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# SHIFT OF LITTERFALL TIMING DURING EXTREME CLIMATEIN SECONDARY DRY DIPTEROCARP FOREST, WESTERN THAILAND

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## ABSTRACT

**Climate change and variability could result in a shift of forest phenology. The climate extremesare further projected to be more frequent and server under future climate change. Thus its impact on forest ecosystem is crucial for evaluating forest carbon sequestration, adaptation and ecosystem services. However, our understanding of interaction between phenology and climate extreme in tropical forest is still poor. In this study, we investigated the monthly litterfall production for eight years(2009-2017) in a secondary dry dipterocarp forest in Thailand. During the study period, El Niño and La Niña were observed and its impacts on litterfall were evaluated. During these eight years, the amount of total litter production was in the range of 5.37-9.62Mg ha$^{-1}$yr$^{-1}$ and 70-85% of litter production occurred in dry season (November- April of the following year). The trend of the annual litter production has increased. However, the annual litter production was significantly dropped in the El Niño years, compared to other years. In the El Niño years (2009/2010 and 2015/2016), the peaks of litterfall production was in January, a shift of 1-2 months earlier than in the other years. In contrast, in La Niña year (2010/2011) peak of litter production was in March, delayed1-2 months. The litterfall production for five months between November to March was related to the rainfall amount at two months preceding of litterfall timing, to the level of soil moisture at one month preceding of litterfall timing and to vapor pressure deficit, with the coefficient correlation of -0.70, -0.62 and 0.53, respectively. In order to quantify the effects of this phenological shift, currently the relationships among the end of season, carbon sequestration and nutrient cycle in this forest ecosystem are being investigated.**

**KEYWORDS:** Dry Dipterocarp Forest, Extreme Climate, Litterfall, Phenology

The phenology is the study of recurring biological lifecycle stages, their timing and relationship to environment [1][2]. Phenology is the most proximate biological response that is expected to shift during climate change. Under climate change, severe and frequent extreme climate are expected to occur[3].ENSO (El Niño-Southern Oscillation) is one of the key phenomena that affect ecosystem function and services worldwide. During El Niño, a weakening of the monsoon circulation leads to reduce moisture flux and negative rainfall anomalies. These are reflected in drought conditions over Indo-China peninsula. In contrast, amount of rainfall was higher during La Niña events[4][5][6].Our understanding of responses of forest ecosystem to such extreme events have been improving, however little is still known in tropical areas especially in Southeast Asian tropical forests[7][8].

Dry dipterocarp forests are important as valuable timber resources, biodiversity and other ecosystem services including carbon sequestration. High temperature and seasonal precipitation patterns are the dominant controlling factors of phonological dynamics in the dry deciduous dipterocarp forest[9].Normally, the deciduous forests avoid the costs of maintaining leaves in the unfavorable season by falling leaves and carry the costs of constructing new leaves every year [10]. Because of its high seasonality, climatic variables would immensely affect its dynamics including the start, end and the length of its growth season [11]. The duration of growing season is important because it would indicate the capability of forest ecosystem to sequester carbon and to provide other ecosystem services [12]. In general, the end of season is related to litterfall production, which is linked forest composition, productivity and biomass, and ecosystem process. The litterfall is also the important input parameter for dynamic vegetation models [13].A better understanding of litter production in secondary vegetation will be crucial and will assist in managing the expanding secondary forests in tropical regions [14].

This study analyzed the long-term litterfall production that could define the end of season for eight years between 2009-2017. The objective is to investigate extreme climate variability as El Niño and La Niña in secondary dry dipterocarp forest and to determine the impact of these extreme events on the characteristics and shifts of litterfall.

