Recreational avalanche accidents in Switzerland: Trends and patterns with an emphasis on burial, rescue methods and avalanche danger

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During the last 20 years (1992/93 to 2011/12) more than 90% of the avalanche fatalities in Switzerland occurred in uncontrolled avalanche terrain (recreational winter sport activities). Although the recreational activities have increased, the number of fatalities did not increase in recent decades. This positive trend can be attributed to improved prevention measures (e.g. better avalanche education and communication of avalanche danger) and faster and more efficient rescues. The median burial time of fully buried people decreased to 30 minutes and consequently the chance of survival increased, for both rescue by companions and by rescue teams. Most of the fully buried people were found using avalanche transceivers; although in organized rescue avalanche dogs still play an important role. About 85% of the deceased were fully buried. Their main cause of death was asphyxia. Most of the other victims died of trauma-related injuries. Even though the survival chance in an avalanche has increased, an avalanche involvement is still a very serious event. The main focus in avalanche prevention must therefore still be to avoid being caught by an avalanche.

KEYWORDS: avalanche accident, avalanche survival, mortality, rescue methods

1. INTRODUCTION

Each year avalanches cause the loss of life or health and/or property. In recent decades, considerable effort was undertaken to learn from these avalanche incidents, both for catastrophic avalanche situations as well as for winter outdoor sport activities. With the increase in winter tourism during the second half of the last century, there has also been a strong increase in backcountry winter recreation activities. Accordingly, the number of avalanche accidents involving people in uncontrolled terrain increased.

Avalanches reported to SLF that involved people or caused damage to property are stored in the avalanche data-base (ADB), which currently contains 13'000 avalanche records for the years 1936/37 to 2011/12. Based on the ADB avalanche accidents in Switzerland have been investigated for different time periods in the past (e.g. Tschirky et al., 2000; Harvey, 2002; Harvey and Zweifel, 2008; Zweifel et al., 2012).

In the last 20 years not only has the number of recreational activities increased, but there have also been considerable developments in the knowledge about avalanche formation (e.g. Schweizer et. al., 2003), avalanche warning and information to the public (Etter et al., 2008). New technologies (e.g. avalanche balloon pack, mobile phone) and improved avalanche safety equipment (e.g. avalanche transceiver, shovel) as well as rescue methods allow faster and more efficient response by companions and rescue teams (e.g. Atkins, 2008).

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In this paper we analyze accident data and discuss how these developments may have affected avalanche accidents in uncontrolled terrain in Switzerland. First, we give a brief historical overview (76 years), than we focus on trends and patterns in the last 20 years.

2. DATA AND METHODS

Of the 13'000 avalanches recorded in the ADB for the years from 1936/37 to 2011/12, 3540 avalanches involved 8356 people. Before 1994/95, mostly (85%) avalanches that had serious consequences, i.e. caused full burials, injuries or fatalities were recorded. With the possibility of reporting avalanches via fax (from 1996/97) and much later directly per internet (for SLF observers from 2001/02, for the public from 2008/09), the number of reported avalanches has increased (Fig. 1). The ratio between serious accidents (full burial, injury, death) and accidents without causing harm decreased (from 85:15 before 1994/95 to 50:50 after 1994/95). However, we attribute this to more accidents without causing harm being reported rather than to a decrease in seriousness of incidents. Consequently, the number of cases going unreported was likely much less in the last 18 years than before. However, regional differences in the reporting are visible. For the surroundings of Davos, where the SLF is located, relatively more recreational accidents causing no harm were recorded than in the other parts of Switzerland (last 20 years: 67% in Davos vs. 47% elsewhere). If a similar number of accidents causing no harm would have been reported in all regions in Switzerland, the ADB would contain approximately 1000 accidents more for the last

20 years. Even in the region of Davos, certainly not all avalanches where people were caught were reported.

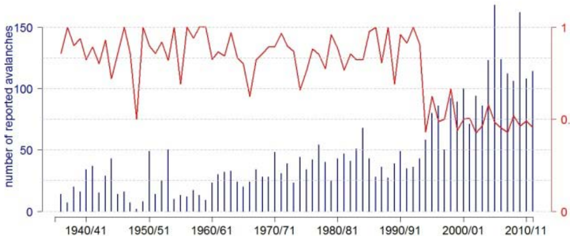

Fig. 1: Reported avalanche accidents involving people (blue bars) and the ratio of reported serious accidents to accidents without harm (red line). In this case, we consider serious accidents as those who caused injuries, fatalities or full burials.

