Please find our responses given in bold blue text below after each individual comment or section provided by the reviewer.

Brief Summary of the manuscript:

Barnes and co-authors investigate the effects of wildfire burn severity on phosphorus (P) mobilization in Douglas-fir forests and sagebrush shrublands. Through laboratory leaching experiments, they examine how different burn severities influence particulate and aqueous P release. The authors find that higher burn severity increases particulate P mobilization while decreasing aqueous P availability, with particulate P controlled by total char P and aqueous P driven by solubility changes. Using nuclear magnetic resonance and X-ray absorption spectroscopy, they show that organic P compounds are thermally mineralized into inorganic calcium- and magnesium-bound forms. The study highlights that fire severity and vegetation type drive post-fire shifts in P cycling, with implications for nutrient transport and ecosystem recovery.

The paper is well-written and presents compelling results on phosphorus (P) transformations following fire. The findings provide valuable insights into how burn severity and vegetation type influence P retention and mobilization. However, several issues need to be addressed before the manuscript is suitable for publication.

I recommend the paper for publication after moderate revision, focusing on clarifying key mechanisms, improving data presentation, and addressing inconsistencies in comparisons.

Response: Thank you for the favorable review of our manuscript. In a revised manuscript, we will focus on clarifying the key mechanisms in the discussion section, improve the data presentation by including figures and tables in the main text that were previously only in the SI, and clarify text related to inconsistencies in comparisons in the discussion section.

Major Issues Requiring Revision:

1. Unjustified Burn Severity Comparisons:

The authors compare moderate-severity burns in sagebrush shrublands to high-severity burns in Douglas-fir forests without justification. This prevents direct comparisons and raises concerns about bias in data interpretation. Either compare the same burn severities across vegetation types or provide a clear justification for the chosen comparison.

Response: We will include more complete justification for the comparison between Douglas-fir and sagebrush at different severities done in the discussion section. We will do this by emphasizing that these are compared in the manuscript because they appear chemically similar.

1. Unclear Mechanisms of P Transformation and Mobilization:

The study claims burn severity influences P transformations, yet the chemical mechanisms behind these changes remain vague. For example, the authors state that aqueous P mobilization is “composition-controlled” by Ca-Pi, but later indicate that Ca-Pi concentrations are similar across vegetation types, suggesting other factors must be involved.

Response: We will clarify language regarding P transformations, particularly when compared across the burn gradients or between vegetation types. We will also revise the discussion around path analysis design and results, by clarifying lines 264-266 and 444-481, and in the Conclusions 493-497. Namely, we included only Ca-Pi in the path analysis to aid in interpretation of the path analysis results, but in reality, there are other drivers of aqueous P mobilization such as Mg-Pi, organic P speciation, and pH. We will revise other locations in the manuscript that suggests Ca-Pi as the only driver of aqueous P mobilization.

1. Fire Temperatures in Experimental Burns Are Lower Than Real Wildfires:

The highest recorded burn temperature for sagebrush (530°C) and Douglas-fir (704°C) is significantly lower than real wildfire conditions, which can exceed 1,000°C. Since P volatilization occurs above ~700°C, the study may underestimate P losses in real wildfire conditions. Discuss how P retention might differ if sagebrush shrubland was burned at higher temperatures (e.g., 800–1,200°C).

Response: We will add in additional context about how burn temperature and duration in our experiments relate to natural wildfires. We note that the aim of using our experimental burns was to better represent field burning conditions than what is currently commonly used in the P chemistry community; most of the literature on chemistry post-wildfire are based on burning materials in ovens, which is not representative of heterogenous burns that are common of field conditions (Brucker et al., 2022). Temperature is included in our study to better compare back to oven-based studies. Therefore, although we may not reach maximum temperatures experienced by a natural wildfire in our experiments, we believe the range of temperatures and durations of heating achieved by our experimental burns are largely representative of a large range in temperature and durations of heating experienced during wildfire (as noted in a

similar study Brucker et al., 2024). We will reference these studies and this justification in the revised manuscript.

References:

Brucker, Carli P., et al. "A review of simulation experiment techniques used to analyze wildfire effects on water quality and supply." ***Environmental Science: Processes & Impacts*** **24.8 (2022): 1110-1132.**

Brucker, Carli P., et al. "A laboratory-scale simulation framework for analysing wildfire hydrologic and water quality effects." ***International Journal of Wildland Fire*** **33.12 (2024).**

1. Post-Fire Ecosystem Recovery:

The manuscript discusses P mobilization and transformation but does not address how these changes affect ecosystem recovery after fire. It is unclear whether particulate P will eventually become bioavailable or remain locked in ash.

