ANALYSIS OF STREAM WATER TEMPERATURE CHANGES ON DIFFERENT FOREST TYPE WATERSHEDS; CASES STUDY AT FIELD MEASUREMENTS IN KOCHI REGION AND COMPARING WITH OTHER REGIONS IN JAPAN

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ABSTRACT

The changes in stream water temperature help to identify the mechanism that generates the initial response as direct inputs of solar radiation or air temperature and rainwater or discharge of groundwater. The objective is to clarify the stream water temperature changes on different forest type watersheds. A total of 23 events at 16 streams at Aichi, Kochi, Mie and Tokyo were chosen for analysis. Water level and temperature (Tw) were measured at the interval of 5 minutes from January 2004 to December 2005. We used air temperature data (Ta) at the nearest AMeDAS *stations to the respective streams. The specific discharge (Qs) was calculated from water level data. In particular, field measurements also have been done at Kochi 3 (*broadleaf*) and Kochi 8 (bad managed hinoki) at the interval of 30 minutes from June 2005 to November 2006. Based on field measurements, soil temperatures (Ts) at Kochi 8 were smaller than those at Kochi 3 at 50 cm (0.9^{o}C and 1.7^{0}C, respectively) and 70 cm depths (0.8^{0}C and 0.9^{0}C, respectively), indicating smaller proportions of precipitation infiltrated into the ground compared with broadleaf forest. Stream water temperature fluctuation expressed by Rms Tw/Rms Ta at broadleaf and hinoki were 0.18 ± 0.04 and 0.24 ± 0.11, respectively. In addition, the values of |ΔTw| at broadleaf and bad managed hinoki watersheds (2.0 ± 1.0^{o}C and 1.9 ± 0.7^{o}C, respectively) were significantly larger than those at well managed hinoki watersheds (1.3 ± 0.5^{o}C), possibly suggesting the difference in flow path proportion.*

Key words: Stream water temperature, forest, specific discharge, hinoki, broadleaf

ABSTRAK

*Perubahan suhu air dapat membantu usaha identifikasi mekanisme respon awal dari radiasi atau suhu udara dan proses input air hujan dan pola aliran air tanah yang masuk ke badan air. Tujuan pada studi ini adalah untuk menjelaskan perubahan suhu air pada jenis hutan yang berbeda. Total dari 23 event pada 16 sungai-sungai kecil di 4 lokasi (Aichi, Kochi, Mie dan Tokyo) telah dianalisa. Ketinggian air dan suhu (Tw) telah diukur dengan interval 5 menit dari Januari 2004 sampai Desember 2005. Kami menggunakan data suhu udara (Ta) dari badan meteorology setempat (*AMeDAS*) yang dekat dengan lokasi penelitian. Spesifik arus (Qs) dihitung berdasarkan data ketinggian air. Secara khusus, pengukuran lapangan yang lebih detail telah dilakukan di Kochi 3 (*broadleaf*) dan Kochi 8 (bad managed hinoki) pada interval 30 menit dari Juni 2005 sampai November 2006. Berdasarkan pengukuran lapangan, suhu tanah (Ts) pada Kochi 8 lebih kecil daripada Kochi 3 pada kedalaman 50 cm (0.9^{o}C dan 1.7^{0}C) dan 70 cm (0.8^{0}C and 0.9^{0}C), mengindikasikan proporsi yang kecil dari air hujan yang masuk kedalam tanah (infiltrasi) dibandingkan broadleaf. Fluktuasi suhu air yang diekspresikan dalam nilai Rms Tw/Rms Ta pada broadleaf dan hinoki adalah 0.18 ± 0.04 and 0.24 ± 0.11. Analisa lainnya, nilai |ΔTw| pada broadleaf dan hinoki bad managed (2.0 ± 1.0^{o}C and 1.9 ± 0.7^{o}C) signifikan lebih besar daripada hinoki well managed (1.3 ± 0.5^{o}C) memungkinkan adanya perbedaan proporsi pola aliran*