In a first step we investigated the fatal accidents (1936/37 – 2011/12); this dataset is probably complete as very few events went unreported. Also, these incidents are comparably well investigated.

We then focused on accidents which occurred in uncontrolled terrain during the 20 years 1992/93 to 2011/12. Although the number of reported avalanches has further increased during this period, the ratio of serious incidents to those causing no harm has remained relatively stable. It is an interesting period to investigate, as there have been considerable technological developments in avalanche rescue.

Statistical analysis was performed using non-parametric statistics. Groups were compared using the Wilcoxon rank sum test (Crawley, 2007). Monotonic trends in time were investigated using the Mann-Kendall test (Mann, 1945). Differences between groups or trends in time were considered significant if the level of significance $\alpha \leq 0.05$.

3. RESULTS AND DISCUSSION

3.1 Avalanche fatalities – historical overview (1936/37 – 2011/12)

During the last 76 years 1884 people died in 1194 avalanches in Switzerland (annual mean: 25). The annual number of fatalities showed no significant trend during this period. However, the number of avalanches causing fatalities increased slightly (p=0.03), while the number of fatalities per avalanche decreased accordingly (p<0.01).

During the first half of the study period, 30% of the fatalities occurred in or around buildings, while travelling or working on roads, railways or on groomed ski runs. 44% of the fatalities occurred in uncontrolled terrain and 26% at unknown locations. During the second half of the period, since the mid 1970s, the vast majority occurred during winter sport activities in uncontrolled terrain (88%). The number of avalanche fatalities in buildings and on roads etc. has decreased significantly from 8.2 (1942/43 – 1961/62) to 1.5 (1991/92 – 2011/12, p<0.01) per year. At the same time, there was a strong increase in the number of avalanche fatalities during winter recreational activities (p<0.001). The number of fatalities doubled from 11 (1st half of the period) to 22 (2nd half of the period) per year. However, the largest numbers of recreational avalanche fatalities occurred during the 20 years between 1972/73 and 1991/92 (24 per year); then it slightly decreased to 21 per year during the last 20 years.

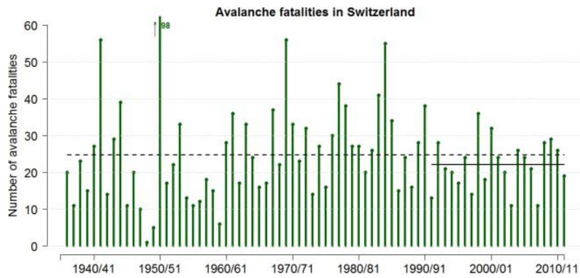

Fig. 2: Avalanche fatalities in Switzerland since 1936/37 (green bars). The lines show the means for 76 years (25 fatalities, black dashed line) and for the last 20 years (22 fatalities, black line).

Technological developments had a large impact on search methods. In particular the avalanche transceiver (mainly developed during the 1960s) has become the most important device for searching completely buried subjects during companion rescue (first successful find recorded in ADB in 1976/77; last decade: 92% of cases where search method was known); it is also very important in organized rescue (last decade: 46% of cases where search method was known). Avalanche search dogs and probing are still two important search methods (about 30%) during organized rescue, while the transponder was used in 4% of cases. Often, a combination of search methods was used. With the advance of technology, fully buried people were less often found by avalanche dogs (from more than 70% between 1962/63 and 1981/82 to 30% during the last decade). However, even during the most recent decade, if people could not be found by avalanche transceiver (either no transceiver or not activated), avalanche dogs located the buried subject in 80% of the cases where search method was known.

3.2 Avalanche accidents during the last two decades (1992/93 to 2011/12)

3.2.1 General characteristics of avalanche accidents

3519 people were caught in 1902 avalanches. 51% of these 1902 recorded avalanches resulted in full burial, injury or death. 3166 people (90%) were caught in uncontrolled terrain during recreational activities, while backcountry touring (67%) or off-piste skiing or boarding (33%). Out of these 3166 involvements, 805 were full burials (26%), 1149 partial burials (38%) and 1074 (36%) persons were not buried. For 138 people the burial type was unknown. About two thirds (2090) had no injuries, 617 were injured and 417 died (for 42 subjects consequences are unknown).

