General Comments

We thank Anonymous Referee #1 for the careful and critical evaluation of our manuscript. We have reread our manuscript in the context of these comments and have thoroughly considered each suggestion which we believe will strengthen this work considerably. One of the repeating themes throughout Anonymous Referee #1's comments is that we have not been clear with our discussion of the source of nitrate anomalies as they relate to our two main regions of study (Juan de Fuca Strait [JdF] and Central Strait of Georgia [SoG]). This omission will be addressed by more clearly laying out the different dynamics specific to each of these regions in the Introduction, followed by more clarification in the Discussion. Another major concern raised by Anonymous Referee #1 is the inclusion of the NEP-MHW years in the climatology to which we compare our time series in our anomaly calculations. We address this concern as well as the line-by-line comments below.

G1. The paper mentions other contributing effects from El Nino Southern Oscillation (ENSO) and North Pacific Gyre Oscillation (NPGO). These events are known to affect regional weather/climate which in turn cause interannual variability in the meteorological and hydrological forcing. As a result, these events likely affect not only circulation and mixing, but also nutrient loads from rivers and streams, and upwelling. My concern is that there is no discussion of how changes in nutrient loads over pre-MHW, MHW, and post-MHW contributed to the biogeochemical (BGC) response, how loading changes were affected by MHW vs natural interannual variability.

Thank you for this comment. We agree that there is a lack of discussion about the effects of nutrient loads vs. natural interannual variability. While we already discuss the effects of El Niño events on upwelling and the subsequent impact on nutrient loading into the Salish Sea (L360-374), we will be strengthening this section as outlined below in our response to S4. P17., 365.

The revised manuscript will include a discussion on nutrient loading from rivers and streams in relation to the NEP-MHW years and natural interannual variability. Specifically, we will discuss the general patterns of nutrient loading via rivers and streams as well as the impacts of estuarine flow on nutrient enhancement. A previous modelling study of the Salish Sea by Khangaonkar et al., (2021) found that increased freshwater flow during the NEP-MHW years resulted in increased nutrients due to higher exchange flows relative to the pre-MHW reference year. Here our focus is the SoG; in the SoG, estuarine flow is a function of river flow (primarily the Fraser River), offshore upwelling, and the characteristics of the water currently sitting in the surface and intermediate layers in the SoG (Allen et al., 2025). In the present study we did not see high Fraser River discharge during the NEP-MHW years relative to the other years in our time series (Figure 2).

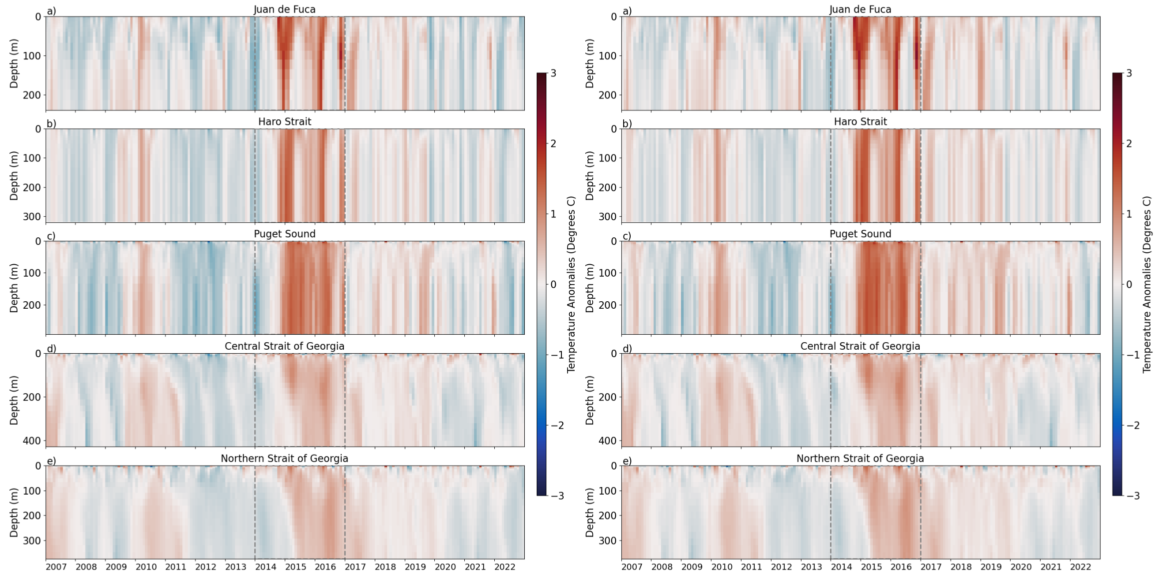
G2. The effect of MHW on BGC response has not been successfully teased out relative to natural variability that could be attributed to ENSO and NGPO. This is hard to do from analysis of observed data alone but is feasible using model sensitivity tests. The paper would be significantly strengthened with such an effort.

