# Proceedings of

## 10<sup>th</sup> International Workshop on

# Forest Watershed Environment Research in Cambodia,



Akira Shimizu, Sophal Chann, Haruo Sawada,

Yasuhiro Ohnuki, Koji Tamai (Eds.)



Forestry and Forest Products Research Institute, Japan

Forestry Administration, Cambodia

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## **Forestry and Forest Products Research Institute, Japan**

Forestry Administration, Cambodia

## **Scientific Committee**

DR. AKIRA SHIMIZU CWCM Project Coordinator Industry-University-Government Coordinator Kyushu Research Center Forestry & Forest Products Research Institute (FFPRI) 4-11-16 Kurokami, Kumamoto, Kumamoto, 860-0862 JAPAN

MR. SOPHAL CHANN CWCM Project Coordinator Forest and Wildlife Research and Development Institute (IRD) Hanoi Street, Phoum Rongchak, Sankat Phnom Penh Thmei, Klan Sen Sok, Phnom Penh, Cambodia

## **DR. HARUO SAWADA**

Visiting Professor, Geoinfomatics Center (GIC), Asian Institute of Technology (AIT) 58 Moo 9,Paholyothin Highway Klong Luang, Pathumthani 12120 Thailand Emeritus Professor, Institute of Industrial Science, The University of Tokyo 4-6-1 Komaba, Meguro, Tokyo, 153-8505 JAPAN

## **DR. YASUHIRO OHNUKI**

Chief of Soil Geochemistry Laboratory Forestry & Forest Products Research Institute (FFPRI) Matsunosato 1, Tsukuba, Ibaraki, 305-8687 JAPAN

DR. KOJI TAMAI Chief of Forest Hydrology Laboratory Forestry & Forest Products Research Institute (FFPRI) Matsunosato 1, Tsukuba, Ibaraki, 305-8687 JAPAN

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Forestry & Forest Products Research Institute Matsunosato 1, Tsukuba, Ibaraki, 305-8687 JAPAN

Forestry Administration 40 Preah Norodom Blvd., Phnom Penh, Cambodia

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## Preface

The Workshop started in 2004 aiming to release the results of research to society widely from the beginning of the collaborative research project between Cambodia and Japan, and considering it as a part of solutions of all kinds of problems through the friendship with people of different fields. The tropical seasonal forests in flat lands are now very precious in the Indochinese Peninsula, because there are hardly remaining forests except for this region. Firstly, we have gained many kinds of information about vegetation composition, soil characteristic, water balance, evapotranspiration, forest climate, etc. in Cambodian evergreen forests. In addition, we have also studied the deciduous forest and compared the observed results at two forest watersheds in Cambodia for comprehensive understandings of energy, water, and carbon dioxide cycling in forests of Mekong River Basin.

This is the 10th workshop holdings once a year. In these more ten years research periods, the situation of surrounding forests in this region has been changing a lot, and we need to deal with various problems, such as natural disasters, the influence of global warming, maldistribution of water resources in connection with climate change, human impacts in forest utilization, etc. In particular, many meteorological disasters have occurred frequently over the past several years in the Asia monsoon zone. We had the severe flood disaster in the south part of Indochina Peninsula, especially in Thailand and Cambodia in 2011. The severe typhoon attacked Philippines in 2013. This year, flood disaster and induced large-scale landslide occurred in Afghanistan in April. And, in August, flood damage occurred in Bangladesh, Myanmar, and Nepal. Furthermore, in September, the large area from South Asia to China was hit by the heavy rain, severe and serious damage was caused by the large-scale flood in Pakistan or India and also China.

The global warming might be the important factor concerning to the flood, and the disorderly deforestation might be set to one of the causes of the flood. What is significant in these arguments is that we must interpret on the basis of the exact integrated continuous observation data using the stable experimental watershed. Since these extreme meteorological disasters have higher possibility of happens hereafter owing to influence of global warming, accumulation of high-precision hydro-meteorological observation data with forest information is indispensable. Accordingly, the significance of accumulated data over more than 10 years until now is increasing much more, and they are expected to be effectively utilized for flood disaster prediction and global warming adaptation in the future. Investigating the cause of the disaster by analyzing this kind of data contributes to suitable and sustainable forestry management and sustainable development greatly.

There would be no greater pleasure than if, better forest management or an improvement of a life environment were promoted by profound understanding about forest through this workshop. I deeply appreciate many efforts of Cambodian Forest Administration staff.

> SHIMIZU Akira: Conference Secretariat Industry-University-Government Coordinator in Kyushu Research Centre Forestry and Forest Products Research Institute, Japan

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Forestry Hydrology

## Preliminary estimation of interception loss in an evergreen forest located in Kampong Thom province, Cambodia

IIDA Shin'ichi<sup>1</sup>, SHIMIZU Takanori<sup>1</sup>, TAMAI Koji<sup>1</sup>, KABEYA Naoki<sup>2</sup>, SHIMIZU Akira<sup>2</sup>, CHANN Sophal<sup>3</sup>, SATHA Saing<sup>3</sup>, PHALLAPHEARAOTH Op<sup>3</sup>

## **Introduction**

Cambodia is located in the southern part of the Indochina peninsula, and experiences the distinct wet and dry seasons characterized by the Asian monsoon. The forested area occupies 57% of the land area of Cambodia (FAO, 2010), and valuable forests are remaining in the lowland area, which have been vanished in the neighboring countries of Thailand and Vietnam (Tani et al., 2007). Many studies from the viewpoints from hydrology and ecology have been carried out for the lowland evergreen forest (e.g., Sawada et al., 2007). However, although Nobuhiro et al. (2006) reported the interception process in the evergreen forest, the measurements of the interception process is very limited. Thus, we measure gross rainfall (P), throughfall (TF) and stemflow (SF) in a lowland evergreen forest, and show the preliminary estimates of interception loss (I) based on their measurements.

## Site and Methods

We carried out the measurements in an evergreen stand near the tower site in Kampong Thom, Cambodia ( $12^{\circ}44$ 'N,  $105^{\circ}28$ 'E). In this study, we analyzed data obtained during 10 months from September 2013 to June 2014. This stand has the multilayered canopies, and the mean tree height of overstory layer, in which tree height is more than 20 m, is 27.2 m (Shimizu et al., 2007). To prevent the low capturing raindrops by rainfall gauge due to the high wind, we set the gauge with the resolution of 0.5 mm at the height of 24 m on the tower, slightly shorter than the mean tree height of overstory trees, and measured *P*.

Throughfall is collected by 5 circle-shape vessels with the diameter of 80 cm (i.e., a total area of 2.4 m<sup>2</sup>), and quantified by tipping type flow meter with the one tip volume of 500 cm<sup>3</sup>. We used total 2 sets of the equipment to measure *TF*, that is, rainwater was collected with the area of 4.8 m<sup>2</sup>, and obtained *TF* as the average of measurements by 2 sets. On the other hand, we collect stemflow for 16 trees in the stand, and quantified with 15 rainfall gauges of the resolution of 0.5 mm: among 16 trees, stemflow from two trees are measured by one gauge. Note that we applied the equation to correct the underestimation due to the high flow rate of rainwater input to rain gauges (Iida et al., 2012), and newly developed the equation for 500 cm<sup>3</sup> flow gauges. We calculated the linear relationships between *P* and single-tree amounts of stemflow, and found that the slopes and intercepts of them are correlated with the diameter of the breast height (R > 0.7). By using this correlation, we estimated the amount of stemflow for 229 trees existing within the plot area (25 m × 25 m). Based on the *P*, *TF* and *SF*, we evaluated the interception loss (*I*) as I = P - (TF + SF).

## **Results and Discussion**

 $\overline{TF}$  and  $\overline{SF}$  show the high correlation with P (Figures 1-A, B). However, relatively large dispersions are found between P and I (Figure 1-C). As discuss in later in detail, it is necessary to reanalyze the relationship between P and I for the larger rainfall events (P > 40 mm/event).

The total amount of P is 1255 mm for the analyzing period of 10 months. However, due to the lack of measurements of TF and SF caused by falling leaves and branches and by some electrical problems on the gauges and/or flow meters, we evaluated I for the rainfall events excluding lacks of

## Keywords: dry evergreen forest, interception loss, throughfall, stemflow

<sup>&</sup>lt;sup>1</sup> Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato Tsukuba, Ibaraki, 305-8687 Japan. E-mail: iishin@ffpri.affrc.go.jp

<sup>&</sup>lt;sup>2</sup> Kyushu Research Center, FFPRI, 4-11-16 Kurokami, Kumamoto 860-0862, Japan.

<sup>&</sup>lt;sup>3</sup> Institute of Forest-Wildlife Research and Development, Forestry Administration, Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia

*TF* and *SF*. As a result, for the total amount of available *P* of 780 mm, *TF/P* is 75.6%, *SF/P* is 1.5%, and *I/P* is 22.9%. The *SF/P* in this site is corresponded well with the values reported in the hill evergreen forest in Thailand (Tanaka et al., 2005), *TF/P* is slightly smaller, and therefore *I/P* is slightly higher than the hill evergreen forest. Kuraji and Tanaka (2003) reported that the range of *I/P* for tropical forests are mainly from 10% to 20%, and we concluded that our estimate of *I/P* is not significantly larger than the reports conducted among tropical forests.

The large year-to-year differences in I/P have been found in the tropical forest and reported in literatures (e.g., Kuraji and Tanaka, 2003). We analyzed the data obtained during 10 months, and the available number of rain events with P > 40 mm/event is only 3 (Figure 1). To evaluate the average and representative value of I/P in this site, we need more number of data, especially for large rainfall events with P > 40 mm/event. I/P of each event decreases with increase of P (data not shown), and shortage of larger events should result in the overestimation of I/P for longer duration (i.e., year). Moreover, when we add the data of large



Figure 1. Relationships between gross rainfall (*P*) and A) throughfall (*TF*), B) stemflow (*SF*) and C) interception loss (*I*)

rainfall events, there are some possibilities that, instead of the linear equation used in Figure 1-C, the parabolic equation is more suitable for regression between P and I.

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## Water budgets in a deciduous broad-leaved forested watershed of Cambodia in 2010 to 2013

SATHA Saing<sup>1</sup>, KABEYA Naoki<sup>2\*</sup>, CHANN Sophal<sup>1</sup>, SHIMIZU Akira<sup>2</sup>, IIDA Shin'ichi<sup>3</sup>, OHNUKI Yasuhiro<sup>3</sup>, SHIMIZU Takanori<sup>3</sup>, TAMAI Koji<sup>3</sup>, PHALLAPHEARAOTH Op<sup>1</sup>

### **Introduction**

The Mekong River, the largest river in Southeast Asia, runs from Yunnan Province in China, through Myanmar, Laos, Thailand, and Cambodia before reaching its outlet in Vietnam. The appropriate distribution of the water resources of this international and continental river is critical for sustainable development and environmental conservation in the provinces and countries through which the Mekong flows. The Mekong River Commission (MRC) plays an important role in managing water resources among the Mekong countries. The MRC has collected hydrological data, including rainfall and discharge data, at many observation sites in the lower Mekong. However these observation sites are limited to the main channel of the Mekong and relatively large branches. Moreover, few hydrological observations have been conducted in forested watersheds of the Mekong River basin.

To elucidate the water cycle in lowland forests of the Mekong River basin, our research group established four experimental watersheds in the Stung Chinit (Kampong Thom, Cambodia) where the evergreen forest is distributed widely. The drainage areas of these experimental watersheds ranged from small (4 km<sup>2</sup>) to mesoscale (3,659 km<sup>2</sup>) (Kabeya *et al.*, 2008). On the other hand, in a total forest area (114,000 km<sup>2</sup>) of the country, the deciduous forest (the rate of occupying in a total forest area: 42%) is distributed more widely than an evergreen forest (33%) (Araki, 2009). Then, our research group additionally established a new experimental watershed (2,245 km<sup>2</sup>) in the O Krieng (Kratie, Cambodia) where the deciduous forest is distributed widely. In the last year, we reported water level change and water balance of this watershed (Kabeya *et al.*, 2011, Kabeya *et al.*, 2012). In this study, we discussed annual water budget of this watershed during four years from 2010 to 2013.

#### Site and Observation Descriptions

O Krieng experimental watershed was established in Kratie Province and daily water level measurement has been observed by buzzer type water level gauge (Million Water Level Measure WL50M, Yamayo Measuring Tools, Japan) since August 2009 (Kabeya et al 2011). The climate of Cambodia is sub-tropical and governed by two monsoons: the cool, dry north-eastern monsoon from November to March and the humid south-western monsoon from May to October. In the inland region of the Indochina Peninsula, the rainy season usually begins in late April to early May and retreats in mid-October to mid- November (Matsumoto 1997). The geology is mainly sedimentary rock. The soil type and soil thickness are *Plinthosols* and 2.6 m, respectively (Ohnuki *et al.*, 2008). Watershed drain area is 2,245 km (Kabeya *et al.*, 2011). Vertical topography of river at the water level measuring point is shown in Kabeya *et al.*, 2011.

