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Evaluation of the Potential Effect of Global Warming on Soil Carbon Emission of Japanese Forest Ecosystems（Abstract of the Final Report）

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1. Introduction

The world's soils contain about 1,550 Pg of organic carbon, which is more than twice the amount in the atmosphere [1]. On the other hand, the soil respiration (*R*s), the second-largest terrestrial carbon flux after gross primary production (GPP), from global terrestrial ecosystems was estimated to be 98 ± 12 Pg C in 2008. Moreover, between 1989 and 2008, the global *R*s increased by 0.1 Pg C yr^{-1} [2]. Furthermore, by using a process based model (VISIT), the annual global heterotrophic respiration (*R*h) was estimated to be 58.2 Pg C yr^{-1} [3, 4]. This amount comparable to 6 times of annual anthropogenic carbon (9.5 Pg C yr^{-1}) and 21 times of annual carbon absorption by global terrestrial ecosystem (2.8 Pg C yr^{-1}) [5]. Therefore, relatively small change in the carbon flow into or out of soils can potentially strongly influence global cycles of carbon, nitrogen, and water. However, this modeling prediction has been very difficult to confirm from measurements because *R*s is highly spatially and temporally variable, it cannot be measured by large-scale remote sensing, and the soil medium is not easily accessible.

2. Research Objective

The ultimate objective of this project is to evaluate the potential of carbon sink and/or source of whole Japanese forest soils with climate change by using multi-approaches, including the soil warming experiment, long-term monitoring soil CO_2 efflux at natural and disturbed ecosystems, measurement of soil organic ^{14}C, and model simulation.

3. Results and Discussion

(1) Effects of soil warming on *R*s

(1-1) Soil warming experiment

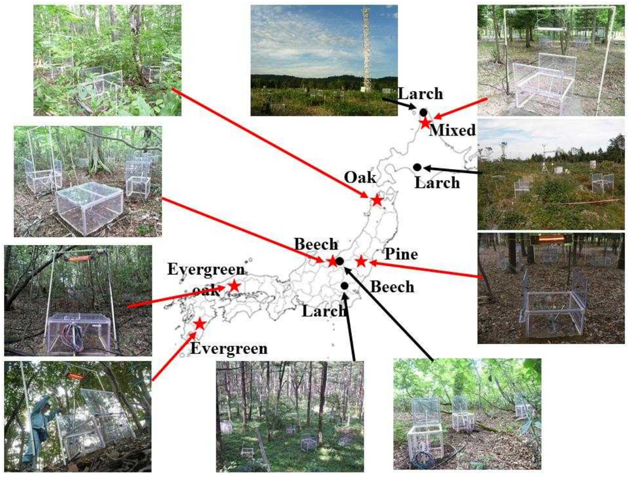

Fig 1. Distribution of the experiment sites. ★: soil warming sites; ●: tower flux and long-term monitoring sites.

From 2006 to 2014, we continued the soil warming experiment at six typical Japanese forest ecosystems, including a 35-year-old cool temperate mixed forest in northern Hokkaido (Teshio of Hokkaido University Forest), a 70-year-old deciduous oak forest in northeast region (Shirakami maintain range), a natural (>100-year-old) beech forest in Hokuriku region (Mt. Naeba), a 55-year-old Japanese red pine forest in Kantou region (Tsukuba), a 30-year-old ever-green Japanese oak forest in Setonaikai region (Higashi-Hiroshima), and a 55-year-old subtropical evergreen forest in Kyusyu (Miyazaki University Forest) (fig 1). We started *R*s measurement on the cool-temperate mixed forest from 2007 (fig.2). Soil warming (+2.5 ºC in 5cm depth of soil) enhanced the *R*h rate during whole measurement period by 98.2%. The annual warming effect gradually increased from 2007 (60.7%) to 2014 (130.7%) on this site. The difference of the Q_{10} value (during whole measurement period) was not significant between the warming (2.32) and control (2.37) plots. We did not find the acclimation of *R*s after eight years of warming experiment, probably due to the soil in this region contains much portion of soil organic matter [6].

