論文の内容の要旨

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平成 26 年度博士課程入学
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論文題目　Influences of ambrosia beetle (*Platypus quercivorus*) attacks on evapotranspiration in a secondary warm-temperate forest

（暖温帯二次林の蒸発散量に及ぼすカシノナガキクイムシ（*Platypus quercivorus*）の加害の影響）

ABSTRACT

The incidence of Japanese oak wilt (JOW), which is caused by an Ascomycetes fungus *Raffaelea quercivora* vectored by an ambrosia beetle, *Platypus quercivorus,* has been intensified in Japan since the late 1980s. Previous studies described that the JOW is likely to cause severe impacts on Fagaceae tree dominated forested ecosystems with canopy loss and changes in water and nutrient uptake. Changes in canopy cover, interception, evapotranspiration (ETI), nutrient, and water uptake have the potential to alter hydrologic processes including stream flow and soil moisture following the incident of JOW.

Therefore, the estimation of changes in ETI rate following JOW is important for assessing the water balance of infested catchments. However, changes of transpiration in infested but surviving oak trees, the transpiration response of surrounding trees to the dead oak and changes of watershed level ETI remain unclear in JOW infested forested catchments in Japan. Therefore, this dissertation contributes to filling the knowledge gap in scientific understanding of these intertwined processes by measuring sap flux density variation of infested but surviving oak trees, the measuring transpiration response of surrounding trees, and evaluating the changes of watershed level ETI after a mass attack of *P. quercivorus*. Thus, the purpose of this study was to investigate the influence of *P. quercivorus* attacks on ETI in the secondary warm-temperate forest. The research was conducted in Akazu Research Forest (AKRF), which is a warm-temperate secondary forest own to Ecohydrology Research Institute (ERI), the university of Tokyo Forests in the University of Tokyo. Two main experiments with historical hydro-climatological data analysis were conducted to achieve the objectives.

It was hypothesized that whole-tree sap flux would be reduced in surviving oak trunks owing to sapwood dysfunction; however, part of this reduction would be compensated by enhanced sap flux density (F_d) in the remaining functioning sapwood. To test this hypothesis, 25%, 50%, and 75% of sapwood was removed at breast height to simulate xylem dysfunction for nine *Quercus serrata* trees in AKRF. Granier probes were used to measure the F_d of the treated and three control trees before and after the treatment. Even though tested trees were still alive until at least the end of

the second growing season, external symptoms of weakening were detected in 75% treated trees. The analysis using a linear mixed model showed that whole-tree sap flux was significantly reduced in all treatments. However, 25% and 50% treated trees showed significant F_d compensation, whereas 75% treated trees showed significantly smaller whole-tree sap flux than the value expected from the treatment. These results suggest that the threshold of tree weakening lies between 50% and 75% of sapwood removal, above which the F_d compensation cannot be attained. Therefore, whole-tree sap flux in infested but surviving trees varies with respect to the intensity of sapwood damage.

ETI is more variable following the JOW as decreased transpiration from attacked but surviving trees and die-off of oak trees. However, decreased ETI may be offset by increased transpiration by surrounding trees. The transpiration response of individual tree-scale associated with JOW eventually leads to a larger scale response such as stand-scale or catchment-scale. In order to clarify this hypothesize, girdling treatments were applied to the top canopy oak trees in three treatment groups. F_d of 40 neighboring trees representing canopy, sub-canopy, and understory in control and treatment groups were measured for 104 days using Granier sensors in pre and post-treatment conditions. Permanent canopy wilting was observed on 10 days following the girdling treatment.

There were clear seasonal dynamics of F_d s in trees in the control group, with obviously lower F_d values on rainy and cloudy days compared to that of sunny days. Moreover, F_d tended to be decreased with the season, showing that whole-tree F_d decreased with season progression from summer to autumn. However, F_d of some trees in the treated groups showed unusual higher F_ds, compared to the controls at two different timings; (1) the following day of the treatment, (2) after canopy wilt of treated oak. Moreover, F_d decreases with season progression were absent in the trees which showed unusually higher F_ds. Out of the 31, studied trees in the treated groups, 16 trees (52%) showed F_d increases either one of the above-mentioned occasions. The increased F_ds of neighboring trees indicates that transpiration increases in neighboring vegetation following JOW. However, data analysis using LMM showed that F_d increases of neighboring trees in the treatment groups were not significant ($p>0.05$) when compared with the F_d of trees in the control group. In this experiment, F_d measurement was restricted to the first growing season of the study trees. Therefore, time might be the limiting factor for neighboring trees to increase tree leaf foliage and adjusting tree hydraulic architecture for new micro-climatic condition following the oak die-off. Therefore, the result implies that transpiration increases of surrounded vegetation were not large enough to trade-off transpiration losses due dead oak by JOW in the same growing season. Thus, it can conclude that no significant F_d increases imply no transpiration increases in neighboring trees during the first growing season following the girdling treatment. Therefore, ETI reduction can be anticipated in forested watershed following a mass attack of *P. quercivorus*.

