論文の内容の要旨

論文題目　Regeneration sites for deciduous broad-leaved trees and evergreen conifers in a cool-temperate forest: An approach from light-availability and whole-plant growth rate

（冷温帯の遷移後期的落葉広葉樹と常緑針葉樹の更新場所はどこか―光環境と個体の成長からのアプローチ）

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In a cool-temperate forest, deciduous (summer-green) broad-leaved trees are apparently dominant, although in other temperate forests evergreen tree species are dominant. However, the structure of a cool-temperate forest is not fully understood; dominant deciduous trees cannot seem to regenerate successfully; evergreen coniferous species are also distributed in a cool-temperate forest, tough, their growth and regeneration have been never compared to deciduous species'. In this study, we detected which is later-successional, evergreen coniferous species or deciduous broad-leaved tree species in a cool-temperate forest, to understand the structure of a cool-temperate forest.

First, we investigated the light availability for photosynthesis in the understory of a cool-temperate forest. Second, we contrasted the regeneration success of an evergreen conifer, *Abies firma* (AF), and typical late-successional deciduous broad-leaved tree species, *Fagus crenata* (FC) *and F. japonica* (FJ), at various light-availability sites. Last, we tried to clarify what physiological- and morphological traits explain the differences in growth and regeneration success in the forest understory.

Long-term, short-interval measurements of incident photosynthetically active photon flux density (PPFD; μmol m^{-2} s^{-1}) on the forest floor are essential for estimating the leaf carbon gain of understory plants. Such PPFD data, however, are scarce. We measured PPFD at 1-min intervals for more than 12 months in cool–temperate forest sites and reported the data as a PPFD frequency distribution. We chose five sites: an open site (OPN), the understory of a deciduous broad-leaved tree stand with no visible gaps (DCD), that of an evergreen conifer stand (EVG), that of a deciduous broad-leaved tree stand with a gap of approximately 80m^2 (GAPDCD), and that of an evergreen conifer stand with a gap of approximately 100m^2 (GAPEVG). DCD were divided into three sub sites (DCD1-3) to investigate variation within a small area. GAP-sites were consisted of two sub sites (GAPDCD1-2 and GAPEVG1-2) differing in the distance from the gap center. Using the PPFD data, we estimated the summer seasonal (May–October) net assimilation rate of leaves (NAR_L) at each site for various photosynthetic capacities (A_{max}: μmol m^{-2} s^{-1}) and other parameters of a light response curve of CO_2 assimilation rates. At OPN, the average daily accumulated PPFD (mol m^{-2} day^{-1}) was highest in May (28.2) and lowest in December (8.2). Even at OPN, the class of instantaneous PPFD that contributed most to NAR_L was 250–300 μmol m^{-2} s^{-1}. Such a large contribution of lower PPFD is suggested to be an important feature of a field light-availability. At DCD, the relative PPFD (RPPFD, %) to OPN was 7.2 during canopy closure and 49.4 after leaf shedding (averaged for 3 sites). EVG had the lowest light environment throughout the year. Its average RPPFD was 3%. For GAP sites, summer seasonal RPPFD (%) was 15.6, 18.8, 6.4 and 15.6 for GAPDCD1, GAPDCD2, GAPEVG1 and GAPEVG2, respectively. At OPN, the NAR_L increased with A_{max} (which ranged from 1 to 40), suggesting that plants at OPN do not maximize NAR_L. In contrast, at DCD and EVG, A_{max} values were attained that did maximize NAR_L, suggesting that plants at these sites could maximize the NAR_L. A_{max}-NAR_L relationships for GAPDCD and GAPEVG showed similar trend to closed canopy sites, DCD and EVG, while NAR_L and A_{max}^* of GAP sites were larger than at these sites. Among DCD1-3, the daily accumulated PPFD (mol m^{-2} day^{-1}) averaged in summer ranged 1.3-1.8 and the maximum NAR_L value differed up to 1.5 times. It indicates that A_{max} and NAR_L can be various among plants under a similar canopy conditions.

At field sites under the three different canopy conditions like OPN, DCD and EVG, we evaluated regeneration success for AF, FC and FJ mainly by sapling height-growth rate and seedling relative growth rate (RGR) and survival rate. In parallel, we measured physiological- and morphological traits of leaf for seedlings, such as net assimilation rate (NAR), leaf mass per area (LMA), leaf-lifespan (LL), allocation rate of assimilates to leaf (Lp), etc. Using these traits, we offered "leaf reproductive index (LRI)". LRI is expressed as (NAR*Lp*LL / LMA), and indicates long-term whole-plant carbon balance, or potential RGR. LRI also shows multiple effects of the traits on potential RGR. By LRI, we tried to explain how these traits affect plant growth and regeneration in the forest understory. Our result shows that an evergreen conifer, AF grow well and can regenerate without gap opening at DCD, whereas, deciduous broad-leaved trees, FC and FJ cannot. FC and FJ had smaller growth- and survival rate than AF. In addition, at EVG, AF continues to grow for longer time than FC and FJ, yet, for the regeneration success, improvement in light-availability will be needed. LRI showed that at DCD evergreen species can maintain positive carbon balance because of sufficiently large NAR by assimilating during leafless period of deciduous trees and long

LL which can make potential RGR > 0 even in the case of NAR < LMA. On the other hand, late-successional deciduous broad-leaved species like *Fagus spp.* was indicated to hardly keep the positive carbon balance under the closed canopy. This is because their LMA is too large relative to the NAR. For maintaining positive carbon balance, for example, FC must have Lp of over 0.9 at DCD, it is not realistic. LRI can be applied to any plant and light-availability if NAR and leaf traits are collected.

Our result clearly indicated that an evergreen conifer, AF, is later-successional than deciduous broad-leaved trees, FC and FJ. We concluded that evergreen tree species can be the latest-successional also in a cool-temperate forest. Deciduous broad-leaved trees will be replaced by evergreen conifers with the succession. However, now in Japanese cool-temperate forest, deciduous forests are seen. It is clear that another mechanism rather than "most shade-tolerant" is needed to explain the current dominance of FC and FJ. Past time human disturbance like logging exerted strongly on conifers can be one of the plausible factors.