Research paper

Investigation of Temperature Regimes for Air, Streamflow, and Topsoil Layers in a Riparian Area of Harpen Creek

Shiang-Yue Lu,[1,2] Liang-Shin Hwang,[1] Fu Ho-Chiao[1]

【Summary】

Primary important temperatures in forest ecosystems are associated with the air, topsoil, and streamflow. However, previous studies mostly examined these factors individually. Limited studies investigating these temperatures in the same plot can be found especially in a forest environment. We recorded temperatures of the air, topsoil layers and streamflow in a riparian area of Harpen Creek of the Fushan Experimental Forest from 2005, and we accumulated more than 5 yr of continuous records. The analytical results showed that the average yearly temperatures for air, streamflow, and 5-, 30-, and 50-cm soil layers during the monitoring period were 17.7, 17.6, 17.9, 18.0, and 18.1℃, respectively. The highest average monthly temperature for air and streamflow occurred in July, while those for the soil layers occurred in August. The minimum monthly average temperatures for all monitoring items occurred in January. Air, streamflow, and topsoil layers had nearly the same monthly average temperature of about 16.5℃ in the month of April for the Harpen Creek drainage basin. When the air temperature was < 15.5℃, the streamflow had the highest temperature among all monitored items, and the second highest was the 30-cm soil layer. Yearly temperature fluctuations for all monitoring items were significant, and the descending rank of ranges of yearly temperature changes was air, 5-cm soil layer, 30-cm soil layer, 50-cm soil layer, and streamflow. Air temperature had the maximum magnitude of changes within a day for all months, and the second was the temperature of the 5-cm topsoil layer. However, the maximum magnitude of daily changes was < 0.5℃ for soil layers deeper than 30 cm, and this indicated that there was only a small and insignificant diurnal change in temperatures of deeper soil layers. The magnitude of changes of streamflow temperature within a day was less than that for the 5-cm soil layer except for the period from September to December. In addition, the linear regression relationships for air temperature versus streamflow temperature and air temperature versus temperatures of the monitored topsoil layers were also established in this report. Hopefully those investigations will provide knowledge of the riparian ecosystem of Harpen Creek.

Key words: temperature regime, streamflow temperature, soil temperature, Harpen Creek.

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研究報告

哈盆溪濱水帶大氣、溪流水及表層土壤溫度變化及其關係性之探討

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摘 要

溫度為影響生態系運作的主要環境因子，而在森林生態系中，又以大氣溫度、表層土壤溫度及溪流水溫度對生態系運作影響最顯著；此等溫度要項相互影響，並因能量的轉移而在空間與時間分佈上呈動態的變化。以往的研究多屬於三者間的個別探討，少有涉及其相互關連與變動的研究，尤以森林生態系的研究更屬罕見。基於此，本研究選擇福山試驗林哈盆溪濱水帶為對象，自2005年起開始監測大氣溫度、溪流水溫以及表土5、30與50公分處的溫度。由累積5年的資料，獲知：試驗期間哈盆溪濱水帶區之大氣溫度、溪流水及土壤5、30、及50 cm深處之年均溫度分別為17.7、17.6、17.9、18.0及18.1℃，大氣及溪流水的最高月均溫發生在7月，而土壤各層次的最高月均溫則發生在8月；大氣、溪流水及土壤各層次的最低月均溫則均發生於1月。哈盆溪流域氣溫、水溫與表土溫度在4月，三者最為接近，約為16.5℃，而當大氣溫度低於15.5℃時，溪流水溫為三者中最高者，深層土壤的溫度則次之。全年度溫度的變化幅度由大至小依次為：大氣、5 cm深土溫、30 cm深土溫、50 cm深土溫、溪流水溫，且均呈顯著的變化。大氣溫度的日變化最為顯著，表土5 cm深的土壤溫度次之，再次為溪流水溫，30 cm深的土壤溫度的日變化則多屬不顯著。除9~12月外，溪流水溫的日變化幅度均小於表土5 cm深的土壤溫度變化幅度。30 cm以下的土壤溫度日變化的幅度均小於0.5℃，顯示深層土壤溫度幾乎無日變化。此外，本報告亦建立各月份溪流水溫及監測深度之土壤溫度與大氣溫度的相關回歸方程式。希望藉著本研究能提供哈盆溪濱水帶生態系運作的基礎資料。