Kata kunci: Suhu air, hutan, specifik arus, hinoki, broadleaf

INTRODUCTION

Stream water temperature is a major water quality variable driving physical, chemical and biological processes in aquatic systems (Ward, 1985; Hawkins *et al.*, 1997) an it remains as the subject of world-wide environment research (Webb *et al.*, 2008). Most physical properties of water and the rates of many chemical and biological processes in water are expressed as functions of water temperature (Bogan *et al.*, 2004; Caissie, 2006). In addition, most aquatic species have respective specific ranges of water temperature that they can tolerate (Jensen *et al.*, 1989; Eaton and Scheller, 1996; Dunham *et al.*, 2003). For example, water temperature changes have striking effects on food intake rates, metabolic processes, enzyme processes and protein synthesis rates that affect the organism habitat and life in aquatic environments.

Stream water temperature as a supplementary tracer is used to identify and evaluate the water sources contributing to runoff processes at forested watershed (Shanley and Peters, 1988; Kobayashi *et al.*, 1999). Tracers can be used to obtain a better insight in thermal processes and possibly to separate hydrographs into different runoff components (Kobayashi, 1985; Westhoff *et al.*, 2007). In addition, rainfall event influences the changes in stream water temperature by different characteristic of flow paths. From ecological viewpoints, the extremes of runoff and stream water temperature are critical events that influence species composition and the productivity of aquatic and wetland communities (Resh *et al.*, 1988; Meyer *et al.*, 1999). An understanding of the processes driving stream temperature dynamics is fundamental for assessment and prediction of thermal response to climatic variability and forest type conditions.

Forested watersheds which are one of the representatives of natural water sources have been taken as an important subject in water temperature research. Besides the characteristics of the precipitation and climatic condition, forest types as another aspect could be considered as a factor that influenced stream water temperature characteristics. It influences the infiltration rate and surface runoff during rainfall events. In addition, the conditions of understories and litter layers as land cover at forested hillslopes prevent forming the surface crust, and sustaining high infiltration rate (Onda and Yukawa, 1994). In previous study, Subehi *et al.* (2009) confirmed that watershed area and various flow paths influenced stream water temperature fluctuations.

The lack of study concerning on flow paths in various forest types has suggested the necessity of its investigation. The objectives of this study are: to examine stream water temperature characteristics on different forest type conditions, especially between small and large watershed areas. We analyzed stream water temperature at field measurements in Kochi 3 and Kochi 8. We also compared them with 16 sampling points in four regions in Japan from January 2004 to December 2005 (Figure 1).

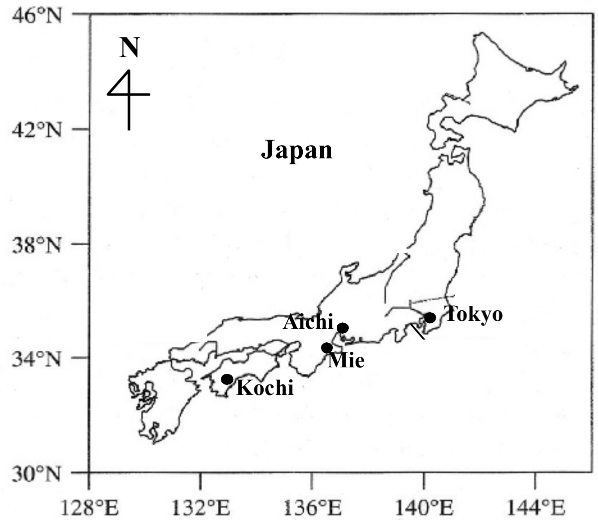

Figure 1. Locations of study area

METHODS

Analysis and observation at field measurements

We did the field measurements for more detailed analysis at two sampling points: Kochi 3 and Kochi 8, both located in Kochi prefecture in southern Japan. The watershed area of Kochi 3 was 4.9 ha and its forest tree type was broadleaf. That of Kochi 8 was 0.6 ha and its forest tree type was hinoki (Japanese cypress).

