

Abstract

Forest ecosystems in Maine are crucial in sequestering atmospheric carbon through photosynthesis, a process heavily influenced by climate conditions and CO₂ fertilization. The interactions between these variables are complex and dynamic, reflecting the delicate balance of forest ecosystems. However, climate change and rising atmospheric CO₂ concentrations are potentially reshaping this balance, altering the carbon sink in forests significantly.

Project overview

In this study, we used forest inventory, flux-tower measurements, and process-based model estimates to investigate the primary factor correlated with forest production in Maine. Additionally, we assessed the influence of climate change and rising atmospheric CO₂ concentration on this dynamic equilibrium.

Forests in Maine

The three climate zones in Maine exhibit significant differences in conditions such as temperature and precipitation, which greatly shape their respective forests.

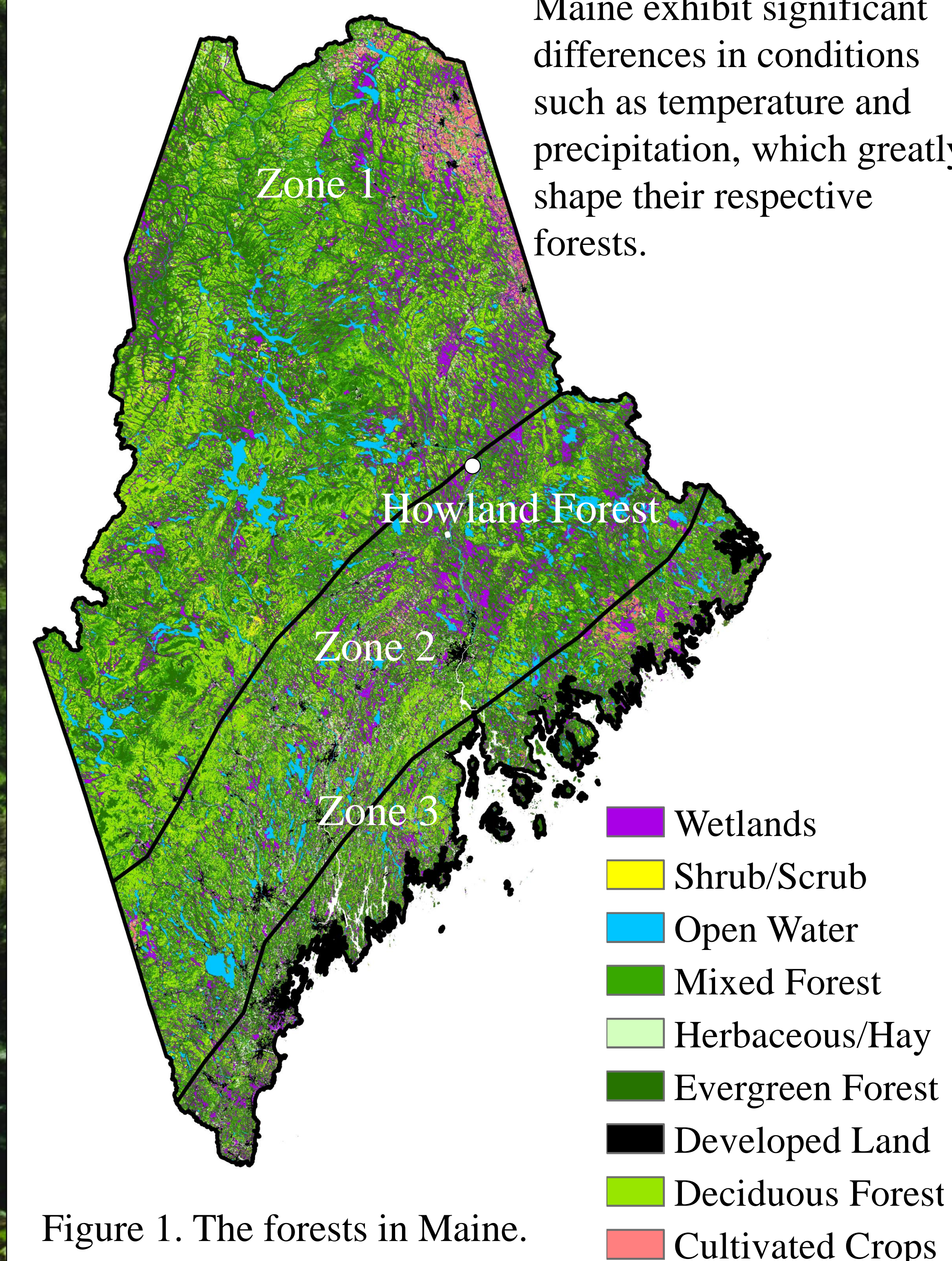


Figure 1. The forests in Maine.

