Quantitative Assessment of Risks Involved in Mechanized Skiing in Canada

by

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B.Sc., Technische Universität Dresden, 2014

Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of

Master of Science

in

Water Management and Environmental Engineering

- Mountain Risk Engineering -

UNIVERSITY OF NATURAL RESOURCES AND LIFE SCIENCES, VIENNA

2017

AFFIDATIVE

I hereby declare that I am the sole author of this work. No assistance other than that which is permitted has been used. Ideas and quotes taken directly or indirectly from other sources are identified as such.

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Innsbruck, 10 November 2017 ....

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Abstract

Guests and guides partaking in commercial mechanized backcountry skiing are exposed to numerous types of hazards (e.g., avalanches, tree wells, cliffs, crevasses) that can result in injury or death. While guides have extensive practical experience in managing the risk associated with these hazards, detailed quantitative estimations of the associated risks are currently lacking. This represents a considerable barrier for evaluating existing risk management practices and impedes the further improvement of backcountry safety within the mechanized skiing industry.

This study collected historical incident and exposure information from helicopter- and snowcat-skiing operations to perform a quantitative retrospective risk analysis. The collected dataset spans 47 winter seasons (1969/70 to 2015/16) with a total of 2,792,570 skierdays and 763 incidents that resulted in injuries or fatalities among guests or guides.

The overall mortality rate for mechanized skiing between the seasons 1996/97 and 2015/16 was 21.0 x 10^{-6} per day skiing. The highest risk was associated with avalanches (14.4 x 10^{-6}), followed by non-avalanche related deep snow immersion. Avalanche mortality decreased substantially over the study period. Comparing the two types of mechanized skiing, avalanche mortality was higher in helicopter-skiing, and the risk of NARSID was higher in snowcat-skiing.

The highest risks of major injury were associated with ski accidents and collisions. Higher values of morbidity were found for guides engaged in snowcat-skiing, compared to helicopter-skiing guides.

Keywords: Risk analysis, avalanche risk, mortality rate, mountain mortality, mountain guides, backcountry safety, backcountry skiing, helicopter-skiing, snowcat-skiing.

ACKNOWLEDGEMENTS

This piece of work would not have been possible without the help and guidance of my supervisor Dr. Pascal Haegeli. Thank you for the great mentoring throughout this project and all the skills you have taught me – it was a real pleasure to work with you.

Thanks also to Dr. Sven Fuchs who supported me right from the beginning in my intention to write my thesis abroad, and helped me with his constructive advice and support in the preparation of the present work.

The SARP team of the Simon Fraser University in Burnaby created a very pleasant working atmosphere and made me feel comfortable in Canada very quick. Thank you for all the interesting talks and the shared adventures! The skiing with you was fantastic!

HeliCat Canada, the association of helicopter- and snowcat-skiing in Canada, sponsored my research but also provided me with data for my research. Thanks Ian, Miranda and Andrea for your support! Also, I would like to gratefully acknowledge the financial support from Mitacs Accelerate Program, as well as WorkSafeBC and the BC Coroners Service for providing me data for the analysis. Acknowledgements also to all operations who supplied me with the sensitive incident information for this research. Your confidence was utmost important for carrying out the analysis. It is great to see such an industry, where competing companies meet in friendship and work closely together for a mutual success and the safety of the clients.

Lastly, and most of all, I would like to thank my family and friends for being there for me, whenever I am in need!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Acronyms

CAA	Canadian Avalanche Association
CADORS	Civil Aviation Daily Occurrence Reporting System
CI	Confidence interval
DQ	Data Quality Level
gd	Guidedays
HCC	HeliCat Canada
InfoEx	Industry Information Exchange platform
MM	Micromort
MP	Microprobability
NARSID	Non-avalanche-related snow immersion death
sd	Skierdays
SIS	Snow immersion suffocation
TSB	Transportation Safety Board
UNISDR	United Nations International Strategy for Disaster Reduction

"We wanted to inhale and breathe life again [...] We were rebelling against an existence full of distorted values, against an existence where man is judged by the size of his living room, by the amount of chromium in his car. But here we were ourselves again; simple and pure. We were ready to trust each other, help each other and give to each other our everything.

This mountain to us is not a sports arena. To us it is a symbol of truth and a symbol of life as it should be. This mountain teaches us that we should endure hardships and not drift along the easy way, which always leads down."

– HANS GMOSER[1]

[1] pioneer of Helicopter-skiing and founder of Canadian Mountain Holidays (Donahue, 2008).

1 INTRODUCTION

1.1 Problem definition

Mechanized backcountry skiing refers to a skiing activity, where helicopters and snowcats are used to transport skiers and snowboarders to the top of untracked powder slopes that would otherwise be difficult to access. The commercial provision of mechanized backcountry skiing emerged in the mid-1960s in the mountains of Western Canada and since then evolved to an important industrial sector in the province of British Columbia (BC). Helicopter- and snowcat-skiing operations provide local and international tourists with tens of thousands of days of backcountry skiing every winter season and have contributed substantially to BC's world-renowned reputation for its vast mountain landscape, the high-quality snow and perfect skiing conditions.

Skiing in the uncontrolled backcountry is inherently risky, and both guests and guides expose themselves to numerous natural and man-made hazards that can result in injury or even death. Example of such hazards include cliffs, crevasses, tree wells, deep snow or helicopters, but the most prominent hazard in the winter backcountry are snow avalanches, which frequently cause fatalities also among skiers and snowboarders participating in helicopter- and snowcat-skiing. Between the winter seasons 1970 and 2016, 81 mechanized backcountry skiers lost their lives in snow avalanches in Canada (Avalanche Canada, n.d.).

Fatality numbers alone, however, only tell half of the story. To assess and compare the riskiness of different activities or hazards with one another, fatality or injury numbers must be divided by the exposure. Having an in-depth understanding of the mortality and morbidity rates in mechanized skiing is critical for operations that are interested in continuously improving their safety practices. Tracking risks over time helps to assess the effectiveness of risk management practices and serves as a compass for future actions to improve the safety for clients and employees.

So far, there have been no studies that have comprehensively examined the risks associated with the different hazards in commercial mechanized backcountry skiing in a quantitative way. Existing research on risks in the winter backcountry has almost exclusively focused on avalanches (e.g., Jamieson, Heageli, & Gauthier, 2010; Grimsdottir & McClung, 2006), but stated avalanche mortalities rarely rely on collected exposure data, and often are based on survey results or rough estimates (e.g., Valla, 1984; Winkler, Fischer, & Techel, 2016). Furthermore, most of these studies focus on primarily self-guided backcountry ski touring in Europe, which is not comparable with organized, helicopter- and snowcat-supported skiing in Canada. The current lack of reliable risk figures for commercial mechanized backcountry skiing is a serious barrier for examining the effectiveness of existing risk management practices and initiating new, evidence-based and targeted initiatives to further improve backcountry safety.

1.2 Objectives and hypothesis

The aim of this thesis is to address this knowledge gap by providing a detailed risk analysis of commercial mechanized backcountry skiing in Canada. The specific research objectives are as follows:

1) Objective:

   To compute and compare mortality rates for the main incident types, calculated separately for guests and guides as well as helicopter- and snowcat-skiing operations.

   Hypothesis:

   a. The avalanche mortality rate in commercial mechanized skiing decreased substantially over the last 50 years of operation.

b. The avalanche mortality is lower for snowcat-skiing operations than for helicopter-skiing operations.

c. The mortality rate associated with non-avalanche-related deep snow immersion represents the second largest risk for mechanized skiers.

2) Objective:

To determine the risk of major injuries (morbidity rate) associated with the main incident types, both, for guests and guides.

Hypothesis:

a. For both, guests and guides in the mechanized skiing industry, the highest morbidity rates are associated with the same incident types.

b. Snowcat-skiing operations have a higher morbidity rate than helicopter-skiing operations.

3) Objective:

To compare calculated mortality and morbidity rates for mechanized skiing with mortality and morbidity rates of other mountain and everyday life activities published in the literature.

Hypothesis:

a. Mechanized skiing is associated with higher mortality rates than hiking, trekking, marathon running or alpine skiing.

b. The mortality rates for guests are higher than mortality rates for guides.

c. The mortality rate of driving a vehicle is higher than the risk of dying in an avalanche while participating in mechanized skiing.

d. Morbidity rates for mechanized skiing are not substantially higher than for other mountain sports.

1.3 Document organization

This thesis starts with a brief review of the history of helicopter- and snowcat-skiing, followed by a delineation of the industry profile of mechanized skiing in Canada. I then define various key terms that are important for understanding the content of the proceeding chapters and provide a detailed description of the different hazards inherent to mechanized backcountry skiing. Subsequently, existing operational risk management practices, which represent the current industry safety standard, are described. At the end of the chapter, mortality rates and morbidity rates associated with various adventure sports and everyday life activities are reviewed to provide context for the interpretation of the mortality and morbidity calculated for mechanized skiing.

The methods section of this thesis describes the details of the data collection, incident classification, and statistical analysis. First, the criteria according to which the data was collected and classified are introduced. Then, the individual data sources and their contributions to the composition of the exposure and incident datasets are described in detail. At the end, the methods used for the statistical analysis are presented.

A summary of the collected data and the individual results of the statistical risk analyses are presented in detail in the results section. In the discussion section, the results are interpreted, and the specific research hypotheses are evaluated. The calculated mortality and morbidity rates are also compared to the relevant risk values in other domains and limitations of the analysis are described. The conclusion at the end of the thesis contains a short summary of the research, the contributions of the findings to the field of study and some thoughts on future research.

2 BACKGROUND

2.1 Mechanized backcountry skiing in Canada

2.1.1 Overview

The term *mechanized backcountry skiing* summarizes all skiing and snowboarding activities which use mechanized transportation, particularly helicopters or snowcats, to access the backcountry.

This type of sport activity was born in the province of British Columbia (BC) in Canada in 1964, when Hans Gmoser and Leo Grillmaier established the first helicopter-skiing operation in the Bugaboos, a mountain range in the Purcell Mountains of Eastern BC (Donahue, 2008). Snowcat-skiing did not emerge until much later. It was in 1975 when the first operation of this type surfaced in the Kootenay region in the southeast of the province (Selkirk Snowcat Skiing, n.d.).

Figure 1: Hans Gmoser and a group of guests on a helicopter-skiing trip in the Cariboo Mountains, 1969 (McLeish, 2014).

Over the last five decades numerous other mechanized skiing operations have been founded all over the world: from Canada and the United States to Chile, Japan, Europe, New Zealand, India and Russia. However, the conditions for the growth of this industry was most ideal in Western Canada, where large mountain ranges are covered with large amounts of low density snow every winter season. High operational reliability due to the terrain and weather conditions, and the presence of wide and barely inhabited areas were main reasons why BC became the world leader in helicopter- and snowcat-skiing (Williams & Hunter, 2002).

2.1.2 Industry profile

Since the start of commercial mechanized skiing in 1964, the industry in BC grew with an average of three new helicopter- and snowcat-skiing operations starting up every four years. There are currently a total of 41 operations spread over all mountain ranges across the province, accounting for the vast majority of mechanized skiing operations in Canada (HeliCat Canada [HCC], 2016). In fact, I am currently only aware of one small operation that operates outside of BC. This particular operation is based out of Whitehorse, Yukon territory, and the skiing is taking place along the border to Alaska and BC.

The mechanized skiing industry in Canada accounts for more than 30,000 skiers and approximately 100,000 days of skiing every year (HCC, 2016; Figure 2). Typical trips are about three days long (HCC, 2016) and on average, guests ski between 4,000 and 7,000 vertical meters per day (Heliskiing Canada, n.d.). The actual amount of skiing done in a day depends on the ability of the skier, the group size, as well as the current snow and weather conditions.

On a skiing day, certified ski guides lead groups of 4 to 11 skiers and snowboarders from predetermined starting points down a variety of different terrain to pick-up spots at the bottom of the runs. Thereby, the selection of the skiing runs follows a clearly defined, hierarchical and iterative process, to keep the residual risks at an acceptable level. In the morning, the avalanche hazard in the skiing tenure is assessed, on which the guiding team during the daily ‘guides meeting’ decides whether predefined runs are open or closed. Based on the resulting ‘run list’, according to the prevailing snow and weather conditions, as well as the ability and motivation of the guests, the guides decide which runs are skied (Sterchi, Haegeli, & Israelson, 2016).

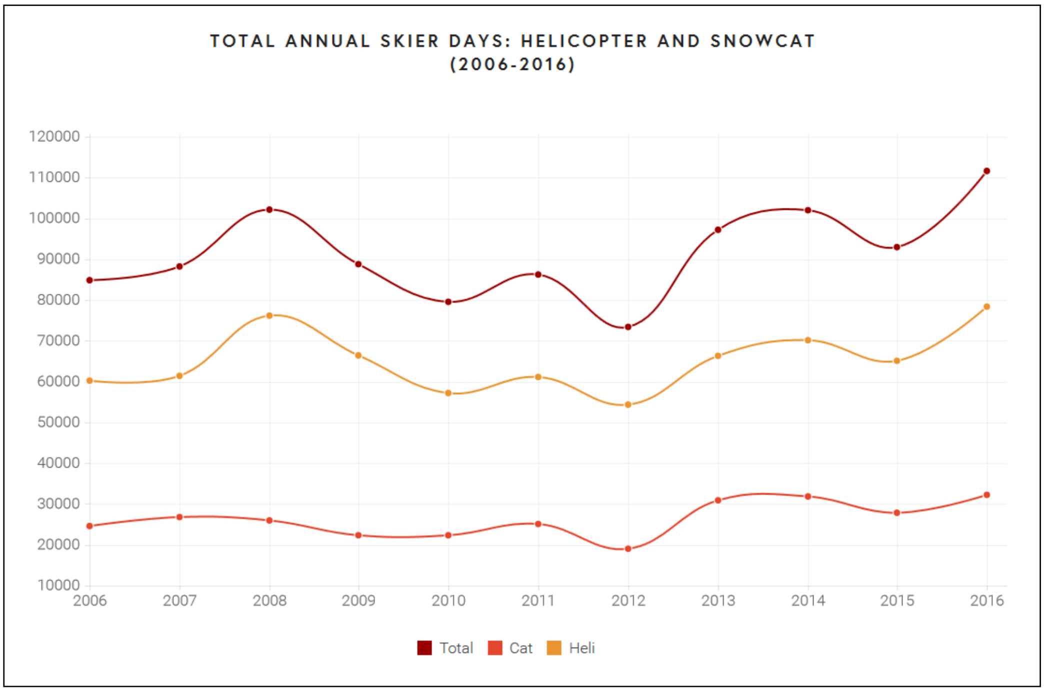

Figure 2: Total annual skierdays in the mechanized skiing industry between the winter seasons 2006 and 2016 (HCC, n.d.-a).

Helicopters and snowcats are used to transport guests and guides uphill to the starting points of the skiing runs. The high flexibility and speed of helicopters, allows helicopter-skiing operations to make use of large tenures and operate in various terrain with a variety of skiing options. Snowcat-skiing operations at the other hand, use snowcats – truck-sized fully tracked vehicles – to drive up the mountain on snow roads, which have been built by the operation throughout the winter. Compared to helicopters, snowcats are much slower and limited to the extent of their road network. Snowcat-skiing operations therefore have smaller tenures and often have larger parts of their skiing terrain around treeline. However, unlike helicopters, snowcats cannot get grounded by bad weather conditions and are therefore able to operate under all weather conditions during the winter season.

Specialized mechanized skiing operators usually do not only provide transportation and guides for exclusive ski trips, but also include specialized ski equipment and avalanche safety gear, lodging and hospitality in their services. Guests can choose between packages of different lengths, among different ski group sizes and according to their skiing ability. The prices vary greatly between the different packages, the type of mechanized skiing, and the season. A package can cost between C$440, for a single snowcat-skiing day during low season (K3 Cat Ski, n.d.) and more than C$180,000, for an exclusive seven-day private helicopter-skiing package during high season (Mike Wiegele Helicopter Skiing, n.d.). Calculations from HCC (2016) over a period of three winter seasons from 2013 to 2015 show mean revenues per skierday of about C$1,800 for helicopter-skiing operators and C$900 for snowcat-skiing operators. With 100,000 skierdays per year (HCC, n.d.), this results in a total yearly revenue of more than C$150 million for the BC mechanized skiing industry.

The helicopter and snowcat skiing industry is a significant employer in small, rural mountain communities in BC. Overall, the sector directly and indirectly employs over 2,000 people in BC (HCC, 2016).

2.2 Hazards and risks in mechanized skiing

2.2.1 <u>Definitions</u>

Hazard

A *hazard* is "a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage" (UNISDR, 2009, p. 17). More simply expressed, a hazard is any situation or source that can potentially result in harm.

People involved in commercial mechanized backcountry skiing are exposed to many potential sources of harm that can lead to injuries or even death (see Chapter 2.2.2 for details). However, no matter how large the avalanche, or how big the cliff; a hazard is of no consequence if nothing of value is exposed to it.

Exposure

Exposure is understood as "people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses" (UNISDR, 2009, p. 15).

Exposure describes the overlap in space and time of a hazardous source or situation, and persons or property. It is therefore essential for the risk concept as a whole. Only the exposure can transform the hazard into a risk.

In mechanized backcountry skiing, guests and guides expose themselves constantly to hazards of the winter wilderness. The act of exposing oneself to the 'pristine wilderness environment' and 'skiing untouched powder in the remote mountains' are main attractions for guests to participate in this sport (HCC, 2016). In addition to guests and employees, helicopter and snowcats are also exposed to mountain hazards during mechanized skiing.

Risk

The likelihood of a hazard to cause damage to exposed persons or other objects of value is called *risk*. Risk is "the combination of the probability of an event and its negative consequences" (UNISDR, 2009, p. 25).

$$Risk = Probabilty\ of\ occurrence\ (f, hazard, exposure) \\ * Expected\ damage\ (f, hazard, vulnerability)$$

In this work, risk is estimated quantitatively using historic incident records. Risk is calculated by relating the frequency of past incidents with serious consequences (e.g. fatalities, major injuries) to the overall exposure (e.g. skierdays, guidedays) during a specific period of time.

- Mortality rate

The *mortality rate* is the ratio of deaths to a particular population (e.g. backcountry skiers), per unit of time. It can also be described as the risk to die, death rate, or probability of death and is often related to a particular hazard (e.g. snow avalanches). Mortality rates are usually expressed relative to an even population size or exposure unit (e.g., deaths per 1,000 individuals, deaths per 1,000 hours of activity). In cases where the mortality risk is relatively small, the term *micromorts* (MM) has been used in the literature as a short hand to describe fatalities per one million individuals or one million exposure units (e.g., Howard, 1980).

- Morbidity rate

Similar to the mortality rate, the *morbidity rate* usually relates to a certain hazard and a specific population, but indicates the probability of injury within a specific time period. In this work, morbidity rate is referred to the probability (or risk) of major injury.

Analogous to the mortality rate, also the morbidity rate is usually expressed to an even population size or exposure unit. Small probabilities are commonly expressed as *microprobabilities* (MP) to describe a probability of injury per one million individuals or exposure units (e.g., Howard, 1989; Moedden, 2015).