At both sites, we measured not only water temperature but also air and soil temperatures at intervals of 30 minutes with completely sealed underwater temperature loggers with optical communication (StowAway Tidbit by Onset Computer Corporation, USA). The loggers can measure temperatures from -20°C to 50°C with a precision of ± 0.4°C. We measured air temperature (Ta) at 1 m above the ground, soil temperature (Ts) at three depths (10, 50 and 70 cm under the soil surface) and at the same location as Ta on the stream side, and water temperature (Tw) in the stream. Water discharge (water depth) was also measured as explained below. These measurements were done from June 2005 to November 2006.

Analysis and observation at 16 sampling points

The studied watersheds at the sites were located over a wide range of latitude (~6^0) from $133^0$08'E to $139^0$19'E in Japan. We selected 16 streams with various forested watersheds in four regions (Aichi, Kochi, Mie and Tokyo). The watershed areas ranged from 0.5 ha to 100 ha with various slope gradients.

The data on water temperature and water depth were taken at the interval of 5 minutes from January 2004 to December 2005. These measurements used the sensors of water temperature with range of -30°C to 70°C with accuracy of 0.3°C and water depth with accuracy of 1 mm (TruTrack WT-HR by Intech Instruments Ltd, New Zealand). These sensors were sets at the Parshall flumes in the streams. Data on hourly air temperature from the nearest Automated meteorological data acquisition system (AMeDAS) station to each respective stream was used for analysis. The correlation analysis between AMeDAS and measured air temperatures at field measurements indicated fairly similar variations (R^2 = 0.967) from the viewpoint of daily analysis (Subehi *et al.*, 2009). In addition, their hourly temperatures were compared during several rainfall events and the differences seemed to be not considerable (R^2 > 0.50, the values of ΔTa at field measurement/ΔTa at AMeDAS station were around 0.67, ΔTa: see below). Water discharge was calculated using the formulas based on the given size of the Parshall flume and observed water depth (Herschy, 1985). Precipitation was measured by a tipping bucket rain gauge (Davis Instruments Company, Rain collector Metric Standard #7852 M) located at open area adjacent to our monitoring watersheds. The topological, meteorological, and vegetational information of each site is summarized based on the data for the two years (Table 1). Subehi *et al.* (2009) provided geological and geographical descriptions for all sites.

Analytical methods for temperature fluctuations and analysis Tw during rainfall events

In order to analyze the temperature fluctuations, we used not only the standard deviation (σ) but also the root mean square variation over 7 days (*Rms 7-days*). The equation can be described in the following manner:

$$\text{Rms 7-days} = \sqrt{(1/n)\sum_{i=1}^{n}(x_i - \bar{x}_i^m)^2} \quad (1)$$

where n represents the number of days analyzed (monthly: 28-31, yearly: 365), x_i is the daily average temperature (^{0}C), and $\bar{x}_i^m$ is the m-day moving average of daily temperature. We used 7 days for m. The weekly average temperature is commonly used to quantify stream temperature changes

Table 1. Information of geological, topological, meteorological and vegetation at 16 sampling points in four regions