At the deciduous oak forest, we started measurement from 2011. The warming enhanced the *R*h rate during whole measurement period by 23.5%. The annual warming effect gradually increased from

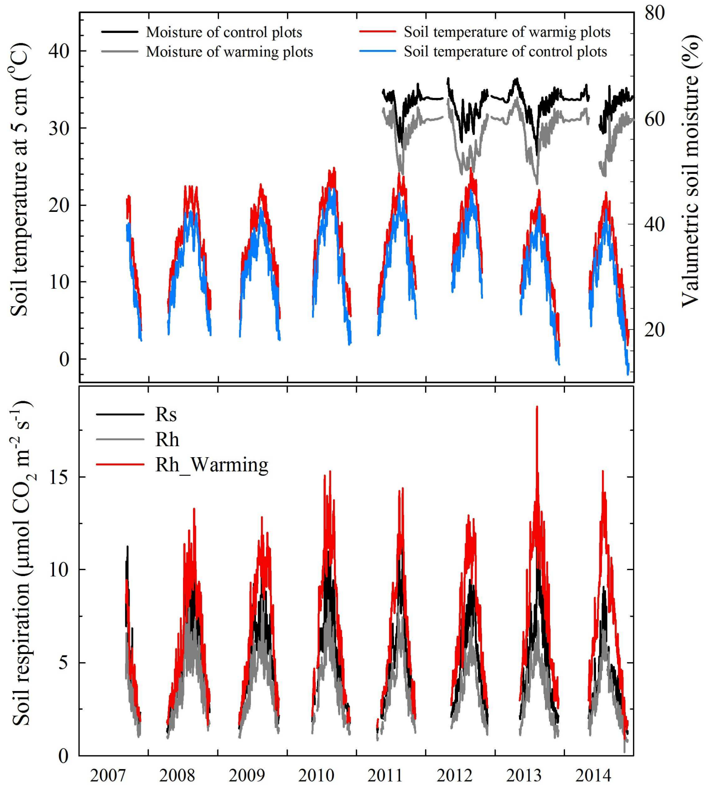

Fig 2. Seasonal changes in soil temperature and soil moisture (upper), and soil respiration rates (lower) in the cool-temperate mixed forest in northern Hokkaido (Teshio).

2011 (+15.1%) to 2014(+30.1%). The Q_{10} was 2.51 and 2.22 for the control and warming plots, during whole measurement period. Warming experiment started in this site from September in 2011, and 4 years passed from the start. This site is the newest site in this project. Further measurement of *R*s and warming effect on *R*h will be necessary.

At the beech forest, we started measurement from 2008. The warming enhanced the *R*h rate during whole measurement period by 31%. The annual warming effect peaked in 2010 (+48.3%), and gradually decreased until 2013 (+16.1%). However, in 2014, warming effect increased to +28.8%. The Q_{10} was 2.9 and 2.58 for the control and warming plots, during whole measurement period.

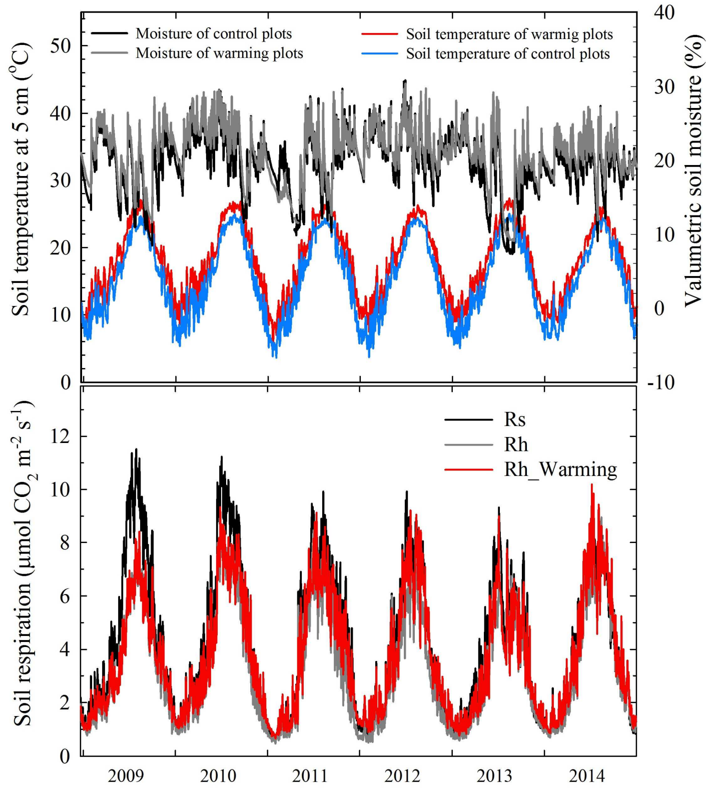

Fig 3. Seasonal changes in soil temperature and soil moisture (upper), and soil respiration rates (lower) in the subtropical evergreen forest in Miyazaki.

