様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

令和　６ 年　６ 月　４ 日現在

機関番号：３４３１６
研究種目：基盤研究(C)（一般）
研究期間：2021～2023
課題番号：２１Ｋ０５６８９

研究課題名（和文）Will tree seedling fitness and survival decline in the face of climate change? A novel quantitative approach with implications on forest regeneration

研究課題名（英文）Will tree seedling fitness and survival decline in the face of climate change? A novel quantitative approach with implications on forest regeneration

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交付決定額（研究期間全体）：（直接経費）　　3,200,000円

研究成果の概要（和文）：気候温暖化が苗木の炭素収支に及ぼす影響（LFPと名付けた）をシミュレートし、その光合成反応プロファイルを用いて、数種の樹木の苗木のLFPを定量化するという目的を達成した。その結果、1）森林の樹冠タイプはLFPに大きな影響を及ぼし、深い日陰の落葉樹林では苗木のLFPを維持するのに十分なエネルギーが得られない（LFP < 0）；　2）シミュレートされた温暖化（現在の+1.5℃）のLFPは種固有の影響を及ぼし、すべての種がマイナスの影響を示したわけではない。

研究成果の学術的意義や社会的意義
Facing the onslaught of climate change, it is incumbent upon us to anticipate its impact- on forest dynamics, in this case. This study addressed the issue of quantifying the fitness of tree seedlings under simulated climate change and found a surprising diverse response to a +1.5oC warming.

研究成果の概要（英文）：We have achieved the objective of quantifying tree seedling fitness for several species by using their photosynthetic response profiles in simulated effects of climate warming on seedling fitness (which we named LFP). Our findings suggest 1) forest canopy type has a large effect on LFP where the deeply shaded deciduous forest offer insufficient energy to sustain seedling fitness (LFP < 0); 2) simulated warming (current +1.5oC) has a species-specific effect on LFP and not all species showed a negative impact; 3) in a future with a longer canopy cover duration, LFP will decline in all species examined, some below the break-even point of LFP < 1.

研究分野：Plant Ecophysiology

キーワード：Forest ecology　Carbon gain　Climate warming

１．研究開始当初の背景

Our motivation for this study came from the desire to predict the performance (in terms of carbon gains) of tree seedlings under a warm-temperate forest canopy and ask what would happen to that performance if climate change were to alter the dynamics of the seedling-canopy relationship. That relationship is predicated on 1) dim forest light strongly depresses seedling carbon gain and 2) high temperatures inhibit carbon gain especially under dim light. Since climate change is expected to subject seedlings to longer canopy shade (canopy leaves emerge earlier) and higher summer temperatures, we predict that future climate will lead to reduced carbon gain, seedling fitness and their long-term survival.

２．研究の目的

To validate these expected seedling outcomes, we employed a technique that quantifies seasonal carbon balance in seedlings of several common forest tree species with different suites of ecophysiological traits. We simulated their season carbon gains under different canopy types (evergreen, deciduous and gap) to obtain a diverse range of seedling-canopy response outcomes. These simulations intend to show deviations from current expected seasonal carbon balance (i.e. Leaf Functional Parity) resulting from future warming scenarios. The extent of lowering LFP allows us to quantify the impact of climate change on seedling fitness and survival.

３．研究の方法

This study provides species-specific seedling fitness outcome under a warming scenario useful in predicting future changes in forest seedling dynamics. The seedling fitness outcome central to this study is based on first producing an irradiance x temperature profile of photosynthetic response for each seedling species. Then, we apply this response profile to actual forest microclimate data to derive daily, monthly and seasonal carbon gain. If seasonal carbon gain exceeds the expected leaf cost-carbon contribution, then LFP is achieved, leading to a prediction of high seedling fitness. Our aim is to quantify the degree of LFP decline through simulating early canopy expansion (longer understory shade) and increased summer temperature. Changes in LFP values offers a direct assessment of climate warming on the fitness of different species under different forest canopy covers.

４．研究成果

Quantifying seedling photosynthetic response profiles

Our primary aim of quantifying forest seedling carbon gain patterns and using these to simulate Leaf Functional Parity (LFP) has been achieved. The first step of this effort was to describe the ecophysiological properties of six common forest species. The result of this, i.e., the instantaneous carbon assimilation rate for a given light (Photosynthetically-Active Radiation, PAR) and air temperature, is shown in Figure 1.