關鍵詞：溪流水溫、表土溫度、大氣溫度、哈盆溪。

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INTRODUCTION

Temperature is an extremely important factor in ecosystems. It plays important roles in soil chemical reactions, development of physical characteristics, and biological interactions. Therefore, it exerts major influences on biological activities, growth, water chemistry, soil structure, soil aeration capacity, decomposition of organic matter, and phonological phenomena (Hillel 1982, Marshall and Holmes 1996, Seyfried et al. 2001). The primary important temperatures in forest ecosystems are the air, topsoil, and stream temperatures. Those temperatures in ecosystems affect each other and vary temporally and spatially in response to changes in radiant, thermal, and latent energies which take place primarily at the soil surface. However, previous studies mostly examined these factors individually or focused on the relationship between air and soil temperatures (Mueller 1970, Andrade and Abreu 2002, Gülser and Ekberli 2002, Johnston and Shmagin 2008, Lu et al. 2008). Very limited work in investigating these temperatures in the same plot has been carried out especially in forest environments. We monitored temperatures of the air, 5-, 30- and 50-cm topsoil layers, and streamflow at Harpen Creek of the Fushan Experimental Forest (FEF) of the Taiwan Forestry Research Institute (TFRI) from 2005, and we have accumulated more than 5 yr of continuous records. These historical records are considered valuable information for understanding relationships among those temperatures and its regime in this area. In addition Harpen Creek is the main location for long-term ecologic research in Taiwan, and this information is considered valuable for ecosystem studies.

MATERIALS AND METHODS

Site description

The study plot was located in a riparian area of an upstream reach of Harpen Creek which is the main stream in the FEF. Elevation in the FEF range 400~1400 m, and the vegetation is the typical moist, subtropical, mixed evergreen forest of northeastern Taiwan. Harpen Creek has a gentle slope and an alluvial stratum in the upstream area and is considered unique in Taiwan. The monitoring plot was located at 121°34'E, 24°46'N and was at 570 m in elevation (Fig. 1). Soil of the monitoring plot is classified as silty loam and is covered by natural weeds which are about 10~15 cm tall. Weather conditions of the FEF are classified as a warm and humid subtropical climate with a yearly average temperature, total rainfall, total evaporation, average relative humidity (RH), average discharge, and average solar radiation of 18.1℃, 4246.8 mm, 839.1 mm, 93.7%, 2.054 mm, and 3036.87 MJ m^{-2}, respectively. Detailed climatic conditions from January 2005 to December 2009 are tabulated in Table 1 (Lu et al. 2000, 2009).

Monitoring instruments

The Hygrometer MP100A temperature and humidity probe (Campbell Scientific,

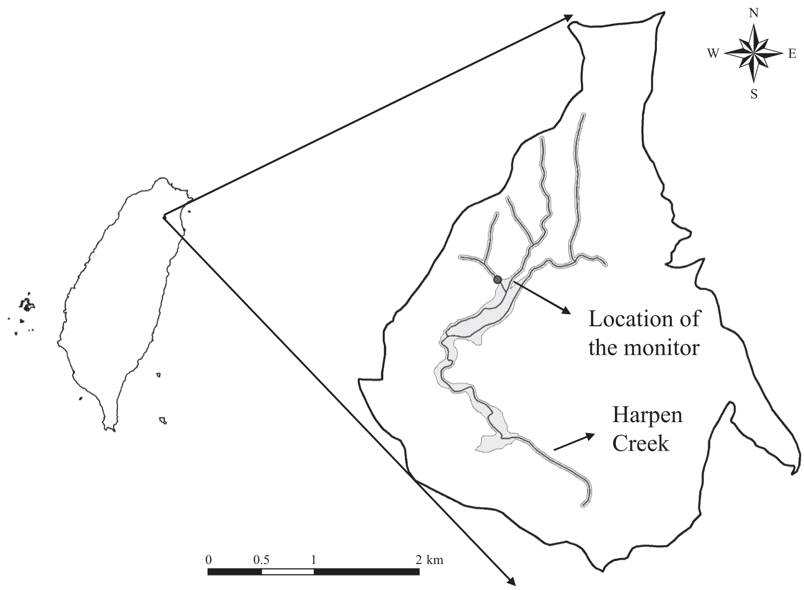

Fig. 1. Location of the study site.

