REPORT
ISSN 1174 - 1406
Volume 23 No. 2 1998

Psycho-Physiological Assessment of Thinning-to-Waste Operations

Patrick Kirk
Mark Sullman

Summary

An average working heart rate of 127 beats per minute ($bt.min^{-1}$), and an energy expenditure of 49 kilojoules per minute ($kJ.min^{-1}$), ranked thinning-to-waste silvicultural operations as a heavy to very heavy workload task. All workers studied noted increased feelings of fatigue, sleepiness and decreased muscular strength as the day progressed. No change was recorded for measures of tenseness and boredom. The ability of workers to utilise spontaneous rest pauses, combined with an effective 60 minute meal break at midday, enabled the worker to operate at a sustainable level throughout the working day (48% Heart Rate Range). Hazard ratios were very low.

Recommendations

Forest workers undertaking thinning-to-waste operations should use frequent short rest pauses, regular meal breaks and fluid intake to achieve an optimal work rate in terms of constant productivity, sustainable physical strain and low hazard ratios over the entire working day.

Liro limited
PO BOX 2244, ROTORUA, NEW ZEALAND
TELEPHONE: 07 348 7168 FAX: 07 346 2886
Email:Pat@liro.fri.cri.nz

Introduction

Many of the advancements made within the forest industry, in terms of genetic tree improvement, are all too frequently squandered at the time of planting and tending. This can be attributed to a range of factors including low motivation, poor morale, ineffective communication, low level of life skills, physical and mental fatigue, and poor training.

Within the New Zealand logging industry, the importance of these aspects have been recognised and there has been extensive work undertaken to identify the physical hazards (Parker and Kirk,1993; Kirk and Sullman, 1996), accident type and frequency (Parker,1995; Parker,1996), physiological strain (Kirk and Parker,1994a, Kirk and Sullman, 1995; Kirk et al., 1996a; Parker and Kirk,1993b), the role of personal protective equipment (Kirk,1993; Kirk, 1996; Kirk and Parker,1994b, Sullman, 1996) fluid (Paterson and Kirk, 1997) and nutrition (Kirk et al., 1996b; Sullman et al., 1997).

However, the same cannot be said for silvicultural operations, where research has been limited to a few pruning studies (Ford et al., 1996; Hartsough and Parker, 1993; Kirk and Parker, 1996) and two planting studies (Trewin and Kirk, 1992; Sullman and Byers, 1996).

The objective of this project was to measure the psycho-physiological demands of motor-manual thinning-to-waste under normal operating conditions, in an attempt to determine the acceptability of this silvicultural task in terms of physical and mental demands.

Acknowledgments

Liro Limited would like to sincerely thank Wenita Forest Products Limited and their contractors for their assistance with this project.

Method

Subjects

The subjects were six professional chainsaw operators working in thinning-to-waste operations.

Location

The study area was located in the Otago region of the South Island (Figure 1) in the Otago Coast and Mount Allan plantation forest estates.

