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DATABASE

FraneItalia: a catalog of recent Italian landslides

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Abstract

Background: In Italy landslides are widespread natural phenomena causing a significant number of fatalities and huge economic losses throughout the country every year. Information on the spatial and temporal distribution of landslides at national scale is critical for developing landslide susceptibility, hazard and risk maps, as well as, more generally, for decision making in landslide risk management.

Description: The paper presents, after a brief review on global and national landslide databases, a new geo-referenced catalog of recent landslides affecting the Italian territory. The catalog, called Franeitalia, includes both fatal landslide events and events that did not produce physical harm to people. It has been developed consulting online news sources from 2010 onwards. The following seven steps have been performed to define and populate the catalog: i) selection of news sources; ii) identification of effective search keywords; iii) collection of relevant news articles; iv) identification of landslide categories; v) definition of catalog fields; vi) information mining from news articles; vii) geo-referencing of the events. Landslide events are classified considering two numerosity categories and three consequence categories. The numerosity categories are: single landslide events (SLE), for records only reporting one landslide; and areal landslide events (ALE), for records referring to multiple landslides triggered by the same cause in the same geographic area. Both SLEs and ALEs are divided in three consequence classes according to whether the event produced victims and/or missing people (C1, very severe), injured persons and/or evacuations (C2, severe), or did not cause any physical harm to people (C3, minor). Information on the landslide events collected in the catalog always includes: data on the location of the event, day of occurrence of the landslide (s), source (s) of information, and number of landslides in case of areal events. Additional information may include: onset and duration of the landslide event, landslide characteristics, phase of activity, details on the consequences.

Conclusions: Reports and statistics on the landslides included in the catalog are presented highlighting: the main figures of the landslide inventory, currently spanning from the 2010 to 2017 and including 8931 landslides; and time-dependent national and regional trends, with a focus on the consequences induced by the events. The paper also compares and discusses the figures in relation to other catalogs reporting recent landslides that occurred in the Italian territory.

Keywords: Landslide, FraneItalia, Database, Susceptibility, Hazard, Risk, Newspaper, Consequences, Italy

Background

Landslide inventories and databases are critical to support investigations of where and when landslides have happened and may occur in the future (Kirschbaum et al. 2015). According to Guzzetti et al. (2012), landslide inventory maps may be prepared for multiple scopes, including: documenting the extent of landslide phenomena; investigating the distribution, types and patterns of landslides in relation to morphological and geological characteristics; studying the evolution of landscapes dominated by mass-wasting processes; as a preliminary step toward landslide susceptibility, hazard, and risk assessment. The potential of databases to be used as tools in the assessment of landslide susceptibility, hazard and risk at national scale is also discussed by Van Den Eeckhaut and Hervás (2012) in a study presenting a detailed analysis of existing national databases in Europe.

Landslide inventories may be compiled in three different ways considering their temporal and spatial

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characteristics (Kirschbaum et al. 2015): i) developing maps highlighting historical landslides over local or regional scales; ii) recording single catastrophic triggering events; iii) compiling information from a combination of newspaper reports, published articles, aerial photographs and other sources, typically as point-based databases at national, international or global scale. The first example reported in the literature of a national database employing the latter methodology is the AVI project (Guzzetti et al. 1994), a bibliographical and archive inventory of landslides and floods in Italy, which included a systematic search of articles from 22 Italian journals for the period 1918–1990. In recent years, many similar initiatives have been carried out, at national or global scales. These initiatives have been mainly relying on information retrieved from the news rather than on technical reports or scientific investigations. An overview of natural hazard databases that use newspapers and other documentary evidence is provided by Raška et al. (2014).

This paper presents a new landslide catalog for the Italian territory developed consulting exclusively online news sources from 2010 onwards. The principal aim of the project was to realize, organize and populate a comprehensive spatio-temporal catalog of recent landslides affecting the Italian territory. The catalog includes both fatal landslide events and events that did not produce physical harm to people.

Global and national landslide databases: Review and current trends

Landslide databases developed at global, continental and national scales, differently from landslide inventory maps produced over smaller areas, often lack details of the inventoried phenomena, such as their areal distribution or insights into their type, size, activity and causal factors. Nevertheless, the acquisition and analysis of historic data of landslide events, although comprising only basic information, is essential for evaluating and managing landslide risk at small scales (e.g. Nadim et al. 2006). In the last decade, many initiatives have been carried out to compile global and national landslide databases.

At global scale, Kirschbaum et al. (2010) compiled a landslide catalog for rainfall-triggered events for 3 years, 2003, 2007 and 2008, drawing upon news reports, scholarly articles, and other hazard databases. The majority of the landslide reports have a radius of confidence within 25 km and are described as multiple sliding events over a region or medium to large event affecting a large area or population. Petley (2012) presented a global data set of fatalities from nonseismically triggered landslides that resulted in loss of life between 2004 and 2010. In total, 2620 fatal landslides were recorded during the 7-year period, causing 32,322 fatalities. The total numbers of landslides and victims are an order of magnitude greater than the figures that emerge from global disasters data sets, such as EM-DAT (Guha-Sapir et al., 2015) or NatCatSERVICE (Munich Re, 2014), yet the author suggests that they may still slightly underestimate the true human costs of landslides worldwide. Sepulveda and Petley (2015) presented a continental database of landslides that caused loss of life in Latin America and the Caribbean from 2004 to 2013. In 10 years a total of 11,631 people died across the region in 611 landslides. Kirschbaum et al. (2015), updating the analysis presented in Kirschbaum et al. (2010), developed a catalog from 2007 to 2013 that includes 5741 landslides, mostly occurring from July to September in Asia and North America. Finally, Haque et al. (2016) presented a spatio-temporal distribution of deadly landslides for 27 European countries over the years 1995–2014, reporting 476 landslides resulting in 1370 deaths.

National landslide databases exist in many countries. An overview of 24 national landslide databases in Europe is provided by Van Den Eeckhaut and Hervás (2012). The information available in each database is heterogeneous; at the time of the study six countries had sufficient data to perform landslide risk assessment at national scale, one country could use the data to assess landslide hazard and 14 countries could only produce landslide susceptibility maps. For most of these 14 countries the impossibility to estimate the hazard is due to the lack of information on the dates of the landslides. In recent years, Great Britain (Taylor et al. 2015), Portugal (Zêzere et al., 2014), Germany (Damm and Close 2015), Slovenia (Komac and Hribernik 2015) and Norway (Oppikofer et al. 2015) also developed national databases including, for a significant number of records, information on the date of occurrence of the landslides. Outside Europe, national databases that include both spatial and temporal information of the inventoried landslides were developed in Nicaragua (Devoli et al. 2007), Nepal (Petley et al. 2007) and New Zealand (Rosser et al. 2017).

Mass media has long been used by scientists and practitioners in the field of hazards in a number of ways (Taylor et al. 2015; Battistini et al. 2017). In New Zealand, the collection of news media accounts of landslides started in 1996 and has continued since (Rosser et al. 2017). In Great Britain, Taylor et al. (2015) proposed a method to supplement existing records of landslides stored in the national landslide database by searching an electronic archive of regional newspapers. In Germany, almost a quarter of the records of the national landslide database come from press archives (Damm and Close 2015). In Switzerland, newspapers and magazines are the main source of information for the flood and landslide damage database managed by the Federal Research

Institute (Hilker et al. 2009). Clearly, there are biases in using news sources as a proxy for information about landslides, and hazards in general (Raška et al. 2014). Nonetheless, regular publishing intervals and low costs make the analysis of news articles a useful complement to other methods for building hazard databases (Taylor et al. 2015). Moreover, the data quality of press reports and newspaper articles is usually good enough to provide some basic information on landslide location and date and, to some extent, landslide impact (Damm and Close 2015).

