors could improve with **minor revision** (see specific comments).

We thank Reviewer 2 for these very helpful comments and suggestions which have clarified and strengthened the manuscript. We have responded to each of these below:

Will the authors provide the final compiled dataset? This reviewer could not tell where those would be made available. A reader would appreciate access to all data that were compiled rather than piecing together on their own.

Yes, the data have been compiled, in accordance with the Communications Earth & Environment guidelines. A data availability statement is now provided.

Specific comments:

What is the connection between water use and BOD. Why is BOD an issue? You state “harmful” algal bloom. BOD can be considered harmful if waters go hypoxic or if drinking water treatment are affected?

Thank you for highlighting this. We have modified the wording to “and biological oxygen demand (BOD, a measure of organic-matter contamination linked to water body hypoxia)”.

Main title: this reviewer does not follow “treading water.” Is that a metaphor for something? You later imply that managers are only treading water. This reviewer does not follow the message nor really backed by any type of evidence. Throughout the manuscript, you provide a history that over 80% of TRP have been reduced. That is amazing progress yet the authors imply we are only treading waters. The opinion of this review is it only adds confusion for the reader; however, that is only honest feedback and this reviewer encourages the authors to use whichever writing style they prefer.

We thank Reviewer 2 for this helpful feedback. To improve readability, we have now removed the idiom “treading water” in all locations in the manuscript. We have also amended the title in accordance with the editor’s suggestion.

33: why is N left off the list here? Because nitrate is its own record already published? Ah I see.
Yes, the long-term nitrate record for the River Thames has already been published. We have now added “along with the historical nitrate record (which has already been published[3])” to help clarify this.

33: Suggest to also state here reconstruction of water temperature. And what about records regarding amount of treated wastewater instead of population proxy?

We have added “a reconstructed daily water temperature record (see Methods)”. To the best of our knowledge, there are no long-term/historical datasets on treated wastewater discharge amounts for all the wastewater treatment plants within the Thames catchment, and so we use population here as a proxy.

41: What is the current crisis explicitly? This statement is not convincing nor backed with evidence. Reference 5 in an opinion piece—this reviewer does not view that as a viable citation.

We state that the current water quality crisis is linked to discharges of untreated sewage and we have added the Hammond et al (2021) reference (which was originally cited later in paper) along with an additional reference added, as follows:

- **Giakoumis T. and Voulvoulis N. Combined sewer overflows: relating event duration monitoring data to wastewater systems' capacity in England. Environmental Science: Water Research & Technology 9, 707-722 (2023).**

44: “troubled waters”. So, these are not also murky? What is troubled? These words add confusion.

We have removed all instances of “troubled waters” and “murky waters” from the manuscript to avoid confusion.

67: "this" refers to what? This "decadal lag in response" indicates…?

Thank you for this suggestion: we have inserted "decadal lag in response" to clarify this sentence.

67: perhaps another helpful reference: https://doi.org/10.1016/j.scitotenv.2023.169361

Thank you; we have added this reference:

- **Cravotta CA, et al. Legacy sediment as a potential source of orthophosphate: Preliminary conceptual and geochemical models for the Susquehanna River, Chesapeake Bay watershed, USA. Science of The Total Environment 912 169361 (2024).**

99: "Murky waters" So, these are not also troubled? Are they always murky? So, if murky they are no longer troubled? This reviewer does not find theses word helpful and actually cause the sub-title to be less clear. The picture of successes is murky. The metaphors are adding confusion.

We have removed "troubled waters" and "murky waters" from the manuscript to avoid confusion

123: Nice, it is helpful to also include nitrate. Thank you. **Thank you (no response is needed here).**

123: Careful. Yes, this reviewer is also certain that the nutrients are important, but you started your story with a warming climate too. Would HABs still be increasing in frequency in the climate was not warming? Meaning, a key driver, in addition to nutrients, is the increase in heat energy stored within surface waters. The connection between nutrients and temperature is not altogether clear—it is fine to state that.

This section explores the implications of improvements in wastewater and agricultural nutrient management have impacted the nutrient water quality timeseries of the River Thames. We then go on to address the potential impacts of warming on algal blooms in the section below, entitled "Warming waters: Increasing the potential for nuisance and harmful algal blooms".

