University of Alberta

An investigation of noise levels in Alberta sawmills

by

Niels Kevin Koehncke ©

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Abstract

The present study documents noise levels in the sawmill industry in the province of Alberta, Canada. Only 10% of the personal monitoring measurements were below the Alberta Occupational Health and Safety eight hour exposure limit of 85 dB(A). 27% of the personal monitoring measurements were 95 dB(A) or higher. Overall there were no significant differences in average personal monitoring noise exposure levels between mills. The planermill production group had the highest percentage of personal monitoring measurements that were 95 dB(A) or higher (61%), as well as the highest average personal noise exposure overall. The planermen and planer infeed operators were the job categories with the highest percentage of personal monitoring measurements 95 dB(A) or higher (62% and 82%, respectively). It was concluded that a risk of excess noise exposure exists even when wearing recommended hearing protection due to the very high noise levels found in this study. Those workers in the vicinity of the planer are at particularly high risk of excess noise exposure.

Acknowledgements

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Abbreviations and Definitions

8-hr TWA = 8 hour Time Weighted Average

AFPA = Alberta Forest Products Association

Blowdown = Use of high pressure air to blow dust from surfaces, generates considerable dust and noise

Cant = Outer pieces of a round log left behind after cutting it into a 4-sided piece of lumber

dBA = Decibel level weighted on the "A" scale. "A" scale weighting refers to the subtraction of sound levels from the very high and very low frequency ranges, thereby reflecting what the human ear can detect. An "A" weighted sound level reading de-emphasizes the very high and very low frequencies which the human ear can not detect.

HCP = Hearing Conservation Program

HPD = Hearing Protection Device

LEQ = Level Equivalent (in this study, refers to the 8-hr TWA)

NIOSH = National Institute for Occupational Safety and Health

OEL = Occupational Exposure Limit

OSHA = Occupational Safety and Health Administration

Introduction

In an occupational setting, failure or inability to understand the spoken word can compromise worker safety, especially the safety of those in hazardous occupations. Hearing loss may also impair and constrain activities of daily life and personal enjoyment. Noise exposure in industry has been a considerable concern with respect to functional impairment arising from noise induced hearing loss (NIHL) and other physiological and psychological effects on exposed workers (Bulteau, 1978; Kendrick, 1997; Lamb, 1981; Stekelenburg, 1982). These non- auditory effects can include increased stress responses, hypertension, tinnitus, and annoyance (Bulteau, 1978; Rom, 1998). Often, early NIHL is misinterpreted as lack of attention or unwillingness to communicate, and only when more severe is it recognized and often concealed by the worker (Hetu et. al., 1995). Interest in the impact of noise on both hearing acuity and on performance has raised awareness of this particularly ubiquitous exposure and has emphasized that this is an occupational risk that does not seem to be well controlled (Lamb 1981, Melamed et al 1994).

The present study documents the level of noise exposure in the sawmill industry in the province of Alberta, Canada. As it turns out, similar studies of this magnitude have not been done in the past in Alberta. In 1981, it was estimated that 1 in every six workers in British Columbia was exposed to an 8-hr TWA in excess of 90 dBA (Tupper, 1981). In the United States, it has been estimate that approximately 30 million workers are exposed on their jobs to hearing hazards, whether in the form of noise or toxic hazards (Franks et al, 1996). Surprisingly, the first set of regulations on the subject of noise exposure was not adopted at the federal level in the United States until 1969 by the US

Department of Labor. Since then many changes have occurred in U.S. regulations, which now fall under the mandate of the Occupational Safety and Health Administration (OSHA) (Patrick, 1981). In Canada, regulations governing occupational noise exposure fall under provincial jurisdiction. The results of the present study should provide a considerable foundation of preliminary sawmill noise exposure information in Alberta, a hazard which fortunately can be prevented or reduced through awareness and application of effective hearing loss prevention programs.

Pathophysiology of Noise Induced Hearing Loss

Hearing loss can generally be divided into two categories: conductive hearing loss and sensorineural hearing loss. Conductive hearing loss refers to any condition or illness that interferes with the transmission of sound through the outer or middle ear, while sensorineural hearing loss refers to damage to the inner ear, auditory nerve, or both (Sataloff and Sataloff, 1993). Within the inner ear is the cochlea, a structure that houses the organ of Corti which contains thousands of microscopic sensory hair-like cells. Sound transmitted to the inner ear produces vibrations and motion in the inner ear fluid that moves (stimulates) the sensory cells in the organ of Corti. These cells then send a signal to the brain via the auditory nerve, which is then interpreted as sound (Sataloff and Sataloff, 1993).

NIHL, a form of sensorineural hearing loss, occurs when the sensory cells in the organ of Corti are damaged or sustain trauma from severe acoustically generated forces in the inner ear. Risk of damage to these sensory cells (and hence risk of permanent hearing impairment) is related to both duration of exposure and intensity of the noise (LaDou, 1990). The hearing loss is usually bilateral, symmetrical and in the range of

3000 to 6000 Hz (Sallusito et al, 1998), although some exposures (such as shooting guns) can cause an asymmetrical hearing loss. In fact, recent studies have shown a progression of cochlear damage after exposure to very high levels of impact noise. At levels around 131 dB, the basilar membrane of the organ of Corti separates and the tissue was autolyzed over several days (Spongr et al, 1998). There was also evidence of immediate mechanical trauma to the cochlear anatomy at lower levels (125 dB), but less severe than those seen at 131 dB (Spongr et al, 1998). There was greater damage seen one day after exposure, which the authors speculated might be "a reflection of the cell death associated with the primary mechanical trauma." (Spongr et al, 1998).

The amount of air pressure change a noise source creates is called sound pressure which is interpreted as loudness (greater sound pressures result in louder sounds). Because the range of audible sound pressure levels can vary from 0.00002 Pascals to 200 Pascals (or more), sound pressure levels are converted to a logarithmic scale and referred to as decibels or dB, named after Alexander Graham Bell (Canadian Center for Occupational Health and Safety, 1988). The decibel scale makes the range of values for sound intensities much more practical, even for noise sources that differ in intensities 10 or 100 fold. The table below gives an example of common sounds and the average dB levels associated with them (from the Canadian Center for Occupational Health and Safety, 1988; LaDou, 1990).

Noise Level (dB)	**Example**
120	Jet taking off
100	Pneumatic hammer
90	Subway train
80	Vacuum cleaner
50-60	Conversation
30	Quiet room, library

Review of the Literature

Many industries have been studied with respect to noise exposure and occupational noise induced hearing loss. These include but are certainly not limited to the trucking industry (Seshagiri, 1998; van den Heever and Roets, 1996), railroad and shooting (Kryter, 1991), military (Ylikoski et al, 1994), farming (Holt, 1993), the airforce and private flying (Fitzpatrick, 1988; Ribak 1985; Tobias JV, 1969), construction (Lusk, 1998), oceangoing vessels (Bowes, 1990) and even the Apollo space program (French, 1967). There have been many noise exposure studies of sawmills, particularly in the 1970s and 1980s pertaining to the technology of the time (Chung, 1983; Dost, 1974a;b; Lamb, 1971; Lamb, 1981; NIOSH, 1991; Patrick, 1981; Pyykko, 1989; Ruedy et. al., 1976; Tupper, 1981). The environment inside most sawmills is particularly hazardous from a noise exposure standpoint, simply due to the nature of the work being done (cutting and sawing and the associated machinery) and the volume of lumber that passes through on a daily and weekly basis. A series of detailed studies from Japan showed that blade geometrical designs, tooth height, blade thickness and clearance angle all affected sound pressure levels (Tanaka et al, 1982 a;b; Ikegiwa, 1982). The whistling noise of an idling circular saw is itself a considerable noise source, sometimes over 90 dBA, even if effects of the factors mentioned above are minimized (Hattori and Noguchi, 1992). Furthermore, it has been estimated that the idling time of some sawblades is around 80% of the operating time (Hattori and Noguchi, 1992). These types of noise sources, together with running machinery engines and air cylinder exhausts create a substantial noise hazard in any sawmill or planermill (Dost and Gorvad, 1979).

Dost (1974a) published a study on noise levels in California softwood lumber mills. Octave band analysis was done on individuals at various positions throughout the mill. Exposure ranges were plotted for each job position, all mills combined, along with arithmetic averages. The chipper tender, tailsawyer and planer feeder tended to have the highest recordings (106 dB, 107 dB and 104 dB respectively). In a second paper by Dost (1974b), the highest recordings in planermills belonged to the feeders at unenclosed planers (104.2 dB) while the highest in the sawmills was the tailsawyer at 104.5 dB. Dost described quite correctly that saws and cutterheads are not necessarily the only important noise sources in a sawmill. Differences between idling and processing noise levels (i.e., the differences in noise levels between a machine that is idling and a machine that is actively cutting or processing lumber) are important in determining what corrective engineering or other controls might need to take place (Dost, 1974b). In a review of noise in the woodworking industry, Smith (1971) also alluded to the fact that no-load cutterhead noise can be quite significant, especially in the cases of planers or moulders. Lamb (1971) in a review of industrial noise exposure, described planers as the loudest overall out of a variety of woodworking machines (108 dB). A detailed noise survey by Ruedy et al (1976) identified the planer, multiple cutoff saw, edger and bandsaw as being high on a list of priorities for noise-abatement procedures. Octave band analysis showed frequency spectrums of the most critical machines similar to the prior study by Dost (1974a). The results of their analysis included critical areas singled out as needing noise control methods or procedures (such as maintenance, area enclosures and / or machine enclosures), one of these areas being the planer area (Ruedy 1976). Dost and Gorvad (1979) looked at noise control of compressed air cylinders used to transfer and position logs throughout mills. They found that simple plenum chambers lined with fiberglass or foam increased noise reduction efficiency substantially over standard (un-muffled) air cylinder exhausts.

Lamb (1981) looked at effects of noise in inducing annoyance and degrading performance and applied previously published guidelines to noise levels measured in a southern pine sawmill. Noise levels measured in the sawmill exceeded the suggested guidelines for annoyance potential, speech interference and effect on job performance (the latter being the most important according to Lamb). Fairfax (1989) described a successful noise reduction program in two mills using abatement methods such as barriers, machinery isolation, enclosures, acoustically treated infeed and outfeed tunnels, and employee rotation. Noise levels were reduced from the high 90s and low 100s (dB) to the low 90s and upper 80s (Fairfax, 1989).

Noise exposures in other facets of the forestry industry have also been investigated. Myles et al (1971) studied noise levels of logging machinery in eastern Canada. They found that chain saws produced average noise levels of 106 dBA at the operator's ear, and skidders an average of 104 dBA at the operator's ear. They concluded that "due to their estimated duty cycle of 0.6, the operator works in an excessive noise environment and risks suffering damage to hearing over an extended period of time" (Myles et al, 1971). A similar study by Reif and Howell (1973), although limited, concluded that the duty cycle "is the primary vehicle which should be considered in attempting to control the noise exposure of operators of logging equipment." In a study of noise exposure to logging equipment in British Columbia, Howell (1974) concluded that "while 45% of the operators were working in noise conditions within the limits of

OSHA criteria, 55% were working in conditions where precautions should be taken to avoid hearing loss." Finally, a study of noise exposure from power saws by Voronitsin et al (1962) demonstrated maximum noise levels for power saws of 80-96 dB while idling and 100-114 dB while under load. Their conclusions were that "almost all the power saws in use are sources of vibration and noise which in most cases exceed the permissible limits and are therefore prejudicial to the workers' health." Noise is clearly a considerable concern in the forest industry as a whole, and not a problem limited to sawmills or planermills.

Frank (1996) described eight identifiable elements of an effective hearing conservation program (HCP). These included monitoring, controls (engineering and administrative), audiometric evaluation, personal hearing protection, education and motivation, record keeping, program evaluation, and an audit process (Frank, 1996). The effectiveness of one type of engineering control, enclosing the operator in a cab, will be discussed in relation to data collected in the present study. Two mills will also be examined more closely in terms of hearing protection device (HPD) usage. As will be discussed later, there is considerable evidence in the literature that noise reduction ratings as listed on the HPDs can be considerably *less* effective than assumed, even with "proper use" (Frank 1996, Giardino and Durkt, 1996).

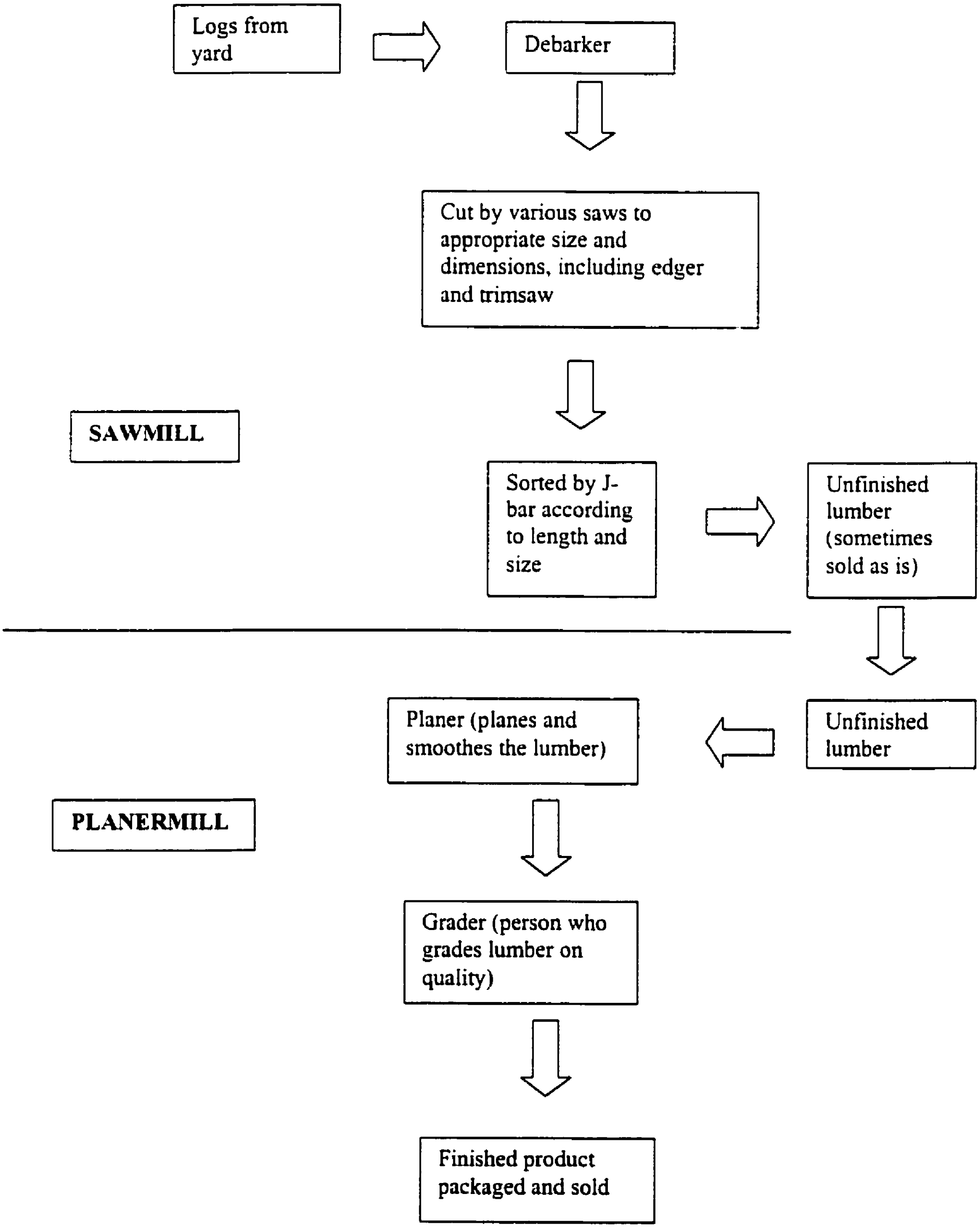
The Alberta Sawmill Noise Study

Figure 1 illustrates in general terms the processes that occur in a typical mill (modified from Yamanaka, 1999). Usually the sawmill and planermill are separate buildings on the same site. However, on occasion they may be combined into one large building. Logs from the yard first travel through the debarker, which removes the bark, dirt and rocks from the log. From the debarker the log is conveyed into the mill to the headsaw, which starts the process of cutting the log into boards. The edger then further breaks the logs down into smaller boards and pieces. The trimsaws cut the lumber to the proper lengths, and the j-bar sorts the different sized pieces into various piles. The unfinished lumber is either shipped as is or planed down to a fine surface in the planermill, which is often the noisiest function in the mill (Patrick, 1981). The planer basically takes the unfinished product from the sawmill and planes or smoothes it down to a fine finished product. The grader simply inspects (usually visually) the planed pieces of lumber as they pass by and sorts them by quality.

Given the substantial noise hazard that exists in sawmills, and the fact that no comprehensive information existed on comparative noise levels in various Alberta sawmills, the Alberta Forest Products Association (AFPA) began a noise and wood dust exposure study of nine Alberta sawmills in the winter of 1997. Information on wood dust exposure levels is reported elsewhere (Yamanaka, 1999).

The purpose of the noise study was to establish noise exposure levels within these sawmills and compare them to the noise exposure limits set by the Alberta Occupational Health and Safety Act. This study was strictly intended to be an exposure assessment study. All of the mills involved in the study have hearing conservation programs with requirements for all workers to wear class A hearing protection while working in the mill. (See Appendix 3 for definition of Class A hearing protection). The present analysis provides a detailed look at the exposure data from the noise surveys from all nine sawmills and provides a discussion of HPD usage in two of the sawmills reported in the study.

Figure 1. Sawmill and Planermill Processes.



