Journal of Experimental Biology and Agricultural Sciences

<http://www.jebas.org>

ISSN No. 2320 – 8694

EFFECT OF HEAT-STRESS AND PHYSICAL WORKLOAD ON WORK-REST CYCLE AND PRODUCTIVITY IN MANGROVE FOREST OF PENINSULAR MALAYSIA

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Received – September 20, 2020; Revision – November 22, 2020; Accepted – December 20, 2020

Available Online – December 30, 2020

DOI: [http://dx.doi.org/10.18006/2020.8\(6\).859.866](http://dx.doi.org/10.18006/2020.8(6).859.866)

KEYWORDS

Physical workload

Heat stress

Energy, productivity

Forest operation

Mangrove

ABSTRACT

The main objective of this study was to determine the effects of heat stress on the health and productivity of forestry workers. The study included a method of assessment involving the use of standardized measuring equipment on several types of forestry works in mangrove forests. In this study, the thermal conditions and physical workload of workers were measured under various conditions, i.e., logging site, charcoal kiln, and nursery. A structure of the work-rest cycle could be designed properly using the standards of the American Conference of Governmental Industrial Hygienists (ACGIH). Result of the study showed that the mangrove forestry works in the logging site and charcoal kiln could be carried out continuously with 25% of working efficiency on achieving maximum productivity and 75% of the rest needed, while at the mangrove's nursery site it could be carried out continuously with 75% of working on achieving productivity and 25% of the rest needed. The adjustment of working productivity is therefore established between WBGT and the work-rest cycle in the design of work. Thus, it can be concluded that consideration in modifying the work-rest cycle will result in better management of heat stress rate on productivity and health being of the workers. Besides, this study recommends that more shaded areas for forestry workers to take rest to prevent heat illness and enhance working efficiency.

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Peer review under responsibility of Journal of Experimental Biology and Agricultural Sciences.

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1 Introduction

Heat stress refers to the conditions when the body can no longer dissipate body heat appropriately to the surrounding. The implication of heat stress on the workers is discomfort, increases physiological strain, decreases productivity and performance, and increases accident rates (Lucas et al., 2014). Heat stress occurs when a person's environment (air temperature, radiant temperature, as well as humidity and air velocity), clothing, and activity combined resulting in raising the body temperature (Parsons, 1998). Also, an overexposed and prolonged working condition under a high-temperature environment contributes to the extent of heat-related illnesses. There are different severity of heat-related illnesses from mild to a serious health condition, such as heat rashes and heat cramps; or more complicated events such as heat exhaustion and heat stroke (Jagai et al., 2017), accordingly. Since heat-related complications can be prevented, due consideration should be made to promote the culture of occupational health among workers (Farough et al., 2019). Therefore, an understanding of the effects and identifying a suitable approach to reduce such impacts on the workers has been the focus of considerable researches.

Labor productivity can be defined as the output rate per worker, while efficiency includes other variables, in particular the output to input ratio. The extreme climate not only causes heat stress to the worker but also results in physical workload discomfort. This discomfort directly affects the worker's performance and productivity (Lucas et al., 2014). Most of the work construction, agriculture, and forest sectors are outdoors, in these workers directly exposed to sun, where the climate cannot be controlled. For example, the working conditions of forest workers are commonly an open area where direct sunlight is fully or partially exposed, particularly at harvesting sites. The forestry operation with the highest exposure to occupational risks and accident rates is harvesting work (FAO, 2020). In the scarcity of the data on health, climate, productivity, and other related data, it is difficult to estimate the impacts of climate change in particular, the heat stress on the health of forestry workers and their productivity.