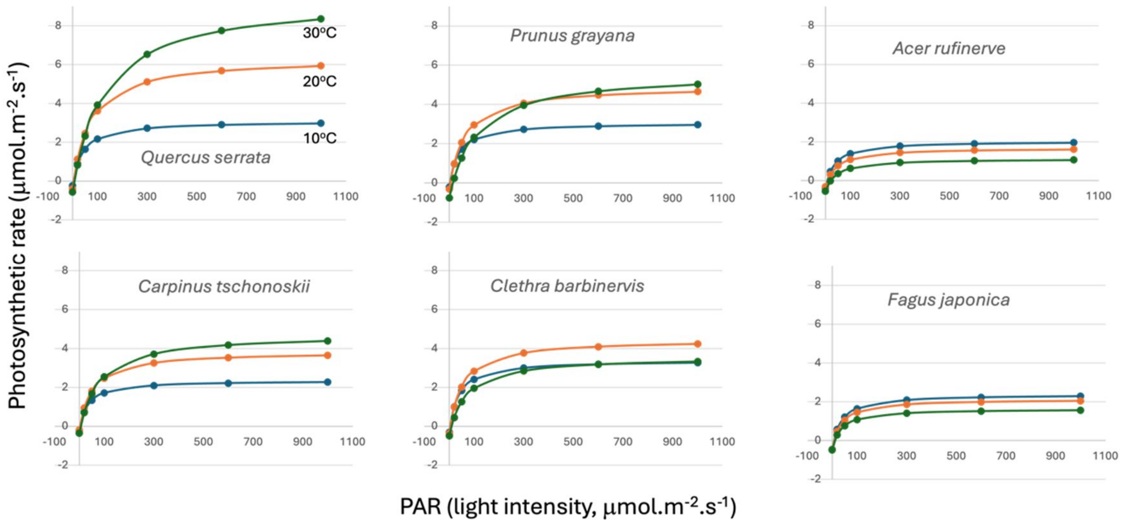

Figure 1. Profiles of photosynthetic responses to PAR and temperature variations in 6 common forest tree

seedlings. Some species showed highest activity at 30ºC (e.g., *Quercus*) while others prefer lower optimal temperatures (e.g., *Clethra*).

Simulating seasonal carbon gain in seedlings

From the photosynthetic response profile of Fig. 1, we estimated net leaf carbon gain of each species using actual microclimate data collected at three typical forest sites (i.e., forest gap, evergreen conifer and deciduous oak). By summing the data, we can obtain daily, monthly, or seasonal carbon gain for each species. By presenting the cumulative carbon gain across a growing season under different forest canopies, we show (Figure 2) that species vary in their ability to achieve Leaf Functional Parity (LFP). Depending on their ecophysiological and leaf construction cost (LMA) profile, species such as *Quercus serrata* attained significant carbon surplus (explain graph) while *Acer rufinerve* showed carbon deficits in most situations.