Methods

Background information

In the winter of 1997 the AFPA initiated a series of exposure assessments at nine Alberta sawmills. The objective of the survey was to learn where the participating members of the AFPA stood with respect to both noise and dust exposure, compared to each other and to the Alberta Occupational Health and Safety Guidelines. Occutech Services (HSE) Inc. (OSI) was contracted to provide occupational hygiene services, to assist in the development of a sample protocol and to collect samples for the survey. The project director was Mr. Lloyd Harman, Director, Safety and Loss Management, AFPA. Dr. Tee L. Guidotti, medical consultant to the AFPA and Mr. Lloyd Harman wrote the proposal which outlined the study plan. Dr. Guidotti and Mr. Ken Wong, senior occupational hygiene consultant to the AFPA, designed the study in greater detail including selection of exposure measurements and when the survey was conducted. The project was funded in part by the AFPA, Alberta Department of Economic Development and Tourism, Industry, Technology and Forestry Development, Forest Industry Development, the Network of Centers of Excellence in Sustainable Forest Management, and each of the participating sawmills.

Unless otherwise specified in this report, dB refers to dB(A).

Survey Techniques

Noise Sampling

A total of nine sawmills in Alberta (all members of the AFPA) agreed to participate. Noise samples were collected on two separate occasions, first in the winter of

1997 and then in the following summer (1997). For each season, information was collected on various factors, including location of workers, activity descriptions, nearby noise sources, whether or not blowdown was occurring nearby, and any additional notes deemed important by OSI at the time. Blowdown refers to the removal of sawdust from machinery and the mill floor with high pressure air hoses. These data were recorded for each worker at four separate times during the day (while wearing the dosimeter, referred to as "spot checks") and the time of observation was noted in each instance. Study subjects were those working in the mill on the day that OSI was performing the sampling and who agreed to wear the personal noise dosimeters. Results of the personal noise dosimetry are referred to an A-weighted Level Equivalent (LEQ), which in this study is identical to the 8-hour Time Weighted Average (or 8-hr TWA). Area monitoring was also done both in winter and in summer.

Personal Monitoring: Winter Survey

Individual noise dosimetry data were collected using Quest M-7 noise dosimeters. This dosimeter produces a continuous reading of the percentage allowable noise dose to which the worker wearing the device has been exposed, and has a maximum exposure percentage of 999.99%. Whenever possible the dosimeters were checked, recorded and re-set in mid-sample to prevent loss of data. A 3 dB exchange rate was used to calculate personal exposures, and this was based on a maximum exposure of 85 dB over 8 hours with a threshold of 80 dB. Dosimeter calibration was done with a Quest CA-12 calibrator before and after each sample. During the winter survey it was discovered that the dosimeters would not record higher than 95 dB because of the 999.99% exposure limit mentioned above. Any noise levels at 95 dB or higher were recorded as 95 dB. Because of this, when comparisons were made between seasons the categorical data (explained below) was used, and only summer values were used to calculate overall average exposures etc.

Personal Monitoring: Summer Survey

Individual noise dosimetry data were collected using a CEL-281 computing noise dosimeter. This dosimeter stores and integrates noise measurements over time and can provide a graph of exposure and mean noise exposure. Microphones were placed on workers shoulders approximately 10 cm away from the ear. As in the winter survey, personal exposures were calculated using a 3 dB exchange rate, based on a maximum exposure of 85 dB over 8 hours and a threshold of 80 dB. The CEL calibrator was used to calibrate the dosimeters before and after each sampling period.

Area Monitoring

At various designated points throughout each mill, sound levels were measured in the form of spot checks using a Bruel & Kjaer (B&K) Pulse Precision Type 1 sound level meter (SLM), model 2204. Calibration was carried out before and after each use with a Quest sound calibrator, model CA-12B. Data were recorded with the SLM set at the "A" and "slow" settings. At each location one set of readings was taken in each of four directions for both typical and peak sound levels and the results were averaged. Floor plans were either sketched or provided by the sawmills, and the location of each SLM in the sawmill was noted on the floor plan. Area monitoring for each mill was done once in the summer and once in the winter. Results were averaged arithmetically and presented as overall area monitoring results for each mill and season. For certain areas, closer examination of results was undertaken (debarker cabs and planer).

Data Categorization

Each worker was categorized by job title and occupational group. Job titles were selected based on the type of work being performed and were chosen to be representative of an employee performing that job in any of the nine mills. Each employee has a specific function or task in a sawmill and hence a specific job title that describes that task. These titles were chosen to be the same for all nine mills. There were thirteen different job titles or categories (Table 1).

Table 1. Job and Occupational Group Categorizations

Occupational Group	Job Category	Job #
Maintenance	Millwright	1
	Sawfiler	2
	Planerman	3
Cleanup	Cleanup (planer)	4
	Basement cleanup	5
Sawmill production	Edger operator	6
	Trimsaw operator	7
	Log chaser	8
	Debarker operator	9
	Stacker operator	10
Planermill production	Grader (planer)	11
	Planer infeed operator (PIO)	12
	Tilt hoist operator	13

The following is a brief description of each of the job categories or titles (modified from Yamanaka, work in progress).

Millwright:	Repairs machinery / corrects any mechanical problems in the sawmill
Sawfiler:	Maintains saw blades
Planerman:	Similar to a millwright, but limited to the planermill
Cleanup (planer):	Cleans the planermill
Basement attendant:	Cleans the sawmill
Edger operator:	Operates edger saw
Trimsaw operator:	Operates trimsaw, which removes ends off of the lumber
Log chaser:	Observes flow of logs into sawmill from yard, watches for logjams along conveyor.
Debarker operator:	Controls and monitors logs as they enter debarker machine
Stacker operator:	Operates stacker, which stacks and bundles pieces of lumber from the sawmill
Grader (planer):	Responsible for inspecting (grading) the finished lumber
PIO:	Controls infeed of lumber into planer
Tilt hoist operator:	Operates tilt hoist used for stacking planed wood.

Each job title was categorized into one of four occupational groups (Table 1). Dividing workers into occupational groups for comparison was necessary because, on occasion, workers within occupational groups rotate jobs (for example, a worker in sawmill production might spend a few hours as an edger operator, then as a trimsaw operator, followed by a few hours as a debarker operator). No worker ever "crossed" occupational groups during a job rotation (for instance, a worker in sawmill production never rotated at a job in cleanup or maintenance on a given day).

Personal monitoring noise data for each mill were compared with the other eight mills and with the exposure limit as defined by Alberta Occupational Health and Safety Guidelines (Alberta Occupational Health and Safety Act, 1981).

Statistical Analysis

Statistical analysis of the data was completed using the statistical software package SPSS (SPSS 8.0 for Windows™ analytical software, Chicago Illinois). Normal Q-Q plots of the summer data as well as data for each mill revealed a normal overall distribution of the noise data. Because of this, differences in means were compared using ANOVA and post-hoc multiple comparisons tests (when performed) were done using the Bonferroni method. A value of $p < 0.05$ was considered to indicate statistical significance. When personal monitoring data were classified by noise intensity categories, chi-squared tests were used to determine statistical significance. Noise intensity categories were either "< 85 dB", "85-95 dB" and "≥ 95 dB" or simply "< 95 dB" and " ≥ 95 dB." These two methods of categorizing the noise levels were used for several reasons. Because relatively few measurements were below 85 dB, the chi-square test for some of the analyses would not have been valid if all three categories had been maintained. Dichotomizing the data at 95 dB was reasonable given the fairly extensive use of personal hearing protection in the workforce and concerns that these devices may not provide protection above 95 dB (see Discussion). Where possible, all three categories were used in the analysis.

Means were calculated as both arithmetic means and "logarithmic means" (or "energy averages"). The logarithmic mean represents the actual value that would be seen if the same dosimeter were to be worn by all individuals and an "overall" exposure dose were calculated (as one 8-hr TWA equivalent). For statistical purposes, arithmetic means were used when testing hypotheses. In most cases (as can be seen in the data tables) there was little difference between the arithmetic mean and the logarithmic mean (or "energy mean"). The formula for calculating the logarithmic mean is as follows (Workers Compensation Board of BC, 1995):

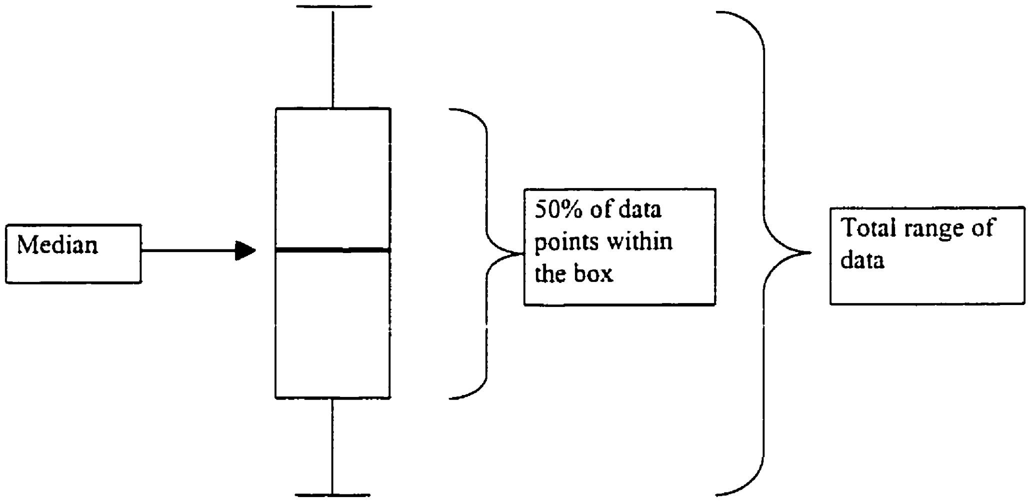
$$L_{eq} = 10\log_{10} \frac{\{10^{L1/10} + 10^{L2/10} + \ldots\ldots 10^{Ln/10}\}}{n}$$

where L1, L2, ... Ln represent measured 8-hr TWAs from each worker.

Box Plots

Box plots were often used to describe the data. This is primarily because they are an effective way to illustrate both central tendency and data outliers. Outliers were often of interest in this survey. Two categories of outlying values are identified in the box plots. Values more than 3 box-lengths from the upper or lower edge of the box are called extreme values and labeled with an asterisk (*). Values between 1.5 and 3 box lengths from the upper or lower edge of the box are called outliers and are labeled with a circle. Figure 2 below is a representation of a typical box plot.

Figure 2. The Box Plot



o → outlier
* → extreme value

Results

Personal Monitoring Data

In each mill, approximately 12 personal samples were obtained during the winter and summer testing sessions (Table 2). Tables 3 and 4 show the number of samples taken for each mill by job category and occupational group. Although 214 workers had personal monitoring measurements, one worker had invalid results due to mechanical difficulties with the recording equipment. Those results were omitted from the calculations. Therefore, the total number of workers on which calculations were based was 213. Table 5 shows the results of the personal monitoring data for all nine mills in winter and summer. All values are 8 hour TWAs. Not every mill had workers in all 13 job categories (Table 5). Also, some mills had two workers with the same job category (for instance, mill # 4 had two trimsaw operators in the winter, job #7). The asterisk in Table 5 indicates one worker whose recording equipment failed.

Table 2. Number of study participants for each mill and season.

MILL	Winter	Summer	Total
1	12	12	24
2	12	12	24
3	12	12	24
4	12	11	23
5	12	11	23
6	12	12	24
7	12	12	24
8	*11	12	23
9	12	12	24
TOTAL	107	106	213

*One worker had invalid recordings, and results were omitted from calculations

Table 3. Number of study participants for each Occupational Group and Season

Occupational Group	Season		Total
	Winter	Summer	
Cleanup	14	14	28
Maintenance	24	24	48
Planermill Production	21	20	41
Sawmill Production	48	48	96
Total	107	106	213

Table 4. Number of study participants for each job and season

Job	Winter	Summer	Total
Millwright	9	8	17
Sawfiler	7	8	15
Planerman (Planer)	8	8	16
Cleanup (Planer)	6	7	13
Basement attendant	8	7	15
Edger operator	9	12	21
Trimsaw operator	12	9	21
Log chaser	9	9	18
Debarker operator	9	9	18
Stacker operator	9	9	18
Grader (Planer)	9	9	18
Infeed operator	9	8	17
Tilt Hoist Operator	3	3	6
Total	107	106	213

Table 5. Personal monitoring data for all nine mills, winter and summer. All values are in decibels and are 8 hour time-weighted averages (TWAs). * denotes failed recording

Season	Job	Occ Grp	Mill 1	Mill 2	Mill 3	Mill 4	Mill 5	Mill 6	Mill 7	Mill 8	Mill 9
Winter	1	Maintenance	87.6	90.3	92.9	94.4	87.1	84.6	92.5	89.1	90.8
	2		89.4	83.4	84.5	86.4		81.4	84.0	*	86.1
	3		95.0	95.0	95.0		90.4	88.4	95.0	92.5	95.0
	4	Cleanup	93.0	94.7	88.3	95.0		85.8	90.5		
	5		91.6	95.0	95.0	91.8	91.7	92.7		92.7	92.6
	6	Sawmill Production	94.1	92.6	95.0	95.0	93.2	94.7	93.3	95.0	92.1
	7		95.0	88.2	94.6	77.4 94.2	92.1 96.1	93.7	91.3 85.2	95.0	94.1
	8		92.9	89.2	87.8	92.1	94.4	84.6	92.0	93.2	92.2
	9		79.7	80.6	80.9	94.3	80.1	86.7	89.6	89.9	81.4
	10		85.5	85.5	95.0	93.5	92.2	90.0	89.3	89.7	88.5
	11	Planermill Production	95.0	95.0	95.0	95.0	94.2	87.1	87.9	94.5	92.6
	12		95.0	95.0	94.7	95.0	91.9	95.0	95.0	95.0	95.0
	13						95.0			94.2	92.2
Summer	1	Maintenance	92.1	89.9	92.2		86.6	88.8	90.4	86.7	90.0
	2		97.1	83.1	87.6	87.9		82.7	81.8	91.6	97.1
	3		92.3	105.0	97.9		92.7	87.4	99.1	97.2	100.2
	4	Cleanup	93.8	95.9	90.5	93.5		87.0	93.8		95.7
	5		92.6	98.1	92.8	96.5		95.2		92.3	94.0
	6	Sawmill Production	94.7	91.9	98.8	91.0 96.3	90.5 95.6	94.7	78.9 92.3	98.9	93.1
	7		91.5	89.1	93.6	94.4	93.5	91.2	90.6	96.6	96.7
	8		93.0	89.9	92.5	91.3	89.8	89.4	89.7	93.3	94.6
	9		73.4	62.8	87.9	87.0	72.9	70.4	89.0	88.0	73.6
	10		84.8	87.6	95.1	92.2	91.8	88.8	90.0	91.6	86.5
	11	Planermill Production	92.7	97.4	94.0	95.0	93.9	92.3	90.7	98.6	98.3
	12		97.4	100.0	96.5		96.9	90.5	100.0	100.7	98.9
	13					96.0	90.3			96.8	

Noise Intensity Categories

Figures 3 and 4 represent the distribution of the personal monitoring data for winter and summer combined (figure 3) and for each season (figure 4). Table 6 shows the data (counts) for these figures. Approximately 10 percent of noise reading were below 85 dB (figure 3). The distributions did not vary significantly by season (figure 4 and table 6) ($p = 0.61$).

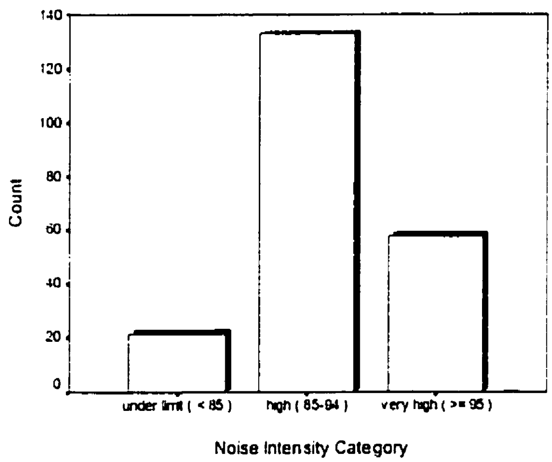


Figure 3. Total counts by noise category (three categories)

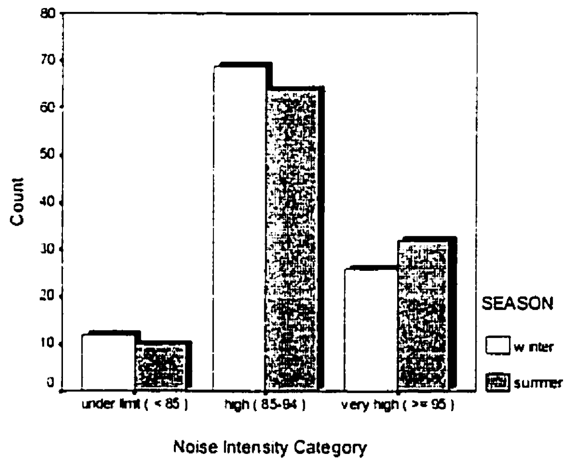


Figure 4. Total counts by noise category and season (three categories)

Table 6: Total counts by noise category (three categories)

		Winter	Summer	Total
Under limit	**Count** %	**12** (11)	**10** (9)	**22** (10)
High	**Count** %	**69** (65)	**64** (60)	**133** (63)
Very high	**Count** %	**26** (24)	**32** (31)	**58** (27)
Total	**Count** %	**107** (100)	**106** (100)	**213** (100)

Table 7 divides the overall data into two categories, less than 95 dB and equal to or greater than 95 dB. Figures 5 and 6 show the distribution of the personal monitoring data by these two categories for winter and summer. There was no statistically significant difference between seasons for noise category in table 7 (Chi-square (1df) = .93, p = 0.33).

Table 7: Total counts by noise category (two categories).