2.2.2 Hazards and risks

In the following, hazards and associated risks inherent to mechanized backcountry skiing are described in detail. The selection is based on the content of the existing waiver for 'wilderness activities' (Kennedy, 2015) used by mechanized backcountry skiing operations in Canada.

Snow avalanches

Avalanches are the biggest risk for winter recreationalists in the Canadian backcountry. About 45% of all winter activity deaths in BC from the 2007/08 season to the 2015/16 season were avalanche related (BC Coroners Service, 2017). Between the winter seasons 2007/08 and 2016/17, 132 people lost their lives in avalanches in Canada. Apart from one fatality at an outdoor worksite, all avalanche fatalities were winter backcountry recreationists, either making their own decisions (92%) or under the care of a professional guide (8%). Among the self-directed recreational fatalities, 48% were mountain snowmobile riders, 31% backcountry skiers, 5% out-of-bounds skiers and 16% pursued other winter backcountry activities. Over the last ten winters, an average of 13.2 individuals lost their lives in 10 avalanche fatal accidents every winter. In the commercial mechanized skiing industry, 8 fatal avalanche incidents resulted in 10 deaths (8%) during the same ten-year period. This corresponds to an average of one fatality in 0.8 accidents per year (Avalanche Canada, n.d.).

Studies that estimate avalanche mortality rates are rare, primarily because of the general lack of exposure data. Haegeli (2015) is the only study that estimated avalanche mortality in Canada (Table 1). Using ten years of avalanche fatality records and annual skierday numbers from HCC (1994/1995 to 2013/2014), he estimated the mortality rate from avalanche accidents in mechanized backcountry skiing to be 19.5 MM. Grimsdottir and McClung (2006) examined the relative risk of accidentally triggering an avalanche greater than size 1 as a function of elevation band, aspect, stability rating and time of the year, based on long-term records of Canadian Mountain Holidays. Their analysis showed that the risk of accidentally triggering an avalanche greater than size 1 was higher during ‘poor’ stability, at higher elevations and earlier in the season. However, Grimsdottir and McClung (2006) did not explicitly calculate mortality rates because of the small size of their dataset.

Haegeli (2015), and Grimsdottir and McClung (2006) were only able to calculate risk values because commercial backcountry skiing operations need to keep records of backcountry use for government reporting purposes. This information is unfortunately typically not available for non-commercial backcountry recreation. The various authors have used different approaches for addressing this issue (Table 1). Winkler et al. (2016), one of the most recent studies, calculated the mortality in backcountry ski touring based on the percentage of the Swiss population engaged in this activity, which was determined by two large surveys about the sport behavior of the Swiss population. Valla (1984), who estimated the daily avalanche mortality rate of backcountry ski tourers in France between the winter seasons 1971/72 and 1983/8, also used survey data for his calculations. Zweifel, Raez and Stucki (2006) calculated avalanche mortality by extrapolating exposure data from trail counters over a small number of winters to a 20-year period. Due to the considerable uncertainties in exposure data estimates and the small sample sizes (e.g., Zweifel et al., 2006), the published mortality rates must be interpreted with extreme caution.

Table 1: Studies providing estimates for avalanche related mortality rates for backcountry skiers and snowboarders.

AUTHORS	LOCATION	ACTIVITY/ COMMERCIAL	PERIOD	MORTALITY [$*10^{-6}$]	UNIT	DATASET
Haegeli (2015)	Canada	Mechanized Backcountry skiing/ Yes	1994/95-2013/14	19.5	/day	31 fatalities 1.59 $x10^6$ skierdays
Munter (2009)	Switzerland	Backcountry ski touring/ No	1980/81-1990/91	20	/day	17 fatalities/season 850,000 touring days/season (estimated)
Valla (1984)	France	Backcountry ski touring/ No	1971/72-1983/84	9	/day	180 fatalities 20 $x10^6$ touring days (estimated)
Winkler et al. (2016)	Switzerland	Backcountry ski touring/ No	2004/05-2014/15	8.7	/day	78 fatalities Survey-based approach (approx. 21,000 participants)
Zweifel et al. (2006)	Davos, Switzerland	Backcountry snow sport/ No	2005/06	30	/day	3 fatalities (in 20 years) 5,576 counted users (assumption: constant activity over 20 years = 111,520 users)

Tree wells and deep snow

Tree wells and deep snow hazards refer to the possibility of falling into a tree well or into deep snow and dying of snow immersion suffocation. These two hazards are primarily a concern in deep snowpack areas in mid-winter, especially following extreme snowfall events. Such meteorological conditions can be found in Western North America, particularly in the Cascades, Sierra Nevada and mountain ranges of BC (Van Tilburg, 2010).

Tree well immersion is the most prominent type of non-avalanche related snow immersion. *Tree wells* refer to hidden void spaces around the trunks of large conifers (e.g., fir, spruce, cedar), where overhanging branches efficiently shelter the trunk, preventing snow from being deposited. Such holes, or wells, at the base of trees can be 3 or more meters deep, depending on the seasonal snowpack (Van Tilburg, 2010). The hazard of *deep snow* refers to other situations or locations where unconsolidated snow accumulates and poses a risk to recreationists in the winter backcountry. This includes depressions (e.g., creeks, drainages) and areas around obstacles such as rocks and boulders. However, after an extreme snowfall event, when more than a meter of soft, unconsolidated snow is present, deep snow immersion can even happen when a skier simply loses balance and falls over.

Snow immersion suffocation, also known as 'Non-avalanche-related snow immersion death' (NARSID), is a significant threat to people falling into tree wells or deep snow, but academic literature on this topic is sparse. A review article by Van Tilburg (2010) states that more than 70 snow immersion related asphyxia deaths were documented in Western North America between the winter seasons 1990/1991 and 2009/2010. Baugher (2012) reports that 64 NARSIDs had occurred in U.S. ski areas in the winter seasons 1990/1991 to 2011/2012. An earlier study by Baugher (2006, as quoted by Van Tilburg, 2010) highlights that the mortality due to NARSID in U.S. ski resorts might be at a similar level as the mortality from avalanches. During the winter seasons 1990/1991 to 2005/2006, Baugher documented six in-bounds and 46 out-of-bounds NARSIDs, compared to three in-bounds and 45 out-of-bounds avalanche fatalities. Cadman (1999) reports that eight of a total of 32 skiing fatalities in ski areas in BC between 1993 and 1998 were NARSID related; six were related to tree well incidents and the remaining two to deep snow immersion.

Cliffs, cornices, and steep terrain

Cliffs, cornices and steep terrain are hazards that can lead to major falls in backcountry skiing, which can result in major injuries or even death.

The term *cornice* or *snow cornice* refers to an overhanging edge of snow, which is formed from wind transported snow building up on the lee side of a mountain peak or ridge (Figure 3). The deposited snow can eventually break off under additional load or due to a change in weather conditions.

Figure 3: Snow cornices on the lee side of a mountain ridge (Flann, 2017).

A helicopter-ski guide and one of his guests died due to a cornice collapse and a consequent major fall in Switzerland in 2014 (Blick, 2014). George (2004) showed that during the 2003/04 winter season, fatalities due to major falls (15 cases) were the second major cause of death, following avalanche fatalities (24 cases), among off-piste and backcountry skier accidents in France.

Glaciers

Glacial features like crevasses, bergschrunds, and glacier moulins represent serious hazards to backcountry skiers, which can cause major falls and result in serious injuries or even death.

Crevasses refer to deep cracks and fractures in the upper brittle part of the glacier ice. They form due to extensional changes in velocity or gradient and are typically up to 30 meters deep and 5 meters wide (Swissduc, 2017, "Crevasse"). *Glacier moulins* are cylindrical, vertical holes on flat areas on a glacier, where water enters from the surface (Figure 4; Swissduc, 2017, "Moulin"). *Bergschrunds* are a special type of cracks that appear between the moving glacier ice and stagnant ice, firn or rock above (National Geographic, n.d., "crevasse").

During mid-winter, many of the existing crevasses, moulins and bergschrunds are covered by the seasonal snowpack. This allows skiers to travel on glaciers relatively freely, without being roped up. However, the snow bridges may be weak and break under the weight of a skier, leading to unintended falls into hidden openings.

Figure 4: Glacier moulin on the Unteraargletscher, Bernese Alps, Switzerland (Swissduc, 2017, "Moulin").

George (2004) reported three crevasse fatalities during the winter season 2003/2004 among off-piste and backcountry skier accidents in France. This corresponds to 7% out of a total of

42 fatalities. Pasquier et al. (2014) reported of 415 crevasse falls which led to a helicopter rescue mission between January 1, 2000, and December 31, 2010, among recreationalists in Switzerland. 239 of them were backcountry or off-piste skiers and snowboarders and 30 out of 239 incidents ended fatal. This corresponds to an average of three fatalities per year for the respective time period.

Another potential hazard from glaciers is being hit from debris of icefalls. Icefalls develop when glaciers flow over steeper terrain and ice constantly breaks off due to the movement of the glacier. Such icefalls form a hazard for backcountry skiers travelling by underneath, and can result in major injuries and death. In the winter of 2014/15, an Italian helicopter-skiing guest was killed in Alaska when he was hit by a piece of ice that broke off an icefall (McLaughlin, 2015).

Helicopters

Helicopters represent a substantial hazard for employees and guests of helicopter-skiing operations. Flight incidents can arise from technical failures and/or human errors during take-off, en route, in final approach, and landing. Running helicopters also pose a hazard to people moving round helicopters or carrying objects around the aircraft. Getting hit by a turning blade or an object that is blown around by the downwash of the helicopter can cause serious injuries and death as well as damage the helicopter. Furthermore, helicopter parked in mountainous terrain can be exposed to natural hazards, such as avalanches or unexpected strong gusts. The air blast of an avalanche can potentially lift a standing helicopter and cause damage to the aircraft and threaten passengers inside the machine (Honig, Bartelt, & Bühler, 2014).

The Transportation Safety Board of Canada (TSB) routinely investigates aviation incidents that result in injuries, fatalities or damage to the aircraft in Canada, and publishes detailed statistical summaries of reported incidents every year. The 2016 summary reports of 344 accidents of

Canadian registered helicopters that resulted in 53 fatalities between 2007 and 2016 (TSB, 2017a). Sixty-three of these accidents, involving eight deaths were classified as "Pleasure/Travel".

While the TSB investigations include helicopters involved in mechanized skiing, there is currently no research that explicitly examines helicopter incidents in this industry.

Snowcats and vehicles

Snowcat-skiing operations use snowcats to a) build and maintain a network of temporary snow roads, and b) to transport guests and guides to their skiing terrain via this road network. Some helicopter-skiing operations also have snowcats to provide skiing on days when helicopters cannot fly or to maintain their road systems around the lodge.

Hazards associated with travelling in snowcats involve tipping on a steep section or due to a collapse of the road. In addition, moving around a snowcat, loading and unloading of equipment, and entering or exiting the cabin has the potential to cause incidents that result in injuries.

Some mechanized skiing operations also use other vehicles, such as golf carts, tractors, cars and busses, to transport equipment or skiers to helicopter staging areas to reduce flight times. Hazards associated with vehicles are collisions or roll-overs, due to hazardous winter driving conditions or inattentiveness.

While individual cases of snowcat incidents have been documented (e.g., Staka et al., 2013), no detailed studies on snowcat accidents in mechanized skiing exist.

Obstacles

Skiing through forests does not only involve the risk of falling into a tree well, but there are also obstacles, such as trees and branches, tree stumps, or dead fall, skiers can collide with.

Outside of forests, skiers can collide with rocks and boulders, which can be hidden under the snow surface.

Other hazards caused by trees are falling branches and snow mushrooms. *Snow mushrooms* (Figure 5) are large blocks of snow developing on top of trees and rocks. They can get very heavy and have the potential of seriously injuring skiers when they fall off trees as *tree bombs*.

Figure 5: Snow mushrooms on Rogers Pass, BC, Canada.

The frozen debris tree bombs, avalanches or other chunks of hard snow or ice can also pose a hazard to skiers as they can make for challenging skiing conditions. Skiing is particularly challenging when these obstacles are covered by just a little bit of snow, preventing skiers from spotting the challenge ahead of time.

Other objects skiers can collide with are snowcats and snowmobiles, man-made structures such as road banks or fences, as well as other skiers.

Open water

Creeks, ponds, small lakes and other bodies of water can pose another hazard in the winter backcountry. Backcountry travelers can accidentally fall into cold water when skiing next to or trying to cross open water. In addition to the potential injuries that can be sustained from the fall, victims falling into cold water can also suffer from a cold shock response (hypothermia, drowning and cardiac arrest), which can lead to severe injuries or death (Giesbrecht, 2000).

High physical exertion and cold weather

The physical demands of mechanized backcountry skiing are high. Skiers ski several thousand vertical meters every day, are exposed to cold weather, wind and high altitudes. The combination of high physical exertion and cold weather can lead to inattentiveness and overexertion, which increases the risk associated with other hazards. However, it can also directly result in non-traumatic medical emergencies, such as asthma attacks, strokes, and heart attacks. Under particularly cold conditions, guests and staff might suffer from frost bite or hypothermia.

Considerable research exists on the risk of non-traumatic deaths in ski areas. Ruedl et al. (2011), for example, evaluated all fatalities in Austrian ski areas for the 2005/06 to 2009/10 winter seasons. The authors calculated an incident rate for non-traumatic fatalities of 0.42 per million skier days with heart attacks being the cause of death in the majority of the cases (74%). Similar studies on fatalities in ski areas have been conducted by Weston, Moore, and Rich (1977), Morrow, McQuillen, Eaton, and Bergstein (1988), Sherry and Clout (1988), Tough and Butt (1993), and Xiang and Stallones (2003). However, no comparable studies exist for backcountry skiing in general or mechanized skiing in particular.

Demanding ski and weather conditions

Flat-light and whiteout conditions caused by clouds, fog and/or snowfall can make it difficult for backcountry skiers to see hazardous terrain features (e.g. drainages, creeks, snowcat tracks) and properly judge skiing conditions. Reduced visibility therefore has the potential to increase the risks associated with all other presented hazard types.

Snow conditions often vary substantially in time, as well as among different types of terrain, altitudes or aspects. The snow surface can be hard or soft, supportive or breakable, smooth or rough. There can be powder snow at one place and wet snow lower in the valley, one meter of snow here, almost none there. Skiing in variable snow conditions can be extremely demanding and exhausting for guests. These conditions therefore have the potential to increase the risk of collisions, ski accidents and deep snow immersion incidents.

Other

Another potentially serious hazard in commercial mechanized backcountry skiing is the use of explosive for controlling avalanche hazard and assessing snow stability. While numerous examples of serious incidents exist (e.g., death of a ski patroller at the Squaw Valley resort in California, USA; Miller, 2017), the use of explosives in the mechanized skiing industry is rare and I am not aware of any incidents with this type of hazard.

Other hazards involved in commercial backcountry skiing with potentially serious consequences involve getting lost, being separated from one’s skiing party, or encountering wild animals. Even though, encounters with wild animals in Canada are common and possible even during the winter months (Davies, 2015), I am not aware of any serious encounters in the mechanized skiing industry.

2.2.3 Hazard management

Since staff and guest safety is of highest priority for mechanized skiing operations, the industry has developed sophisticated safety procedures and best practices. Promoting and improving sector safety is a key component of HCC's 2020 strategic plan (HCC, 2016). While the situation of every operation is unique, the operation safety guidelines published by HCC (2014) set the benchmark for safety in the industry by defining the minimum operational safety procedures required for HCC member operations.

According to HCC (2014) guidelines, the most important components of operational hazard management are:

General procedures

- Having a detailed rescue plan, containing universal procedures for rescue and evacuation.
- Every member of a mechanized skiing group (guides and clients) is to be equipped with a functioning transceiver.
- Guides are to be expertly proficient in transceiver use. They are to carry avalanche probe, shovel, medical kit and radio.
- Guides are to be experts in methods of crevasse rescue and must carry sufficient equipment to carry out simple rescues.
- Helicopter landings must be marked adequately throughout the operating season.
- Guides must ensure that skis, poles, and packs are appropriately secured during helicopter flight.
- Guide is to communicate information about the run, hazards, and instructions clearly and concisely to his or her guests.

- Guides are to perform head-counts on regroup-stops to make sure the whole group has come back together.

Daily procedures

- Continuous local observation of weather, snow stratigraphy and avalanche occurrence.
- Observation and being aware of current and predicted weather conditions.
- Observation and evaluation of snow stability and expected changes.
- Guides' meeting to discuss observations and forecasts, exchange information among guides and pilots, evaluate snow stability and formulate the day's program (condition dependent terrain/ run selection).
- Exchange of significant information regarding weather, snow stratigraphy, and avalanche activity to adjacent mechanized skiing operations.
- Recording of weather, snowpack and avalanche observations, as well as snow stability evaluations and skiing programs.

Clients' training and instructions

- Clients are to be instructed in the use of avalanche transceivers and are to undergo a practice exercise conducted by guides.
- Pilot or guide is to present a 'helicopter safety talk' to clients at the start of a helicopter session where he/she points out the major hazards and the procedures clients must respect. In snowcat- skiing operations, equivalent snowcat safety trainings are held for clients.
- Clients must ski behind the guide and follow his instructions.
- Partner ('buddy') system is introduced to the clients and must be emphasized by the guides.

- Alcohol and recreational drug use are prohibited while skiing; clients are to be encouraged to arrive fit and prepared.

Many operations have additional safety videos and/or brochures to provide their clients with more detailed information on hazards involved in mechanized backcountry skiing and how to prevent incidents. Introductory powder ski courses for beginner skiers in some operations help to prevent minor ski accidents (minor falls, twisted knees, etc.) and tree well demonstrations are used to draw attention to the risk of snow immersion. Some operations also have a resident doctor skiing with guests, who can respond immediately if an emergency occurs.

2.3 Risk of death and injury in adventure sports and everyday life

2.3.1 Mortality rates

Considerable research exists on the mortality associated with other mountain activities or adventures sports (Table 2). Mortality rates presented in the studies ranged from 0.11 MM/day for cross-country skiing (Farahmand, Hållmarker, Brobert, & Ahlbom, 2007) to 1,870 MM/day for mountaineering in Mt Cook National Park in New Zealand (Malcom, 2001).

The fatality numbers in most of the studies are related to recorded exposure data, to calculate the respective mortality rates. Ruedl et al. (2011) and Corra et al. (2004) used skier day figures from ski lift companies to calculate the death rates for alpine skiing and snowboarding. Fahramand et al. (2007), Redelmeier & Greenwald (2007) as well as Harris, Henry, Rohman, Haas, & Maron (2010) used numbers of participants in organized competitive races to analyze the mortality of cross-country skiing, marathon running, and triathlon racing, respectively. Shlim and Houston (1989) calculated the death rate associated with trekking in Nepal based on the number of 'trekking permits' issued in the respective time period. Also, Canbek et al. (2015) and Soreide, Ellingson, and Knutson (2006) calculated the chances of dying while paragliding and base jumping based on recorded exposure data. The estimates of the mortality rates associated with high alpine mountaineering and backcountry ski touring in Switzerland by Mosimann (2014), however, are based on the results of a survey about the sport behavior of Swiss residents and members of the Swiss Alpine Club. Also, the risks of dying associated with mountaineering in England and Wales (Avery et al., 1990) and hiking in Austria (Burtscher, Philadelphy, Nachbauer, & Likar, 1994) are based on exposure information collected through surveys.