## MATERIALS AND METHODS

This study was conducted in a dry dipterocarp forest in Ratchaburi province, Western Thailand (Latitude: 13º 35' 13.3" N, Longitude: 99º 30' 3.9" E, elevation of 118 m).This forest was subjected to timber harvesting for charcoal and wood production, before being preserved since 2005 [15].For 12 years since then, the forest has grown and

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recovered. Dominant species are Dipterocarpusobtusifolius Teijsm. Ex Miq, Shoreasiamensis, Miq., Shorea obtuse Wall. ex Blume, ShorearoxburghiiG.Don, and Sindorasiamensis Teijsm. & Miq. The study on litterfall production was performed for eight years between 2009 and 2017, accompanying with micro-climate measurements. The air temperature and relative humidity were measured by Vaisala sensor (Vaisala Inc. Model HMP45C).The photosynthetic active radiation and rainfall were collected by quantum sensor (model LI-190SZ, LI-COR) and tipping bucket rain gauge (model TE525, Cambell Scientific, Inc.). These sensors were installed on tower at10 m above the ground. Soil temperature and soil moisture were measured at 5 cm below ground, with soil thermocouple probes (TCAV, Campbell Scientific, Inc., USA.) and soil water content reflectometers (CS615, Campbell Scientific, Inc.), respectively. These micro-meteorological sensors were connected with data logger (CR1000,Cambell Scientific, Inc.), which recorded data every 30 minutes. The climate data were divided into wet and dry seasons, following those described by Tanaka et al. (2008) [16]. The wet season covers May to October and dry season covers November to April of the following year. Long-termlitterfall production was collected monthly by 13 litter traps with size of 1 x 1 mat 1 m above the ground. The litter was dried at 80 °C before and then weighted. To ease the comparison of litter production during these periods, the litterfall amount was normalized as the ratio of monthly litterfall to annual litterfall. Pearson correlation was then used to evaluate the relationships between climate variables and normalized litterfall.

## RESULTS AND DISCUSSION

### Micrometeorological Conditions

The annual rainfall at the study site was in a range of 569.2 – 1239.7 mm. The impact of extreme climate events was markedly evident at seasonal than annual time scales. During El Niño, the rainfall was very low. In dry season 2009/2010 and 2015/2016, the rainfall were about 34.5 and 41.67% lower than the average rainfall of all dry seasons during the study period. The rainfall in wet season 2015 was 64.8% lower than all wet season rainfalls. During La Niña, extremely high rainfall was found in wet season 2010, a 30.1 % higher than the average. Less impact of La Niña on rainfall in wet season 2016 was observed (Fig.1a and Table 1).The average temperature for both seasons was not different. However, the maximum temperature was much higher in April and May during El Niño than during normal period. Moreover, the pattern of temperature in the end of 2014-2016 remained high for an extended time. It slightly dropped in short time in November and December in 2015 and it reached the peak in May 2016 (Fig.1a).

