NEW GEOREFERENCED AVALANCHE DATABASE IN ANDORRA: A BRIEF CHARACTERIZATION OF ACCIDENTS OVER THE LAST 60 YEARS

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ABSTRACT: Although avalanches have affected Andorra for as long as can be remembered, the first fatality recorded by rescue services dates to the winter of 1964. Since then, a total of 21 people have died and at least 35 others have been injured due to avalanches. Andorra Research + Innovation has been recording avalanche accidents that have occurred in Andorra since 1964 until the present day, based on data from newspapers, records of Andorran fire and police mountain rescue teams; and more recently, from information shared on social media by users of various profiles. The information collected is therefore very heterogeneous. This work presents a brief characterization of avalanche accidents and incidents in Andorra carried out through the creation of a geo-referenced database and discusses the limitations and potential of this database.

KEYWORDS: Avalanche accidents, avalanche database, Pyrenees.

1. INTRODUCTION

Andorra is a small country (468 km^2) located in the central Pyrenees, between France and Spain (Fig. 1). The average altitude is 1.893 m, with values ranging from 840 m to 2.942 m, and with 65 summits more than 2.500 m high. The country is carved by two main rivers and its corresponding valleys: Valira del Nord in the west and Valira d'Orient in the east. These two rivers converge in Andorra la Vella to form the Valira river.

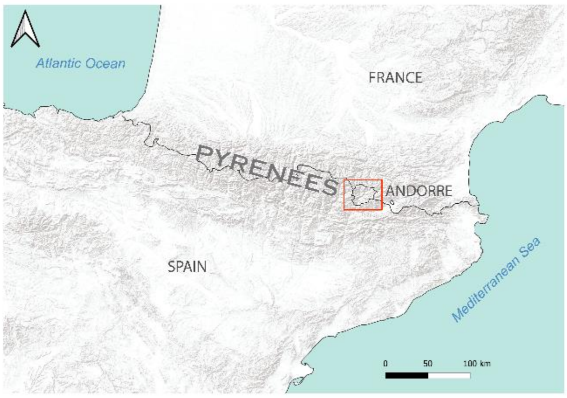

Figure 1: Location of Andorra in the Central Pyrenees.

Due to the altitude, much of the territory is, in some extent, frequently snow-covered during winter, and the highest parts may remain under snow for about 5 months (Batalla et al., 2016). The population density in the country is of about 184 inhabitants/ km^2 in 2024 (http://www.estadistica.ad). There are three main alpine ski resorts that occupy 30,75 km^2 (6,6% of its territory) which counts with 308 km of slopes (https://skiandorra.ad/ca/informacio-general/) (Fig. 2) and a small cross-country ski resort with 15 km of slopes in the south of the country.

One of the tasks of Andorra Research and Innovation is to collect and analyze avalanche events, both natural and accidental, in order to characterize them and determine measures to reduce the risk. Since 1964, 21 deaths due to avalanches have been reported in Andorra, as well as numerous damages to infrastructures (e.g. the Arinsal avalanche in 1996, which destroyed entire inhabited buildings and is considered one of the largest avalanches in Europe in an inhabited area) (Furdada et al., 2020). This paper describes the main physical and temporal parameters of the accidents and incidents recorded during these years.

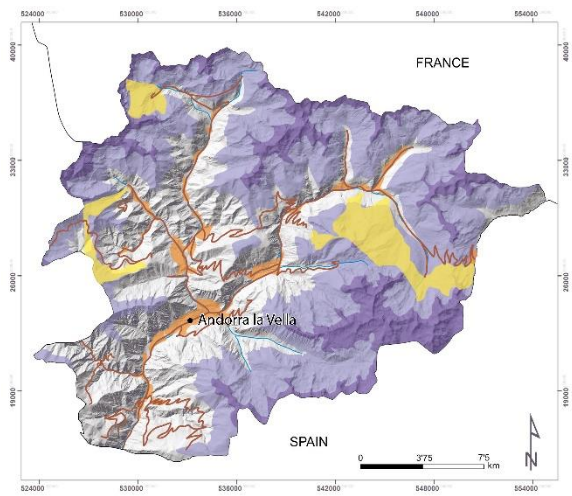

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Figure 2: Map of Andorra. Light blue: 2.000 m level height; purple: 2.500 m level height; orange: main inhabited zones; yellow: ski resort areas; brown lines: main roads; blue lines: main rivers.