130: this reviewer is not sure this is true, "which approximates to the ratio of N:P needed by algae." It is useful to compare to the 16:1 ratio, but did that reference from 1958 conclude that for algae in rivers?

We thank Reviewer 2 for highlighting this. We have amended the wording, and added supporting references, as follows: "The Redfield ratio[26] (16N:1P) is widely used as a reference 'optimum' ratio for primary production across diverse aquatic ecosystems, including algae in streams and rivers[22,27], and deviations from the Redfield ratio can indicate potential for nutrient limitation in rivers.[22,28,29] "

Accordingly, we have also added the following references to justify and demonstrate the use of the Redfield Ratio in rivers (including the River Thames):

- **Hillebrand H. and Sommer U. The nutrient stoichiometry of benthic microalgal growth: Redfield proportions are optimal. Limnology and Oceanography 44, 440-446 (1999).**
- **Smith D.R., et al. Carbon, Nitrogen, and Phosphorus Stoichiometry and Eutrophication in River Thames Tributaries, UK. Agricultural & Environmental Letters 2, ael2017.06.0020 (2017).**
- **Wachholz A., et al. Stoichiometry on the edge—humans induce strong imbalances of reactive C:N:P ratios in streams. Environmental Research Letters 18, 044016 (2023).**

135: Perhaps useful here: https://www.science.org/doi/10.1126/science.1245279. Is increased nitrate as a result not a concern? Is there a way to also promote denitrification or is that a lost cause?

We have added the refence that the reviewer recommends:

- **Bernhardt ES. Cleaner Lakes Are Dirtier Lakes. Science 2013; 342: 205-206.**

We have also clarified that we are referring to river eutrophication here (and have added "river" to this sentence:
"….and this indicates that reducing P inputs to achieve lower, ecologically-limiting concentrations may offer the greatest opportunity to curtail algal growth and reduce river eutrophication pressures."

And we have added the following text:

"However, there remain concerns about the impacts of nitrate on eutrophication in downstream receiving water bodies, including lakes and, in the case of the River Thames, estuarine and coastal waters, where there can be N-limitation or dual N and P co-limitation[30,31]. Reducing phosphorus inputs can potentially also impact the export of reactive nitrogen from lakes[32]. These concerns provide a strong rationale for dual reductions of N as well as P to manage eutrophication in downstream receiving water bodies.[31,33]"

Accordingly we have also added the following references:

- **Maier G. et al (2009). Estuarine eutrophication in the UK: current incidence and future trends. Aquatic Conservation: Marine and Freshwater Ecosystems 19, 43–56 (2009).**
- **Paerl H.W., et al. It Takes Two to Tango: When and Where Dual Nutrient (N & P) Reductions Are Needed to Protect Lakes and Downstream Ecosystems. Environmental Science & Technology 50: 10805-10813 (2016).**
- **Finlay JC, Small GE, Sterner RW. Human Influences on Nitrogen Removal in Lakes. Science 2013; 342: 247-250.**
- **Bernhardt ES. Cleaner Lakes Are Dirtier Lakes. Science 2013; 342: 205-206.**

137: Confusing sentence, this review does not follow "Diatoms (phytoplankton)"? Diatoms are one type of many types of phytoplankton. Are diatoms the dominant form of phytoplankton algal blooms in the River Thames? Are diatoms an issue, the main issue? Is BOD the concern there? Cyanotoxins are less of a concern? So, chlorophyll-a paired with SiO2 is used as a proxy for diatoms?

We have amended this sentence (also in accordance with Reviewer 1's recommendations).

At lines 151-152, we state upfront (at the start of the paragraph) that "Diatoms are the dominant phytoplankton in the River Thames and give rise to pronounced spring algal blooms when river-water chlorophyll-a reaches maximum concentrations.[34]", also citing other work (Bowes et al, 2016) that confirm that diatoms are the dominant phytoplankton in the Thames. This is also supported by the strong negative relationship between chlorophyll-a and SiO_2 (Figure 5a); only diatoms assimilate SiO_2 resulting in pronounced SiO_2 depletion during diatom blooms.