#### Water-Balance in Forested Watershed

If we average these quantities over a reasonably long time,  $\Delta S$  can be neglect, and the water-balance can be written as below:

#### Keywords: water budget, deciduous board-leaved forest, Mekong river basin

- <sup>3</sup> Forestry and Forest Products Research Institute (FFPRI), 1 Matsu-no-sato Tsukuba, Ibaraki, 305-8687 Japan.
- \*:Corresponding author E-mail: kabeya@affrc.go.jp

<sup>&</sup>lt;sup>1</sup>Institute of Forest-Wildlife Research and Development, Forestry Administration, Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia.Phnom Penh, Cambodia

<sup>&</sup>lt;sup>2</sup> Kyushu Research Center, Forestry and Forest Products Research Institute (FFPRI-KYS), 4-11-16 Kurokami, Kumamoto Kumamoto, 860-0862 Japan.

$$\mathbf{P} = \mathbf{R} - \mathbf{ET} \tag{1}$$

where P, R and ET are precipitation, runoff, and evapotranspiration.

In this equation, we have been measuring major 3 components (P, R, ET), and precipitation has been measured by rainfall observation sites (Deciduous Tower site), stream-flow has been measured by a stream-water level observation site (O Krieng), evapotranspiration has been measured by the bandpass eddy covariance method at the observation tower.

#### **Precipitation Measurement**

Precipitation was observed at Deciduous Tower site located about 10 km of south direction by rain gauge (OHTA KEIKI OW-34-BP, JAPAN). This rain gauge was installed on the roof of a small house beside the Deciduous Tower. The observed value was calibrated using the method by Iida et al 2012.

### **Stream-flow Measurement**

A buzzer type water level gauge (Million water level, Yamayo) is used for measuring daily water height. Local employee records the values once a day at 9 am. Pressure (mini-TROLL, Air brown) gauge is monitoring values in one-hour interval. Those pressure gauges included data logger, and were downloaded by laptop PC.

Flow velocities were measured by floating buoys on various water level conditions. When water level is less than 8 m, we used floating buoys with 30 cm length. When water level is more than 8 m, we used floating buoys with 150 cm length. We also have been used water current meter (KENEK and HIRIOI type) and floating buoys to measure flow velocity at the site for getting flow velocity distribution.

(2)

#### **Relationship between Water height (H) and Discharge (Q)**

$$\mathbf{Q} = \mathbf{a} \left(\mathbf{H} \cdot \mathbf{b}\right)^2$$

Where a, b are fitting parameter. Discharge was calculated using H-Q curves (or rating curves) constructed from the flow velocity measured in the field. Flow velocity measurements were carried out under various water-level conditions at each stream water-level observation site. The runoff was determined as the daily discharge divided by the drainage area (mm/day). We observed that the flow velocity was in a stagnant water state mostly in the case of 2 m or less of water levels. Thus, parameter "b" was set to 2 (m) from the field observation. When the flow velocity measurement by a floating buoy was carried out, the highest water level was 8.6 m. According to the cross-sectional survey, the maximum depth of water of this river is 16.7 m. A more than 8.6-m water level was sometime recorded on the rainy season. For this reason, the parameter "a" was determined by try and error by the closing the annual water budget in September 2009 to August 2010. Tentative Annual ET of this period was used the estimated value by the bandpass eddy covariance method (Shimizu *et al.*, 2011a, b). These parameters were adapted for the data for four years of 2010 to 2013 and each annual runoff amount was calculated. And the water budget of this watershed was examined, comparing them with annual precipitation.

### **Results**

The relationship between daily precipitation and daily runoff for the O Krieng watershed was shown in Figure 1. The rainfall of the the pre-monsoon period (March, April) of changed into the dry season from the rainy season had not contributed to the increase in the river water which comes out from a catchment. This observation result is in agreement with the result which Kabeya et al 2008 observed in the evergreen forest experimental watershed. The strong rain exceeding intensity-of-rainfall 100 mm/day occurred 3 times in 2013 during the observation. The sum total of the rain for these three days

is about 400 mm, and forms about twenty percent of annual precipitation. However, the big value of runoff amount is observed in not 2013 but 2009, or 2011. From these things, it is thought that the more detailed examination about the flood runoff process of this catchment is required.

Annual water budget in calibration period was shown in Table 1. The precipitation of the calibration period was 1762 mm. The evapotranspiration of this period was tentatively estimated to be 825 mm by the bandpass eddy covariance method (Shimizu *et al.*, personal communication). The parameter "a" of the H-Q curve was determined that discharge amount will serve as 939 mm for closing water budget during the calibration period. This parameter and H-Q curve were adapted to data for calculating annual runoff in 2010 to 2013. From this result, annual precipitation was 1501 mm in 2010, 2003 mm in 2011, 1798 mm in 2012 and 2224 mm in 2013. Annual runoff was 428 mm in 2010, 1215 mm in 2011, 620 mm in 2012 and 716 mm in 2013 respectively. Evapotranspiration was calculated 1072 mm in 2010, 788 mm in 2011, 1178 mm in 2012 and 1508 mm in 2013. Thus, average values of precipitation, runoff and evapotranspiration during these four years were 1881 mm, 745 mm, 1137 mm respectively. And the average ratio of runoff to precipitation over these four years was 0.39. This shows that about 40% of rain is changed into river water at this object catchment.

## **Conclusion**

This research showed that it had arisen that the rain of a pre monsoon period (March, April) does not contribute to the runoff from a catchment not only at the evergreen forest catchment but at the a deciduous broad-leaved forested watershed of Cambodia.

This study showed annual water budget of a deciduous forest watershed of O Krieng. About 2220 mm of year rainfalls were the maximum in 2013. The amount of losses of this year in 2013 was the maximum also in 1500 mm per year. It is necessary to verify whether record of such a big amount of year losses is appropriate. However, the year runoff amount of this year was not the maximum in 720 mm. In 2013, especially it exceeded 100 mm/day, strong rain was recorded 3 times. This strong rain formed about 20% of year precipitation. Therefore, in order to understand more deeply the catchment water budget in the deciduous broad-leaved forest experimental watershed, it is necessary to advance the actual condition elucidation of the flood runoff process and interception evaporation process under strong rainfall events over 100 mm/day.

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![](_page_15_Figure_2.jpeg)

Figure 1. The relationship between daily precipitation and daily runoff for the O Krieng watershed.

	Precipitation* mm/y	Runoff mm/y	Evapotranspiration mm/y	Runoff/ Precipitation
Calibration period <sup>**</sup>	1762	937	825**	0.53
2010	1501	428	1072	0.29
2011	2003	1215	788	0.61
2012	1798	620	1178	0.34
2013	2224	716	1508	0.32
AVE (±STD)	$1881 \pm 308$	$745 \pm 335$	1137±297	$0.39 \pm 0.15$

## Table 1 Annual water budget of the O Krieng watershed during 2010 to 2013

\* This value was calibrated using the method by Iida et al 2012.

\*\* 1 Sep 2009to 31Aug 2010

\*\* This value was tentatively estimated values by the bandpass eddy covariance method at the Deciduous Tower Site.

# Characteristics of soil moisture-respiration relation in dry evergreen and deciduous forests in Cambodia

## TAMAI Koji<sup>1</sup>, TORIYAMA Jumpei<sup>1</sup>, OHNUKI Yasuhiro<sup>1</sup>, SHIMIZU Akira<sup>2</sup>, SHIMIZU Takanori<sup>1</sup>, IIDA Shin'ichi<sup>1</sup>, KABEYA Naoki<sup>2</sup>, CHANN Sophal<sup>3</sup>, PHALLAPHEARAOTH Op<sup>3</sup>, SATHA Saing<sup>3</sup>

## **Introduction**

The characteristics of the water cycle and water conditions influence various phenomena in forested watersheds. For example, extractable water retained in the soil during the dry season is a main factor explaining the distribution of dry evergreen and deciduous forests in Thailand (Murata et al., 2012). The carbon cycle in a forest community is also affected by the water cycle, of which soil moisture is a key component. Soil respiration is also a significant feature of the carbon cycle in a forest community. In this study, the relationship between soil moisture and soil respiration was investigated in the soil of a dry evergreen and deciduous forests in Kampong Thom and Kratie Provinces, respectively, Cambodia.

### Site and observation description

Observations were made at an evergreen forest site (KPT) located in the O Thom I Basin (12°44'N, 105°28'E) in Kampong Thom Province, and a deciduous forest site (KRT) located in the O krieng Basin (12°55'N, 106°11'E) in Kratie province, Cambodia. Evergreen trees in KPT including *Vatica odorata, Calophyllum inophyllum*, and *Myristicaceae* species dominate the forest (Shimizu et al., 2007). This area of lowland evergreen forest has a Quaternary surface geology with river terraces overlying sedimentary rocks, and the main soil types in the area are Acrisols, according to the Food and Agriculture Organization of the United Nations (FAO) classification (Toriyama et al., 2007).

Deciduos trees in KRT are consisted with *Dipterocarpus tuberculatus*, *Shorea obtuse*, *Terminalia alata* and *Xylia xylocarpa* (Kenzo et al., 2013). The surface geology is basalt and shale. The main soils distributed in the survey plot for soil respiration is Plinthosols (Ohnuki et al., 2013).

Soil respiration was measured within soil columns using a chamber with a diameter of 9.4 cm and a height of 13.5 cm. An infrared gas analyzer (IRGA:  $CO_2$  Engine K30, SenseAir, Sweden) and a thermocouple enclosed in the chamber monitored the ratio of  $CO_2$  concentrations and air temperatures. Nobuhiro et al. (2003) previously verified the accuracy of this type of enclosed IRGA chamber. Each chamber was closed for 12 min. Soil temperatures and soil moistures were also monitored at a depth of 5 cm. The soil temperature and moisture sensors used were the S-TMB (Onset, USA) and S-SMA (Onset, USA), respectively. Soil respiration was recorded on some days in 2010-2013.

### **Observation and calculation methods**

Soil respiration ( $F_c$ :mg CO<sub>2</sub> m<sup>-3</sup> s<sup>-1</sup>) was calculated using Eq. (1) and based on the increase in the rate of CO<sub>2</sub> accumulation ( $\frac{\Delta c}{m}$  m<sup>3</sup> m<sup>-3</sup> s<sup>-1</sup>) in a chamber.

$$F_{c} = \rho \frac{V}{A} \frac{\Delta c}{\Delta t} \frac{273}{273 + T_{a}}$$
(1)

where V is the chamber volume (m<sup>3</sup>), A is the cross sectional area of the chamber (m<sup>2</sup>),  $T_a$  is the air temperature in the chamber (°C), and  $\rho$  is the mass density of the CO<sub>2</sub> (1.96 x 10<sup>6</sup> mg CO<sub>2</sub> m<sup>-3</sup>). Eq. (1) can be transformed as follows:

Keywords: IRGA enclosed chamber method, soil moisture

<sup>3</sup> Forest-Wildlife Research and Development Institute (FWRDI), Forestry Administration, Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia.

<sup>&</sup>lt;sup>1</sup> Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato Tsukuba, Ibaraki, 305-8687 Japan. E-mail: a123@ffpri.affrc.go.jp

<sup>&</sup>lt;sup>2</sup> Kyushu Research Center, Forestry and Forest Products Research Institute (FFPRI-KYS), 4-11-16 Kurokami, Kumamoto 860-0862, Japan.

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$$\rho \frac{V}{A} \frac{273}{273 + T_a} \Delta c = F_c \Delta t \tag{2}$$

According to Figure 1, when we plot the fluctuations of the left side of Eq. (2) against time elapsed after closing the chamber ( $\Delta t$ ), the gradient of the plots is equal to  $F_c$ .

Thus,  $F_c$  is calculated as the gradient of the regression line between the left side of Eq. (2) and  $\Delta t$ .

24 Soil collars are settled in each forest site. One data of  $F_c$  is obtained as the average for 24 colors. Undisturbed soil samples were collected from the surface soil layers using three 100-ml steel cylinders to obtain the soil water retention curves with the method shown in Toriyama et al. (2011).

#### **Results**

Figures 1 and 2 shows the relationship between soil temperature  $(T_s)$ , soil moisture  $(\theta)$ , and  $F_c$ . The range of  $T_s$  was so narrow that the effect of  $T_s$  on  $F_c$  was not recognized in this study. In contrast,  $F_c$  shows the much dependency on  $\theta$ . However, their relations are very different from each other.

In KRT,  $F_c$  increases monotonically with the increase of  $\theta$ . In this case, the relations between them are expressed as Eq. (3) (e.g. Bunnell et al., 1977, Subke et al., 2003).

$$F_c = \frac{\theta}{a + \theta} \tag{3}$$

Where, a is a constant. In this study, a is identified to be 0.7910 with RMSE to be 0.0263 mgCO<sub>2</sub>  $m^{-2} s^{-1}$ .

In KPT,  $F_c$  increases with  $\theta$  to peak at  $0.11 \text{m}^3 \text{m}^{-3}$  and then decreases with increasing  $\theta$ . In this case, the relations between them are often expressed with quadratic function (e.g. Adachi, et al., 2009, Takahashi et al., 2014). In this study, eq. (4) is identified with RMSE to be 0.0164 mgCO<sub>2</sub> m<sup>-2</sup> s<sup>-1</sup>.

$$F_c = -5.649\theta^2 + 1.2693\theta + 0.165 \tag{4}$$

Figure 3 shows the soil water retention curves in KPT and KRT. Saturated  $\theta$  value is larger in KRT than in KPT. Thus it is judged that pore volume of surface soil is larger in KRT than KPT.

![](_page_17_Figure_13.jpeg)

Figure 1 Relashionship between soil respiration and soil temperature.