Methods and Results

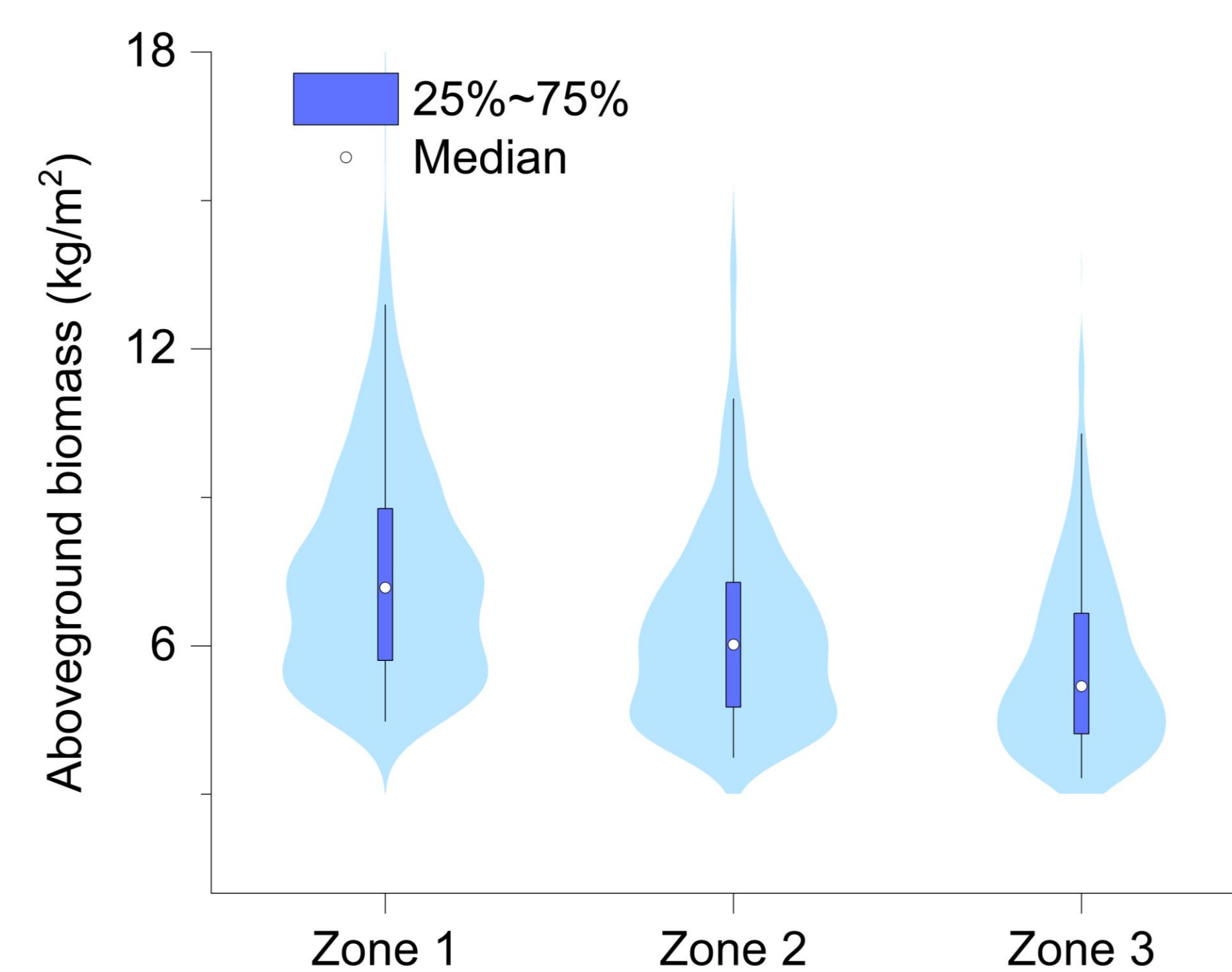


Figure 2. The aboveground biomass (AGB) in the three climate zones in Maine.

To investigate the shifts of interactions between rising atmospheric CO₂ concentration and climate change on forest production, we employed a mixed-effects model using flux tower measurements from Howland Forest.

$$GPP \sim CO_2 + \omega + CO_2:\omega$$

$$GPP \sim \omega + CO_2 + \omega:CO_2$$

where GPP is the gross primary production, ω is the temperature, and $CO_2:\omega$ represents the interaction effect between CO₂ and temperature on GPP.

- Temperature can exert significant constraint on the GPP-CO₂ fertilization relationship.
- The effects of CO₂ fertilization on forest productivity are significantly amplified by higher temperatures, potentially leading to an enhanced response in forest photosynthesis under elevated temperature levels.
- In addition, climate warming has a similar effect on forest productivity. Particularly, when the concentration of atmospheric CO₂ surpasses a critical saturation point, the effects of temperature become more significant.

To investigate the influence of climate conditions on the carbon stock in the three climate zones, we used the AGB inventoried by the Forest Inventory and Analysis (FIA).

- All the plots are covered by forests and experienced no disturbances in the past 20 years.
- Forests in climate zone 1, characterized by lower temperatures and less precipitation, have the highest biomass. In contrast, zone 3, with its higher temperatures and greater precipitation, has the lowest aboveground biomass.