2. DATA RETRIEVAL

In 2006, Andorra Research + Innovation (AR+I from now on) started a natural hazards database project, with the gathering of information on past events from media and reports from the rescue teams of the Andorran Fire and Mountain Rescue Department and the Andorran Police. The first "modern" information we have dates to 1964. The 2008-2009 season saw the beginning of the collection of real time information and the start of observations on the ground after fatalities. From 2008, with the beginning of training courses in snow and avalanche science by AR+I, Andorra firefighters and the school of mountain guides (EFPEM), the information began to be collected by other means such as e-mail, with photographs attached, allowing a more accurate characterization of the avalanches. Finally, in the 2017-2018 season, AR+I technicians became part of a WhatsApp (social media app) group with the ski resort areas chiefs, the National Meteorological Service (SMN from now on), some mountain guides, rescue teams and other people linked to the world of snow. In parallel, AR+I lunched out an online form of avalanche observations that can be filled in with mobile phone, with the aim of facilitating the communication of new accidents.

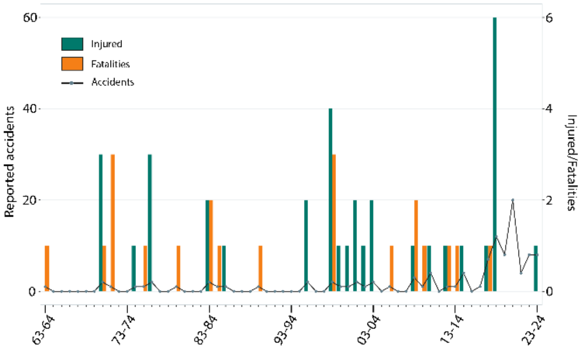

Figure 3: Number of accidents reported, and people injured and killed per accident in Andorra during the period 1964-2024. There is a slight increase in the number of accidents from the mid-2000s and a more important increase from the 2017-2018 season.

This heterogeneity in data collection is evident in the number of accidents reported over the years. While in the period 1964-2008 there was only information about accidents with victims where the action of a rescue teams was necessary, normally without related graphic information, from the 2008-2009 season the number of reported accidents increased, and it is from the 2017-2018 season, when receiving information through the WhatsApp group, when the number of reported accidents raised up exponentially, as it is shown in Figure 3. This increase in the number of reported accidents from the late 2000s has also been identified in other sectors and regions (e.g. Techel and Zweifel (2013) for Switzerland). The type of information collected is also very different. In the period 1964-2008 it is basically the number of deaths and injuries and some place names, a fact that makes it very difficult to characterize the terrain where the accident occurred; whereas from 2008 onwards, photographs and even the testimony of the involved provide a more detailed cartography that has allowed us to obtain information on the characteristics of the terrain.

3. METHODOLOGY

Regarding to the data used, we have worked with those avalanches that have a human component: either natural avalanches that have caused death or injury (this is especially the case in the avalanches of the 1970s); or accidental avalanches, that have been caused by people, whether they have been caught or have been able to escape. In the results section it is explained which data have been used to analyze each factor. The information provided in the database is based on the fields of the "Fatal avalanche accidents in Switzerland since 1936/37" (WSL, 2023) and the figures and events of the paper have been temporally-related using the concept of hydrological year (from 1st October of one solar year to the 30th September of next one).

The geo-referencing of the avalanches has been a relevant challenge. The heterogeneity in the source and type of data available has led to generate two types of input: point data and polygons. When the information related to the geometry of the avalanche was very limited (toponym, slope) it was represented with a point at the name of the summit, the hill, or near the toponym in question. The database has 38 entries of this type. When it has been possible to determine the release zone with precision, either thanks to photographs or to testimonies, the avalanches have been mapped with polygons, which can be of two categories: high precision or low precision. This second case is applied especially when the arrival zone and, therefore, the length cannot be observed. In total there are 70 polygons, 53 of which are mapped with high precision. This georeferencing has allowed to analyze for the first time in Andorra several variables related to the terrain: the main aspect, the maximum slope and the maximum altitude of the departure zone, the type of ATES terrain, or the measures of the avalanches, among others.