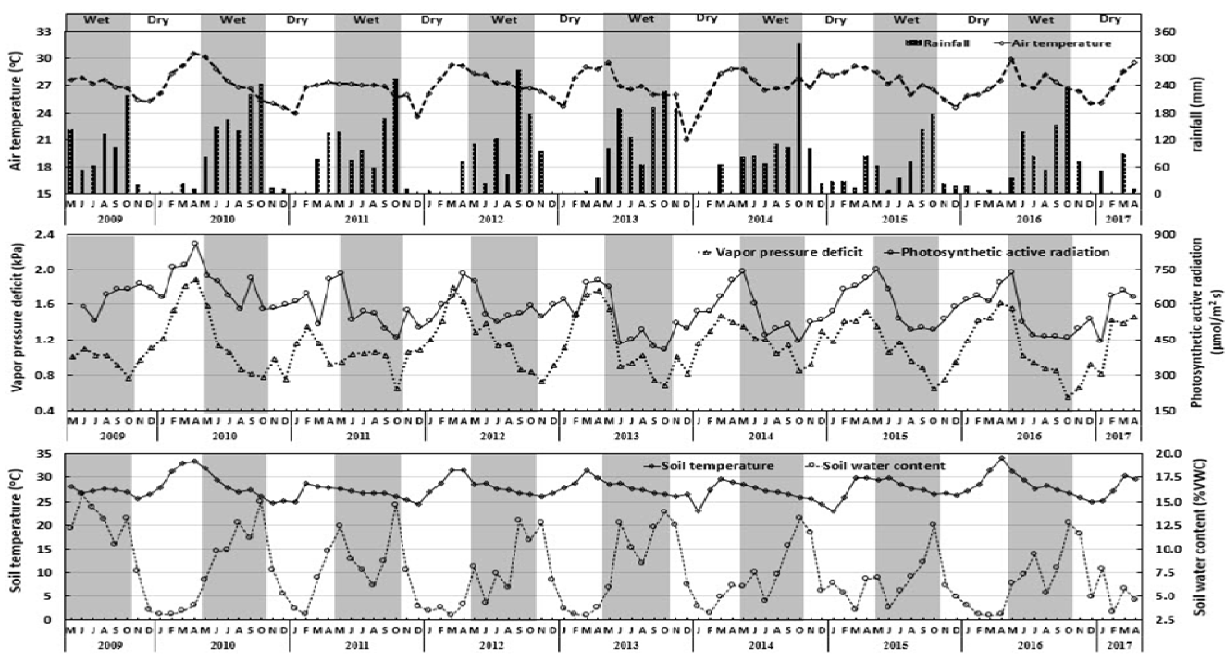


**Figure 1: Monthly micro-climate characteristics for eight years; including a) air temperature and rainfall b) vapor pressure deficit and photosynthetic active radiation c) soil temperature and soil moisture in term of soil water content: (dark area : wet season during May to October in each year, white area: dry season during November to April of the following year)**

**Table 1: Summary of climate variable(±SD) within wet season, dry season and annual period; including rainfall (P), air temperature (Ta), vapor pressure deficit (VPD), photosynthetic active radiation (PAR), soil temperature (Ts) and soil moisture (SWC)**