Lines 151 to 158 focus on the use of the long-term (1936-2020) SiO_2 dataset to explore diatom blooms. In accordance with the reviewer's recommendations, we have added "proxy" at line 158: "thus, SiO_2 depletion is used here as a long-term indicator (proxy) of diatom blooms[36]."

Regarding BOD, we address this in our response regarding connecting diatom blooms to BOD issues (immediately below).

Regarding cyanobacteria as an issue, we address this below in our responses to Reviewer 2's question below "Where do cyanobacteria fit into this picture?"

A concise statement that connects diatom blooms to BOD issues seems missing, even though that is shown in Fig 5d.

Algae are not the only source of BOD. As discussed earlier (lines 98-103), wastewater effluent is an important source of BOD, and we discuss the changing contributions of algae to BOD and connect diatom blooms to BOD issues at lines 209-220.

145: Are you sure it is water temperature? This reviewer thought that diatoms tended to bloom in nutrient rich, less turbid waters, and could bloom when temperatures were cooler. Warmer temperatures tend to give opportunity to cyanobacteria.

We have reworded this section to emphasize that, in addition to nutrients and water temperature, other factors, such as river flows and light levels potentially impact algal blooms.

Lines 162-170 now read:

"Phytoplankton blooms are highly dynamic, responding to changes in physio-chemical conditions on sub-daily scales[34] and monthly monitoring is insufficient to characterize these dynamics. Recent higher-resolution monitoring has shown that, with an overabundance of P and N in the River Thames, water temperature during the spring is a key driver of diatom blooms in the River Thames[34,38,39], among other multiple controls on bloom dynamics, including light[40]. In many rivers, flow and flushing rate also provides a key control on phytoplankton blooms; however, flow in the lower River Thames is highly regulated by locks.[41,42,43] Moreover, while there is large interannual variability in river flow, analyses have shown little evidence for any long-term trends in river flow, floods or droughts related to climate change since 1880[41,44]. Here, we focus on the potential impacts of changes in water temperature on algal blooms."

And, in the next section, we then go on to identify the temperature range favourable to diatom blooms in the lower River Thames (9.6-18.25°C), and explain that warmer waters (>20°C) are likely to favour cyanobacteria.

156: 100 ug/L is high, especially for rivers. It seems that threshold (4.5 mg/L) identifies the clear cases of growth of blooms dominated by diatoms, but there seems to still be a lot of activity between 40 and 100 ug/L. In rivers, this reviewer has assumed that a 40 ug/L threshold of chlorophyll-a is an indicator of a bloom.

We agree that phytoplankton growth occurs between 40 and 100 μg/L; however, we have used the 100 μg/L chlorophyll concentration threshold for our definition of a "nuisance" diatom bloom in this paper, because 100 μg/L is the published threshold for the control of chlorophyll concentrations, specific to this location in lower River Thames (please see citation #37).

In citation #37, chlorophyll thresholds were identified according to each site. For larger, slow flowing rivers, like the lower Thames, ambient chlorophyll-a concentrations are higher and, accordingly, the bloom thresholds are higher, to ensure that changes in chlorophyll-a in response to a chlorophyll-a 'peak' (bloom) can be identified.

Accordingly, lines 158-161 now read:

"Here, a diatom 'bloom' was defined as SiO_2 depletion to concentrations below 4.1 mg L^{-1}; this corresponds with the 100 μg L^{-1} chlorophyll-a concentration threshold that indicates the onset of algal blooms in the lower River Thames[37] (Figure 5a)."

Where do cyanobacteria fit into this picture?

We have clarified how cyanobacteria fit into this picture at the start of the section on "Warming waters: Increasing the potential for nuisance and harmful algal blooms". Lines 179 – 186 now read:

"Water and air temperature datasets were used to reconstruct a daily river water temperature record for the Thames at Teddington from 1870 to 2020 (see Methods). The daily river water temperatures were then used to calculate the number of days, per month, when the water temperature was favourable for diatom blooms, i.e., within the range 9.6-18.25°C (Figure 6a). Seasonal phytoplankton succession in the River Thames follows a similar pattern to temperate eutrophic lakes: from dominance of nuisance diatoms in spring, with growth in potentially harmful cyanobacterial groups in late summer.[46] A similar analysis was then undertaken to assess the potential for growth of cyanobacteria that dominate at higher water temperatures (>20°C)[47,48] (Figure 6b)."