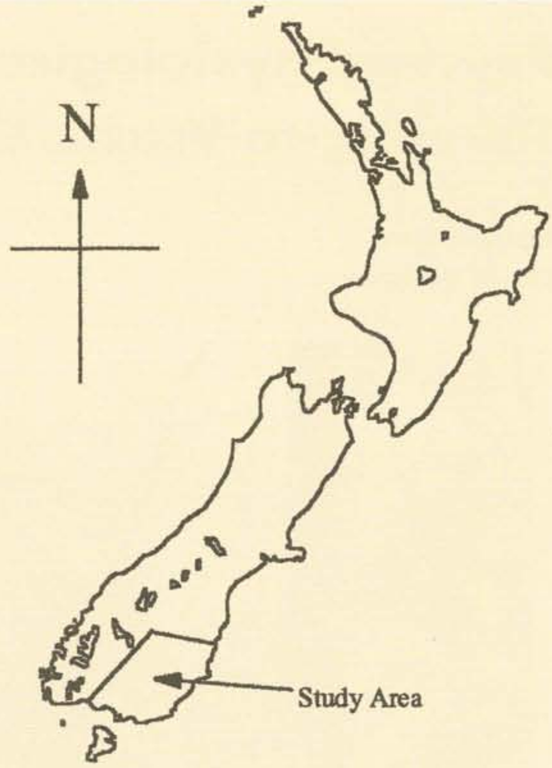

Figure 1 - Study Location

Physiological Measures

Heart Rate

Working heart rate and aerobic capacity were determined for each worker and applied to heart rate indices, in order to determine the level of physical strain experienced by the workers.

Energy Expenditure

The study used a method based upon the subject's heart rate recordings, using reliable workload/oxygen uptake relationships which were obtained through cycle ergometry testing. Accordingly, estimated mean aerobic capacity (Vo_2) figures were multiplied by 20 in order to obtain the mean kilojoules per minute (kJ. min^{-1}). These per minute (min^{-1}) values were then multiplied by the time spent at work in minutes, to obtain an estimation of energy expenditure for the working day.

Production

The number of trees felled per hour by each worker was recorded and used to calculate individual hourly production rates.

Safety

Hazardous situations were recorded and used to determine hazard type and frequency of occurrence.

Temperature

The temperature at each work site was recorded throughout each working day by a portable automatic weather station placed as close as possible to the operator. This information was then used to calculate the thermal index (wet bulb globe temperature - wbgt) for each site.

Subjective Measures

Subjective comfort and sensation assessments were measured using standard questionnaires administered at one hour intervals throughout the working day. The questionaires measured subjective thermal comfort and sensation, skin wettedness, thermal regulation, physical fatigue, body part discomfort and mental fatigue.

Results and Discussion

Table 1 - Worker characteristics

Subject	1	2	3	4	5	6
Age (yrs)	43	55	26	29	27	24
Years Experience	22	25	4	7	9	8
Weight (kg)	102	75	105	70	76	82
Height (m)	1.88	1.71	1.92	1.72	1.75	1.77
Body Mass Index (BMI)	28.9	25.7	28.5	23.7	24.8	26.2
Resting Heart Rate (b.min^{-1})	71	70	72	76	71	66
Est Vo_{2max} (l.min^{-1}) (age corrected)	4.7	3.0	4.9	3.0	3.1	4.1
Est. Vo_{2max} (ml.kg^{-1}/min^{-1})	45.6	39.8	46.7	43.5	41.2	50.0
Average working Heart Rate (b.min^{-1})	120	114	130	129	144	122
Percent Heart Rate Range (%HRR)	46	46	48	46	60	43

Worker Characteristics

The workers had a mean age of 34 years (range 24 to 55), height of 1.79 m (range 1.71 to 1.92) and weight of 85kg (range 70 to 102) (Table 1). Their mean body mass index of 26 (range 24.8 to 28.9) revealed that they were the correct weight for their height. The workers had a mean estimated maximum aerobic capacity (Vo_{2max}) of 44.5 millilitres per kilogram per minute (ml.kg^{-1}.min^{-1}) (range 39.8 to 50.0), indicating that they possessed above average aerobic capacities. The mean forest industry experience was 12 years (range 4 to 25), indicating a wide range of experience within the group.

Physiological Measures

Working Heart Rate

The workers recorded a mean working heart rate of 127 beats per minute (bt.min^{-1}) (range 114 to 144). When compared against other occupations, thinning-to-waste operations recorded working heart rates higher than breaking-out, motor-manual felling, 2nd lift chainsaw pruning, skidwork and mechanised operations. However, thinning-to-waste produced a working heart rate lower than both manual 2nd lift pruning and planting (Figure 2).