Site	Location	Precipitation (mm/year)	Mean Air Temp. (^{0}C)	Mean Elevation of Watershed (m)	Meteorological Station (Met. Sta)	Headwater Catchment and Distances to the Met. Sta	Code	Vegetation	Area (ha)	Slope Gradient
Aichi	136 57.9' E 35 10.0' N	1285.7	15.5	165.5	Nagoya	Kiso River Watershed 21.0 km	A1	Hinoki WM	5.0	0.09
							A2	Broadleaf	7.5	0.08
							A3	Hinoki BM	3.0	0.12
Kochi	133 07.7' E 33 12.4'N	2820.4	13.4	483.8	Kubokawa	Tsuzura River Watershed 14.5 km	K2	Broadleaf	45.0	0.29
							K3	Broadleaf	4.9	0.33
							K4	Sugi	2.4	0.50
							K5	Hinoki WM	56.0	0.40
							K6	Hinoki WM	5.7	0.36
							K7	Hinoki WM	33.0	0.35
							K8	Hinoki WM	0.6	0.50
Mie	136 23.4'E 34 26.9'N	1589.4	14.6	180.0	Kayumi	Miyagawa River Watershed 11.5 km	M2	Hinoki (WM)	1.2	0.56
							M3	Hinoki (BM)	3.5	0.48
Tokyo	139 18.7'E 35 47.3'N	1,441.5	11.4	705.5	Oume	Nariki River Watershed 13.0 km	T1	Mixing	34.0	0.20
							T2	Mixing	7.8	0.25
							T5	Sugi & Hinoki	1.3	0.30
							T6	Broadleaf	1.3	0.30

WM: Well Managed, BM: Bad Managed

(Bogan *et al.*, 2004) because the weekly (7 days) timescale gives a good correlation between air and stream temperatures and also eliminates most transient variations, including diurnal effects of solar radiation and air temperature.

We had selected the rainfall events of which the total rainfall more than 5.0 mm/hour. Based on that criterion, we obtained 23 rainfall events at 16 watersheds in four regions (Aichi, Kochi, Mie and Tokyo) in various forested watersheds and seasons. The changes (the difference between maximum and minimum) of stream water temperature (ΔTw), specific discharge (ΔQs) as a discharge divided by area and air temperature (ΔTa) during those events were also calculated. In addition, two statistical test methods were employed. The t-test was used with the value of $p < 0.05$ for statistically significant differences and the F-test for the precision of the spread of data from two samples (similar or dissimilar), with the value of $p < 0.05$ for statistically significant.

RESULTS AND DISCUSSION

Analysis of Tw at Kochi watersheds (K2, K3, K7 and K8)

Based on field measurements analysis, soil temperature changes (ΔTs) at 50 and 70 cm depths at Kochi 8 (bad managed hinoki) were smaller than those at Kochi 3 (broadleaf), except on December 2005 (Table 2). It was suggested that smaller proportion of precipitation infiltrated into the ground at Kochi 8 compared with Kochi 3.

Comparison of daily air and stream water temperatures between small watershed areas (Kochi 3 and Kochi 8) and large watershed areas (Kochi 2 and Kochi 7) are described in Figure 2. Stream water temperatures at Kochi hinoki forests (K7 and K8) fluctuated more and were close to air temperatures than those at Kochi broadleaf forests (K2 and K3). This indicates that more groundwater flow at Kochi broadleaf forest than that at Kochi hinoki forest and different meantime exposed to solar radiation.

In addition, Rms 7-days of air and stream water temperatures were proportional to each other at K2, K3, K7 and K8. Similarly results for soil temperature at field measurements (Figure 3). It could be explained that the seasonal variability of atmospheric conditions influence air, soil and stream water temperature fluctuations nearly proportionally (Subehi *et al.*, 2009). Next, the fluctuations of Tw, expressed by Rms Tw/Rms Ta were larger at Kochi hinoki (K7 and K8) than those at Kochi broadleaf (K2 and K3) (Figure 4).

Table 2**.** The values of ΔQs, | ΔTw| and |ΔTs| at field measurements

Rainfall Event	Site	ΔQs (mm/30 minutes)	|ΔTw| (^{o}C)	|ΔTs| 10 cm (^{o}C)	|ΔTs| 50 cm (^{o}C)	|ΔTs| 70 cm (^{o}C)
Jul-05	K3	0.50	0.5	0.1	0.3	0.2
	K8	0.49	0.3	0.3	0.2	0.2
Sep-05	K3	1.29	0.7	0.5	0.2	0.2
	K8	0.21	0.2	0.5	0.01	0.01
Nov-05	K3	0.79	0.8	0.6	1.4	0.2
	K8	0.93	0.9	1.0	0.1	0.1
Dec-05	K3	0.01	0.3	0.2	1.2	0.3
	K8	0.08	1.2	0.3	0.9	0.5
Apr-06	K3	3.92	0.7	2.2	4.1	2.5
	K8	7.88	1.8	3.0	2.6	2.5