As Anonymous Referee #1 suggests, one of the major advantages of modelling studies is that sensitivity tests may be used to tease apart complicated processes and the subsequent biogeochemical responses. We used model experiments in our previous work examining the mechanistic link between the NPGO and plankton in the Central SoG (Suchy et al., 2025). However, after running a series of model experiments in that study it became evident that none of these warming signals acts alone, which is also one of the main takeaways from the current work. In order to effectively tease out the effects of the MHW relative to natural variability, such an analysis could look like running a number of years (ideally the entire time series) holding the boundary conditions at climatology conditions while letting the atmospheric conditions vary and then completing another model run wherein the boundary conditions are allowed to vary, but the same atmospheric conditions are held year after year. While we think this is a great idea, this type of analysis is beyond the scope of this study and would require considerable time (months of additional model runs) and computational costs. We believe that such an undertaking would warrant a whole paper on its own.

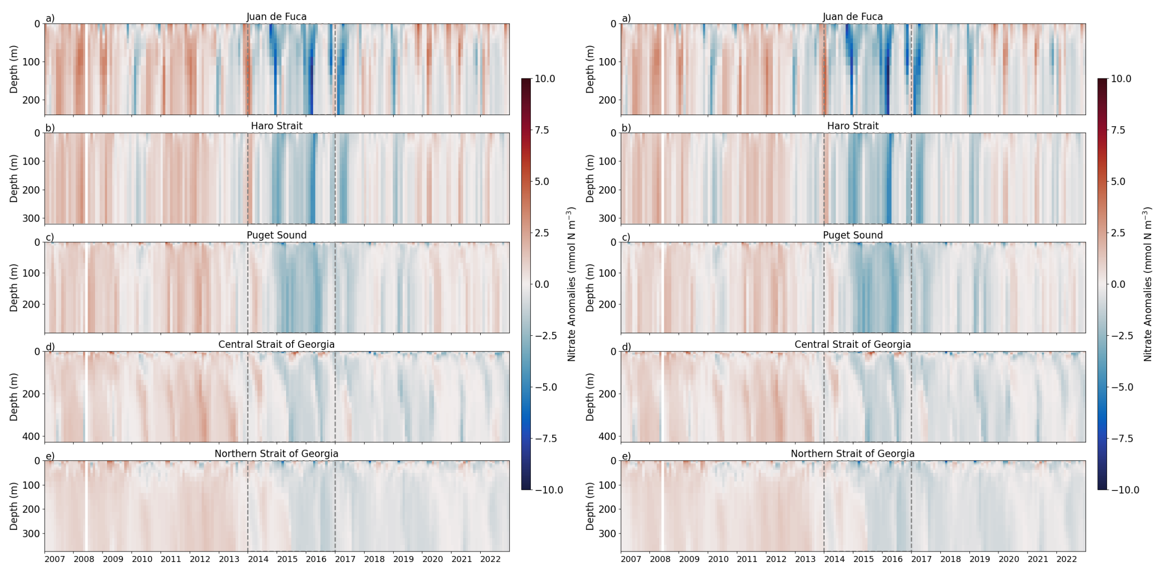
G3. In its present state the material presented does not allow the reader to clearly distinguish between cause and effect with respect to nutrient concentrations and plankton biomass in the upper 50 m. The climatological mean over the 16 years relative to which anomalies are discussed, includes NEP-MHW and other warming events. I recommend a reanalysis relative to a new baseline with NEP MHW years excluded.