Table 1. Climatic conditions for the Harpen Creek weather station (January 2005~December 2009)

	Total rainfall (mm)	Average daily temp. (℃)	Average daily max. temp. (℃)	Average daily min. temp. (℃)	Average relative humidity (%)	Average discharge (mm)	Average solar radiation (MJ/m^2)
Jan	150.0	11.8	15.9	8.6	94.8	0.057	163.28
Feb	200.4	12.6	17.3	9.1	95.1	0.296	178.86
Mar	229.3	13.8	19.3	9.4	92.1	0.646	243.43
Apr	155.5	17.1	22.5	13.0	93.7	0.550	240.63
May	318.0	20.1	26.2	15.6	92.7	2.398	295.70
June	283.4	23.0	29.2	19.1	93.1	6.775	314.14
July	404.4	24.3	30.7	19.8	91.1	4.609	455.51
Aug	712.7	23.8	29.8	19.8	91.7	6.633	353.83
Sept	995.5	22.0	26.2	19.0	94.2	2.066	221.97
Oct	439.3	20.2	24.1	17.4	95.0	0.436	246.28
Nov	205.8	16.4	19.9	13.7	96.2	0.346	156.57
Dec	152.5	12.5	16.9	8.9	94.7	0.072	166.67
Avg.		18.1	23.2	14.5	93.7	2.054	253.07
Total	4246.8						3036.87

UK) was the instrument we used to monitor temperature and RH. Temperature measurements range -40~60℃ and the accuracy of the measurement is ±0.3℃ (at -20~40℃). The 111 temperature probe was used for sensing temperatures of topsoil layers and streamflow. It has a measurement range of -40~55℃ with an accuracy of about ±0.3℃. The MP100A was installed on the stream bank 2.5 m above the ground. One 111 temperature probe (Thermometrics) was submerged at the bottom of the river where the streamflow is constant throughout the year for monitoring streamflow temperature, and other probes were installed in soil layers at depths of 5, 30, and 50 cm from the soil surface for monitoring soil temperatures. The spot for soil temperature measurements was above the floodplain, and the soil was usually unsaturated unless it was during a period of successive heavy rainfall. Temperatures were measured every 10 min and measurements were stored in a Campbell CR10 data logger (Campbell Scientific, UK).

Methods

The hourly mean temperatures were the average of 6 observations within a specific hour. The daily mean temperatures were the average of 24 records within a day. The monthly mean was the average of all daily records for that month. Daily means of temperatures were arranged in order as the Julian calendar (with January 1 as day 1), then the average temperatures for each consecutive 5 d in the Julian calendar were calculated to evaluate seasonal temperature variations for 1 yr. Daily fluctuations were evaluated from average hourly records observed at the same hour during a day for each month. A regression analysis was used to establish and evaluate the quality of predictions of streamflow and topsoil temperatures from the air temperature.

Records were dropped if there were more than 15 missing records within a month. In fact, records from only December 14, 2006 to February 6, 2007 were missing due to instrument breakdown. Therefore only 2-mo's records were not included in the analysis.

RESULTS AND DISCUSSION

Average monthly temperatures

Monthly average temperatures for air, streamflow, and soils at different depths from 2005 to 2009 are shown in Fig. 2. The maximum monthly average temperatures for air and streamflow occurred in July, while that of soil layers of all desired depths occurred in August. The minimum monthly average temperatures of the monitored items all occurred in January. The inconsistency of maximum temperature occurrence was associated with heat capacity and transmission. Heat contained in the soil and streamflow mainly comes from 2 sources in general, i.e, from the sun by means of solar radiation and from inside the earth by means of conductivity. However, heat from the latter is far less than that from the first for topsoils during the daytime under most conditions and can be considered insignificant for topsoils (Hillel1982, Geering 1995). The basin of Harpen Creek received the strongest solar radiation during the period from June to August (Table 1) and higher monthly average temperatures for all monitored items occurred in the same period. In addition, the occurrence of maximum monthly average temperatures of air and streamflow paralleled that of the maximum solar radiation which indicated that the air and streamflow quickly responded to input heat from radiation. The later occurrence of maximum soil temperatures was probably due to lower conductivity of the soil and the slow response of exchanges of heat with the air.

