## General Comments:

This manuscript investigates the relationship between fire induced changes in ecosystem C and N stocks and climate in Sweden. The manuscript addresses relevant and important scientific questions related to the influence of climate on boreal forest fire C and N emissions and redistribution within an ecosystem. The novel dataset of field measurements along gradients in climate is valuable to the scientific community. However, the methods are unclear in several places, and the excessive use of abbreviations hinders both readability and comprehension. The manuscript needs additional plots showing their raw data and model fits to aid in the interpretation of the methods and results. The relationships between boreal forest fire C and N emissions and precipitation, temperature, and soil moisture are a key finding in this study but are not strongly represented in the figures. Overall, the manuscript represents an important contribution to the scientific community, but it needs minor adjustments to make the overall presentation well-structured and clear.

## Specific Comments:

**Comment 1**

Page 2, line 25: The predominant disturbance to this C balance is approximately centurial outbreaks of wildfire (Bond-Lamberty et al., 2007).

This sentence sounds like the author is suggesting the carbon balance in boreal forests is predominantly determined by wildfire outbreaks that occur *once* every century. While the return interval of fire in a local area of the boreal forest is centurial, boreal forest fires occur every year. I suggest re-wording this sentence for clarity.

**Comment 2**

Page 2, line 30: Along with a changing climate, these effects have the power to influence community structure and **process rates** shaping future forest C and N cycles on decadal to centurial timescales.

It is unclear what "process rates" the author is referring to.

**Comment 3**

Page 2, line 31: Changing patterns of temperature and precipitation in recent decades have caused increases in frequency, intensity and size of fires with further amplification predicted in the future.

The author needs to specify if they are referring to fires globally or regionally (Eurasian boreal forest fires).

**Comment 4**

Page 2, line 40: These factors dictate fuel availability, a **highly temporal measure** of the proportion of total fuel that is readily combustible.

I'm not sure what a "highly temporal measure" means. If the author is referring to the high temporal variability in available fuel, the phrase could be changed to "a highly temporally variable measure."

**Comment 5**

Page 2, line 45: Spatial arrangement of overstory fuel loads has also been shown to have a strong impact on fire severity and intensity and distinguishes the boreal wildfire regimes of the North American and Eurasian continents (Rogers et al., 2015).

The major difference in the boreal wildfire regimes in North America and Eurasia is the dominant tree species and corresponding ecosystem characteristics. The spatial arrangement of overstory fuels certainly contributes to crown fire behavior in the North American boreal forest, but the underlying reason for the difference is tree species. See Rogers et al., 2015.

**Comment 6**

Page 2, line 56: While total area burned may be evaluated through remote sensing (Ruiz et al., 2012), per area emissions are generally derived from labor intensive field sampling which are extrapolated to the larger scale either directly or through weighting by poorly constrained free parameters such as total fuel load (French et al., 2004; Soja et al., 2004). This field sampling has been regionally limited and biased towards a few high intensity burn complexes in North America which may in turn bias global emission estimates (van Leeuwen 60 et al., 2014).

The authors describe the commonly called "bottom-up" approach to calculate emissions, but fail to address alternative methods to calculate emissions, such as a "top-down" based approach (Ichoku and Ellison et al., 2014). Carbon emissions per unit area are calculated using a bottom-up approach as the product of fuel loading, combustion completeness and the carbon content of fuel. While some fire emissions inventories do rely on extrapolated field measurements to estimate one or more of the variables needed in the bottom-up approach, many rely on remote sensing observations (van der Werf et al., 2017; Veraverbeke et al., 2015).

**Comment 7**

The methods section is missing a detailed description of fire severity in each of the 50 burnt plots. This omittance (and missing subsequent discussion) incumbers the interpretation of the results. The manuscript would also greatly benefit from the inclusion of an overview of the ecosystems sampled (by dominant tree species, for example) in each of the burnt plots. A histogram showing fire severity and ecosystem type could be helpful.