In Italy, as already mentioned, the first national landslide database was created with the AVI project (Guzzetti et al. 1994). AVI originally covered the period 1918–1990; successive revisions of the project put the final number of recorded landslides to 22,346 in the period 1009–2001 (National Research Council, 1990). Since the early 2000s, following a major landslide disaster that occurred in 1998 and the subsequent new legislation (e.g. Cascini 2005), landslide inventory maps at regional scale have been produced by the River Basin Authorities adopting different methodological approaches (Ferlisi and De Chiara 2016). An integration at national scale of available information coming from different sources, including the AVI Project and the River Basin Authority inventory maps, is provided by the IFFI Project (Trigila et al., 2010). As of today, the IFFI database holds 614,799 landslide phenomena, covering an area of approximately 23,000 km^2, which is equivalent to 7.5% of the Italian territory (ISPRA, 2014). Since 2010, yearly reports on landslide events that caused victims, injuries, evacuees or damage to buildings, infrastructures, service networks and environmental and cultural heritage sites are published by the Italian Institute for Environmental Protection and Research, ISPRA (ISPRA, 2009). From 2010 to 2016 (year of latest available report), 1033 landslide events have been recorded. Since 2011, the National Research Council (CNR) also compiles an inventory of landslides that caused direct consequences to people, i.e. deaths, missing persons, evacuations or injuries (National Research Council, 2011). The total number of landslide events recorded from 2011 to 2017 is 138. These events caused 43 deaths and 151 injuries. Published yearly reports also include maps and figures of the consequences to people in the previous 50 years. In the latest report, considering data from 1967 to 2016, the consequences are distributed as follows: 1205 deaths, 12 missing persons, 1509 injures and almost 150,000 evacuated people.

Construction and content

The methodology developed herein aims at collecting and organizing, within a new national landslide catalog called "FraneItalia", information retrieved from online news sources on landslides that occur in Italy. To this aim, the following seven steps have been performed.

(i) Selection of sources. A certain number of online news media, published in Italian language, were preliminarily screened in order to compare the consistency and the quality of the outcomes. As a result of this activity, the following two news aggregators were selected as sources of information for the catalog: 1) Google Alert, GA (http://www.google.com/alerts), a web service that sends daily emails when it finds web pages or news articles that match users' search term (s); 2) the Italian Civil Protection press review, CP (http://ilgiornaledellaprotezionecivile.it/), a selection of articles available in pdf format collected daily from national, regional and local press.

(ii) Identification of effective keywords. Both the selected news aggregators may be searched employing a Boolean keyword approach. Key landslide terminology was assessed to select the terms that are more commonly used in Italian language to deal with landslide events. As a result of this activity, the two keywords selected for the searches are: "frana" (the Italian word for "landslide") and "frane" (the Italian word for "landslides").

(iii) Collection of relevant news articles. When one of the two search terms appears in daily searches conducted on the two information sources, the related online article is flagged as a potential entry for the landslide catalog. If the article refers to a new landslide event a record is added to the landslide database. If the article refers to a landslide event already existing in the database, the relative record is updated.

(iv) Identification of landslide categories. Landslide events are classified considering two numerosity categories and three consequence categories. The two numerosity categories are: single landslide events (SLE), for records only reporting one landslide; and areal landslide events (ALE), for records referring to multiple landslides triggered by the same cause in the same geographic area (at most coincident with an administrative Province). The latter category is used to simplify collection and reporting of the landslide records for the numerous cases when many landslides are mentioned together in the news. The consequence classification is based on the severity of the effects to human life, not considering other consequence measures (e.g., economic loss, environmental damage). The three categories are: very severe consequences (C1), for landslide events with victims and/or missing people;

severe consequences (C2), for events with injured persons and/or evacuations; minor consequences (C3), for landslide events that did not cause physical harm to people.

(v) Definition of other fields of database. Information on the landslide events collected in the catalog always include: data on the spatial location of the event, day of occurrence of the landslide (s), source (s) of information, and number of landslides in case of ALEs. Additional information may include: onset and duration of the landslide event, landslide characteristics, phase of activity, details on the consequences (Fig. 1).

(vi) Mining of information from the articles. For each record of the database, i.e. for each inventoried landslide event, as much information as possible is obtained from the articles in relation to each field.

(vii) Geo-referencing of the events. A single set of geographic coordinates (WGS84 datum) is assigned to each record of the database, both for single and areal landslide events. The following categories of spatial positions are considered for SLEs: i) certain, if the news source clearly specifies the position of the landslide; ii) approximated, when the position of the landslide can be inferred, although it is not clearly indicated; iii) unknown, when the only information reported is the name of the municipality affected by the landslide. In the latter case, the geographic coordinates of the town hall are assigned. For ALEs, the assigned geographic coordinates are only meant to represent a point within the area affected by the landslide event and are thus useful only for maps drawn at national scale.

The FraneItalia catalog was constructed adopting PostgreSQL version 9.6, an open source Relational DataBase Management System, with the PostGIS extension version 2.3. Tables, fields and relationships—designed in a logical model and described in detail in the "Availability of data and material" section—were translated into PostgreSQL physical tables, fields, and one-to-one relationships. Figure 1 shows all the fields of the database. Each

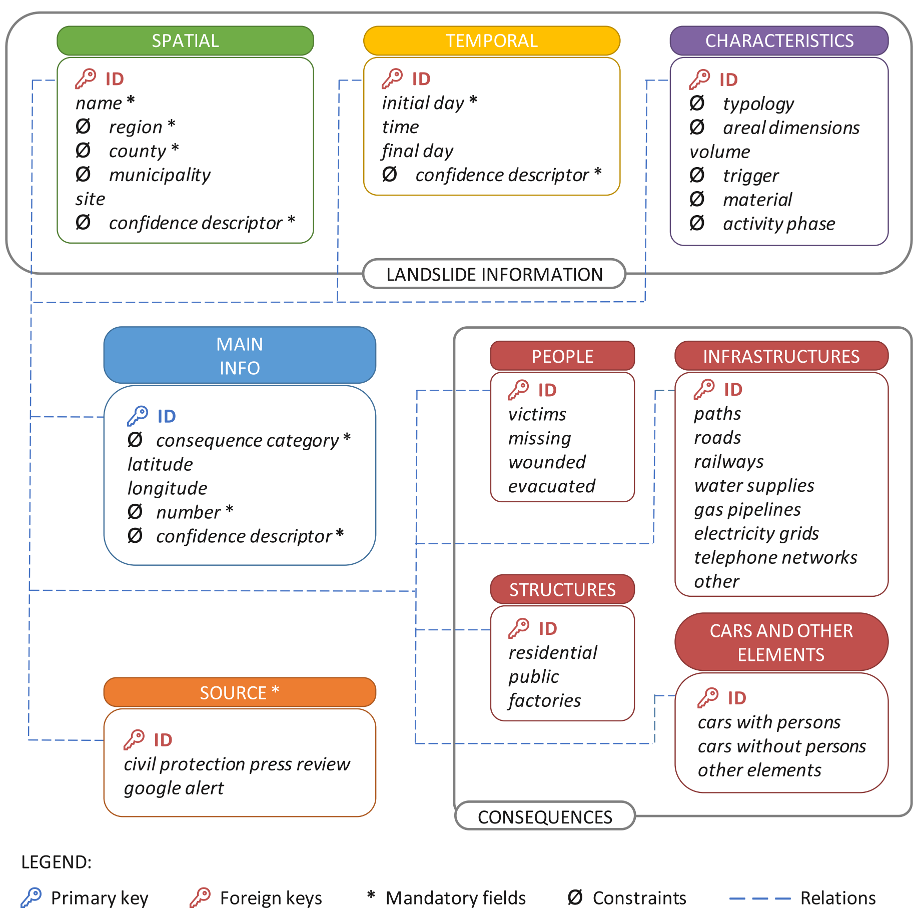

Fig. 1 Structure of the "FraneItalia" landslide database

reported landslide event is characterized by 40 unique fields, which are grouped in 9 thematic tables: main info; spatial information; temporal information; landslide characteristics; consequences to people, structures, infrastructures, cars and other elements; and source. Not all fields are mandatory.