For the red pine forest, we started measurement from 2006. The warming enhanced the *R*h rate during whole measurement period by 5.5%. The annual warming effect from 2007 to 2014 varied from +6.3% to +26.3%. The Q_{10} was 2.82 and 2.49 for the control and warming plots, during whole measurement period. The trend of annual warming effect was not clear on this flux site after 9 years of warming treatment.

At the evergreen oak forest, we started measurement from 2007. The warming enhanced the *R*h rate during whole measurement period by 15.6%. The annual warming effect peaked in 2011 (+27.6%), and slightly decreased until 2014 (+10.8%). The Q_{10} was 3.03 and 2.76 for the control and warming plots, during whole measurement period. The trend of annual warming effect can be seen as decreasing trend after 2011. In this flux site, soil moisture influence remarkably on *R*s during summertime due to small amount of rainfall.

For the evergreen forest in kyusyu, we started measurement from the end of 2008 (fig.3). The warming enhanced the *R*h rate during whole measurement period by 13.1%. The annual warming effect gradually increased from 2009 (+5.1%) to 2012 (+28.5%). After the peak of 2012, warming effect of 2013 (+9.0%) and 2014 (+11.5%) were relatively low value. For the low value of warming effect in 2013, small amount of rainfall and decreased soil moisture in summer time influenced remarkably. The Q_{10} was 3.03 and 2.90 for the control and warming plots during whole measurement period. The trend of annual warming effect can be seen as decreasing trend after 2012.

(1-2) Soil transplantation experiment

In 2011, we installed 48 soil cores (11 cm in diameter with height of 30 cm) at each of the soil warming experiment sites, and half (24) of the cores were transplanted to the relative warmed site, including from Teshio (annual mean temperature 5.5°C) to Shirakami maintain range (annual mean temperature 8.3°C), from Shirakami maintain range to Mt. Naeba (elevation of 900 m; annual mean temperature 7.7°C), from Mt. Naeba to Tsukuba (annual mean temperature 13.8°C), and from Tsukuba and Hiroshima (annual mean temperature 13.5°C) to Miyazaki (annual mean temperature 17.4°C).

In 2013, we measured the CO_2 efflux of transplanted soil cores on Mt. Naeba flux site. During the measurement on 900 m site, average soil temperature was 17.5°C, and CO_2 efflux of the control cores (original cores of 900 m site) and the transplanted cores (from 1500 site to 900 m site) were 3.45 and 3.84 μmol CO_2 m^{-2} s^{-1}, respectively. During the measurement on 1500 m site, average soil temperature was 15.9°C, and CO_2 efflux of the original cores (1500 m) was 2.28 μmol CO_2 m^{-2} s^{-1}.

In 2014, we transplanted new soil cores from Okutama artificial forest (*Cryptomeria Japonica*, annual mean temperature 11.8°C) to Tuskuba (annual mean temperature 13.8°C), and measured *R*s. *R*s of transplanted soil cores was bigger than control cores in Okutama thorough out the experimental period.

Results were consist with the soil warming experiment and suggest that global warming will enhanced the decomposition of soil organic carbon.

(2) Detection of the impact of climate change and disturbance of forest ecosystem on *R*s

At Fuji-Hokuroku flux site (larch forest), we started measurement in 2006, and continuous data have been collected until now. Total *R*s and *R*h varied between 6.0-8.1 tC ha^{-1} yr^{-1} and 5.2-6.9 tC ha^{-1} yr^{-1}. The influence of annual variability of temperature was thought to be strong. The amount of fixed carbon by forest floor plants were estimated to be 0.3 tC ha^{-1} in 2013 and 1.2 tC ha^{-1} in 2014. This value shows the low carbon fixation capability of forest floor plants. This reason should be weak light intensity of larch forest floor under the larch forest canopy.