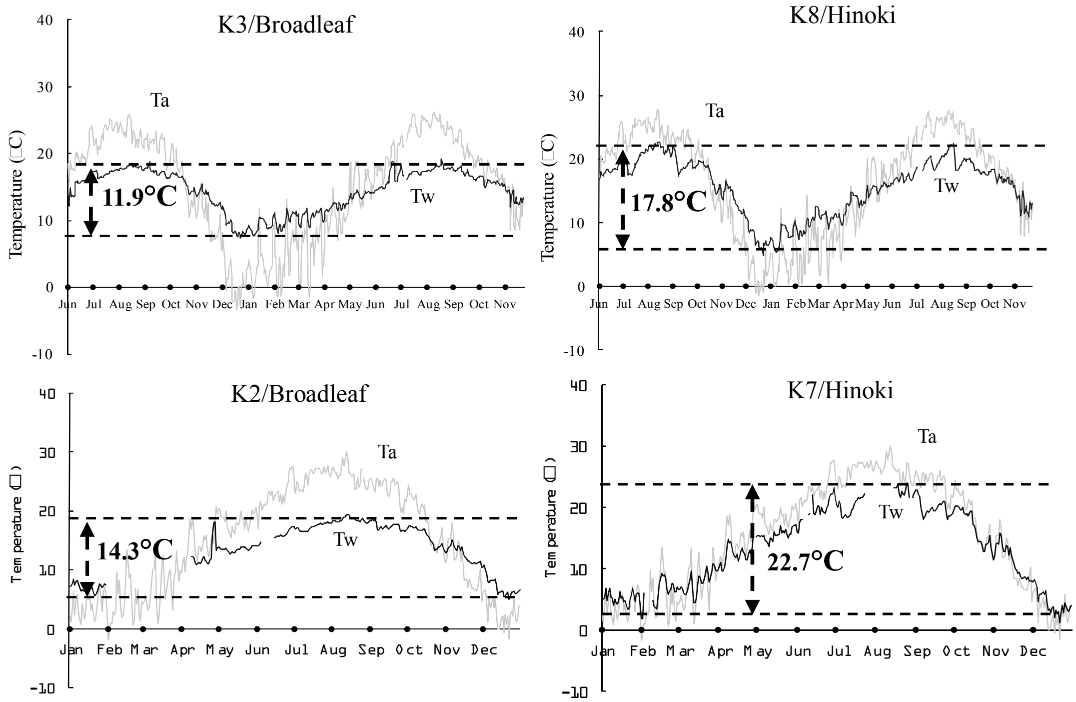

Figure 2. Daily air and stream water temperatures at K2, K3, K7 and K8 watersheds