161: What does this density look like with chlorophyll-a? Could it be that 15 degrees C is just the temperature that diatoms like? If the dominant phytoplankton are diatoms, this statement with temperature would make sense, but only if there are not many other types of algae contributing to that chlorophyll-a signal.

The temperature range identified in Figure 5c is the range of temperatures favourable for diatoms, as this is based on SiO_2 depletion. However, please see our earlier response confirming that diatoms are the dominant phytoplankton in the River Thames and a dominant control on chlorophyll-a concentrations in the lower Thames as demonstrated by Figure 5a. Unfortunately, we do not have a long-term continuous chlorophyll-a record: measurements did not begin until 1976, the data are more sparse and there are substantial data gaps. Therefore, we use SiO_2 depletion as a proxy for diatom blooms. We have added the following sentence at lines 155-158 to highlight this:

“Chlorophyll-a concentrations have only been measured since 1976 in the River Thames at Teddington, at varying sampling frequency and with data gaps (see Supplementary Figure S5), whereas SiO_2 has been measured continuously, on a monthly basis, in the Thames since 1936 (Figure 5b); thus, SiO_2 depletion is used here as a long-term indicator (proxy) of diatom blooms[36].”

The temperature range identified in Figure 5c (9.6-18.25°C) for diatom blooms is consistent with other studies undertaken in the Thames using high-frequency monitoring of phytoplankton blooms and flow cytometry to distinguish diatoms from other algal communities (here, we cite Bowes et al 2016 and 2024).

166-176: this reviewer gets lost with the many uses of “optimal”. Plus, a temperature range of 9.6 to 18.25 seems quite cool. This reviewer thought that diatoms tended to favor cooler waters and do not do as well during the hottest temperatures. So, a water temperature of 9.6 C is quite cool to this reviewer, and tracks with that assumption. However, the title is “Warming waters” as increasing algae and the authors say diatoms decrease in warm June. This reviewer is not convinced that the relationship stated by the authors is altogether accurate. Is warming water temperature really the main driver? The changing nutrient conditions, yes, but temperature seems less clear.

We thank Reviewer 2 for this important clarification. To avoid confusion, we have removed the term ‘optimal temperatures’ and replaced this with ‘favourable temperatures’ and ‘an ecological range in water temperature that is favourable for diatom blooms’. As stated above, the temperature range identified here of 9.6-18.25°C is consistent with existing ecological temperature ranges for diatom blooms in the Thames, and we have cited these papers as supporting evidence.

Our results show that, over the last 50 to 60 years, warming water temperatures in the River Thames have resulted in conditions more favourable to diatom blooms in March and April, and more favourable for cyanobacteria growth in July and August. Rising water temperatures in June are increasingly exceeding 18.25°C and therefore becoming too warm for diatom blooms.

Accordingly, we have changed the title of this section to: “Warming waters: Changing the potential for nuisance and harmful algal blooms”.

179: Ah, it would help the reader to state this upfront when diatoms and phytoplankton are introduced. As this reviewer read above, this statement was missing.
We have now moved this sentence so that it now reads:

“The daily river water temperatures were then used to calculate the number of days, per month, when the water temperature was favourable for diatom blooms, i.e., within the range 9.6-18.25°C (Figure 6a). Seasonal phytoplankton succession in the River Thames follows a similar pattern to temperate eutrophic lakes: from dominance of nuisance diatoms in spring, with growth in potentially harmful cyanobacterial groups in late summer.[46] A similar analysis was therefore undertaken to assess the potential for growth of cyanobacteria that dominate at higher water temperatures (>20°C)[47,48] (Figure 6b).”

189: this gets lost down here. Suggest opening this section with this. A concise statement that says temperatures were more favorable to diatoms, but lately have shifted to favor more cyanobacteria blooms. Then, your temperature story makes sense.

Thank you for this helpful suggestion. We have also moved this sentence to the start of the paragraoh, and it now reads "The results show that, over the last 50 to 60 years, warming water temperatures in the River Thames have resulted in conditions more favourable to diatom blooms in March and April, and more favourable for cyanobacteria growth in July and August".