Regarding the snow and meteorological analysis of the accidents, the degree of danger and the problem as defined by the EAWS have been used. Meteo-France (MF) has been conducting the Avalanche Bulletin for Andorra since 1984, but it was not until 1993 that the scale was standardized for EAWS member countries. Therefore, for accidents prior to 1993, the degree of risk has not been analyzed. In January 2016, the National Meteorological Service (SNM) started to issue its own avalanche bulletin and since then the two bulletins (MF and SMN) have been coexisting. For the analysis of the degree of risk, the SMN data has been prioritized, and only when there was no data, the MF data has been used. Another factor to be analyzed was the problem observed in accidents. In the most recent avalanches, it is relatively easy to deduce, since the problem is included in the avalanche report and the access to pictures, the weather forecast of the day before and even the access to the avalanche crown face facilitates the assignment of a problem to the accident. In the oldest cases we used information gathered from newspapers or reports, as well as pictures in case there were any. In other cases, it has not been possible to determine the problem.

4. RESULTS

In the period 1964-2024 a total of 21 deaths and 35 injuries were reported in Andorra of varying severity in a total of 108 accidents involving people (Fig. 3), of which 69 have involved caught people during the incident. On average, over the study period, the number of deaths per season was 0.35. The average rate of deaths/accident involving rescue teams was 0.72, even though this rate varies greatly depending on the decade (Fig. 4). If we take into account accidents with injured people, including those involving rescue teams and those that do not; differences among decades are even greater, but so is the bias due to effectiveness reporting accidents, much higher in the two last decades. For that reason, we made the comparison between accidents involving rescue teams.

Although the number of reported accidents has been increasing (fig. 3), so has the number of mountain sports practitioners, the number of deaths does not show an upward trend (fig. 4). This situation is generally found in different studies throughout Europe (Biskupic et al., 2018; Martí et al., 2023; Techel et al., 2016; Techel and Zweifel, 2013; https://www.avalanches.org/fatalities/fatalities-statistics/). On the other hand, if we consider the number of deaths in relation to the number of accidents involving rescue teams, we can see a slightly decreasing trend, especially in the last decade. It is worth highlighting the high number of deaths in the 2004/2014 decade, with 6 people killed in 5 fatal accidents, congruent to the trend observed in the Catalan Pyrenees in a similar period (Fig. 1 in Martí et al., 2023).

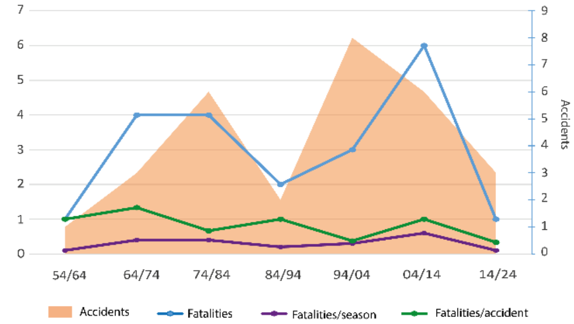

Figure 4: Number of accidents reported by the rescue teams (orange area), and evolution of number of deaths, deaths per season and deaths per accident, per decade.

If we look at the cause of the triggering, in most of the cases these have been accidental, with a similar proportion if we consider all accidents (96%) or only fatal accidents (93%). In the last two decades, all accidents have been human-caused (Fig. 5).

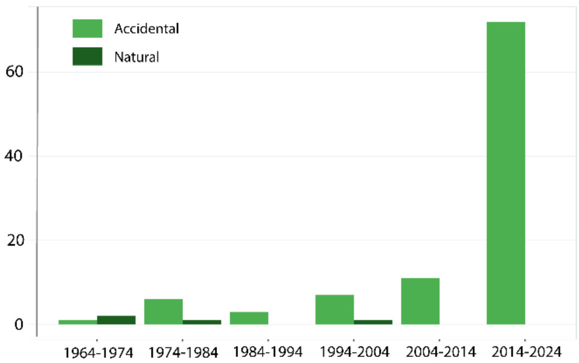

Figure 5: Frequency of accidents by cause, per decade. n=104.

In the last decade and a half, the number of accidents on uncontrolled mountain terrain has also increased with the popularization of ski mountaineering in the Pyrenees (Fig. 6, fig. 7).