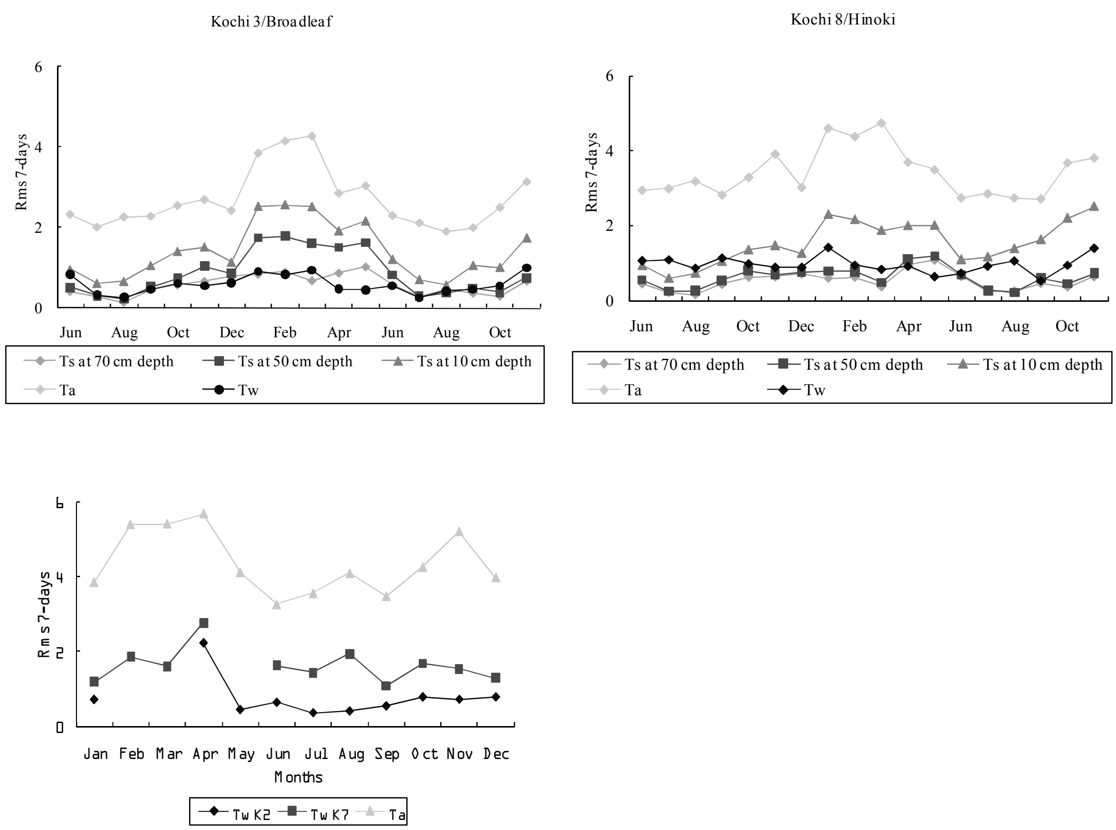

Figure 3. Rms 7-days of Ts, Tw and Ta at K2, K3, K7 and K8 watersheds

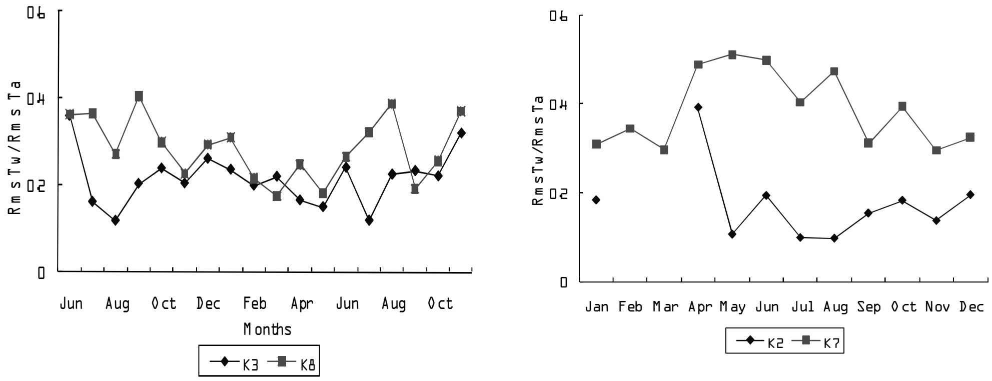

Figure 4. The fluctuations of Tw based on the values of Rms Tw/Rms Ta at K2, K3, K7 and K8 watersheds

Analysis of Tw on various forest types at all sites

The fluctuations of Tw on various forest types are described in Figure 5 as a sample on October 2005. The averaged Rms Tw/Rms Ta was 0.18 ± 0.04 for broadleaf and 0.24 ± 0.11 for hinoki forests from January 2005 until December 2005. Moreover, the tendency of larger Rms Tw/Rms Ta at hinoki bad managed (0.28) than that at hinoki well managed (0.21) could be shown in all months. In addition, the F-test indicated that the curve model was statistically significant ($p < 0.05$) for Figure 5. It could be explained that hinoki bad managed with less solar radiation, would result in poor understorey vegetation and this condition might raise a surface flow proportion in stream. The conditions of understory vegetation at hinoki and broadleaf forests influenced the infiltrations rates (Onda and Yukawa, 1994).