Soil temperature continuously varies in response to meteorological regimes and energy exchange processes that take place primarily through the soil surface. Solar radiation, the soil water content, surface conditions, soil structure, soil texture, and biological activities are factors that might influence the soil temperature and its fluctuation. Among them, solar radiation and soil water content are primary influencing factors. Monthly average soil temperature is results from the overall influences of exchange processes and the soil's own changing properties (Adjepong and Odupa-Afriyi 1979, Lu et al. 2008). The

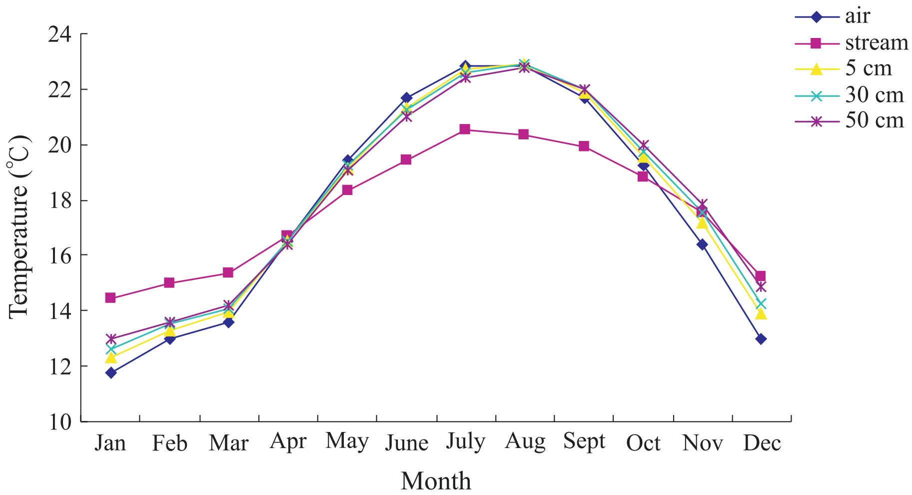

Fig. 2. Monthly average temperatures for air, streamflow, and soils at different depths for a riparian area of Harpen Creek.

highest monthly average soil temperature (22.91℃) occurred in August in the top 5-cm soil layer which was the results of the effect of the strongest input of radiation in that and the previous month and the soil's own properties such as its heat capacity and thermal conductivity. Soils in the riparian area of Harpen Creek are usually wet because of the high water table and humid climatic conditions. Wet soils usually do not have a high temperature due to the high specific heat of water and the consumption of heat by evaporation. Therefore, temperatures of topsoil layers in the study area generally do not rise too high even in the summer. In addition, ground cover, the canopy, and snow cover can block heat transfer between the soil and the atmosphere and hence will maintain soil temperature in a relatively stable range. Soil temperatures in the study areas are relatively low compared to those of other land use types (Lu et al. 2002, 2008) because most incoming solar radiation is consumed by evapotranspiration and photosynthesis even though there was only 10 cm of weed coverage, and hence only a small portion of the solar radiation is absorbed by the soil (Abdul et al. 1986, Ogee et al. 2001, Lu et al. 2002). There was no large temperature gradient in the topsoil layer in the study area.

Seasonal fluctuations

Figure 3 shows the changes of the average temperatures for groups of 5 consecutive days over an entire year. Variations in air temperature were more abrupt than those of streamflow and soil temperatures at all layers. Changes in air temperature are associated with atmosphere and ocean water temperatures (Seyfrid et al. 2001). The mobility of the atmosphere, especially horizontal air mass movements, is a factor of primary importance. The movement of air especially in the northeastern corner of Taiwan is sometimes abrupt and strong and results in abrupt oscillations in air temperature. Variations in streamflow temperature were also relatively abrupt and inferred that changes of streamflow temperature were affected by changes in air temperature. Curves of temperature in deeper soil layers were relatively smoother. The smooth curves indicated that changes in temperature of deeper soil layers were gentle. Ranges of yearly daily temperature fluctuations were