| Period | Season | P (mm) | Ta(°C) | VPD(kPa) | PAR(μmol/m²s) | Ts (°C) | SWC (%) |
|---|---|---|---|---|---|---|---|
| 2009/2010 | Annual | 773.3 | 27.4±1.5 | 1.2±0.4 | 678.0±89.6 | 28.4±2.6 | 8.6±5.0 |
| | Wet | 714.2 | 27.3±0.5 | 1.0±0.1 | 618.0±58.9 | 27.3±0.5 | 13.1±1.8 |
| | Dry* | 59.1 | 27.4±2.2 | 1.4±0.4 | 727.9±81.7 | 29.6±3.4 | 4.2±1.7 |
| 2010/2011 | Annual | 1239.9 | 26.7±1.8 | 1.0±0.2 | 632.3±66.0 | 27.4±2.1 | 8.5±3.6 |
| | Wet** | 999.2 | 27.5±1.7 | 1.0±0.3 | 654.3±65.1 | 28.2±2.1 | 10.9±2.8 |
| | Dry | 240.7 | 25.8±1.5 | 1.1±0.2 | 610.3±64.6 | 26.5±1.8 | 6.1±2.6 |
| 2011/2012 | Annual | 893.9 | 26.9±1.5 | 1.2±0.3 | 576.7±85.5 | 27.4±2.1 | 7.0±3.7 |
| | Wet | 795.6 | 26.8±0.6 | 1.0±0.2 | 558.5±92.9 | 26.8±0.5 | 9.7±3.1 |
| | Dry | 98.3 | 27.0±2.2 | 1.4±0.3 | 594.8±81.4 | 28.0±3.0 | 4.3±1.7 |
| 2012/2013 | Annual | 888.5 | 27.2±1.3 | 1.2±0.3 | 598.7±65.2 | 28.0±1.6 | 6.9±3.6 |
| | Wet | 751.7 | 27.4±0.7 | 1.1±0.2 | 580.4±62.5 | 27.6±1.0 | 8.3±3.2 |
| | Dry | 136.7 | 27.0±1.8 | 1.3±0.4 | 617.0±68.1 | 28.5±2.0 | 5.5±3.8 |
| 2013/2014 | Annual | 1160.7 | 26.3±2.3 | 1.1±0.3 | 530.3±100.6 | 27.2±1.8 | 8.3±3.8 |
| | Wet | 903.7 | 27.0±1.3 | 1.0±0.3 | 478.9±100.3 | 27.6±1.0 | 10.5±3.0 |
| | Dry | 257.0 | 25.7±2.9 | 1.2±0.2 | 581.7±76.6 | 26.9±2.4 | 6.1±3.3 |
| 2014/2015 | Annual | 1064.1 | 27.8±1.0 | 1.2±0.2 | 578.9±99.2 | 26.8±2.1 | 7.3±2.9 |
| | Wet | 784.7 | 27.4±0.9 | 1.1±0.2 | 543.8±109.4 | 27.2±1.0 | 8.1±3.1 |
| | Dry | 279.4 | 28.3±0.9 | 1.3±0.2 | 613.9±82.2 | 26.4±2.9 | 6.6±2.8 |
| 2015/2016 | Annual | 569.2 | 26.6±1.1 | 1.1±0.3 | 593.2±84.3 | 28.6±2.3 | 5.7±2.8 |
| | Wet* | 497.8 | 27.2±0.9 | 1.0±0.2 | 572.3±108.7 | 28.2±1.3 | 7.4±3.0 |
| | Dry* | 71.4 | 26.0±1.0 | 1.2±0.3 | 614.1±52.4 | 29.0±3.1 | 4.0±1.3 |
| 2016/2017 | Annual | 926.6 | 27.3±1.6 | 1.0±0.3 | 543.3±98.3 | 27.8±2.1 | 7.3±2.8 |
| | Wet** | 698.0 | 27.6±1.3 | 1.0±0.3 | 518.5±108.8 | 28.5±1.7 | 8.2±2.6 |
| | Dry | 228.6 | 26.9±1.8 | 1.1±0.4 | 568.0±89.1 | 27.2±2.3 | 6.3±3.0 |
| * El Niño period, ** La Niña period | | | | | | | |

The vapor pressure deficit and photosynthetic active radiation seem substantially high during El Niño (Fig.1b). The trend of soil temperature was similar to air temperature but it was slightly higher and more contrast of the peak during El Niño than normal periods. The soil moisture was the parameter that showed markedly different between extreme events and normal conditions, and seems to correspond to rainfall. During El Niñoof2009/2010 and 2015/2016, the soil water content dropped steadily for whole dry season and they were lower than5% VWC for five months between December to April, comparing to two-four months in otherdry season, except dry season in 2011/2012 (Fig.1c and Table 1). Thus, the extreme droughtduring El Niñoat the study site was characterized by low rainfall and soil moisture. For La Niña, it showed high impact only in wet season of 2011 but there was less impact in wet season 2016. However, dry season of 2011/2012 was not the El Niño period but the drought due to low rainfall and soil water content was found. This result corresponds to Wolf et al (2016) who reported that this was during the extreme warm period[17].During the study period, two extreme climate events were observed. First, strong El Niño occurred in 2009 and weak El Niño in early 2010, followed by La Niña in late 2010-2011. Second, there were strong El Niño in 2015- early 2016, followed by La Niña during mid-2016 [18][19].