Table 2 - Grades of physical work

Grade of Work	Energy Expenditure (kcal/min)	Energy Expenditure 8 h (kcal/day)	Heart Rate (beats per minute)
Resting	1.5	< 720	60 - 70
Very Light Work	1.6 - 2.5	768 - 1200	65 - 75
Light Work	2.5 - 5.0	1200 - 2400	75 - 100
Moderate Work	5.0 - 7.5	2400 - 3600	100 - 125
Heavy Work	7.5 - 10.0	3600 - 4800	125 - 150
Very Heavy Work	10.0 - 12.5	4800 - 6000	150 - 180
Unduly Heavy Work	> 12.5	> 6000	> 180

Percent Heart Rate Range (%HRR)

All except one worker chose to work within 40 to 50% of their heart rate range (HRR). The recommended level for continuous physical work over an eight hour period ranges from 33% (NIOSH, 1981), to 45% (Evans et al., 1980; Levine et al., 1982), with 40% the most frequently adopted (Apud et al., 1989).

In the current study, the mean relative heart rate was 48% (range 43 to 60), a figure which falls slightly outside the recommended limits previously outlined. Evans et al., (1980) found that when male and female soldiers were requested to work hard at self-paced rates, they both chose a level equivalent to 45% of their Vo_{2max}. Other studies using male soldiers operating under the same criteria (Hughes and Goldmen, 1970; Soule and Levy, 1972), found that the level chosen represented 40 to 50% of the subjects Vo_{2max}.

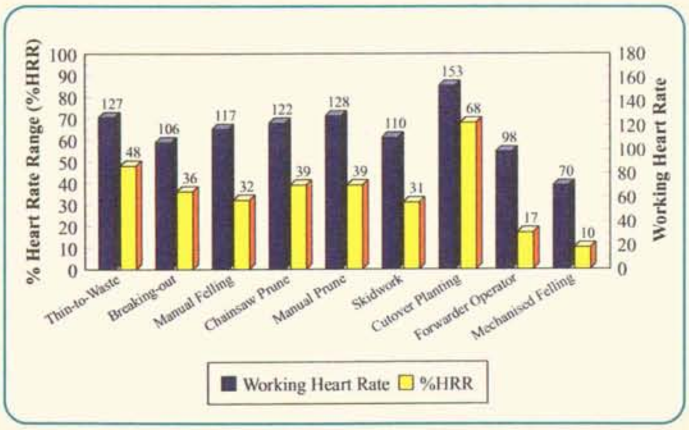

Figure 2 - % heart rate range and working heart rate

It appears that when a work motivator is introduced, in this case production targets, workers will choose to work at a slightly higher level than the recommended 40%. When compared to other occupations, it is evident that the task of thinning-to-waste can be placed within the higher physical effort level (Figure 2).

This result strongly supports previous research findings which revealed that when allowed to select their own working pace, workers will automatically choose a level somewhere between 30 and 50 % HRR (Sullman and Byers, 1996). The ability to work within this range results in the workers being able to maintain a sustainable working pace for the entire day without causing physical degradation or damage to the body. Selecting a work pace which falls within the 30 to 40% HRR level appears to be a work method chosen by many workers undertaking a wide range of jobs performed within the forest industry (Figure 2).

Energy Expenditure

The predicted oxygen uptake curves calculated from the heart rate data collected from the cycle ergometer tests are shown in Figure 3. Each worker's curve shows the level of energy (watts) generated by that person for any given heart rate. It is shown that in order to generate 200 watts of energy, worker 1 only needs to increase his heart rate to 125 $bt.min^{-1}$, while workers 4 and 5 need to increase their heart rate to 157 $bt.min^{-1}$. This means that if workers 1, 4 and 5 were to do the same job, worker 1 would require significantly less energy to complete the work than that required by workers 4 or 5.

Using the curves shown in Figure 3, a mean estimated energy expenditure of 49 kilojoules per minute (kJ/ min^{-1}) was obtained. Total estimated work expenditure for the working day was 4300 ±900 kilocalories (kcal), with the average working day consisting of 420 minutes (7 hours). Considering all of these factors, the workload of thinning-to-waste operations, in terms of energy expenditure, would have to be rated as being within the "heavy" range according to internationally recognised strain scales (Table 2).

