学　位　論　文　内　容　の　要　旨

博士の専攻分野の名称：　博　士（食資源学）　　　　氏名　　二宮秀輝

学　位　論　文　題　名

The impact of non-structural carbohydrate production on the forest dynamics under climate change estimated by spatially explicit individual-based global dynamic vegetation model
（空間明示的個体ベース動的全球植生モデルを用いた気候変動下における非構造性炭水化物の生産が森林構造に与える影響の将来予測）

Global warming, which has been ongoing since the Industrial Revolution, has intensified extreme weather such as droughts, wildfires, and insect outbreaks. Understanding the global carbon cycle is crucial for accurately assessing the impacts of climate change.

Non-structural carbohydrates (NSCs) are essential carbon reserves for plant growth, metabolism, and defense against environmental stress. NSCs compensate for energy shortages when stomata close and photosynthesis rates decline. However, during prolonged droughts, the depletion of NSCs can create an imbalance between supply and demand, resulting in carbon starvation and contributing to drought-induced tree mortality. Because carbon starvation is challenging to estimate based solely on ground measurements, modeling NSC dynamics within ecosystem models is vital for simulating the global carbon cycle accurately. However, current vegetation models often oversimplify these dynamics and lack mechanisms to simulate NSC-driven mortality effectively. The objectives of this research were to develop a new NSC compartment based on observational data within the spatially explicit individual-based dynamic global vegetation model (SEIB-DGVM), and to simulate the effects of carbon starvation on forest dynamics under climate change.

I developed a new module to estimate NSC dynamics based on observational data. NSCs are allocated among three plant organs (leaf, trunk, and root) respectively, and the amounts depends on the biomass of each organ and the daily carbon assimilated through photosynthesis. The parameters governing NSC accumulation vary across climate regions (boreal, temperate, and tropical). I validated the modeled NSC concentrations against observations at both point and global scales. Results of validation at the point scale s demonstrated a strong agreement between simulated NSC concentrations and observed data. At the global scale, I analyzed the mean NSC concentrations across different climate regions and biome types, which also showed a strong alignment with observed data.

Next, I simulated the new model under Shared Socio-Economic Pathway (SSP) scenarios to analyze forest composition and biome type percentages across Asia, Europe, and

North America. In the new model, taller trees accumulated more NSCs, which inhibited their growth, resulting in lower mean tree height and diameter at breast height (DBH) compared to the previous model. However, under SSP scenarios, the new model predicted a bimodal distribution of trees, with taller, thicker trees dominating northern regions and shorter trees in southern regions, particularly in Europe. These results aligned well with previous research on drought effects, reflecting the sensitivity of trees to warm and dry conditions.

I also incorporated a carbon starvation mortality process where tree mortality rates increased as NSC concentrations decreased, and analyzed its impacts on global forest composition from 2015 to 2100. When carbon starvation occurred, taller and thicker trees became more dominant, while overall tree numbers and tree age decreased across Asia, Europe, and North America. This indicated that carbon starvation reduces tree density, allowing surviving trees to grow taller, but it also shortens tree lifespans. The number of grids affected by carbon starvation is projected to expand in North America, where vegetation productivity was increasingly constrained by water availability between 1982 and 2015 due to drought impacts. These results showed that the growing number of regions experiencing carbon starvation as CO_2 levels rise further supports the notion that plants are becoming increasingly sensitive to drought. In these areas, plants are expected to become more vulnerable to carbon starvation, leading to reduced tree populations and shorter lifespans.

The new model significantly improved simulations of vegetation distribution, gross primary production (GPP), and forest composition on a global scale by incorporating the NSC compartment. As more observed NSC data becomes available, the model could be further refined to simulate NSC dynamics across different plant functional types. This research contributes to a better understanding of how NSC production in plants influences the terrestrial global carbon cycle and the effects of carbon starvation under climate change.