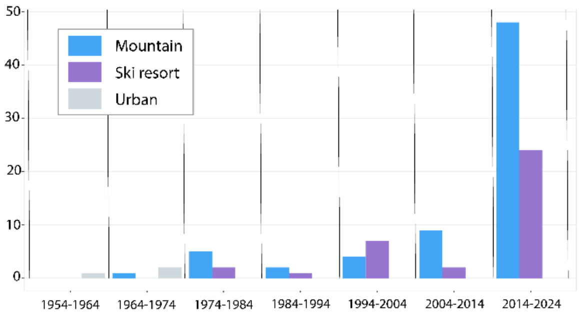

Figure 6: Area in which accidents occurred, per decade. n=108.

Regarding the area where they have occurred, the last accident with people injured in an urban area dates back to April 1971. It should be noted that there have been other accidents that have affected infrastructures, such as the example of the Arinsal avalanche in 1996 (Furdada et al., 2020), but without leading to any casualties.

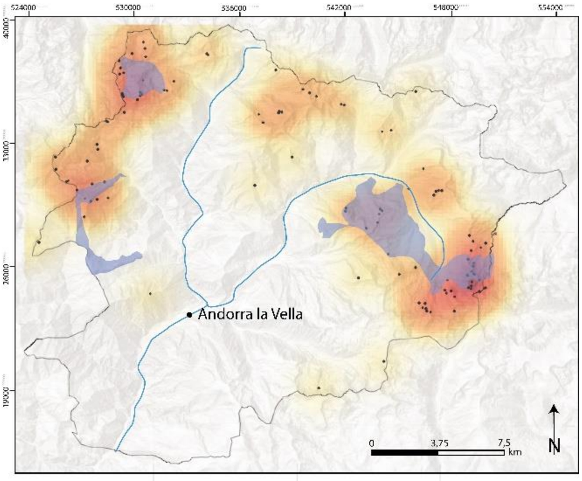

Figure 7: Hotspot map of the 108 accidents reported in Andorra in the studied period. Polygons are represented by their central points calculated with ArcGIS Pro. Blue polygons represent the ski resort areas.

For the analysis carried out in the following sections, only the accidents that occurred outside the urban area, i.e. on or near ski slopes (33%) or in uncontrolled mountain areas (64%), are considered, with the aim to characterize the accidents that affect the practice of mountain sports.

4.1 *Time and seasonal distribution*

Regarding monthly distribution, the months with the highest number of accidents are January, March and December (Fig. 8).

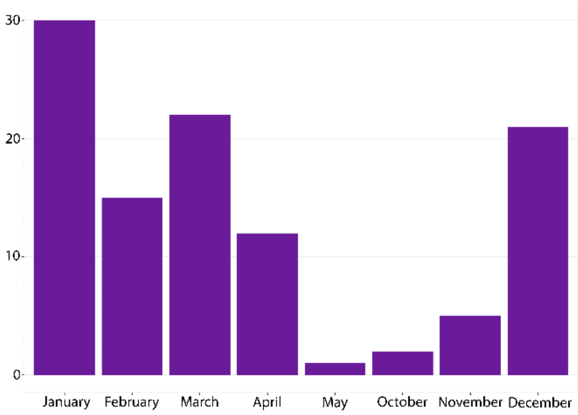

Figure 8: Frequency of accidents per month in which they occurred. N= 108.

Regarding the distribution of accidents according to whether the day is a working day or a holiday, we can see that until the last decade most accidents occurred on holidays (weekends, Christmas and Easter holidays), while in the decade 2014-2024 this trend is reversed, and we find more accidents occurring on working days (Fig. 9).

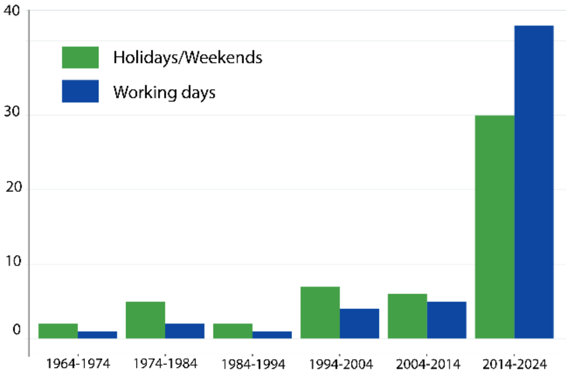

Figure 9: Frequency of accidents on holidays or weekdays, per decade. N=107.