Inspection of Fig. 1 reveals that the core of the catalog structure is the main info table, that maintains a unique hierarchical relation with tables containing information on the landslides, their consequences and the sources of information, i.e. links to online articles. The tables are connected through the identification code (ID), which is unique for each record and whose format is designed to highlight the landslide event category and the initial date of the event. The name of the landslide event is not a compulsory entry and, when possible, it quotes the terms most commonly used to refer to the event. The landslide categories, as already mentioned, are based on landslide numerosity and on the consequences to human life of the landslide event. Both SLEs and ALEs are divided in three consequence classes. Further compulsory information for each record are the geographical coordinates of the landslide event and the source (s) of data. When the GA service is used, the references are the web addresses of the online news articles. When the CP press review is used, the references include the day (the press review is published each working day), the type (5 daily reviews are published in relation to the geographical location of the source: national, northern Italy, central Italy, southern Italy, main islands) and the pages of the PDF documents reporting the information. To facilitate data visualization and editing in the FraneItalia database, we developed (i) a specific procedure—described in the "Availability of data and material" section—that exploits QGIS software (QGIS Development Team, 2018) as a client, and (ii) a dedicated data visualization web interface.

According to many authors (e.g., Guzzetti, 2000; Kirschbaum et al., 2010), characterizing landslide events from news reports and other text-based sources is challenging, as information varies widely in terms of both accuracy and availability, resulting in possible biases and uncertainties affecting the catalogue. Compulsory information in the FraneItalia catalog include the geographical coordinates and the date of each landslide event, as well as the number of landslides of ALEs. If, for a given record of the database, the needed data are not directly reported in any news, the operator is requested to compile the related fields using his/her own judgement to infer from the available sources. The uncertainty of the position of SLEs is specified by means of three confidence descriptors associated to the geographical coordinates of the landslide event, named: certain (Sd1); approximated (Sd2); municipality (Sd3). In the latter case, the operator has to identify the municipality wherein the landslide event occurred and assign to the event the geographical coordinates of the town hall. The geographic coordinates attributed to ALEs are always indicative (Sd4) and are only meant to approximately identify the geographical region affected by the mentioned landslides. A second source of uncertainty may result from lack of detailed information on the time of the event. In the vast majority of cases, the day of the landslide event is reported in the news; quite often, a general indication of the time of occurrence (e.g., "in the morning") is also available; sometimes, the date of the event is not reported and the news article only generically refers to the event as a past occurrence (e.g., "few days ago"). The temporal uncertainty related to the occurrence of the landslide events is specified by means of two confidence descriptors, named: certain (Td1), when the news sources report at least the day of the event; estimation (Td2), when the operator has to interpret the news reports to assign a date to the event. In the first case, if more information on the time of the event is reported the "time" field is also filled, either by inserting the hour of the event or by specifying a time range (e.g., "in the morning"). In both cases, if the landslide event lasts longer than 1 day, the final day of the event is also reported. Finally, the uncertainty associated to the number of landslides in ALEs is specified by means of two descriptors, named: reported (Nd1), when the news reports that number; and estimation (Nd2), when the operator has to infer from the news to assign it. Most typically ALEs are due to extreme weather conditions triggering, in one or more days, multiple landslides over wide areas. In these case, the news typically identifies the area affected by the events and highlights the landslide (s) that produced the highest consequences, only rarely reporting a number that can be considered representative of all the landslides occurring during the areal event.

Four types of constraints are adopted to guarantee the correctness and semantic integrity of the inserted records. A first group of constraints is adopted to ensure the appropriateness of the information related to the landslide numerosity class (SLE or ALE) and to the number of landslides within a landslide event (i.e. the number of landslides must be equal to one for SLEs and

Table 1 News aggregators used to populate FraneItalia from January 2010 to December 2017

News aggregator	Period
Civil protection daily press review (CP)	From January 2010 to August 2014; from January 2015 to December 2017
Google Alert service (GA)	From January 2011 to December 2012 (via Google News search engine); year 2013; from September 2014 to February 2015; November 2015

higher than one for ALEs). A second constraint limits the values of the possible choices of the confidence descriptors that quantify the uncertainties related to the number of landslides, their location and their time of occurrence. Next, geographical data are validated by means of a dictionary valid for Italy (first level for the regions, second level for the counties, and third level for the municipalities). Finally, lists of pre identified values are adopted to standardize and harmonize the following characteristics of the landslide events: typology, areal dimensions, trigger, material, and activity phase.

Table 1 reports how the two selected news aggregators, GA and CP, were used to populate the FraneItalia catalog from January 2010, i.e. the beginning of the survey, to December 2017, i.e. the end of the period reported herein. The CP was predominantly used for a series of reasons. The daily press reviews from the Civil Protection are stored as an online archive accessible at a later date. When the study started, at the end of 2012, it was thus possible to go back in time and set January 2010, the month of first available CP press reviews, as starting date. On the contrary, the daily GA service has to be activated from a user. Therefore, GA was fully operational for the FraneItalia catalog only from January 2013. To overcome this limitation, the Google News search engine was also used to look for landslide news published in the year 2012. Yet, the search results were conditioned by the availability of the original online news when the searches were performed, i.e. first few months of 2013. Moreover, it has been empirically found that GA results depend on the location of the user as well as on its "habits" when using the Google search engine. The same GA search queries may thus generate different sets of online news articles for different users. Another important advantage of CP over GA is that the searches and the data entries performed using CP are less time-consuming. Indeed, the daily press reviews are already organized in 5 searchable PDF documents: one document collecting news of national relevance, mainly from countrywide news sources; the other four documents referring to news from Northern Italy, Central Italy, Southern Italy and the main Islands, respectively. This aspect of the CP, i.e. non-automatic pre-processing of online news from personnel of the civil protection, which may be considered a time-saving asset of this news aggregator, turned into a drawback when the civil protection agency either did not provide the press reviews (end of 2014) or performed limited reviews (November 2015). In summary, the CP was used to populate the FraneItalia catalog throughout the considered time period whenever available, whereas GA was only used in 2013, from September 2014 to February 2015, in November 2015 and, by means of the Google News search engine, from January 2011 to December 2012.

Utility and discussion

The utility of the FraneItalia catalog is stated in Section "Utility". Section "Recorded landslides: January 2010–December 2017" highlights the main figures of the landslide inventory, which currently spans from the beginning of the year 2010 to the end of December 2017. Section "National and regional trends" presents analyses on time-dependent national and regional trends, with a focus on the consequences induced by the recorded landslide events. In Section "Comparison with national landslide catalogs" FraneItalia is compared to other existing landslide catalogs. Finally, Section "Example of analysis at regional scale: Campania region" demonstrates the potential use of FraneItalia, showing a first application at regional scale.