**Litterfall Production**

The amount of annual litter production was in the ranges of 5.37-9.62 Mg $ha^{-1}yr^{-1}$ (537.23–961.77 $gm^{-2}yr^{-1}$).The similar range was reported for the secondary tropical forest in South America, which was about 8.01±1.91 Mg $ha^{-1}yr^{-1}$[20].During these eight years, the annual litter production have increased. This is expected since it is a secondary forest and growth has continued. The increasing trend of total litterfall was found in dry and wet season. Out of total amount, 70-85% of litter production occurred in dry season. It was noticed that the litterfall production slightly dropped from the trend line during El Niño in May 2014-April 2015 and May 2015-April 2016 and drought period in May 2011-April 2012 (Fig.2).The earlier timing of litterfall production were found during dry season 2009/2010, 2015/2016 (Fig. 3), corresponding to drought events during El Niño (Fig. 1 and Table 1).The peak of normalized litterfall was in January, compared to February or March in other periods. Moreover, the trend of litterfall production in 2009/2010 took place only during shorter time span. This indicates the responses of forest to El Niño, characterized by lower soil moisture and lower rainfall as mentioned above. In contrast, a large amount of rainfall in 2010/2011 as a La Niña years and in 2013/2014 was resulted in late timing of litterfall in March. Although, La Niña occurred in 2016 but there was no late of litterfall timing because of the less amount of accumulated rainfall and shorter rainfall duration during this period.

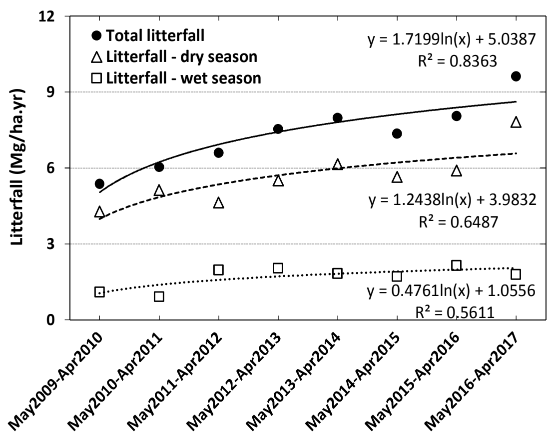


**Figure 2: Trend of total litterfall production and the litterfall in dry and wet season during 2009-2017.**

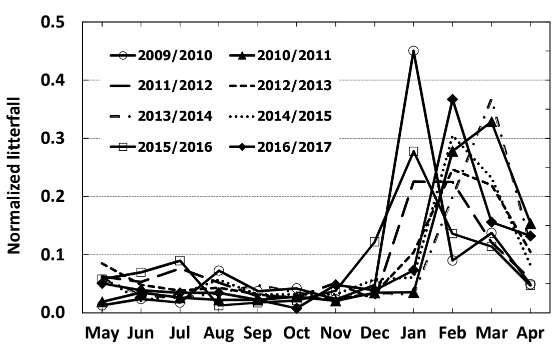


**Figure 3: Patterns of litterfall production during the eight periods of this study. Notes that the growth season starts in May and ends in April of the following year.**

**Influence Of Climate Extremes On Litterfall Production**

The correlation between climate variables and litterfall production was analyzed during the five months periods of November to March in dry season. Results revealed that the litterfall production was significantly related to many climate variables. The main three variables that had highest correlation coefficient are the rainfall amount at two months preceding litterfall timing, the level of soil moisture at one month preceding litterfall timing and vapor pressure deficit, with the coefficients of correlation of -0.70, -0.62 and 0.53, respectively. The multi-regression equation that could explain the normalized litterfall and key driver variables can be expressed as equation;

$$\text{Normalized litterfall} = -0.00062(P_{2mt}) - 0.00648(SWC_{1mt}) + 0.008802(VPD) + 0.232481 \quad (1)$$

($R^2 = 0.72$; $P < 0.0001$)