The values of |ΔTw| at broadleaf and bad managed hinoki forests (2.0±1.0°C and 1.9±0.7°C, respectively) were significantly larger than those at well managed hinoki (1.3±0.5°C), possibly suggesting the difference in flow path proportion (Figure 6). Broadleaf and bad managed hinoki forests may store largely the precipitation underground during small rainfall events than that at well managed hinoki forest and may take high specific discharge during extreme rainfall events due to saturated soil. In addition, there are strong links between geology and stream water temperature regimes via geological differences in run-off mechanisms and

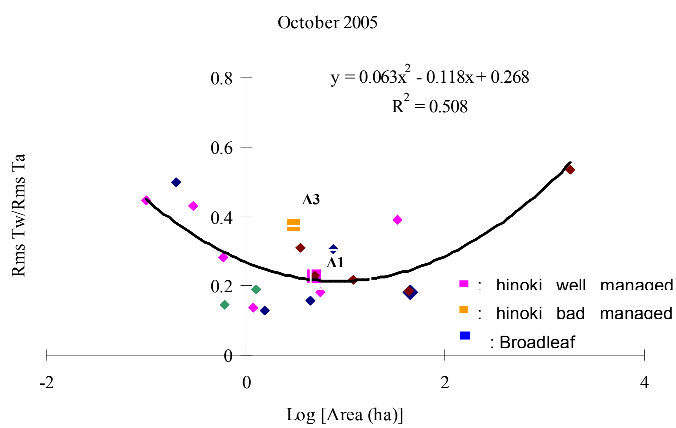

Figure 5. Influence of forest types and management on fluctuations of Tw

surface-subsurface water interactions (Sugita, 1983; Jones and Holmes, 1996; Ward and Robinson, 2000; Poole and Berman, 2001; Subehi *et al.*, 2010).

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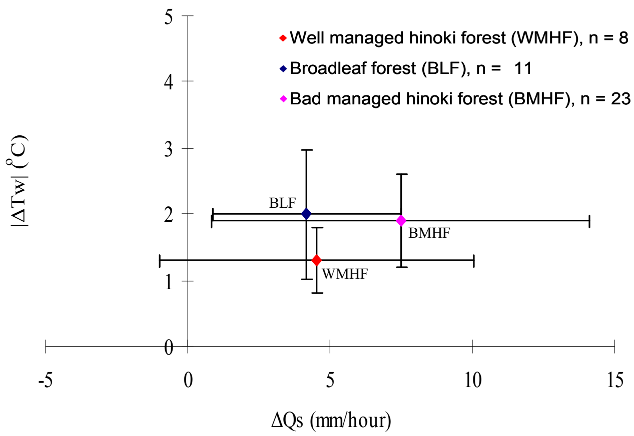

Figure 6. The values of ΔQs and |ΔTw| at different forest types during rainfall events

CONCLUSION

Different forest type watershed conditions had influenced stream water temperature fluctuation. It also indicated the different flow paths, several of topological, and hydro-meteorological conditions influenced the fluctuations of stream water temperature.

Based on the analyses, our findings suggest that stream water temperature had different levels of fluctuations among broadleaf, well managed hinoki and bad managed hinoki forest types. The changes of stream water temperature for broadleaf and bad managed hinoki forest watersheds were larger than those for well managed hinoki forest watershed. Further, modeling of water flow and heat exchange during rainfall events should be done to clarify the water temperature dynamics more quantitatively in the future.

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