You found a range in which diatoms exist, great, that is not necessarily "optimum," but an ecological range where they can grow, optimum would imply peak growth (that is more like 15 C), but any more than that, other species will dominate.

We thank reviewer 2 for picking up on this important point. To avoid confusion, we have removed the term 'optimal temperatures' and replaced this with 'favourable temperatures' and 'an ecological range in water temperature that is favourable for diatom blooms'.

212: "there has been no corresponding improvement in the eutrophication status." Is that true? And it seems the eutrophication status has simply shifted to a new status. Is shifting back to levels 150 years ago even possible? There seems to be a clear reduction in BOD following a reduction in TRP. Suggest a revision here as that could be misleading to the reader. Suggest trying and write in a more positive tone. What if there were no reductions in P, or no management? The problem would be much worse. By those standards, one could argue that there has been a lot of improvement. Sure, we need to do much more. Also, this reviewer would not necessarily classify management action as "treading water." Treading water doesn't even happen in most of the world. Having data in the River Thames itself is a huge accomplishment. It is helpful to state for the reader what the authors recommend need to be done, but "treading water" reads as a bias opinion and is of course up to the authors if they want to keep that tone. This reviewer is supportive of the authors, but that was my reaction.

We thank Reviewer 2 for this helpful comment and we agree that a more positive tone is needed in relation to the huge accomplishments in reducing P loads by ~80%!

We have therefore reworded this to: "Consequently, despite the remarkable successes in reducing P loads in the River Thames, owing to substantial investments in reducing wastewater and agricultural P emissions over the last 40 years[48] (Figures 1a and 4a), there has been no corresponding reductions in algal growth potential.".

As stated above, we have removed all instances of the use of the idiom "treading water" from the manuscript to improve clarity.

222: "in a major world river system" suggest to just state River Thames. The reader will follow.
This has now been removed.

224: diffuse not needed, redundant
"(diffuse)" has now been removed

230: Are there any turbidity records? That could be useful for estimating shading effects as light penetration is an important control.
Unfortunately, there is no 150-year continuous turbidity record (or any means of

reconstructing a continuous daily turbidity record from 1870 to 2020) that could be used in conjunction with the daily water temperature record.

269: But what happens if more nitrate gets delivered to estuaries? Could reducing the occurrence of algal blooms by starving them of P cause unintended consequences in the N delivery to marine waters? Could that just shift the BOD issue downstream, causing more frequent hypoxic zones?

We have added the following: "… although dual P and N controls may be needed to address eutrophication in downstream estuarine and coastal waters[30,31]"

Please see comments above: we also added text earlier in the manuscript to address the potential issues of P controls alone on downstream receiving waters (lakes, estuaries and coastal waters) and the need for dual (N and P) control at lines 143-148.

Accordingly, at lines 23 and 273, we have replaced "P" with "nutrient".

Fig 3: What about streamflow? Has that changed from 1880?
Existing papers have undertaken detailed hydrological analyses of flow over the last 150 years in the River Thames. It is beyond the scope of this paper to re-analyse these long-term hydrological records, but we have added the following sentence: "Moreover, while there is large interannual variability in river flow, analyses have shown little evidence for any long-term trends in river flow, floods or droughts related to climate change since 1880[41,44]." And we have now cited the following references that have assessed the Thames flow record from 1880:

- **Marsh T, Harvey CL. The Thames flood series: a lack of trend in flood magnitude and a decline in maximum levels. Hydrology Research 43: 203-214 (2012).**
- **Hannaford J. Climate-driven changes in UK river flows: A review of the evidence. Progress in Physical Geography-Earth and Environment 39, 29-48 (2015).**

Fig 5d: the reader needs to work too hard to figure out the blue line is BOD. And it would be helpful to add the 4.5 SiO2 threshold. Add BOD 5 mg/L threshold perhaps.

We have now also added a key so that the reader no longer needs to work hard to figure out the blue line is BOD. As the purpose of Figure 5d is to show the synchronicity between BOD peaks and SiO_2 depletion, we feel that adding additional SiO_2 and BOD threshold lines would reduce the clarity of this figure. The 4.1 mg/L SiO_2 threshold is clearly shown in the adjacent Figure 5b and the 5 mg/L BOD threshold is explained in the text.