Table 2: Mortality rate estimates associated with different mountain and sport activities.

AUTHORS	LOCATION	ACTIVITY	PERIOD	MORTALITY [*10^{-6}]	UNIT	DATASET
[1]*Avery et al. (1990)*	England & Wales	Mountaineering	1982- 1988	2.3	/day	70 fatalities
[1]*Corra et al. (2004)*	South Tyrol (ITA)	Alpine skiing and snowboarding	2001/02	1.6	/day	9 fatalities 500,000 skierdays
[1]*Farahmand et al. (2007)*	Vasaloppet (SWE)	Cross country skiing	1970- 2005	0.11	/day	13 fatalities 581 person-years
[1]*Malcom (2001)*	Mt. Cook NP (NZE)	Mountaineering	1981- 1995	1870	/day	33 fatalities
[1]*McIntosh et al. (2008)*	Mt McKinley NP (USA)	Mountaineering	1990- 2006	100	/day	96 fatalities
Burtscher et al. (1994)	Austria	Hiking	1986- 1992	[2]5.7	/day	
Canbek et al. (2015)	Fethiye Baba Mountain (TUR)	Paragliding	2004- 2011	70	/jump	18 fatalities 242,355 jumps
Harris et al. (2010)	United States	Triathlon racing	2006- 2008	15	/race	14 fatalities 959,214 participants
Mosimann (2014)	Switzerland	Backcountry ski touring	2004- 2013	40	/year	Recorded number of fatalities
		High alpine mountaineering	2004- 2013	80	/year	Survey-based approach for estimating exposure
Redelmeier & Greenwald (2007)	United States	Marathon racing	1975- 2004	8	/run	26 fatalities 3,292,268 runners
Ruedl et al. (2011)	Austria	Alpine skiing and snowboarding	2005/06-2009/10	0.79	/day	207 fatalities 259.19 x10^6 skierdays
Shlim & Houstan (1989)	Nepal	Trekking	1984- 1987	[2]11	/day	23 fatalities 148,000 trekkers ([2] estimate: 14 days/trekker)
Soreide et al. (2006)	Kjerag Massif (NOR)	Base jumping	1995- 2005	432	/jump	9 fatalities 20,850 jumps
Tough & Butt (1993)	Alberta (CAN)	Alpine skiing	1985- 1990	1.2	/day	19 fatalities

[1] study cited in Windsor et al (2009)
[2] mortality rates calculated by Burtscher et al. (1995)

In everyday life, most of the deaths are not caused by accidents but rather by diseases and illnesses. In 2013, the leading causes of death in Canada were cancer (29.8%) and heart diseases (19.8%). Unintentional deaths caused by accidents only accounted for 4.5% of all deaths. The overall risk of dying for the average Canadian was approximately 20 MM per day (Statistics Canada, 2017).

Relatively high risks are associated with driving on the road. The mortality rate for vehicle driving in BC in 2015 was 0.77 MM/100 km of driving (Transport Canada, 2017). In 2007, the probability of death associated with motorcycle riding in the United States was 39 MM/100 miles (24 MM/100 km) of riding (National Center for Statistical Analysis, 2007).

There is also a substantial risk of death for women giving birth. The average maternal mortality rate in Canada between the years 1997/1998 and 2010/2011 was 86 MM/delivery (Public Health Agency of Canada, 2013).

2.3.2 Morbidity rates

Several authors calculated probabilities of injury associated with different types of sport activities (Table 3). Schöffl, Hoffmann, and Küpper (2013) calculated an injury rate for indoor climbing of 0.02/1000 hrs of climbing activities. For the analysis, all injuries graded as a 2 to 4 on the Medical Commission of the Union Internationale des Association d'Alpinisme score were considered. Schöffl et al. (2013) also cites Limb (1995) and Schöffl and Winkelmann (1999), who reported injury rates of 0.027 and 0.079/1000 hrs of indoor climbing respectively. However, Schöffl and Küpper (2006) found a substantially higher injury risk for competition climbing (3.1/1000 hrs). Schöffl, V., Schöffl I., Schwarz, Hennig, and Küpper (2009) used questionnaires to examine injury rates in ice climbing. Their analysis reveals that ice climbing has a considerably morbidity rate of 4.1/1000 hrs of climbing.

Canbek et al. (2015) found an injury rate of 260/million paragliding flights in Turkey between August 2004 and September 2011. In this study, the morbidity rate was calculated based on the number of patients which sustained an injury requiring hospitalization.

Mölsä, Kujala, and Näsman (2000) reported an injury rate in ice hockey at the highest competition level in Finland in the 1990s of 83/1000 player-hrs. In this case an injury was defined as any sudden trauma requiring examination and treatment by a physician.

Table 3: Morbidity rate estimates associated with different mountain and sport activities.

AUTHORS	LOCATION	ACTIVITY	PERIOD	MORBIDITY [$*10^{-3}$]	UNIT	DATASET
[1]*Limb (1995)*	England, Scotland, and Wales	Indoor climbing	1991-1993	0.027	/hour	55 injuries 1.021 $x10^6$ visits
[1]*Schöffl & Winkelmann (1999)*		Indoor climbing		0.079	/hour	4 injuries 25,163 visits
Aschauer et al. (2007)	Austria	Alpine skiing and snowboarding	2005	[2]1,1	/hour	2,261 injuries 1,783,054 hours
Canbek et al. (2015)	Fethiye Baba Mountain (TUR)	Paragliding	2004-2011	0.26	/jump	64 injuries 242,355 jumps
Mölsä et al. (2000)	Finland	Ice hockey	1992/1993	87	/hour	97 injuries 1,170 exposure hours
Schöffl & Küpper (2006)	Munich, Germany	Climbing (competition)	2005	3.1	/hour	4 injuries 1,300 hours
Schöffl et al. (2009)	International	Ice climbing		4.1	/hour	95 injuries 88 climbers
Schöffl et al. (2013)	Stuttgart, Germany	Indoor climbing	2007-2011	0.02	/hour	30 injuries 1.4 $x10^6$ exposure hours
Schussman et al. (1990)	Grand Teton NP, Wyoming, USA	Rock climbing	1981-1986	0.56	/hour	108 injuries 192,800 hours

[1]study cited in Schöffl et al. (2013)
[2]calculated under the assumption that a skier or snowboarder skis 6 hours on a typical skiing day

Transport Canada (2017) estimated the 2015 morbidity rate as 583.7 injuries[2] per billion vehicle-kilometers on roads in BC. The statistics published by the Australian Department of Infrastructure, Transport, Regional Development and Local Government (Johnston, Brooks, & Savage, 2008) reveal that motorcycle riders show much higher morbidity rates. The serious injury rate[3] for motorcycle riding in the fiscal year 2003/2004 amounted to 3,640 per billion

[2] Include all reported severities of injuries ranging from minimal to serious.
[3] Injury which results in the person being admitted to a hospital, and subsequently discharged alive.

vehicle-kilometers, while the injury rate for cars amounted to only 90 serious injuries per billion vehicle kilometers.

3 METHODS

3.1 Data collection

Various sources were scanned, to collect information on historical incidents and exposure. The obtained data was entered into an electronic database and incident types were classified for an efficient and transparent analysis.

The classification of the incident and injury data is based on specific characteristics.

3.1.1 Definitions

General

A *season* (synonymous to *winter season*) refers to a hydrological year, which is defined as the 12-month period between October 1 of one year and September 30 of the following. The season is designated by the calendar year in which it ends. For example, the season 1970 started on October 1, 1969 and ended on September 30, 1970. Alternatively, a season can be displayed by indicating both years separated by a slash (e.g., 1969/70).

Exposure data

Exposure in the mechanized skiing industry is recorded and displayed as *skierdays* (sd), which represents one guest skiing one day.

While skierdays provide information about the number of clients skiing per day, *guidedays* (gd) display the same information for guides.

Incident data

To perform the risk analysis, the collected incident data needed to be classified. Therefore, the following classification parameters were introduced.

- Activity

Incidents were classified as *helicopter-skiing* or *snowcat-skiing* incidents, depending on the activity that was pursued when the incident happened.

- Provider

Dependent on whether the organizer of the helicopter- or snowcat-skiing trip, where the incident happened, was a registered mechanized skiing business, a film production company or a non-commercial provider, the incident was classified as *commercial*, *film crew* or *non-commercial*.

- Incident type

Records were assigned to an incident type based on the nature of the incident (Table 4).

Table 4: Incident type classification.

INCIDENT TYPE	DEFINITION
Avalanche	Incidents caused by moving snow masses, such as avalanches or small sluffs.
Collision	Incidents caused by the collision of a person's body part with an object. Objects include trees, stumps, logs or branches as well as rocks and boulders, avalanche debris and chunks of frozen snow, fences, other skiers, animals, non-running helicopters and vehicles, and any other objects skiers might collide with while skiing.
Crevasse	Any incidents caused by skiers falling into crevasses, bergschrunds or glacier moulins, and consequential impacts (e.g. frostbite, snow immersion).
Snow immersion	Every non-avalanche related snow immersion incident, except tree well immersion. This includes snow immersion around obstacles (e.g. rocks, boulders, huts), in open terrain or in natural depressions (e.g. creeks, drainages).
Emergency	Every incident caused by high physical exertion or cold weather. This includes heart and asthma attacks, strokes, hypothermia, frostbites and altitude sickness. Furthermore, incidents caused by food allergies, intolerances or intoxications and any kind of illness.
Fall from height	Incidents caused by falls from heights of more than two meters. This refers to falls of backcountry skiers and snowboarders from cornices, over cliffs, drops, or steep terrain.
Helicopter	Helicopter crashes or breakdowns, as well as people-created incidents, such as collisions between people or objects and helicopter rotors or fuselage, or loose objects passing into air intakes. Emergency exits, or doors may be opened accidentally in flight.

Lodge	Every incident, which happened at the lodge or base station and was not directly related to skiing activities.
Ski accident	Accidental falls of backcountry skiers over drops or into natural depressions (e.g. creek beds, moats, wind scours) of heights less than two meters, as well as incidents caused by changing or demanding snow conditions, bad visibility or inattentiveness, overexertion and reckless behavior of the skier.
Snowcat	Incidents caused by a moving snowcat.
Tree well	Incidents caused by deep snow immersion in the void space around tree trunks (tree wells).
Vehicle	Incidents caused by a moving vehicle, other than a snowcat.
Other	Every other incident, related to helicopter- and snowcat-skiing activities, which cannot be attributed to another incident type.

- Person role

Persons involved in an incident were classified as guests, guides, pilots or staff, according to their function in the field.

- *Guest:* Everybody who was not employed by the mechanized skiing operation, regardless whether they were a paying client or not.
- *Pilot:* Any helicopter pilot.
- *Guide*: Any employee in a leadership position during skiing. This includes lead guides, assistant guides and tail guides.
- *Staff*: Any other employee. This includes photographers, physicians, and snowcat-drivers, as well as lodge or maintenance staff skiing with the guests without an active role.

- Injury severity

All of the recorded injuries were classified as *minor*, *major* or *fatal*. While the distinction between fatal and non-fatal injuries was straight forward, the distinction between major and minor injury was more challenging. In the case of worker injuries, the differentiation between *minor* and *major injuries* was based on the reported recovery period as defined by WorkSafe

BC's classification profile for "Serious Injury Claim" (Scarlett, 2017, personal communication). Every injury that resulted in a recovery period of 50 or more days was classified as a major injury. Injuries with recovery periods less than 50 days were classified as minor injuries. For non-worker injuries Table 5 was used as a guide to distinguish between major and minor injuries.

Table 5: Mechanized skiing injury classification.

INJURY TYPE	INJURIES
Minor	- Bruises - Contusions - Distortions - Minor concussion - Minor dislocation (e.g. finger, ankle, elbow, shoulder) - Minor fracture (e.g. finger, toe) - Partial tendon rupture - Shock and Hypothermia - Sprains - Swellings - Wounds (e.g. lacerations)
Major	- Artificial respiration needed - Complete tendon rupture (e.g. Achilles, ACL) - Heart attack - Major dislocation (e.g. hip) - Major fracture (e.g. leg, ankle, jaw, lumbar) - Resuscitation efforts needed - Stroke

In cases where the type of injury was not reported, or its degree could not be determined conclusively, it was classified as *unspecified injury severity*.

3.1.2 Data sources

Exposure data

Exposure data was provided by two main sources, HCC and individual operations. *HCC* provided detailed, reported and estimated seasonal skierday numbers for individual member-and non-member operations since the winter season 1995. For the seasons between 1970 and 1994, HCC provided best estimates of skier days for the entire mechanized skiing industry based on historic records (e.g., presentation of skierday numbers at previous association meetings). Some *operations* provided detailed information on skierdays for certain seasons on request.

Incident data

Different industry and out-of-industry sources were used to collect information on historical incidents in the mechanized skiing industry.

- Out of industry sources

The *Avalanche Accidents in Canada* books published by the Canadian Avalanche Association (Stethem & Schaerer, 1979, 1980; Schaerer, 1987; Jamieson & Geldsetzer, 1996; Jamieson, Haegeli, & Gauthier, 2010) summarize the fatal avalanches in Canada between the winter seasons 1943 and 2007. Most of the fatal avalanche incidents in the history of commercial mechanized skiing in Canada are described in detail in these books. Each book was screened for fatal avalanche incidents in the mechanized skiing industry and relevant cases were entered to the database.

Avalanche Canada, Canadian's national public avalanche safety organization, hosts the so-called *Avalanche Canada Incident Report Database*, which is publicly accessible on their homepage (http://old.avalanche.ca/cac/library/incident-report-database/view). The online interface of the database makes it possible to filter the available records according to activity (e.g., backcountry skiing, mechanized skiing, snowmobiling, etc.), province, season and severity of accident (fatal, non-fatal). A short incident summary, information on the weather and avalanche properties and additional external information is provided for each incident. The dataset includes information on avalanche accidents from 1885 to today. The database has been queried for “fatal avalanches” and “non-fatal avalanches” in “Mechanized skiing” in all seasons.

The TSB is a government agency, responsible for advancing transportation safety in Canada. Besides other tasks, the agency investigates aviation accidents. According to TSB Regulations (TSB, 2017-b), all air occurrences resulting in a person’s injury or death or in any damage to the aircraft must be reported to the TSB. These so-called *TSB Aviation Investigation Reports* are published, and can be accessed on the TSB homepage (http://www.tsb.gc.ca/eng/rapports-reports/aviation) and filtered by keywords. The reports provide a very detailed description of the incident and the underlying causes. The online incident database dates back as far as 1990. To find helicopter-skiing related helicopter incidents, the keyword “helicopter” was entered in the search bar and the resulting output was examined for relevant cases.

The *Civil Aviation Daily Occurrence Reporting System* (CADORS) is an online database maintained by Transport Canada that provides initial information on events involving Canadian-registered aircrafts and occurrences at Canadian airports and in Canadian airspace. The main information provider is the Canadian air traffic control (NAV Canada), but anybody can report occurrences. The reported information is therefore preliminary and unsubstantiated (Geisinger et al., 2003). The CADORS database goes back to 1993 and various filters can be used to submit specific database queries. For this study, the database was screened for “Helicopter” (Aircraft Category) occurrences in “British Columbia” (Province) and “ski” was entered in the ‘Narrative’ search bar. The results of the query were scanned for relevant cases.

The *British Columbia Coroners Service* is a provincial government agency that is responsible for investigating all unnatural, sudden and unexpected, unexplained or unattended deaths in BC (Province of British Columbia, n.d.). Upon request the Coroners Service provided an overview- list of all ski- and snowboard-related fatalities in Canada from the winter season

1993 until the season 2016. The list included activity (e.g. resort skiing, heliskiing, etc.), incident-type (e.g. avalanche, tree well, collision, etc.), date of occurrence, date of death, as well as the location of the incident and the victim's municipality. Furthermore, it was indicated if the death was caused by an avalanche.

Upon request, *WorkSafeBC* – the Workers' Compensation Board of BC – provided me with a list of worker incidents in the mechanized skiing industry in Canada from the seasons 2007 to 2016. The file included information on the date and location of the incident, the occupation of the employee, an incident and injury description, information on the loss of work days and the total claim amount, as well as the company name. According to the Workers' Compensation Act (WorkSafeBC, n.d. section 53) "an employer must report to the Board […] every injury to a worker that is or is claimed to be one arising out of and in the course of employment". This suggests, that all major injuries among employees in the mechanized backcountry skiing industry between the winter seasons 2007 and 2016 were included in this file.

Online news media frequently reported fatal incidents in the mechanized skiing industry. Such articles provided additional information about the circumstances of incidents and involved parties, and helped to complement the information available for single events.

- Industry-wide sources

The *Industry Information Exchange platform* (InfoEx) is a product of the Canadian Avalanche Association (CAA) that allows subscribing avalanche safety operations to privately exchange technical snow, weather, avalanche, and terrain information on a daily basis. The objective is to improve subscribers' awareness of avalanche and snowpack conditions across Western Canada and thereby enhance their ability to manage their local avalanche risk (CAA, n.d.). Helicopter- and snowcat-skiing operations are a key InfoEx subscriber group that uses the platform extensively to share operational avalanche safety information. For this study mechanized skiing operations were asked for permission to scan their records. If permission was granted, the database was queried using the following keywords: "injury", „injured", „hospital", „clinic", „medical", „helicopter", „damage", „loss", „destruct", „accident", „incident", „suffer", „harm", „hurt", „crash", „collapse", „demolish", „severe", „hypothermia", „conscious", „passed out", „resuscitation", „respiration", „burial", „involved", „involvement". The results of the query were scanned for any information on incidents and relevant information was entered into the database.

If a serious incident or close-call among mechanized skiing -operations gets voluntarily reported to HCC, a *HCC Incident Report* form is filled out (Appendix 1). Such a report contains a summary of the event including the main facts, followed by a detailed description of the incident and the resulting rescue operation. HCC Incident Reports are confidential and anonymous documents, which are circulated to all HCC member-operations to enhance awareness and prevention. HCC Incident Reports date back until 2014 and included avalanche, tree well, and helicopter occurrences.

Individual helicopter- and snowcat-skiing operations who participated in the study used either internal computerised databases or paper forms to document incidents and injuries within their company. These recordings were the main source of information on non-fatal incidents of guests. The type of operational incident recording and its reliability has evolved over time and varied substantially between the different operations (Table 6).

Table 6: Description of operator sources for incident data.