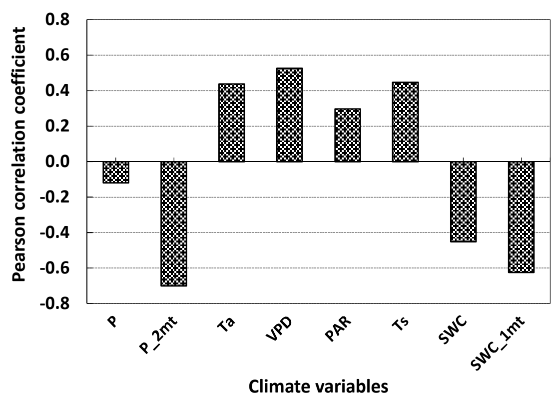


**Figure 4: Pearson correlation coefficient from the regression between normalized litterfalland rainfall (P), rainfall at two months preceding litterfall timing (P_2mt), air temperature (Ta), vapor pressure deficit (VPD), photosynthetic active radiation (PAR), soil temperature (Ts), soil water content (SWC), SWC at one month preceding litterfall timing (SWC_1mt). Level of statistic significant: ns (P > 0.05), ** (P < 0.01), *** (P< 0.0001).**

In tropical forests, drought was usually resulted in enhanced amounts of litterfall [13]. Drought induces several responses in plant such as leaf senescence which is accompanied by leaf abscission and avoids large loss through transpiration for maintenance of a water balance[21]. Many studies reported that rainfall had great influence on the response of litterfall. For example, the litterfall in earlier regeneration stages in tropical dry forest is strongly affected by rainfall variation. Moreover, the stronger decrease in litterfall was found during the lowest rainfall year and this affects in earlier regenerating stage than mature stage[22]. Leaf fall in primary and secondary forests in Brazilian Amazon were also negatively associated with rainfall [23]. The response of litterfall in Southeastern Brazil showed a delay of one month in relation to rainfall regime. Moreover, the relative humidity and water storage in soil related to timing of litterfall production[24]. Litterfall in Amazon forest declined during the severe drought(35-41% reduction of effective rainfall) with a maximum difference of 23%(compare to control plot of total incoming rainfall).However, it recovered rapidly following cessation of the drought[25]. This consistent with results in this study, that the timing of litterfall production was shifted to March in 2010/2011 and February in 2016/2017, and to January during El Niño in 2009/2010 and 2015/2016. Moreover, this secondary dry dipterocarp forest seems to effectively adapt to long dry period because it did not have any significant effects on the annual net ecosystem productivity (NEP, data not shown) between the extreme drought period (5 months in dry season) in 2010, compare to normal condition (3 months in dry season) in 2009. The NEP were 12.06 and 12.26 ton C $ha^{-1}$ $yr^{-1}$ for 2009 and 2010, respectively[26]. We found that litterfall production was continuous, and principally accompanied the rainfall rate, with the greatest accumulation at the beginning of the dry season and the least during the rainy season[27]. However, the results in this study are different from the characteristic of litterfall in dipterocarp forest in Sabah, Malaysia where no clear seasonal variation was found due to high amount of rainfall of about 3000 mm $yr^{-1}$. In Sabah, therefore the monthly rates of litterfall production seem unrelated to rainfall [28]. Nevertheless, earlier shift of litterfall timing and shorter time span during El Niño was similar to the leaves fall of forest in Spain that their leaves have fallen in summer during warmer periods, instead of autumn. Thus, if there are warmer summers in future, the primary annual production in deciduous trees would be declined[29].

## CONCLUSION

Under the future climate change, the extreme climate extremes such as El Niño and La Niña will become more common, the study of its impact on tropical forest phenology is thus crucial. In this study, the eight years measurements revealed that warm El Niño and cool La Niña were found and litterfall production in the secondary dry dipterocarp forest shifted in responses to that climate extreme events. Drought due to low rainfall and low soil moisture were evident in the forest during El Niño.The La Niña induce the late timing of litterfall production. In contrast, El Niñohad resulted in earlier timing and shorter time span of litterfall production period. We concluded that the climate extreme events directly influence on this forest phenology and its potential adaption.

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## REFERENCES

E.E. Cleland, I. Chuine, A. Menzel, H. A. Mooney, and M. D. Schwartz, “Shifting plant phenology in response to global change,” Trends Ecol. Evol., vol. 22, no.7, pp.357–65. May 2007.