**Comment 8**

Page 4, line 100: Sentinel-2 infrared imagery taken during the time of fire assisted in delineating the exact locations of burnt plots by placing them where there had been a strong and consistent infrared signal that was well within the mapped final fire boundaries.

The method described here should be more quantitative. How was a “strong and consistent” infrared signal determined?

**Comment 9**

Page 4, line 112: Due to their documented effects on emissions, long and short term approximations of moisture were introduced as exogenous variables to models in order to test the ability of the study design to isolate variation in C and N stock losses to the effects of climate. Long term moisture was represented by the TEM used in plot selection while short term moisture balance used the Standardized Precipitation-Evapotranspiration Index (SPEI) over the period January to June 2018 (i.e. spei06 2018-06) to capture the desiccation process leading up to the fire season.

The methods described here are vague. What models were these variables introduced to? Is the goal to isolate variation in C and N stock losses caused by variability in climate? Why is long term moisture determined using only soil moisture, but short-term moisture is quantified using precipitation and evapotranspiration? Where did the SPEI data come from? The reference is unclear.

**Comment 10**

Page 5, line 123: Each compartment was further sorted by weight into characteristic features to form compartment compositional variables (CCVs) which were used in regression to test for relationships between compartment composition and the quantity and quality of fuel loading as well as C and N loss.

More detail is needed. What type of regression was performed? How were the relationships quantified? What metrics were used? What exactly are compartment compositional variables and how were they defined? What is meant by “quality of fuel loading”? The methodology described here is ambiguous.

**Comment 11**

Page 5, line 137: Duff samples were taken near the mineral cores by excavating four soil volumes (at least 400 cm3 each) and trimming the mineral and moss/litter layers off the bottom and top of the volumes respectively. Duff and mineral soils were kept frozen until portions were freeze dried for separate analysis. Moss/litter samples were collected at approximately equal intervals along the soil profile transects in a 553 cm3 steel container with attention to preservation of the natural in situ volume. Char was similarly collected in a 112 cm3 container. On the upper surface of the char layer were small portions of dry, unburnt material, much of which may be new additions of litter to the forest floor. This material was discarded from the char collection and was not included in stock estimates.

More information is needed on the sample collection protocol. How was the size of the duff and moss/litter sample collected determined? What, if any, steps were taken to avoid duff compaction? Was volume measured in situ?

**Comment 12**

Page 6, line 156: In all plots, understory was clearly distinguished from overstory by pronounced height differences and samples were taken from control plots by cutting all non-moss, non-tree plant material at the surface of the soil from within four 40 x 40 cm2 patches. Patches were chosen for their representativeness of plant abundance and composition for the portion of the plot that was vegetated, which was always all non bare rock surface.

The methodology described here is not quantitative. What defined "pronounced height differences"? What metrics were used to select patches, or were the choices purely subjective?

**Comment 13**

Page 6, line 169: All samples were pulverized, except the mineral soil where only the fine earth fraction (< 2 mm) was analyzed (C and N content was set to 0 for the coarse fraction), and run through a Costech ECS4010 elemental analyzer to produce ratios of C and N weight to sample total weight (CR and NR respectively).

More information is needed on the elemental analyzer used to calculate the ratios. How were the samples prepared? What was the measurement protocol? How was the instrument calibrated? Also, the abbreviations are confusing. Perhaps consider changing to carbon (nitrogen) mass percentage or something similar.

**Comment 14**

Page 6, line 185: Changes between control and burnt plots were first calculated by subtracting control plot values of a variable from those of its burnt pair thereby forming a single distribution of 50 elements for statistical testing.

This sentence should be re-worded for clarity. Or, an equation could be introduced here using the delta ($\Delta$) notation to indicate change. Additionally, the author does not state exactly what variables are compared between control and burnt plots in this sentence.