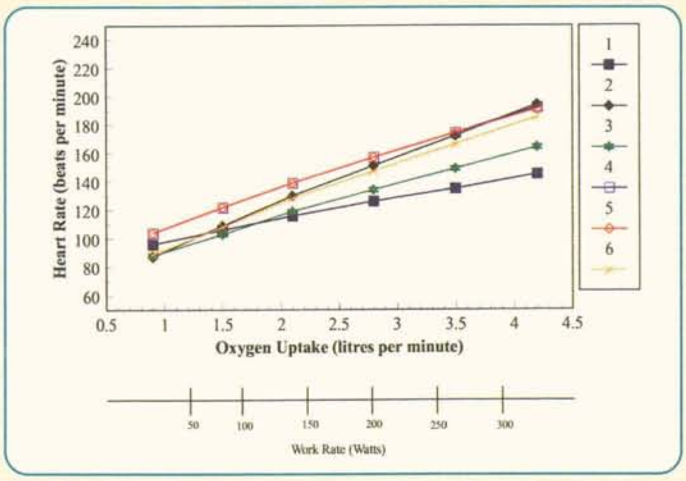

Figure 3: Predicted oxygen uptake (l.min-1)

Figure 4 provides a relative measure of how thinning-to-waste energy expenditure rates against other jobs and activities.

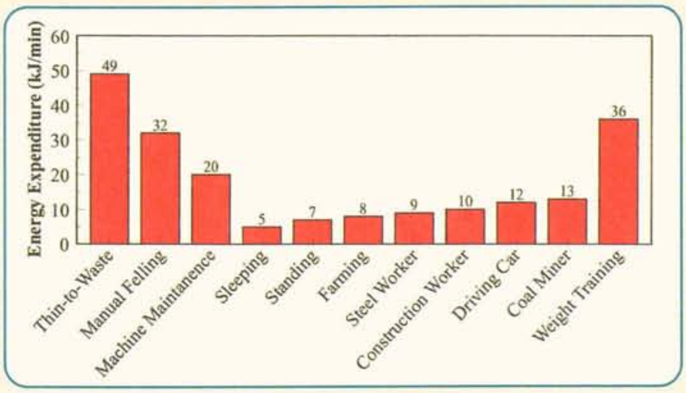

Figure 4: Rates of Energy Expenditure (Kilojoules per minute)

Subjective Measures

The subjective measures showed a consistent trend towards greater physical fatigue as the day progressed. All workers noted increased feelings of exhaustion, fatigue, sleepiness, weariness and decreased muscular strength. No change was identified for measures of both tenseness and boredom.