Malaysia has the sixth largest mangrove forest area with accounting for approximately 4.7% of the world's mangrove area (Satyanarayana et al., 2018). Mangrove forest plays a crucial role in the conservation of the coastal area, protecting complex marine habitats (Veettil et al., 2019), controlling nutrient cycle and storing carbon (Donato et al., 2011). Matang Mangrove Forest Reserve (MMFR) in Peninsular Malaysia has been declared as the largest mangrove forest in Malaysia and has been the longest actively and formally managed mangrove forest in the world (Goessens et al., 2014; Arriffin & NikMohd Shah, 2013). The first management plan for MMFR was established in 1902 to manage this forest to become sustainable timber and

fuelwood production (Goessens et al., 2014). This plan involves clear-cutting forest patches of 30 years for the production of charcoal and intermediate thinning to obtain poles for every 15 to 20 years old forest patch (Arriffin & NikMohd Shah, 2013). Charcoal production involves harvesting the tree from the forest, moving the logs to the charcoal plant, converting the logs to charcoal, and replenishing the soil in the nursery. All these processes are typically performed manually by the workers and involve in various activities such as felling, marking and bucking, loading and unloading, wood stacking, and filling soil.

Lucas et al. (2014) claim that it will be too hot to work safely outdoors and perform heavy labor for at least half of the working day (40%–60% of current working hours lost). As a result, such impacts have obvious ramifications for harvesting productivity. Moreover, climate change has been extremely severe, especially in tropical countries where the levels of heat exposure are already verging in the day time. According to Schulte & Chun (2009), there is a high relationship between global climate changes; occupational safety and health have not been substantially characterized. Current research indicates that the direct effect of climate change is increased with ambient heat exposures. It can be proven, whereby recent estimates for Thailand and Cambodia highlighted that in 2050, as the hottest month of the year. Based on the geographically located area, there is a high possibility for Malaysia to have the same phenomena shortly (Singh & Singh, 2012).

To improve work performance among the forest workers, a working design has to be adjusted to suit the environmental condition of the surrounding area (2005). For instance, a work-rest cycle involves alternating between work and rest periods to limit the excessive accumulation of body heat storage. This cycle of work-rest can be refined to fit in with the work environment. A proper rest period with a conducive environment condition will imply better work performance and the health condition of the workers. However, even during recovery, the sustained heat gain beyond dissipation capacity from evaporation may persist under uncompensable heat stress (McLellan et al., 2013). A typical work/rest schedule often has a 15-minutes rest every hour of work during hot weather, but 45 minutes per hour when extreme temperature and humidity.

Lack of studies and less attention to heat stress assessment and productivity among forestry workers in Malaysia motivates this study to better understand the critical heat stress to those workers. Information on the health of forestry workers focusing on heat stress, physical workload, work environment, and daily productivity is needed to provide an insight into this issue. These findings will be useful to forest management in offering a better work-rest schedule and ultimately helping to improve the productivity of the workers.

The overall aim of this study is to identify the effects of heat stress on the health and productivity of forest workers using manual and semi-mechanized working methods. The specific objectives of this study are to measure the heat stress of the forest working environment; to evaluate the relationship between heat stress and the workload of forestry workers, and to determine the percentage of productivity in the working environment according to heat stress. This study will be an approach study to expand a framework to determine the effects of climate change on the occupation conditions and performances among the workers in the tropical mangrove forest.

2 Materials and Methods

2.1 Study area

Mangrove Forest Reserve (MMFR) has been identified as a study area as shown in Figure 1. It is the largest Mangrove Forest in Peninsular Malaysia, particularly in Perak state, with a total acreage of 40, 466 hectares. MMFR lying between the latitude of 4°N – 5°N and the longitude 100°2'E - 45'E which is situated within the administrative district of Krian, Larut & Matang, and Manjung in Perak. The role of the forest in this area is mainly for the production of fuel-wood and pole.

The production of fuelwood consists of three stages viz., harvest at the logging site, transport logs to the charcoal factory, and finally replenish the soil. Each contractor is given 2.2 ha per year and a clear-cutting method is practiced with a harvesting rotation age of 30 years. Only manual cutting is allowed by using an axe or

chainsaw with a standardized cutting log length of 1.6 m. At these stages, physiological loads and productivity of the forest workers were assessed. This study site is chosen due to the manual working condition at the worksite and this area is classified as the best location for mangrove forest management. Therefore, it makes the assessment of the heat stress on the forest workers and their productivity very appropriate.