SOURCE	DESCRIPTION
Operational electronical database	Computerized databases are used to store detailed information on skierdays, weather, avalanche activity, run selection, incidents, and close-calls in a digital format. Electronical incident recording was only performed recently by a few operators.
Incident- Accident-, or Injury Report	'Incident Report', 'Accident Report', and 'Injury Report' are all synonyms for the most common paper form, used for incident recording (Appendix 2). These reports are filled out by guides or radio operators, whenever

	a guest or guide cannot continue skiing due to any occurrence. The reports are patient specific, and include generally the date, time and location of the occurrence, the name of the affected person and the responsible guide, the nature of injury and the actions, which have been taken. In many cases, these reports did not comprise the circumstances of the accident, neither the degree of injury of the patient. However, in many cases they were the only available information source of low risk incident types (e.g., ski accidents, collisions).
First Aid Incident Report, Ski Area Incident Report	These reports represent more detailed versions of the 'Incident Report' described above (Appendix 3). They usually contain most of the important information about the circumstances of the occurrence, as well as detailed descriptions of the resulting injuries, and documentation of the rescue procedures. Just like the 'Incident Report', also these reports are patient specific and are usually filled out by the guide, accompanying the ski group. In many operations this type of reports were the only form of incident recording. However, if filled out regularly, they provided am excellent source of data.
Base Rescue Radio Log	A Base Rescue Radio Log contains information on organizational and coordination procedures during a rescue scenario. This type of report gets only produced for incidents with complications, requiring additional support from other guides and helicopters. The information content regarding the incident and the resulting injury is limited. They helped in part to complement incident information retrieved from other sources.
Medical and First Aid Services	Some operations employ a medical physician who treats smaller injuries in the in-house clinic of the operator. Whenever the doctor attends to a patient, a patient record gets drafted, containing information about the medical state of the patient and the injury patterns. Such reports presented an excellent information source regarding the degree of injury of the patient.
Incident Witness Report	Witness reports contain detailed descriptions of conditions prior to the incident, information about the sequence of events from the witness's point of view, and the actions he took subsequently. Witness reports are filled out irregularly, and typically for serious incidents or close-calls.
Other Sources	Other intra-operational sources included other, less frequent document types (e.g., letters, claims, official investigation reports, medical/hospital reports, press releases), as well as anecdotal information from current and former staff members (e.g., guides, managers) of commercial mechanized skiing operations and helicopter companies.

3.2 Statistical analysis

Prior to analysis the incident and exposure information was adjusted and prepared. Missing values in exposure records were filled in, and the guide's exposure was defined. The incident records from individual operators were classified into different quality classes according to the completeness of their recordkeeping.

Mortality and morbidity rates were calculated for different hazards and different time periods. If the risk values were estimated based on samples of the industry, the estimates were extrapolated to the entire population by calculating confidence intervals for a finite population using the Clopper-Pearson approach (Clopper & Pearson, 1934).

3.2.1 Data pre-processing

Exposure data

Single missing seasonal skierday numbers within the dataset of individual operations were eliminated by linearly interpolating between skierday numbers of the two adjacent winter seasons.

Information on guidedays was unavailable from operations or other sources scanned in the process of data collection. I therefore estimated guidedays based on the guests' skierdays and the assumption that on average across the entire industry and study period one guide guided about six guests. Guidedays were therefore calculated by dividing skierdays by six, regardless of the activity (helicopter-/ snowcat-skiing) and the season.

No information on the exposure of staff or pilots was collected. Estimating pilot- or staffdays based on guests' skierdays was impossible because there is no obvious consistent ratio of guests to pilots, or guests to staff in the mechanized skiing industry.

Incident data

Incidents which could not be attributed to commercial mechanized skiing or which were not assignable to a specific incident type, were excluded. Furthermore, only guest and guide incidents were taken into account, since no exposure information could be gathered or derived for pilots or staff.

Information on non-fatal guest injuries was mainly provided by individual operations (see Chapter 3.1.2). Among the individual operations participating in this study, the type, the extent and quality of their incident records varied substantially. Dependent on the interplay of the various sources and the completeness of the provided incident records, different levels of data completeness were achieved for individual operations. This level of completeness – or data quality – also varied among years, since detailed information could be available for one year, but missing for the subsequent year.

To take this fact into account, and ensure that the data I used for the guest morbidity calculations had the required minimal data quality needed to perform the analysis, I assigned Data Quality Levels (DQ) to each winter and individual operation (Table 7).

Table 7: Data Quality Levels for non-fatal incidents, assigned for every year and individual operation.

DATA QUALITY LEVEL	DESCRIPTION
1	Detailed incident records of all severities, complete.
2	Detailed incident records of all severities, there might be missing data.
3	Single documented cases (reports, avalanche safety records); often only severe cases.
4	Anecdotal information from operation members; not documented.

3.2.2 Mortality rates

Mortality rates were calculated by dividing the fatality numbers by the exposure. Because the entire population was sampled, no statistical inference was needed and single estimates without confidence intervals were calculated. Mortality rates were displayed as fatalities per one million exposure days (skierdays, guidedays).

As a general guideline, observed differences in calculated daily mortality rates were regarded as being substantially different from each other if the difference was greater than 2 MM.

Avalanche mortality

The available information on avalanche fatalities was of high quality throughout the study period due to different high qualitative data sources. Therefore, it was reasonable to assume that the dataset of fatal avalanche incidents in the mechanized skiing industry was complete between the winter seasons 1970 and 2016.

I calculated average avalanche mortality rates for the entire study period from 1970 to 2016, as well as for 10-year intervals, to detect trends in the evolution of mechanized skiing. The calculations were performed for guests, guides and both groups together.

Incident type specific mortality

Non-avalanche related fatality records could be assumed to be complete for the last two decades, due to information provided by the BC Coroners Service, HCC and individual operators. Therefore, I was able to calculate incident type specific mortality rates for the winter seasons from 1997 until 2016.

I estimated average mortality rates for the different incident types, and compared them against each other. Mortality rates were also calculated separately for helicopter- and snowcat-skiing operations as well as for guests and guides, to allow direct comparisons.

3.2.3 Morbidity rates

Guide morbidity

For the winter seasons from 2007 until 2016 a complete dataset on major injuries among guides was collected for the entire mechanized skiing industry, based on information provided by WorkSafe BC.

Similar to the calculation of mortality rates, single estimates without confidence intervals were calculated, since the entire population was sampled. For the calculation, the number of major injuries was divided by the guidedays. The resulting morbidity rates were displayed as major injuries per one million guidedays.

I considered a difference of 20 MP per day as a meaningful threshold value to describe substantial differences between calculated morbidity rates.

Risk figures were estimated for different incident types and separately for snowcat- and helicopter-skiing operations.

Guest morbidity

Data on guest injuries was mainly collected from operational records and information from HCC. For the calculation of morbidity rates, I only included major injuries and injuries with unspecified injury severity from operations and years of DQ 1. The guest morbidity rates were calculated for the years from 2007 until 2016, since for this period the highest amount of data from operations of DQ 1 was collected.

For the estimation of the risk values, the number of major incidents was divided by the respective skierday data of operations with DQ 1. The result was subsequently extrapolated to the entire industry by calculating confidence intervals (CIs) using the Clopper-Pearson method (Clopper & Pearson, 1934) employed by the binom.test function in R and correcting it for a finite population. In the Clopper-Pearson method, the upper and lower boundary of the CI for an infinite population are defined by

$$\sum_{k=0}^{k} \binom{n}{k} p_{UCI}{}^{k}(1-p_{UCI})^{n-k} = \frac{\alpha}{2}$$

$$\sum_{k=x}^{n} \binom{n}{k} p_{LCI}{}^{k}(1-p_{LCI})^{n-k} = \frac{\alpha}{2}$$

where p_{LCI} and p_{UCI} are the lower and upper CI respectively, n is the number of trials, k the number of successes in the n trials, and 1- α is the confidence level. For the calculation of CIs, a CI level of 95 % (α = 0.05) was used. However, since the population of skierdays is actually finite and my sample typically represented a substantial proportion of the overall sample, I was able to further narrow the CI using a finite population correction.

The same risk calculation was then repeated, using the sum of major injuries and injuries of unspecified severity as input for the risk calculation. This was necessary to account for major injuries which were not classified as such.

Both calculations combined generate a range of risk values in which the true morbidity rate can be expected. The lower bound of this range is formed by the morbidity rate calculated using the major injuries only. The upper bound, however, is defined by the morbidity rate estimated by including the injuries with unspecified injury severity. The upper bound represents the situation, when all cases with unspecified injury severity were major injuries.

The morbidity rates of guests were displayed in major injuries per one million skierdays.

I considered two population risk values to be significantly different from each other if the CI of one risk estimate did not include the other risk estimate.

4 Results

4.1 Summary of the dataset

4.1.1 Exposure data

The mechanized skiing industry experienced a continuous growth in skierdays since its beginning (Figure 6). The increase was especially strong between the 1970 and 2000 winter seasons. In recent decades the growth was less marked than in the years before with several fluctuations. The highest exposure number within the industry was recorded in the season 2016 with 111,900 skierdays. During the 47 winter seasons between 1970 and 2016, a total of 2,792,570 skierdays were recorded in the mechanized skiing industry.

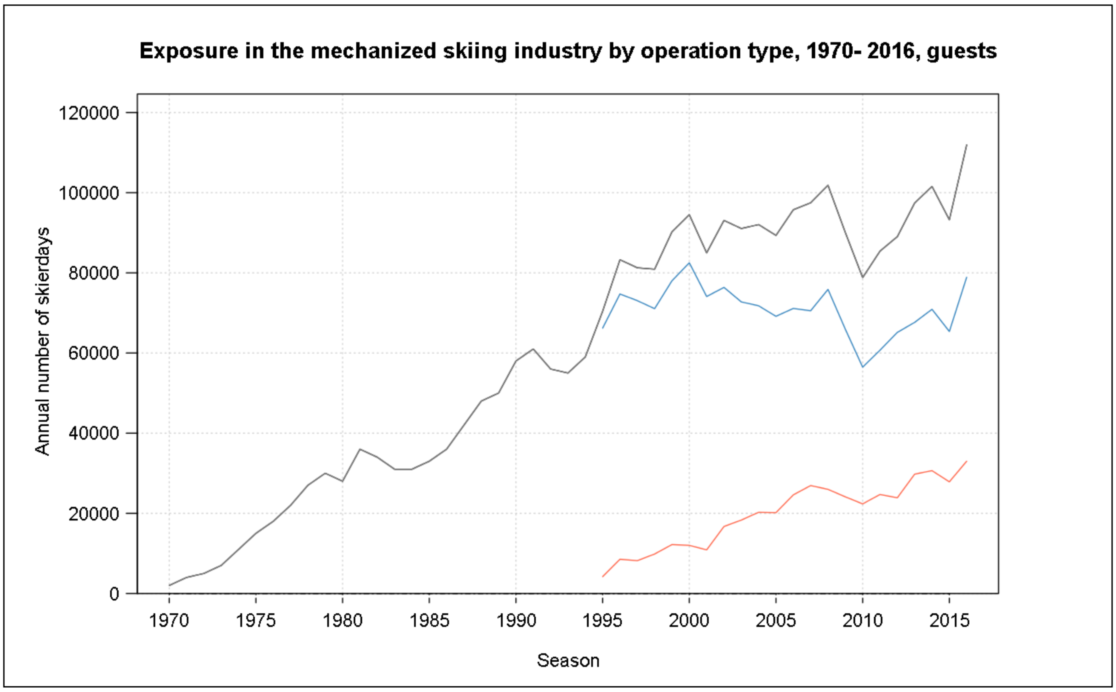

Figure 6: Skierdays in the mechanized skiing industry between the winter seasons 1970 and 2016 (grey: entire industry, blue: helicopter-skiing operations, red: snowcat-skiing operations).

4.1.2 Incident data

Overall

In the course of this research, 763 incidents in commercial mechanized skiing from the winter seasons 1970 to 2016 were collected, that resulted in injuries or fatalities among guests or guides (Figure 7).

Ski accidents make up by far the biggest share among the different incident types (54%, 409 cases), followed by collisions (21%, 158 cases), avalanches (11%, 83 cases) and falls from height (5%, 37 cases).

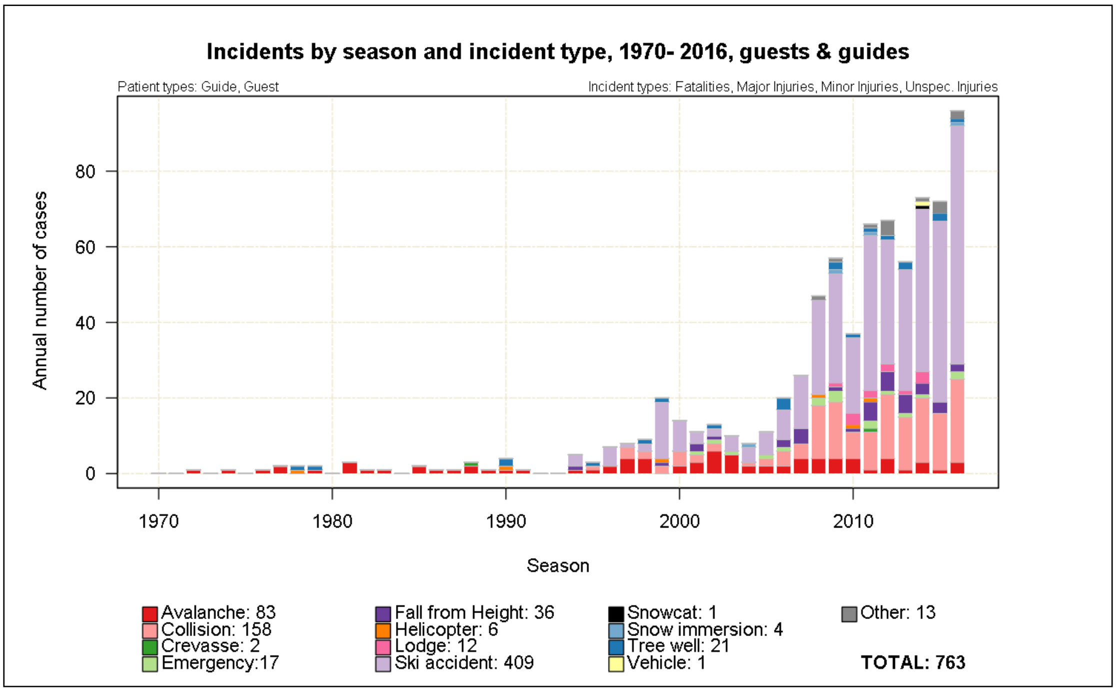

Figure 7: Overview of collected and classified incidents from guests and guides in the commercial mechanized skiing industry between the winter seasons 1970 and 2016 (red: avalanches, pink: collision, dark green: crevasse, light green: emergency, purple: fall from height, orange: helicopter, dark pink: lodge, mauve: ski accident, black: snowcat, light blue: snow immersion, dark blue: tree well, beige: vehicle, grey: other).

The collected data until 1995 mainly consists of information on fatalities (Figure 8). Regarding the entire study period, information on 107 fatalities, caused by 66 fatal incidents was collected. The lion's share of all collected incidents (91%, 697 cases) relates to events which did not result in any fatalities. Of the complete dataset, 90% (683 cases) came from helicopter-skiing operations. Close to 80% (597 cases) of the collected incidents occurred between the seasons 2007 and 2016. All but 15 (3%) of these incidents resulted in no deaths.

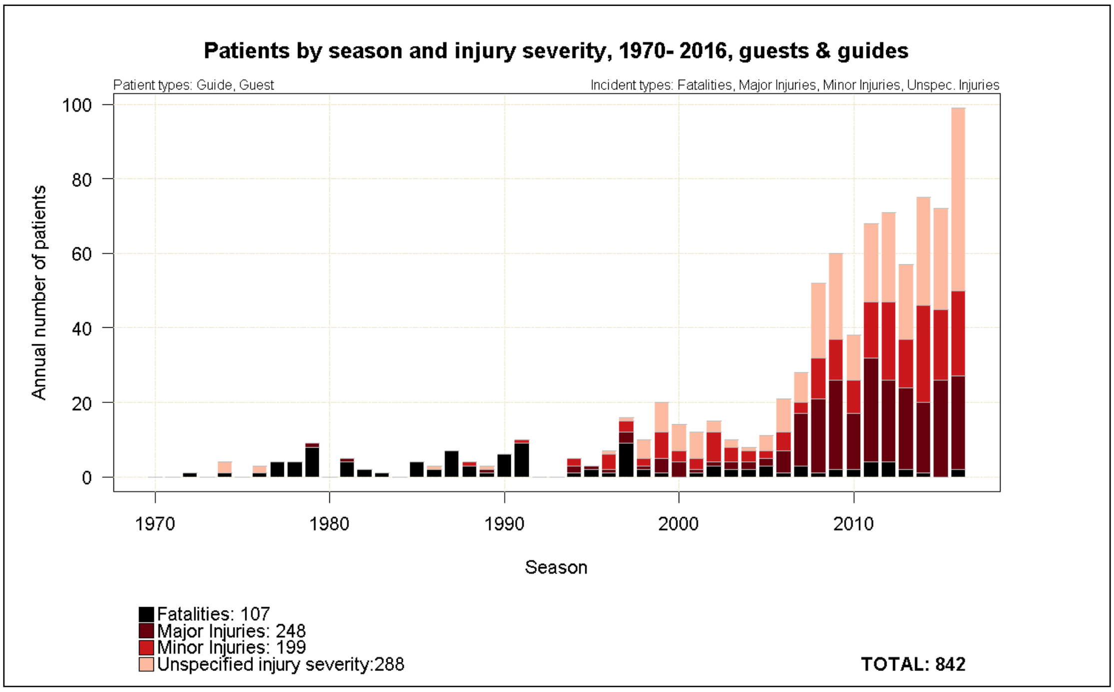

Figure 8: Overview of patients and their injury severity, among collected and classified incidents from guests and guides in the commercial mechanized skiing industry between the winter seasons 1970 and 2016 (black: fatalities, deep red: major injuries, medium red: minor injuries, light red: unspecified injury degree).

Mortality data

- <u>Avalanche fatalities, 1969/70- 2015/16</u>

Between the winter seasons 1970 and 2016, 81 individuals, 71 guests (88%) and 10 guides (12%), lost their lives in 44 different avalanche accidents (Figure 9). Seventy-six fatalities (94%) in 39 incidents (89%) occurred during helicopter-skiing. On average, there have been 1.7 avalanche fatalities in 0.9 fatal incidents per winter in commercial mechanized backcountry skiing in Canada. The deadliest avalanche accident occurred in 1991 in the Bugaboos of the Purcell Mountains, resulting in 9 guest fatalities. The deadliest winter seasons were 1991 (1 incident) and 1997 (4 incidents), with 9 fatalities in each season.