Response: We will modify lines 513-521 to include more discussion on how our findings on P concentration, composition, and transport from burned material alter bioavailability by revisiting concepts from the Introduction (lines 93-98). We will also discuss how our results may translate to ecosystem recovery across different timescales using key examples in the literature (i.e., Santin et al., 2018, Silins et al., 2014, Emelko et al., 2016, Bodi et al., 2014, and Rust et al., 2018).

References:

Santín, C., Otero, X. L., Doerr, S. H., and Chafer, C. J.: Impact of a moderate/high-severity prescribed eucalypt forest fire on soil phosphorous stocks and partitioning, Sci. Total Environ., 621, 1103–1114, 2018.

Silins, U., Bladon, K. D., Kelly, E. N., Esch, E., Spence, J. R., Stone, M., Emelko, M. B., Boon, S., Wagner, M. J., Williams, C. H. S., and Tichkowsky, I.: Five-year legacy of wildfire and salvage logging impacts on nutrient runoff and aquatic plant, invertebrate, and fish productivity, Ecohydrol., 7, 1508–1523, 2014.

Emelko, Monica B., et al. "Sediment-phosphorus dynamics can shift aquatic ecology and cause downstream legacy effects after wildfire in large river systems." ***Global Change Biology*** **22.3 (2016): 1168-1184.**

Bodí, M. B., Martin, D. A., Balfour, V. N., Santín, C., Doerr, S. H., Pereira, P., Cerdà, A., and Mataix-Solera, J.: Wildland fire ash: Production, composition and eco-hydro-geomorphic effects, Earth-Sci. Rev., 130, 103–127, 2014.

Rust, A. J., Hogue, T. S., Saxe, S., and McCray, J.: Post-fire water-quality response in the western United States, Int. J. Wildland Fire, 27, https://doi.org/10.1071/WF17115, 2018.

Missing Data or Discussion on Ash Color:

The conclusion states that ash color (black charring and white ash) increases with burn severity, yet this was not discussed in the results or presented in any figure or table. If ash color was recorded, include data or observations in the results and discuss its significance. If it was not recorded, remove the statement from the conclusion.

Response: We will revise this part of the conclusions (see responses below in minor revisions) and refer to Figure S4. We will remove word "appear" in the referenced conclusion, which decreases clarity in the intended meaning.

Minor Revisions:

Abstract:

Lines 33–34: The magnitude of P mobilization (e.g., "Burning increased particulate P mobilization (6.9-fold and 29-fold) but decreased aqueous P release (3.8-fold and 30.5-fold)") varies significantly between Douglas-fir and sagebrush. Why? Briefly mention the mechanism driving these differences.

Response: We will revise this sentence and the following on in the abstract for clarity. We will add in an additional sentence bridging between the two sentences that will state the following "Particulate and dissolved phases were under contrasting mechanisms."

Line 29–31: The sentence "However, it is unclear if post-fire responses are primarily driven by changes to the molecular composition of the charred material or from the transport of P-containing compounds." is difficult to follow. Consider rewording.

Response: We will reword the sentence as follows "However, it is unclear if shifts in P composition or P concentration are responsible for changes in P dynamics post-fire".

Line 39: "Thermally mineralized to inorganic P moieties"—clarify how this affects P availability in soils.

Response: After this sentence we will add in a short description of how this impacts P availability/solubility to the end of the sentence.

Introduction:

Lines 60–63 and 67-68: Long sentences—consider breaking them up for clarity.

Response: As suggested by the reviewer, we will break up the sentences on lines 60-63 and 67-68 to increase clarity.

Lines 111–119: Burn severity should be introduced earlier when discussing fire intensity and nutrient cycling.

Response: We will introduce burn severity on line 67, when we first discuss these concepts.

Methods:

What was the collection timeframe? Seasonal variations can influence plant moisture content, affecting fire behavior and P release.

Response: We will add in additional details to clarify the study design. Exact conditions are detailed in our data package, Grieger et al., 2022 which we will also reference here. Please note that we did manipulate moisture conditions of the vegetation prior to burning as part of our experimental design.

References:

Grieger, S., Bailey, J., Barnes, M., Bladon, K. D., Forbes, B., Garayburu-Caruso, V. A., Graham, E. B., Goldman, A. E., Homolka, K., McKever, S. A., Myers-Pigg, A., Otenburg, O., Renteria, L., Roebuck, A., Scheibe, T. D., and Torgeson, J. M.: Organic Matter Concentration and Composition of Experimentally Burned Open Air and Muffle Furnace Vegetation Chars across Differing Burn Severity and Feedstock Types from Pacific Northwest, USA (V3), https://doi.org/10.15485/1894135., 2022.