![](_page_18_Figure_1.jpeg)

Figure 2 Relashionship between soil respiration and soil moisture content ratio.

Solid line: approximated lines with quadratic function. Broken line: approximated line with eq.(3). These approximated functions are shown in each figure.

![](_page_18_Figure_4.jpeg)

Figure 3 Water retention curves in KPT and KRT.

## **Discussion**

The relations between  $F_c$  and  $\theta$  are obtained to be monotonic increase shape and mountainous shape in KRT and KPT, respectively. In the previous studies about the soil respiration in the Asian tropical forests, both shapes have been reported. Takahashi et al. (2011) reported the monotonic increase shape in the plot located on lower slope and mountainous shape in the plot located on ridge and upper slope in the mixed deciduous forest in Mae Klong, Thailand. The monotonic increase shapes are also shown in Takahashi et al. (2009) and Ohashi et al. (2008) as the results of the observations in the teak plantations in Mae Klong, and the tropical rainforest in Lambir, Sarawak, Malaysia, respectively. On the other hand, the mountainous shapes have been also obtained in the dry evergreen forest in Huai Kha Khaeng, Thailand (Adachi et al., 2009). The mountainous shape means that soil respiration rate is low in the wet soil condition. Water-filled soil pore is caused that the decline in microbial activities due to the shortage of oxygen and the disturbance of gas diffusion through soil pores (Adachi et al., 2009, Takahashi et al., 2011). On the other hand, Takahashi et al. (2011) supposed the monotonic increase shape in lower slope in the mixed deciduous forest and teak plantations in Mae Klong that their locations were well-drained and soil gas exchange would be smooth.

Following to these previous discussion, the maximum peak may appear in the higher range of  $\theta$  than observed ones. Eq. (5) is obtained as the approximated quadratic function for the relations of  $F_c$  and  $\theta$  obtained in KRT with RMSE to be 0.0206 mgCO<sub>2</sub> m<sup>-2</sup> s<sup>-1</sup>.

$$F_c = -2.2705\theta^2 + 1.4667\theta + 0.0094 \tag{5}$$

In eq.(5),  $F_c$  is maximal when  $\theta$  is around 0.32 m<sup>3</sup>m<sup>-3</sup> to be almost equal to the highest observed  $\theta$ . In eq.(4) obtained from the observation in KPT,  $F_c$  is maximal when  $\theta$  is around 0.11m<sup>3</sup>m<sup>-3</sup> to be much smaller than around 0.22 m<sup>3</sup>m<sup>-3</sup> shown in Adachi et al. (2009) and Takahashi et al. (2011). The lower values of  $\theta$  when  $F_c$  is maximal may have more porosity. This is followed the fact as shown in figure 3 that pore volume in surface soil layer is judged to be larger in KRT than in KPT.

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## H-04

## Inter-annual variation of water vapor exchange measured by the bandpass eddy covariance method over a dry evergreen forest in the central Cambodia

# SHIMIZU Takanori<sup>1</sup>, SHIMIZU Akira<sup>2</sup>, IIDA Shin'ichi<sup>1</sup>, KABEYA Naoki<sup>2</sup>, CHANN Sophal<sup>3</sup>, TAMAI Koji<sup>1</sup>

## **Introduction**

The bandpass eddy covariance method is one of the best options to estimate water vapor flux over a land surface where the commercial electricity is not supplied. Using a sonic anemo-thermometer (SAT) and a capacitance hygro-thermometer (CHT), the method can be operated with low power consumption. Further, as CHT is usually more robust than an open-path infrared gas analyzer (IRGA), we can expect the method to cover the missing data occurring in the open-path IRGA. For these reasons, we have carried out the bandpass eddy covariance measurement over a lowland evergreen forest in Cambodia since 2008, and the measurement has been continued after setting up an open-path IRGA since September 2011. Originally, the attenuated (or noisy) water vapor flux co-spectrum in the high frequency region in the bandpass method is converted by the temperature flux co-spectrum measured from a SAT, on the assumption of co-spectral similarity between these scalars. However, the assumption is sometimes broken, and it leads to abnormal vapor flux estimation. To reduce the error, several correction methods have been proposed to recover the attenuated signal obtained from CHT (Watanabe et al., 2000; Diaz et al., 2007). Meanwhile, for a long-term measurement, Asanuma et al. (2005) proposed to check the coherence of SAT temperature and CHT humidity, to follow the change of CHT response which may vary when it is degraded and/or ventilation status changes. Based on these previous studies, we submit an improved and relatively easily applicable correction, in which the coherence is checked, and the correction function has only 1 parameter. The method is examined through the comparison with an open-path IRGA flux, and then applied to estimate water vapor exchange between the lowland evergreen forest in Cambodia and the atmosphere.

## **Materials and Method**

## Measurement

The measurement has been operated over a lowland evergreen forest in Kampong Thom province, Cambodia. The terrain is almost flat around the hydro-meteorology observation site, which was set at 12° 44' N, 105 ° 28' E. The mean overstory tree height is around 28 m and the dominant trees reach beyond 45 m (Shimizu et al., 2007). The leaf density is kept high throughout the year, and the year-round variation of LAI is not so large, between 4-6 (Ito et al., 2007). A 60 m-height observation tower was built in the observation site. The instruments to measure the exchange of water vapor were attached at the height of 51.0 m above ground. A SAT (K-Probe, Applied Technologies Inc., CO, USA; Since September 2011, CSAT3, Campbell Sci., UT, USA) was installed to measure wind speed fluctuation, which correspond to heat and mass transport rate, and sonic virtual temperature. To apply the bandpass eddy covariance method, a CHT (HMP-45A, Vaisala, Finland) was also attached at the same height. Since September 2011, a fast response open-path IRGA (LI-7500, LI-COR, NE, USA) was additionally installed to measure water vapor and carbon dioxide concentrations.

Keywords: Water vapor exchange, Bandpass eddy covariance method, Long-term measurement, Lowland evergreen forest in Cambodia

<sup>&</sup>lt;sup>1</sup> Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato Tsukuba, Ibaraki, 305-8687 Japan. E-mail: simizuta@ffpri.affrc.go.jp

<sup>&</sup>lt;sup>2</sup> Kyushu Research Center, Forestry and Forest Products Research Institute (FFPRI-KYS), 4-11-16 Kurokami, Kumamoto Kumamoto, 860-0862 Japan.

<sup>&</sup>lt;sup>3</sup>Institute of Forest-Wildlife Research and Development, Forestry Administration, Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia.Phnom Penh, Cambodia.

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## Method applied

Referring to Asanuma et al. (2005), we initially checked the coherency of SAT temperature (*T*) and CHT vapor concentration (*q*) to determine bandpass base frequency range (*f<sub>b</sub>*). Using the data obtained under ideal turbulent condition ( $u_*>0.25 \text{ ms}^{-1}$  and  $|w'T'|>0.05 \text{ Kms}^{-1}$ ;  $u_*$  and *w* are friction velocity and vertical wind velocity both measured by the SAT, respectively. Overbar means 30-minute time average and dashes mean the fluctuations from the averages.), we calculated the coherence  $R_{Tq}(f) = C_{Tq}(f)/(S_{TT}(f) \times S_{qq}(f))$ , where  $C_{Tq}$  is co-spectrum of *T* and *q*,  $S_{TT}$  and  $S_{qq}$  are spectrum of *T* and *q*, respectively, and *f* is certain frequency. Then we calculated moving average of  $R_{Tq}(f)$  (here,  $MR_{Tq}(f)$ ) by  $f \pm 0.0011$  Hz. we sought for the highest value of  $MR_{Tq}(f)$  (here,  $HR_{Tq}$ ) in the range of f = 0.036-0.01 Hz,. When  $MR_{Tq}(f) = HR_{Tq}$  occurred, the value of f + 0.0011 was set as  $f_{bl}$ . When  $MR_{Tq}(f)$  expression  $f_{bl} \leq f_b \leq f_{bh}$ . Until the next "ideal turbulent condition" emerged, the  $f_b$  was kept for the bandpass calculation.

Then we corrected the higher frequency range, to apply a correction function H(f) to the range of  $f_{bh} < f \le 0.1$  Hz, considering the CHT response from the previous study's result (Watanabe et al., 2000). According to Watanabe et al. (2000), the process would stabilize the estimation of water vapor flux from the bandpass method, especially for morning and evening, when the co-spectral similarity of temperature flux and water vapor flux often break. The function H(f) applied here is:

$$H(f) = \left\langle \frac{(1-A)[1-A\cos(2\pi f / f_s) - jA\sin(2\pi f / f_s)]}{1-2A\cos(2\pi f / f_s) + A^2} \right\rangle^{-1}$$
(1)

This function is low-pass complement of high-pass recursive filter (see Massman and Lee, 2002). Here **j** is imaginary unit, A is the parameter. The shape of the function is similar to that applied in Watanabe et al. (2000), both the real part and the imaginary part (Fig 1). However, only one parameter is included in Eq. 1. To determine the parameter A, we executed iterative calculation of the ratio

 $\sum_{\substack{f_b < f \le 0.1}} h(f) C_{wq}(f) ] / \sum_{f=f_b} C_{wq}(f) : \sum_{\substack{f_b < f \le 0.1}} C_{wT}(f) / \sum_{\substack{f=f_b \\ f=f_b}} C_{wT}(f) \text{ with varying } A, \text{ after determining } f_b. \text{ The parameter } A \text{ is fixed when the ratio became the nearest to unity, and we corrected } C_{wq}(f) \text{ using the } H(f) \text{ function and the parameter } A. \text{ Then we converted } \sum_{\substack{f>0.1 \\ f \le 0.1}} C_{wq}(f), \text{ total water vapor flux co-spectrum in the higher frequency region, to } \sum_{\substack{f>0.1 \\ f \le 0.1}} C_{wT}(f) / \sum_{\substack{f \le 0.1 \\ f \le 0.1}} C_{wT}(f) / \sum_{\substack{f \le 0.1 \\ f \le f_b}} C_{wq}(f) / + \sum_{\substack{f \ge 0.1 \\ f_b < f \le 0.1}} h(f) C_{wq}(f) ] \text{ as the original bandpass method.}$ 

### **Results**

After the above correction, we compared water vapor fluxes calculated by the bandpass method to those estimated with the open-path IRGA, using the data obtained in 20 July–1 August, 2012 (Fig 2A). Water vapor flux values were converted to latent heat flux by multiplying  $\lambda$  (latent heat of water). We also calculated the flux estimated by the original bandpass method without the correction of Equation 1 (Fig 2B). The improved bandpass method was well agreed with the open-path IRGA data, and the plots were less scattered by using the H(f) correction. These results suggest that the high potential of the submitted procedure for application of the long-term estimation of water vapor exchange in the lowland evergreen forest in Cambodia, without preliminary examination. Accordingly, we applied the method to estimation of the water vapor flux obtained from July 2008 to May 2009 and from September 2011 to December 2002, for the discussion about the seasonal trend and inter-annual variation between the two periods.

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![](_page_22_Figure_4.jpeg)

Figure 1. Comparison with the shape of Equation 1 and the transfer function of Watanabe et al. (2000). The left and right panels show the real and imaginary parts of the functions, respectively.

![](_page_22_Figure_6.jpeg)

Figure 2. Comparison of latent heat fluxes calculated with the open-path infrared gas analyzer to those calculated by the bandpass eddy covariance method. (A): Fluxes calculated by using Equation 1 in the text. (B): Fluxes calculated by the original bandpass procedure.

## H-04

# The effect of partial harvesting on streamflow in an evergreen broadleaved watershed

KABEYA Naoki<sup>1</sup>\*, CHAPPELL Nick A.<sup>2</sup>, TYCH Wlodek<sup>2</sup>, SHIMIZU Akira<sup>1</sup>

## **Introduction**

Forests and water are both important natural resources. Many research studies related to land-use change (i.e. deforestation or afforestation) have described the relationships between forests and water resources very well. Also, the rainfall-runoff process is naturally complex because of the existence of various pathways of water flow within a watershed. In addition, long-term rainfall and streamflow records may be affected by trends in climate change. Thus, to understand the forest and water relationship, one must quantitatively evaluate the effects of both agroforestry and climate on changing water resources.

Previously, inference drawn from time-trend studies was weaker than that from paired watershed studies simply because there is no climatic control to separate vegetation cover effects from climatic effects (Whitehead and Robinson, 1993). Recently, Chappell and Tych (2012) have developed a new method for time-series analyses of hydrological data. Their work was the first application the Unobserved Components-Dynamic Harmonic Regression (UC-DHR) model for watershed hydrological data. Their technique uses a single time-series (monthly, fortnightly or daily), evaluating model estimation associated with uncertainty information, and a non-linear analysis. Their method can be used for quantitatively evaluating and comparing the effect of agroforestry versus climate on changing water resources and can also be used for non-paired basins. These characteristics are suitable for regions lacking extensive data sets, such as the humid tropics of many developing countries.

The aim of this study is to quantitatively evaluate the effect of agroforestry versus climate on changing water resources in a long-term research watershed in Japan using the UC-DHR method. Specifically, the study focuses on the effects of a partial harvest in 1982 on streamflow recorded in an evergreen broadleaved contributory basin of the Sarukawa Experimental Watershed. This experimental watershed is one of five long-term forest experimental watersheds observed and managed by the Forestry and Forest Products Research Institute of Japan. The watershed has three sub-basinss where high quality hydrological observations have been made for more than 39 years and where the history of the growing stocks was well known (Shimizu et al, 2008; Asano et al., 2011).