2.2 Observation of thermal conditions

The Wet Globe Bulb Temperature (WGBT) is used to observe the global temperature to determine a parameter of the heat stress index. The WGBT under the exposure of direct sunlight can be calculated by using Eq. 1 (Rohles & Konz, 1987);

$$\text{WGBT} = 0.7\text{NWB} + 0.2\text{GT} + 0.1\text{DB} \quad \dots \text{Eq. 1}$$

Where, WGBT is Wet Globe Bulb Temperature (°C); NWB is Natural Wet Bulb Temperature (°C) on exposure to natural air currents; GT as a Globe Temperature (°C) measured using a black globe thermometer and DB is Dry Bulb Temperature (°C) upon exposure to natural air currents while being protected against radiation of heat sources.

2.3 Measurement of physiological loads

The forestry workers studied from three different locations of mangrove forests, i.e., logging site, charcoal kiln, and nursery. Physical workload analysis of the forestry workers was carried out using a heart rate memory device. The workers were equipped with

Figure 1 Study area at Matang Mangrove Forest Reserve in Taiping, Perak (Google map)

the device to automatically measure their heart rate during working time. To calculate the energy metabolism (Eq.2), a step test was conducted for each worker to evaluate heart rate response and regression models were computed between the step test and heart rate. Using these regression models, the heart rate during the working time was converted to physical work and the energy metabolism was estimated using Eq. 2 (Hirakawa, 1983).

$$Eg = 0.0163 \times W \times N \times H + 1.2Bm \quad \dots \text{Eq.2}$$

Where, **Eg is the energy metabolism (kcal/min); W is the weight of a worker (kg); H is the height of step test platform (m); N is stepping rate (times/min); Bm is basal metabolism (kcal/min). Obtained data were converted from kcal to kilojoule by multiplying values in kcal by 4.2.**

2.4 Work-rest Cycle and productivity

The volume or units of work performed corresponding to the productive time data collected in the field were used to calculate the productivity (P) by using Eq. 3 (Giovannini, 2001).

$$P = \frac{\text{Volume/ Units}}{T} \quad \dots \text{Eq.3}$$

Where P is the productivity for the given work (m³ or units/ hour) and T is the total productive time (minute). The P-value is calculated based on Eq. 3. The working time adjustment was determined following the standards of the American Conference of Governmental Industrial Hygienists (Seca et al., 1997). This adjustment is made to the percentage of working time and rest period or work-rest cycle according to the WBGT values as well as the category of work.

3 Results and Discussion

3.1 Thermal conditions

Figure 2 shows the WBGT at three sites in the MMFR area from 9.00 am to 12.00 pm. The lowest WBGT was observed at 9.00 am, regardless of the sites. When comparing the study sites at 9.00 am, the logging site had the lowest WBGT, followed by the nursery and charcoal kiln site with a mean temperature of 26.1°C, 26.9 °C, and 27.0 °C, respectively. The lowest WBGT at the logging site may contribute by the existing mangrove trees in the area. According to EPA (2017), an area surrounded by trees and other plants help cool the environment through shading trees, depending on the data collection location. There are two types of mangrove species in MMFR that covers 2.2 ha of the logging area, namely *Rhizophora mucronata* and *R. apiculata*. About a quarter of the area was already harvested during data collection.

In general, the WBGT in all sites were increased with time and had the highest recorded temperature at 12.00 pm. The lowest WBGT recorded at 12.00 pm was observed in the nursery with a temperature of 27.9 °C because the nursery was very conducive, well ventilated, and fully shaded. The workers were much less exposed to heat, and the workers carried out work more comfortably. Meanwhile, both logging and charcoal sites had higher WBGT values than nursery sites. The logging and charcoal site had WBGT of 29.7 °C and 30.0 °C, respectively at 12.00 pm. High WBGT in these sites was also influenced by the activity/process on-site. For instance, high WBGT at the logging site was due to the exposure to direct sunlight with limited shading locations as a result of the harvesting process. Similar example of

Figure 2 Heat Stress (WBGT, °C) at Logging site, Charcoal Kiln and Nursery for mangrove forest

work that is exposed to environmental heat is construction work (Rowlinson & Jia, 2015; Al-Bouwarthan et al., 2019). For instance, the location of construction workers is commonly outdoors such as site preparation, formwork, etc. Al-Bouwarthan et al. (2019) have found that the highest hourly mean WBGT values during construction work was 31-33 °C which represents extreme heat exposure that can cause a serious risk.