In order to study the long-term (7 years) watershed level ETI change before and after the JOW, oak tree mortality and changes of ETI rates were analyzed in North creek (NC) and South creek (SC) a two paired watersheds in AKRF. The first appearance of JOW in the AKRF was reported in 2007, the epidemic peaked in 2011. From January 2008 to Jun 2011 and July 2011 to December 2012 considered as a pre and post infestation period respectively. Before the onset of JOW, basal area (BA) composed by *Q. serrata* was reported as 9.4 $m^2 ha^{-1}$, and 8.7 $m^2 ha^{-1}$ in NC and SC, respectively. The analysis of annually recorded ambrosia beetle attack data from 2007 to 2014 showed that a rapid tree die-off in 2011 and 27% to 33% of oak tree mortality at the end of 2014 in NS and SC, respectively. At the end of 2014 percentage of BA composed by *Q. serrata* was 50% in NC and 49% in SC. The daily observed ETI rates were determined using short-time period water balance method, while potential ETI were calculated using a simple ETI model developed based on the Priestley-Taylor equation. The observed ETI for before infestation period showed good agreement with a similar study in the past. Moreover, calculated ETI was highly correlated (0.84) with observed ETI for before infestation period. To examine how JOW influenced on watershed ETI, an LMM was employed, in which "ETI" was a response variable, "TYPE of ETI" was a fixed effect, and "date" was a random effect. If the observed ETI of each year negative and significantly smaller than 0, it was decided that observed ETI smaller than that of calculated ETI. Results show that there was no significant difference between observed and calculated ETI in the pre-infestation period in both watersheds. In contrast, observed ETIs were significantly smaller in post-infestation period indicating that JOW caused significant ETI reduction. Furthermore, the comparison between annual observed and calculated ETI showed that 6% and 21% reduction in annual ETI in SC and NC respectively.

As shown in the partial sapwood removal experiment, attacked but surviving trees showing significant transpiration reduction owing to sapwood dysfunction. Moreover, tree girdling experiment showed that increased transpiration in neighboring trees did not significant enough to trade-off the ETI reduction due to oak tree die-off. Therefore, a number of dead oak trees, attacked but living trees, as well as transpiration response of surrounding vegetation, are key factors for determining the watershed scale ETI changes following JOW infestation. Comparison between observed and calculated ETI showed a significant ETI reduction following the incident of JOW. The reductions of ETI in two watersheds were not similar. Results showed that the reduction of ETI varied with reduction of BA coverage by *Q. serrata* in spite of the percentage of BA reduction or tree mortality rate. However, the watershed level ETI analysis showed that compensatory sap flux effect and transpiration increases of surrounding vegetation were not significantly trade-offs the ETI reduction due to oak tree mortality. Previous studies suggested that within a first or second growing season, the reduction of stand-scale ETI is more common in spite of increases of individual tree scale transpiration. Moreover, researchers' emphasis that remaining vegetation and newly recruited vegetation seems to offset the loss of ETI within approximately 8 years following a forest disturbance event. In this study, the post disturbance period was limited to 3.5 years. Therefore, it can be assumed that T response of remaining and newly recruited vegetation small compared to the decreased ETI by oak die-off. In other words, the results suggest that transpiration response for 3.5

years following JOW is not significant enough to trade-off the ETI reduction by oak tree die-off. In conclusion, results demonstrate that JOW infested watershed experience a reduction of ETI, due to the reduction of T in attacked but surviving trees and reduction of T and interception by dead oak trees.

Based on the literature review on, it could be stated that this study is the first attempt to investigate the hydrological influence of JOW. The identification of whole-tree sap flux compensatory effect in treated but surviving *Q. serrata* trees one of the important findings in this study. Moreover, the observed transpiration response of the neighboring vegetation to the girdling treatment and watershed level ETI reduction response following the JOW will be remarkable recordings for filling the knowledge gaps. This information will be useful in better understanding watershed-scale hydrology in forests disturbed by JOW.