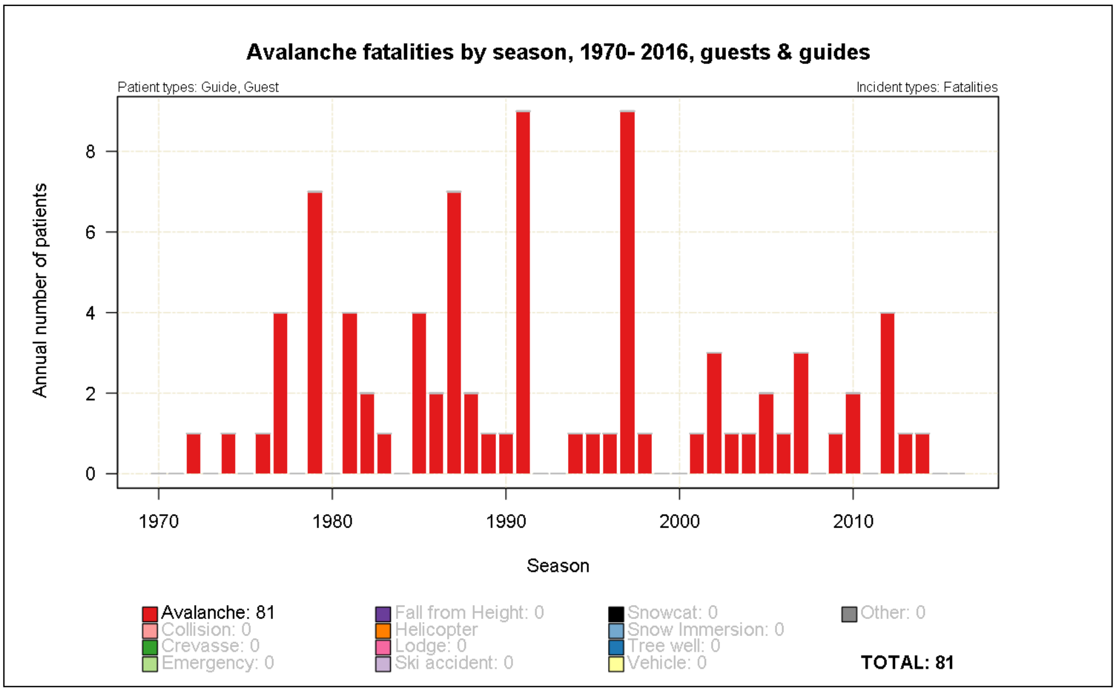

Figure 9: Avalanche fatalities in the commercial mechanized skiing industry between the winter seasons 1970 and 2016.

- <u>Fatalities from all causes, 1996/97- 2015/16</u>

During the 20 operating seasons between 1997 and 2016, 40 guests and 5 guides lost their lives in 36 fatal accidents from all causes in the commercial mechanized skiing industry (Figure 10).

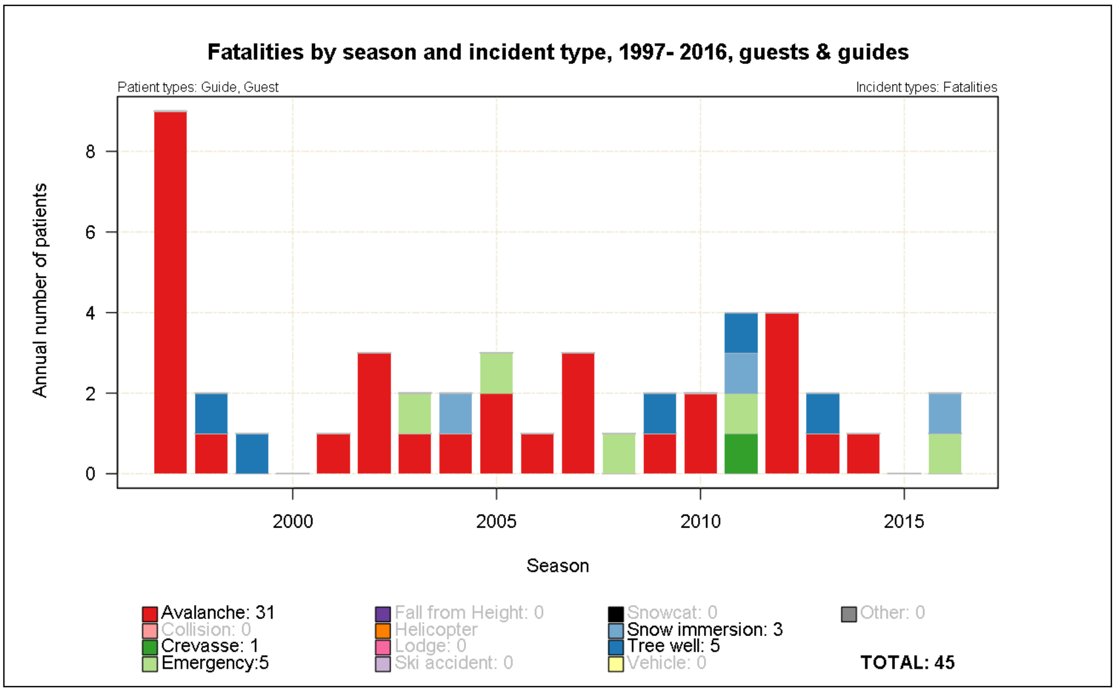

Figure 10: Fatalities of guests and guides in the mechanized skiing industry between the winter seasons 1997 and 2016, divided by the incident type (red: avalanche, dark green: crevasse, light green: emergency, light blue: snow immersion, dark blue: tree well).

Most of these fatalities (78%, 35 cases) occurred in helicopter-skiing operations, the remaining 10 fatalities in snowcat-skiing operations (Table 8). On average, 2.0 guests and 0.3 guides lost their lives in 1.8 incidents per winter during the last 20 operating seasons.

Sixty-nine percent of the fatalities from all causes (31 cases) were due to avalanches. Tree wells and emergency incidents were each responsible for 11% (5 cases), snow immersion incidents for 7% (3 cases) of the fatalities. Fatal avalanche incidents resulted on average in 1.4 deaths. In helicopter-skiing, one fatal avalanche incident caused on average 1.5 fatalities (27 fatalities, 18 incidents), whereas in snowcat-skiing every fatal avalanche always only resulted in one fatality (4 fatalities, 4 incidents). Fatal tree well, snow immersion, crevasse and emergency incidents also always resulted in one fatality only.

Table 8: Fatal incidents and fatalities in the mechanized skiing industry between the winter seasons 1997 and 2016, divided by incident type, activity, as well as guests and guides.

INCIDENT TYPE		HELICOPTER-SKIING		SNOWCAT-SKIING		HELICOPTER- & SNOWCAT-SKIING		[1]SUM
		Guests	*Guides*	*Guests*	*Guides*	*Guests*	*Guides*	
Avalanche	*Incidents*	18	3	3	1	21	4	22
	Fatalities	24	3	3	1	27	4	31
Tree well	*Incidents*	4	0	1	0	5	0	5
	Fatalities	4	0	1	0	5	0	5
Snow immersion	*Incidents*	0	0	3	0	3	0	3
	Fatalities	0	0	3	0	3	0	3
Crevasse	*Incidents*	0	1	0	0	0	1	1
	Fatalities	0	1	0	0	0	1	1
Emergency	*Incidents*	3	0	2	0	5	0	5
	Fatalities	3	0	2	0	5	0	5
All incident types	*Incidents*	25	4	9	1	34	5	36
	Fatalities	31	4	9	1	40	5	45

[1]sum of guests and guides incidents and fatalities in helicopter- and snowcat-skiing. Incident number can be lower than the sum of the columns to the left, because guests and guides might have lost their lives in the same incident.

In addition to the 45 guest and guide fatalities reported in this chapter, in 2008 a pilot flying for a helicopter-skiing operation in the Purcell Mountains near Golden lost his live in a helicopter incident. Due to the focus of this research on guest and guides, this case was not included in the overview graphs and statistics.

Morbidity data

- <u>Major injuries among guides, 2006/07- 2015/16</u>

Between the winter seasons 2007 and 2016, 110 guides in the mechanized skiing industry sustained major injuries (Figure 11). Sixty-five percent of these injuries (72 cases) occurred during helicopter-skiing and the other 35% (38 cases) at snowcat-skiing operations. Slightly more than half of the major injuries were caused by skiing accidents (54%, 59 cases), followed by collisions (26%, 29 cases), falls from height (7%, 8 cases) and avalanche incidents (6%, 7 cases). None of the other incident types was responsible for more than 5% of all major injuries.

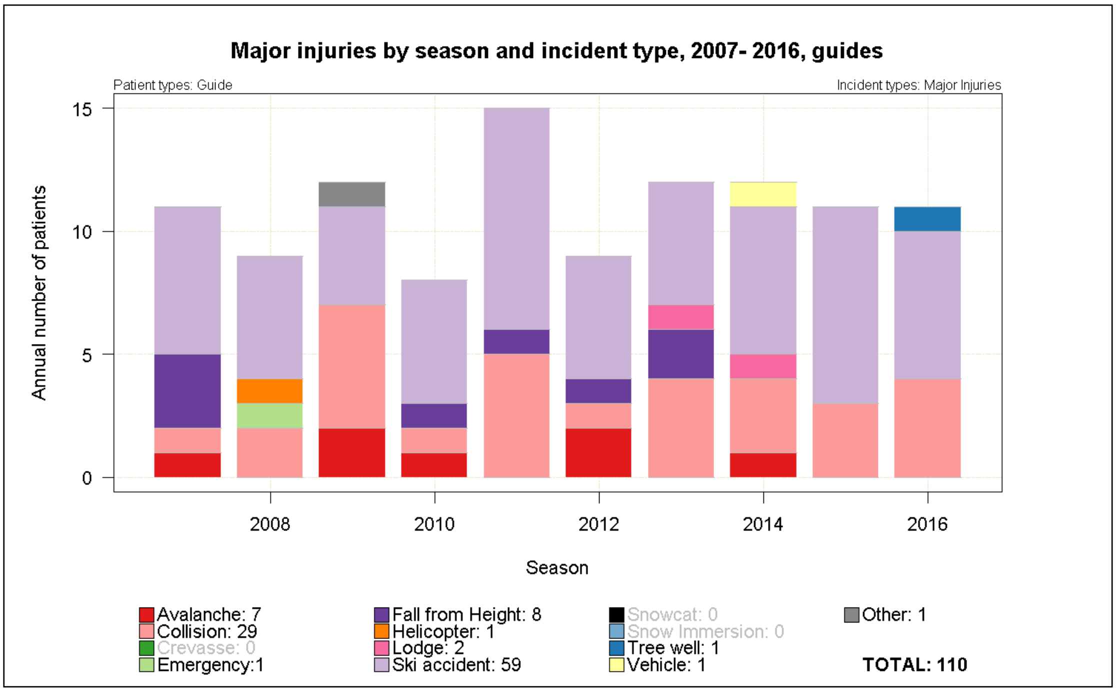

Figure 11: Major injuries among guides in the mechanized skiing industry between the winter seasons 2007 and 2016 (red: avalanches, pink: collision, light green: emergency, purple: fall from height, orange: helicopter, dark pink: lodge, mauve: ski accident, dark blue: tree well, beige: vehicle, grey: other).

- Major injuries among guests, 2006/07- 2015/16

Since information of data quality of DQ 1 was only available from a number of helicopter-skiing operations, morbidity rates could only be calculated for the helicopter-skiing segment of the mechanized skiing industry. The helicopter-skiing operations providing information on major guest injuries with DQ 1 accounted between 13% to 76% of the total annual number of skierdays in the helicopter-skiing industry between the seasons 2007 and 2016 (Figure 12). The average percentage for the 10-year period was 65%.

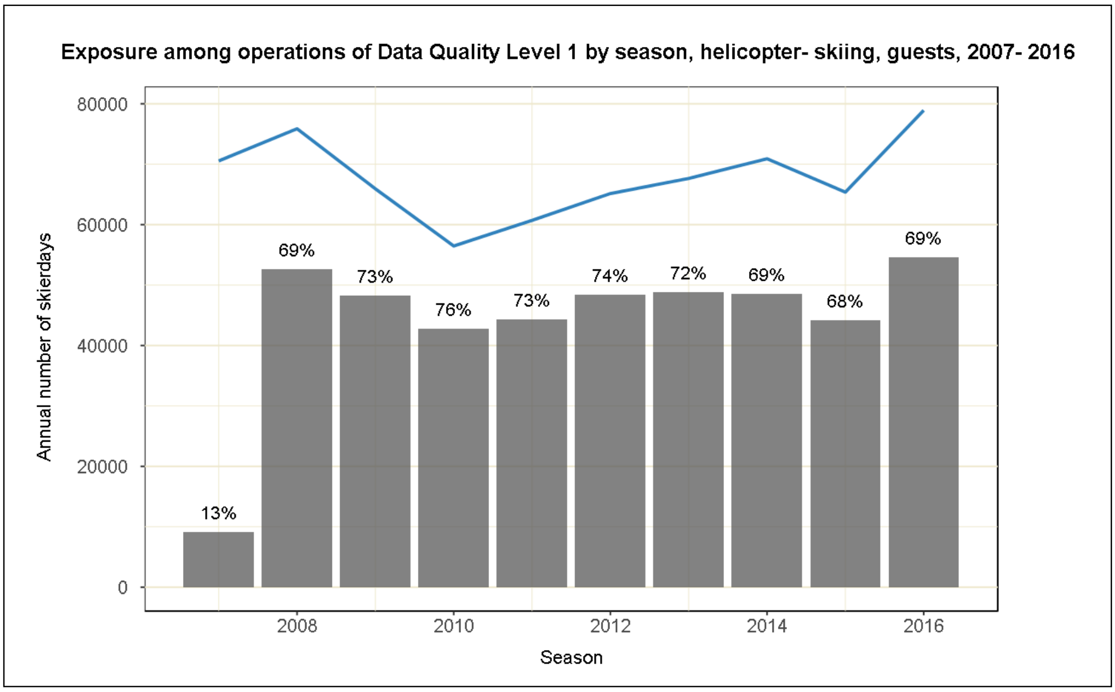

Figure 12: Annual number of skierdays among helicopter-skiing operations of Data Quality Level 1 in relation to total number of skierdays among all helicopter-skiing operations between the winter seasons 2007 and 2016 (grey bars: annual number of skierdays of helicopter-skiing operations of Data Quality Level 1, blue line: total skierdays of all helicopter-skiing operations).

Between the winter seasons 2007 and 2016, 94 major guest injuries were recorded among helicopter-skiing operations of DQ 1 (Figure 13). Ski accidents were the principle cause for major injuries, accounting for 53% (50 cases) of all cases. Collision incidents were the second largest contributor, causing 24 major guests injuries and accounting for 26% of all cases. Emergency incidents accounted for 5% (5 cases) of all major injuries, while lodge incidents (4 cases), falls from height (3 cases), avalanches (2 cases), tree well (2 cases) and snow immersion (1 case) incidents, as well as other incidents (3 cases) only played subordinate roles with each incident type accounting for less than 5%.

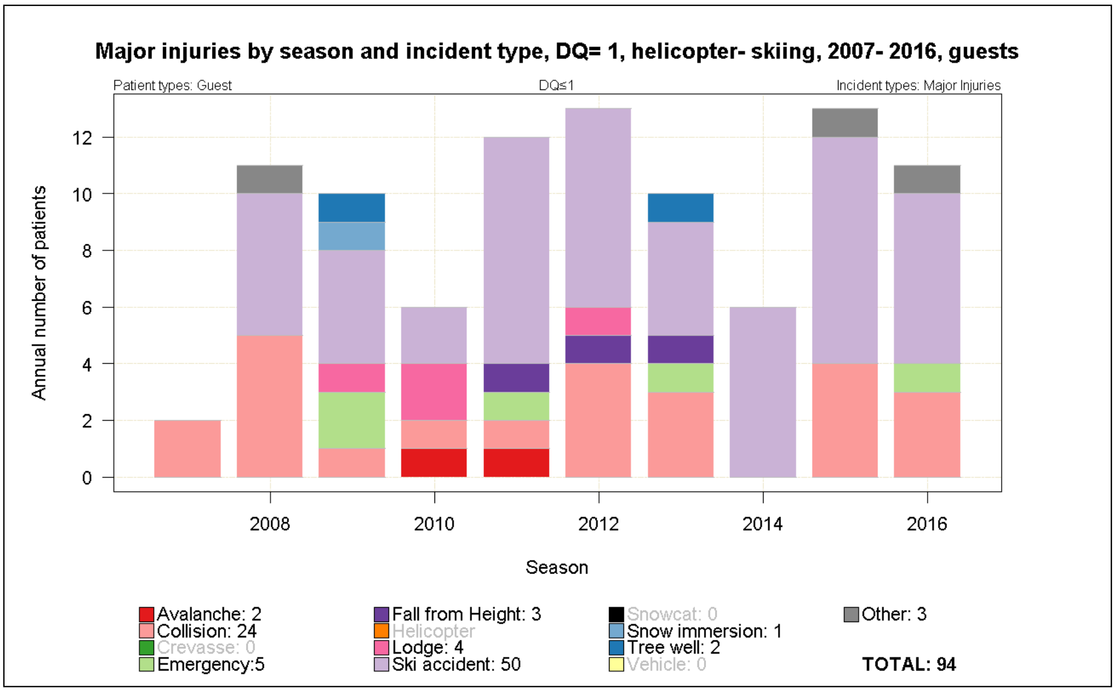

Figure 13: Major injuries of guests in the helicopter-skiing industry between the winter seasons 2007 and 2016, collected from operations and years of Data Quality Level 1 (red: avalanches, pink: collision, light green: emergency, purple: fall from height, dark pink: lodge, mauve: ski accident, light blue: snow immersion, dark blue: tree well, grey: other).

The injury severity could not be determined conclusively for 207 guests who got injured while participating in helicopter-skiing between the winter seasons 2007 and 2016 (Figure 14). The distribution of injury types among these guests was similar to the ones sustaining major injuries. Skiing accidents accounted for the majority of all cases (69%, 142 cases) and collisions were the second most important contributor (21%, 43 cases). All other incident types played only a minor role as none of them exceed 5% of the overall number of patients.

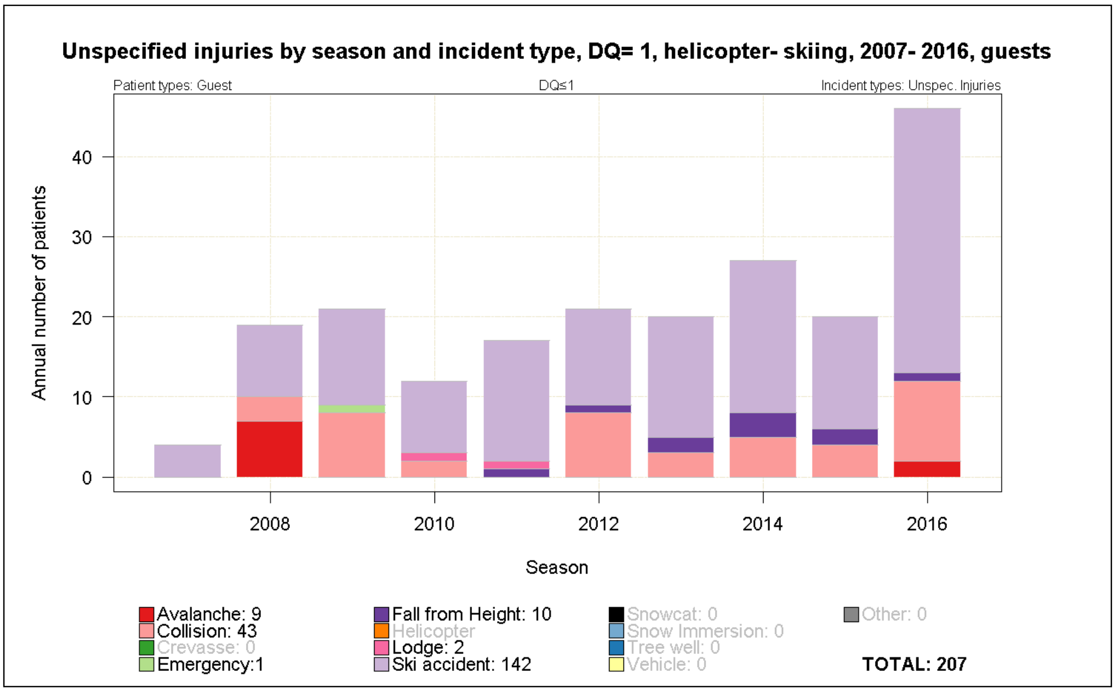

Figure 14: Injuries of guests with unspecified severity in the helicopter-skiing industry between the winter seasons 2007 and 2016, collected from operations and years of Data Quality Level 1 (red: avalanches, pink: collision, light green: emergency, purple: fall from height, dark pink: lodge, mauve: ski accident).