While backcountry touring, avalanches were more frequently triggered during descent than in ascent (52% vs. 36%, 12% unknown). However, there were significantly more people caught per incident while ascending (mean: 2.6) compared to descending (1.6 per accident, $p<0.001$). 54% of the recreational accidents occurred on weekends. For a more detailed description of avalanche victims refer to recently published data (Zweifel et al., 2012).

Slab avalanches were the main type of avalanche (97%). Most often, recreational avalanche accidents occurred in dry-snow conditions (90%). Avalanches resulting in fatalities were slightly larger than the remainder of the recreational avalanches involving people (Table 1). 59% of the avalanches causing fatalities had unfavorable terrain conditions (rocks, rock cliffs, single trees, forest, gully), compared to 27% for the avalanches causing neither fatality nor injury. Whereas these characteristics are relatively well known for avalanches resulting in fatalities, data quality decreases for avalanches causing no harm. Snowpack characteristics of skier-triggered avalanches were described in Schweizer and Lütschg (2001).

Serious avalanches (dry-snow slab avalanches) at danger level 1 had a significantly larger fracture depth and larger vertical drop than at the other danger levels, while most avalanches without causing harm at danger level 1 were smaller (width, fracture depth, vertical drop, length) than at the other danger levels (although this finding is statistically not significant). There were no significant differences in maximum slope angle, measured on the Swiss topographic map (scale 1:25'000) within the outline of the avalanche, between the different danger levels. However, when also considering the frequency of avalanche occurrence at a given danger level, an increase with danger level and slope angle is noticeable (Table 2) and corresponds to risk reduction tools like the graphic reduction method (Schweizer et. al., 2005), which is generally educated in Switzerland.

Tab. 1: Avalanche characteristics of recreational accidents during the last 20 years, for accidents causing no harm (no full burial, no injury), for serious avalanches (full burial, injury, death) and for avalanches causing fatalities (median values). Unfavorable terrain indicates the proportion of accidents with unfavorable terrain conditions in the avalanche path: rocks, rock cliffs, single trees, forest, gullies.

Characteristics	no harm	serious	fatal
Fracture depth (cm)	40	50	50
Width (m)	50	50	70
Vertical drop (m)	90	150	180
Length (m)	150	250	320
Unfavorable terrain	27%	57%	59%

Tab. 2: Proportion of avalanche accidents (dry-snow slab avalanches, N=600) by forecasted avalanche danger level and slope angle. The maximum slope angle was measured on a 1:25'000 topographic map within the outline of the avalanche. Avalanches where the slope angle could not be measured due to rocky terrain were assumed to be steeper than 39°.

	forecasted avalanche danger		
slope angle	1	2	3
< 30°	0%	1%	3%
31 to 35°	1%	5%	10%
36 to 39°	1%	15%	21%
≥ 40°	1%	16%	27%

3.2.2 Avalanche accidents and avalanche danger

Accidents caused by dry-snow avalanches occurred most often at danger levels 2 and 3 (36% and 57%, respectively). During the last ten years (2002/03 – 2011/12), the proportion of accidents at danger level 3 increased by about 10%, while it reduced at the other danger levels (Fig. 3). Off-piste accidents occurred most often with a forecasted avalanche danger level 3 (73%) while accidents during backcountry touring were almost evenly distributed between danger levels 2 and 3 (each 47%). At danger level 2 about 25% and at danger level 3 about 55% of the accidents occurred off-piste.

At danger level 1, few serious accidents occurred as avalanches were relatively rare and small (ratio serious accidents to accidents without causing harm was 1:2). For danger level 2 about 50% and for danger level 3 and 4 about 60% of the accidents were classified serious.

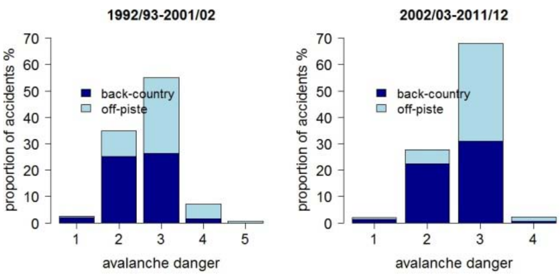

Fig. 3: Distribution of serious avalanche accidents by forecasted avalanche danger grouped by back-country touring and off-piste riding for the decade 1992/93 – 2001/02 (N=198) and 2002/03 – 2011/12 (N=310).