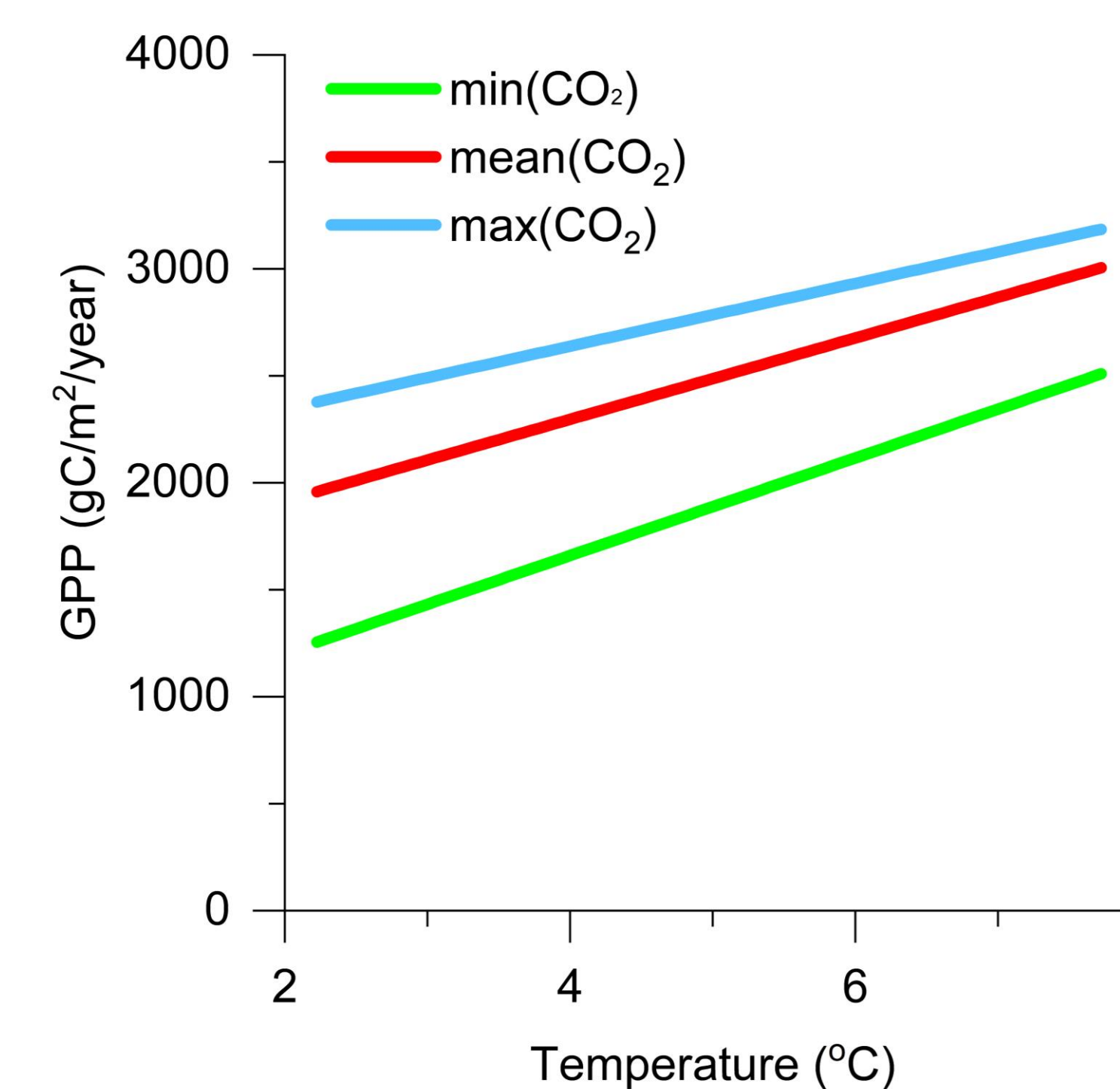


Figure 3. The mixed-effect model generated predictions of Gross Primary Productivity (GPP) at the minimum, mean, and maximum levels of temperature.