4.2 Mortality rates

4.2.1 Avalanche mortality, 1969/70- 2015/16

On average, the avalanche mortality rate for guests and guides in the commercial mechanized skiing industry between the seasons from 1970 to 2016 was 24.9 MM (Appendix 4). However, the decadal avalanche mortality rate for guest and guides in the mechanized skiing industry has been decreasing steadily since 1970 (Figure 15). While the mortality due to avalanche involvement was 85.1 MM in the 1970s, it dropped substantially during the subsequent decades (1980s: 53.4 MM; 1990s: 28.4 MM; 2000s: 12.0 MM). This corresponds to an 86% reduction in avalanche mortality between the 1970s and the 2000s. The avalanche mortality rate only dropped marginally in the most recent time period between the 2010 and 2016 winter seasons (10.4 MM).

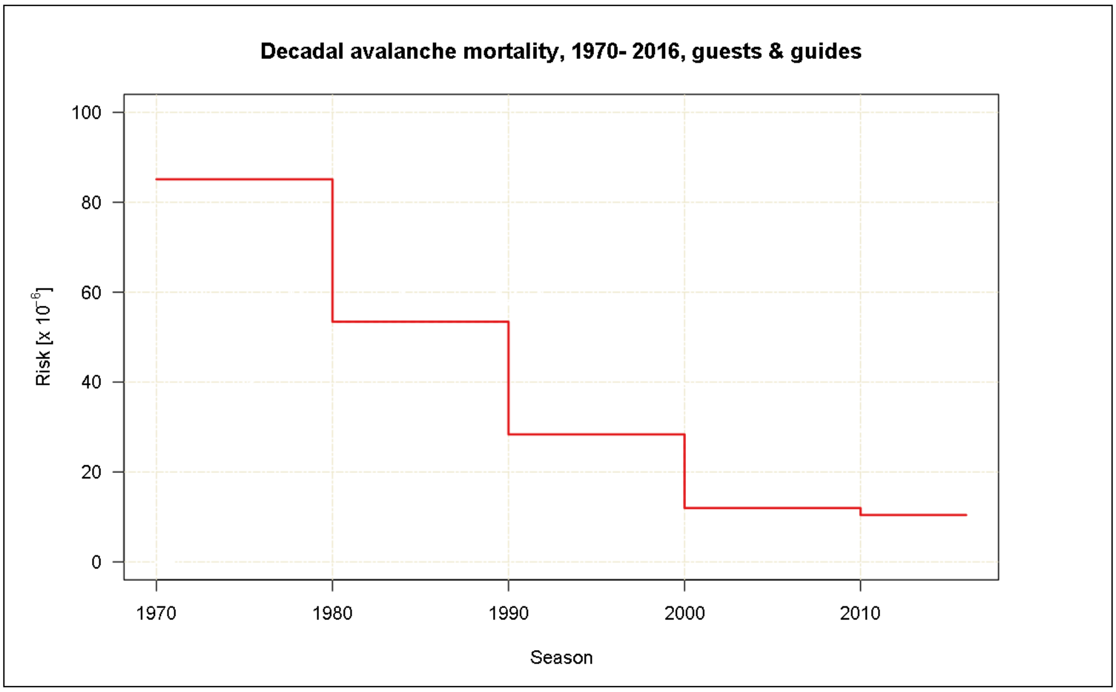

Figure 15: Decadal avalanche mortality for guests and guides in the mechanized skiing industry between the winter seasons 1970 and 2016.

The average avalanche mortality rate for guests only in the commercial mechanized skiing industry between the winter seasons 1970 and 2016 was 25.4 MM. Similar to the trend in the overall mortality rate for guests and guides, the mortality rate for guests only also decreased steadily from 1970 until 2010 (Figure 16). There were substantial drops in every decade from the 1970s to the 2000s decade. During that period, the avalanche mortality decreased by 87% (1970s: 92.2 MM; 2000s: 11.8 MM). The decadal guest only avalanche mortality rate essentially stayed unchanged for the most recent time period from 2010 until 2016 (12.2 MM).

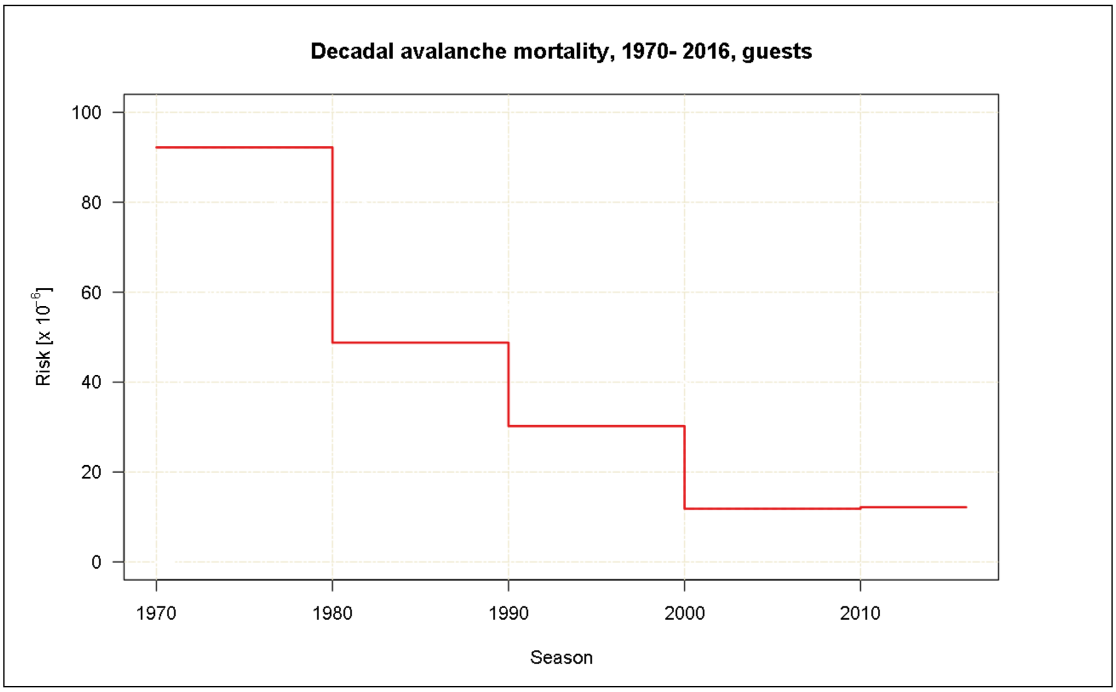

Figure 16: Decadal avalanche mortality for guests in the mechanized skiing industry between the winter seasons 1970 and 2016.

A different pattern can be observed in the decadal guide avalanche mortality rate (Figure 17), which experienced a substantial increase from 42.6 MM in the 1970s to 81.3 MM in the 1980s. However, the increase was followed by sharp decline in the subsequent decades (1990s: 17.3 MM; 2000s: 12.9 MM). There were no guide avalanche fatalities during the most recent decadal time period, which results in 0.0 MM between 2010 and 2016. On average, the avalanche mortality rate for guides in the commercial mechanized skiing industry from 1970 until 2016 was 21.5 MM per guideday.

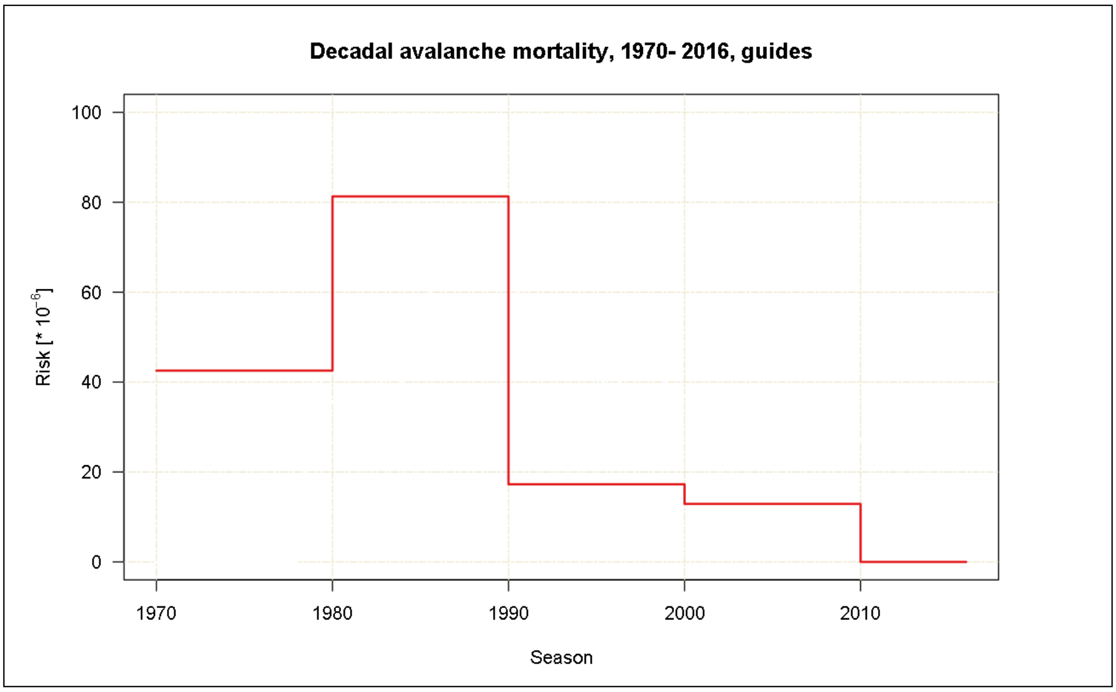

Figure 17: Decadal avalanche mortality for guides in the mechanized skiing industry between the winter seasons 1970 and 2016.

4.2.2 Incident type specific mortality, 1996/97- 2015/16

In the last two decades, the mortality from all incident types for guests and guides was 21.0 MM per skier- and guideday (Table 9). The overall mortality rate was higher for guests than for guides (19.6 versus 16.3 MM). No substantial difference between the mortality rates of helicopter-skiing and snowcat-skiing was found (21.2 versus 20.3 MM).

The avalanche hazard was responsible for 14.4 MM per skier- and guideday for the entire industry. However, a substantial difference was observed between the avalanche mortality rates of helicopter-skiing and snowcat-skiing. During the study period from 1996/97 to 2015/16, the avalanche mortality in helicopter-skiing was roughly twice as high as for snowcat-skiing (16.3 versus 8.1 MM). The low avalanche mortality rate in snowcat-skiing was primarily caused by a low mortality among guests (7.1 MM), whereas the guide avalanche mortality was similar between the two activities (14.2 MM in snowcat-skiing versus 12.7 MM in for helicopter-skiing).

Incident types classified as other, show a similar extent with industry-wide mortality rates for guests and guides amounting to 0.5 MM to 2.3 MM per skier- and guideday. The combined mortality rate for tree well, snow immersion, emergency and crevasse incidents were 6.5 MM, which accounts for approximately 45% of the avalanche mortality rate. In other words, the avalanche mortality is twice as high as the combined mortality from all other incident types. Tree well and snow immersion incidents together (NARSIDs) showed the second biggest risk (3.7 MM) after avalanches. When comparing helicopter-skiing to snowcat-skiing, there are some interesting patterns regarding the risk of NARSID. In snowcat-skiing, the NARSID mortality rate was approximate equal to the avalanche mortality rate (8.1 MM). In helicopter-skiing, however, the mortality due to NARSID was substantially lower (2.4 MM). Mortality rates due to emergency incidents were slightly larger in snowcat-skiing compared to helicopter-skiing (4.0 versus 1.8 MM), and are comparable to the mortality rates associated with tree wells.

Table 9: Daily mortality rates in the mechanized skiing industry (in micromorts, $x10^{-6}$) between the winter seasons 1997 and 2016, divided by incident type, activity, as well as guests and guides.

INCIDENT TYPE	HELICOPTER-SKIING *(Exposure: 1,653,632)*			SNOWCAT-SKIING *(Exposure: 492,912)*			HELICOPTER- & SNOWCAT-SKIING *(Exposure: 2,146,543)*		
	Guests *(1,417,398 sd)*	Guides *(236,234 gd)*	Total	Guests *(422,495 sd)*	Guides *(70,415 gd)*	Total	Guests *(1,839,893 sd)*	Guides *(306,650 gd)*	Total
Avalanche (Fatalities)	16.9 *(24)*	12.7 *(3)*	16.3 *(27)*	7.1 *(3)*	14.2 *(1)*	8.1 *(4)*	14.7 *(27)*	13.0 *(4)*	14.4 *(31)*
Tree well (Fatalities)	2.8 *(4)*	0	2.4 *(4)*	2.4 *(1)*	0	2.0 *(1)*	2.7 *(5)*	0	2.3 *(5)*
Snow immersion (Fatalities)	0	0	0	7.1 *(3)*	0	6.1 *(3)*	1.6 *(3)*	0	1.4 *(3)*
Emergency (Fatalities)	2.1 *(3)*	0	1.8 *(3)*	4.7 *(2)*	0	4.0 *(2)*	2.7 *(5)*	0	2.3 *(5)*
Crevasse (Fatalities)	0	4.2 *(1)*	0.6 *(1)*	0	0	0	0	3.3 *(1)*	0.5 *(1)*
All incident types (Fatalities)	21.9 *(31)*	16.9 *(4)*	21.2 *(35)*	21.3 *(9)*	14.2 *(1)*	20.3 *(10)*	21.7 *(40)*	16.3 *(5)*	21.0 *(45)*

4.3 Morbidity rates

4.3.1 Guide morbidity, 2006/07- 2015/16

The morbidity rate of guides in the mechanized skiing industry between the winter seasons 2007 and 2016 was 697.1 MP per guideday (Table 10). Guides morbidity was substantially higher for snowcat-skiing than for helicopter-skiing (846.7 versus 637.6 MP). The higher overall morbidity of snowcat-skiing guides compared to helicopter-skiing guides can mainly be attributed to higher risks associated with ski accidents and collision incidents. While in snowcat-skiing, the guides' morbidity rate caused by ski accidents and collisions amounted to 515.5 MP and 222.8 MP, respectively, helicopter-skiing guides showed substantially lower morbidity rates for both incident types (318.8 MP, 168.3 MP). However, for both operations types, ski accidents showed by far the highest morbidity, followed by collisions. Morbidity rates associated with falls from height and avalanches for helicopter-skiing guides were of same size (44.3 MP), and substantially lower than the risks associated with collision incidents. Guides working in the snowcat-skiing industry showed a higher risk of falls from height (66.8 MP) than of avalanches (44.6 MP), but both morbidities as well were substantially lower than the morbidity rate associated with collisions. All other incident types showed substantially lower morbidity rates, both for helicopter-skiing and snowcat-skiing guides.

Table 10: Daily morbidity rates for guides in the mechanized skiing industry (in microprobabilities, $x10^{-6}$) between the winter seasons 2007 and 2016, divided by incident type.

INCIDENT TYPE	HELICOPTER-SKIING <u>*Guides*</u> *(112,915 gd)*	SNOWCAT-SKIING <u>*Guides*</u> *(44,879 gd)*	HELICOPTER- & SNOWCAT-SKIING <u>*Guides*</u> *(157,794 gd)*
Ski accident *(Major injuries)*	318.8 *(36)*	512.5 *(23)*	373.9 *(59)*
Collision *(Major injuries)*	168.3 *(19)*	222.8 *(10)*	183.8 *(29)*
Fall from height *(Major injuries)*	44.3 *(5)*	66.8 *(3)*	50.7 *(8)*
Avalanche *(Major injuries)*	44.3 *(5)*	44.6 *(2)*	44.4 *(7)*
Lodge *(Major injuries)*	17.7 *(2)*	0	12.7 *(2)*
Tree well *(Major injuries)*	8.9 *(1)*	0	6.3 *(1)*
Emergency *(Major injuries)*	8.9 *(1)*	0	6.3 *(1)*
Helicopter *(Major injuries)*	8.9 *(1)*	/	6.3 *(1)*
Vehicle *(Major injuries)*	8.9 *(1)*	0	6.3 *(1)*
Other *(Major injuries)*	8.9 *(1)*	0	6.3 *(1)*
All incidents *(Major injuries)*	637.6 *(72)*	846.7 *(38)*	697.1 *(110)*

4.3.2 Guest morbidity, 2006/07- 2015/16

The morbidity rates of guests associated with all incident types in helicopter- skiing from 2007 to 2016 was between 212.8 MP [188.7, 240.9] based on major injuries (Table 11) and 681.4 MP [637.7, 729.5] based on major and injuries of unspecified severity (Table 12).

Morbidity rates for ski accidents and collisions were significantly higher, than the morbidity rates associated with all other incident types. The morbidity for ski accidents was between 113.2 MP [96.0, 134.5] and 434.7 MP [399.7, 473.6], and the morbidity for collisions was between 54.3 MP [42.8, 70.0] and 151.7 MP [131.5, 175.8].

Table 11: Daily morbidity rates for guests in the helicopter-skiing industry between the winter seasons 2007 and 2016 by incident type, calculated based on the number of major injuries.

INCIDENT TYPE	HELICOPTER-SKIING *Guests* *(441,713 sd)*		
	Risk [x 10^{-6}]	Lower confidence interval [x 10^{-6}]	Upper confidence interval [x 10^{-6}]
Ski accident *(Maj. injuries: 50)*	113.2	96.0	134.5
Collision *(Maj. injuries: 24)*	54.3	42.8	70.0
Emergency *(Maj. injuries: 5)*	11.3	6.8	20.2
Lodge *(Maj. injuries: 4)*	9.1	5.2	17.4
Fall from height *(Maj. injuries: 3)*	6.8	3.6	14.5
Tree well *(Maj. injuries: 2)*	4.5	2.2	11.5
Avalanche *(Maj. injuries: 2)*	4.5	2.2	11.5
Snow Immersion *(Maj. injuries: 1)*	2.3	1.0	8.4
Other *(Maj. injuries: 3)*	6.8	3.6	14.5
All incidents *(Maj. injuries: 94)*	212.8	188.7	240.9

Table 12: Daily morbidity rates for guests in the helicopter-skiing industry between the winter seasons 2007 and 2016 by incident type, calculated based on the number of major injuries and injuries of unspecified severity.