3.2.3 Avalanche rescue – burial and rescue methods, cause of death

In the last 20 years (1992/93 to 2011/12) 805 people were fully buried with a median burial depth of 80 cm and a median burial duration of 30 min (626 cases with reliable data on burial time). Of those, 44% did not survive the avalanche accident (median burial time 64 min, median burial depth 100 cm). In contrast, those who survived had a median burial depth of 50 cm and a median burial time of 10 min.

During the companion rescue time period (within the first 20 min) the frequency of victims dug out of the snow increased from 40% to 43% (first to second decade). In 88% of cases, rescue by companions of fully buried people without visible parts was possible due to the avalanche transceiver (median burial time 15 min, median burial depth 80 cm, survival-rate 67%). In the second decade people were freed much faster than during the first decade (10 vs. 15 min, $p < 0.01$, Fig. 4). This resulted in an increase in survival rate of 60% to 72%. If parts of the body or equipment were visible the chance of survival was highest (median burial time 5 min, median burial depth 30 cm, survival rate 89%). However, even if companions were able to free their friends, in 85% of the avalanche accidents with fully buried people organized rescue were called on site and assisted with extracting or transporting people off the accident site.

The median burial depth (median: 100 cm) and extraction time (median: 70 min) was greater for organized rescue teams than for companion rescue. Correspondingly, the survival rate of fully buried victims extracted by organized rescue was lower (27%). Organized rescue was significantly faster extracting victims in the second decade (60 vs. 105 min., $p = 0.01$, no change in depth 100 cm, Fig. 4). This also resulted in a minor increase in survival rate from 25 to 28%.

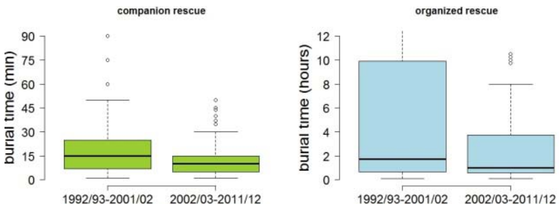

Fig. 4: Burial duration by rescue type for two decades (1992/93 – 2001/02, 2002/03 – 2011/12). Both, companion and organized rescue extracted fully buried people significantly faster in the second decade (n=626, reliable burial data only).

Figure 5 shows the proportion of people who survived an avalanche accident and their extraction time for 582 full burials (last 20 years). The decrease in burial times during companion rescue (median 15 to 10 min) occurs during a very time-critical period in avalanche rescue and has therefore a large impact on the survival rate. With a slightly longer burial duration the proportion of persons who survived drops significantly (Fig. 5, see also Brugger et. al., 2001). Although median burial times of people extracted by organized rescue were also reduced considerably (from 105 to 60 minutes), the survival rate during this period decreases less drastically (30% to 20%, Fig. 6, see also Brugger et. al., 2001). This highlights why the faster recovery of fully buried persons by companions had a much larger impact on survival rate than the also considerably reduced burial times for subjects recovered by organized rescue.

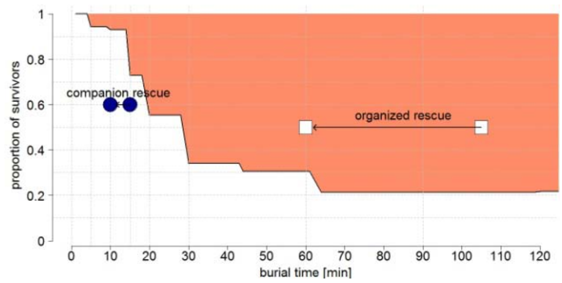

Fig. 5: Extraction time and proportion of people who survived in uncontrolled terrain for 582 full burials with known burial duration (20 years 1992/93 – 2011/12, reliable data only, excluding 44 cases where cause of death was trauma). The curve was calculated by splitting the dataset into ten groups with equal number of persons. The decrease in the median burial time is shown for companion rescue (dark-blue points) and organized rescue (light squares) for the two decades 1992/93 – 2001/02 and 2002/03 – 2011/12. The curve does not represent a survival curve

Advances in communication, travel, search technology and emergency medical care (Atkins, 2008) probably contributed to faster response by organized rescue teams and companions. In particular the wide-spread use of the avalanche transceiver has revolutionized the first response by companions. This has resulted in reduced burial times and hence an increase in survival chances, a trend which was discussed in previous studies (e.g. Harvey and Zweifel, 2008). During the investigated 20-year period (1992/93 – 2011/12), 56% of the fully buried avalanche victims survived the burial. Haegeli et. al. (2011) compared burial times and survival chances in Canada and Switzerland analyzing a 35-year data-set. The authors noticed significant differences between extraction times between the two countries (less victims are extracted within the first 20 minutes in Switzerland than in Canada, 40% vs. 56%, the median burial duration is 18 minutes in Canada and 35 minutes in Switzerland). While the presented Swiss data (this study) shows a reduction in burial times (median 30 minutes) and hence also an increase in the proportion of victims who were found within the first 20 minutes (42%), it remains unclear why there are such large differences between the two countries.