We understand Anonymous Referee #1's concern regarding calculation of the baseline which includes NEP-MHW years. We reanalyzed our data by calculating a climatology with the NEP-MHW years (2014-2017) removed. The additional figures shown below compare our anomaly results for the original climatology (all years) versus a climatology with the NEP-MHW years removed. The results show that our findings are robust even after removing the NEP-MHW years from the climatology. Given that our time series is 16 years long (2007 to 2022), our results show little sensitivity to how the climatology is defined.

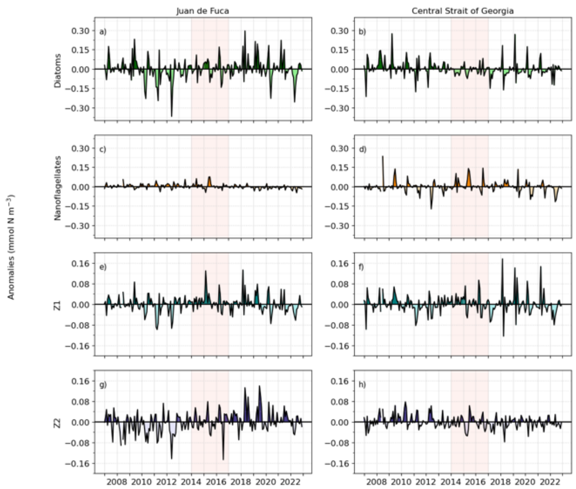
Temperature (left = original climatology; right = MHW years removed)

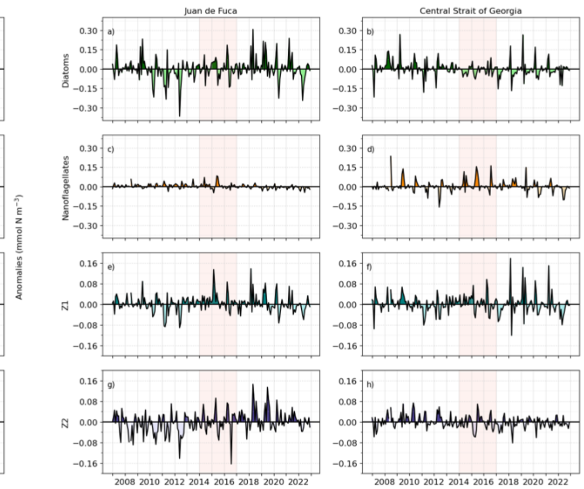


Nitrate (left = original climatology; right = MHW years removed)



Plankton (left = original climatology; right = MHW years removed)





Specific Comments

S1. P3., 89: The flushing time of 47 days for a waterbody the size of Puget Sound seems too low. Is this value corroborated by other published literature?

> Here we are talking about flushing time as opposed to residence time. The value is from MacCready et al (2021) who note that, for Puget Sound, flushing time is about one third of the residence time and we will clarify this difference in the text. MacCready et al. 2021's value of 47 days from Table 1 is compared directly with another study (Sutherland et al. 2011) which gives a value of 57 so this value is similar to other studies previously reported.

S2. P13., 310: Negative Nitrate anomaly during NEP-MHW showing reduction in nitrate in surface layers is interesting and consistent. However, it is not clear if this is tied to stronger stratification and reduced mixing with surface layers or higher primary productivity from increased surface layer temperatures.