Utility

Landslide catalogs may be prepared for multiple scopes and may be compiled in different ways. In recent years, a significant number of initiatives has been relying on information retrieved from the news rather than on technical reports or scientific investigations. Indeed, the analysis of newspaper articles is widely seen as a useful complement to other methods used for building landslide inventories. In Italy, a number of national scale landslide catalogs and inventories already exist, including landslide inventory maps produced by river basin authorities and databases of recent landslides developed using news articles as sources of information (see section "Global and national landslide databases: review and current trends" for details). The "FraneItalia" catalog supplements the already available information in the following terms: it contains all the landslide events reported in the news since 2010, not only the ones that caused direct consequences to people or major damage; it is structured as a geo-referenced open access database containing information on a variety of landslide features and consequences by means of 40 unique fields grouped in 9 thematic tables. The "FraneItalia" catalog should thus be considered a useful source of information that can be used, together with other landslide inventories and catalogs, for landslide analyses aimed at assessing landslide susceptibility, hazard and risk at territorial scale.

Recorded landslides: January 2010–December 2017

The "FraneItalia" catalog currently spans from January 2010 to December 2017, containing a total of 8931 landslides, grouped in 4231 SLEs and in 938 ALEs (Table 2). About 2% of the 5169 landslide events had very severe consequences to human life (C1), 14% of the records refer to events with severe consequences to human life (C2), while the vast majority of records deals with landslide events that had minor consequences to human life (C3).

Figure 2 reveals that the sites affected by landslides are not equally distributed in Italy. SLEs are abundant in

Table 2 Landslides inventoried in the "FraneItalia" catalog from 2010 to 2017

Year	Single Landslide Events (SLE)				Areal Landslide Events (ALE)				Number of landslides
	C1	C2	C3	TOT	C1	C2	C3	TOT	
2010	12	100	498	610	2	36	171	209	1584
2011	16	60	302	378	4	20	68	92	821
2012	9	51	393	453	2	14	85	101	949
2013	12	77	538	627	1	39	114	154	1503
2014	15	111	844	970	3	36	144	183	1936
2015	9	63	377	449	2	17	58	77	801
2016	5	43	368	416	1	5	59	65	801
2017	3	45	280	328	1	13	43	57	536
TOT	81	550	3600	4231	16	180	742	938	8931

many regions and, as expected, there is a clear evidence of a correlation between an increasing density of landslide events and the location of the main Italian mountain chains, the Alps and the Apennines. ALEs are more common in the eastern sectors of the Alps (Lombardia and Veneto regions) and in the central and northern sectors of the Apennines (Toscana, Liguria, Emilia Romagna, and Marche regions). Among the southern regions, the one most affected by both single and areal events are Campania, Calabria and Sicilia.

National and regional trends

The monthly distribution of single and areal landslide events (Fig. 3) suggests similar trends in different years. This is not surprising given that most of the recorded events are rainfall-induced landslides, strongly influenced by seasonal rainfall patterns. Reported landslides are particularly abundant between October and March. The number of events peaks at the end or at the beginning of the year and shows a minimum in the summer season. During the summer months, however, the

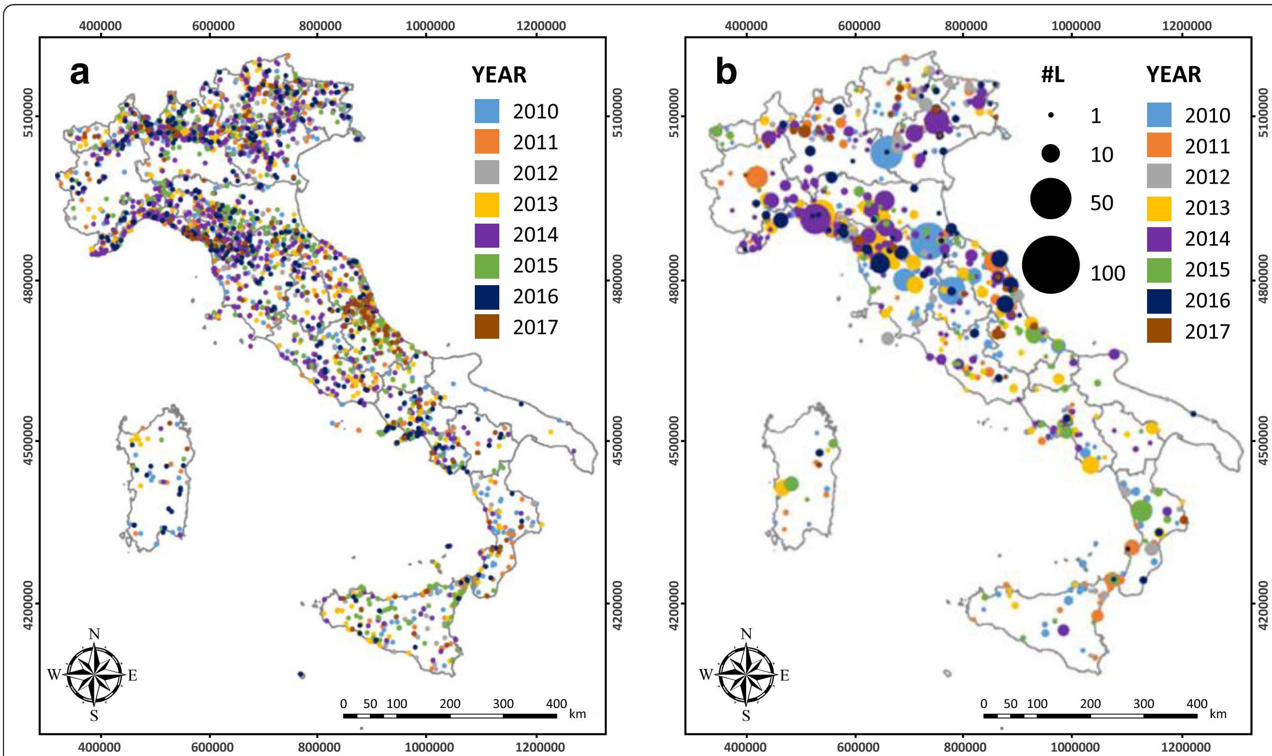

Fig. 2 The "FraneItalia" landslide catalog for the period 01/01/2010–31/12/2017: (**a**) SLE records; (**b**) ALE records [Legend: #L = Number of landslides]

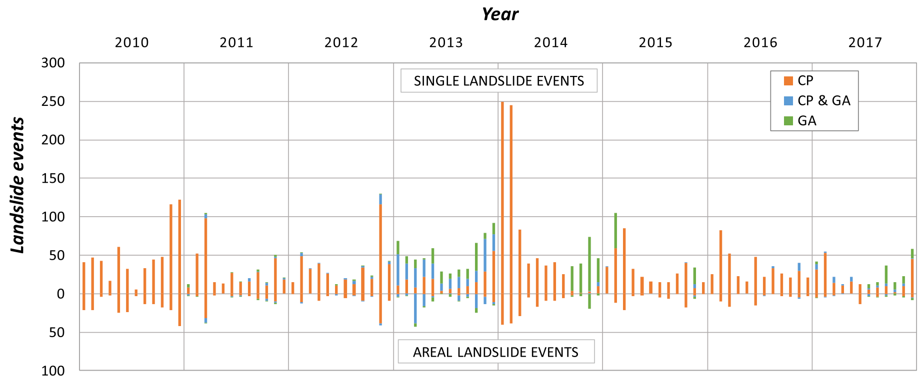

Fig. 3 Number of monthly single and areal landslide events, differentiated by source of data. [Legend: CP=Civil Protection press review; GA = Google Alert]

number of events is not negligible. As already mentioned, CP and GA were both systematically used to populate the catalog only during the year 2013. A comparison between the two sources of information reveals that more than 45% of the records in 2013 were retrieved from both sources (CP & GA), yet a not insignificant percentage of events (25%) was only retrieved from GA. It is thus reasonable to assume that, when GA is not used, the records are slightly underrepresenting the actual number of landslide events reported in the news. It is comforting to note, however, that almost all the events retrieved only from GA, thus missed from CP, are SLEs and not ALEs. A further analysis on these events also reveals that they are, for the vast majority, events posing minor consequences for human life (consequence class C3).