The differences between the survival rate at different burial times in open terrain between the Canadian data and Swiss data, which Haegeli et al. (2011) have shown, was confirmed even if only the more recent Swiss data were considered (Table 3). It remains unclear why in Switzerland the chances for survival at longer burial duration are higher than in the Canadian data-set. Haegeli and his colleagues presumed this difference to be due to either limitations in skills at the avalanche site and during transport as well as to longer distances between the accident site and the hospital. It is unclear whether differing data-collection methods (many accidents without causing harm are reported in Switzerland) contribute to the observed differences.

Tab. 3: Comparison of survival rates by duration of burial between study by Haegeli et al., 2011 (Canadian data CA [1980/81 – 2004/05, 66% of cases after 1992], Swiss data CH [1980/81 – 2004/05, 48% of cases after 1992]) and the most current Swiss data (20 years: 1992/93 – 2011/12).

	% who survived		
Duration of burial (min)	CA (35 yrs)	CH (35 yrs)	CH (20 yrs)
≤ 10	90	94	92
11 - 20	36	71	66
21 - 35	24	44	33
≥ 36	4	16	18

Cause of death for victims in uncontrolled terrain (not in buildings or vehicles, N=417) is not consistently investigated in Switzerland (34% no information). Based on the victims with known cause of death (N=276), established either on-site or sometimes by postmortem, 55% died of asphyxia, 42% of mechanical injuries and 3% of hypothermia. Of victims who died due to mechanical injuries (N=115), about 50% were not or only partially buried. For fully buried victims, 70% died of asphyxia, 27% of mechanical injuries and 3% hypothermia.

At first glance, the Swiss data on cause of death in avalanches looks very different compared to datasets from other countries (e.g. for Western Canada (Boyd et al., 2009), Austria (Würtl and Bilek, 2011), Utah/U.S. (McIntosh et al., 2007), Table 4). However, while relatively complete datasets exist for Austria (N=143, 92% of cases with known cause of death), western Canada (N=204, 100%) and Utah (N=56, 100%), the Swiss dataset has a large proportion of not investigated cases (34%). Also, for the cases where cause of death was given, it was only rarely established by full postmortem investigation. We suspect that the non-investigated cases in the Swiss data may include relatively fewer cases with trauma-related deaths. Therefore, we follow the conclusion of Brugger et al. (2009) and advise caution when interpreting (Swiss) data on cause of death in avalanches.

*Tab. 4: Cause of death in avalanches for all victims (a) and full burials (b) for Switzerland (1992/93 – 2011/12), western Canada (1980/81 – 2004/05, Boyd et al. 2009), Austria (2005/06 – 2010/11, Würtl and Bilek, 2011) and Utah/U.S. (*1989/90 to 2005/06*).*

a) Cause of death (%)	CH* (20 yrs)	AUT* (6 yrs)	CA (21 yrs)	US (17 yrs)
trauma	42	35	24	5
asphyxia	55	63	65	86
asphyxia & trauma			10	9
hypothermia	3	2	1	0

b) full burials	CH (20 yrs)	AUT (6 yrs)	CA (21 yrs)
trauma %	27 (16**)	20	15

** - percentage given for known cases only,*

*** - proportion of all cases (including missing cases)*

4. CONCLUSIONS

The increase in recreational avalanche fatalities in uncontrolled terrain from the 1960s onwards has halted in the 1990s. Since then the number of avalanche fatalities has remained rather steady despite the increase in winter recreation activities in uncontrolled terrain. Analyzing this long-term data-series showed that changing data collection methods and the introduction of new technologies require a careful approach when comparing datasets from different time periods and different countries. Data-collection and avalanche reporting might even play a role at a regional scale: for instance, in the surroundings of Davos, the ratio between reported less serious to serious avalanche accidents was much higher than in other areas of Switzerland. Based on this difference, we assume that currently approximately 20% of avalanche involvements are not recorded in Switzerland.