		Winter	Summer	Total
Less than 95	**Count**	**81**	**74**	**155**
	%	(76)	(70)	(73)
95 or greater	**Count**	**26**	**32**	**58**
	%	(24)	(30)	(27)
Total	**Count**	**107**	**106**	**213**
	%	(100)	(100)	(100)

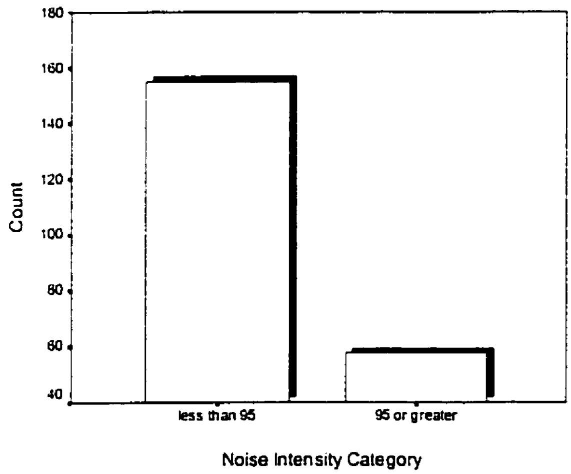


Figure 5. Total counts by noise category (two categories)

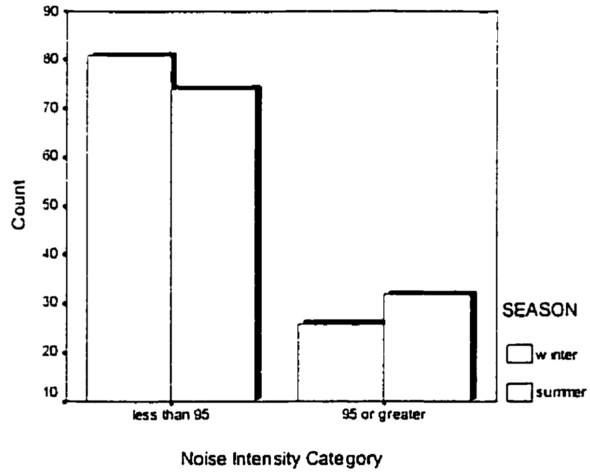


Figure 6. Total counts by noise category and season (two categories)

Table 8 , Table 9 and and figure 7 illustrate the distribution of noise category data by occupational group. Data from Table 9 were used for assessing statistical significance. Results of the Chi-squared tests for Table 9 suggested a statistically significant difference between noise categories for the occupational groups (Chi-square (3df) = 32.8, $p < 0.01$). There were no statistically significant differences between seasons for any of the occupational groups in figure 7. The between-season analysis is of questionable validity for the cleanup group since it had 2 cells (50%) with an expected count less than 5 (cleanup group, chi-square (1df) = .70, p = 0.40, maintenance group chi-square (2df) = .833, p = .66, planermill production group chi-square (1df) = .27, p = .61, sawmill production group chi-square (2df) = 0.091, p = .96).

Table 8: Total counts by occupational group (three noise categories).

		Cleanup	Maint.	Planermill prod.	Sawmill prod.	Total
Under limit	**Count** %	*	8 (17)	*	14 (15)	22 (10)
High	**Count** %	20 (71)	28 (58)	16 (39)	69 (72)	133 (62)
Very high	**Count** %	8 (29)	12 (25)	25 (61)	13 (13)	58 (28)
Total	**Count** %	28 (100)	48 (100)	41 (100)	96 (100)	213 (100)

* No workers under limit in these occupational groups. Top number = count, bottom number (parentheses) = percent of total

Table 9: Total counts by occupational group (two noise categories)

		Cleanup	Maint.	Planermill prod.	Sawmill prod.	Total
Less than 95	**Count** %	20 (71)	36 (75)	16 (39)	83 (87)	155 (73)
95 or greater	**Count** %	8 (29)	12 (25)	25 (61)	13 (13)	58 (27)
Total	**Count** %	28 (100)	48 (100)	41 (100)	96 (100)	213 (100)

Figure 7. Total counts by occupational group (two categories)

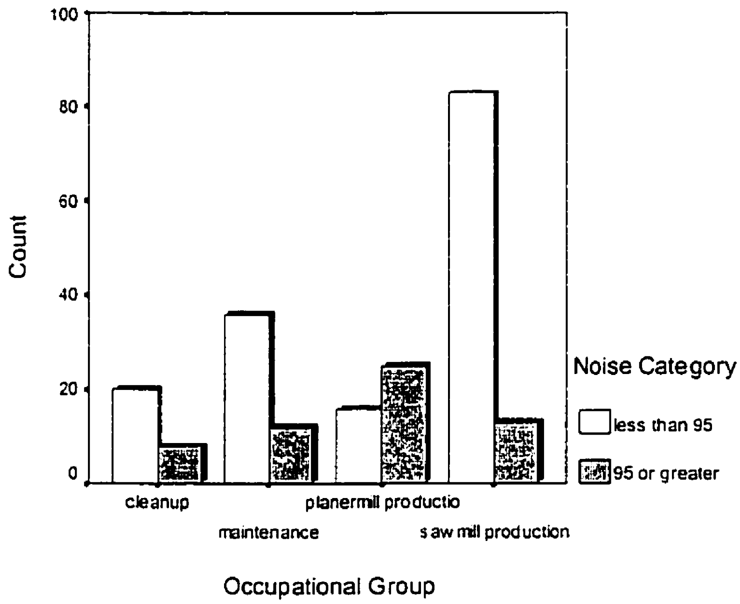


Table 10 and figure 8 illustrate the distribution of noise category data by job (using only 2 categories, < 95 and ≥ 95). Chi-squared analysis was of questionable validity due to the fact that 12 cells (46.2%) had an expected count less than 5. Results of the Chi-squared tests suggested a statistically significant difference in noise category by job (Chi-square (12df) = 65.53, $p < 0.05$).*

• Note: When this analysis was repeated separately for summer and winter the results were similar although cell sizes were smaller and the number of expected counts less than 5 was high (15 cells or 58% in the winter and 16 cells or 62% in the summer had expected counts less than 5). For winter the difference in noise exposure between noise categories (by job) was significant (p=0.037) while for the summer data the difference was not (p=0.121).

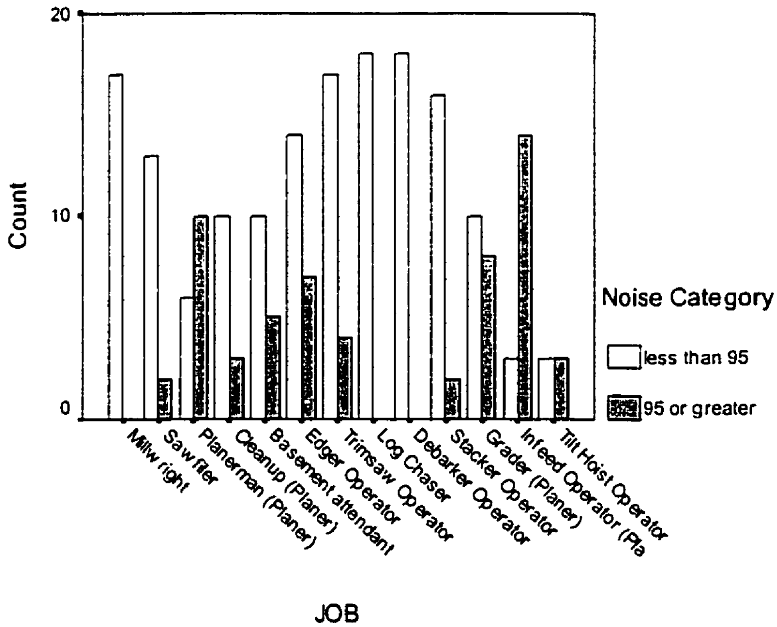
Table 10: total counts by job, two noise categories.

Top number = count
Bottom number = %

* no counts in these categories

Job	Less than 95	95 or greater	Total
1	17 (100)	*	17 (100)
2	13 (87)	2 (13)	15 (100)
3	6 (38)	10 (62)	16 (100)
4	10 (77)	3 (23)	13 (100)
5	10 (67)	5 (33)	15 (100)
6	14 (67)	7 (33)	21 (100)
7	17 (81)	4 (19)	21 (100)
8	18 (100)	*	18 (100)
9	18 (100)	*	18 (100)
10	16 (89)	2 (11)	18 (100)
11	10 (56)	8 (44)	18 (100)
12	3 (18)	14 (82)	17 (100)
13	3 (50)	3 (50)	6 (100)
Total	155 (73)	58 (27)	213 (100)

Figure 8. Total counts by job (two categories)



Noise Intensity Categories by Mill

Figures 9-11 and corresponding tables 11-13 show the frequencies (counts) of personal monitoring TWAs that fell into one of the three categories: "under limit" (< 85 dB), "high" (85 to 94 dB) and "very high" (≥ 95 dB). Figure 10 and Table 11 show the frequency distribution of noise intensity categories by mill for summer and winter combined. The average number of LEQs measured in either the "high" or "very high" categories was 90% across all mills, with a low of 79% (19 out of 24) in mill # 6 and a high of 100% (23 out of 23) in mill # 8. In other words, an average of 90% of all LEQs recorded were over the OEL of 85 dB. All nine mills had the majority of counts in the "high" category (85-94 dB). An average of 27% of all LEQs in each mill were in the "very high" category, ranging from 39% (9 out of 23) in mill #8 to 8% (2 out of 24) in mill # 6. Figures 10 and 11 and the corresponding tables 12 and 13 show the frequency distributions for each noise intensity category in winter and summer separately.

Table 14 provides an overall summary for job categories and occupational groups with respect to noise intensity categories. From Table 14, 61% (25 out of 41) of all LEQs in the planermill production group were in the "very high" category (shaded grey), and the remaining 39% were in the "high" category (none in the "below limit" category). For the other three occupational groups (cleanup, maintenance and sawmill production), the majority of LEQs were in the "high" range of noise intensity. For individual job categories in Table 14, two jobs in particular stood out as having a substantial number of counts in the "very high" category. 62.5% of planermen LEQs were in the "very high" category (shaded grey), and 82.4% of planer infeed operators were in the "very high" category (shaded grey). Appendix 2 lists data in the same format as Table 14 for each of the nine mills separately.

Although there was a slight increase in the average percentage of "very high" values from winter to summer (24% to 30%, see tables 12 and 13), trends between seasons varied between the mills. Table 15 illustrates the changes (in percent) for each mill from winter to summer.

Figure 9. Total counts by mill, seasons combined.

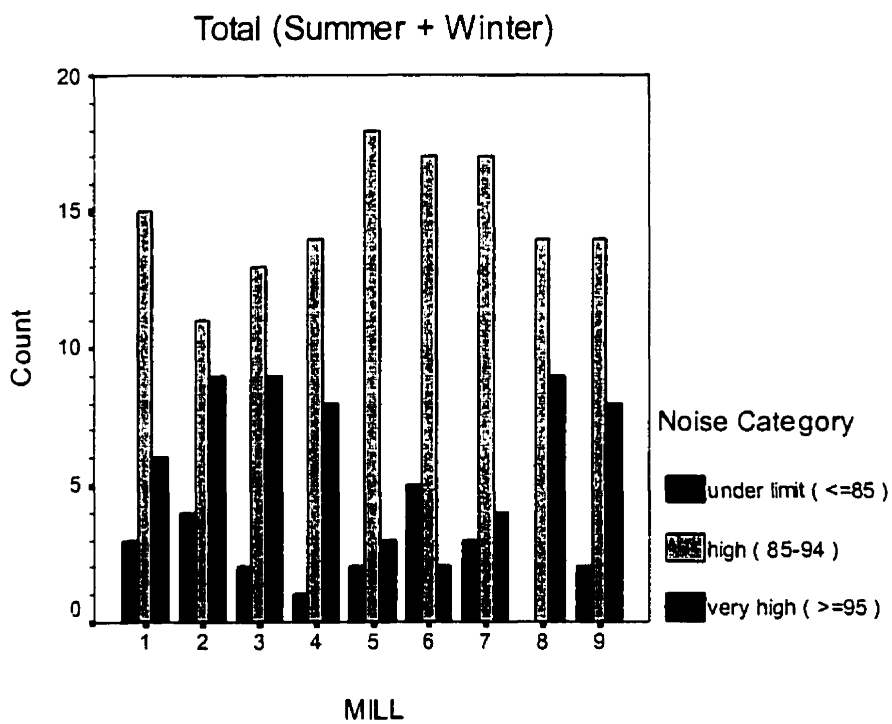


Table 11. Frequency distribution of noise intensity categories, summer + winter

Mill		1	2	3	4	5	6	7	8	9	Average
Counts	very high	6	9	9	8	3	2	4	9	8	
	high	15	11	13	14	18	17	17	14	14	
	under limit	3	4	2	1	2	5	3	0	2	
% very high		25	38	38	35	13	8	17	39	33	27
% very high + high		88	83	92	96	91	79	88	100	92	90

Figure 10. Total counts by mill, winter

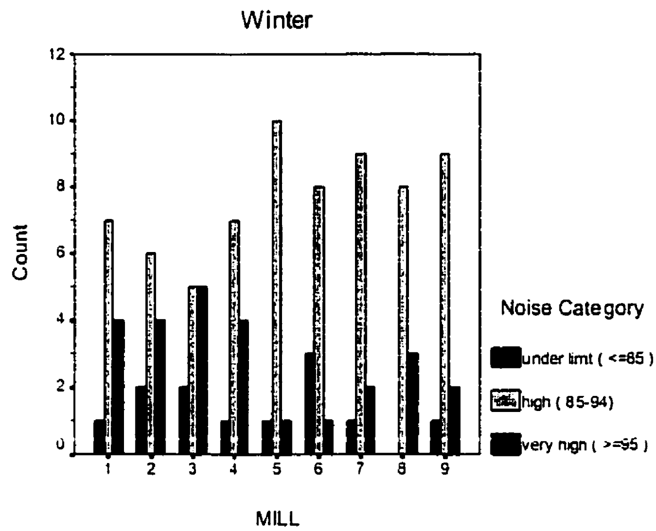


Table 12. Frequency distribution of noise intensity categories, winter

Mill		1	2	3	4	5	6	7	8	9	Average
Counts	**very high**	4	4	5	4	1	1	2	3	2	
	high	7	6	5	7	10	8	9	8	9	
	under limit	1	2	2	1	1	3	1	0	1	
% very high		33	33	42	33	8	8	17	27	17	24
% very high + high		92	83	83	92	92	75	92	100	92	89

Figure 11. Total counts by mill, summer.

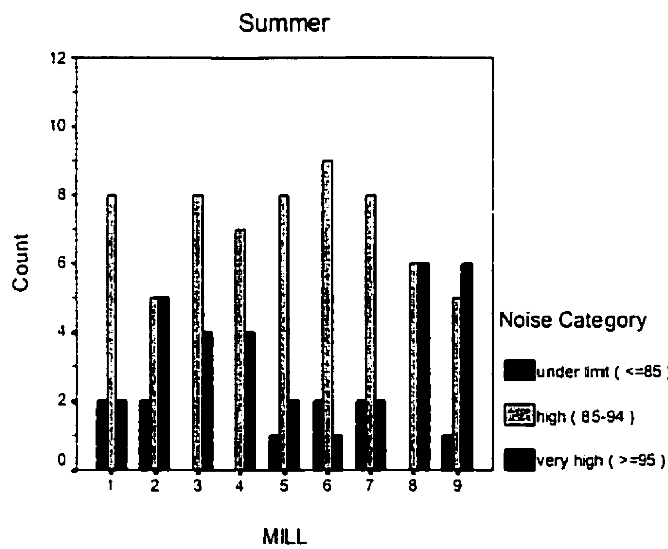


Table 13. Frequency distribution of noise intensity categories, summer

Mill		1	2	3	4	5	6	7	8	9	Average
Counts	**very high**	2	5	4	4	2	1	2	6	6	
	high	8	5	8	7	8	9	8	6	5	
	under limit	2	2	0	0	1	2	2	0	1	
% very high		17	42	33	36	18	8	17	50	50	30
%very high + high		83	83	100	100	91	83	83	100	92	91

Table 14. Frequency (counts) of personal monitoring data (LEQs) by noise intensity category

	Counts (percent)		
Job	**under limit (<85)**	**high (85-94)**	**very high (>95)**
Millwright	1 (5.9)	16 (94.1)	
Sawfiler	7 (46.7)	6 (40.0)	2 (13.3)
Planerman (Planer)		6 (37.5)	***10 (62.5)***
Cleanup (Planer)		10 (76.9)	3 (23.1)
Basement Attendant		10 (66.7)	5 (33.3)
Edger Operator	1 (4.8)	13 (61.9)	7 (33.3)
Trimsaw Operator	1 (4.8)	16 (76.2)	4 (19.9)
Log Chaser	1 (5.6)	17 (94.4)	
Debarker Operator	10 (55.6)	8 (44.4)	
Stacker Operator	1 (5.6)	15 (83.3)	2 (11.1)
Grader (Planer)		10 (55.6)	8 (44.4)
Infeed Operator (Planer)		3 (17.6)	***14 (82.4)***
Tilt Hoist Operator (Planer)		3 (50.0)	3 (50.0)
Occupational Group	**Counts (percent)**		
Cleanup		20 (71.4)	8 (28.6)
Maintenance	8 (16.7)	28 (58.3)	12 (25.0)
Planermill Production		***16 (39.0)***	***25 (61.0)***
Sawmill Production	14 (14.6)	69 (71.9)	13 (13.5)

Table 15. Percent change in readings classified in the "very high" noise category from winter to summer.*

Mill	1	2	3	4	5	6	7	8	9
% change	-16%	+9%	-9%	+3%	+10%	Same	Same	+23%	+33%

*A negative number means that there were fewer very high readings in the summer. A positive number means that there were more very high readings in the summer.

Summer Data

Mill Data

Overall summer results of the personal monitoring data are presented in Table 16 for each mill. Mill # 8 had the highest arithmetic average of all nine mills (94.4 dB), while mill # 6 had the lowest (88.2 dB). Mill # 2 had the widest range of values (42.3 dB), due to one very high and one very low recording (105.0 dB and 62.8 dB). These values for Mill # 2 represented highest maximum and lowest minimum of any of the nine mills.