The geographic description ("Pacific Northwest, USA") is too vague. Include specific sites or coordinates for clarity.

Response: We will add in additional details to clarify the study design. Briefly, vegetation was collected to be representative of different land cover types present across the Pacific Northwest and we are not representing exact sample sites or locations, but rather archetypic dominant vegetation across PNW ecosystems. See Figure 1 in Roebuck et al. 2025 and description of vegetation and burn experiments in Myers-Pigg et al., 2024. If of interest, exact sites where the representative vegetation was collected can be found in our data package, Grieger et al., 2022. We will add references to these other studies in the main text in this section, to clarify the study design.

References:

Grieger, S., Bailey, J., Barnes, M., Bladon, K. D., Forbes, B., Garayburu-Caruso, V. A., Graham, E. B., Goldman, A. E., Homolka, K., McKever, S. A., Myers-Pigg, A., Otenburg, O., Renteria, L., Roebuck, A., Scheibe, T. D., and Torgeson, J. M.: Organic Matter Concentration and Composition of Experimentally Burned Open Air and Muffle Furnace Vegetation Chars across Differing Burn Severity and Feedstock Types from Pacific Northwest, USA (V3), https://doi.org/10.15485/1894135., 2022.

Myers-Pigg, A. N., Grieger, S., Roebuck, J. A., Jr, Barnes, M. E., Bladon, K. D., Bailey, J. D., Barton, R., Chu, R. K., Graham, E. B., Homolka, K. K., Kew, W., Lipton, A. S., Scheibe, T., Toyoda, J. G., and Wagner, S.: Experimental Open Air Burning of Vegetation Enhances Organic Matter Chemical Heterogeneity Compared to Laboratory Burns, Environ. Sci. Technol., 58, 9679–9688, 2024.

Roebuck, J. A., Jr, Grieger, S., Barnes, M. E., Gillespie, X., Bladon, K. D., Bailey, J. D., Graham, E. B., Chu, R., Kew, W., Scheibe, T. D., and Myers-Pigg, A. N.: Molecular shifts in dissolved organic matter along a burn severity continuum for common land cover types in the Pacific Northwest, USA, Sci. Total Environ., 958, 178040, 2024.

Lines 138–140: The statement that “Douglas-fir burns at higher intensities due to fuel loading, while sagebrush burns at lower intensities” is too general. Explain why these fuel differences affect fire behavior.

Response: Thank you for bringing this to our attention. We plan to revise this section to increase clarity in our meaning here. Briefly, we will 1) add in several sentences about the design and rationale for the vegetation studied from our data package Grieger et al., 2022 and 2) bring in relevant literature on burn severity differences observed across fires in Douglas-fir and sagebrush ecosystems (Stavi, 2019; Roebuck et al., 2024 Fig 1; Halofsky et al., 2020; Reilly et al., 2017).

References:

Grieger, S., Bailey, J., Barnes, M., Bladon, K. D., Forbes, B., Garayburu-Caruso, V. A., Graham, E. B., Goldman, A. E., Homolka, K., McKever, S. A., Myers-Pigg, A., Otenburg, O., Renteria, L., Roebuck, A., Scheibe, T. D., and Torgeson, J. M.: Organic Matter Concentration and Composition of Experimentally Burned Open Air and Muffle Furnace Vegetation Chars across Differing Burn Severity and Feedstock Types from Pacific Northwest, USA (V3), https://doi.org/10.15485/1894135., 2022.

Roebuck, J. A., Jr, Grieger, S., Barnes, M. E., Gillespie, X., Bladon, K. D., Bailey, J. D., Graham, E. B., Chu, R., Kew, W., Scheibe, T. D., and Myers-Pigg, A. N.: Molecular

shifts in dissolved organic matter along a burn severity continuum for common land cover types in the Pacific Northwest, USA, Sci. Total Environ., 958, 178040, 2024.

Halofsky, Jessica E., David L. Peterson, and Brian J. Harvey. "Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA." *Fire Ecology* 16.1 (2020): 1-26.

Reilly, Matthew J., et al. "Contemporary patterns of fire extent and severity in forests of the Pacific Northwest, USA (1985–2010)." *Ecosphere* 8.3 (2017): e01695.

Lines 146–147: What ratio of woody to canopy material was used? The relative proportion of wood vs. foliage affects combustion properties and nutrient release.

Response: These details exist in our accompanying data package, Grieger et al., 2022. We will include relevant details in the revised manuscript text directly. Briefly, the ratio was 40% canopy (materials <0.5cm) and 60% woody (materials >0.5cm). We will also reference the data package in this part of the manuscript.