4.2 *Terrain and avalanche characteristics*

In this section we will analyze the terrain and snow characteristics of the accidents. As some of these data are not available for all accidents, it is indicated for each graph how many data is available.

Orientation: Most of the avalanches have their departure zone on N and E slopes (Fig. 10), similar to what is observed in the rest of the Catalan Pyrenees (Bacardit et al., 2016; ICGC, 2020) and in Canada (Jamieson et al, 2007).

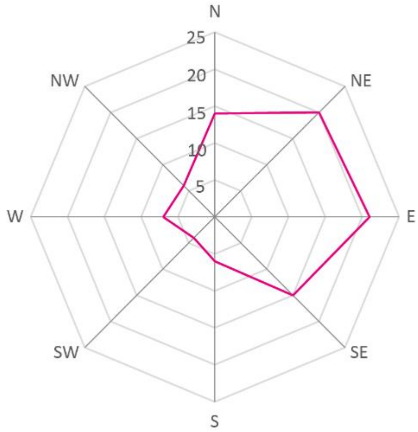

Figure 10: Frequency of accidents according to the orientation of the release zone. n=93.

Altitude: Regarding the elevation of the start zone, the data were divided by 200-meter intervals. The interval with the highest number of accidents was 2400-2600m, with 53%, followed closely by the 2600-2800 and 2200-2400 intervals with 16% and 13% respectively (Fig. 11).

This finding is slightly higher than other published data, e.g. in the Catalan Pyrenees where 31% of fatal accidents occur in the 2100-2400 m range

(Bacardit et al., 2016; Martí et al., 2023) or in regions such as the Italian Alps between 2200-2500 m (Valt, 2010), the Swiss Alps at 2400 m or in Canada at 2000 m (Schweizer and Jamieson, 2001).

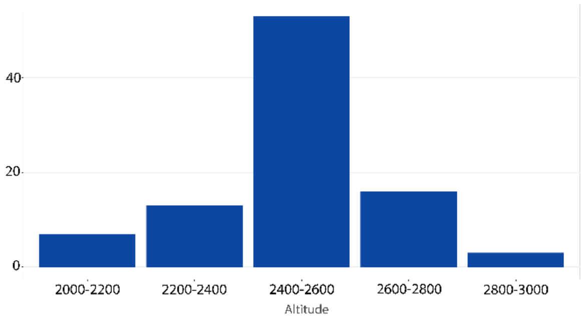

Figure 11: Frequency of accidents in the elevation range of the release zone. n=92.

Departure angle: This information is not known for many of the accidents, and in some others, it may have a considerable margin of error, so we have worked with ranges and we have measured them on a 5x5m DTM. As expected, most of the accidents have a departure angle between 36-40º (54%), followed closely by 41-45º (19%) and 31-35º (13%), similar to other regions around the world (Bacardit et al. (2016) for the Catalan Pyrenees; Biskupic et al. (2018) for Slovakia; Schweizer and Jamieson (2001) for Switzerland and Canada; Valt (2010) for the Italian Alps) (Fig. 12).

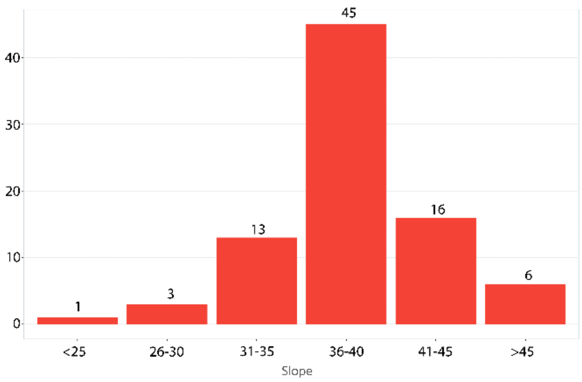

Figure 12: Frequency of accidents according to the angle of the release zone. n=84.

Avalanche Terrain Exposure Scale (ATES): According to the ATES classification of Andorra (https://visor.allaus.ad/), most of the run-off zones of the studied avalanches were on complex terrain and only the remaining 13% of accidents on challenging terrain, similar numbers that the ones found in Canada (Jamieson et al., 2007).