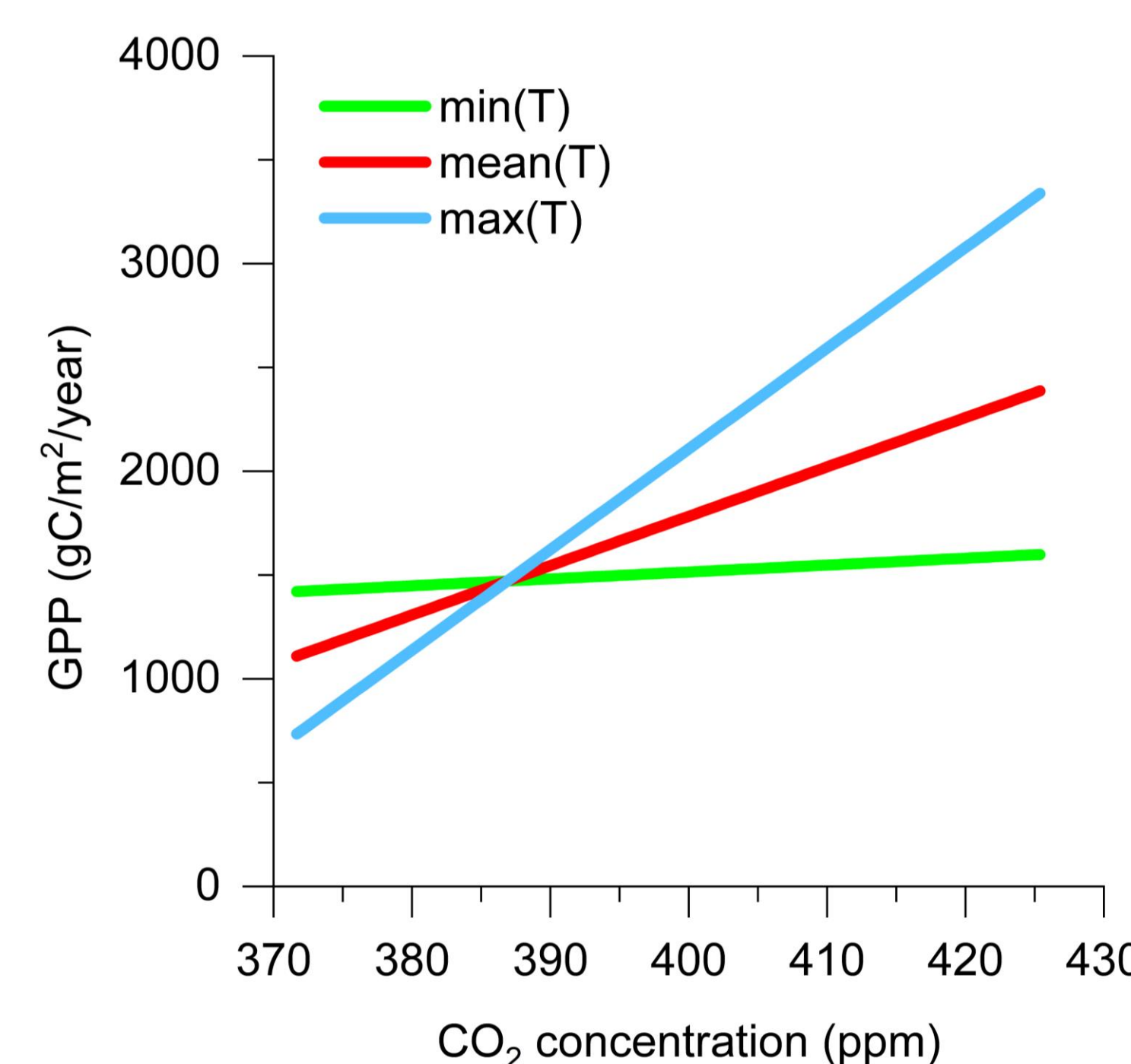


Figure 4. The mixed-effect model generated predictions of Gross Primary Productivity (GPP) at the minimum, mean, and maximum levels of atmospheric CO₂ concentration.

To further understand how climate warming and increased atmospheric CO₂ concentration impact forest production, we utilized the Functionally Assembled Terrestrial Ecosystem Simulator (FATES). This simulator was coupled with the Energy Exascale Earth System Model (E3SM) land model (ELM), and we conducted a site simulation for the Howland forest ecosystem.

- Scenario 1: Climate data and CO₂ concentration as recorded by the flux tower in Howland Forest.
- Scenario 2: Elevated temperature (+2°C).
- Scenario 3: Increased temperature (+2°C) and elevated CO₂ concentration (430 ppm).