INCIDENT TYPE	HELICOPTER-SKIING Guests *(441,713 sd)*		
	Risk [x 10^{-6}]	Lower confidence interval [x 10^{-6}]	Upper confidence interval [x 10^{-6}]
Ski accident *(Maj. injuries: 50; Unsp. injuries: 142)*	434.7	399.7	473.6
Collision *(Maj. injuries: 24; Unsp. injuries: 43)*	151.7	131.5	175.8
Emergency *(Maj. injuries: 5; Unsp. injuries: 1)*	13.6	8.5	23.0
Lodge *(Maj. injuries: 4; Unsp. injuries: 2)*	13.6	8.5	23.0
Fall from height *(Maj. injuries: 3; Unsp. injuries: 10)*	29.4	21.3	41.8
Avalanche *(Maj. injuries: 2; Unsp. injuries: 9)*	24.9	17.5	36.5
Tree well *(Maj. injuries: 2; Unsp. injuries: 0)*	4.5	2.2	11.5
Snow Immersion *(Maj. injuries: 1; Unsp. injuries: 0)*	2.3	1.0	8.4
Other *(Maj. injuries: 3; Unsp. injuries: 0)*	6.8	3.6	14.5
All incidents *(Maj. injuries: 94; Unsp. injuries: 207)*	681.4	637.3	729.5

5 DISCUSSION

5.1 Objective 1

5.1.1 Hypothesis a

The avalanche mortality rate in commercial mechanized skiing decreased substantially over the last 50 years of operation.

The hypothesis was accepted. My calculations show that the avalanche mortality rate in the mechanized skiing industry, both for guests and guides, decreased drastically within the last almost 50 years. The overall mortality dropped from 85.1 MM per skier- and guideday in the 1970s to 12.0 MM in the 2000s decade and stayed almost constant for the remaining study period until 2016.

There are various factors which, in my eyes, played a role for the extraordinary improvement of avalanche safety within the industry. In the 1970s and 1980s, helicopter- and snowcat-skiing was still in its early stage and best practices or regulated operational procedures developed only slowly, simultaneous to the growing experience. At the same time, the profession of mountain and ski guiding in Canada, along with professional training programs just developed, as a result of an increasing demand in qualified guides within the fast-growing mechanized skiing industry (Donahue, 2008). Finally, knowledge about avalanche formation was scarce and means and strategies for avalanche rescue were limited. It was in the late 1960s and early 1970s when avalanche transceivers were invented and used for the first time, to locate victims more efficiently (Dawson, 2013). Since then not only the technology and equipment got better and better, but also rescue procedures were improved and perfected. Avalanche and snow research tremendously increased the knowledge in the field, helped to understand the formation of avalanches and enhance risk management procedures (Ancey et al., 2005; CAA, 2016). Scientific and technological progress in the field of meteorology improved weather observation and forecasting, which in turn helped to better capture and predict the avalanche situation in the field (Golding & Mylne, 2004; Lynch, 2007; Strangeways, 2003). Operations started to collaborate more closely among each other, share information and experience, and support each other in the case of an accident (CAA, n.d.; HCC, 2007). Not to forget about the medical achievements which have been made in the course of this period to help maintain life (e.g., Bocka, 2014). Simultaneously also the perception of risk in the public changed, which forced the government to introduce regulating laws and the industry to implement guidelines, in order to provide the highest possible safety standards (Marek, Karwowski, Frankowicz, Kantola, & Zgaga, 2014). It was an interplay of different reasons which helped to decrease the avalanche mortality in the industry.

5.1.2 Hypothesis b

The avalanche mortality is lower for snowcat-skiing operations than for helicopter-skiing operations.

The hypothesis was accepted. The avalanche mortality for helicopter-skiing guests and guides is more than double as high (16.3 MM) than for their peers in partaking in snowcat-skiing (8.1 MM).

From my viewpoint, this difference can most likely be explained by considering the different ski terrains and different skiing patterns of helicopter- and snowcat-skiing operations. Helicopter-skiing operations occupy large tenures with a high number of runs at every altitude. Snowcat-skiing operations often have comparable small tenures, and large parts of it at treeline or below (Chapter 2.1.2). This has two essential implications: First, snowcat-skiing operations, due to their existing network of roads and therefore limited accessible terrain, ski many of their runs more often during a winter season. By repeatedly skiing the same runs, in many cases the formation of undisturbed weak layers for avalanche formation, can be prevented, which in turn decreases the avalanche risk (Institut für Schnee und Lawinenforschung SLF, n.d.). Second, due to the forested nature of large parts of the tenure of snowcat-skiing operations, avalanche formation is less likely, and eventual avalanches are smaller than in open terrain, which is more often to be found above treeline (Bebi, Kulakowski, & Rixen, 2009). On the contrary, helicopter-skiing operations presumably more often ski runs for the first time during a winter season and spend more time above treeline. Larger avalanches which may release in open terrain, compared to forested area, also have a higher potential to involve more parties at once and therefore increase the fatality number and thus the avalanche mortality rate. The latter explanation is also supported by the data, which shows that the average number of fatalities per fatal incident is lower in snowcat-skiing than in helicopter-skiing (Chapter 4.1.2).

5.1.3 Hypothesis c

The mortality rate associated with non-avalanche-related deep snow immersion represents the second largest risk for mechanized skiers.

The hypothesis was accepted. The mortality due to tree wells and snow immersion during the period from 1996/97 to 2015/16 was 3.7 MM per skier- and guideday. This represents the largest mortality rate for mechanized skiers after avalanches (14.4 MM).

However, substantial differences exist between helicopter-and snowcat-skiing as well as between guests and guides. The mortality rate due to non-avalanche related deep snow immersion for guests partaking in snowcat-skiing was substantially higher than for helicopter-skiing guests (9.5 versus 2.8 MM). Similar to the differences in avalanche mortality (Chapter 5.1.2), this can be attributed to differences in the skiing terrain between the two operation types. Tree wells and deep snow hazards are more prominent in forests. Because snowcat-skiing operations presumably spend more time in forested terrain than helicopter-skiing operations, their exposure to the hazards is higher, which in turn increases their risk. The mortality of a snowcat-skiing guest due to NARSIDs is thereby just as high as his risk to die in an avalanche. Therefore, tree wells and snow immersion should be put in focus more strongly when it comes to risk reduction within the scope of operational risk management.

Within the study period, no NARSIDs among guides were recorded. In part this might be due to the generally better skiing ability of guides, since many NARSIDs are the consequence of minor falls or ski accidents. However, it might also be argued that the equipment of guides with radios decreases their vulnerability to such hazards and thus, leads to lower mortality. The introduction of communication devices, together with an intense awareness making could help to further decrease the risk of NARSIDs, in particular among snowcat- but as well among helicopter-skiing operations.

5.2 Objective 2

5.2.1 Hypothesis a

For both, guests and guides in the mechanized skiing industry, the highest morbidity rates are associated with the same incident types.

The hypothesis was partly accepted. For guests partaking in helicopter-skiing, as well as for guides in the mechanized skiing industry between the winter seasons 2007 and 2016, ski accidents and collisions are associated with the highest risks of major injury. All other incident types showed a significantly lower risk. Due to lack of data, this analysis could not be performed for guests partaking in snowcat-skiing.

5.2.2 Hypothesis b

Snowcat-skiing operations have a higher morbidity rate than helicopter-skiing operations.

The hypothesis was partly accepted. Due to the composition of the dataset, this comparison could only be performed for guides in the mechanized skiing industry. Guides in snowcat-skiing operations though, indeed show a substantially higher morbidity rate than their colleagues in helicopter-skiing operations (846.7 versus 637.6 MP).

The difference, which is mainly caused by higher morbidity rates associated with ski accidents, collisions and falls from height, can be attributed to differences in the skiing terrain of the two operation types. Snowcat-skiing operations often have comparatively larger parts of their tenure at or below treeline (Chapter 5.1.2). Therefore, skiers in snowcat-skiing operations are more exposed to forest hazards (see “Obstacles”, Chapter 2.2.2), which are, along with changing snow conditions, the main reason for collisions and ski accidents.

5.3 Objective 3

5.3.1 Hypothesis a

Mechanized skiing is associated with higher mortality rates than hiking, trekking, marathon running or alpine skiing.

The hypothesis was accepted. The calculated mortality rate of 21.0 MM per day for guests and guides in the mechanized skiing industry between the seasons 1997 and 2016 is higher than the mortalities associated with hiking, trekking, marathon running or alpine skiing (Figure 18). Paragliding in Turkey (Canbek et al., 2015) or mountaineering on Mt. McKinley (McIntosh et al., 2008) however, result in death more than three times as often as commercial mechanized skiing.

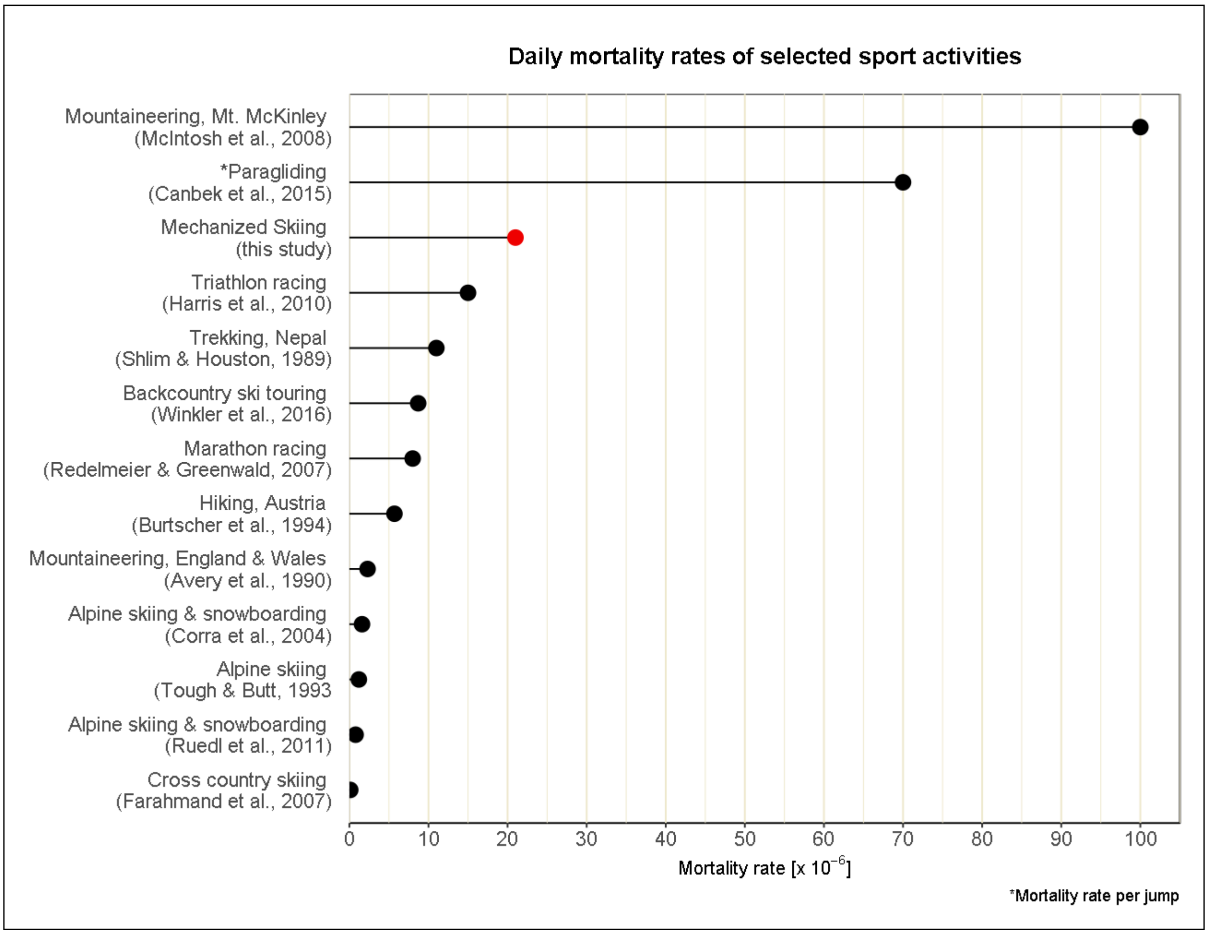

Figure 18: Daily mortality rates of selected sport activities (red dot: mortality rate in the mechanized skiing industry between the winter seasons 1997 and 2016).

5.3.2 Hypothesis b

The mortality rates for guests are higher than mortality rates for guides.

The hypothesis was accepted. My calculations from the study period 1996/97 to 2015/16 show that guests partaking in mechanized-skiing are more likely to die than their accompanying guides (21.7 versus 16.3 MM). This result was observed for both operation types. Also, the calculated average avalanche mortality for guests between the seasons 1970 to 2016 was higher than the one for guides (25.4 versus 21.5 MM).

These differences might in part be caused by the fact, that guides, compared to guests, on the big picture are more proficient in skiing, well trained, physically fit and familiar to the terrain characteristics. All these factors decrease the overall risk of death or injury of a skier (see Chapter 2.2.2).

5.3.3 Hypothesis c

The mortality rate of driving a vehicle is higher than the risk of dying in an avalanche while participating in mechanized skiing.

The hypothesis was rejected. The daily mortality risk of mechanized-skiing corresponds to approximately 2,700 km of vehicle driving in BC in 2015 (Transport Canada, 2017). On an average day of driving, the average distance travelled is presumably substantially lower than 2,700 km.

However, only 88 km of motorcycle riding on roads in the United States in 2007 bears the same mortality than one day of mechanized skiing. Giving birth to a child (86 MM/delivery; Public Health Agency of Canada, 2013) is more than 4 times riskier than an entire day of mechanized backcountry skiing at a helicopter- or snowcat-skiing operation in Canada.

5.3.4 Hypothesis d

Morbidity rates for mechanized skiing are not substantially higher than for other mountain sports.

The hypothesis was accepted. The risk of major injury for guests in the helicopter-skiing industry between the seasons 2007 and 2016 was between 212.8 MP [188.7, 240.9] considering major injuries only, and 681.4 MP [637.7, 729.5] considering major injuries and injuries of unspecified severity. The daily morbidity rate for guides during the same period in the entire industry was 697.1 MP. Based on the assumption that one skierday consists of 6 hours of skiing, hourly mortality rates between 35.5 MP [31.45, 40.15] and 113.6 MP [106.28, 121.6] for guests and 116.2 MP for guides can be calculated. These values are very similar to the morbidity rates in indoor climbing (Figure 19).

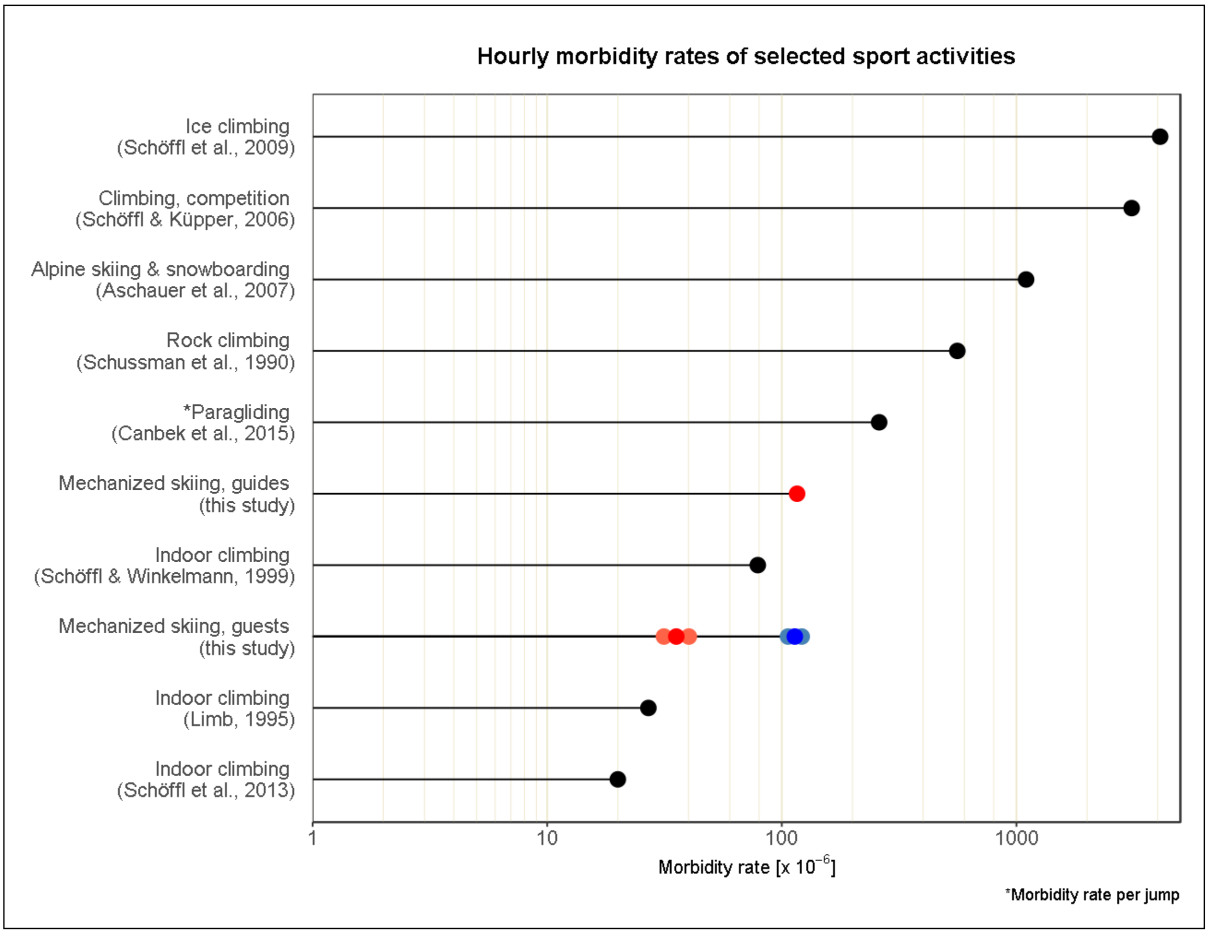

Figure 19: Hourly morbidity rates of selected sport activities on a logarithmic scale (red dots: morbidity rates and CIs calculated based on major injuries, blue dots: morbidity rates and CIs calculated based on major injuries and injuries of unspecified severity in the mechanized skiing industry between the winter seasons 1997 and 2016).

Morbidity rates for alpine skiing and snowboarding (Aschauer et al., 2007), or paragliding (Canbek et al., 2015) are much higher than the calculated morbidity rates in mechanized backcountry skiing.

The morbidity rate for guests which was calculated based on major injuries and injuries of unspecified severity, is very similar to the morbidity rate for guides. This gives reason to suspect, that vast majority of unspecified injuries among guests were likely major injuries. However, in my belief this correlation is rather a coincidence. Guest and guide morbidity have been calculated based on different classifications of injury severity (see Chapter 3.1.1) and therefore naturally differ from each other. A direct, detailed comparison of guest and guide morbidity is therefore not appropriate. Also, comparisons with other authors must be made with caution. While the comparison of data regarding their magnitudes allows to draw meaningful conclusions, more detailed considerations might lead to wrong results.

5.4 Limitations

As Lowrance (1980) pointed out already, risk estimates cannot escape containing elements of subjectivity and the present work is no exception. While conducting this research, various classifications and definitions were made.