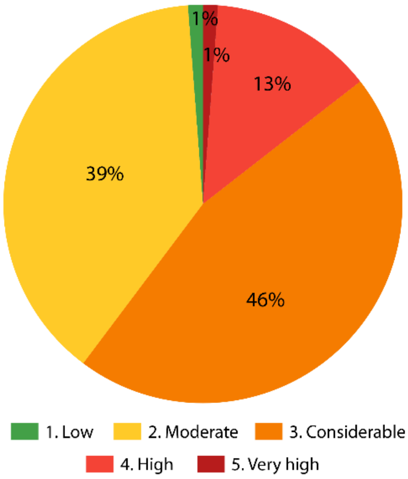

Figure 13: Frequency of accidents according to the degree of danger reported to the avalanche report. Data from 1993. n=83.

Avalanche forecasting: Most of the accidents have occurred with a danger level of 3 (46%) and 2 (39%), following the predominant trend in the neighbouring Catalan Pyrenees (ICGC, 2020; Martí et al. 2023), in the Swiss Alps (Techel and Zweifel, 2013), and in Italy (Valt, 2010) (Fig. 13). There is one accident with danger level 1 with wet snow; and one accident with danger level 5 of natural origin. In some cases, we do not have the level of danger for that given day, either because the prediction services have not elaborated it, or because there were notes without an assigned number. This is especially true at the beginning and the end of the season. These data have not been considered in the analysis.

Regarding the problems observed, in most of cases was wind slab (49%), followed by the problem of recent snow (29%). The problem of persistent week layers represented 16% of the accidents (Fig. 14). According to the latest information from newspapers and Police and Fire Department reports, traditionally, when the avalanche was of hard slab, it was always considered as a wind slab, since the concept of persistent weak layer did not exist. Thus, the number of accidents caused by this problem may be underestimated.

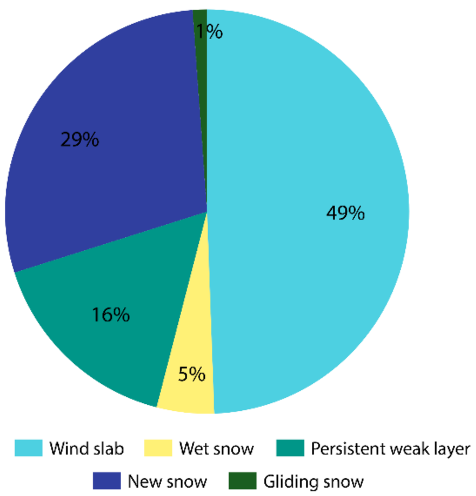

Figure 14: Frequency of accidents by type of avalanche problem. n=87.

Most of the accidents occurred in sizes <2 (46%), close to the values of the Catalan Pyrenees (Bacardit et al., 2016). Regarding the accidents with fatalities for which the avalanche measures are known (n=7), all of them have been with D3 (Fig. 15).

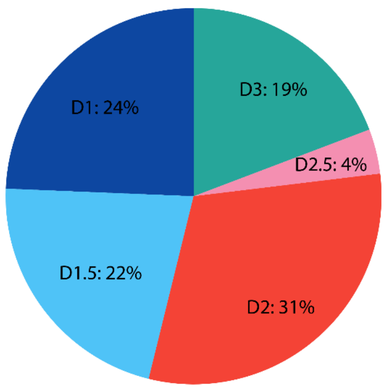

Figure 15: Frequency of accidents according to the size of the avalanche. n=78.

4.3 <u>Activity</u>

Most accidents occurred during ski mountaineering, followed by off-piste skiing or snowboarding. These data are similar to those observed in the Alpine Arc, where backcountry skiing accidents represent 49% in Italy, 46% in France, 50% in Switzerland and 53% in Austria (Valt, 2010). Snowmobile accidents account for 7%, in contrast to the rest of the Catalan Pyrenees where this activity is almost non-existent and where no accidents have ever been recorded (https://www.acna.cat/estadistiques-daccidents/), in contrast with other regions like Canada where snowmobile accidents can account up to 40% (Boyd et al. 2009) (Fig. 16).