P. L. Warren, and L. Barnett., “Phenology : Using phenology as a tool for education, research and understanding environmental change,” The university of Arizona-college of agriculture and life sciences, pp.1-3, July 2014.

W. Cai, A. Santoso, G. Wang, S. Yeh, S. An, K.M. Cobb, … and M. J. Mcphaden “ENSO and greenhouse warming,” Nature Publishing Group, vol.5, no. 9, pp.849–859, August 2015.

A. Limsakul and P. Singhruck, P. “Long-term trends and variability of total and extreme precipitation in Thailand,” Atmos. Res.,vol. 169, pp. 301–317, October 2015.

C. C. Ummenhofer, R. D. D’Arrigo, K. J. Anchukaitis, B. M. Buckley, and E. R. Cook, “Links between Indo-Pacific climate variability and drought in the Monsoon Asia Drought Atlas,” Clim. Dynam., vol. 40, no. 5-6. pp. 1319–1334, July 2012.

H. Weng, S. K. Behera, and T. Yamagata, “Anomalous winter climate conditions in the Pacific rim during recent El NiñoModoki and El

Niñoevents," Clim. Dynam., vol. 32, no. 5, pp. 663–674, April 2009.

J. M. Carter, M. E. Orive, L. M.Gerhart, J. H.Stern, R. M. Marchin, J. Nagel, and J. K. Ward, "Warmest extreme year in U.S. history alters thermal requirements for tree phenology," Oecologia, vol. 183, no. 4, pp. 1197-1210, February 2017.

J. Zhao, Y. Zhang, F. Song, Z. Xu, and L. Xiao, "Phenological response of tropical plants to regional climate change in Xishuangbanna, south-western China,"J. Trop. Ecol., vol.29, pp. 161-172, March 2013.

C. Wohlfart, M. Wegmann, and P. Leimgruber, "Mapping threatened dry deciduous dipterocarp forest in South-east Asia for conservation management," Trop.Conserv.Sci., vol.7, no. 4, pp. 597–613, December 2014.

E. C. February and S. I. Higgins, "Rapid leaf deployment strategies in a deciduous savanna," PLOS ONE, pp. 1-11, June 2016.

A. D. Richardson, T. F. Keenan, M. Migliavacca, Y. Ryu, O. Sonnentag, and M. Toomey, "Climate change, phenology, and phenological control of vegetation feedbacks to climate system," Agric. For. Meteorol.,vol. 169, pp. 156-173, February 2013.

N. Yoshifuji, N. Tanaka, and C. Tantasirin, "Inter-annual Variation in Growing Season Length of a Tropical Seasonal Forest in Northern Thailand," For. Ecol. Manage., vol. 229, no. 1-3, pp. 333-339, July 2006.

Y. J. Zhang, P. M. Cristiano, Y. F. Zhang, P. I. Campanello, Z. H. Tan, Y. P. Zhang, K. F. Cao, and G. Goldstein, "Carbon economy of subtropical forests,"In G. Goldstein, and L. S. Santiago, ed. Tropical tree physiology. Springer International Publishing Switzerland,pp. 337-355, 2016.

M. Uriarte, B. L. Turner, J. Thompson, and J. K. Zimmerman, "Linking spatial of leaf litterfall and soil nutrients in a tropical forest: a neighborhood approach,"Ecol. Appl., vol. 25, no. 7, pp. 2022-2034, October 2015.

P. Hanpattanakit, A. Chidthaisong, M. Sanwangsri, and N. Lichaikul, "Improving allometric equations to estimate biomass and carbon in secondary dry dipterocarp forest,"Singapore SG, vol.18., no. 3, pp.208-211, March 2016.

N. Tanaka, T. Kume, N. Yoshifuji, K. Tanaka, H. Takizawa, K. Shiraki, C. Tantasirin, N. Tangtham, and M. Suzuki, " A review of evapotranspiration estimates from tropical forests in Thailand and adjacent regions," Agr. Forest. Meteorol., vol. 148, no. 5, pp.807–819, May 2008.