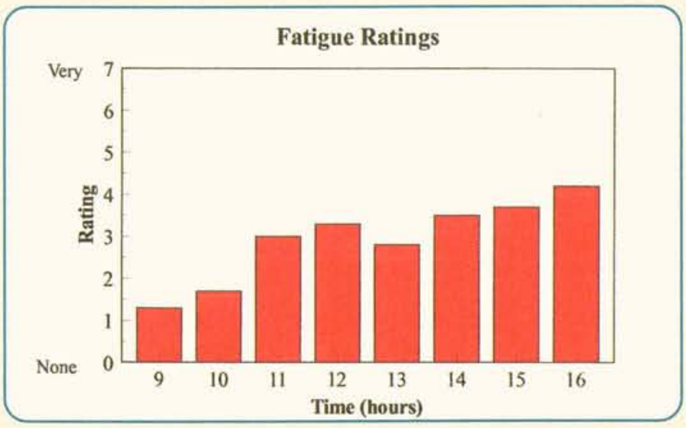

Figure 5 - Subjective fatigue ratings

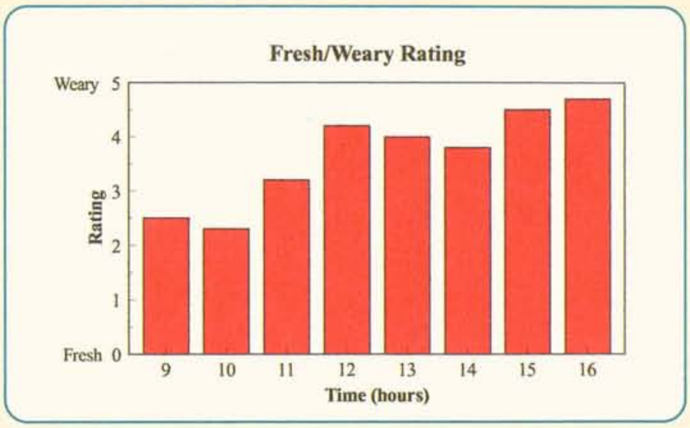

Figure 6 - Subjective fresh/weary ratings

Mental Fatigue

The digit symbol substitution test for mental fatigue showed workers experienced no reduction in mental performance as the day progressed. This is not uncommon in forestry tasks and has been noted in other forestry related studies (Kirk and Sullman, 1995; Kirk et al., 1996a). The very physical nature of the work may help offset any build-up of mental fatigue.

Body Part Discomfort

Three out of the six workers recorded body part discomfort during the day. Reports of pain were recorded for the neck, forearm, shoulder, lower back, thighs and knee. The discomfort increased as the day progressed from low to moderate pain. These recordings are the result of the posture adopted by workers undertaking thinning-to-waste operations as well as the very steep terrain that they were working on.

Production

The number of trees per productive hour remained consistent throughout the working day for all of the workers. This supports the physiological finding that the workers operated at a sustainable work pace for the entire day.

Temperature

The climatic conditions during the study were consistently cool, with an average wet globe bulb temperature (wbgt) of only 6°C. Therefore it can be safely concluded that the environmental temperature did not affect workers' heart rates through the addition of an external heat source.

Hazards

The number of trees per productive hour remained consistent throughout the working day for all of the workers. This supports the physiological finding that the workers operated at a sustainable work pace for the entire day.

These hazards are typical of the nature of thinning-to-waste work and are primarily a result of the steep slopes, difficult terrain and heavy undergrowth in the blocks being thinned (Figure 7).

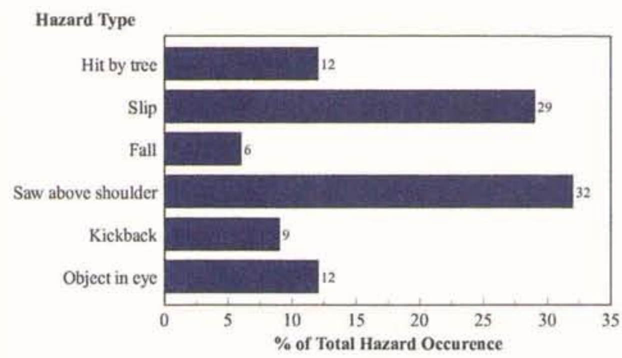

Figure 7 - Hazard type and occurrence

Table 3 - Hazard per 100 trees (morning verus afternoon)

Time of Day	Subject					
	1	2	3	4	5	6
Morning	0.7	0.4	1.0	1.4	1.3	6.0
Afternoon	1.1	0	1.8	2.6	1.1	3.6
Significant Difference	No	No	No	No	No	Yes

Hazard ratios for all workers were low, with a mean rating of 1.8 hazards per 100 trees for the morning, and 1.7 hazards per 100 trees in the afternoon (Table 3).

Considerations

Self-Pacing and Rest Breaks

Work undertaken by Vic (1984) investigated several different forest harvesting tasks, and clearly showed that the body maintains an internal equilibrium under differing stressors such as slope and difficult terrain, by decreasing work output. Smith et al; (1985) also found that subjects modified their work behavior when subjected to hotter environmental conditions in order to maintain their physiological stress at a tolerable level. Vogt et al; (1983) suggested that workers have an inherent natural ability to set a work pace in response to increased stress which results in average heart rates being maintained in a relatively narrow range. They term this phenomenon *constant strain behaviour* and suggested that the increase in environmental heat load is compensated by a decrease in muscular work.