High WBGT was also observed in charcoal production. The conversion of logs to charcoal requires a high temperature between 100 and more than 500 °C in a furnace, depending on the technology used (Kajina et al. 2018). The temperature inside the charcoal kiln may exceed 220°C, depends on the burning stages. The outer surface of the furnace was high when compared to other sites in MMFR and contributed to high WBGT on this site. Fahed et al. (2018) reported that the highest WBGT in a steel plant in Turkey had an approximate mean of 31.3 °C. This value was observed near a reheat furnace in the plant. Other than the high temperature used in the charcoal site, the workers were also exposed to extreme conditions outside the factory, especially in the unloading area.

3.2 Physiological loads

Table 1 shows the physiological loads of workers at different study sites based on the work types, an average heart rate throughout the working period, energy used to carry out each activity, workload classifications, and heat stress. Based on the results, the highest energy used by the workers at the logging sites was when felling, marking and bucking, as well as loading and unloading. These works have been classified as being extremely heavy and very heavy to work.

Felling mangrove tree activity consumed the highest workload and mean of heart rate by having a value of 108.44 KJ/min and 175 bpm, respectively. The use of a semi-mechanized chainsaw to cut the tree requires a greater amount of energy is listed as a heavy workload Balamunsi et al. (2011). Meanwhile, work at the charcoal factory involves unloading, debarking, and wood stacking which is classified as extremely heavy, moderate, and very heavy workload, respectively. These tasks were carried out manually without any tools except for debarking, using a wooden tool to remove the bark. At this site, the unloading activity consumed the highest energy by having 54.05 KJ/min compared to other works. This is because the worker needed to carry the log manually from the log pond to the wood assembling area. The exposure to heat stress at both Mangrove felling sites and charcoal factory was considered high which was 28.5°C and the work routine of the workers is highly influenced. The least energy expenditure at the felling and charcoal site was by debarking workers. They used a little amount of energy to carry out this task and it is classified as moderate work.

Meanwhile, the nursery site had the lowest measured heart rate and workload with mean values of 100.94 bpm and 14.04 kJ/min respectively. The workers from the mangrove nursery site used energy ranging from 11.05 kJ/min to 17.72 kJ/min to conduct a soil filling activity and this work is classified as light work.

Overall, the work performed in MMFR is classified as high workload associated with high heat stress exposure. The energy that workers at MMFR needed to carry out the assigned tasks was high. The level of heat stress is high at MMFR, by having WBGT values of 27.3°C, 28.5°C, and 29°C, for all three stages involved in charcoal production. Closer observation indicates that the varying

Table 1 Classification of Physiological load of workers

Table 1 Classification of Physiological load of workers				
Types of work	Heart rate (bpm)	Work load (KJ/min)	Classification	Heat stress (WBGT) (°C)
Mangrove Felling Site				
Felling	175.22	108.44	Extremely heavy	28.5
Marking and Bucking	161.89	48.37	Very heavy	
Loading and unloading	146.67	51.28	Extremely heavy	
Charcoal Factory				
Unloading	136.22	54.05	Extremely heavy	28.5
Debarking	109.11	20.67	Moderate	
Wood Stacking	146.44	46.96	Very heavy	
Nursery Mangrove				
Filling soil 1	92.5	11.05	Light	27.3
Filling soil 2	105	17.72	Light	
Filling soil 3	105.33	13.36	Light	

working environment with a different type of works implies changes in the heat stress level, the poor working environment with fewer shades contributes to heat exposure.