Figure 4 shows the number of recorded SLEs, ALEs and landslides (L) grouped by region. The highest number of landslides reported in the database occurred in Toscana, mainly as a consequence of a series of major areal events triggered by heavy rainstorms. The lowest number of events is recorded in Puglia, whose territory mainly comprises plains. Most of the other regions experiencing a large numbers of landslides are located in northern Italy (Veneto, Lombardia, Emilia-Romagna and Liguria). In particular, Lombardia is the region most affected by SLEs, mainly occurring in the Alpine area where the presence of high relative relief and outcropping rocks, such as granite, metamorphic rocks, massive limestone and dolomite, facilitate rock falls, rock slides and rock avalanches (Guzzetti, 2000). As reported in Fig. 5, for several of these regions (Lombardia, Veneto and Piemonte) a non-negligible number of events occurred in the summer, possibly in relation to extreme rainfall events or snowmelt processes in the Alpine environment. On the contrary, in most parts of central and southern Italy (e.g., Emilia-Romagna, Campania, and Sicily) a considerable number of landslides occurred during the autumn and winter seasons. These findings are consistent with the different seasonal failure scenarios

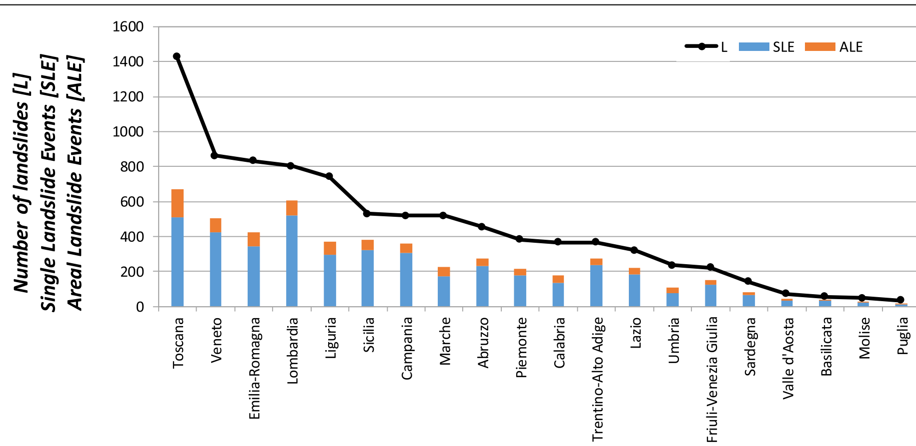

Fig. 4 Number of single landslide events (SLE), areal landslide events (ALE) and landslides (L) in the 20 Italian regions, ordered by decreasing number of landslides

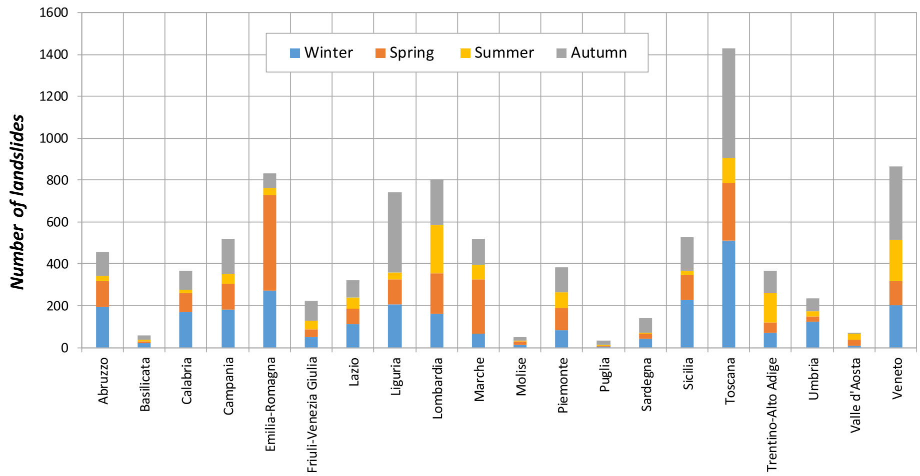

Fig. 5 Number of landslides inventoried in the 20 Italian regions, differentiated per season

reported by Cascini et al. (2014) for the Campania region: distributed or widespread first-time shallow slides triggered by frontal rainfall and propagating as debris flows or debris avalanches between November and May; local erosion phenomena and small first-time shallow slides triggered by isolated convective storms between June and August; widespread erosion phenomena triggered by hurricane-like rainfall, often turning into hyperconcentrated flows, between September and October.

Figure 6 displays the landslide events in relation to the three consequence classes. The analysis of the landslide catalog reveals that 150 people died and 16 were missing in 97 C1 events (81 SLEs and 16 ALEs) from 2010 to 2017, an average of 21.4 fatalities per year. Despite the limited number of C1 events, some remarks about their geographical distribution are possible (Fig. 6a). These landslides were more frequent in the Alpine regions of Northern Italy. This can be correlated with the fact that Alpine areas are strongly prone to fast-moving landslides that pose significant risks for human life. For instance, rockslides, rock falls and rock avalanches are common over the whole Alpine area. In the Eastern Alps, moreover, debris flows may be 'strengthened' by the presence of loose debris on steep slopes in mountain basins. An example of such a condition is the catastrophic shallow landslides that occurred in Veneto in August 2014, killing 4 people. Very severe consequences were also associated to few ALEs triggered by extreme rainfall conditions, such as the ones that occurred in Liguria (40 landslides, with 11 deaths and 2 missing persons in October 2011), northern Tuscany (14 landslides with 3 deaths in November 2012) and Sardinia (21 landslides with 4 deaths and 2 missing persons in November 2013). Fatalities were also caused by SLEs. In these cases, they are mainly associated with the collapse of temporary retaining structures for excavations in urban environments and with the occurrence of rock failures in mountainous environments. The number of C2 events, 550 SLEs and 180 ALEs (Fig. 6b), is considerably higher than the number of C1 events. During these 730 events, 338 persons were injuried and thousands of people were left homeless. The Alpine regions are once again the areas most affected by SLEs, yet the number of single events is also considerable in many other regions. ALEs are mainly located in Liguria, Tuscany and Emilia-Romagna, where heavy rainfall mobilized a large number of shallow landslides and debris flows in a number of occasions. Finally, Fig. 6c shows that C3 events are widely distributed over the whole Italian territory, except for the flat lands of the Po Valley and Puglia region. A total of 4342 landslide events (3600 single and 742 areal) that did not cause any physical harm to people have been recorded in the catalog from January 2010 to December 2017.