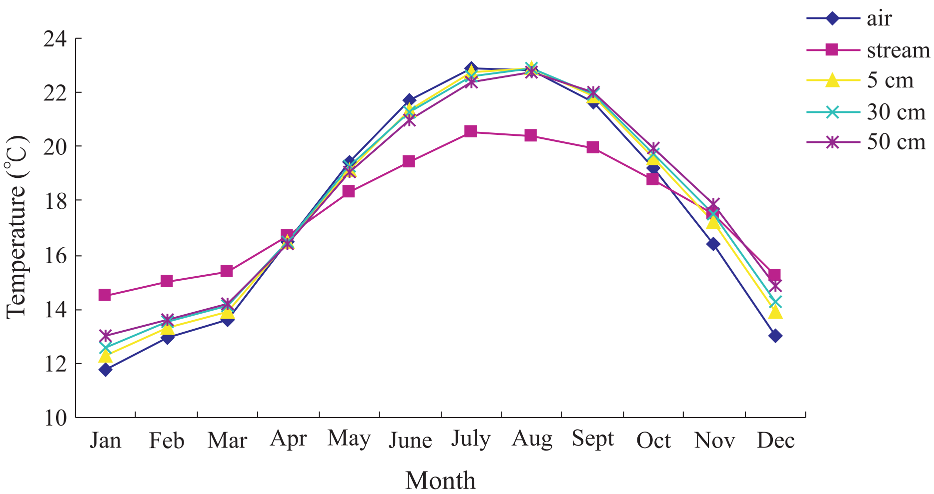

Fig. 3. Yearly temperature fluctuations in a riparian area of Harpen Creek.

15.15, 7.79, 12.28, 11.65, and 10.62℃ for air, streamflow and soil depths of 5, 30, and 50 cm below the soil surface, respectively. Although changes in the deep soil were gentle, they still showed significant changes over the course of a year. In fact, seasonal soil temperature fluctuations can reach the deep soil layers, sometimes even reaching more than 10 m below the soil surface especially in temperate continental climate regions due to great difference of air temperatures between summer and winter (Marshall and Holmes 1996, Seyfried et al. 2001). The observed maximum and minimum average daily temperatures and their occurrence dates during the study period are tabulated in Table 2. The highest temperature of air was occurred on the 189th day (8 July), those of streamflow and of all soil layers occurred on around the 198th day (17 July) of the year. The possible reason for the discrepancy of the occurrence of highest temperatures was the occurrence of instantaneous high air temperature on the 189th day and only a small amount of heat from the air being transmitted to streamflow and topsoils. The lowest temperatures occurred in coincidence on the 15th of the year (15 January) for air, streamflow, and soil of different layers.

Weather conditions, including cloud cover and occurrence of rain, may significantly influence temperatures. However, changes in the weather do not exactly follow the period of 1 yr. Therefore temperatures on the same day on the Julian calendar of different years can greatly differ. Although we grouped 5 consecutive days on the Julian calendar, curves of yearly temperatures still showed great abruptness. If the period of observation was prolonged, the curves would tend to be smoother.

Diurnal fluctuations

The average hourly temperatures of the air, streamflow and soil layers at different depths for each month are shown in Fig. 4. The descending order of magnitudes of diurnal temperature changes was air, streamflow, 5-cm soil layer, 30-cm soil layer, and 50-cm soil layer in general. However, ranges of daily temperature fluctuations of streamflow were less than those of the 5-cm topsoil layer except for the period from September to December. The reasons for this phenomenon need to be further investigated. The ranges of diurnal temperature fluctuations of the 30-cm soil layer were 0.20 to 0.48℃ and the maximum diurnal fluctuation occurred in May. The maximum range of diurnal temperature change for the 50-cm soil layer was 0.11℃ and occurred in September; the other months' changes were all < 0.10℃. Fluctuations in deeper soil layers were insignificant. In fact, daily fluctuations in soil temperature at 30 cm below the soil surface seldom exceeded 3℃ and did not exceeded 1℃ at 60 cm below the soil surface. The magnitude of the fluctuation

Table 2. Maximum and minimum daily temperatures for air, streamflow, and soils at different layers (℃)

	Air	Streamflow	5 cm	30 cm	50 cm
Maximum	25.43	21.85	25.02	24.44	24.05
Day of occurrence[1)]	189	197	197	197	198
Minimum	5.15	11.76	7.55	7.83	10.22
Day of occurrence	15	15	15	15	15
Range	20.28	10.09	17.47	16.61	13.83

[1)] On the Julian calendar with 1 January as day 1.