At Teshio flux site (larch plantation after clear cut), *R*s was measured from 2003-2014. Estimated *R*s (from May 13^{th} to November 16^{th} :common observation period) was varied from 7.4 tC ha^{-1} to 11.2 tC ha^{-1}. From 2012-2014, the percentage of *R*s against ecosystem respiration was 102% (2012), 96% (2013), 91% (2014). Most of ecosystem respiration was occupied by *R*s. It will be necessary to focus on the value according to the growth of larch plantation.

Tomakomai flux site was attacked by large typhoon in September 2004, and the canopy of larch forest was totally destroyed. To know the influence of typhoon disturbance on *R*s, we start *R*s measurement from 2006. During common measurement period (from May 10^{th} to November 6^{th}) in 2007, the estimated *R*s was 3.2 tC ha^{-1} (fig. 4). The average of estimated R_s and *R*h during common measurement period from 2011 to 2014 was 5.5 tC ha^{-1} and 5.4 tC ha^{-1}, respectively. *R*s increased after typhoon disturbance, and *R*h occupied large percentage of *R*s. That means *R*h increased after typhoon disturbance due to temperature increase (loss of larch canopy lead to soil temperature increase) or dead root decomposition of fallen trees. Gross primary production (GPP) during common measurement period on this flux site in 2007 was 6.6 tC ha^{-1}. GPP from 2012 to 2014 were 16.9 tC ha^{-1}, 13.5 tC ha^{-1} and 13.2 tC ha^{-1}, respectively. The value increased from 2007 to 2012, and slightly decreased after the peak of 2012. Most of plants covered on this flux site after the typhoon disturbance were herbaceous plants, and tree plants are now growing on this site. It will be important to know the trend of carbon balance on this site according to the vegetation recovery.

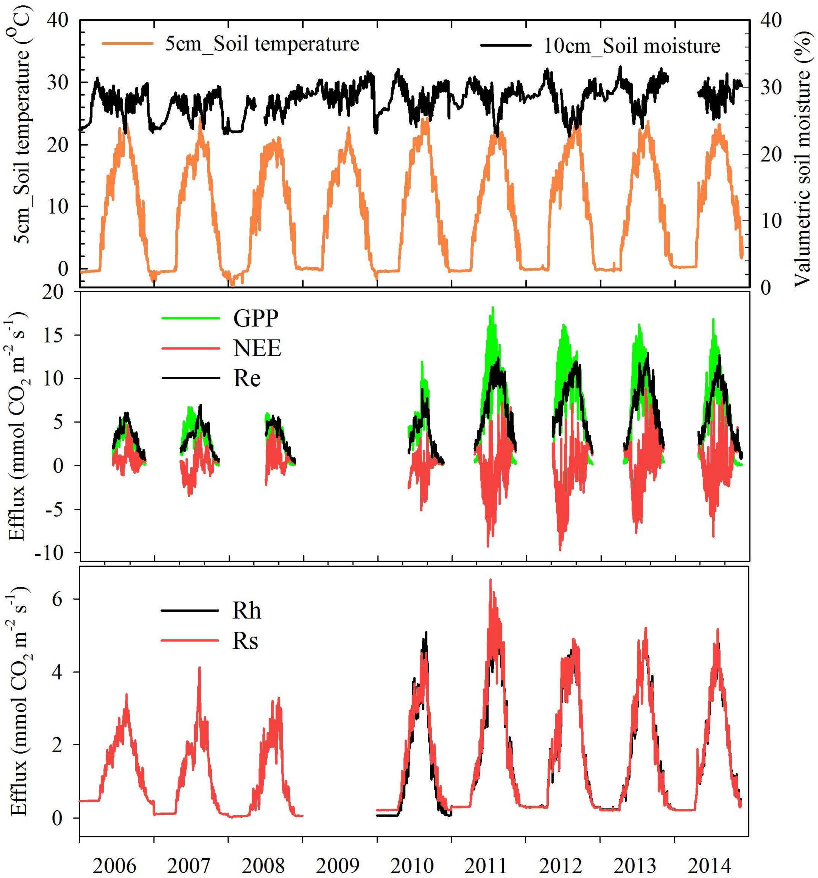

Fig. 4 Seasonal pattern of soil temperature and soil moisture (upper), gross primary production (GPP), net ecosystem CO_2 exchange (NEE), and ecosystem respiration (*R*e, middle), soil respiration (*R*s) and heterotrophic respiration (*R*h, bottom).