On average, about 15% of the recorded landslide events had direct effects on people every year (Fig. 7a). Landslides also affected other elements, with infrastructures experiencing most of the consequences (they are involved in over 70% of the recorded events). This might be due to the capillary distribution of roads, railways and other utilities networks all over the Italian territory, thus also in many landslide prone areas. By contrast, a significantly lower number of events produced effects on structures (10% per year, on average) and on vehicles (about 5% per year). Vehicles have been singled out as elements at risk in the catalog mainly for two reasons: they are often mentioned in the news to highlight the impact of the landslide event, and they are typically associated to harm to human life. A number of charts reporting the consequence figures of the recorded landslide events are presented in Fig. 7b. Despite the differences in the absolute numbers of the recorded landslide events, the relative distribution of their

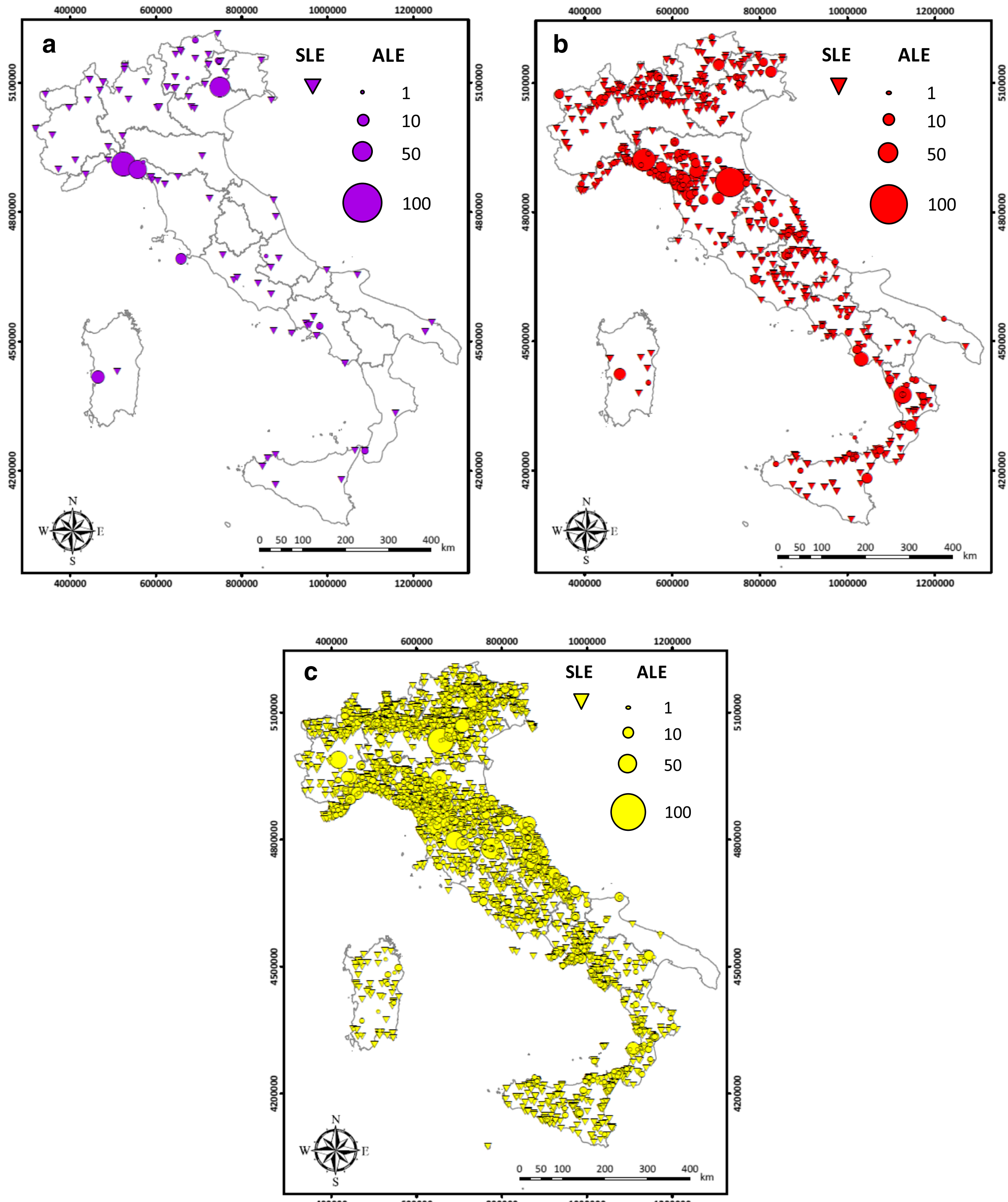

Fig. 6 Single (SLE) and areal (ALE) landslide events associated with: (**a**) victims and/or missing persons (i.e. C1, very severe consequences); (**b**) injured persons and/or evacuations (i.e. C2, severe consequences); (**c**) no physical harm to people (i.e. C3, minor consequences)

consequences is similar in each year of the considered time frame. With reference to infrastructures and structures, the most affected ones are roads and houses, respectively. These results are not surprising, since these elements are the most numerous in their respective groups. The catalog also allows recording consequences to "other elements" not