Table 16. Personal monitoring results summarized by mill (summer only)

Mill	Log Avg[1]	Arith Avg[2]	Median	Max.	Min.	Range
1	93.5	91.3	92.7	97.4	73.4	24.0
2	97.2	90.9	90.9	105.0	62.8	42.3
3	94.5	93.3	93.2	98.8	87.6	11.2
4	93.8	92.8	93.5	96.5	87.0	9.5
5	92.6	90.4	91.8	96.9	72.9	24.0
6	90.7	88.2	89.1	95.2	70.4	24.8
7	93.8	90.5	90.5	100.0	78.8	21.3
8	96.1	94.4	95.0	100.7	86.7	14.0
9	96.0	93.2	95.1	100.2	73.6	26.6

[1] Logarithmic average
[2] Arithmetic average

Mill # 8 had the lowest range of values (14.0 dB). Mill # 9 had the highest median value (95.1 dB) while mill # 6 had the lowest (89.1 dB). Figures 12 and 13 represent the overall data from Table 16 in graphical format. Including the low outlier, it is fairly clear from figure 13 that mill #2 had the widest range of values. Analysis of variance showed no significant difference in average noise exposure between the mills (df=8, p = 0.41). Figure 13 also shows that the majority of the LEQs in the summer were above the 85 dB OEL (96/106, or 91%). Only 10 values (9%) were below the 85 dB OEL. Combining summer and winter data, 191/213 or 89.7% of all values were above the 85 dB OEL. Only 22 of the LEQs (10.3%) were below the 85 dB OEL for summer and winter combined.

Figure 12.
Personal noise dosimetry, summer means by mill

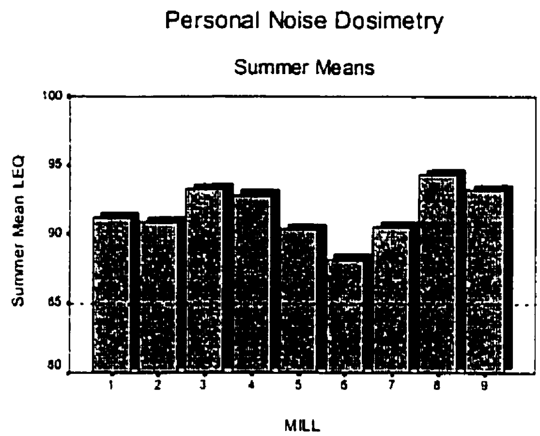
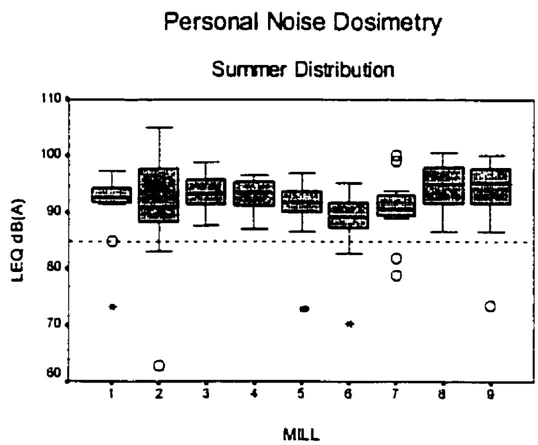


Figure 13.
Personal noise dosimetry, summer distribution by mill



Occupational Group data

Overall summer results for each of the four occupational groups are shown in Table 17 (all mills combined). The planermill production group had the highest arithmetic average of all four (95.9 dB) and the highest median value (96.7 dB), while the sawmill production group had the lowest arithmetic average (89.4 dB). The maintenance group had the lowest median value (91.0 dB). The planermill production group had the smallest range of values (10.3 dB) while the sawmill production group had the largest (36.2 dB). Figure 14 shows the arithmetic averages and figure 15 shows the distribution of the data from table 17. In figure 15, note the predominance of low outliers and extreme values, particularly in the sawmill production group, which will be discussed later.

Table 17. Overall personal monitoring results by occupational group (summer only)

Occupational Group	Log Avg.[1]	Arith Avg.[2]	Median	Max.	Min.	Range
Cleanup	94.4	93.7	93.8	98.1	87.0	11.2
Maintenance	95.6	91.6	91.0	105.0	81.8	23.2
Planermill production	96.9	95.9	96.7	100.7	90.3	10.3
Sawmill production	92.5	89.4	91.2	98.9	62.8	36.2

[1] Logarithmic average
[2] Arithmetic average

Figure 14. Personal noise dosimetry, summer means by occupational group

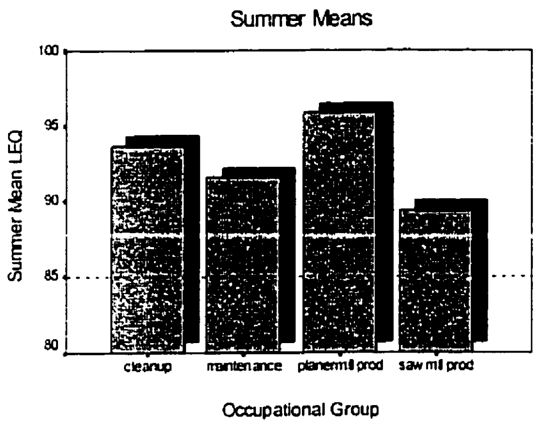
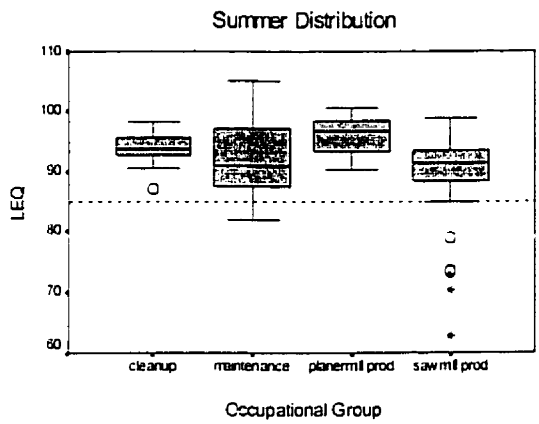


Figure 15. Personal noise dosimetry, summer distribution by occupational group



From table 17, note that the arithmetic means as well as the median for each of the occupational groups are above the 85 dB 8-hour occupational exposure limit. Analysis of variance of the data from table 17 showed a statistically significant difference between occupational groups (df=3, $p < 0.05$). Figures 14 and 15 show that the planermill production group had the highest average noise levels and highest median noise levels. The sawmill production group had the lowest average exposure levels in the summer. The highest maximum exposure occurred in the maintenance group during the summer (see figure 17 and table 17, 105.0 dB). This very high exposure level occurred in a planerman working around the planer.

Figures 16-19 compare the summer distribution of LEQs between the nine mills for each of the four occupational groups. Note that mill # 5 had no measurement in the cleanup group. In the cleanup and planermill production groups, none of the mills had any values below the 85 dB occupational exposure limit. As mentioned previously, the highest measurement belonged to a planerman in the maintenance category (105.0 dB, figure 17). The low outliers in the sawmill production group (figure 19) were mostly cab operators, and represent the same group of outliers as those seen in figures 13 and 15.

NOTE: For Figures 16-19, box plots without whiskers represent occupational groups with no more than 2 data points in that mill. A single line denotes only one data point. Mill # 5 had no operators in the cleanup category.

Figure 16. Cleanup group distribution by mill

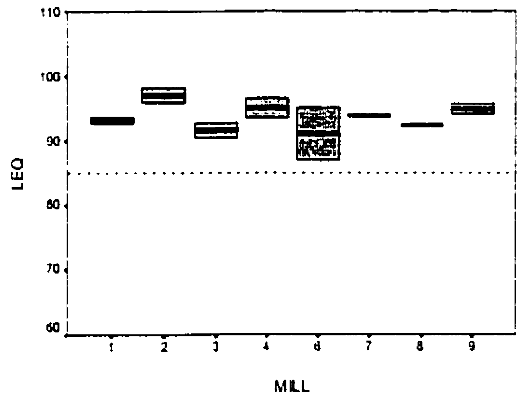


Figure 17. Maintenance group distribution by mill

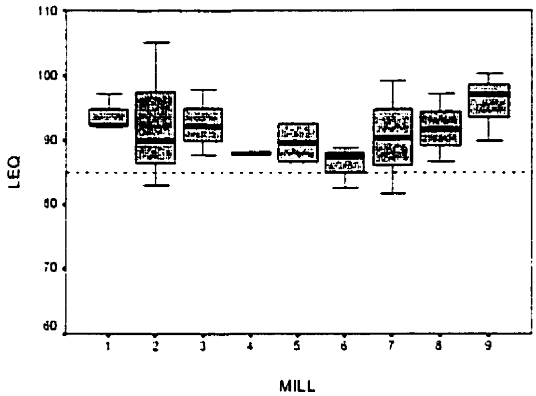


Figure 18. Planermill Production group distribution by mill

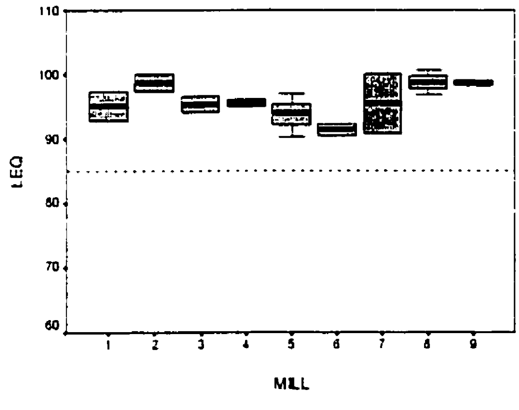
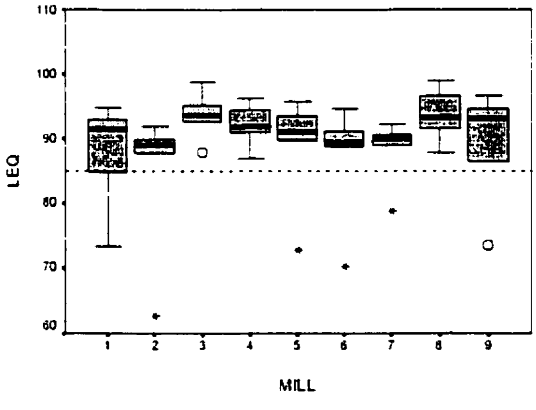


Figure 19. Sawmill Production group distribution by mill



Analysis of variance for the difference between mills for each of the four occupational groups (figures 16-19) showed no statistically significant differences for any of the four occupational groups (df=7 for cleanup, 8 for the other three groups, all p values > 0.20).

Job Category Data

Table 18 summarizes the summer personal monitoring results by job category. Figure 20 is a bar graph of the arithmetic averages of LEQs for each job category in each mill. The lowest arithmetic average occurred in the debarker operators (78.3 dB) while the two highest averages occurred in planermill workers (job # 3, planerman, 96.5 dB and job # 12, planer infeed operator, 97.6 dB).

Table 18. Summer personal monitoring results by job category.

Job	Log Avg	Arith Avg	Median	Max.	Min.	Range
1	90.0	89.6	89.9	92.2	86.6	5.6
2	92.3	88.6	87.8	97.1	81.8	15.3
3	99.2	96.5	97.5	105.0	87.4	17.6
4	93.6	92.9	93.8	95.9	87.0	8.9
5	95.0	94.5	94.0	98.1	92.3	5.8
6	94.9	93.1	93.9	98.9	78.8	20.1
7	93.7	93.0	93.5	96.7	89.1	7.5
8	91.9	91.5	91.3	94.6	89.4	5.3
9	84.7	78.3	73.6	89.0	62.8	26.3
10	90.9	89.8	90.1	95.1	84.8	10.3
11	95.6	94.8	94.0	98.6	90.7	7.9
12	98.4	97.6	98.2	100.7	90.6	10.2
13	95.1	94.4	96.0	96.8	90.3	6.4

Figure 20 makes it fairly clear that there are substantial differences in means between some of the 13 job categories, and analysis of variance showed a statistically significant difference between job categories (df = 12, $p<0.001$). A post-hoc multiple comparisons procedure (Bonferroni procedure, Devore and Peck, 1994) demonstrated that the debarker operator job category was significantly different from all 12 other job categories (p <

0.01). Graphs showing the LEQs for each job category in each of the nine mills are in Appendix 1.

Figure 21 shows the distributions of summer LEQs across job categories from all nine mills (using data from table 8). From figure 21 and Table 18, note that the debarker operators had the widest range of exposures (26.3 dB) and also the lowest minimum value (62.8 dB). The highest maximum value occurred in the summer in a planerman (105.0 dB) and the second highest maximum also in the summer with an infeed operator (in the planermill, 100.7 dB).

Figure 20. Personal noise dosimetry, summer means by job.

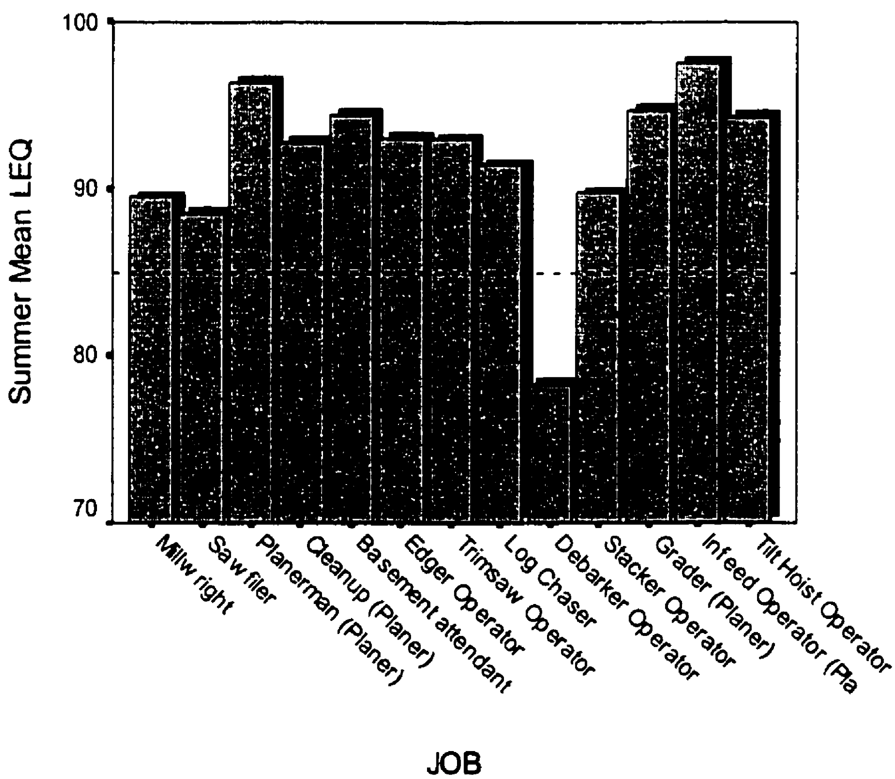
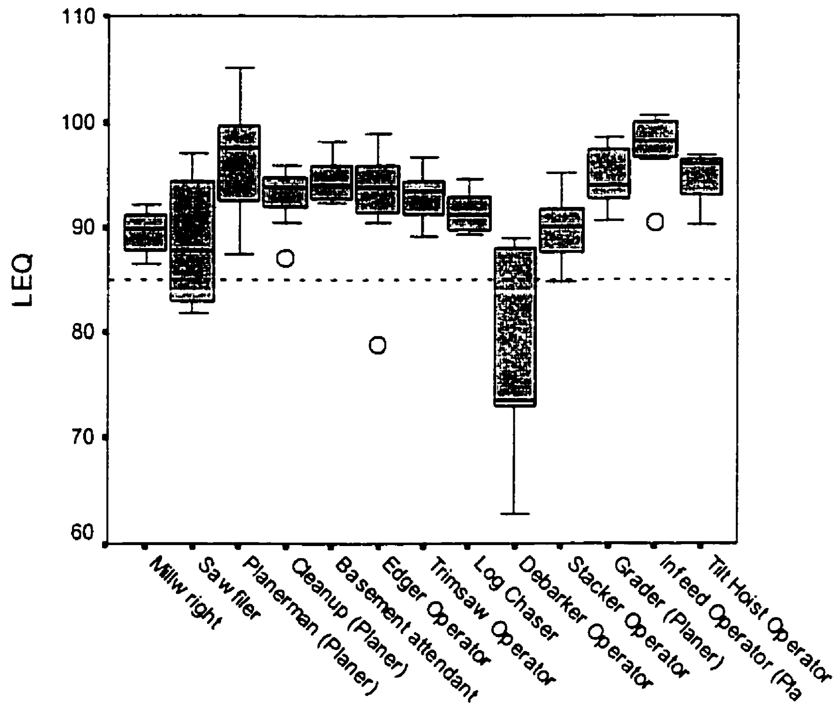


Figure 21. Personal noise dosimetry, summer distributions by job.



Logarithmic Averages ("Energy Averages") for summer data.

Tables 19-21 and corresponding figures 22-24 show the logarithmic means for the summer personal noise dosimetry data by mill (figure 22), occupational group (figure 23) and job category (figure 24). Overall, mill # 2 had the highest logarithmic average (97.2 dB, figure 24) and mill # 6 had the lowest (90.7 dB). The planermill production group had the highest logarithmic average overall (figure 23, 96.9 dB), while the sawmill production group had the lowest (92.5 dB). Finally, the planerman job category had the highest logarithmic average (figure 24, 99.2 dB) while the debarker operator had the lowest (84.7 dB).