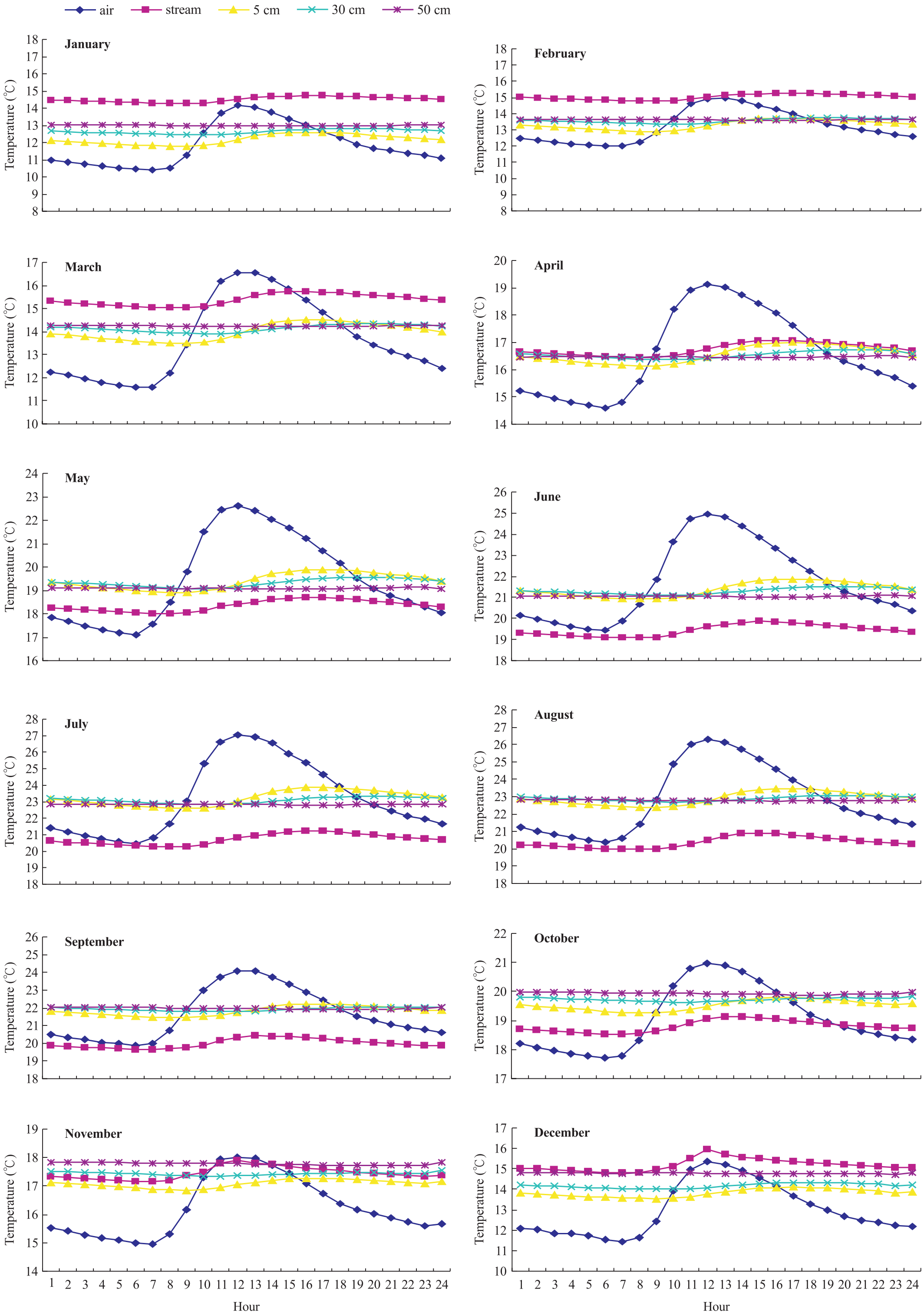

Fig. 4. Hourly temperatures of each month for a riparian area of Harpen Creek.

was nearly equal to 0℃ at 100 cm below the soil surface within a day (Tange et al. 1988, Brevik et al. 2004, Coskun and Imanverdi 2004). The diurnal fluctuation for the topsoil will be smaller if the surface is covered by vegetation or the soil has a higher moisture content. In addition, the magnitude of diurnal fluctuations in winter was generally smaller than that in the summer due to less solar radiation that was received.