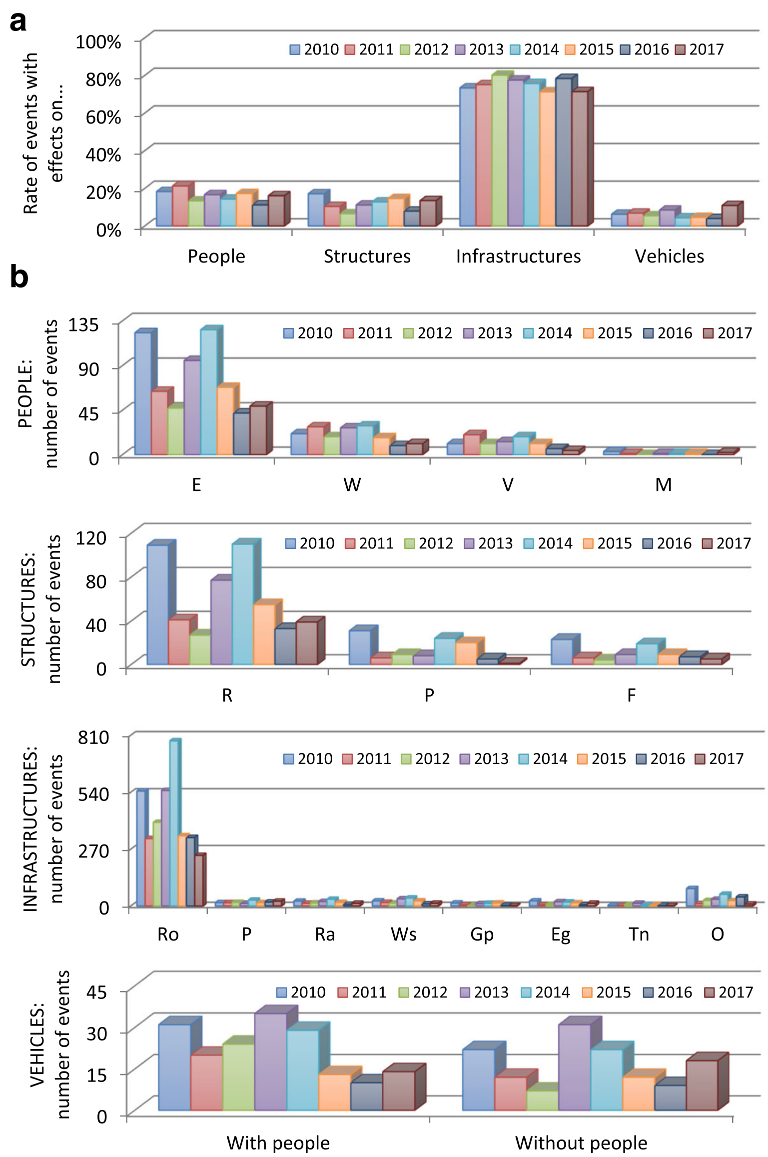

Fig. 7 Percentage of landslide events: (**a**) by year and category of consequences, i.e. people, structures, infrastructure and vehicles; (**b**) by year and subcategories of consequences. (Legend: E = evacuated; W = wounded; V = victims; M = missing; R = residential; P = public; F = factories; Ro = roads; P = paths; Ra = railways; Ws = water supplies; Gp = gas pipelines; Eg = electricity grids; Tn = telephone networks; O = other)

included in above mentioned categories, such as: retaining walls, embankments, bridges, parking areas, and beaches.

Comparison with national landslide catalogs

In Italy, many initiatives have been carried out, from the early 1990s, to systematically collect information on past landslide events over the entire Italian territory. Listed in chronological order, considering the starting day of the projects, they are: the AVI archive (Guzzetti and Tonelli, 2004), the landslide inventory maps of the River Basin Authorities (e.g. Cascini 2005), the IFFI inventory (Trigila et al., 2010), the yearly landslide reports published by ISPRA (http://annuario.isprambiente.it/entityada) and the CNR-Polaris initiative (http://polaris.irpi.cnr.it/report/). The only two catalogs chosen for the comparisons performed herein are the ones developed by ISPRA and CNR-Polaris, since they are similar to FraneItalia in the following aspects: types of landslide events considered, sources of information, and period of investigation. The number of landslides recorded in the 3 considered catalogs differs significantly: 1033 for ISPRA, 138 for CNR-Polaris and 8931 for FraneItalia.

The comparison between ISPRA and FraneItalia is performed following a normalization procedure. The 20 Italian regions are the territorial units used to normalize the different populations of data over the territory of interest, i.e. Italy. For each territorial unit a landslide index, LI_i, is defined employing the records of each catalog as follows:

$$LI_i = \frac{NL_i/NL_{tot}}{A_i/A_{tot}} \quad (1)$$

where: NL_i is the number of landslides recorded in the i-th territorial unit; NL_{tot} is the total number of landslides recorded in the territory of interest; A_i is the area of the i-th territorial unit; A_{tot} is the area of the territory of interest.

The values of LI, which is a proxy of the density of the recorded landslides in a given area, have been classified in 5 classes. Values lower (or higher) than 1.0 indicate that the density of landslides in a given territorial unit is lower (or higher) than the average density of landslides in Italy. As shown in Fig. 8, FraneItalia and ISPRA portray very similar pictures of landslide densities in many areas of the country. Indeed, a significant number of regions (11) falls within the same class of LI.

For the comparison with the CNR-Polaris catalog, the FraneItalia landslide events that did not cause any physical harm to people (consequence class C3) were excluded because CNR-Polaris only reports events that caused deaths, missing people, evacuations and injuries. The comparison is performed for the time period for which data from the two inventories overlap, i.e. from January 2011 to December 2017. Figure 9 reports the geographical distribution of the landslide records reported in the two catalogs grouped according to their consequence class: C1, for landslides causing deaths and/or missing people; C2, for landslides causing injuries. There is a substantial agreement between the two inventories with respect to the areas where these phenomena occurred: eastern and central Alps, Liguria and some isolated hot spots in northern Tuscany, Sardinia and Campania. However, despite the sources of information used by Polaris and FraneItalia are essentially the same, a significant number of landslides are only reported in one of the two inventories. The temporal distribution of the events and their presence in the catalogs is summarized in Fig. 10. The number of events recorded by both inventories account for about 1/3 of the total number of records. Only few C1 events are not reported in FraneItalia, while the distribution of the C2 events is not too different in the two inventories. These results seem to indicate that both inventories "miss" a good number of landslide events that have been reported in the news, mainly C2 events in the case of the FraneItalia inventory.

Example of analysis at regional scale: Campania region

The focus of the analysis shown herein is the Campania region, one of the areas that experienced the major number of landslides according to the data showed in

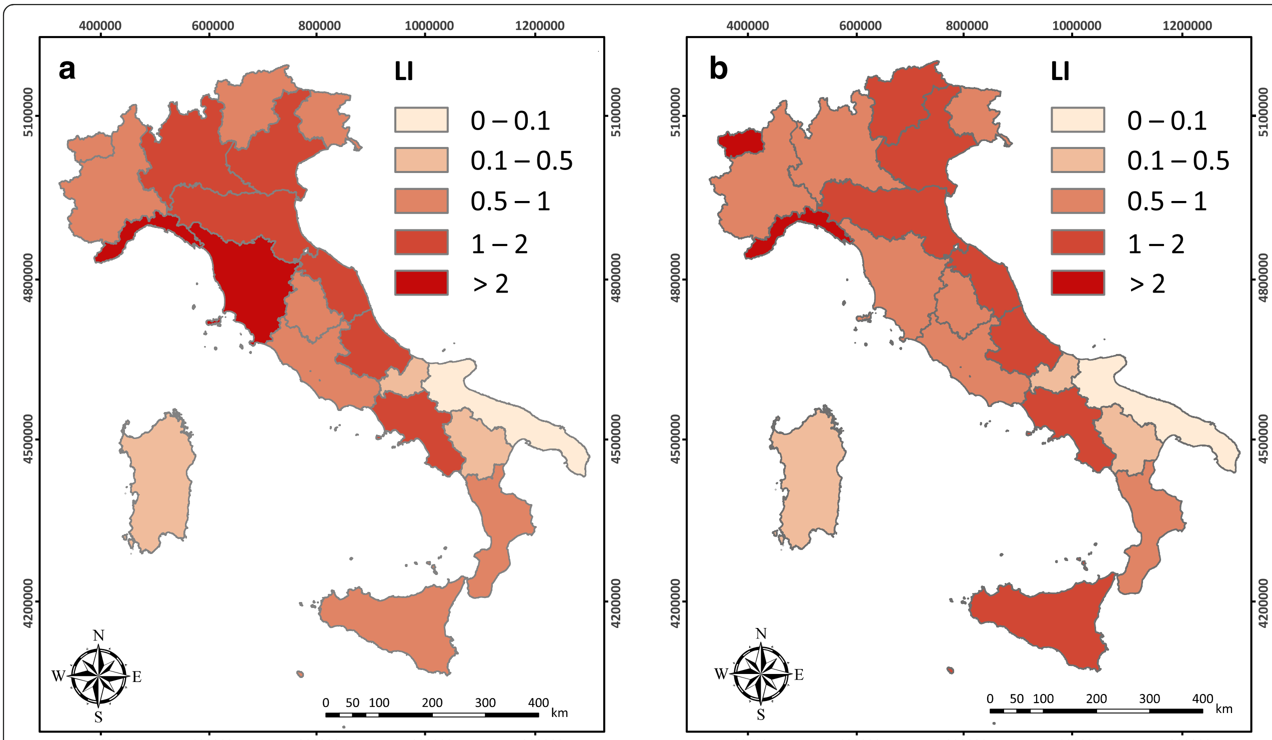

Fig. 8 Values of the Landslide Index (LI) in the 20 Italian regions, comparison between landslide inventories: (**a**) FraneItalia, (**b**) ISPRA