A factor which played a large role in the worker's overall average working heart rate, and therefore on their self-pacing ability, was the effective use of rest pauses. Rest pauses have been shown to provide periods for workers to gain some respite from the physiological and psycho-physiological stressors affecting the worker (Brzezinska, 1968; Krueger, 1991; Rosa and Colligan, 1988).

Åstrand and Rodahl (1986) introduced the concept that the level of activity in many industrial tasks was self-regulatory, due to the rate of work and spacing of rest pauses being set by the individual's level of physical fitness. Fibiger and Henderson (1984) in their study of Australian hardwood tree fallers found very similar work-rest schedules being utilised as those found in the current study, with fallers frequently having what they termed "spontaneous rest pauses".

As stated by Alluisi and Morgan, (1982), short rest breaks in self-paced jobs do not reduce output even though less time is worked. The reasons for maintaining productivity with shorter work time can be attributed to the fact that rest breaks serve to provide a relief from boredom, physiological stress, muscle fatigue and cardiac strain (McCormick and Tiffin 1974).

Conclusions

The workers in the current study used both *spontaneous rest pauses* and *constant strain behaviour.* When combined with an effective 60 minute meal break at midday, this achieved an optimal work rate in terms of constant productivity, sustainable physical strain and low hazard ratios over the entire working day. Such work methods should be encouraged whenever possible.

References

Alluisi, E.A. and Morgan, B.B. 1982. Temporal factors in human performance and productivity, Chapter 6. In E.A. Alluisi and E.A. Fleishman (Eds.), Human performance and productivity, Volume 3: Stress and Performance Effectiveness. Hillsdale, NJ: Lawrence Erlbaum.

Apud, E., Bostrand, L., Mobbs, I.D. and Strehlke, B.(Eds.) 1989. Human Biological Methods for Ergonomics Research in Forestry. In Guide-lines on Ergonomic Study in Forestry. International Labour Organisation, Geneva.

Åstrand, P.O. and Rodahl, K.,1986. Textbook of work physiology. New York, McGraw Hill Book Company.

Brzezinska, Z. 1968. The problem of general fatigue in jobs where active work is associated with a need for vigilance. Prace Centralnego Instytut Ochrony Pracy, 18, (59), 341 - 351.

Evans, W.J., Winsmann, F.R., Pandolf, K.B., and Goldman, R.F., 1980. Self-paced hard work comparing men and women. Ergonomics, 23, 613 - 621.

Fibiger, W,. and Henderson, M, E,. 1984. Physical workload in thinning pine plantations. Australian Forest Research. 14 pp135-146.

Ford, D., Kirk, P. and Parker, R. 1996. An ergonomic comparison of manual and chainsaw ladder pruning. LIRO Report 21, (31).

Hartsough, B. and Parker, R.J. 1993. Pruning Douglas Fir. LIRO Technical Note TN- 10.

Hughes, A.L. and Goldman, R.F. 1970. Energy cost of hard work. Journal of Applied Physiology, 29, 570 - 572.

Kirk, P.M. 1993. Earmuff effectiveness against chainsaw noise over a 12 month period. Applied Ergonomics: Human Factors in Technology and Society. 24 (4). London. United Kingdom.

Kirk, P.M. 1996. Effect of outdoor weathering on the life of forestry safety helmets. LIRO Report 21, (15).

Kirk, P.M. and Parker, R.J. 1994a. Physical Demands of Steep Terrain Forestry Work in New Zealand. In proceedings of the International IUFRO/NEFU/FAO Seminar on Forest Operations Under Mountainous Conditions with special attention to Ergonomics, Accessibility and Environmental Protection. Harbin, P.R. of China.