> The negative nitrate anomalies during the NEP-MHW were present through all depth layers, which was particularly evident in the JdF, Haro Strait, and Puget Sound regions. These results suggest a link to larger-scale processes such as upwelling near the open ocean boundary (related to El Niño events) for the Juan de Fuca region and NPGO-modulated nutrient variability which has been shown to be important in the Central SoG (Suchy et al., 2025). Looking at the JdF region, specifically, the strong nitrate anomalies were not associated with an increase in stratification. Phytoplankton biomass was slightly elevated but was not the highest observed throughout the time series. In our new version, a better framing of our two regions in the Introduction, as well as more careful discussion of the links between the climate indices and nutrients, will make the processes more clear. Specifically, we will highlight how the JdF region, with its direct connection to the open ocean is more strongly influenced by the shorter term (1-3 years) influences of SOI effects on the upwelling/downwelling of nutrients into the region. In contrast, the deep basin of the Central SoG is semi-enclosed and affected by regional scale forcing (from all of

the atmosphere, open ocean and rivers) that is integrated over longer time scales (such as the decadal time scales associated with the NPGO).

S3. P15. Figure 6 is about Nitrate anomalies, but caption text refers to temperature

Thank you. The figure caption will be corrected.

S4. P17., 365: Assessment of wind here would have helped strengthen this argument as it pertains to upwelling of nutrient rich waters into the estuary. Is reduced Northeasterly wind strength due to NEP-MHW or ENSO?

Our original statement here is confusing because the finding cited here (Hayashida et al., 2020) does not differentiate marine heatwaves from El Niño events. In general, a reduction in northeasterly wind strength is associated with ENSO. In the revised manuscript we will rewrite this statement to read: “Globally, marine heatwaves, in the form of El Niño events, have been shown to suppress nutrients in some regions by weakening the upwelling of nutrient-rich waters (Hayashida et al., 2020).” Winds directly relevant to upwelling on the west coast of Vancouver Island are outside of our SalishSeaCast model domain. However, we agree that this argument can be strengthened and will include a brief discussion of more recent studies related to upwelling/winds in the waters near the mouth of Juan de Fuca.

Papers to cite:

Fain & Peña 2025 (https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2025JC022696)

Beutel et al., 2025 (https://doi.org/10.5194/bg-22-7309-2025)

S5. P18, 413: It is not clear from the data and modeling results whether Nitrate anomalies in Figure 10 are due to reduction in nutrients fluxes to the surface waters or because of increased phytoplankton consumption. As such we cannot speculate based on observed nutrient levels since effects of MHW are not isolated from other sources and sinks of nutrients. I suspect that simpler explanation is that nutrient concentrations in the surface layers are lower during MHW is because they have been consumed by higher primary productivity during that period. But then this argument fails during the post MHW period. Would it be possible to provide some clarification for this inconsistency between Pre- and Post-MHW

We agree with Anonymous Referee #1 that the lower nutrient levels in the observed 0-10 m nitrate appear to coincide with higher chlorophyll *a* concentrations, suggesting that the phytoplankton may be consuming more nutrients in this depth layer. The model outputs productivity and we see a maximum of 0.07 mmol N/m3/day increase in productivity during the NEP-MHW years compared to the climatology. Given a transit time of ~2.3 days (based on Thomson et al, 2007), we will show that extra nitrate draw down would be <15% which is insufficient to explain the nitrate decreases we see. This calculation will be included in the new version of the paper.

Indeed, as stated above, the model results show that the negative nitrate anomalies during the NEP-MHW occur throughout the water column and are linked to larger-scale processes. The JdF region is almost constantly mixed relative to the other regions. We will create new regional subplots to show this more effectively instead of including stratification results for all regions on one plot.

S6. P20., 432: What is the cause of this nitrate limitation in the upper 50 m. Is it reduced mixing (due to change in hydrodynamics and stratification) from the heatwave or is it a limitation caused by increased phytoplankton growth and consumption earlier in the year from higher temperatures.

"Overall, nitrate was the most limiting to diatom growth during the summer months throughout the study, with persistent nitrate limitation occurring in the upper 50 m during all seasons from 2017 to 2022"

Thank you for this comment as we now realize how poorly worded this statement was. A more accurate statement here would be: "Overall, nitrate was the most limiting to diatom growth during the summer months in the Central SoG. Nitrate limitation occurred periodically in the upper 50 m from 2017 to 2022, likely due to a combination of factors including increased stratification and weaker winds which prevented nutrients from being replenished into the surface waters (Moore-Maley & Allen 2022, Suchy et al., 2025).