## Site and Observation Descriptions

The Sarukawa Experimental Watershed was established for forest hydrological studies in a warm temperate rain forest in Miyazaki Prefecture, Japan. This basin is located in the upstream parts of the Oyodo River as it flows through the city of Miyazaki. Hydrological observations began in 1959. The results of observations from this experimental watershed were gradually released in the years following 1967, when standard observations methods were established. Thus, observational data for the 39 years of 1967–2005 was previously summarized and published every 10 or 20 years during this period. In this study, the UC-DHR method was adapted for the partial harvest experiment carried out for the ??? km<sup>2</sup> Srk2 in 1982 using reliable and higher quality daily rainfall and streamflow data from 1967–2005.

## **UC-DHR** analysis

Chappell and Tych (2012) first described the UC-DHR model as an application for measuring hydrological change. Thus, this study explains the analysis procedure briefly. The UC-DHR model is a type of univariate UC model, a group of models that also includes the Basic Structural Model and the

Keywords: evergreen broadleaved forest; harvesting impact; Dynamic Harmonic Regression

<sup>&</sup>lt;sup>1</sup> Kyushu Research Center, Forestry and Forest Products Research Institute (FFPRI-KYS), 4-11-16 Kurokami, Kumamoto Kumamoto, 860-0862 Japan.

<sup>&</sup>lt;sup>2</sup> Lancaster Environment Centre, Lancaster University, United Kingdom

LA1 4YQ Lancaster United Kingdom

<sup>&</sup>lt;sup>3</sup> Forestry and Forest Products Research Institute (FFPRI), 1 Matsu-no-sato Tsukuba, Ibaraki, 305-8687 Japan.

<sup>\*:</sup>Corresponding author E-mail: kabeya@affrc.go.jp

Dynamic Linear Model. The UC-DHR model is characterized by a trend component ( $T_t$ : inter-annual), a short-term periodic component ( $C_t$ : cyclical annual and sub-annual and a zero mean observation error component ( $e_t$ , with variance,  $\sigma e^2$ ).

The simulated time-series of rainfall, streamflow  $(y_t)$ , was calculated using formula (1):

$$y_t = T_t + C_t + e_t \tag{1}$$

The most important component characterized in the present study is Ct, which is calculated using formula (2):

$$C_t = \sum_{i=1}^{S_s} \left( a_{i,t} \cos(t\omega_i) + b_{i,t} \sin(t\omega_i) \right)$$
(2)

where  $a_{i,t}$  and  $b_{i,t}$  are stochastic Time Variable Parameters (TVPs) defining the amplitude of the harmonic sine and cosine components and  $\omega_i$ , i = 1, 2, ..., Ss are fundamental and harmonic frequencies associated with the periodicity in the series. In this study, the trends in the rainfall and streamflow are modelled using an integrated random walk process and all of the TVPs in the periodic component are modelled using scalar random walk processes.

As for rainfall and streamflow in the three watersheds (Srk1, Srk2, and Srk3), the daily mean was calculated for each month from a daily dataset. Each individual record was analysed by UC-DHR using the CAPTAIN Toolbox (http://captaintoolbox.co.uk).

## Quantification of partial harvesting effect on streamflow record

Although harvest of 25% of growing stock did not significantly increase water yield in the UC-DHR analysis, the shape of the trends and peaks were similar for both treatments and all three catchments studied here, however the peak amounts were the greatest for the Srk2 subbasin. This peak runoff amount was created by the interaction of the harvest impact and the effects of climate.

We calculated the increase in the peak value from the 1st month after harvest to the longterm average before harvest for each sub-basin. We estimated harvest impact while removing the effect of climate using paired basin analysis at 1 month after harvest. The impact was estimated as 256–427 mm/yr. This impact was 21% or 36% of the annual evapotranspiration of this sub-basin and was equivalent to the percentage of growing stock removed. These results clearly demonstrate that UC-DHR analysis can be used to quantitatively evaluate the effect of agroforestry versus climate on changing water resources.

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## Prediction of increase in surface temperature due to declines of overstory trees in a deciduous forest, central Cambodia

CHANN Sophal<sup>1</sup>, SATHA Saing<sup>1</sup>, PHALLAPHEARAOTH Op<sup>1</sup>, IIDA Shin'ichi<sup>2</sup>, SHIMIZU Takanori<sup>2</sup>, ITO Eriko<sup>3</sup>, SHIMIZU Akira<sup>4</sup>, KABEYA Naoki<sup>4</sup>, TAMAI Koji<sup>2</sup>, OHNUKI Yasuhiro<sup>2</sup>

## **Introduction**

Tropical dry deciduous forests widely distribute in South and Southeast Asia, and have very unique phenology: they flush leaves 1-2 months before the first monsoon rain (e.g., Elliott et al., 2006). The rainfall amount in this region might be decreased by El Niño Southern Oscillation (ENSO) (Malhi and Wright, 2004), and Timmermann et al. (1999) predicted that ENSO events will be observed more frequently due to the global warming. Annamalai et al. (2013) reported based on the calculation results derived from the coupled climate model that Asian monsoon circulation would be affected by the global warming, and the amount of rainfall would decrease in this region. In this case, there are some possibilities that the water resources for deciduous trees would decrease, and that tropical deciduous forests would decline. To estimate possible changes in environmental factors due to the declines of deciduous forest, we calculated fluctuations of surface temperature by using Jarvis-type surface conductance models.

## Site and Methods

General description and measurement of micrometeorological factors

We built a 30-m-high observation tower in a dry deciduous forest in Kratie Province, some 200 km northeast of Phnom Penh, Cambodia ( $12^{\circ}55'$  N and  $106^{\circ}11'$  E). A stand density of 350 stems/ha, a mean tree height (*TH*) of 11.3 m, and a mean diameter at breast height (*DBH*) of 24.5 cm were obtained within an area of  $20 \times 20$  m near the tower. The forest had open canopy, and very dense understory vegetation (*Vietnamosasa pusilla*). More detailed information of this stand was described in Iida *et al.* (2012) and Iida et al. (2013).

## Calculation of vapor and heat fluxes

The eddy covariance instruments, a sonic anemo-thermometar (CSAT3, Campbell, USA) and a ventilated thermo-hygrometer (HMP45D, Vaisala, Finland) were installed at the top of the tower. And also blow the forest canopy, a sonic anemo-thermometar (SAT-540, Kaijo, Japan) and a ventilated thermo-hygrometer (HMP45D, Vaisala, Finland) were installed. The former and later set detected vapor and heat fluxes from the whole ecosystem and the understory vegetation, respectively. Due to the slow response of thermo-hygrometer, we applied bandpass-eddy covariance method for both sets of instruments, and finally obtained latent heat flux ( $\lambda E$ ) and sensible heat flux (H) from whole ecosystem and understory vegetation. Detailed descriptions about the bandpass-eddy covariance method are found in Shimizu et al. (2008).

Jarvis-type surface conductance model

We calculated surface conductance of whole ecosystem ( $G_{SW}$ ) and of understory vegetation ( $G_{SU}$ ) based on the Penman-Monteith equation (for detail, refer to Iida et al., 2009). And, we developed the Jarvis-type model to estimate  $G_{SW}$  and of understory vegetation  $G_{SU}$ :

$$G_{SW} = G_{SW-MAX} \cdot f(PPFD_W) \cdot f(VPD_W) \cdot f(T_W) \cdot f(SWC)$$
(1)

$$G_{\rm SU} = G_{\rm SU-MAX} \cdot f(PPFD_{\rm U}) \cdot f(VPD_{\rm U}) \cdot f(T_{\rm U}) \cdot f(SWC) \tag{2}$$

## Keywords: dry tropical forest, sap flow, single-tree transpiration, tree phenology

<sup>&</sup>lt;sup>1</sup> Institute of Forest-Wildlife Research and Development, Forestry Administration, Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia.

E-mail: sophal.chann@yahoo.com

<sup>&</sup>lt;sup>2</sup> Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato Tsukuba, Ibaraki, 305-8687 Japan.

<sup>&</sup>lt;sup>3</sup> Hokkaido Research Center, FFPRI, 7 Hitsujigaoka, Hokkaido 062-8516, Japan.

<sup>&</sup>lt;sup>4</sup> Kyushu Research Center, FFPRI, 4-11-16 Kurokami, Kumamoto 860-0862, Japan.

where subscripts of  $_{\rm W}$  and  $_{\rm U}$  means whole ecosystem and understory vegetation, respectively. *PPFD* is photosynthetic photon flux density, *VPD* is vapor pressure deficit, *T* is air temperature, and *SWC* is weighted mean soil water content at depth from 0 to 60 cm.

Estimation of increase in surface temperature due to declines in overstory trees

To estimate the possible change in surface temperature (*TS*) due to decline in overstory trees, we input data of  $PPFD_W$ ,  $VPD_W$ ,  $T_W$ , *SWC* into Equation 2, and obtained surface conductance of understory vegetation without overstory trees ( $G_{SU-NO-TREE}$ ). Next, we calculated latent and sensible heat fluxes of understory vegetation without overstory trees ( $\lambda E_{NO-TREE}$  and  $H_{NO-TREE}$ , respectively) from Penman-Monteith equation with  $G_{SU-NO-TREE}$ . Finally, assuming that surface temperature (*TS*) for  $\lambda E_{NO-TREE}$  is equal to that for  $H_{NO-TREE}$ , *TS* when overstory trees are cut (*TS*<sub>NO-TREE</sub>) is calculated by the following equation derived from the bulk method (Kondo, 1994):

$$TS_{\text{NO-TREE}} = \frac{H_{\text{NO-TREE}}}{C_{\text{P}} \cdot \rho \cdot G_{\text{A}}} + T_{\text{U}}$$
(3)

where  $C_{\rm P}$  is the specific heat of air at constant pressure,  $\rho$  is the density of moist air, and  $G_{\rm A}$  is aerodynamic conductance above understory vegetation.

#### **Results and Discussion**

Figure 1 shows *PPFD*, *H* and  $\lambda E$  above forest canopy and understory vegetation in the wet season. This ecosystem is comprised from the sparse overstory trees and dense understory vegetation. Although this period is equivalent to the mature season of phenology, the ratio of *PPFD*<sub>U</sub> and *PPFD*<sub>W</sub> is about 0.4, and this value is relatively high compared with forests having closed canopy (Figure 1A). Also, the contribution of the latent heat flux from understory vegetation ( $\lambda E_{\rm U}$ ) to that from whole ecosystem ( $\lambda E_{\rm W}$ ) is around 40% to 50% (Figure 1B).

![](_page_26_Figure_8.jpeg)

Figure 1. Day-to-day changes in measured (A) photosynthetic photon flux density (*PPFD*), (B) sensible heat flux (*H*) and (C) latent heat flux ( $\lambda E$ ) from July 1<sup>st</sup> to 15<sup>th</sup>, 2010. Thin and thick line shows whole ecosystem and understory vegetation, respectively.

![](_page_27_Figure_1.jpeg)

Figure 2. Environmental responses of surface conductance of the whole ecosystem  $(G_{SW})$  to (A) photosynthetic photon flux density  $(PPFD_W)$ , (B) vapor pressure deficit  $(VPD_W)$ , (C) air temperature  $(T_W)$ , and (D) soil water content from the depth of 0 to 60 cm (SWC). Solid and open squares show the data in the wet and dry season, respectively. Note that model is fitted for only data in the wet season.

![](_page_27_Figure_3.jpeg)

Figure 3. Environmental responses of surface conductance of the understory vegetation ( $G_{SU}$ ) to (A) photosynthetic photon flux density ( $PPFD_U$ ), (B) vapor pressure deficit ( $VPD_U$ ), (C) air temperature ( $T_U$ ), and (D) soil water content from the depth of 0 to 60 cm (SWC). Solid and open squares show the data in the wet and dry season, respectively. Note that model is fitted for only data in the wet season.

![](_page_28_Figure_1.jpeg)

Figure 4. Comparisons of the environmental condition between the current environment including overstory trees and understory vegetation and the case when overstory trees are completely removed. (A) latent heat flux, (B) sensible heat flux and (C) surface temperature

Figures 2 and 3 show the environmental responses of  $G_{SW}$  and  $G_{SU}$  with the fitted Jarvis-type model, respectively. Clear differences in response to light condition were found. The understory vegetation can only use about 40% of *PPFD*<sub>W</sub> (Figure 1A), and thus the light saturation point of  $G_{SU}$  is smaller than that of  $G_{SW}$ . However, other environmental conditions, *VPD* and *T*, are similar among the overstory trees and understory vegetation, and these members of the ecosystem use the same resource of soil water. Differences in the responses to *VPD* and *SWC*, and the optimal temperature are small.

Based on the Jarvis-type model, we estimated  $\lambda E_{\rm U}$  and  $H_{\rm U}$  without overstory trees. Although increases in the available energy for the understory vegetation result in the increase in  $\lambda E_{\rm U}$  and  $H_{\rm U}$ , the degree of increase is larger for  $H_{\rm U}$  than  $\lambda E_{\rm U}$  due to smaller surface conductance of the understory vegetation than overstory trees (Figures 2 and 3). As a result, the significant increase in the surface temperature is estimated (Figure 4C). On the average, the increase in surface temperature is estimated to be 3°C. If overstory trees are declined completely by the lack of water resources caused by the global warming, the environmental condition might be severe. Thus, we need to clarify the capacity of the water resources, and to estimate the potential risk of forest degradation.