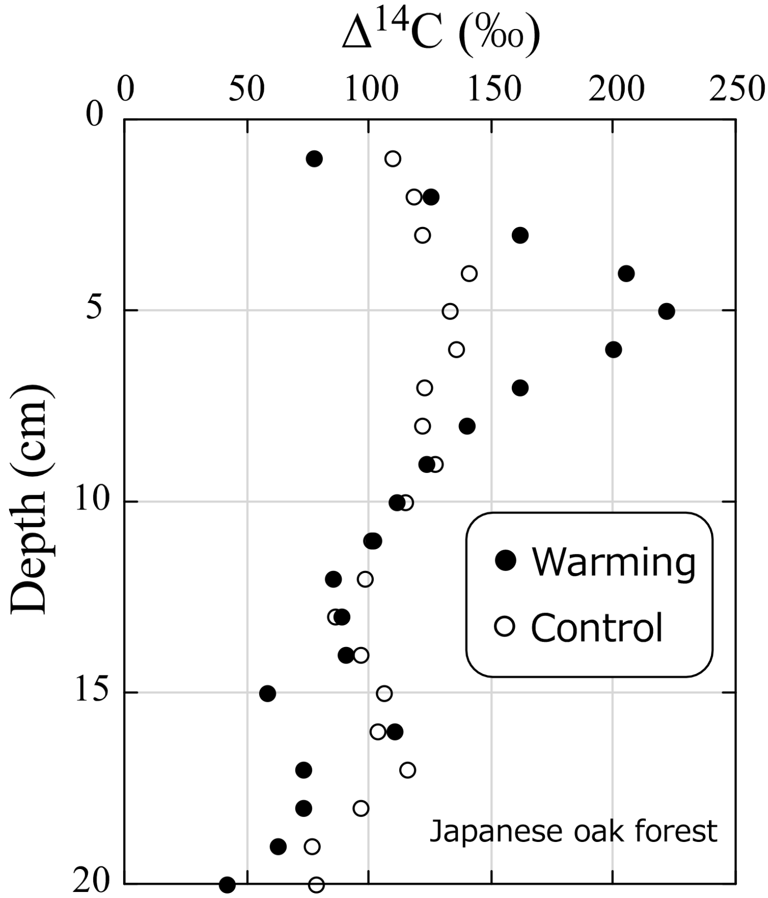

Fig.5 Vertical profiles of $\Delta^{14}C$ in the soil of the warming plot (●) and the control plot (○) at even-green Japanese oak forest in Higashi-Hiroshima.

(3) Soil organic radiocarbon measurements

We collected soil cores (11 cm in diameter, 30 cm depth) from both the soil warming and the control plot at 3 sites; even-green Japanese oak forest in Higashi-Hiroshima, cool-temperate mixed forest in Hokkaido and Red pine forest in Tsukuba. The core was cut into every 1 cm layers and each soil sample was analyzed particulate organic carbon (POC) and organic nitrogen (PON), stable carbon isotope ratio ($\delta^{13}C$), stable nitrogen isotope ratio ($\delta^{15}N$) and radiocarbon ($\Delta^{14}C$). Comparing vertical profiles of POC and $\Delta^{14}C$ of the warming plot with those of the control plot, it was indicated that the soil warming experiment was encouraged the microbial decomposition of organic matter up to 10-15 cm depth at all sites. The $\Delta^{14}C$ profile of the warming plot at the even-green Japanese oak forest was unique with a maximum at 5cm depth, although the $\Delta^{14}C$ of the control plot was approximately constant from surface to 10 cm depth (Fig. 5). We concluded the result that microbes selectively decomposed “young” POC at surface layer and “old” POC at intermediate layer by the warming experiment. On the other hand, at cool-temperate mixed forest in and pinus densiflora forest, “young” POC was decomposed by the warming experiment regardless of depth.

(4) Model evaluation of *R*s for natural ecosystems in Japan and *R*s simulation in Asia

*R*s fluxes at the eight sites were compared between chamber observation and ecosystem model estimation. The model captured seasonal change in *R*s, i.e. low fluxes in winter and high fluxes in summer, at each site. However, the model overestimated *R*s in young forest sites and underestimated summer peak fluxes at several sites. These results indicate that the present model requires further parameter calibration in terms of environmental responsiveness. A regional simulation captured spatial and seasonal variability in *R*s in Asia, and we need further model validation for that scale.

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