**Comment 15**

Page 7, line 192: Simple regression was performed using the stats.linregress method from SciPy (Virtanen et al., 2020) providing significance (p), correlation (r), and slope (b). Multiple regression was carried out with the OLS method in the Python 3 statsmodels package (Seabold and Perktold, 2010) with models evaluated in order of increasing Akaike information criterion. Standardized regression coefficients (B) were produced by normalizing all variables (converting to z scores) before regression. CCVs were assessed in regression models both using original variables and their principal components produced by the PCA method in statsmodels.

What type of regression was performed? Linear, least squares, orthogonal distance? OLS needs to be defined. It is unclear what is meant by CCVs were assessed in regression models. What were they assessed for? Akaike information criterion needs a reference.

**Comment 16**
Page 7, line 212: The largest total loss of C in burnt plot compartments due to fire was from the duff layer (Fig. 2a) About three quarters of the moss/litter C was removed from burnt plots, comprising about half as much as the total amount of C that was removed from the duff layer. Understory C removal due to fire was near complete, but had a relatively small contribution to overall elemental stocks and their changes. **Of the average amount of C lost from these three compartments, 54.3% was found in the averaged char layer and only 0.19% in the increased C found in burnt plot mineral layers which themselves had no significant overall change in C between control and burnt plots.**

This sentence is confusing. Does this mean 54.3% of the C lost from duff, moss/litter and understory was redistributed into the char layer? Was the rest emitted to the atmosphere?

**Comment 17**
Page 7, line 204: Section 3.1

This section is difficult to follow. Maybe consider adding subsections for clarity and readability.

**Comment 18**
Section 3 Results:

It would be helpful to see how these results vary as a function of ecosystem type to extrapolate the results to other boreal regions.

The authors mention adding variables to models to improve fits in numerous places in the results, but do not adequately describe the models or variable combinations in the methods.

The results focus primarily on the redistribution of C and N into different forest pools (or compartments). Perhaps the title of the manuscript should be changed to reflect this focus?

**Comment 19**
Page 8, line 235: To quantify the relative contribution of fire induced changes in organic layer depth, bulk density and elemental weight ratios on organic layer C and N losses they were linearly combined and entered into multiple regression.

More information is needed to describe the multiple regression. “entered into” is unclear. Do the authors mean they performed a multiple regression on the linearly combined variables? What is meant by linearly combined? Added? The following discussion concerning the combination of variables in an attempt to explain changes in C and N stocks is unclear. Plots showing the raw data and model fits would be tremendously helpful in understanding this section.

**Comment 20**

Section 3.3

While the p values are significant, the correlations are poor. The author should more fully address the low correlations.

**Comment 21**
Page 9 line 266: MAT was negatively quadratically related to losses in CO (p = 0.008, R2 = 0.186) and NO (p = 0.002, R2 = 0.233), both peaking near 4°C.

There is no clear description of applying a quadratic model fit to the variables in the methods. Again, plots of the data and model fits would be extremely helpful.

**Comment 22**
Section 4.3

Has the transport of N via aerosol emissions from nearby fires or even re-distribution within the same area due to a fire been considered?

## Technical Corrections

Suggested changes in red.

Page 1, line 22: The balance of C transferred between atmospheric and terrestrial stocks on ~~the~~ a yearly timescale is dictated by rates of terrestrial net primary production and respiration, which are ~~strongly~~ controlled by temperature, moisture and nitrogen (N) availability.

Page 2, line 29: Further, bioavailability of energy sources and nutrients is substantially affected as elements such as C and N are lost, and their chemical structure is altered by heating.

Page 2, line 30: Along with a changing climate, these effects have the power to influence community structure and process rates, thereby shaping future forest C and N cycles on decadal to centurial timescales.

Page 2, line 38: However, in order for this fuel to be available to ignite and ~~propagate~~ sustain fire, it must be sufficiently dried and spatially arranged to be ~~susceptible~~ amenable to high heat and oxygen exposure during an active fire.