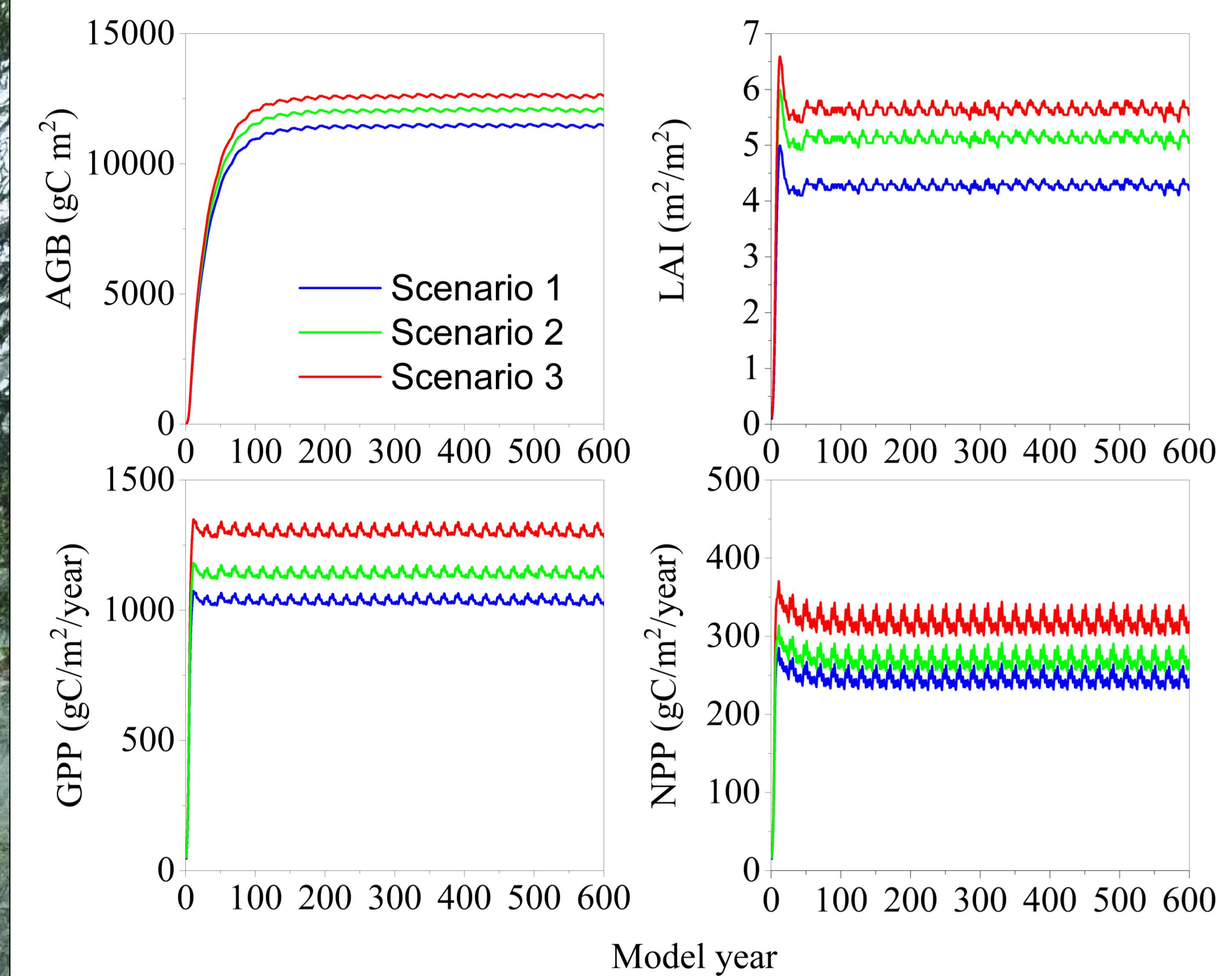


Figure 5. The simulated the Aboveground Biomass (AGB), Leaf Area Index (LAI), Gross Primary Production (GPP), and Net Primary Production (NPP) for the Howland forest under the three simulation scenarios.

Conclusions

- Climate warming potentially reduces the forest carbon storage in Maine.
- A surge in CO₂ concentration can boost the production of forest ecosystems in Maine. However, as atmospheric CO₂ concentration continues to rise, temperature will act as a significant limitation, inhibiting the CO₂ fertilization effect.
- Climate warming might help to mitigate this limitation and rising atmospheric CO₂ concentration will enhance forest productivity in Maine.