Table 19. Summer log averages by mill

Mill	Log Avg
1	93.5
2	97.2
3	94.5
4	93.8
5	92.6
6	90.7
7	93.8
8	96.1
9	96.0

Figure 22. Summer log averages by mill

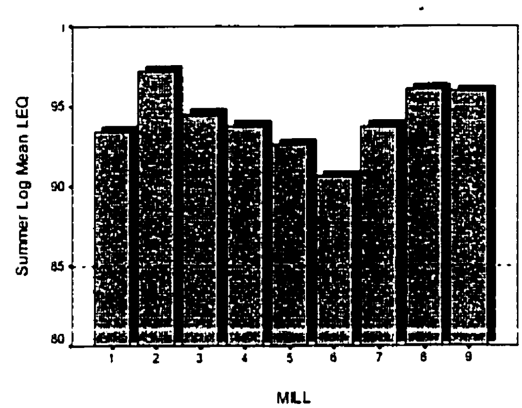


Table 20. Summer log averages by occ grp

Occupational Group	Log Avg
Cleanup	94.4
Maintenance	95.6
Planermill production	96.9
Sawmill production	92.5

Figure 23. Summer log averages by occ grp

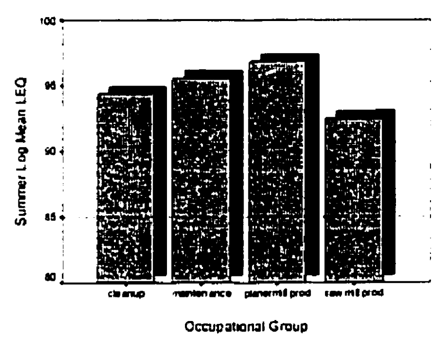
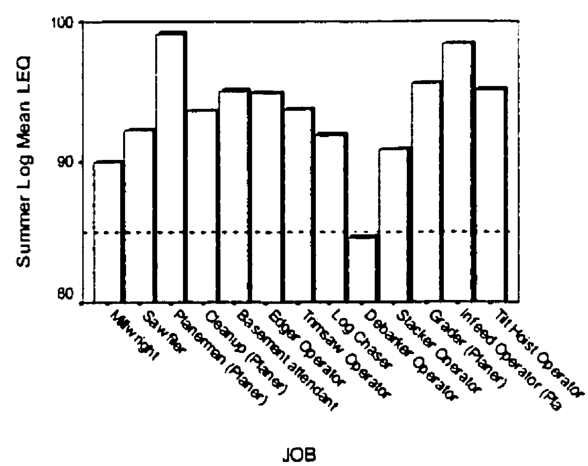


Table 21. Summer log averages by job

Job	Log Avg
1	90.0
2	92.3
3	99.2
4	93.6
5	95.0
6	94.9
7	93.7
8	91.9
9	84.7
10	90.9
11	95.6
12	98.4
13	95.1

Figure 24. Summer log averages by job



Debarker Cabs

Table 22 shows data for 8 different debarker operators with LEQs over the Alberta 85 dB 8-hour OEL (8 out of a total of 18, or 44%). The LEQs for the remaining 10 out of 18 debarker operators (56%) were below the 85 dB OEL. Included in the table is information on season, area monitoring levels inside each cab, and specific notes about activities the worker was undertaking during that shift that might have accounted for the elevated readings. Only one of the 8 debarker operators did not appear to leave the cab at some point during monitoring, although as indicated in table 22, there were other noise sources inside the cab. Note that all of the personal monitoring LEQs were considerably louder than the area monitoring levels inside the cab, with differences ranging from 5.0 dB to 26.7 dB. All of the area monitoring LEQs inside these cabs were below the 85 dB OEL.

Table 22. Debarker operator and cab data. 8 out of 18 (44%, shown here) debarker operator LEQs were over the 85 dB OEL.

Season	Personal Noise Level (dB)	Cab Noise Level (dB)	Δ (dB)	Time Outside Cab?	Notes
Winter	94.3	77	17.3	Yes	Occasionally straightened logs, Log entrance open 40 ft away
Winter	86.7	60	26.7	Yes	Rotates between mill and cab
Winter	89.6	74	15.6	Yes	Log chaser for three out of nine hours
Winter	89.9	71	18.9	Yes	Cab door open, rotates between two cabs
Summer	87.8	75	12.8	Yes	Using Chainsaw, near loader (loud engine)
Summer	87.0	82	5.0	No	Loud radio in cab, nearby log loader noticeably loud
Summer	89.0	76	13.0	Yes	On log decks once
Summer	88.0	66	22.0	Yes	Cleaned up around cab once, loud stereo

Area Monitoring Data

Tables 23 and 24 summarize the area monitoring data for both winter and summer seasons (table 23 = impulse data, table 24 = background data). Figures 25-27 show the overall average area noise levels in all nine mills for winter and summer (arithmetic averages). Overall, mill # 4 had the highest area noise levels in both winter and summer, background and impulse noise combined (figure 25). The overall average area noise levels were higher in the summer than in the winter for seven out of nine mills (figure 25). Mills 1 and 3 had slightly higher winter average winter noise levels. There were no statistically significant differences between seasons for impulse, background or combined (impulse and background) average noise levels (all p values > 0.05). Analysis of variance did show a statistically significant difference between mills for background average and impulse noise levels, seasons combined (background average df=8, $p < 0.01$, impulse df = 8, $p < 0.01$). Table 25 compares the average area monitoring data in the planer area for each mill with the personal monitoring data for the planermen and planer infeed operators (summer only). The area data represents the immediate vicinity around which the planerman and planer infeed operator was working in each mill. Figure 28 shows the arithmetic averages of the three groups. Paired t-tests showed no significant differences between the area and planerman data ($n=8$, $p = 0.14$) and a significant difference between the are and planer infeed operator data ($n=8$, $p = 0.04$). There was an overall 1.1 dB difference in arithmetic averages between all three groups, and a 0.9 dB difference in logarithmic averages (log average graph not shown).

Table 23. Area monitoring data results (impulse)

Mill	Season	Log Avg	Arith Avg	Max.	Min.	Range
1	Winter	98.0	92.2	105	67	38
	Summer	98.1	93.8	106	74	32
2	Winter	97.5	93.8	103	74	29
	Summer	98.8	93.6	105	72	33
3	Winter	98.7	94.2	106	72	34
	Summer	99.8	94.1	108	60	48
4	Winter	100.8	96.5	109	70	39
	Summer	101.2	97.0	109	76	33
5	Winter	97.4	93.4	104	68	36
	Summer	99.2	95.1	107	66	41
6	Winter	95.2	91.6	101	67	34
	Summer	97.0	92.4	105	64	41
7	Winter	96.4	93.8	106	77	29
	Summer	99.0	96.2	106	79	27
8	Winter	98.8	94.3	108	70	38
	Summer	101.0	95.7	109	72	37
9	Winter	96.9	92.2	110	65	45
	Summer	99.4	93.0	116	64	52

Table 24. Area monitoring data results (background)

Mill	Season	Log Avg	Arith Avg	Max.	Min.	Range
1	Winter	93.7	88.1	102	61	41
	Summer	94.8	89.1	106	68	38
2	Winter	92.1	87.0	99	69	30
	Summer	95.2	88.6	105	65	40
3	Winter	95.3	89.9	103	61	41
	Summer	94.6	89.7	102	55	47
4	Winter	95.1	91.2	104	70	34
	Summer	96.7	91.6	107	70	37
5	Winter	91.8	87.3	98	63	35
	Summer	90.1	85.8	96	60	36
6	Winter	90.2	85.1	97	60	37
	Summer	91.8	86.1	102	60	42
7	Winter	90.9	87.4	101	70	31
	Summer	92.0	88.6	101	71	30
8	Winter	94.4	89.1	101	6	40
	Summer	96.1	89.9	105	62	43
9	Winter	91.3	87.2	100	60	40
	Summer	94.0	87.7	110	60	50

Figure 25. Overall area data by mill (background + impulse)

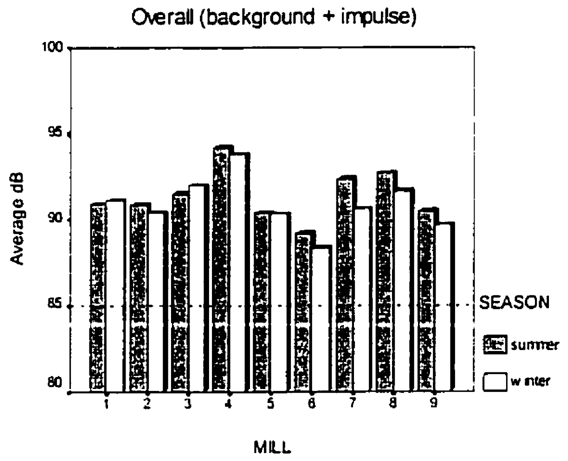


Figure 26. Overall area data by mill (background average)

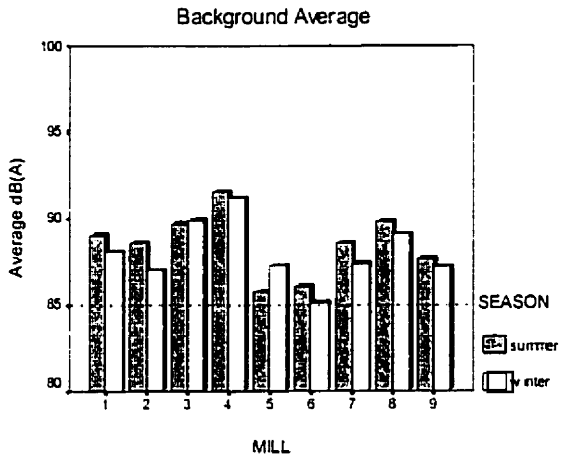


Figure 27. Overall area data by mill (impulse average)

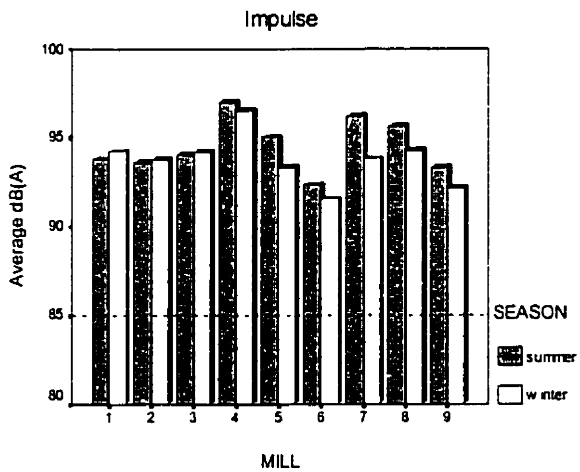
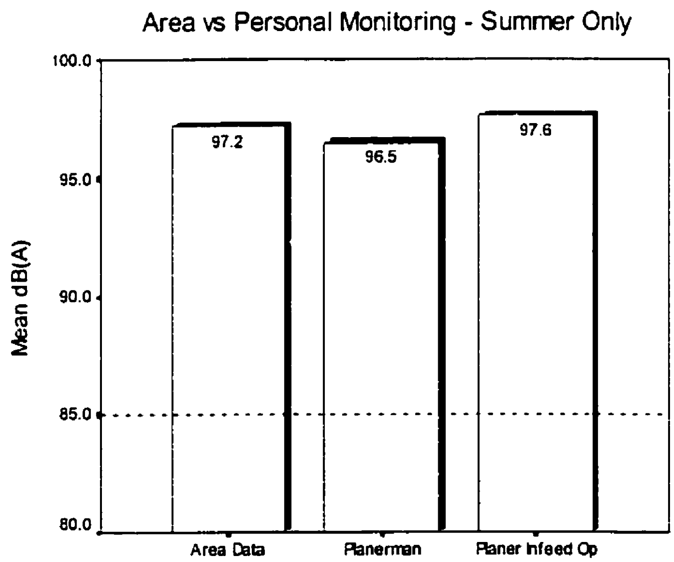


Table 25. Planer area monitoring vs personal monitoring data (summer only).

Mill	Area Data	Planerman	PIO[1]
1	102.5	92.3	97.4
2	103.0	105.3	100.1
3	95.8	97.9	96.5
4	98.7	*	*
5	92.0	92.7	96.9
6	89.2	87.4	90.5
7	98.8	99.1	100.0
8	101.1	97.2	100.7
9	93.6	100.2	98.9
Arith. Avg.	**97.2**	**96.5**	**97.6**
Log Avg.	**99.2**	**99.3**	**98.4**

[1] PIO = Planer Infeed Operator (planer)
* No worker in this position

Figure 28. Area vs Personal monitoring – summer only (arithmetic means)



Hearing Protection in Two Mills

Closer analysis of data on the use of hearing protection in two of the nine mills is described here. Data from mills # 6 and # 7 on observed use of hearing protection are summarized in tables 26 and 27. In mill # 6, hearing protection was observed to be worn in 87% of the spot checks in the winter and 79% of the spot checks in the summer (average = 83%). In mill # 7, hearing protection was observed to be worn in 69% of the spot checks in the winter and 81% of the spot checks in the summer (average = 75%). The "number of times worn" refers to the number of spot checks during which it was seen that the worker was wearing the hearing protection listed (dual hearing protection was not worn). The "# of times should have been worn" refers to the number of spot checks during which it would have been expected to see that particular worker wearing hearing protection, based on noise levels and exposure in the immediate environment. Note that all types of hearing protection listed in tables 26 and 27 are considered "Class A" hearing protection by the Canadian Standards Association (Appendix 3) and meet the requirements for hearing protection as stipulated in the Alberta Occupational Health and Safety Act (1981). Although specific information on noise reduction ratings (NRRs) for each piece of hearing protection listed in tables 26 and 27 was not available, all had a minimum NRR of 29 dB and a maximum of 33 dB for some of the muffs.

From tables 26 and 27, it should be noted that six of the personal monitoring LEQs were 95 dB or over. Two occurred in mill #6 (one in summer and one in winter) and four occurred in mill #7 (two in summer and two in winter). Of these six workers in the "very high" noise intensity category, five (83%) were noted to be wearing HPDs during periods of exposure, and one (17%) was not (mill #7 summer).

Table 26. Personal hearing protection use, Mill # 6

Season	Personal Monitoring LEQ	Type of Protection	# of times worn[1]	# of times should have been worn[2]	
Winter	89.96	Plugs	4	4	
	87.06	Plugs	4	4	
	95.00	Plugs	4	4	
	93.69	Muffs	4	4	
	94.68	Muffs	4	4	
	92.68	Muffs	3	3	
	85.82	Muffs	4	4	
	88.41	Muffs	3	4	
	86.65	None	0	4	
	84.62	Muffs	3	3	
	Total		**33**	**38**	**87%**
Summer	86.99	Muffs	3	3	
	92.33	Muffs	4	4	
	88.81	Muffs	3	3	
	89.36	Muffs	1	4	
	91.20	Plugs	3	4	
	90.50	Plugs	4	4	
	87.40	None	0	4	
	88.78	Plugs	4	4	
	94.68	Plugs	4	4	
	95.22	Muffs	4	4	
	Total		**30**	**38**	**79%**

[1] This refers to the number of spot checks where the worker was observed to be wearing the hearing protection

[2] This refers to the number of spot checks during which the worker should have been wearing hearing protection, based on nearby noise sources or potential for exposure over 85 dB

Table 27. Personal hearing protection use, Mill # 7

Season	Personal Monitoring LEQ	Type of Protection	# of times worn[1]	# of times should have been worn[2]	
Winter	87.85	?	4	4	
	93.34	Plugs	4	4	
	92.50	None	0	4	
	89.59	None [3]	0	0	
	95.00	Plugs	4	4	
	91.26	Plugs	4	4	
	91.96	Plugs	4	4	
	89.32	None	0	4	
	95.00	Muffs	3	3	
	90.46	Plugs	4	4	
	85.20	None	0	4	
	Total		**27**	**39**	**69%**
Summer	100.04	Plugs	4	4	
	90.37	Plugs	1	4	
	89.02	Plugs	1	1	
	90.61	Plugs	4	4	
	90.72	Plugs	4	4	
	92.27	Plugs	4	4	
	89.73	Plugs	4	4	
	90.06	Plugs	4	4	
	99.09	None	0	4	
	93.79	Plugs	4	4	
	Total		**30**	**37**	**81%**

[1] This refers to the number of spot checks where the worker was observed to be wearing the hearing protection

[2] This refers to the number of spot checks during which the worker should have been wearing hearing protection, based on nearby noise sources or potential for exposure over 85 dB

[3] This worker was in a cab (debarker operator) during each of the spot checks. Noise level in the cab (8-hr TWA) was 74 dB.

Discussion

Personal Monitoring Data

Noise Intensity Categories and Noise Reduction Ratings (NRRs)

The 85 dB cutoff between the "under limit" category and the "high" category reflects the regulatory standards set in the province of Alberta. 85 dB is the current OEL in the province of Alberta.

All hearing protection that was being used in the nine sawmills had a NRR of *at least* 29 dB, most between 29 and 31. It should be noted that the published NRR is designed to be subtracted from C-weighted sound pressure levels, not A-weighted sound pressure levels (Royster and Royster, 1990, Giardino and Durkt 1996). In this exposure study (as with most exposure studies), only the A-weighted values were known. Because of this, when calculating estimated exposures while wearing hearing protection, a correction factor must be subtracted from the NRR as follows:

Noise level dB(A) – [NRR-7] = estimated exposure, dB(A)

As Royster and Royster (1990) state, "The 7-dB correction factor is needed with A-weighted levels because the dB(A) value gives no indication of whether the energy in the noise environment is predominately low-frequency or high-frequency. Since HPDs provide less protection at lower frequencies, then it becomes necessary to add a safety factor unless the dB(C) value is available." Royster and Royster (1990) go on to say that "In general, HCP personnel can count on properly trained and motivated HPD wearers receiving about 50% of the NRR value in attenuation." This 50% de-rating of the NRR has been supported in the past with other studies (Federal Register 1981, Giardino and Durkt 1996, Berger 1984). Giardino and Durkt (1996), in a comprehensive study evaluating muff-type hearing protection in a mining environment, concluded that the NRR can "grossly overestimate HPD performance", and that 50% of all workers had an observed noise reduction of 16 dB or less while 20% of workers had an observed noise reduction of 10 dB. 5% of the workers had an observed noise reduction of 5 dB or less (Giardino and Durkt 1996).

Similar findings have been reported for earplugs or other insert-type devices (Carter and Upfold 1993, Padilla 1976). Citing data from Berger et al. (1994), Frank et al. (1996) also note the considerable differences between "lab fit" NRRs and "real world" NRRs, both for various earplugs and earmuffs. For example, while some types of earplugs would report NRRs in the range of 25 dB, "real world" NRRs would sometimes turn out to be less than 5 or 10 dB (Frank et al, 1996). Earmuffs, being somewhat less prone to "user error", usually showed less of a difference between laboratory NRRs and "real world" NRRs. Frank et al (1996), again citing Berger et al. (1994), stated that many ear muffs with NRRs listed at 23-25 dB would actually have "real world" NRRs of 11-18 only.