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Forestry Ecology

## Net Primary Production (NPP) estimation in Cambodia: comparison between the Kampong Thom and Kratie meteorological observation tower plots

TITH Bora<sup>1</sup>, ITO Eriko<sup>2</sup>, FURUYA Naoyuki<sup>2</sup>, KURAMOTO Shigeo<sup>2</sup>, OHNUKI Yasuhiro<sup>3</sup>, TORIYAMA Jumpei<sup>3</sup>, MONDA Yukako<sup>3</sup>, ARAKI Makoto<sup>3</sup>, SHIBATA Mitsue<sup>4</sup>, YAGI Takanobu<sup>4</sup>, SAKAI Yoshimi<sup>5</sup>, KANZAKI Mamoru<sup>6</sup>, KETH Samkol<sup>1</sup>, CHANDARARITY Ly<sup>1</sup>, PHALLAPHEARAOTH Op<sup>1</sup>, POL Sopheavuth<sup>1</sup>, LIM Sopheap<sup>1</sup>, PITH Phearak<sup>1</sup>, KHOM Saret<sup>1</sup>, CHANN Sophal<sup>1</sup>

## **Introduction**

Net primary production (NPP) is defined as the rate of accumulation of organic matter by vegetation, and is calculated as the difference between photosynthesis and autotrophic respiration. Because it accounts for the net carbon (C) fixed by vegetation per unit area per year, NPP represents the role of live vegetation in global C cycles. Forest biomass comprises close to 90% of all terrestrial vegetation biomass on earth (Dixon et al. 1994). Forest biomass is important component in the global C cycle. There are several approaches to predict forest NPP. One is meteorologically  $CO_2$  flux based prediction. Another is tree-census based prediction. FFPRI and FA constructed two meteorological towers located in the Kampong Thom evergreen forest and the Kratie deciduous forests. In order to clarify forest C cycle and relating forest water cycle possibly differing by the forest type, quantification of NPP is required. This study presents the NPP estimates in the Cambodian two main forest types, i.e., evergreen forest and deciduous forest, by using ground measurement approach.

## **Research site**

The study was conducted in Kratie meteorological observation tower plot (Kratie plot, 12.92°N, 106.20°E), located at 50 km northern from Kratie provincial capital in eastern Cambodia (ca. 50 km<sup>2</sup>), and Kampong Thom meteorological observation tower plot (Kampong Thom plot, 12.73°N,

Keywords: Evergreen forest, Deciduous forest, Vegetation, Carbon

Institute of Forest and Wildlife Research and Development (IRD), Forestry Administration, Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia. E-mail: tithbora@yahoo.com

<sup>2</sup> Hokkaido Research Center, Forestry and Forest Products Research Institute, 7 Hitsujigaoka, Sapporo 062-8516, Japan.

<sup>3</sup> Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato Tsukuba, Ibaraki, 305-8687 Japan.

<sup>4</sup> Tohoku Research Center, Forestry and Forest Products Research Institute, 92-25 Nabeyashiki, Shimokuriyagawa, Morioka, 020-0123, Japan.

<sup>5</sup> Kyushu Research Center, Forestry and Forest Products Research Institute, 4-11-16 Kurokami, Kumamoto, 860-0862, Japan.

<sup>6</sup> Graduate School of Agriculture, Kyoto University, Kitashirakawa, Sakyo, Kyoto City, Kyoto, 606-8502 Japan.

	Forest type		
	Evergreen plot	Deciduous plot	
Stem density [ha <sup>-1</sup> ]	1499 (with 77 vein)	553	
Max. DBH [cm]	111.1	45.8	
Max. tree height [m]	51.2	27.1	
Basal area [cm <sup>2</sup> / m <sup>2</sup> ]	29.5 (with 0.44 of vein)	13.3	
Biomass [t ha <sup>-1</sup> ]	246.0 (without vein)	98.5	

Table 1. Plot-based forest statistics in the evergreen and deciduous 4 ha plots.

105.47°E). Forest type was deciduous forest in Kratie (hereafter, DF) and evergreen forest in Kampong Thom (hereafter, EF). In order to investigate topographical pattern of the soil and vegetation, we set 4 ha permanent plots (200 m x 200 m) with centers of meteorological towers of evergreen and deciduous forests. Plot-based forest statistics are displayed in Table 1. Added to the two 4ha plots, we also estimated NPP for two 0.24ha permanent sample plots for reference in the Kampong Thom where we have measured tree increment and forest demography over 10 years. One plot (DEF) was dominated with evergreen dipterocarps, located in drier condition rather than EF and on deep soil layer. Another plot (DDF) was dominated by *Dipterocarpus obtusifolius* (Tbeng), located on poor nutrient soil with seasonally flooding.

### **Methods**

Chronological tree census have been conducted in the two 4 ha plots. For tree census, we divided the 4 ha plot into 10 m x 10 m orthogonal cross grids (10 m quadrat), which divided into four 5 m x 5 m orthogonal cross grids (5 m sub-quadrat). Within each quadrat, all trees > 5 cm DBH were enumerated since 2011 in DF and 2013 in EF. Total NPP was computed as summing up wood biomass increment, leaf production, fine root production, and forest floor production. Total (aboveground + belowground) tree biomass increment based on time-series tree censuses using allometry equations to estimate total biomass from the basal area, the tree height, and basic density of the stem wood (Kiyono et al, 2011, Monda et al, in submittion). Biomass was converted to carbon stock using the carbon fraction of 0.5. Annual leaf fall was estimated using a litter trap method in EF, and allometry equations in DF. Annual fine root production was based on the common assumption that fine root production equals fine leaf litter fall (Jenkins et al, 2001). Forest floor biomass and climber biomass was not accounted for in EF, while annual grass and shrub biomass production was investigated in DF based on destructive sampling conducted at 24 cross points by 50 m x 50 m except of the center of plot (i.e., the tower). Above-ground biomass of grass and shrub disappeared during dry season because of fire and drought. Fine root production of forest floor vegetation was also assumed to be equal to above-ground production.

## **Results and Discussion**

Samreth et al. (2012) demonstrated the average forest tree carbon stocks in Cambodia based on governmental permanent sampling plots survey, where  $163.8 \pm 7.8$  Mg C ha<sup>-1</sup> for evergreen forests and  $56.2 \pm 6.7$  Mg C ha<sup>-1</sup> for deciduous forests. Forest tree carbon stock in EF (123.0 Mg C ha<sup>-1</sup>) was 75% of the national average, while that in DF (49.3 Mg C ha<sup>-1</sup>) was 88 % of the national average. Frequent distribution of 10m x 10m quadrat tree carbon stock displayed that quadrates with low stock are majority in both plots, and plot's carbon stock depends on how many high-biomass quadrates there in (Figure 1).

NPP estimates in the two 4 ha plots and two 0.24 ha plots were displayed in Table 2. To be surprised, total NPP estimates were similar in EF and DF, while parts of high production were different. Wood biomass increment was very small in the deciduous plot. But forest floor production was very large. In particular, flat area without trees displayed high grass production (data not shown). Compared to DF, EF displayed similar value in wood and leaf productions. Flower and fruits production in EF was relatively large. It was partly because female trees of *Myristica iners* (Kuok) biannually produce much fruits.

The 0.24 ha evergreen plot has larger biomass than the evergreen plot, however, wood biomass increment was larger in the evergreen plot than 0.24 ha evergreen plot. It might be resulted from water availability. The lowest groundwater level at the end of dry season was about 2-5 m near swamp in the evergreen 4ha plot, on the other hand more than 10 m in 0.24 ha evergreen plot.

## **Conclusion**

We quantified NPP in two different forest ecosystems. In the deciduous 4 ha plot, wood biomass increment was very small, while grass biomass was so large. In the evergreen 4 ha plot, wood biomass increment was large, which may be achieved by high water availability. Nevertheless of contrasting plot-based forest statistics, NPP estimates were not so different each other. Our numerical results would help comprehend hydrological processes obtained by the meteorological tower observation.

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![](_page_35_Figure_0.jpeg)

Table 2. NPP estima	ates for 4ha plots a	nd 0.24 ha plots.		[unit: t ha <sup>-1</sup> year <sup>-1</sup> ]
_		Forest type (p	olot area [ha])	
	EF (4.0)	DF (4.0)	DEF (0.24)	DDF(0.24)
Wood	$4.0^{1)}$	0.7	1.6	1.2
Leaf	$5.0 \pm 1.4$	3.7	$6.9 \pm 0.4$	4.5
Fine root <sup>2)</sup>	<u>5.0</u>	<u>3.7</u>	<u>6.9</u>	<u>4.5</u>
Forest floor (aboveground + <u>belowground<sup>2)</sup></u> )	-	3.6+ <u>3.6</u>	-	-
Flower and fruits	$1.6 \pm 2.6$	0.5	$0.4 \pm 0.3$	0.3
Total (with fl. & fr.)	14.0 (15.6)	15.4 (15.9)	15.4 (15.8)	10.2 (10.5)

There are elements of uncertainty in 1) wood increment in EF did not count vein increment; 2) fine root production is based on assumption.

## Impact of selective logging on stand carbon storage in *Dipterocarpus* obtusifolius stand

ITO Eriko<sup>1</sup>, FURUYA Naoyuki<sup>1</sup>, MONDA Yukako<sup>2</sup>, TORIYAMA Jumpei<sup>2</sup>, OHNUKI Yasuhiro<sup>2</sup>, KIYONO Yoshiyuki<sup>2</sup>, ARAKI Makoto<sup>2</sup>, TITH Bora<sup>3</sup>, KETH Samkol<sup>3</sup>, CHANDARARITY Ly<sup>3</sup>, PHALLAPHEARAOTH Op<sup>3</sup>, CHANN Sophal<sup>3</sup>, KANZAKI Mamoru<sup>4</sup>

### **Introduction**

Forest degradation has been seriously concerned as a cause of carbon emission (GOFC-GOLD 2009). However, there is still less convincing information exhibiting reliable impacts of forest degradation. To assess convincing information on forest degradation, ground-based monitoring and measurement of C stocks are highly required (UNFCCC 2011). However, there is still less convincing information exhibiting impacts of forest degradation in Cambodia, which possibly differs among forest types.

In Cambodia, three main types of forests are recognized: evergreen, semi-evergreen, and deciduous (Forestry Administration 2011). Open forest patches scattered in dense evergreen forest are a landscape peculiar to lowland Cambodia. The forests dominated by *Dipterocarpus obtusifolius* (Khmer local name, Tbeng) are characterized by 50 % canopy openness, poor species richness, ground fire (Hiramatsu et al. 2007), nutrient-poor soil (Toriyama et al. 2007a, b), and seasonally flooded edaphic condition (Rollet 1972). These features suggest that site environment of the *D. obtusifolius* forests is severe for plant growth, which imply that the *D. obtusifolius* forests are vulnerable to anthropogenic disturbance.

This paper examine the situation of selective logging operation occurred at a permanent sample plot located in a *D. obtusifolius* forest, central Cambodia.

## **Research site and methods**

Study site is located in Kampong Thom Province in central Cambodia. We set permanent sample plot (30 m x 80 m) for vegetation and soil study in 2003, after that field survey examined in 2003, 2008, 2009, 2011, 2012, and 2014 to investigate tree growth and demography. Measurement of tree diameter was conducted to the nearest 1 mm at breast height (DBH, 1.3m) for all free-standing woody stems  $\geq$  5 cm dbh at every census. Selective logging was examined between November 2012 and February 2014, presumably in the end of 2013 or the beginning of 2014. The stand had an open canopy, and was dominated by *D. obtusifolius* (ca. 50% of stand basal area) and *Gluta laccifera* (35%) with minor composition of *Parinari annamensis* (6%), *Syzygium oblatum* var. *oblatum* (4%), and *Memecylon scutellatum* (1%).

## Keywords: Dry dipterocarp forest, Forest biomass, Forest degradation, Selective logging

<sup>1</sup> Hokkaido Research Center, Forestry and Forest Products Research Institute (FFPRI-HKD), 7 Hitsujigaoka, Toyohira, Sapporo, Hokkaido, 062-8516 Japan. E-mail: iter@affrc.go.jp

<sup>2</sup> Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato, Tsukuba, Ibaraki, 305-8687 Japan.

<sup>3</sup> Institute of Forest and Wildlife Research and Development (IRD), Forestry Administration, Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia.

<sup>4</sup> Graduate School of Agriculture, Kyoto University, Kyoto City, 606-8502 Japan.

In order to evaluate logging impact, we estimated tree biomass stock, increment and C loss accompanied with selective logging. Whole individual tree biomass was estimated using the following generic equations applicable to tropical and subtropical dry land trees having DBH: 1-133 cm (Kiyono et al. 2011).

$$TB = 1.77 \times DBH^{1.05} \times WD^{1.11} \times H^{0.535}$$

Where TB is the total biomass, indicating whole tree biomass as aboveground biomass plus belowground biomass (kg), DBH is the basal area of a stem at a height of 1.3 m ( $m^2$ ), WD is the basic density (kg  $m^{-3}$ ) of stem wood, and H is tree height (m).