Page 2, line 40: Therefore, boreal wildfire models often incorporate short term fire weather variables (e.g. drought indices, temperature, wind speed, relative humidity) and separate ~~as well as separate~~ fuel loads into distinct compartments, such as surface litter, to address the temporal variability in fuel availability. Fuel structure ~~which~~ influences ignition and rate of spread, and the more compactly arranged layers below ~~which~~ act as a heat reservoir that supports ~~extending~~ smoldering combustion over days to weeks.

Page 2, line 49: Fuel chemical composition ~~chemistry~~, arrangement, moisture content, applied heat and oxygen availability in turn have all been related to the efficiency of the combustion reaction during fire and therefore emission chemistry and the charring of remaining non-volatilized fuel.

Suggest adding reference: Lobert, J.M. and Warnatz, J., 1993. Emissions from the combustion process in vegetation. *Fire in the Environment*, *13*, pp.15-37.

Page 3, line 60: For example, the Eurasian boreal region is dominated by relatively fire resistant vegetation that promotes lower intensity fire (Rogers et al., 2015; de Groot et al., 2013a) and C loss (**0.88 kgC/m2**) (Ivanovaet al., 2011) than that in typical ~~(Walker et al., 2020)~~ North American wildfire (**3.3 kgC/m2**) (Boby et al., 2010; Walker et al., 2020).

Are the C loss estimates an average over many years? More description is needed.

Page 3, line 64: Although ~~Though~~ Eurasia contains over 70% of the boreal global land area (de Groot et al., 2013a)~~,~~ and about 50% (20 Mha/yr) of its yearly burnt area (Rogers et al., 2015), wildfire emissions from this region are severely under sampled in the field (van Leeuwen et al., 2014).

Missing many references. Suggest adding the following:

Akagi, S.K., Yokelson, R.J., Wiedinmyer, C., Alvarado, M.J., Reid, J.S., Karl, T., Crounse, J.D. and Wennberg, P.O., 2011. Emission factors for open and domestic biomass burning for use in atmospheric models. *Atmospheric Chemistry and Physics*, *11*(9), pp.4039-4072.

Andreae MO. Emission of trace gases and aerosols from biomass burning–an updated assessment. Atmospheric Chemistry and Physics. 2019 Jul 4;19(13):8523-46.

Andreae MO, Merlet P. Emission of trace gases and aerosols from biomass burning. Global biogeochemical cycles. 2001 Dec;15(4):955-66.

De Groot, W.J., Pritchard, J.M. and Lynham, T.J., 2009. Forest floor fuel consumption and carbon emissions in Canadian boreal forest fires. *Canadian Journal of Forest Research*, *39*(2), pp.367-382.

Potter, C., 2018. Ecosystem carbon emissions from 2015 forest fires in interior Alaska. *Carbon balance and management*, *13*(1), pp.1-10.

Rogers, B.M., Veraverbeke, S., Azzari, G., Czimczik, C.I., Holden, S.R., Mouteva, G.O., Sedano, F., Treseder, K.K. and Randerson, J.T., 2014. Quantifying fire-wide carbon emissions in interior Alaska using field measurements and Landsat imagery. *Journal of Geophysical Research: Biogeosciences*, *119*(8), pp.1608-1629.

Page 3, line 75: ~~Analysis intended to~~ The goal of this study is to distinguish the effects of climate on fire induced changes in C and N stocks with direct, fine scale measurements and little **loss of generality** thereby providing insight into both local processes and valuable, globally comparable data from an under sampled region.

Not sure what is meant by "little loss of generality."

Page 3, Line 88: 50 burnt plots were selected from a pool of 325 fires identified during the summer 2018 period which were mapped from remotely sensed data and provided by the Swedish Forest Agency (**Skogsstyrelsen**).