Certainly, many factors can influence these differences between "lab" and "real world" NRRs. Improper wearing of HPDs is arguably one of the main reasons (e.g., not inserting an earplug properly, Frank et. al. 1996). Even when properly worn, however, sound can reach the inner ear by a number of pathways, including leakage around the HPD, transmission through the HPD, vibration of the HPD, and bone conduction

(Feldman and Grimes, 1985). Other aspects such as head size, shape and amount of hair can cause HPD performance to vary from person to person (Giardino and Durkt, 1996). One aspect seldom considered is the activity level of the worker, which may "induce a relative motion between the cup cushion and the side of the head, which degrades the integrity of the seal and reduces HPD performance." (Giardino and Durkt, 1996). Furthermore, removal of HPDs for even a few minutes can have a dramatic impact on its performance. For instance, removing a HPD with an NRR of 30 for only 30 minutes reduces its effectiveness to an NRR of approximately 12, while removing it for 60 minutes reduces the effective NRR to approximately 7 (Franks et al, 1996).

Applying the above information on NRR adjustments to the minimum NRR in this study (29dB) would result in the following:

Correcting for the fact that the NRR is C-weighted:
29-7 = 22 dB(A) protection

Assuming ~ 50% attenuation value = **11 dB(A) protection**

There has been no consensus reached on how much to "de-rate" the laboratory reported NRRs (Berger, 1984). The problem is nevertheless well recognized in the professional community, and for the purposes of this discussion (and based on literature) a 50% reduction of the adjusted NRR has been used.

Assuming a worker was wearing 29 dB NRR equipment (range of NRRs for equipment in all nine mills was from 29 dB to 33 dB), the adjustments and calculations above would suggest an "actual" NRR of 11 dB(A) for an HPD with a rated NRR of 29 dB. Therefore, if the worker was in an environment louder than 96 dB(A) (85 + 11), hearing protection would not reduce exposure below the 85 dB(A) limit. In the present study, the lower limit of the "very high" category was set at 95 dB for simplicity and due to the problem of not being able to record above 95 dB for the winter data.

There were no statistically significant differences between seasons in the number of readings that were observed in each noise category. Overall, 90% of all the 8-hr TWAs were above 85 dB (89% in the winter, 91% in the summer, tables 11-13) and 27% were above 95 dB (table 7). Dividing the data into two categories (less than 95 dB or 95 dB and greater) showed no statistically significant differences between seasons in the number of values in each category. Furthermore, there was no consistency in the changes between winter and summer in the categories, reflecting little overall difference between the two seasons. The information presented on NRRs above suggests that the group of workers in the "very high" or "95 or greater" category (27 % of all the workers studied, tables 6 and 7) are potentially at risk of exposure over the OEL despite wearing the required hearing protection. All of the workers in the present study would be adequately protected (down to the OEL of 85 dB) *only* if the HPDs performed in practice at the same levels found in laboratory tests, which is an unlikely situation (workers did not wear dual hearing protection).

Categorical analysis of noise exposure by occupational group showed that all occupational groups except for the planermill production group had the majority of values less than 95 dB (tables 8 & 9, figure 7). In fact, 61% of all LEQs in the planermill production group were 95 dB or higher, suggesting that the majority of planermill production workers could be at risk of noise overexposure despite wearing required hearing protection. This proportion is over twice that of the next highest occupational group, the cleanup group, which had 29% of workers with LEQs of 95 dB or higher. The planermill production group, then, is by far the highest risk group for noise overexposure despite the use of required hearing protection.

Categorical analysis of job data showed that only two jobs had a majority of personal monitoring LEQs 95 dB or higher. These were the planermen and the planer infeed operators (table 10 and figure 8). Only 18% of LEQs from planer infeed operators were less than 95 dB. This suggests that the vast majority of planer infeed operators in this study could be at risk of noise overexposure despite wearing required hearing protection. 50% of the LEQs measured on tilt hoist operators were 95 dB or greater, and 44 % of LEQs on graders (in the planermill) were 95 dB or greater.

Only three job categories had no LEQs greater than or equal to 95 dB (millwright, log chaser and debarker operator, table 10 and figure 8). The millwright usually works in a separate section of the mill devoted to repair and maintenance of machinery and parts, and does not usually spend much time in the mill proper. The log chaser is usually outside the sawmill overseeing the conveyer system bringing logs into the mill. Finally, the debarker operator is usually enclosed in a cab. This would explain why none of these three job categories had LEQs over 95 dB.

Many of the factors that affect the NRR involve proper fitting and compliance and therefore would vary between workers as well as between days for any given worker. This important point was discussed by Berger (1984): "...proper fitting and wearing of HPDs by the industrial work force is probably the single most difficult element to execute in a hearing conservation program. It requires not only education, training, and the selection of comfortable and effective HPDs, but perhaps more importantly, motivation, enforcement and responsiveness to the needs of the hearing protected employees." Gosztonyi (1975) found that there were no greater changes in hearing threshold levels over five years in workers wearing hearing protection in a 90 dB or greater environment compared to workers in areas less than 90 dB. No mention was made of compliance rates for hearing protection usage, other than "ear protection in the form of muffs is mandatory". Further studies are needed to assess the amount of hearing loss experienced by the workers in the "very high" category compared to those in the "high" or "below limit" categories in this study, or if in fact any hearing loss occurs at all.

Summer Data

The problems encountered in recording the winter personal monitoring data make direct seasonal comparisons of averages and distributions impossible. Unfortunately this leaves any seasonal differences that may or may not have existed in terms of personal monitoring noise data open to speculation. It is possible that winter values may indeed have been higher than summer had the dosimeters been able to record > 95 dB noise levels. The initial assumption was that winter levels would be higher than summer because in winter doors and windows tend to be closed, resulting in potentially higher indoor noise levels. However, given that the *area* monitoring survey showed higher summer values for most mills (although not statistically significant), it is difficult to say if the same would have been true for the personal monitoring data. Comparisons between seasons *were* possible using the categorical data as discussed in the previous section. Given that no statistically significant differences were found between winter and summer for the noise intensity categories and for the area data, this section will discuss only summer data as being representative of both seasons.

The literature on noise exposure levels in sawmills (in particular personal monitoring data) is surprisingly sparse. Certainly no literature was found that examined the issue of noise exposure in sawmills with the same breadth as the present study. Of particular interest is the fact that no studies were found that looked at seasonal differences in sawmill noise levels. In that respect it is quite unfortunate that the winter personal monitoring data were limited in their measurement range, making definitive conclusions about seasonal differences very difficult.

Results from overall summer personal monitoring TWAs for all nine mills were similar and showed no statistically significant differences between mills. Of all 213 personal monitoring results across all nine mills, only 22 (10%) were equal to or below the Alberta Occupational Health and Safety Limit of 85 dB, and 90% were above. Average summer personal monitoring noise levels in all nine sawmills were above the 85 dB Alberta OEL. Class A hearing protection was required and used by employees in all nine mills, as per Alberta Occupational Health and Safety regulations. The high noise exposure levels seen in these nine sawmills (both area noise levels and personal noise levels) are comparable to levels found in sawmills in other studies (Ayaz 1989; Ayaz, 1991; Dost, 1974 a;b; Krilov, 1972; Ruedy et al, 1976; Smith, 1971). Dost (1974 b) reported that "Data from noise surveys conducted in California sawmills and planermills in 1971 and 1972 indicate that more than 90% of the work stations are at noise levels in excess of the OSHA limits (note that the OSHA permissible exposure limit is 90 dB). Ayaz (1991) reported that "the noise level of different machines in all types of sawmills is much higher than the threshold noise level of 85 dB(A)..." and that workers standing near the machines had exposures ranging from 90 to 113 dB(A). The high levels of noise found in the nine Alberta sawmills do not appear to be unusual, especially given the nature of the sources of noise in this industry.

Noise in sawmills comes from various sources, including the high speed cutting of lumber, impact noises from falling and moving pieces of lumber, noise from machinery engines and motors, and noise from idling or rapidly spinning circular saw blades. Theses types of noise sources and suggestions for their control have been discussed (Dost, 1979; Ikegiwa, 1982; Klamecki, 1977; Leu and Mote, 1984; Rhemrev and Cano, 1989; Tanaka et al, 1982a;b). Mill # 6, which had the lowest overall summer average, is a relatively new mill and likely had newer equipment with better engineering controls to partially account for the lower overall noise level. Mill # 8, which had the highest average noise level (94.4 dB) was more than 6 dB louder than Mill # 6. Although overall differences between the nine mills were not statistically significant, this nevertheless represents almost 4 times the sound intensity for mill # 2 compared to mill # 8 (sound intensity doubles with every increase of 3 dB). While a detailed explanation of the differences in noise levels in these mills (such as noise control techniques or implementation and use of quieter equipment) is beyond the scope of this thesis, some discussion of engineering controls will follow when discussing the planer area data.

Of the 8 low outliers and extreme values seen in figure 13, 6 were cab operators (primarily debarker operators). One low outlier not working in a cab (the higher of the two low outliers in mill #7, figure 13) was a sawfiler working a "typical day". In this mill (as in most) the sawfilers work in a separate enclosed section of the mill most of the time. Therefore, those workers protected from noise by an enclosed cab or room had personal noise measurements substantially lower than most measurements for a given mill. The other low outlier not working in a cab (mill # 1) was a stacker operator working near the J-bar. The two high outliers seen in mill # 7 represent readings from a planerman and a planer infeed operator working in the same area in the planermill. The highest personal monitoring reading of the entire study, 105.0 dB (mill # 2), belonged to a planerman in the maintenance occupational group (summer). As will be discussed later, these two jobs (planerman and planer infeed operator) had the highest number of personal noise measurements over 95 dB in all nine mills and represent a high risk for serious noise exposure, simply by virtue of their proximity to the planer.

Occupational groups have not been previously analyzed separately as they have in the present study. Overall, the summer mean noise levels of the four occupational groups were significantly different from each other. All of the occupational groups had average exposure and median exposure levels above the 85 dB(A) Alberta OHS exposure limit. In the summer, the planermill production group had the highest noise exposures overall, and sawmill production group had the lowest. This is not surprising as it has been shown in other studies that the planer is one of the loudest machines in a sawmill, if not the loudest (Ruedy et al 1976, Patrick 1981). Sawmill production had the lowest overall summer noise exposure in part because this group included most of the cab operators. The low outliers in the sawmill production group (figure 15) are the same low outliers as those seen in figure 13 (most operate from inside a cab as discussed previously). Workers in the cleanup and maintenance categories would spend time in other parts of the mill that might be noisier, such as the planer area, which could contribute to their average noise exposure being higher than the sawmill production group. None of the measurements for the cleanup or planermill production group were below the 85 dB OEL, and the majority of the measurements in the maintenance and sawmill production group were above the 85 dB OEL (figure 15). Again, these exposure levels are quite consistent with other studies on noise levels in sawmills done in the past (Ayaz, 1991; Dost, 1974 a;b; Klamecki, 1977; Ruedy, 1976).

The job category data revealed some striking differences. Debarker operators had by far the lowest personal exposure levels of all the job categories. The average noise intensity in debarker operators (78.3 dB) was approximately ten decibels lower than the next highest job category (sawfiler, 88.6 dB). The highest maximum was seen in a planerman in mill #2 summer (105.0 dB). A description of his duties revealed nothing unusual, other than a brief 15 minute blowdown. Examination of his dosimetry sample log showed many brief noise peaks in the 115-120 dB range, with the highest up to 130 dB. This particular planerman had multiple high intensity exposures resulting in a very high average noise level. This is comparable with other planer area noise levels from previous studies, which also found noise levels to be in the 100-105 dB range (Dost, 1974 a;b; Ruedy, 1976).

From table 18, the lowest minimum was in the debarker operator job category, mill # 2 summer (Job # 9, 62.8 dB). This operator was working in a cab enclosure with no other significant nearby noise sources, such as loud radios or music. This is considerably lower than values reported previously for operators in enclosures (Dost, 1974 b). There was no evidence from the description of duties that the operator spent any length of time in areas other than the debarker that were quieter than the debarker. Data from workers in the debarker cabs is discussed in more detail below.

While the overall sample size for the study and for the summer data alone was adequate, categorizing exposure data by occupational groups and jobs often resulted in very low sample sizes. This was reflected in some of the statistical analyses described previously. Nevertheless, the consistencies in exposure levels between mills with respect to certain jobs and areas (both high and low) suggest that these represent true findings despite low sample sizes.

Debarker Cabs

When discussing methods of protecting workers from noise exposure, personal protective equipment should always be considered a "last line of defence", and engineering or administrative controls are preferred before having to resort to personal protective equipment. Nevertheless, personal hearing protection still plays a major role in protecting sawmill workers from noise exposure (Patrick, 1981). From the discussion of the overall data, occupational group data, and job category data, it becomes clear that a consistent reason for low noise exposure to noise was isolation of the worker in an enclosed cab (i.e., a form of engineering control). Operating in an enclosure, particularly as a debarker operator, had a significant effect in terms of lowering exposure to high noise levels in all nine mills. Reducing the noise exposure of sawmill workers by putting the operator in an enclosure such as a cab has been suggested as an effective tool to prevent NIHL (Ruedy et al. 1976, Franks et al, 1996). A Health Hazard Evaluation Report by on a Wyoming sawmill also recommended (among other things) that noise reduction controls such as worker enclosures would reduce the operator's exposure to noise (NIOSH, 1981). Patrick (1991) stated that "personnel and machine enclosures have been proven the most used and best methods in today's technology for protecting sawmill employees"(from noise). Dost (1974 b) also noted that the lowest recorded noise levels in his study occurred with operators working in an enclosure. The three lowest values in his case were 72 dB, 78 dB and 84 dB (Dost, 1974 b), all due to cabs or enclosures.

In this study however, *despite* working in a cab enclosure for the majority of a day, 8 out of a total of 18 debarker operators were over the 85 dB OEL (four in the winter, four in the summer, table 22). Note that all of the cabs had area monitoring results below the 85 dB OEL. The information in table 22 (notes) provides some explanation for the discrepancy between apparently "safe" exposure levels (the cab area data) and obviously harmful exposure data (LEQs). For the most part, the cab operators with higher than expected exposure levels had left the cab on one or more occasions to perform some sort of duty in the mill proper. In two cases, it was noted that loud radios or stereos were contributing to a significant noise exposure within the cab, potentially rendering the protective barrier of the cab useless. However, since most of the area monitoring noise levels in the cab were considerably quieter than the personal monitoring levels (range 4.96 dB to 26.65 dB), it stands to reason that the excess noise exposure primarily came from outside the cab, in the mill itself. It had been noted that while outside the cabs, the workers were seen wearing either plugs or decidamps, although it was not possible to observe any one individual over the entire 8 hour period. The evidence from the debarker cab data in table 22 is a good reminder of how even brief excursions from a protected cab onto the mill floor or other noisy areas can result in a total overall noise exposure that is potentially harmful. Cab doors or windows left even slightly ajar can virtually negate noise reduction measures, as can loud noise sources from within the cab. The proper use of hearing protection is important to reduce the risks of noise exposure if leaving the protection of a cab is necessary.

Logarithmic Means ("Energy Averages")

The formula for calculating the energy average has been described in the methods section. For the purposes of averaging a number of values from a sample of different workers, the arithmetic average is an accepted tool when dealing with noise exposure data. However, when interested in a more accurate number reflecting the "energy dose" delivered to the ear of a worker, it becomes important to calculate the energy average (Workers Compensation Board of BC). Calculating averages in this fashion gives more weight to the higher dB values which are often exponentially louder than the lower dB values. Examining the personal monitoring data in this fashion showed mill # 2 to have the highest average overall, 6.5 dB higher than the lowest mill (mill # 6, 90.7 dB). This suggests that mill # 2 had approximately 4 times as much sound energy potentially deliverable to workers ears compared with mill # 6. Analysis of the occupational group data still showed the planermill production group to have the highest overall average (96.9 dB) and the sawmill production group the lowest (92.5 dB). Similarly, analysis of the job category data using energy averages still showed the planerman and the planer infeed operator to have the highest overall means, as was observed with the standard arithmetic averages. These values corroborate the conclusions from the prior discussion of the summer data and reinforce the fact that work in the vicinity of the planer results in substantial sound energy levels that can potentially deliver a damaging noise dose to the ears of inadequately protected workers.

HPD Use in Two Mills

The two mills examined more closely with respect to HPD use (mill #6 and #7) had overall average use rates of 83% and 75% respectively (of those employees with 8-hr TWAs > 85 dB. Ideally HPD use should be 100% when exposures are over the 85 dB limit. Unfortunately, similar deficiencies in compliance have been reported in the literature in the past. In a study investigating trends in hearing protection use in United States manufacturing industries, Davis and Sieber (1998) reported an increase in HPD use in the lumber industry from 7.97% in 1972-1974 to 67.1% in 1989. HPD use in all industries combined increased from a mere 6.3% in 1972-1974 to 43.3% in 1989. The time frame of the study included four major regulatory milestones designed to reduce the incidence of NIHL and from the data presented, these initiatives appeared to be somewhat successful (Davis and Sieber, 1998). In another study, questionnaires filled out by 98 tradesmen on the worksite indicated that although 98% knew they should be wearing HPDs, the reported use averaged only 50.3% (Lusk and Kelemen, 1993). Interview and examination of factory workers in Singapore reported only 53% of workers wearing hearing protectors all the time (168/317) and 17% wearing hearing protectors ">50% of the time" (54/317) (Phoon and Lee, 1993). Ewigman et al (1990) reported 85% "regular" HPD use in firefighters after educational intervention (while only 20% before). Melamed et al (1994) in a study on 2497 male blue collar workers reported 42.6% (150 out of 352) HPD use in those exposed to noise levels greater than or equal to 85 dB(A). Multiple logistic regression analysis indicated that HPD use related not only to exposure level (OR 2.94, 95% CI 2.58-3.3), but even more so to high noise annoyance (OR 3.03, 95% CI 2.77-3.29) (Melamed et al., 1994).

Given these values reported in the literature, it seems that HPD use in the two sawmills examined is similar to or even better than previously reported levels, both in the lumber industry and in other industries. Of those workers in the "very high" noise exposure category in the 2 mills (a total of 6 out of 41), 1 (17%) was seen not wearing hearing protection during any of the 4 "spot checks" (during the summer in mill # 7).