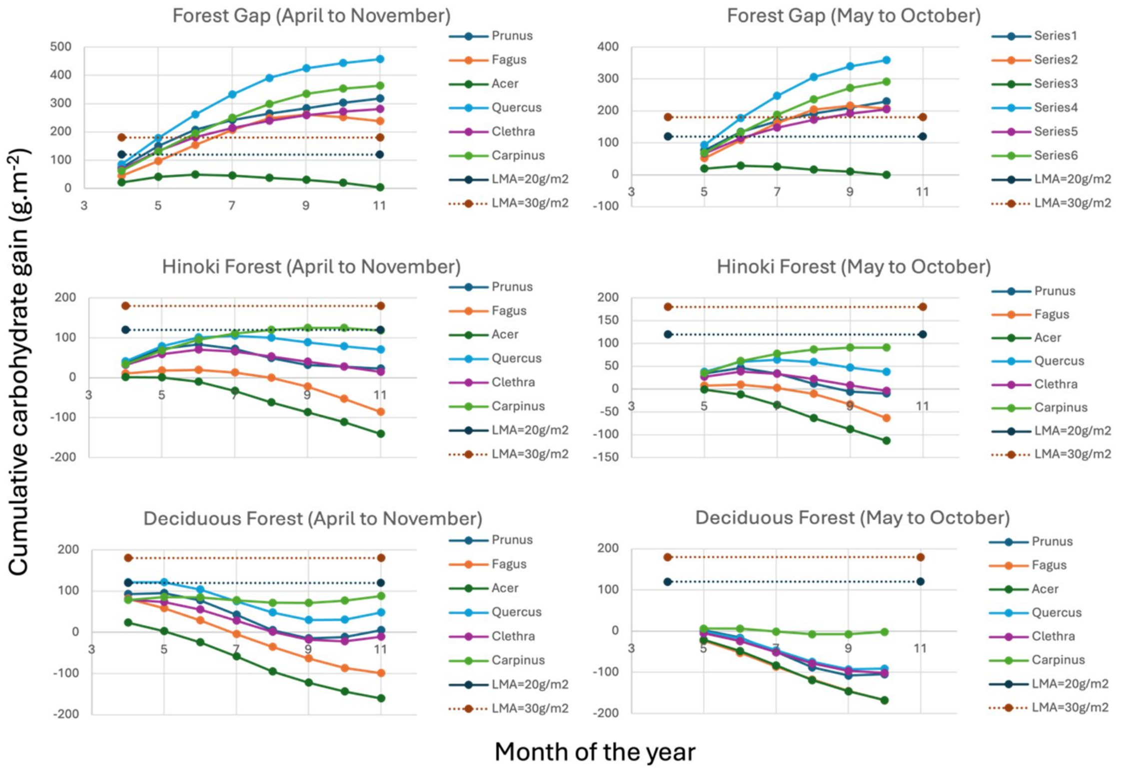

Figure 2. Simulated monthly gain in carbohydrates per leaf area of six common forest species under three canopy types (Forest Gap, Hinoki and Deciduous oak canopy covers). Left three panels simulate a longer growing season beginning in April and ends in November while the three panels on the right simulate a shorter season (May to October). The two dashed lines represent leaf cost (LMA) at two common values. LFP is achieved when the seasonal carbon gain exceeds the cost (e.g., most of the species in Forest Gap).

LFP and forest canopy conditions

Based on the predicted seasonal carbon gain, only the forest gap environment provided sufficient PAR and temperature scheme to achieve LFP; hinoki canopy came in second but most species failed LFP even in an extended growing season. A *Q. serrata* canopy offered the least solar energy where no species reached LFP and if calculated based on a shorter season of May to October, seedlings did not even attain positive carbon gain for the season. These results suggests that some seedlings experience significant carbon deficits which will lead to their death. While seedlings in locations such as under the deciduous forest cover are unlikely to survive even without the impact of climate change, will those showing a carbon surplus in the current environment fail to achieve LFP as a result of climate change?

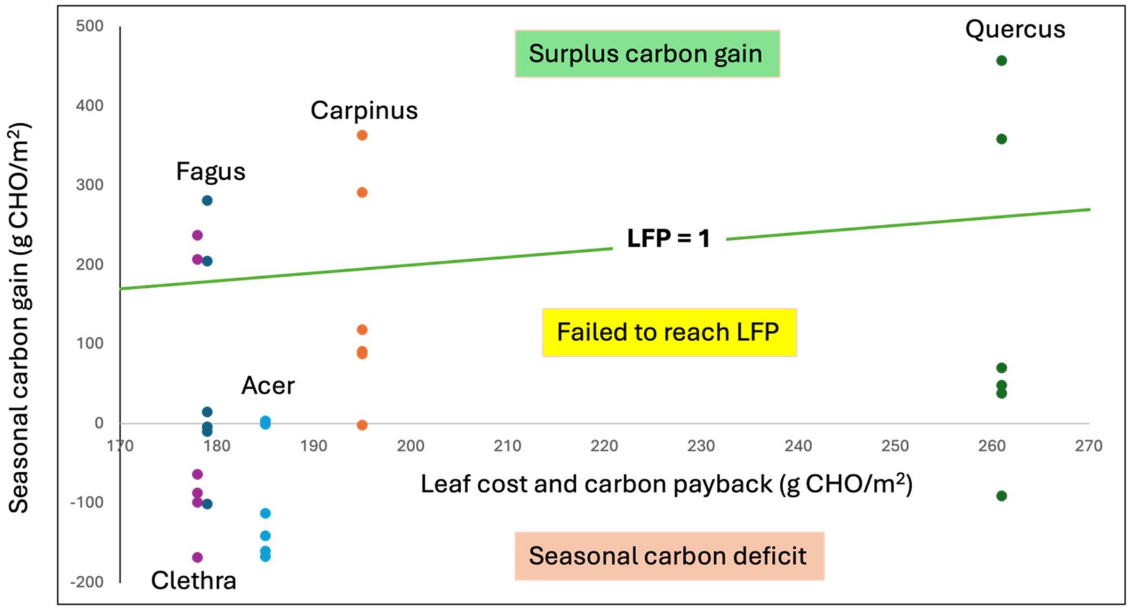

Figure 3. A plot of simulated carbon gain in 5 common tree seedlings over the growing season (based on data given in Fig. 2). For each species, the top two dots are those simulating the two growing season lengths under Forest Gap. There is carbon surplus when LFP>1, carbon gain is considered incomplete at LFP between 0 and 1, carbon deficit occurs when carbon gain is <0. *Acer* stands out as being quite poor in assimilating carbon, showing a deficit even under the best light conditions.