S7. P25, Fig 12: Figure 12 is a good summary demonstrating that the model reproduces observed behavior, Pre-MHW, MHW, and Post-MHW years. Post MHW Nutrient levels in Juan De Fuca go up and are qualitatively supported by reduced growth relative to MHW, but they are still higher than pre-MHW. This indicates that other influences such as ENSO or NGPO which may be causing interannual variability may be at play. Is it possible for you to use the model to extract MHW effect from other influences.

It would be wonderful to use the model to extract individual influences of signals but to do so would require us to be able to extract the individual influences of signals in our forcing files: that is in the boundary conditions, atmosphere, and rivers. We have no idea how to do that and indeed, as, other than ENSO, these signals are empirical, not processes, it may not be possible to separate them even conceptually. Our findings show that the NEP-MHW co-occurs with the 2015-2016 El Nino, which contributes to part of the complication of the story. Our conclusions are that the NEP-MHW is associated with these other signals, not separate from them, which would make it almost impossible to pull the MHW out of the other forcing factors to run the model.

S8. P25, Fig.12: The chlorophyll and zooplankton during pre-MHW years are significantly lower than post-MHW while nutrient concentrations are not (Figure 12). This difference is not strongly reflected in model results (Figure 10), Is this simply due to lack of sufficient data or is there another process at play? It will be great if you could include a discussion on this noticeable difference. Also is it possible that pre-MHW results are influenced by the change in source of Ocean Boundary Conditions after 2013 that was used in the model setup described previusly?

> We suspect that the low chlorophyll *a* and zooplankton during pre-MHW years in the JdF region is largely due to insufficient/patchy data (particularly for the zooplankton) and agree that a discussion on this noticeable difference should be added. Included in this discussion will be details about where in the water column the pre-MHW samples were collected as this information might have skewed the observation results low.
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> Anonymous Referee #1 also raises a valid point about the change in boundary conditions. We have given considerable thought to the unfortunate timing of the change in the model's boundary conditions, i.e., in January 2013 which is just prior to our main time period of interest (2014-2017). However, we do not believe that the pre-MHW results were influenced by this change. First, we do not see evidence of a noticeable impact of the switch to LiveOcean boundary conditions in the temperature or nitrate results (Figures 3 and 6). Second, even if slight changes to the boundary conditions exist, we do not expect them to be large enough to propagate up the food web to the phytoplankton and zooplankton. Nevertheless, the revised manuscript will include this explanation in the context of our results.

S9. P27, L559: Could the authors provide justification for this statement. I may be misreading this but this statement seems to infer that decrease in nitrate during MHW is caused by physical processes independent of phytoplankton growth. If Salish Sea as the authors indicate is nutrient limited (due to healthy primary productivity), it is still nutrient limited with increased phytoplankton during MHW and lower nutrients could be a consequence.

> Original sentence: "*Given that the waters in the JdF region are, on average, cooler and more nutrient-replete compared to other regions, the increased temperatures associated with the NEPMHW favoured phytoplankton growth and a resulted in a subsequent increase in zooplankton biomass, while the decrease in nitrate had little to no effect on the phytoplankton.*"

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> Thank you for this comment. Our original statement is poorly worded. In fact, the JdF region is almost always nutrient replete. Here we were attempting to explain that even during periods of negative nitrate anomalies, phytoplankton are not nitrate-limited in this region as nitrate concentrations remain, on average, >5 μM. "Given that the waters in the JdF region are nutrient replete and, on average, cooler compared to other regions, the increased temperatures associated with the NEP-MHW favoured phytoplankton growth and resulted in a subsequent increase in zooplankton biomass. In contrast, nitrate had little to no effect on phytoplankton growth as nitrate was always replete."