If a goal of 100% compliance is a realistic goal for HPD use, then there is still room for improvement, both in the 2 mills examined here and in industry in general. It was known that workers in the mills in this study generally did not wear dual hearing protection (i.e. muffs and plugs at the same time). Currently, the HCPs in these two mills consist of a brief education of new employees upon starting work as to the hazards of noise exposure, supplying of Class A hearing protection, and audiograms once a year or once every two years. Future studies would certainly be necessary to assess both the HPD use in the other mills as well as the incidence of NIHL in these mills, especially for those workers who are exposed to "very high" noise levels and are wearing the required hearing protection. It goes without saying that the finding of NIHL due to work exposure despite the use of recommended hearing protection could have profound implications on current regulations. In the case of this study in particular, even the consistent use of dual hearing protection could at least reduce the likelihood of workers in high noise exposure areas being overexposed to noise.

Area Monitoring Data

As with the personal monitoring data, average area monitoring results were above the 85 dB OEL in all nine mills in summer and in winter. Results from the area monitoring survey spot checks were comparable to results from other surveys in the literature. Dost (1974 b) described mill noise levels from 72 to 111 dB, with averages ranging from 87.3 dB to 104.5 dB. Ayaz (1991) found noise levels in a Pakistan sawmill ranging from 85 dB to 133 dB. In a detailed noise survey, Ruedy et al (1976) found average noise levels of sawmill machines (with machines running close by) to range from 91-109 dB. Dost (1974 a) found average working noise levels to range from 86 dB to 107 dB. The NIOSH survey of Wyoming sawmills (NIOSH 1991) found planermill noise dosimetry to range from 95 dB to 102 dB and sawmill noise dosimetry to range from 97 dB to 100 dB, although fewer areas were sampled in the NIOSH survey than in this study. Smith (1971) reviewed noise in the wood industry and found most studies showing noise levels in the 80-110 dB range. These studies all demonstrated area noise levels in sawmills very similar to the levels in this study.

There is little doubt, both from this study and from previous studies, that the planer presents a significant noise hazard in a sawmill, if not *the* most significant (Dost 1974 a;b; Patrick, 1981; Ruedy 1976). In this study, this is particularly evident from the data of those who work in the vicinity of the planer frequently (planerman and planer infeed operator). The average values for the planer area data, planer infeed operator and planerman were all within 1.1 dB of each other, ranging from 96.5 dB to 97.6 dB (figure 29). There was no significant difference between the area and planerman data and borderline significant difference between the area and planer infeed operator data.

Looking at figure 28 again it can be reasonably concluded that there is no important difference between area and personal monitoring data for the planer area. Furthermore, most of the personal monitoring results for the planerman and planer infeed operator were over 95 dB, suggesting they are at risk of noise overexposure despite wearing adequate hearing protection.

In mill #1, the planer area levels were considerably higher than the personal monitoring data for either the planerman or the planer infeed operator. Analysis of the activity logs for both of those workers suggested periods of low noise exposure that could account for the overall lower LEQs measured for them compared to the area monitoring. There were some instances (e.g. mill # 9) where the personal monitoring results were notably higher than the area monitoring results, despite lack of statistically significant differences. Worker mobility could again account for this, by virtue of the fact that they occasionally might position themselves in close proximity to loud noise sources, such as a planer. The area monitor, on the other hand, remains stationary and is only a spot reading (not an 8 hr TWA). Note that all averages in figures 25-27 were over the 85 dB OEL.

In general, this study showed that the personal monitoring data obtained from employees working in the proximity of the planer was similar and not significantly different from area monitoring data in the vicinity of the planer. Given that the workers spend most of their shift in that area, this is not unexpected. Still, as the numbers in figure 28 demonstrate, the area around the planer is substantial source of noise exposure for sawmill workers.

There are a number of engineering controls and principles that could help to substantially reduce the noise exposure in the area of the planer. These have been incorporated to various degrees in the nine mills involved in this study. Fairfax (1989) described economical and readily installable noise controls in pine sawmills and planermills, particularly around the planer. For instance, in one mill an average reduction of 5 dB (from 98 dB to 93 dB) near the planer was accomplished by enclosing the planer and constructing tunnels for the infeed and outfeed conveyors. The enclosure was double-walled and insulated with 3 inches of fiber glass (Fairfax, 1989). As well, two insulated barriers between the planer and the graders, along with the enclosure previously mentioned, helped reduce the noise exposures of the graders in the planermill (Fairfax, 1989). Similar changes with similar results were made on a second mill. Despite the changes and improvements, Fairfax (1989) reminded readers that a continuing, effective HCP, including HPDs, was still necessary. The NIOSH Health Hazard Evaluation Report (NIOSH, 1991) described noise reductions in one sawmill due to the separation of the edger saw from the rest of the sawmill. They also reported that enclosing the planer in a concrete block building resulted in a 5 dB lowering of exposure levels for workers (NIOSH, 1991). In some instances it is not practical to enclose a unit or machine. In such cases, an area enclosure may be more appropriate to separate the rest of the mill from the area in question. Though an effective means of reducing operator noise exposure, an operator enclosure is sometimes less practical for a planer, which often requires the worker to manually adjust and select logs that are being fed in to the planer. Another important principle behind effective engineering control of noise is a strict maintenance program. Saws and other moving parts need to be constantly lubricated and exhaust air cylinders should be effectively muffled (Dost, 1974 b; Dost and Gorvad, 1979; Ruedy et al, 1976). When mufflers or silencers fail they need to be replaced, and periodic maintenance can minimize the noise from gear boxes (in some of the heavy equipment on site), control valves or other noise sources (Schaefer 1992). Other noise abatement techniques include dampening tape along infeed and outfeed conveyors, and a combination of dampening underlays and insulating enclosures around machines in question (Smith, 1971).

Other methods of engineering control focus on the saws themselves. Rhemrev and Cano (1989) suggest that damped saws are to be preferred when noise control is a concern. Damping refers to the ability of a saw blade to convert resonant vibrating energy into heat, thereby reducing the energy available to generate noise (Rhemrev and Cano, 1989). Other factors that increase saw blade noise are increasing tooth height and increasing blade thickness (Tanaka et al, 1981a). Leu and Mote (1984) concluded that a number of factors can be expected to help reduce the noise of saws, such as small tooth height, spacing and thickness and large tooth width. They also concluded that resonance noise was due to the interaction of the teeth wit the air, and that reducing blade vibration both reduced noise and improved cutting performance.

The most common engineering control used in the nine Alberta sawmills, particularly with respect to the planer, was a machine enclosure. In some instances, despite the enclosure, noise levels around the planer were still very high due to the fact that the infeed and outfeed tunnels were neither long enough nor properly insulated. In one instance, the door of the planer enclosure was left ajar. Installing engineering controls such as *effective* machine enclosures described above together with a rigorous maintenance program would likely go a long way towards reducing the noise exposure of workers in the area of the planer. Furthermore, a few well placed insulated barriers in a planermill could help reduce noise exposure to others (such as the graders) working in the same vicinity or building.

Summary and Future Directions

This study has provided a thorough descriptive look at noise levels in nine Alberta sawmills, particularly from a personal noise exposure perspective. It is clear from the results (and from previous studies) that average personal and area noise levels in sawmills are above the limits for hearing protection use set by the Alberta Occupational Health and Safety Act. Some areas and workers were exposed to particularly high levels of noise, especially those in the vicinity of the planer. This finding was fairly consistent across the nine mills. While some engineering controls are already in place, particularly in areas like the planer, they are often inadequate and only marginally effective. Effective planer enclosures (insulated, with long infeed and outfeed insulated tunnels) are an example of a simple and economical means to reducing noise exposure. Furthermore, although hearing protection is required and used in each mill, compliance with hearing protection is less than 100% and some workers could be exposed over the OEL even when wearing recommended hearing protection, given concerns regarding the "real world" effectiveness of HPDs as discussed in this study. Workers generally did not wear dual hearing protection.

Excessive noise exposure despite the use of recommended hearing protection (which may not be effective) can have significant consequences to both the hearing health of the worker and the current regulations with respect to HPD use. It would be helpful to measure of "in-muff" noise levels by means of a small microphone during the regular working day of a mill employee. This would provide a much more accurate picture of the amount of noise delivered to the ear of the workers (while wearing muffs), instead of relying on assumptions with respect to real world NRRs. A survey of workers on annoyance effects of the noise and symptoms of noise overexposure (e.g. tinnitus) would provide better information with respect to specific effects of noise exposure. Future studies looking at the physiologic effects of noise exposure in sawmills would provide more definitive evidence of noise overexposure in this type of working environment. For instance, measuring hearing acuity (audiometric evaluation) of workers would be the best way to determine the presence of noise induced hearing loss or temporary threshold shifts.

The major limitation of this study was the failure to accurately collect the winter personal monitoring data and the resulting inability to properly compare winter with summer data. Nevertheless, categorical comparisons of seasonal data, together with comparisons of seasonal area data, suggested that in fact there were minimal differences between winter and summer data. Another limitation of this study was the absence of any information on hearing loss in the workers themselves such as audiometric data. Finally, while providing considerable breadth of information, this study did not go into great detail about specific factors influencing noise levels in particular sawmills.

There is little doubt that the noise hazard in sawmills is very high, as evidenced in this study and in the literature. There is also little doubt that the forest industry plays a crucial role in the economy of many provinces, states and countries and provides employment for thousands of workers. It becomes vital, then, to become as familiar as possible with noise hazards and noise exposure potential in sawmills. The present study has provided a thorough examination of noise exposure in Alberta sawmills across jobs, occupational groups, mills and, to a lesser extent, seasons. It has also shed light on the possibility of overexposure to noise *despite* the use of single HPDs as recommended by the Occupational Health and Safety Act. Further study, as mentioned above, is necessary to determine the exact "noise dose" delivered to a worker's ear while wearing the recommended hearing protection. If, in fact, the assumption made in this analysis is true (that an average of 27% of workers still might be overexposed to noise despite wearing hearing protection), then this would have important implications for hearing protection use standards in the province and perhaps elsewhere. At the very least, it could require more consistent use of dual hearing protection. Furthermore, since reducing noise at the source is the best way of limiting noise exposure, this information could provide the basis for target noise levels for the sawmill industry. This would ensure that workers are indeed protected from noise overexposure when wearing recommended hearing protection.

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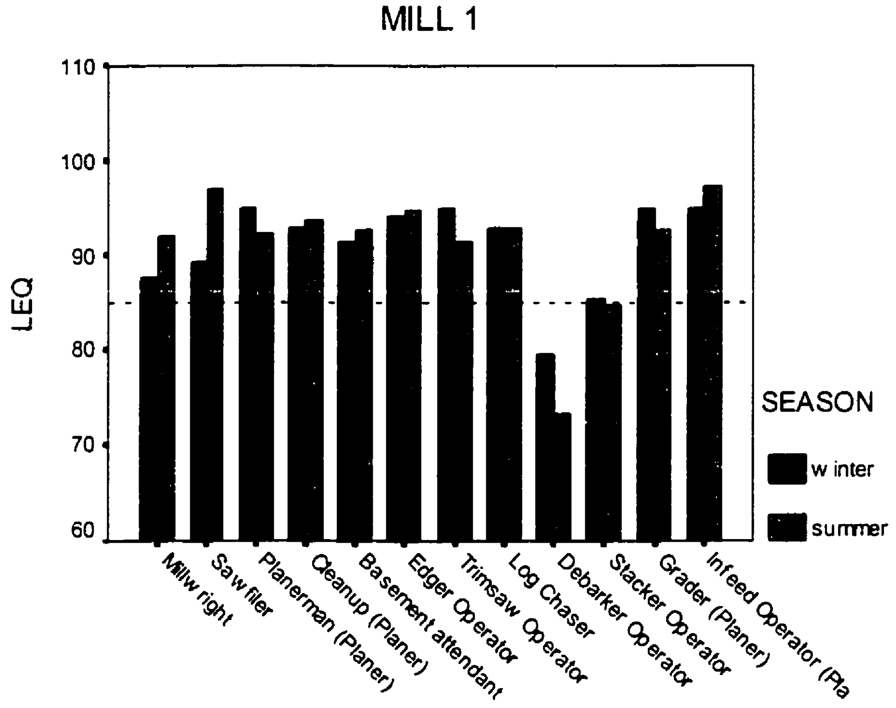
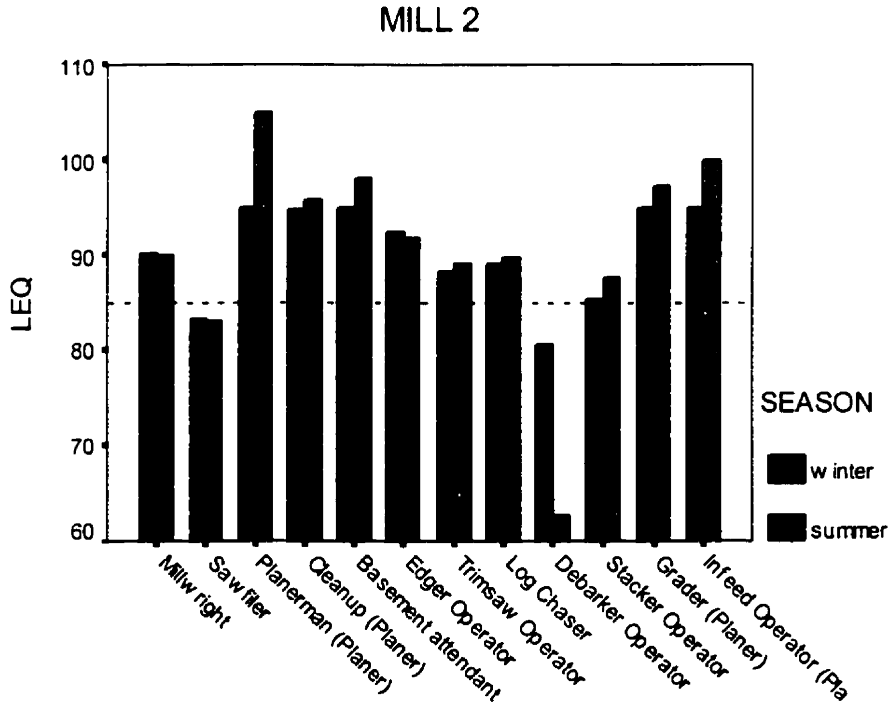
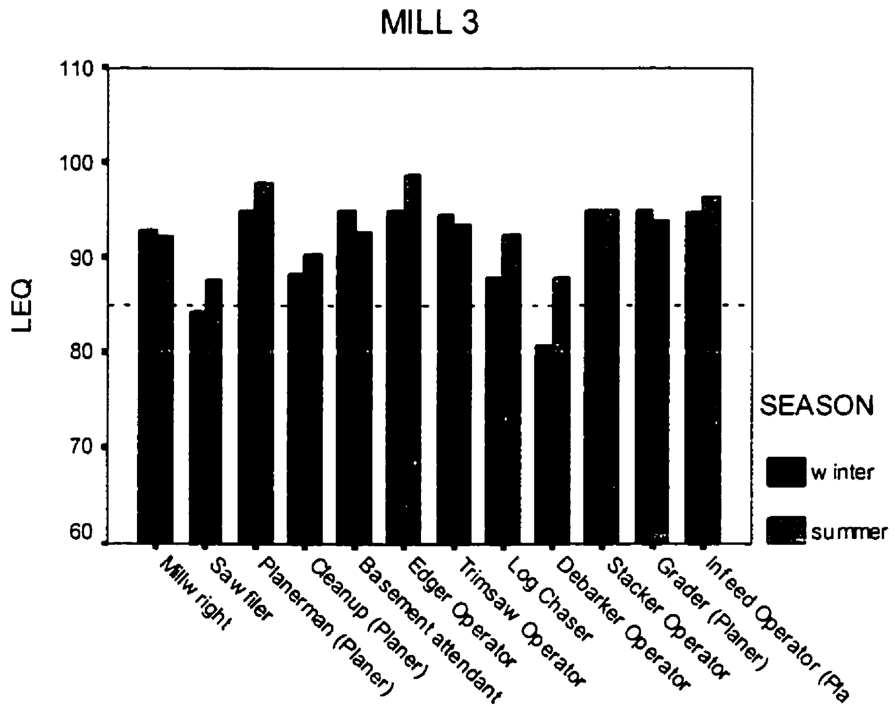
Appendix 1

LEQ's by season for each job category

NOTE: each bar represents one 8-hr TWA
Absent bars mean that job category was not measured for that season in that mill