3.3 Work-rest Cycle and Productivity

Figure 3 shows the productivity of workers at the logging site. The calculated WBGT value at the mangrove logging site was 28.5 °C. The workers were assigned to fall trees, marking and bucking, loading, and unloading. These tasks are classified as heavy workloads. According to the ACGIH standards, mangrove work could be carried out continuously with 25% working on achieving productivity and 75% of the rest needed once when one reaches the productivity targets. Since this work activity is categorized as a heavy workload, more rest time than work is required. Daily working time should be focused on work intensity and thermal exposure, so the productivity target can be achieved, and workers' health is also considered. This result is very different compared to the felling and cutting tree in tropical hill-mix dipterocarp forest in East Kalimantan, Indonesia (Seca et al., 1997), which were these works could be done continuously early in the morning and 75% of working and 25% rest time for the remainder of the workday. It is because the felling and cutting trees were done under the hill-mix dipterocarp forest with WBGT around 24°C to 26°C and no shade needed under the forest canopy.

The productivity of workers in the charcoal factory is shown in Figure 4. The workers in the charcoal factory were exposed to direct and partial sunlight with a WBGT mean value of 28.5 °C. As stated by ACGIH (1996), a WBGT of 28.5 °C is suggested to conduct 25% of the work cycle with the 75% rest ratio mainly for workers who have carried out a heavy workload. Meanwhile, moderate-heavy loads require 50% rest once the target productivity is reached in an hour. Debarking is categorized as moderate work. The productivity should be achieved by 48 logs per hour, but according to ACGIH (2014) the standard workload should be 50% of 48 logs, which are 24 logs per hour. Though, the work-rest cycle for debarking is 50% of the working hour with 50% of rest hours.

Figure 5 shows the productivity of mangrove nursery workers. The WBGT reading was 27.3

Figure 3 Productivity of Workers with Action Limit at Mangrove Felling Site

Figure 4 Productivity of Workers with Action Limit at Charcoal Factory

Figure 5 Productivity of Workers (three different workers who filled soil on polibag) with Action Limit at Mangrove Nursery

°C and the workload of the workers was considered to be a light workload. About this, workers can carry out a continuous workload with an optimum working time of 75% and need to rest for 25% after the work has been carried out. The filling soil productivity rate is 180 polybags per hour; however, the hourly work cycle allocated is 135 poly bags. In consideration, the workers should take 25% rest from the actual working hours once they have filled 135 poly bags. This result is almost the same with the spreading fertilizer at the nursery of tropical forest plantation in East Kalimantan, Indonesia (Seca et al., 1997), which was the work could be done continuously a half of day and need to rest 25% rest time for the remainder of the workday.

Since the heat stress is higher in the mangrove forest area, so the best way to prevent heat illness is to avoid the long exposure of the worker with a heavy workload to such an environment. In outdoor situations, this should be done by scheduling activities during the cooler times of the day in term of it monitor weather reports daily and reschedule jobs with high heat exposure to cooler times of the day. Other than that, provide more shaded areas close to the work area, and allow frequent rest breaks, highlight the rest and work period associated with the type of work classifications.

Conclusions

The study found that the exposure of the forestry worker to heat stress at the current study site is in a good condition based on the heat stress index. However, further consideration is needed to prevent any severe cases. Most workers had light, moderate to high workloads, and most of them had direct exposure to the sun. The heat stress recorded at the mangrove felling site was 28.5 °C, the energy used to carry out the task was 108.44 kJ/min and the work was classified as heavy workload. According to the thermal conditions and the workload, so the mangrove forestry works in the logging site and charcoal kiln could be carried out continuously with 25% of working on achieving productivity and 75% of the rest needed, and in the mangrove, nursery could be carried out continuously with 75% of working on achieving productivity and 25% of the rest needed. The adjustment of working productivity is therefore established between WBGT and the work-rest cycle in the design of work. Thus, it can be concluded that consideration in modifying the work-rest cycle will result in better management of heat stress rate on productivity and health being of the workers. This study recommends providing more shaded areas to take rest especially for forestry works in the mangrove forest to prevent heat illness.

Acknowledgement

We thank the Director of Perak Forestry Department for the approval given to use the mangrove forest in Matang as the study site and the Charcoal Kiln owner for let us took the data collection on their charcoal kiln workers.

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