And Page 4, Line 94: The first constraints on site selection were to avoid wetland or steeply sloping areas using prefire, topo-edaphic derived soil moisture data (TEM) provided by the Swedish Environmental Protection Agency (**Naturvårdsverket**) (Naturvårdsverket, 2018) and 95 elevation and slope data provided within the ArcGIS software environment.

And Page 4, Line 110.

Is the reference referring to a location? Please clarify.

Page 4, line 90: Remote sensed data was taken as the average pixel value within a 20 m diameter circle centered on the plot with GIS analysis utilizing QGIS (QGIS Development Team, 2019), ArcGIS (Esri Inc., 2019) and the pandas Python 3 package (Wes McKinney, 2010).

The authors describe their methodology for using remotely sensed data before describing exactly what that data is and where it is from. Suggest reorganizing this section.

Page 4, line 100: Sentinel-2 infrared imagery taken during the time of fire was used to delineate ~~assisted in delineating~~ the exact locations of burnt plots by determining ~~placing them~~ where ~~there had been~~ a strong and consistent infrared signal existed ~~that was well~~ within the mapped final fire perimeter ~~boundaries.~~

Page 4, line 121: The compartments included ~~These were the~~ four soil layers, ~~of~~ mineral, duff, moss/litter and char, as well as ~~the~~ two aboveground compartments, ~~of the~~ understory and overstory vegetation.

Page 4, line 122: The organic layer was defined as the ~~considered the grouping of the~~ duff, moss/litter and char layers grouped together.

Page 5, line 146: If a fallen tree was charred only on its lower (in standing orientation) portions, it was deemed standing during fire ignition and its measurements were included if its base was within plot boundaries.

Page 5, line 153: Only bole diameters from the burnt plots were used to investigate ~~When testing~~ the influence of overstory vegetation on C and N loss, while bole diameters from adjacent control plots were ignored. ~~bole diameters from the burnt plots were used and not the adjacent control~~. C and N stock estimates for overstory were not included in this analysis, and the measurements were only used to assess its role in controlling C and N stocks in all other compartments.

Page 6, line 165:CCVs for these two layers were calculated as the sum of the ~~formed by~~ weights of these coarse and fine fractions.

Page 6, line 175: ~~Data was stored in comma-separated value files with minimal redundancy. Calculations were performed with custom written Python 3 code using the pandas library.~~ The measurable properties used in C and N stock calculations within soil compartments are the depth, bulk density and CR or NR.

I suggest deleting the first two sentences in this paragraph, as they are unnecessary. Throughout the manuscript, “stock calculations” need to be defined as C and/or N stocks. Otherwise, it is difficult to understand what is meant by “stock calculations.”

Page 7, line 187: These distributions were approximated as normal and unless otherwise noted, and all confidence intervals were constructed at the 95% level using the formula

Page 7, line 204: C and N stock losses and rearrangement.

Suggest changing the word “rearrangement” to “redistribution” throughout the manuscript.

Page 10, line 315 The char layer was likely largely produced by fire interacting with the understory and moss/litter layer, however averaged char layer C and N stocks were greater than losses from the two layers combined suggesting there were also large contributions ~~also~~ from the duff layer.

Page 11, line 318: Because the char layer was conglomerated and completely blackened, it is unlikely that material was incorporated postfire.

Page 11, line 327: N losses in non-boreal forests have been related to fire ~~fuel~~ temperature during time of fire with lower intensity fires transferring a greater proportion of pools of organic N into soil ammonium and nitrate rather than removing N in gaseous forms (Neary et al., 1999).

Page 11, line 331: Therefore, the N cycle in boreal systems may be highly dependent on active fire properties, fuel type and resulting fuel transformation, and the greater N losses in Alaska compared to Eurasia could be explained by its dissimilar fuel and the characteristically more intense crown fires across the North American boreal zone (de Groot et al., 2013a; Wooster and Zhang, 2004).

Page 11, line 359: This direct effect was largely mediated by the incorporation of measures of fire-induced fuel transformation into the models, i.e. production of char layer C or N.