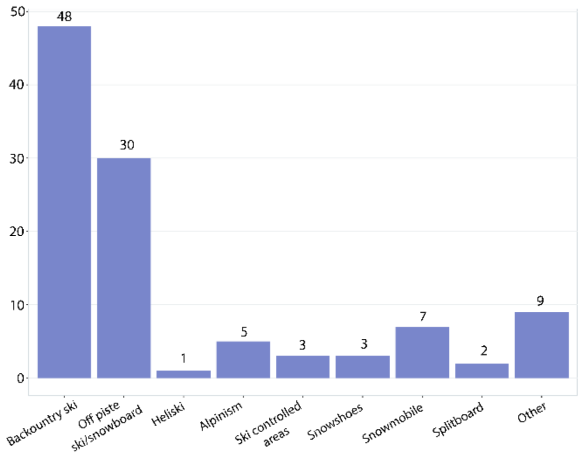

Figure 16: Frequency of accidents according to the activity practiced by the victims. n=108.

We had some data on the state of the sky, either from information provided by the press, from photographs reported by the accidents themselves or, in the most recent cases, by retrieving images from the webcams of the ski slopes. It is possible to observe that in 76% of the analyzed cases the accidents have occurred on days with a clear sky.

5. CONCLUSIONS

In this work we present the first geo-referenced database of the avalanche accidents occurred in Andorra in the last 60 years. One of the limitations is the relatively low number of data, with at best 108 accidents. Another limitation is that the results presented are biased due to lack of information of the non-severe accidents, as well as the lack of information of the older accidents. However, georeferencing has allowed us to obtain information about the characteristics of the terrain that to the date was never considered.

From this analysis we can confirm that:

a) the number of accidents reported has been increasing, especially from the 2017-2018 season onwards. On the one hand it could be due to an increase in the number of people practicing mountain sports in winter and on the other hand due to the ease of communication of accidents made possible by new technologies (social networks, surveys, etc.);

b) even though, there is no positive trend in terms of the number of deaths or injuries. There is, however, a slightly decreasing trend in the rate of deaths/accidents, which may be due both to the practitioners' greater knowledge of avalanches and rescue techniques and to increase and improvement of the gear used (airbag, DVA, shovel, probe and helmet). The use of this gear is a point that will be further analyzed in future work;

c) most of the victims, both fatalities and injuries, were led by human-caused accidents; in a mountain area outside ski resorts, and the victims were mainly practicing backcountry skiing (although in recent years there was an increase in the skiing accidents in boundary areas of ski resorts);

d) until the last decade, most accidents occurred on holidays, but this trend was reversed in the last decade; probably because a change in the trend in the types of work, which allowed many people to have more free time during the weekdays. 75% of accidents occurred on blue sky days;

e) Regarding the terrain characteristics, most of the avalanches occurred in complex terrain and on slopes with a component from N to SE, as was seen in other studies of accidents in the Pyrenees or Canada. This is due in part to the dominant winter atmospheric circulation in the Pyrenees, which is NW, and to the intrinsic characteristics of the N-facing faces in the N hemisphere;

f) The altitudinal range of the starting zones with more accidents was from 2400 to 2600 m. Starting zone slope angle of most accidents was between 36 and 40, as in the other cases studied around the world.

g) Most of the accidents occurred with a hazard level of 3 (46%) and 2 (39%) due to problems of wind slabs (49%) and recent snow (29%). The problem of persistent weak layers represented 16% of the accidents. This assumption requires a re-evaluation of the meteorological conditions of the oldest accidents, because some persistent week layers could be classified as wind slabs. These values are congruent with neighboring Pyrenean areas but differ from other areas like Canada where persistent weak layers are the first problem leading to accidents (Jamieson et al., 2007).

h) All accidents with fatalities were of size D3, similar to Canada where D3 account for more fatalities but contrasts with the data collected in other sectors of the Pyrenees, where the size of fatal accidents is between 1 and 2.5 (ACNA: https://www.acna.cat/estadistiques-daccidents/). This data is considered very skewed due to the low number of fatal accidents for which information on the measure is available (n=7).

As ongoing work, we will carry out a detailed analysis to know if there is a relationship between the avalanche danger level and problem and the size, as well as the relationship of the accidents with the weather circulation patterns. There is also work underway to understand the cause of death of the fatalities.

It is expected to be able to joint this database to the neighboring Catalan Pyrenees accident database - of which Andorra is a geographical part - to further characterize the accidents in this most Eastern sector of the Pyrenees and help to have a greater database able to produce better insights to help to better understand them and prevent them.

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