The occurrence of daily maximum temperatures for the monitored items had no regularity. Maximum air temperatures within a day for each month occurred in the period from 12:00 to 13:00, which coincided with the time when the maximum solar radiation was received. The time periods of occurrences of the maximum daily temperature for streamflow, 5-cm soil layer, 30-cm soil layer, and 50-cm soil layer were at 14:00~17:00, 15:00~17:00, 19:00~24:00, and 23:00~03:00, respectively. The occurrence of the daily minimum temperature for air, streamflow, 5-cm topsoil layer and 30-cm soil layer were all in the morning before the increase in solar radiation in periods at 06:00~07:00, 06:00~08:00, 08:00~09:00, and 09:00~11:00, respectively. The occurrences of minimum daily temperatures for the 50-cm soil layer were at 15:00~20:00 in the afternoon and showed the greatest inconsistency among months. The occurrences of the maximum or minimum temperature within a day are associated with heat conduction. The deeper the soil is, the greater time that is required for the soil to reach its peak temperature by heat from solar radiation due to the slow heat conductivity (about 0.01 $cm^2 s^{-1}$ for wet soil, which can approximately penetrate 0.5 m within a day) of soil (Petterssen 1980). However, the times required for streamflow and topsoil to reach the highest temperature within a day were generally coincident due to the nearly equal speed of heat transfer for air, streamflow, and topsoil. In addition, the time period when the streamflow and soil was at a higher temperature condition was shorter than that when it was at lower temperature conditions, and the latter was estimated to be almost twice as long as the former in a day (Tange et al. 1998).

Hourly records also revealed that when the air temperature was < 15.5℃, the temperature of the streamflow was the highest among all monitored items. The second highest was the temperature of the deeper soil layer. Air temperature was usually the lowest. When the air temperature dropped below 15.5℃, the incoming solar radiation was generally small. With this situation, the influence of temperature by heat from the earth was stronger and resulted in the deeper soil layers having higher temperatures. The primary reasons for streamflow having the highest temperature were that sources of streamflow mostly were base flow or subsurface flow which generally drained from deeper soil layers. In addition, the high specific heat of water means that the heat contained in water will not rapidly dissipate (Brown 1969, James 2002).

Relationships of streamflow and topsoil temperatures to air temperature

Air temperature receives the most concern compared to those of streamflow and soils. Observations of air temperatures can be traced back at least 150 yr (Petterssen 1980). Many institutes concerned with weather forecasting (for example: Central Weather Bureau of the ROC, and Japan Meteorological Agency) have accumulated huge amounts of data of air temperatures all over the world. It is interesting to use air temperature to estimate temperatures of streamflow and topsoil at the same spot. Therefore the linear relationships of daily average air temperature (T_{air}) between streamflow ($T_{streamflow}$) and topsoil layers (T_{s05}, T_{s30}, and T_{s50}) were determined in this report. Daily average temperatures for air, streamflow, and 5-, 30- and 50-cm topsoil layers in 2008 were used to determine the relationships. The relationships are listed below:

$T_{streamflow} = 0.492 \times T_{air} + 8.951$; $r = 0.962$; $n = 366$;

$T_{s05} = 0.826 \times T_{air} + 3.224$; $r = 0.954$; $n = 366$;

$T_{s30} = 0.769 \times T_{air} + 4.392$; $r = 0.929$; $n = 366$; and

$T_{s50} = 0.710 \times T_{air} + 5.538$; $r = 0.903$; $n = 366$.

The coefficients of correlation were all > 0.90, indicating that the strengths of those positive linear relationships are reliable.

CONCLUSIONS

Temperatures of streamflow and topsoil layers in the Harpen Creek riparian area are mostly influenced by the solar radiation received. Yearly average temperatures for air, streamflow, and the 5-, 30- and 50-cm soil layers during the observation period were 17.7, 17.6, 17.9, 18.0, and 18.1℃, respectively. The maximum monthly average temperatures for air and streamflow occurred in July, while those of soil at all studied depths occurred in August. The minimum monthly average temperatures of the monitored items all occurred in January. The largest and smallest yearly temperature discrepancies were 15.2, 7.8, 12.3, 11.7, and 10.6℃ for air, streamflow, and soil depths of 5, 30, and 50 cm below the soil surface, respectively. Although changes over the course of a year in deep soil were gentle, they still were significant. The descending order of the magnitudes of temperature changes within a day was air, streamflow, and 5-, 30- and 50-cm soil layers. Except for air temperature, the magnitude of daily temperature fluctuations exceeding 1.0℃ only occurred in topsoil of the 5-cm depth layer in the months of July and August. Diurnal fluctuations in streamflow and soil temperatures of the deeper layers were insignificant. The occurrence of daily maximum temperatures for the monitored items had no regularity; however, that of the daily minimum temperatures mostly occurred in the morning before the solar radiation increased. Further studies of the effects of the soil moisture content on temperature are needed to improve our understanding of soil and streamflow temperature regimes. Further studies on the influences of temperature on ecological phenomena are suggested.

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