To calculate mortality and morbidity rates for guides, guides' exposure (guidedays) had to be estimated based on the guests' skierdays. The assumed guest to guide ratio of six to one aimed to consider the entire history of mechanized skiing, and was based on experts' opinions in the field. However, in recent years, a trend towards smaller groups could be observed, which goes along with lower guest to guide ratios. On the other hand, reports of historical incidents reveal, that in the early decades, one guide was responsible for groups larger than six clients. These deviations of the assumed guest to guide ratio might lead to underestimations of guide mortality and morbidity rates in earlier years, and overestimations in recent years.

The classification of the incidents into the different classes was not always straightforward and sometimes included considerable subjectivity. For example, if a skier was taken over a cliff by a sluff (small snow avalanche), the incident was classified as an avalanche incident, because the major fall resulted from an avalanche involvement. On the other hand, tree well and deep snow immersions often happened following ski accidents. However, these cases were typically classified as tree wells or snow immersion incidents as they represented the more serious incident type.

The categories of major and minor injuries that were used to determine the severity of guest injuries were created based on my own knowledge and belief. Because the morbidity calculations depended on this categorization, the results are influenced by my personal understanding of major injuries in skiing. However, morbidity rates in current literature in many cases are based on different definitions and classification schemes. Comparing the morbidity estimates presented in the study with other research should therefore only be done with extreme caution.

The BC Coroners Service provided a comprehensive dataset of investigated fatalities in the mechanized skiing industry between the seasons 1993 and 2016. However, the BC Coroners Service is only obligated to investigate unnatural, sudden and unexpected deaths, and fatalities from natural diseases (e.g., heart attack, stroke) are not investigated systematically. In this study, deaths from natural diseases were classified as emergency incidents, and the completeness of emergency fatalities can not be confirmed. Therefore, the mortality rate due to emergency incidents and the overall mechanized skiing mortality rate could be higher than calculated.

The estimation of mortality and morbidity rates critically depend on the collected skierday data from HCC and individual operations. The dataset represents the best possible summary of the available information, and adjustments for increasing its accuracy have been conducted (Chapter 3.2.1). However, it is still possible that there are additional missing skierdays, which were not reported to HCC or were not included in the earlier estimations for the years before 1995. The skierday data therefore, represents the lowest verified exposure, and the calculated risk figures thus, could be slightly overestimated. However, the available exposure data is of much higher quality than what has been used in previous studies (e.g., Winkler et al., 2016; Valla, 1984; Zweifel et al., 2006), which based their exposure data on surveys or small sample datasets. Hence, the risk figures calculated in this study are of higher accuracy and are more reliable than the mortality rates presented in previous literature.

Helicopter incidents only played a subordinate role in mortality and morbidity for guests and guides in mechanized skiing. In fact, between the winter seasons 2007 and 2016 only one guide had suffered from a major injury caused by a helicopter incident. Over the entire study period of 47 years, six injuries and fatalities among guest and guides were recorded (see Chapter 4.1.24.1.1) These figures give rise to the misconception that helicopter related incidents in the industry are rare. However, between the 2007 and 2016 winter seasons, 25 individual helicopter incidents were recorded. Just outside of the study period, during the winter season 2017, a helicopter roll-over resulted in a major injury of a guide at a Canadian helicopter-skiing operation near Valemount (Norwell, 2017). Four additional incidents in the same season luckily ended without injuries or deaths. Without a doubt, helicopter incidents have a high potential of serious consequences for all affected parties. In addition, they usually also entail serious property losses for operations or subcontractors. During this research, I was unable to gather precise costs of helicopter damages, which prevented me from accurately estimate the overall financial losses. Furthermore, the calculation of meaningful risk values was impeded by the lack of relevant exposure data (e.g., pilotdays, flight hours, count of landings). To facilitate future research into the risk associated with helicopter incidents in the mechanized skiing industry, I recommend the systematic collection of detailed information on financial loss and meaningful exposure data across the industry.

6 CONCLUSION AND OUTLOOK

The present thesis aimed to assess the risks of injury and death associated with different hazards in helicopter- and snowcat-skiing in Canada. To complete this task, historical exposure and incident information of guests and guides partaking in mechanized skiing activities were collected and analyzed.

The results of the risk analysis show that the mortality rate associated with avalanches decreased substantially since the beginning of mechanized skiing in Canada. However, avalanches still pose the biggest risk of death for mechanized skiers, accounting for two out of every three fatalities. Tree well and snow immersion hazards exhibit with the second largest mortality rate. While the overall mortality rate of helicopter- and snowcat-skiing are comparable, considerable differences are seen between operation types when examining specific types of mortality. Helicopter-skiing has substantially higher avalanche mortality rates, whereas snowcat-skiing shows higher mortality associated with tree well and snow immersion incidents. Both, the lower avalanche mortality rate and the higher risk of NARSID in snowcat-skiing can likely be attributed to differences in the type of terrain skied. Snowcat-skiing operations more commonly ski at treeline or below, where avalanches are less frequent and generally of smaller size than in open terrain. However, this is also where the risk of tree well and deep snow immersion is at its highest.

The influence of terrain type can also be found in the calculated morbidity rates. The highest morbidity rates for mechanized skiers are associated with ski accidents and collisions. Both incident types are strongly associated with forest hazards, such as trees, stumps, and logs. Therefore, it is not surprising that the morbidity rates among guides are higher for snowcat-skiing than for helicopter-skiing.

The mortality associated with helicopter- and snowcat-skiing in Canada is comparable to triathlon racing in the United States (Harris et al., 2010) or 2,500 km of vehicle driving in BC (Transport Canada, 2017). Calculated morbidity rates are in the same range as risk figures estimated for indoor climbing activities (Limb, 1995; Schöffl & Winkelmann, 1999) or 200 km of vehicle driving on Canadian roads (Transport Canada, 2017).

Even though backcountry skiing involves many hazards that can lead to serious consequences, the calculated mortality and morbidity rates show that mechanized skiing operations have successfully implemented effective management practices to keep the risks at relatively low levels. This achievement was not solely a product of single operations, but rather the result of scientific progress and numerous technical innovations in the last decades. The practical application of improved scientific insight and the use of new technology contributed to a pronounced decrease in avalanche mortality in the 1980s and 1990s. This success story nicely underlines the importance of a close relationship between research and practice.

The risk figures calculated in this study explicitly describe the significance of the different hazards in both helicopter- and snowcat-skiing for the first time. This quantitative information now allows the industry as a whole as well as individual operators to make evidence-based adjustments to their risk management practices to continuously improve guest and employee safety. An industry-wide database for recording incident and near miss information as well as exposure data for the mechanized skiing industry is currently being developed to facilitate the continuous monitoring of existing risks (HCC, 2017).

Commercial leisure providers have a responsibility towards their customers and employees to provide the highest level of safety possible, but every backcountry activity inherently involves some level of risks. While best practices might be able to reduce these risks to a minimum level, they can never be reduced to zero. This especially holds true for skiing untouched powder in an uncontrolled mountain environment, which is associated with a wide range of different risks.

Since every activity in our daily life involves risk to some degree, every individual must decide which risks he or she is willing to take. The quantitative risk estimates presented in this study allow for a more conscious risk-taking based on evidence and provides individuals with the necessary information to independently decide whether or not to engage in mechanized skiing.

♦ ♦ ♦

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Appendix A: Common Types of Incident Recording

HeliCat Canada Incident Report Form

if possible please use the online form here

Complete this form and send it to the the Executive Director at ed@helicat.org

Overview:

Date of Report:

Organization:

Incident Location: (operation, drainage, run, etc)

Date of Incident:

Time of Incident:

Type of Incident:

Number of Clients Involved:

Number of Guides Involved:

Injuries or Fatalities:

Incident Details:

(before, during and immediately following incident)

- Who? Who is involved
- What? What task or activity was happening when the accident occurred?
- Where? Describe the exact location (operation, Zone and Run and physical environment.) Determine altitude, slope angle, snow profile and aspect. Measure distances at accident site. Document all terrain details with photographs if possible.
- When? Note the exact dates and times of the accident. Note the mountain conditions leading up to, and at the time of the accident.
- How? Describe what happened before, during and after the accident.
- Weather: Record the weather conditions at the time of the accident, as well as the time leading up to the accident.

Rescue and Injuries Details:

Number involved

Injuries involved

Fatalities involved

External Responder(s) and contact info:

WorkSafeBC Incident Investigation Form

Has a WSBC incident report form been filed? If so, may HeliCat receive a copy?

Contact Info:

Name, title and contact info of person reporting:

Figure A.1: HeliCat Canada incident report form[4]

[4] HeliCat Canada, 2017, personal communication.

INJURY/INCIDENT REPORT

Date: ____________________ **Time:** ________________

GUEST Name: ____________________

Guide Name: LG – _____________ / G- ____________________

Heli & Location: ____________ / ____________

Injury: ____________

Comments:

- ____
- ____
- ____
- ____

Action Taken:

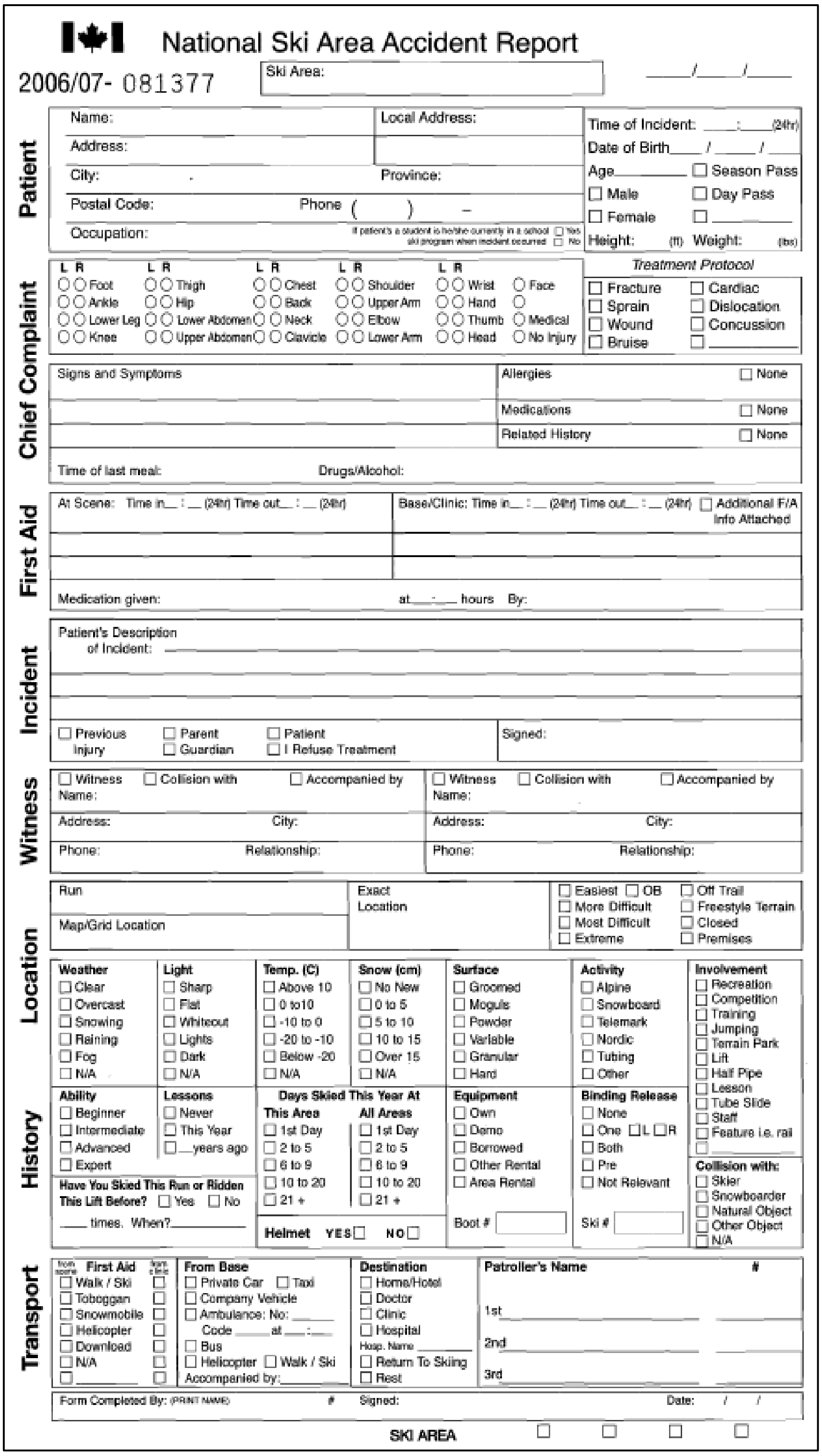
- ____
- ____
- ____
- ____

Update: ____

Signature: ____________

Figure A.2: Template of an injury/incident report form, used by many operations in the mechanized skiing industry to record incidents[5].

[5] adapted from Mike Wiegele Helicopter Skiing, 2017, personal communication.



National Ski Area Accident Report

2006/07- 081377 Ski Area: ____/____/____

Patient

Name: Local Address:

Address:

City: Province:

Postal Code: Phone ( ) -

Occupation: If patient's a student is he/she currently in a school ski program when incident occurred ☐ Yes ☐ No

Time of Incident: ____:____(24hr)

Date of Birth____ / ____ / ____

Age________ ☐ Season Pass

☐ Male ☐ Day Pass

☐ Female ☐ ________

Height: (ft) Weight: (lbs)

Chief Complaint

L R	L R	L R	L R	L R	
○ ○ Foot	○ ○ Thigh	○ ○ Chest	○ ○ Shoulder	○ ○ Wrist	○ Face
○ ○ Ankle	○ ○ Hip	○ ○ Back	○ ○ Upper Arm	○ ○ Hand	○
○ ○ Lower Leg	○ ○ Lower Abdomen	○ ○ Neck	○ ○ Elbow	○ ○ Thumb	○ Medical
○ ○ Knee	○ ○ Upper Abdomen	○ ○ Clavicle	○ ○ Lower Arm	○ ○ Head	○ No Injury

Treatment Protocol

☐ Fracture ☐ Cardiac

☐ Sprain ☐ Dislocation

☐ Wound ☐ Concussion

☐ Bruise ☐ ________

Signs and Symptoms

Allergies ☐ None

Medications ☐ None

Related History ☐ None

Time of last meal: Drugs/Alcohol:

First Aid

At Scene: Time in__ : __ (24hr) Time out__ : __ (24hr)

Base/Clinic: Time in__ : __ (24hr) Time out__ : __ (24hr) ☐ Additional F/A Info Attached

Medication given: at___:___ hours By:

Incident

Patient's Description of Incident:

☐ Previous Injury ☐ Parent ☐ Guardian ☐ Patient ☐ I Refuse Treatment

Signed:

Witness

☐ Witness ☐ Collision with ☐ Accompanied by

Name:

Address: City:

Phone: Relationship:

☐ Witness ☐ Collision with ☐ Accompanied by

Name:

Address: City:

Phone: Relationship:

Location

Run

Map/Grid Location

Exact Location

☐ Easiest ☐ OB ☐ Off Trail

☐ More Difficult ☐ Freestyle Terrain

☐ Most Difficult ☐ Closed

☐ Extreme ☐ Premises

Weather	Light	Temp. (C)	Snow (cm)	Surface	Activity
☐ Clear	☐ Sharp	☐ Above 10	☐ No New	☐ Groomed	☐ Alpine
☐ Overcast	☐ Flat	☐ 0 to10	☐ 0 to 5	☐ Moguls	☐ Snowboard
☐ Snowing	☐ Whiteout	☐ -10 to 0	☐ 5 to 10	☐ Powder	☐ Telemark
☐ Raining	☐ Lights	☐ -20 to -10	☐ 10 to 15	☐ Variable	☐ Nordic
☐ Fog	☐ Dark	☐ Below -20	☐ Over 15	☐ Granular	☐ Tubing
☐ N/A	☐ N/A	☐ N/A	☐ N/A	☐ Hard	☐ Other

History

Ability	Lessons	Days Skied This Year At: This Area	All Areas	Equipment	Binding Release
☐ Beginner	☐ Never	☐ 1st Day	☐ 1st Day	☐ Own	☐ None
☐ Intermediate	☐ This Year	☐ 2 to 5	☐ 2 to 5	☐ Demo	☐ One ☐L ☐R
☐ Advanced	☐__years ago	☐ 6 to 9	☐ 6 to 9	☐ Borrowed	☐ Both
☐ Expert		☐ 10 to 20	☐ 10 to 20	☐ Other Rental	☐ Pre
		☐ 21 +	☐ 21 +	☐ Area Rental	☐ Not Relevant

Have You Skied This Run or Ridden This Lift Before? ☐ Yes ☐ No

____ times. When?________

Helmet YES☐ NO☐

Boot #

Ski #

Involvement: ☐ Recreation ☐ Competition ☐ Training ☐ Jumping ☐ Terrain Park ☐ Lift ☐ Half Pipe ☐ Lesson ☐ Tube Slide ☐ Staff ☐ Feature i.e. rail ☐

Collision with: ☐ Skier ☐ Snowboarder ☐ Natural Object ☐ Other Object ☐ N/A

Transport

from scene First Aid	from clinic	From Base	Destination
☐ Walk / Ski	☐	☐ Private Car ☐ Taxi	☐ Home/Hotel
☐ Toboggan	☐	☐ Company Vehicle	☐ Doctor
☐ Snowmobile	☐	☐ Ambulance: No: ______	☐ Clinic
☐ Helicopter	☐	Code ______at ___:___	☐ Hospital
☐ Download	☐	☐ Bus	Hosp. Name ________
☐ N/A	☐	☐ Helicopter ☐ Walk / Ski	☐ Return To Skiing
☐ ________	☐	Accompanied by:______	☐ Rest

Patroller's Name #

1st

2nd

3rd

Form Completed By: (PRINT NAME) # Signed: Date: / /

SKI AREA ☐ ☐ ☐ ☐

Figure A.3: National ski area accident report form[6]

[6] HeliCat Canada, 2017, personal communication.

APPENDIX B: MORTALITY RATES

Table B.2: Decadal avalanche mortality rates for guests and guides in the mechanized skiing industry (in micromorts, x10^{-6}) between the winter seasons 1970 and 2016.

INTERVAL *(Exposure)*	HELICOPTER- & SNOWCAT-SKIING *(Fatalities)*		
	<u>*Guests*</u> *(Fatalities)*		<u>*Guides*</u> *(Fatalities)*
1970-1980 *(Guests: 141,000 sd* *Guides: 23,500 gd)*	92.2 *(13)*	85.1 *(14)*	42.6 *(1)*
1980-1990 *(Guests: 369,000 sd* *Guides: 61,50 gd)*	48.8 *(18)*	53.4 *(23)*	81.3 *(5)*
1990-2000 *(Guests: 695,088 sd* *Guides: 115,847 gd)*	30.2 *(21)*	28.4 *(23)*	17.3 *(2)*
2000-2010 *(Guests: 930,100 sd* *Guides: 115,017 gd)*	11.8 *(11)*	12.0 *(13)*	12.9 *(2)*
2010-2016 *(Guests: 657,382 sd* *Guides: 109,565 gd)*	12.2 *(8)*	10.4 *(8)*	0.0 *(0)*
Overall (1970-2016) *(Guests: 2,792,570 sd* *Guides: 465,430 gd)*	25.4 *(71)*	24.9 *(81)*	21.5 *(10)*