S. Wolf, T. F. Keenan, J. B. Fisher, D. D. Baldocchi, A. R. Desai, A. D. Richarson, R. L. Scott, B. E. Law, M. E. Litvak, N. A. Brunsell, W. Peters, and I. T. van der Laan-Luijkx, "Warm spring reduced carbon cycle impact of the 2012 US summer drought," PNAS, vol. 113, no.21, May 2016.

P. Wongwises, A. Limsakul, S. Sooktawee, and U. W. Humphries, "Rainfall variability over Thailand related to the El nino –Southern Oscillation (ENSO)," International Journal of Sustainable Energy and Environment, vol. 5, no. 1-6, January 2014.

NOAA.2017.http://www.cpc.ncep.noaa.gov/products/analysis_ monitoring/ensostuff/ensoyears.shtml. April, 13, 2017.

J. Chave, D. Navarrete, S. Almeida, E. Álvarez, L. E. O. C. Aragão, D. Bonal, P. Chãtelet, J. E. Silva-Espejo,J. Y. Goret, P. von Hildebrand, E. Jiménez3, S. Patiño, M. C. Pe ˜nuela, O. L. Phillips, P. Stevenson, and Y. Malhi, "Regional and seasonal patterns of litterfall in tropical South America," Biogeosciences, vol.7, pp.43-55, January 2010.

S. Munné-Bosch and L. Alegre, "Die and let live : leaf senescence contributes to plant survival under drought stress," Funct. Plant Biol., vol.31, pp. 203-216, January 2004.

P. M. Moura, T. D. Althoff, R. A. Oliveira, J. S. Souto, P. C. Souto, R. S. Menezes, and E. V. S. B. Sampaio,"Carbon and nutrient fluxes through litterfall at four succession stages of Caatinga dry forest in Northeastern Brazil,"Nutr.Cycl.Agroecosyst., vol.105, pp.25-38, March 2016.

J. Barlow, T. A. Gardner, L. V. Ferreira, C. A. Peres, "Litter fall and decomposition in primary and secondary and plantation forests in the

Brazilian Amazon," For. Ecol. Manage., vol.247, pp. 91-97, August 2007.

M. L. Ferreira, E. A. Uchiyama, "Litterfall assessment in a fragment of secondary tropical forest, IbiÚna, SP, Southeastern, Brazil," Rev. Árvore, vol.39, no.5, October 2015.

P.M. Brando, D. C. Nepstad, E. A. Davidson, S. E. Trumbore, D. Ray, and P. Camargo, "Drought effects on litterfall, wood production and belowground carbon cycling in an Amazon forest: results of a throughfall reduction experiment," Phil. Trans. R. Soc. B, vol. 363, pp. 1839-1848, February 2008.

M. Sanwangsri, A. Chidthaisong, and P. Hanpattanakit,"Responses of $CO_2$ exchange to drought in dry dipterocarp forest, Western Thailand," 3rdiLEAFS International Science Conference, Garmisch-Partenkirchen Congress Centre, Germany, 18-23 Septemper 2011.

MCA. Lopes, VFP. Araújo, and A. Vasconcellos, "The effects of rainfall and vegetation on litterfall production in the semiarid region of northeastern Brazil," Braz. J. Biol., vol. 75, no. 3, pp. 703-708, August 2015.

T. Burghouts, G. Ernsting, G. Korthals, and T. D. Vries, "Litterfall, leaf litter decomposition and litter invertebrates in primary and selectively logged dipterocarp forest in Sabah, Malaysia," Phil. Trans. R. Soc. Lond. B. vol. 335, pp. 407-416, 1992.

J. Bou, A. Caritat, and L. vilar, "Litterfall and growth dynamics relationship with the meteorological variability in three forests in the Montseny natural park," Folia ForestaliaPolonica, vol. 57, no. 3, pp. 145-159, July 2015.