References:

Grieger, S., Bailey, J., Barnes, M., Bladon, K. D., Forbes, B., Garayburu-Caruso, V. A., Graham, E. B., Goldman, A. E., Homolka, K., McKever, S. A., Myers-Pigg, A., Otenburg, O., Renteria, L., Roebuck, A., Scheibe, T. D., and Torgeson, J. M.: Organic Matter Concentration and Composition of Experimentally Burned Open Air and Muffle Furnace Vegetation Chars across Differing Burn Severity and Feedstock Types from Pacific Northwest, USA (V3), https://doi.org/10.15485/1894135., 2022.

No mention of initial sample preparation—were plant materials cleaned, dried, or processed before burning?

Response: These details exist in our accompanying data package, Grieger et al., 2022. We will include relevant details in the revised manuscript. Briefly, all plant materials were air dried for at least two weeks prior to burning. We also manipulated fuel moisture before burn experiments and kept living and dead plant materials separate. We will also reference the data package in this part of the manuscript.

References:

Grieger, S., Bailey, J., Barnes, M., Bladon, K. D., Forbes, B., Garayburu-Caruso, V. A., Graham, E. B., Goldman, A. E., Homolka, K., McKever, S. A., Myers-Pigg, A., Otenburg, O., Renteria, L., Roebuck, A., Scheibe, T. D., and Torgeson, J. M.:

Organic Matter Concentration and Composition of Experimentally Burned Open Air and Muffle Furnace Vegetation Chars across Differing Burn Severity and Feedstock Types from Pacific Northwest, USA (V3), https://doi.org/10.15485/1894135., 2022.

Results and Discussion:

Lines 282–284: The study may underestimate P volatilization since wildfires can exceed 1,000°C, causing greater P losses. Acknowledge this limitation.

Response: We will add in acknowledgement of these limitations, in the context of our experimental burning results in relation to a real fire. In particular, we will emphasize the heterogeneity of burning that the open air simulations experienced, which are representative of heterogenous wildfire burning conditions.

Lines 292–302: The comparison between moderate-severity sagebrush and high-severity Douglas-fir needs clear justification.

Response: We will clarify language throughout the manuscript where direct comparisons between Douglas-fir and sagebrush at different severities are being made and remove comparisons that are unclear.

Lines 308–313: Which forms of P are retained vs. combusted? Clarify whether organic or inorganic P compounds are responsible.

Response: We are specifically focused on the conversion of organic P to inorganic P in this section and will revise the text accordingly.

Lines 328–331: The phrase “selective protection” explain what protects P from mineralization.

Response: This phrase was in reference to physical protection of P, such as mineral aggregates. We will clarify this in the text.

Lines 373–395: The manuscript claims pyrophosphate forms from orthophosphate, but why did sagebrush chars produce less pyrophosphate than Douglas-fir chars, despite having more phytate initially?

Response: Pyrophosphate can be produced either from orthophosphate or phytate. We will clarify the language around the discussion of the two pathways that pyrophosphate is produced from in the manuscript text.

Lines 460–463: The mechanism by which pH affects P solubility is not clearly explained. Report actual pH values measured.

Response: Thank you for this comment, we will bring up the pH figure from the Supplemental materials into the main text.

Lines 478–479: "This has important implications for P compounds are transported..." grammatical error—revise for clarity.

Response: We will correct this to say "This has important implications for P compounds <u>that</u> are transported..."

Conclusions:

Lines 483–485: The first sentence should summarize the main findings upfront before interpretation.

Response: We will add in a high-level summary of our main findings at the start of the conclusions section.

Lines 486–487: The conceptual model (Fig. 6) is mentioned but not explained. Briefly describe its significance.

Response: The conceptual model was intended to synthesize our main findings. We will increase discussion of the conceptual model in our conclusions section.

Lines 500–503: The phrase "more burned" is vague—does this mean greater P retention, more mass loss, or another factor?

Response: Here we meant greater P transformations and will revise the text to reflect this.

Lines 506–509: The statement on shifting fire severity lacks context—explain why this matters for P retention and post-fire recovery.

Response: This is a great point. We will be more explicit about the P changes that occur with severity that we discovered in our study and how that relates to P in the ecosystem post-fire.

Lines 510–517: Organic soil horizons are introduced but were not a focus of the study. Instead, discuss how P transformations affect bioavailability over time.

Response: The P studied here are the starting (litter) materials that are available for subsequent overland transport and do not include soils, and we agree mention of organic soils is confusing in this context. Therefore, we will modify this discussion to focus on the potential for different P pools (organic/inorganic, particulate/dissolved) to have different cycling in the environment (e.g. dissolved phase will be more reactive/have quicker cycling, solid P may be longer term source of P to the environment) compared to starting vegetation P.