#### **Results and Discussion**

Logged trees were *D. obtusifolius* and *G. cambodiana* with DBH averaged 43.8 cm and ranged from 35.9 to 57.8 cm, where approximately the largest trees were logged (Figure 1). Diameter limit criteria seemed to be applied on selective logging in the *D. obtusifolius* forest similar to most conventional selective logging in tropical forests (Sist et al. 2003).

Forest properties depletion was demonstrated in Figure 2. Stem density, i.e., number of living stem with DBH > 5cm at 1.3 m height (stem / ha), averaged  $395\pm27$  during five census. After selective logging, stem density decreased to 354 (90 % of the five census average). The logging intensity of 20.8 trees  $ha^{-1}$  in the *D. obtusifolius* forest corresponded to range of 50 - 100 m<sup>3</sup>  $ha^{-1}$ , which ranks the considerably severe logging intensity for tropical forests being typical at a small scale less than 10 ha (Putz et al. 2001). Proportion of damaged trees accompanying selective logging was 2.5 % of the original tree population, in which there were stem-broken tree nearby logged trees and unknown purpose cutting trees. Accompanying damage was quite less than other logging operations in tropical forests (Sist et al. 1998; Pereira et al. 2002; Feldpausch et al. 2005), mainly because D. obtusifolius forests are sparse. Basal area and stand biomass severely decreased. Compared among tree censuses examined in February (2003, 2011, and 2014), basal area and biomass of the stand in 2011 increased to 109 % of 2003, but decreased to 74 % and 68 % of 2003 after selective logging. During 2011 and 2014 census, biomass of 43 t/ha reduced, in which logged target trees and damage accompanying logging operation owe to 92% and 3.3%, respectively, while naturally dead was 4 %. Biomass increment was 1.2 Mg ha<sup>-1</sup> year<sup>-1</sup> in this stand; thus impact of selective logging on stand carbon storage corresponds to 35 years stand growth. The remained forest is expected to accumulate the carbon stock with a rate of 0.46 MgC ha<sup>-1</sup> year<sup>-1</sup>. Given this increment estimate, to recover stand carbon depletion accompanying selective logging (22.6 MgC  $ha^{-1}$ ), 50 years needs.

#### **Conclusion**

This study clarified the situation of selective logging in *D. obtusifolius* forests widely scattered in Cambodian land. Target species of *D. obtusifolius* and *G. laccifera*, where diameter limit criteria was applied to logging operation resulting in high logging intensity. This study quantified how much forest properties deplete under selective logging operation, including "involving damage and unknown purpose cutting". The impact of the selective logging operation is not negligible given small tree increment and low recruit rate in *D. obtusifolius* forests. This study evaluated that

selective logging impact corresponds to 35 years' carbon increment, and that carbon stock recovery needs about 50 years.

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![](_page_39_Figure_0.jpeg)

Figure 1. Target tree species DBH distribution in the study forest based on the pre-logging 2011 census. Patterns in bars indicate tree status at the post-logging 2014 census. (a) *Dipterocarpus obtusifolius*; (b) *Gluta laccifera*.

![](_page_39_Figure_2.jpeg)

Figure 2. Forest structure and tree characteristics for stems  $\geq$  5 cm DBH pre and post selective logging in the *D. obtusifolius* forest, Cambodia. (a) Stem density; (b) basal area; (c) tree biomass.

# Spatial variation of soil water content, soil hardness and ground temperature at deciduous and evergreen forests in Cambodia –Continued Report–

OHNUKI Yasuhiro<sup>1</sup>, KETH Samkol<sup>2</sup>, ITO Eriko<sup>3</sup>, TITH Bora<sup>2</sup>, CHANN Sophal<sup>2</sup>, KABEYA Naoki<sup>4</sup>, TORIYAMA Jumpei<sup>1</sup>, ARAKI Makoto<sup>1</sup>

#### **Introduction**

In central Cambodia, in similar altitude of Mekong River bank, different types of forests are distributed: deciduous forest at east bank and evergreen forest at west bank (Ohnuki et al., 2008). Ohnuki et al. (2014) had reported that the spatial fluctuation of the soil hardness and soil water content of both forests: establishing 4 ha (200 x 200 m) plots. However, the study could not discuss enough about the seasonal variation of soil hardness and soil water content.

In this continued study, the authors measured soil water content, soil hardness and ground temperature at 4 ha plots of the deciduous forest and the evergreen forest at many points in dry and rainy seasons. Using the collected data of both forests, we discuss the relationships between the spatial variation of the soil water content, soil hardness and ground temperature, and forest types.

### Study area and Methods

The survey sites for this study were located in Kratie Province and Kampong Thom Province. There, lowland dry deciduous forest (DDF) and lowland dry evergreen forest (DEF) are expanding, respectively.

In the same plots of the previous study (Ohnuki et al., 2014), the authors measured soil water content (volume water content), soil hardness and ground temperature at 24 points in Feb. 2013 (dry season) and Nov. 2013 (rainy season), at 41 points in Feb.2014 (dry season) at DDF 4 ha plot. In contrast, at 4 ha plot of DEF, measuring points were 30 points in Feb. 2013, 27 points in Nov. 2013 and 41 points in Feb. 2014.

#### **Results and Discussion**

Figure 1 shows the soil water content of DDF in Nov. 2013 and Feb. 2014. In the rainy season, all points showed over 10 %; especially at two points near the intermittent stream, over 30 %. In the dry season, 88% of measuring points showed less than 10%; of this total, 6 points were less than 5 %. The variation of both seasons was large at near the intermittent stream.

In contrast, the soil water content of DEF was quite different from that of DDF (Figure 2). In the rainy season (Nov. 2013), 3 points showed over 40 % near streams and marshes; at 3 points in higher elevation,

Keywords: soil water content, ground temperature, soil hardness, deciduous forest, evergreen forest

<sup>1</sup> Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato, Tsukuba, Ibaraki, 305-8687 Japan.

<sup>2</sup> Forest-Wildlife Research and Development Institute (FWRDI), Forestry Administration, Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia.

<sup>3</sup> Hokkaido Research Center, FFPRI, 7 Hitsujigaoka, Toyohira, Sapporo, Hokkaido, 062-8516 Japan.

<sup>4</sup> Kyushu Research Center, FFPRI, 4-11-16 Kurokami, Chuou, Kumamoto, Kumamoto 860-0862 Japan.

we observed less than 10 % value. Even in the dry season (Feb. 2014), 2 points showed over 40 % near streams and marshes; at 6 points in higher elevation, surface soils were quite dry, less than 5 %. The groundwater level (GWL) near the tower was similar in both seasons (-0.3 m and -0.7 m); meanwhile, at higher elevation just outside the 4 ha plot, the GWL were so different in each season (-1.5 m and -2.8 m). This difference would conduce to the distribution of soil water content in rainy and dry seasons.

The soil hardness of DDF was quite different from that of DEF in both seasons. In the rainy season, it had exceeded 1.5 MPa at 4 points in DDF; in DEF, it was over a range of 0~0.4 MPa. In the dry season, the values exceeded 0.5 MPa at all points in DDF, particularly on the hill, reaching 2 MPa; in DEF, many of the points showed less than 0.4 MPa. Similarly, the ground temperatures were different in both plots. In the rainy season, the maximum value was 33°C and only 6 points exceed 30°C; in the dry season, the maximum value was 37.4°C and 9 points exceeded 35 °C at DDF. In contrast, at DEF, the ground temperatures were similar in the rainy season, varied from 24.9 °C to 27.0°C; in the dry season, the values were fluctuated from 23.5 °C to 26.3°C. As observed above, soil hardness and soil temperature were quite different in each season in both plots.

![](_page_41_Figure_3.jpeg)

Figure 1 Soil water content in the 4 ha plot of DDF in Nov. 2013 and Feb. 2014.

![](_page_41_Figure_5.jpeg)

Figure 2 Soil water content in the 4 ha plot of DEF in Nov. 2013 and Feb. 2014.

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## Seasonal changes of photosynthetic properties on dry deciduous forest trees in Cambodia

KENZO Tanaka<sup>1</sup>, IIDA Shin'ichi<sup>1</sup>, SHIMIZU Takanori<sup>1</sup>, TAMAI Koji<sup>1</sup>, KABEYA Naoki<sup>2</sup>, SHIMIZU Akira<sup>2</sup>, CHANN Sophal<sup>3</sup>

## **Introduction**

Dry deciduous forest (DDF) widely distribute through the monsoon area of Southeast Asia such as Thailand, Laos and Cambodia (Corlett 2009). The forest consists of several deciduous trees e.g. *Dipterocarps tuberculatus, Shorea obtusa, S. siamensis, Terminalia* spp., and *Xylia xylocarpa* (Ogawa et al. 1961). Mean canopy height is significantly lower and usually have unclosed canopy compared with other tropical evergreen forests with closed canopy (Ogawa et al. 1961). Although the most of the forest in the area has been converted to agricultural field and rubber plantation, relatively large area of the forest still remain in Cambodia. Forest coverage in Cambodia is approximately 57% and DDF occupies over 40% of the forest area in 2009 (Forestry Administration 2010). Therefore the forest may have important role for carbon cycle in this region, though the forest also rapidly disturbed by anthropogenic activities such as land conversion and logging.

Leaf-level photosynthetic traits are essential for scaling leaf measurements to the whole plant and stand level and for quantifying carbon fluxes from forest ecosystems. Those measurements have been conducted in several forest types in Cambodia such as dry evergreen forest (Hozumi et al. 1969, Kenzo et al. 2012) and plantation forests including exotic eucalyptus (Miyazawa et al. 2013). However little is known about seasonal changes on those photosynthetic properties on the tree species of DDF in Cambodia. In addition, such studies are quite scarce even in the adjacent countries such as Vietnam, Laos and Thailand except for a few tree species (Ishida et al. 2006, 2010).

In this study, our objective is to clarity differences on leaf-level photosynthetic traits between rainy and early dry seasons in typical dry deciduous forest trees in Cambodia. For this purpose, we measured essential parameters to understand the forest carbon exchange mechanisms, such as the leaf maximum photosynthetic rate ( $P_{\rm max}$ ), maximum rate of carboxylation ( $Vc_{\rm max}$ ), and stomatal conductance (gs).

## Site and Methods

This study was carried out in Kratie province, Cambodia (12°55'N, 106°11'E). Annual rainfall was 1500-1700 mm and most rainfall (approx. 90%) occurred during the rainy season from May to October. The vegetation on the study site was classified as dry deciduous forest. Most of the canopy trees were 10-20 m high; mainly consisting of Combretaceae, Dipterocarpaceae and Fabaceae. Tall grasses (1.0-2.0 m in height) such as dwarf bamboo densely covered forest floor (Figure 1).

All measurements were conducted in early dry season on November 2012 and rainy season on August 2013. We selected 32 individuals of 4 tree species ranging from 0.5 to 14.5 m in height for the study. All species are typical DDF tree species in the region. Studied species were *Dipterocarpus tuberculatus* (Dipterocarpaceae), *Shorea obtusa* (Dipterocarpaceae), *Terminalia alata* (Combretaceae) and *Xylia xylocarpa* (Fabaceae). *Terminalia alata* had two variations, which was distinguished by present or absent of dense under surface leaf hair. We collected 1 - 3 branches per sampling trees by using a 15 m-long pole with sickle. We also conducted physiological measurements of understory dwarf bamboo species (*Vietnamosasa pusilla*, Poaceae), which is the most abundant herbaceous species in the site. All sampled shoots were immediately placed in water to prevent the stomata closing. We also directly measured the leaf photosynthetic rate at the attached condition for sampled

Keywords: carbon, dry deciduous forest, photosynthetic rate, Vc<sub>max</sub>

<sup>&</sup>lt;sup>1</sup> Forestry and Forest Products Research Institute (FFPRI), 1 Matsu no sato Tsukuba, Ibaraki, 305-8687 Japan. E-mail: mona@affrc.go.jp

<sup>&</sup>lt;sup>2</sup> Kyushu Research Center, Forestry and Forest Products Research Institute

<sup>&</sup>lt;sup>3</sup> Forest-Wildlife Research and Development Institute, Phnom Penh, Cambodia

trees lower than 2 m in height.

Maximum photosynthetic rate at light saturation ( $P_{max}$ ), stomatal conductance (*gs*) and dark respiration (*Rd*) were measured using a portable photosynthesis meter (LI-6400, Li-Cor, Lincoln, NE). We used fully expanded and apparently non-senescing leaves taken from the top of the crown. The measuring light intensities were 0 and 1500 (µmol photon m<sup>-2</sup> s<sup>-1</sup>) and the temperature was controlled at 30°C. The CO<sub>2</sub> concentration and air humidity in the leaf chamber were maintained at 400 ppm and approximately 60%, respectively (Kenzo et al. 2012).

The same system as used for A-Ci curve (A: net CO<sub>2</sub> assimilation rate, Ci: calculated substomatal CO<sub>2</sub> concentration) measurements. Light and temperature in the chamber were maintained at the saturating photosynthetic photon flux density (PPFD; approximately 1000 to 1500µmol photon m<sup>-2</sup> s<sup>-1</sup>) and at 30 °C using the LED light source and the air conditioner of the LI-6400 (Kenzo et al. 2004, 2006). One or three leaves per individual tree were selected for the measurement. The leaf selection criteria were the same as for measurement of the light curve. The A-Ci curves were analyzed using the mechanistic model of CO<sub>2</sub> assimilation proposed by Farquhar et al. (1980). From the A-Ci curve, the maximum rate of carboxylation ( $V_{cmax}$ , µmol m<sup>-2</sup> s<sup>-1</sup>) and the maximum rate of photosynthetic electron transport ( $J_{max}$ , µmol m<sup>-2</sup> s<sup>-1</sup>) were estimated by non-linear regression techniques by using KaleidaGraph ver 3.52.