Simulating the impact of future warming on LFP

Based on simulations of seasonal carbon gain in a forest gap (Fig. 4) when the canopy duration is April 1 to November 30 versus a shorter one of May 1 to October 31, four species showed a decline in LFP from 1.57 to 1.15 (*Quercus*), 1.86 to 1.49 (*Clethra*), 1.75 to 1.37 (*Carpinus*) and 1.33 to 1.17 (*Fagus*). Notably, *Fagus* is the only species that showed an increase in LFP under the simulated +1.5ºC environment (Fig. 4, *Fagus*). While a shorter canopy duration and warmer conditions can have an additive effect on reducing LFP (see *Clethra* Fig. 4), for some species (i.e., *Carpinus* and *Quercus*), the effect of warming was negligible compared to that of canopy duration. These results indicate that a warmer summer and a longer forest canopy cover resulting from early canopy leaf emergence could reduce carbon gain of understory seedlings to below LFP even under forest gaps. In locations where the light environment is less favourable (such as under Hinoki and Deciduous oak), the shorter growing season will further depress carbon gain. It is interesting that simulated warming had almost no effect or even an increase on LFP.

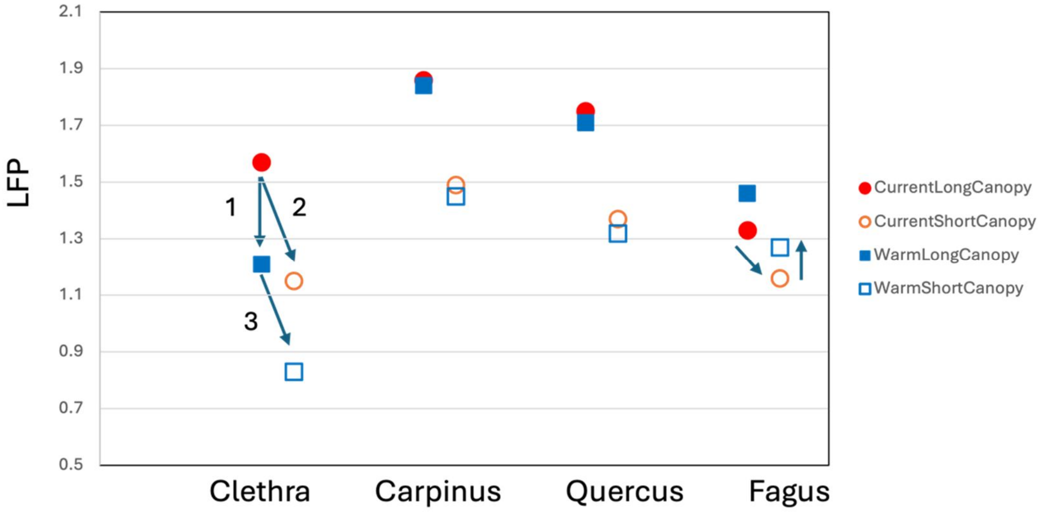

Figure 4. Summary of the simulated effect of climate warming on seedling fitness (i.e., LFP) under Forest Gap. Higher LFP infers higher fitness. For each of the 4 species shown, the change from current climate and forest canopy duration (solid circle) to a +1.5ºC growing season (solid square, 1) or, to a shorter canopy duration (open circle, 2). Open square represents both a warmer summer and a shorter canopy duration, its value relative to a warm longer canopy duration is indicated by 3.

Conclusion

In conclusion, in this study, we have achieved the objective of quantifying tree seedling fitness (in the form of LFP) for several species and using their photosynthetic response profiles we simulated the effect of climate warming on seedling LFP. Our findings suggest 1) forest canopy type has a large effect on LFP where the deeply shaded deciduous forest offer insufficient energy to sustain seedling fitness (LFP < 0); 2) simulated warming (current +1.5ºC) has a species-specific effect on LFP and not all species showed a negative impact; 3) in a future with a longer canopy cover duration, LFP will decline in all species examined, some below the break-even point of LFP < 1. We plan to further investigate how values of LFP relate to long-term seedling survival through forest demographic modeling.

Presentations:

We have presented preliminary findings at the **里山サロン** of **里山学研究センター**in July 2022, entitled "**気候変動下で樹木の苗木の適応度と生存率は低下するのか？新しい定量的アプローチ**"

５．主な発表論文等

〔雑誌論文〕　計0件

〔学会発表〕　計1件（うち招待講演　1件／うち国際学会　0件）

１．発表者名 Lei Thomas Ting
２．発表標題 気候変動下で樹木の苗木の適応度と生存率は低下するのか？新しい定量的アプローチ
３．学会等名 里山学研究センターセミナー（招待講演）
４．発表年 2022年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

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７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関