Kirk, P.M. and Parker, R.J. 1994b. The Effect of Spiked Boots on Logger Safety, Productivity and Workload. Applied Ergonomics: Human Factors in Technology and Society, 24, (2). London. United Kingdom.

Kirk, P.M. and Parker, R.J. 1996. Heart rate strain in New Zealand manual tree pruners. International Journal of Industrial Ergonomics, 18, (4).

Kirk, P.M. and Sullman, M.J.M. 1995. An Ergonomic Investigation of Hauler Breaker-outs'. LIRO Project Report 55.

Kirk, P.M. and Sullman, M.J.M. 1996. Impacts of windthrow salvage on faller and breakerout safety in cable logging operations. LIRO Report 21, (30).

Kirk, P. M., Sullman, M.J.M. and Parker, R. J. 1996a. Fatigue levels in motor-manual tree felling and delimbing operations. LIRO Report, 21, (18).

Kirk, P.M., Gilbert, T. and Darry, K. 1996b. Increased safety and performance through Smart Foods. LIRO Report 21, (26).

Krueger, G.P. 1991. Sustained Military Performance in Continuous Operations: Combatant Fatigue, Rest and Sleep Needs. United States Army Aeromedical Research Laboratory Report No 91 - 19.

Levine, L., Evans, W., Winsmann, F.R. and Pandolf, K.B. 1982. Prolonged self-paced hard physical exercise comparing trained and untrained men. Ergonomics, 5, (5), 393 - 400.

McCormick, E.J. and Tiffin, J. 1974. Industrial Psychology. Englewood Cliffs, NJ: Prentice Hall.

NIOSH, 1981. Work practices guide for manual lifting, NIOSH Technical Report, U.S. Government Printing Office, Washington D.C.

Parker, R.J. 1995. Analysis of lost time accidents - 1994 Logging. LIRO Report 20,(11).

Parker, R.J. and Kirk P.M. 1993b. Physiological Workload of the New Zealand Forest Worker. New Zealand Institute of Forestry Conference Proceedings, Napier, May.

Parker, R.J. 1996. Analysis of lost time accidents - 1995 Logging. LIRO Report 21, (21).

Parker, R.J.and Kirk, P.M. 1993a. Felling and delimbing hazards. LIRO Report 18 ,(22).

Paterson, T and Kirk, P.M. 1997. Fluid and energy for forest workers. Liro Limited Report, 22, (8).

Rosa, R.R. and Colligan, M.J. 1988. Long work days versus rest days: Assessing fatigue and alertness with a portable performance battery. Human Factors, 30, (3), 305 - 317.

Smith, L.A., Wilson, G.D. and Sirois, D.L. 1985. Heart-rate response to forest harvesting work in the south-eastern United States during summer. Ergonomics, 28, (4), 655 - 664.

Soule, R.G. and Levy, C.K. 1972. Voluntary march rate over natural terrain. Federation proceedings, 31, 312.

Sullman, M.J.M. 1996. The effective life of chainsaw chaps. LIRO Report 21, (4).

Sullman, M.J.M. and Byers, J. 1996. Physical workload of planting. LIRO Report 21, (14).

Sullman, M., Darry, K., and Patterson, T. (1997). Truck driver fatigue - How to prevent it! LIRO Report, 22, (6).

Trewin, A.R.D. and Kirk, P.M. 1992. Planting Bare-Rooted Seedlings of Radiata Pine on Difficult Terrain. Proceedings of a seminar on harvesting and re-establishment of difficult terrain, June 1992.

Vik, T. 1984. Impact of terrain on human effort in forest operations. in Human resources in logging: The proceedings of a seminar held in Rotorua. June 1984.

Vogt, J.J., Libert, J.P., Candas, V., Daull, F. and Mairiaux, P.H. 1983. Heart rate and spontaneous work-rest cycles during exposure to heat. Ergonomics, 26, 1173 - 1185.