## **Results and Discussion**

Canopy leaves in all species showed significantly higher photosynthetic capacity that indicated by  $P_{\text{max}}$ ,  $V_{\text{cmax}}$ , and  $J_{\text{max}}$  values than those of understory leaves both rainy and dry seasons (Figure 2). Moreover the most leaf photosynthetic traits linearly increased with tree height regardless of species and seasons. Higher photosynthetic capacity in canopy leaves may contribute to high carbon assimilation ability under the strong light condition in the canopy environment (Niinemets 2002). In general, many tree species growing under strong light condition such as open bare-land and canopy tends to have higher photosynthetic capacity in the same tree species (Koike 1998, Kenzo et al. 2006, 2007, 2014). Cambodian DDF tree species also have similar leaf photosynthetic adaptation to the upper canopy environments with strong light condition. In contrast, Kenzo et al. (2012) reported that canopy trees in Cambodian dry evergreen forest (DEF) showed decreased or limited photosynthetic capacity in DEF may indicate occurrence of stomatal closure by hydraulic limitation with their tall canopy height (Koch et al. 2004, Kenzo et al. 2012).

There were interspecific differences on changes of photosynthetic property between dry and rainy season in Cambodian DDF tree species. Leaf maximum photosynthetic rate  $(P_{max})$  of Shorea obtusa, Terminaria alata (hairy type) and Xylia xylocarpa were significantly higher in rainy season than that of dry season (Figure 2, ANCOVA, P<0.05). Lower drought stress such as low VPD and high soil water content during rainy season may arrow higher  $P_{\text{max}}$  without stomatal limitation of those species. Significantly reduced transpiration rate of Shorea obtusa and Terminaria alata (hairy type) in dry season suggested that those trees suffer drought stress by higher VPD and reduced soil water content, though transpiration rate of Xylia xylocarpa and their stomatal conductance (gs) were not significantly differed between seasons. In contrast,  $P_{\text{max}}$  and gs of Dipterocarpus tuberculatus and Terminaria alata (glabrous type) did not differ between seasons. Moreover, transpiration rate of Terminaria alata (glabrous type) was significantly higher in dry season compared with rainy season, though photosynthetic water use efficiency (WUE, Kenzo et al. 2008) significantly decreased in dry season (data not shown). Sap flow of this species also keep high rate during early dry season compared with rainy season (Iida et al. 2013). This species may have strong tolerance to drought stress or the species did not sensitively close their stomata against drought stress such as high VPD and lower soil water content during early dry season.

Photosynthetic capacity of understory dwarf bamboo (*Vietnamosasa pusilla*, Poaceae, Figure 1) showed similar values between seasons: e.g. mean  $P_{\text{max}}$ ,  $V_{\text{cmax}}$  and  $J_{\text{max}}$  in dry and rainy season were 7.7, 38.6, 87.8 and 7.4, 39.2, 69.0, respectively. Those photosynthetic capacities of dwarf bamboo were also in the range of the values of understory saplings of all studied trees (Figure 2), whereas transpiration rate and *gs* were relatively smaller and *WUE* was higher than understory trees in both seasons (data not shown). Lower transpiration rate with limited stomatal conductance in dwarf bamboo may be caused by limited water absorption by their shallow root system, because about 80%

to 90% of their root biomass exists above 20cm in soil depth (Ruangpanit 2000). On the other hand, high photosynthetic capacity of dwarf bamboo indicated that annual carbon fixation by understory herbaceous species may contribute large proportion of primary production in DDF ecosystems in Cambodia (Ruangpanit 2000).

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![](_page_45_Picture_2.jpeg)

Figure 1. Understory dwarf bamboo (Vietnamosasa pusilla) in the site

![](_page_45_Figure_4.jpeg)

Figure 2. Seasonal changes on leaf photosynthetic traits with tree height

Forest Management

## M-01

## The improvement of the estimation of deforestastion area and land use of the deforestation area in Cambodia, using plural PALSAR data

NAKAZONO Etsuko<sup>1</sup>, SAWADA Haruo<sup>2</sup>

## **Introduction**

Using the forest and vegetation cover map of Cambodia (2002) and MODIS map set, we estimated the deforestation area from 2002 to 2010. And we estimated the land use of deforestation area; plantation and agricultural land. But we found the main 2 problem points;

1. The estimate percentages of plantation in Banteay Meanchey and Pailin provinces are too high. We went field work to these provinces and found that the rate of plantation is very small (under 10 %), however the estimated percentage of plantation in these provinces were about 25%.

2. It was not able to extract the small patched deforestation area from MODIS data (230 m resolution).

So we want to improve these problems. In order to solve these problems, we used the PALSAR 50m mosaic data set, from 2007 to 2010.

## **Method**

1. Estimate the percentage of plantation

1) At first, we want to get the sample data of plantation and agricultural land. So we used the polygon data that already made for the purpose of getting the sample data from estimated biomass data. We made the 89 polygons from plantation area and 52 polygons in agricultural area. The former are selected mainly in Kampong Cham province, and latter are mainly in BattamBang, Banteay Meanchey, and Pailin provinces. For each polygon we calculated the 8 value of PALSAR HH and HV data, from 2007 to 2010 and drew the graph representing the deforestation year (estimated by MODIS data) and PALSAR value.

2) From the graph, we considered the year from when we can separate the plantation and agricultural land and threshold value. And using the result we calculated the percentage of plantation in each province.

2. Extract the small patched deforestation area

1) In order to extract the deforestation area by using the PALSAR data, we calculated

PALSAR data of 2007- PALSAR data of other year

As a result, we picked up the area that the PALSAR data value decreased, in other words the deforestation area from 2007 to other year (2008 -2010).

And we compared the area and ALOS data, we decided the threshold value.

2) But the difference data include the noises, so we made filter in order to reduce the noises. And we compared the result and estimated data using MODIS data set, and conformed by ALOS data.

## **Results and discussions**

1. Estimate the percentage of plantation

We drew the graph representing the deforestation year and PALSAR data, and found that;

• For the purpose to separate the plantation and agricultural land, PALSAR HV data is appropriate than HH data.

•PALSAR data (HV and HH) of 2008 is not appropriate for the purpose.

• From the graph of the deforestation year a nd HV value of 2009 and 2010, about the area that was cut before 2006, we can judge the plantation or agricultural land.

The deforestation area before 2006 can estimate only by using MODIS data, so we separated the estimated deforestation area by using MODIS data for 3 class.

<sup>1.</sup> Institute of Industrial Science, the University of Tokyo, 4-6-1 Komaba Meguro-ku, Tokyo

<sup>2</sup> Asian Institute of Technology, 58 Moo 9, Km. 42, Paholyothin Highway, Klong Luang, Pathumthani 12120, Thailand 1: plantation area : HV value of both 2009 and 2010 > threshold (2500) and cut area before 2006 year 2: agricultural land area : either HV value of 2009 or 2010 > threshold and cut area before 2006 year 3: cannot be judged area : the area that were cut after 2007 year

And we calculated the percentage of plantation (area that were cut before 2006 year) for each provinces and compared the rate this time and last time (using the estimated biomass data). And we found that the percentages of Banteay Meanchey and Pailin provinces are felled to 12% and 4% from 27 % and 25 %, the more valid rate.

### 2. Extract the small patched deforestation area

Because of the result of 1, we did not use the PALSAR 2008. And we picked up the area that were cut between 2007 to 2009 and 2007 to 2010. And we compared the estimated deforestation area by using PALSAR data and area that estimated by using MODIS data set, and we found that

•deforestation area by PALSAR and not deforestation area by MODIS: mainly small patched deforestation area. The area was estimated very well.

•not deforestation area by PALSAR and deforestation area by MODIS: Mainly deforestation area.

One of the reason that the deforestation area by MODIS data was classified to "not deforestation area" by PALSAR data is that the period of the mosaic data. And some of the area were cut before 2007. And also contained MODIS error and PALSAR error.

So we concluded that the PALSAR data set is useful to extract the small patched deforestation area. But the PALSAR mosaic data are covered only from 2007 to 2010, so we must use the MODIS data set in order to estimate the deforestation before 2006. So we will combine the MODIS data set and PALSAR data set; for the purpose to estimate the deforestation area before 2006, we will use the MODIS data set and to estimate the area after 2006, we will use the both of MODIS data set and PALSAR data set. And for the area cut before 2006, we will separate the plantation area and agricultural land by using PALSAR data.

## references

![](_page_49_Figure_10.jpeg)

JAXA. PALSAR 50m Orthorectified Mosaic Product (2007 -2010)

Fig. The example of the graphs; deforestation year and HV value of 2009. The line (HV=2500) is threshold for separating plantation and agricultural land

## Model estimation for rate of fire spread and flame height in forest fire - In case of dry deciduous forest in Kratie, Cambodia –

## TAMAI Koji<sup>1</sup>, GOTO Yoshiaki<sup>1</sup>, SHIMIZU Akira<sup>2</sup>, SHIMIZU Takanori<sup>1</sup>, KABEYA Naoki<sup>2</sup>, IIDA Shin'ichi1, CHANN Sophal<sup>3</sup>, SATHA Saing<sup>3</sup>, PHALLAPHEARAOTH Op<sup>3</sup>

## **Introduction**

Forest fire is clarified into two types as 1)Surface fire burning only litter and understory, and 2)Crown fire burning tree crowns. Generally, fire is started on the ground surface and expands to crowns. The rate of flame spread increases drastically when fire ignite crowns, because fire can fly from crown to crown. Moreover, a crown fires bring greater damages drastically than surface fires. Thus, people often perform the artificial surface fire and try to reduce the fuels on the forest floor under the safety condition in the world. At that time, it is essential to confirm that surface fires will not reach crowns and will not expand crown fires. To do so, estimation method should be developed to predict the rate of fire spread and flame height.

Thus, the rate of fire spread and flame fire height were estimated in case of surface fire in a dry deciduous forest Cambodia, with the fire spread model (Rothermel, 1972) and the estimation equation of flame height (Byram, 1973) in this study. Moreover, the predicted and observed values were compared.

### **Observed forest fire**

The surface fire is observed at the tower site of dry deciduous forest located in O Klieng basin (12°55'N, 106°11'E) in Kratie province, Cambodia at around 13 o'clock  $2^{nd}$  February, 2009. The rate of fire spread and flame height were observed by watch to be around 600m hour<sup>-1</sup> and around 2-4m, respectively. Wind condition was calm or near no windy during flame passed through the site. At the un-burned forest floor, oven-dry fuel loading (w<sub>o</sub>) and fuel depth (dep) were invested to be 0.8kg m<sup>-2</sup> and around 1m, respectively. Slope of ground surface was almost horizontal.

Dominant tree species around the site were *Diptrocarpus tuberculatus* and *Teminalia tomentosa*. Averaged tree height was 11.3m. The bottom surface height of crown was around 4m. Stem density was low to be 350n ha<sup>-1</sup>. Forest floor was covered with grasses.

### **Model**

The outline of Rothermel model (Rothermel, 1972) to predict the rate of flame spread (*R*) is shown in figure 1. The underlined data is the necessary ones to predict *R*. Among them,  $w_0$ , dep, and  $\theta$  are 0.8kg m<sup>-2</sup>, 1.0m and 0°, respectively, from the investigation at un-burned ground. The value of 0.00 and 0m s-1 are input as Moisture content ( $M_F$ ) and wind velocity at midflame height (*U*), because the observation was performed in mid-dry season and in the calm or near no wind condition. 18,768 kJ kg<sup>-1</sup>, 542.06 kg m<sup>-3</sup>, 132.32cm<sup>-1</sup>, 0.28, 0.029, 0.068 to the averaged values of main 41 tree species and 6 glass species Japan were input the Rothermel model in this study as Low heat content (*h*), Oven-dry particle density of fuel ( $\rho_p$ ), Surface-area-to volume ratio of fuel ( $\sigma$ ), Fuel moisture of extinction( $S_E$ ), and Effective mineral content in fuel( $S_T$ ), respectively.

Fire flame length was calculated with eq.(1) (Byram, 1973).

$$Lf = (FLI/259.83)^{0.46} = (hw_n R/259.83)^{0.46}$$
(1)

where *FLI* is Fire line Intensity (kW m<sup>-1</sup>) that is the amount of energy emitted from the flame

Keywords: Rothermel model, Byram equation

<sup>&</sup>lt;sup>1</sup> Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato Tsukuba, Ibaraki, 305-8687 Japan. E-mail: a123@ffpri.affrc.go.jp

<sup>&</sup>lt;sup>2</sup> Kyushu Research Center, Forestry and Forest Products Research Institute (FFPRI-KYS), 4-11-16 Kurokami, Kumamoto 860-0862, Japan.

<sup>&</sup>lt;sup>3</sup> Institute of Forest-Wildlife Research and Development, Forestry Administration, Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia.

with 1m width.