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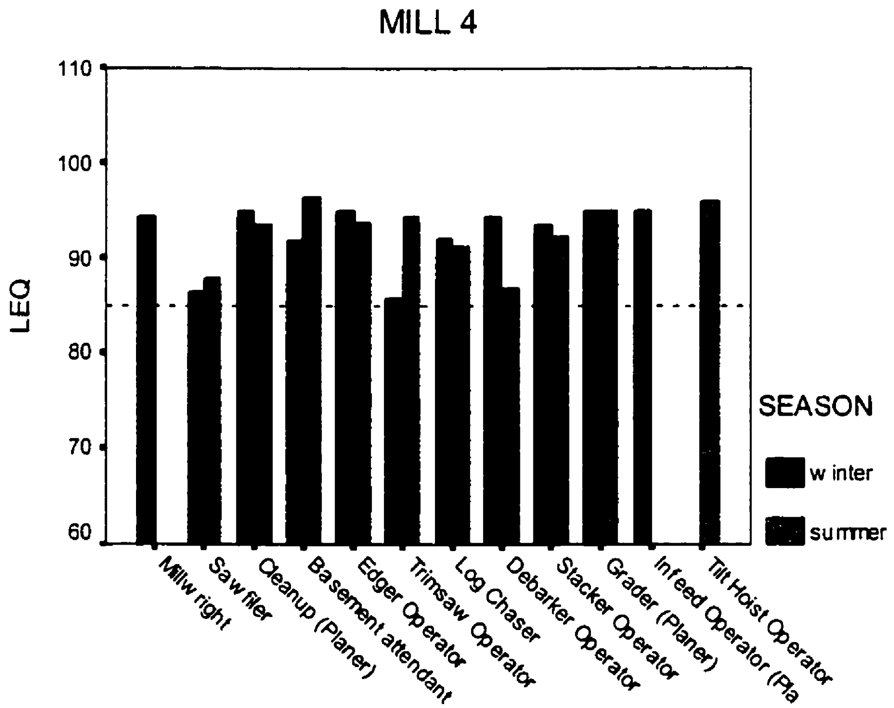
Basement attendant
Edger Operator
Trimsaw Operator
Log Chaser
Debarker Operator
Stacker Operator
Grader (Planer)
Infeed Operator (Pla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Trimsaw Operator
Log Chaser
Debarker Operator
Stacker Operator
Grader (Planer)
Infeed Operator (Pla
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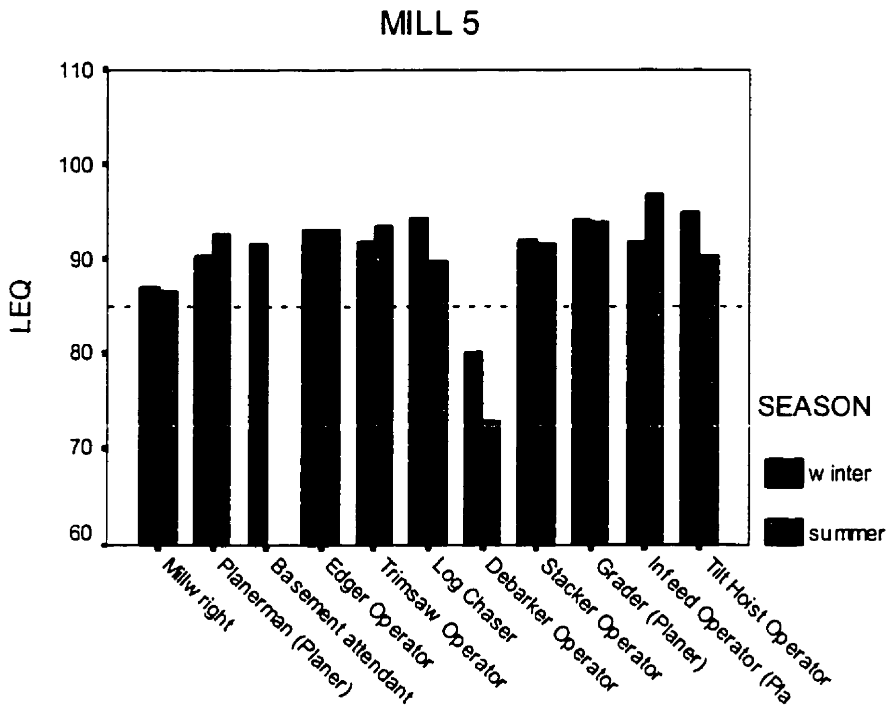
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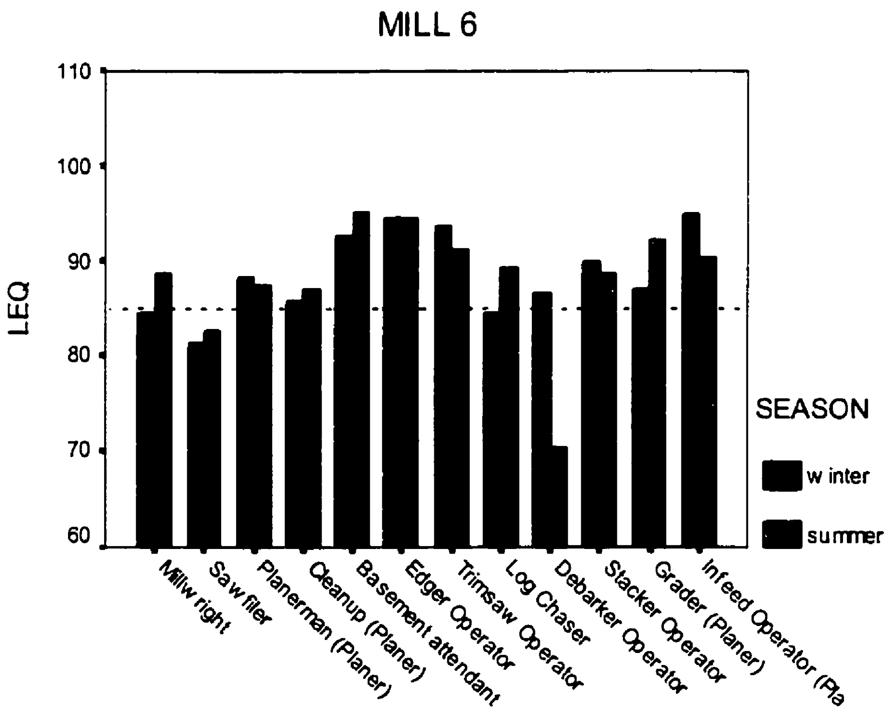
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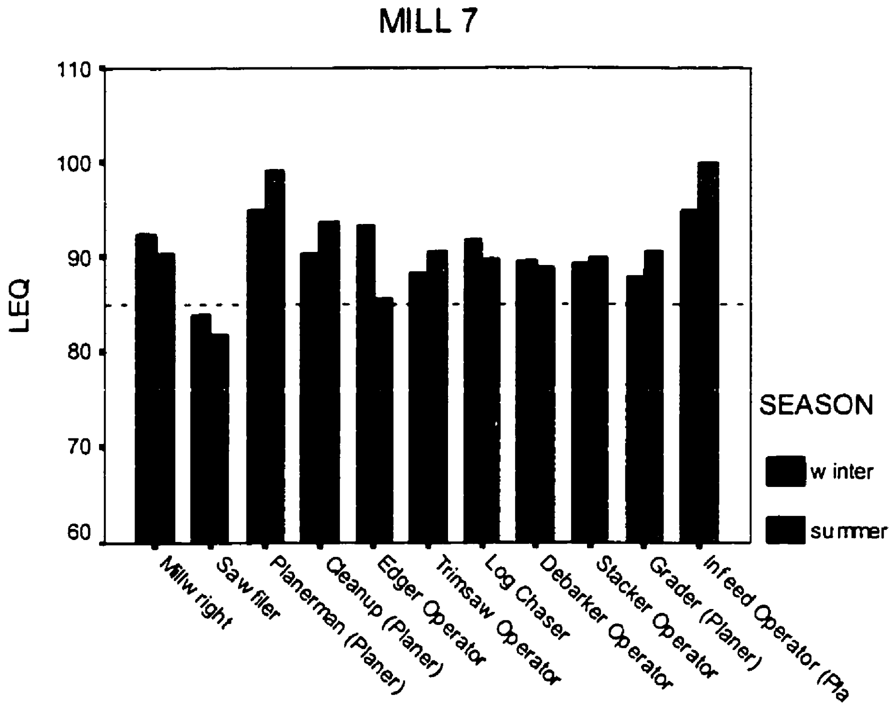
Grader (Planer)
Infeed Operator (Pla


MILL 7
110
100
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SEASON
w inter
summer
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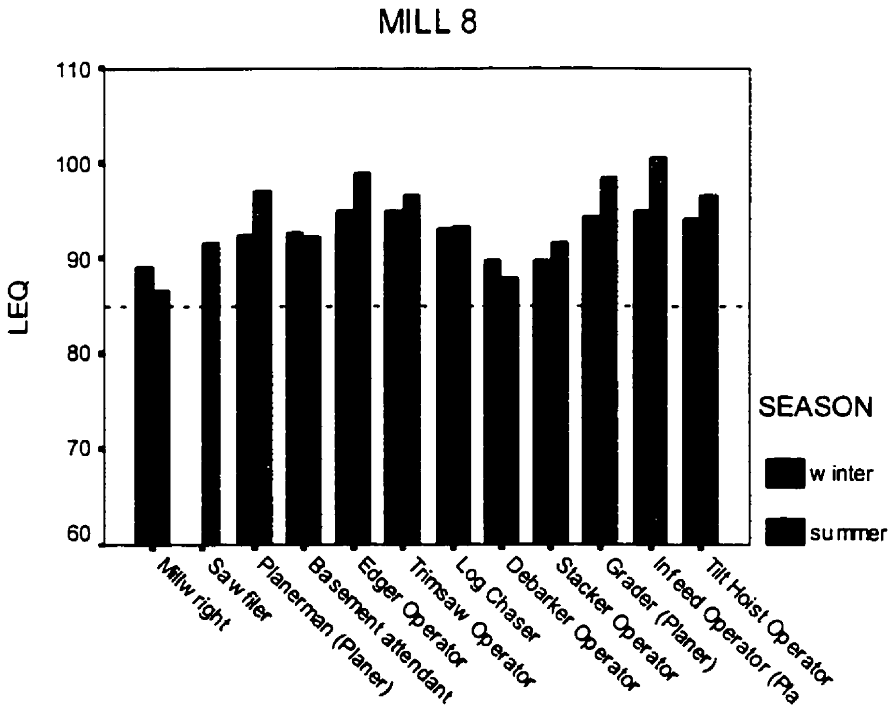
Saw filer
Planerman (Planer)
Cleanup (Planer)
Edger Operator
Trimsaw Operator
Log Chaser
Debarker Operator
Stacker Operator
Grader (Planer)
Infeed Operator (Pla


MILL 8
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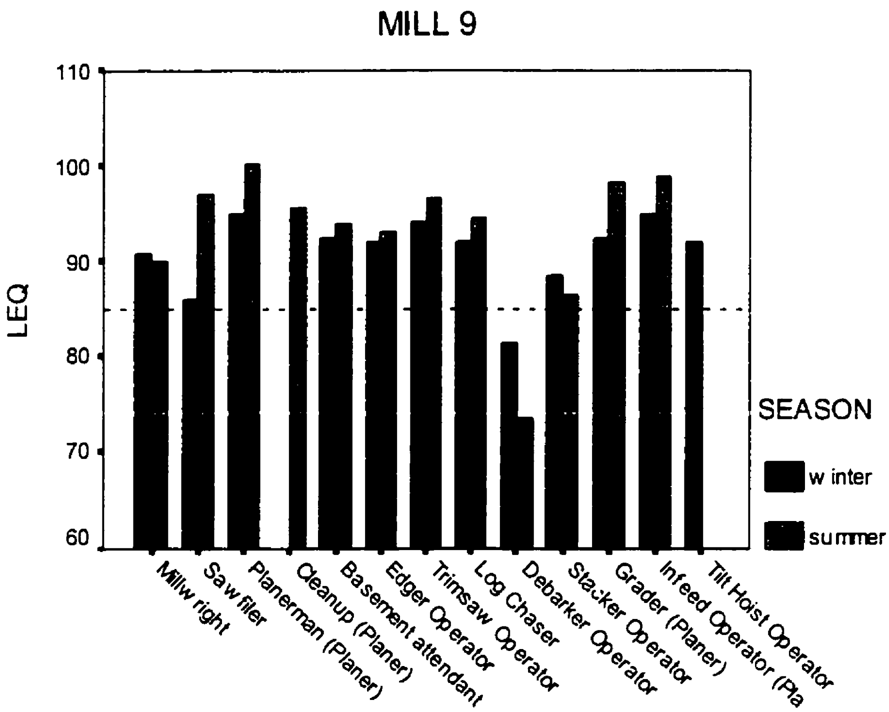
Saw filer
Planerman (Planer)
Basement attendant
Edger Operator
Trimsaw Operator
Log Chaser
Debarker Operator
Stacker Operator
Grader (Planer)
Infeed Operator (Pla
Tilt Hoist Operator


MILL 9
110
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summer
Millw right
Sawfiler
Planerman (Planer)
Cleanup (Planer)
Basement attendant
Edger Operator
Trimsaw Operator
Log Chaser
Debarker Operator
Stacker Operator
Grader (Planer)
Infeed Operator (Pla
Tilt Hoist Operator

Appendix 2

Frequency tables of noise levels for each job and occupational group

NOTE:

- **Each count represents one 8-hr TWA from one worker in that job or group.**
- **Mills have no more than 2 counts per job category, since one 8-hr TWA was measured per job per season.**
- **Bold text in the Job Categories was used when either the planerman or infeed operator had at least one 8-hr TWA in the high category**

Mill 1

	Counts per noise category		
Job	**low (<85)**	**medium (85-95)**	**high (>95)**
Millwright		2	
Sawfiler		1	1
Planerman (Planer)		1	**1**
Cleanup (Planer)		2	
Basement Attendant		2	
Edger Operator		2	
Trimsaw Operator		1	1
Log Chaser		2	
Debarker Operator	2		
Stacker Operator	1	1	
Grader (Planer)		1	1
Infeed Operator (Planer)			**2**
Occupational Group			
Cleanup		4	
Maintenance		4	2
Planermill Production		1	3
Sawmill Production	3	6	1

Mill 2

	Counts per noise category		
Job	**low (<85)**	**medium (85-95)**	**high (>95)**
Millwright		2	
Sawfiler	2		
Planerman (Planer)			**2**
Cleanup (Planer)		1	1
Basement Attendant			2
Edger Operator		2	
Trimsaw Operator		2	
Log Chaser		2	
Debarker Operator	2		
Stacker Operator		2	
Grader (Planer)			2
Infeed Operator (Planer)			**2**
Occupational Group			
Cleanup		1	3
Maintenance	2	2	2
Planermill Production			4
Sawmill Production	2	8	

Mill 3

	Counts per noise category		
Job	**low (<85)**	**medium (85-95)**	**high (>95)**
Millwright		2	
Sawfiler	1	1	
Planerman (Planer)			**2**
Cleanup (Planer)		2	
Basement Attendant		1	1
Edger Operator			2
Trimsaw Operator		2	
Log Chaser		2	
Debarker Operator	1	1	
Stacker Operator			2
Grader (Planer)		1	1
Infeed Operator (Planer)		1	**1**
[redacted]			
Occupational Group			
Cleanup		3	1
Maintenance	1	3	2
Planermill Production		2	2
Sawmill Production	1	5	4

Mill 4

	Counts per noise category		
Job	**low (<85)**	**medium (85-95)**	**high (>95)**
Millwright		1	
Sawfiler		2	
Cleanup (Planer)		1	1
Basement Attendant		1	1
Edger Operator		1	2
Trimsaw Operator	1	2	
Log Chaser		2	
Debarker Operator		2	
Stacker Operator		2	
Grader (Planer)			2
Infeed Operator (Planer)			**1**
Tilt Hoist Operator (Planer)			1
Occupational Group			
Cleanup		2	2
Maintenance		3	
Planermill Production			4
Sawmill Production	1	9	2

Mill 5

	Counts per noise category		
Job	**low (<85)**	**medium (85-95)**	**high (>95)**
Millwright		2	
Planerman (Planer)		2	
Basement Attendant		1	
Edger Operator		2	1
Trimsaw Operator		3	
Log Chaser		2	
Debarker Operator	2		
Stacker Operator		2	
Grader (Planer)		2	
Infeed Operator (Planer)		1	**1**
Tilt Hoist Operator (Planer)		1	1
Occupational Group			
Cleanup		1	
Maintenance		4	
Planermill Production		4	2
Sawmill Production	2	9	1

Mill 6

	Counts per noise category		
Job	**low (<85)**	**medium (85-95)**	**high (>95)**
Millwright	1	1	
Sawfiler	2		
Planerman (Planer)		2	
Cleanup (Planer)		2	
Basement Attendant		1	1
Edger Operator		2	
Trimsaw Operator		2	
Log Chaser	1	1	
Debarker Operator	1	1	
Stacker Operator		2	
Grader (Planer)		2	
Infeed Operator (Planer)		1	**1**
Occupational Group			
Cleanup		3	1
Maintenance	3	3	
Planermill Production		3	1
Sawmill Production	2	8	

Mill 7

	Counts per noise category		
Job	**low (<85)**	**medium (85-95)**	**high (>95)**
Millwright		2	
Sawfiler	2		
Planerman (Planer)			**2**
Cleanup (Planer)		2	
Edger Operator	1	2	
Trimsaw Operator		3	
Log Chaser		2	
Debarker Operator		2	
Stacker Operator		2	
Grader (Planer)		2	
Infeed Operator (Planer)			**2**
Occupational Group			
Cleanup		2	
Maintenance	2	2	2
Planermill Production		2	2
Sawmill Production	1	11	

Mill 8

	Counts per noise category		
Job	**low (<85)**	**medium (85-95)**	**high (>95)**
Millwright		2	
Sawfiler		1	
Planerman (Planer)		1	**1**
Basement Attendant		2	
Edger Operator			2
Trimsaw Operator			2
Log Chaser		2	
Debarker Operator		2	
Stacker Operator		2	
Grader (Planer)		1	1
Infeed Operator (Planer)			**2**
Tilt Hoist Operator (Planer)		1	1
Occupational Group			
Cleanup		2	
Maintenance		4	1
Planermill Production		2	4
Sawmill Production		6	4

Mill 9

	Counts per noise category		
Job	**low (<85)**	**medium (85-95)**	**high (>95)**
Millwright		2	
Sawfiler		1	1
Planerman (Planer)			**2**
Cleanup (Planer)			1
Basement Attendant		2	
Edger Operator		2	
Trimsaw Operator		1	1
Log Chaser		2	
Debarker Operator	2		
Stacker Operator		2	
Grader (Planer)		1	1
Infeed Operator (Planer)			**2**
Tilt Hoist Operator (Planer)		1	
Occupational Group			
Cleanup		2	1
Maintenance		3	3
Planermill Production		2	3
Sawmill Production	2	7	1

Appendix 3.

Class A Hearing Protection Definition

As defined by the CSA standard Z94.2-94, (Hearing Protectors, Occupational Health and Safety), Class A hearing protection is defined as a hearing protection device with the *minimum* attenuation (dB) as listed below at various frequencies:

Frequency (Hz)	Minimum Attenuation (dB)
125	10
250	18
500	26
1000	31
2000	33
3150	33
4000	31
6300	33
8000	33