The faster extrication of fully buried victims and thus the increase in the survival chance is most likely associated to the widespread use and improvement in search and rescue technologies (most of all the avalanche transceiver). With the help of the avalanche transceiver companion rescue has become more efficient and successful. However, in the vast majority of cases, companion rescue was assisted by organized rescue assisting in the on-site extrication and transportation to a hospital. The relatively high proportion of victims who died due to severe traumatic injuries highlights the consequences of unfavorable terrain in the avalanche path and shows how important it is to prevent an avalanche involvement. While the avoidance of such terrain would be the best strategy, wearing helmet and back protection may also reduce the numbers of serious injuries. However, it is unclear whether the potential risk reduction due to the use of such safety devices will simply be compensated (Sole, 2008; Wilde, 1982).

The reason for the difference between the Canadian survival rates and cause of death and the European data (Switzerland and Austria) should be investigated in more detail.

Despite all these positive trends, being caught in an avalanche remains a potentially life-threatening event. The main focus in avalanche prevention must therefore still be to avoid being caught by an avalanche.

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6. REFERENCES

Atkins, D. 2008. Time to change rescue attitudes for a new generation. *Proceedings International Snow Science Workshop Banff*, 80-86

Boyd, J., Abu-Laban, R., Shuster, M. and J. Butt. 2009. Patterns of death among avalanche fatalities: a 21-year review. *Can Med Assoc J*, 180 (5), 507-512

Brugger, H., Durrer, B., Adler-Kastner, L. Falk, M. and F. Tschirky, 2001. Field management of avalanche victims. *Resuscitation* 51, 7-15

Brugger, H., Etter, H.J., Boyd, J. and M. Falk. 2009. Causes of death from avalanche. *Wild & Environ Med*, 20 (1), 93-96

Crawley, M. 2007. The R Book. Wiley, 942 p. ISBN: 978-0-470-51024-7

Etter, H.-J., Stucki, T., Zweifel, B. and C. Pielmeier. 2008. Developments in avalanche forecasting and other prevention measures and their potential effects on avalanche fatalities. In: *Proceedings International Snow Science Workshop, Whistler, Canada*, 628-635

Haegeli, P., Falk, M., Brugger, H., Etter, H. and J. Boyd, 2011. Comparison of avalanche survival patterns in Canada and Switzerland. *Can. Med. Assoc. J.* 183(7), 789-795

Harvey, S. 2002. Avalanche accidents in Switzerland in relation to the predicted danger degree. *roceedings International Snow Science Workshop, Penticton, Canada*

Harvey, S. and B. Zweifel. 2008. New trends of recreational avalanche accidents in Switzerland. *Proceedings International Snow Science Workshop Banff*

Mann, H. (1945), Nonparametric tests against trend, *Econometrica*, 13, 245-259.

McIntosh, S., Grissom, C., Olivares, C., Kim, H. and B. Tremper. 2007. Cause of death in avalanche fatalities. *Wilderness Environ Med.* 18(4), 293–297.

Schweizer, J. and M. Lütschg. 2001. Characteristics of human-triggered avalanches. *Cold Reg. Sci. Technol.* 33(2–3): 147-162.

Schweizer, J., Jamieson B. and M. Schneebeli. 2003. Snow avalanche formation. *Rev. Geophys.* 41 (4), 1016

Schweizer, J. Harvey, S. Hasler, B., Hepting, M. Josi, W., Rhyner, H.U. 2005. Merkblatt “Caution Avalanches!”

Sole, A., 2008. Human Risk Factors in Avalanche Incidents. M.S. Thesis, University of Calgary, Calgary, AB.

Tschirky, F., Brabec, B. and M. Kern. 2000. Avalanche rescue systems in Switzerland. Experience and limitations. *Proceedings International Snow Science Workshop, Big Sky, Montana*, 369-376

Wilde, G., 1982. The Theory of Risk Homeostasis: Implications for Safety and Health. *Risk Analysis*, 2(4): 209-225.

Würtl, W. and H. Bilek., 2011. Zum Tode verurteilt. *Bergundsteigen 4/11*, 46-49

Zweifel, B., Techel, F. and C. Björk. 2012. Who is involved in avalanche accidents? In: *Proceedings International Snow Science Workshop Anchorage, Alaska*. 234-239.