#### **Results of model calcuration**

*R* and *Lf* were calculated to be 690.31 m hour<sup>-1</sup> and 2.93m, respectively. Compared with the observed *R* and *Lf* to be around 600 m hour<sup>-1</sup> and 2-4m, respectively, Rothermel model is judged to simulate *R* and *Lf* very well. *FLI* was calculated to be 2683.26 kW m<sup>-1</sup> in the range reported by Goto et al. (2005) that *FLI* of ground fires in the world is lower than 5,000 kW m<sup>-1</sup> in general.

*R* depends on *U* and  $\theta$ , deeply. Y-axis in figure 2 shows the addition coefficient on the rate of fire spread caused by slope degree and wind speed. Each addition coefficient caused by slope degree and wind speed are around 10 when slope degree and wind speed are at 26° and 1.6m s<sup>-1</sup>, respectively. This means that the rate of fire spread is 10 times faster under the condition at 26° slope or 1.6m s<sup>-1</sup> wind than under the condition at flat topography and no wind. Generally, people would be perform the artificial surface fire. At that time, people have to pay attention to change the wind condition and slope topography.

Figure 3 shows the estimated fire line intensity and flame height (Y-axis) against amount of fuel on the forest floor (X-axis). The values in figures show the rate of fire spread (m hour<sup>-1</sup>) for each line.  $\Diamond$  in figures shows the values for the observed surface fire. Flame height was estimated to be 2.93m lower than the bottom surface of the crown to be around 4m. Thus, the flame could not reach the crown in the observed surface fire. The actual rate of the fire spread was observed to be around 600 m hour<sup>-1</sup>. If the rate of fire spread would be 2.3 times (1,400m hour<sup>-1</sup>) faster than the actual rate, the flame height was estimated to be around 4m and flame can reach the canopy. In this case, the surface fire has the possibility to expand the crown fire.

Only low wind speed to be 0.7m s<sup>-1</sup> cause the addition coefficient  $(1+\Phi_w)$  to be 2.3 and make the flame height to be 4m. Moreover, if the amount of fuel on the forest floor would be 2 times (1.6 kg m<sup>-2</sup>) more than actual amount, the flame height was also estimated to be 4m and raise the possibility to expand the crown fire.

Mentioned above, when people perform the artificial surface fire, they have to estimate the rate of fire spread and flame height from the wind speed, topography, amount of fuel on the forest floor and the bottom surface height of crown to prevent the expansion of surface fire to crown fire. The Rothermel model and Byram equation shown in this study are useful.

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![](_page_52_Figure_1.jpeg)

# Figure 1 The outline of Rothermel model to predict the rate of fire spread.

<u>*M<sub>F</sub>*: Moisture content (= weight of moisture/weight of oven-dry fuel), *M<sub>X</sub>*: Fuel moisture of extinction ( = weight of moisture when fuel can't ignite/ weight of oven-dry fuel), *I<sub>r</sub>*: Reaction intensity (kJ m<sup>-2</sup> min<sup>-1</sup>), *Q<sub>ig</sub>*: Heat of preignition (kJ kg<sup>-1</sup>), *R*: Rate of spread (m min<sup>-1</sup>), *R<sub>c</sub>*: Rate of spread under no wind and flat terrain (m min<sup>-1</sup>), *S<sub>E</sub>*: Effective mineral content in fuel ( = weight of minerals except for silica/ weight of oven-dry fuel), *S<sub>T</sub>*: Total mineral content in fuel ( = weight of minerals/weight of oven-dry fuel), *U*: Wind velocity at midflame height (m s<sup>-1</sup>), *dep*: Fuel depth (m), *h*: Low heat content (kJ kg<sup>-1</sup>), *w<sub>n</sub>*: Net fuel loading (kg m<sup>-2</sup>), <u>*w<sub>o</sub>*: Oven-dry fuel loading (kg m<sup>-2</sup>)</u>, *Γ*': Optimal reaction velocity (min<sup>-1</sup>), *Γ*' max : Maximum reaction velocity (min<sup>-1</sup>), *Φ<sub>s</sub>*: Slope factor, *Φ<sub>w</sub>*: Wind factor, *β*: Packing ratio (*w<sub>o</sub>/dep*), *β<sub>op</sub>*: Optimal packing ratio, *ε*: Effective heating number, *ζ*: Propagating flux ratio , *η<sub>M</sub>*: Moisture damping coefficient, *η<sub>s</sub>*: Mineral damping coefficient, <u>*θ*</u>: slope (degree), *ρ<sub>b</sub>*: Oven-dry bulk density of fuel (kg m<sup>-3</sup>).</u>

![](_page_53_Figure_1.jpeg)

Figure 2 Addition coefficient on the rate of fire spread caused by slope degree and wind speed Left; slope degree Right; wind speed

![](_page_53_Figure_3.jpeg)

# Figure 3 Estimation of the rate of fire line intensity and flame height in each amount of fuel on the forest floor

![](_page_53_Figure_5.jpeg)

## Change and Structure in Household Income of central Cambodian Frontier Villages: Implications for Effective Livelihood Support under New Forest Management Regime

KURASHIMA Takayuki<sup>1</sup>, MATSUURA Toshiya<sup>1</sup>, MIYAMOTO Asako<sup>1</sup>, SANO Makoto<sup>1</sup>, TITH Bora<sup>2</sup>, CHANN Sophal<sup>2</sup>

## **Introduction**

New forest management scheme like REDD+ is intended to reduce deforestation by rewarding communities that change their problematic land use patterns. While many project developers have encouraged incentives for such changes through support for sustainable land use and people's livelihoods, insufficient consideration has been given to the realities of communities, especially change and structure in household (HH) income. Support is likely to be ineffective if developers do not contemplate communities' realities, which arise from their current land-use patterns (Kurashima *et al.* 2014). Here, we clarify the change and structure in HH income experienced by frontier villagers to cheer effective livelihoods' supports.

## **Material and Methods**

## 1. Research site and reason for site selection

We examined data obtained from central Cambodia, specifically three Khmer villages in the eastern part of Kampong Thom Province (Figure 1). We selected this site for the following reasons: Cultivated land for commercial crops has been expanded (Figure 2) by both old and new settlement farmers over the past decade; and a HH income and livelihood study was conducted in the area 10 years ago (McKenny *et al.* 2004), which provides empirical data for temporal comparisons among the HH incomes of the three villages.

## 2. Data collection and interpretation methodology

The data for this study were obtained primarily from the HH survey conducted in the latter half of 2013 based on information from 2012. In addition, village leaders were interviewed in 2013 regarding the land use history and villagers' livelihoods. In total, 146 HHs, more than 30 percent of the total HHs in each village, were surveyed for this study. This is comparable to the ratio surveyed by McKenny *et al.* (2004), although that study surveyed only 85 HHs due to the smaller number of HHs in 2003. To facilitate comparisons between the two surveys, many questions were similar to those used in McKenny *et al.* (2004). Also, some data accounting methods, *e.g.*, the value of rice produced for HH consumption was factored into HH income, were used here to correspond with the data interpretation by McKenny *et al.* (2004).

### **Results and Discussion**

## 1. Changes in average HH income and percentages obtained from each source

Real average HH income has increased notably during 9 years (Table 1). The increases derived primarily from higher income from the cultivation of Other Crops and Business/Wage Labor. The contribution of Other Crops to the average total HH income was 12 percent in 2003, which was much smaller than those from Rice, Resin, and Other NTFPs. However, the contribution from Other Crops was 43 percent in 2012. Similarly, the Business/Wage Labor proportion was very small in 2003, but increased notably by 2012. The combined income from cultivation of Other Crops and Business/Wage Labor comprised two-thirds of the average total HH income in 2012. Correspondingly, the income contribution from Rice declined during this period.

Keywords: Household income, Livelihood, Agricultural cultivation, Frontier community, Cambodia

<sup>&</sup>lt;sup>1</sup> Forestry and Forest Products Research Institute, 1 Matsunosato Tsukuba, Ibaragi, 305-8687, Japan E-mail: kurakura@affrc.go.jp

<sup>&</sup>lt;sup>2</sup> Institute of Forest and Wildlife Research and Development, FA, Phnom Penh, Cambodia

# 2. Comparison of the income and structure of the highest and lowest 25 percent of HH income groups in 2012

To analyze the imbalance of income and structure among HHs in 2012, we focus on the lowest and highest 25 percent of HH incomes (Table 2). We clarified the average total HH incomes of these two groups, as well as the sources and percentages of the various factors in total HH incomes. The results show that there is a large total average income gap between two groups, and such a gap primarily comes from the difference in the proportion of income acquired from Other Crops by the HHs in these two groups. The group with the highest incomes earned over half of their average total HH income from Other Crops, and earned five times in the percentage more from Other Crops than did those with the lowest incomes. Moreover, three-fourths of average total HH income of the high earners came from cultivation of Other Crops and Business/Wage Labor.

# 3. Most important reason of the income gap between the highest and lowest 25 percent of HH income groups

Cassava was the most extensively planted Other Crop. Cashew nuts was the next most planted, but occupied much smaller areas (Kurashima *et al.* 2014). These crops were cultivated for sale rather than HH consumption. The highest 25 percent of earners had noteworthy growth in the proportion of income derived from these cash crops, particularly cassava (Table 3). In contrast, the lowest 25 percent of earners was very different. The lowest 25 percent of earners had much less income from cassava cultivation than did the highest 25 percent of earners, due primarily to lower benefit per HH and smaller farm holdings per HH, rather than a lack of attempts at commercial cultivation (Table 3).

### References

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![](_page_55_Figure_8.jpeg)

### Figure 1. The research site.

Source: True-color band combination from Landsat 8, taken Jan 12, 2014. FA, Kampong Thom. (Cited from KURASHIMA *et al.* 2014).

![](_page_56_Figure_1.jpeg)

Figure 2. Land cover change from early 2003 to early 2014 around the research site.

Source: True-color band combination of (A) Landsat 5 TM taken in Feb 7, 2003; and (B) Landsat 8 taken in Jan 12, 2014. FA, Kampong Thom. (Cited from Kurashima *et al.* 2014).

Target Year	<b>2003</b> <sup>1</sup>		<b>2012</b> <sup>2</sup>	
	( <i>N</i> = 85)		( <i>N</i> = 146)	
	Mean	Percent	Mean	Percent
Source of income		of total		of total
	(USD)	(%)	(USD)	(%)
Rice	199	37	93	10
Other crops	66	12	412	43
Livestock	32	6	29	3
Resin	116	22	156	16
Wildlife	20	4	27	3
Other NTFP	91	17	3	0
Logging	NA	-	11	1
Business/ Wage labor	9	2	226 (176/50)	24
Fishing	4	1	NA	-
Total	538	100	957	100

Table 1. Average total HH incomes and income sources in 2003 and 2012.

<sup>1</sup>Source: McKenny *et al.* (2004). <sup>2</sup>Source: Kurashima *et al.* (2014). The income values for 2012 are adjusted for inflation between 2003 and 2012 (2003 = 1; 2012 = 1.789).

<b>Fable 2.</b> Average total HI	H incomes and sourc
Target Year	<b>2012</b> <sup>1</sup>

Target Year		<b>2012</b> <sup>1</sup>			<b>2012a</b> <sup>1</sup> (Non	ninal incomes)
		( <i>N</i> = 146)			( <i>N</i> = 146)	
	Lowes	Lowest 25% Highest 25%			Lowest 25%	Highest 25%
	Mean	Percent	Mean	Percent	Mean	Mean
		of total		of total		
	(USD)	(%)	(USD)	(%)	(USD)	(USD)
Rice	52	21	117	5	93	210
Other crops	22	9	1,199	53	39	2,146
Livestock	0	0	81	3	0	145
Resin	75	30	266	12	134	475
Wildlife	21	8	18	1	38	31
Other NTFP	3	1	7	0	5	13
Logging	2	1	17	1	4	31
Business/ Wage labor	76 (37/39)	30	562 (520/42)	25	135	1,005
Fishing	NA	-	NA	-	NA	NA
Total	251	100	2,267	100	448	4,056

**Table 2.** Average total HH incomes and sources in 2012 for the lowest and highest 25% of HHs.

<sup>1</sup>Source: Kurashima *et al.* (2014). The income values for 2012 are adjusted for inflation between 2003 and 2012. For the method, see Note 2 in Table 1; the "2012a" values are nominal incomes without any adjustment.

Table 3. Upland farm holdings and cassava cultivation in 2012 for the lowest and highest 25% of HHs.

Target Year	$2012a^{1}$			
	( <i>N</i> =146)			
Land holding/ Cultivation	Lowest 25%	<b>Highest 25%</b> 100		
Upland Farm-holding HHs (%)	97			
Area (ha)				
Mean	2.6	5.4		
SD	1.8	4.3		
Minimum	0.0	1.0		
Median	2.0	4.0		
Maximum	9.0	24.0		
Cassava-cultivating HHs (%)	65	92		
Value per HH (USD)				
Input cost: mean (median)	191 (0)	855 (230)		
Output value: mean (median)	259(150)	2,750 (1500)		
Benefit: mean (median)	68 (0)	1,895 (900)		

<sup>1</sup>Source: Kurashima *et al.* (2014). The 2012a values for input cost, output value, and benefits are not adjusted.

![](_page_59_Picture_0.jpeg)

Forestry and Forest Products Research Institute Matsunosato 1, Tsukuba, 305-8687 Japan

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For more information, please contact us at: kanko@ffpri.affrc.go.jp

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