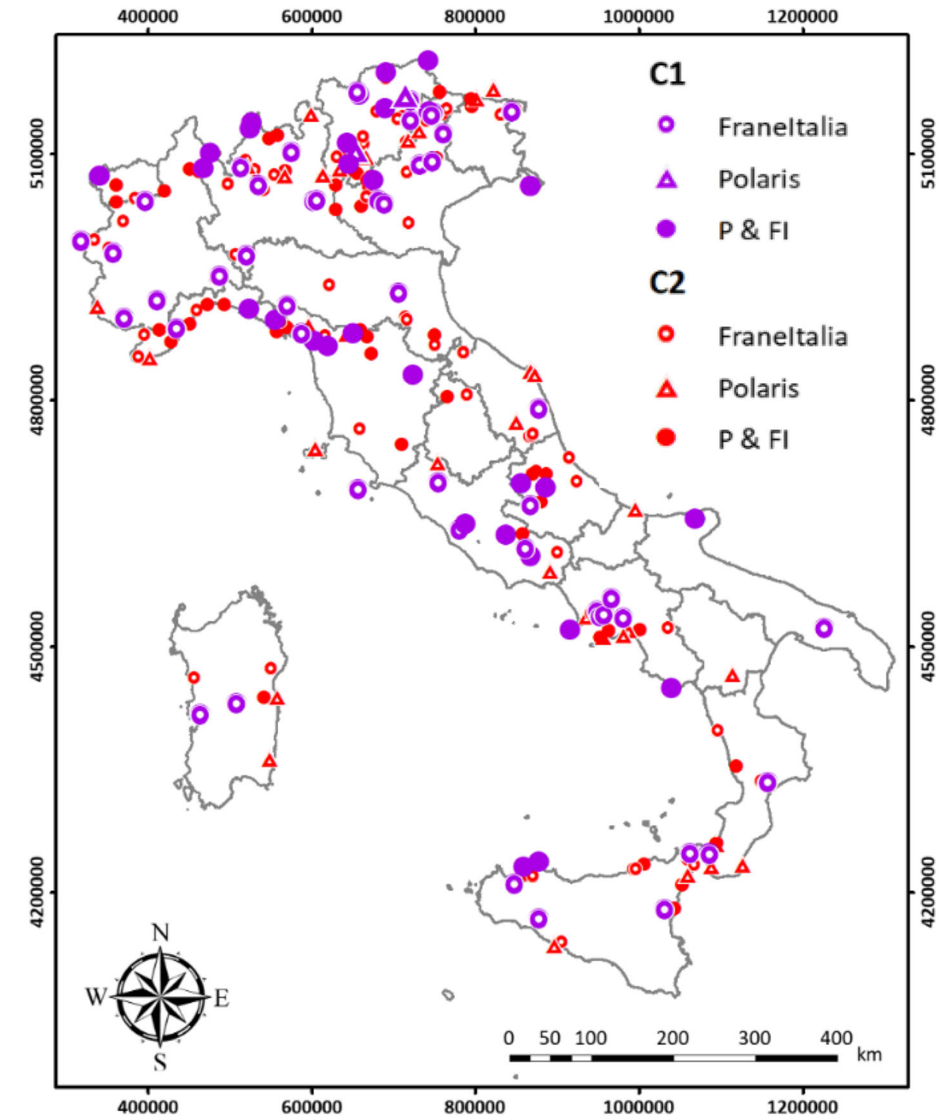

Fig. 9 Landslide records with victims and/or missing persons (C1) and injured persons and/or evacuations (C2) recorded in the FraneItalia catalog, Polaris catalog or both catalogs (P & FI)

the previous sections. To normalize the results, similarly to what has been done for the comparison at national scale with the ISPRA catalog, the Landslide Index defined in Eq. 1 is adopted. In this case, the territorial units used to normalize the available data over the territory of interest are the municipalities. Figure 11a shows the density of the landslides within each municipality of the Campania region. Three areas may be identified in the figure as significantly affected by landslide events: (1) Lattari mountains; (2) Cilento; and (3) area of the Apennines in the north-eastern part of the region. Fig. 11b shows a more detailed view of four municipalities of the Lattari mountains, one of the areas in Campania most affected by disruptive (and often deadly) landslide events (Cascini et al., 2008). In this area, the landslide events recorded in the FraneItalia catalog from 2010 to 2017 are 13. They are mainly occurring along or near the coast where most of the urbanized areas are located, as highlighted by the areas zoned by the river basin Authority at high/very high landslide risk (R3/R4). Therefore, in spite of the limited number of landslides reported in the last few years in these municipalities, the FraneItalia catalog seems to be in good agreement with the risk maps of the river basin Authority, also suggesting that this catalog can be used as a tool for preliminary analyses of landslide risk at regional scale.

Conclusions

The paper presented a new catalog of landslide events occurring in the Italian territory, developed and

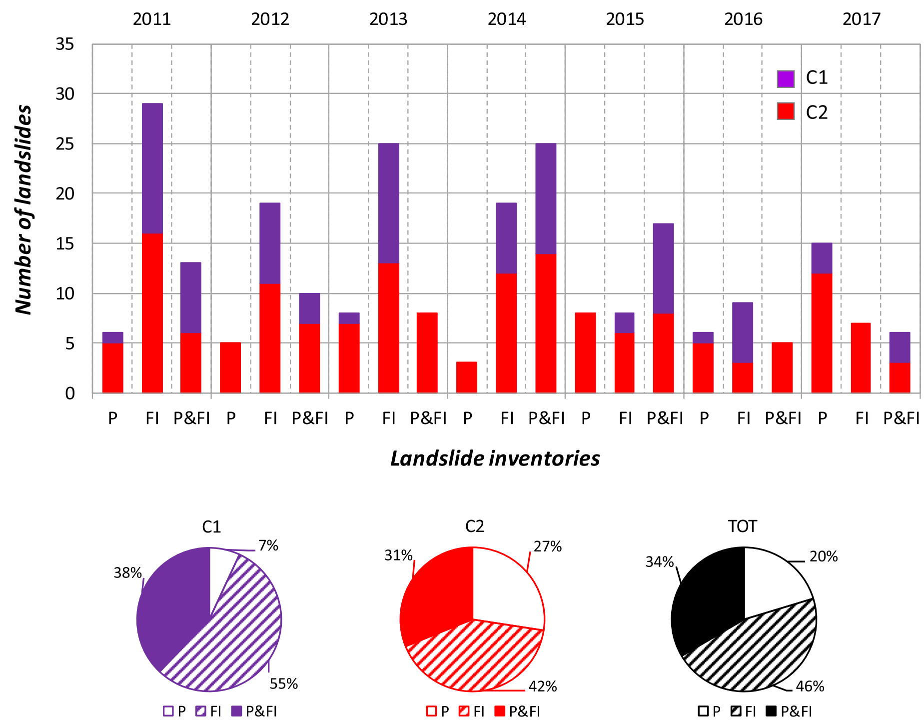

Fig. 10 Comparison between the Polaris (P) and the FraneItalia (FI) inventories, per year and consequence class

populated, since January 2010, searching relevant news from online sources. Landslide events are classified considering two numerosity categories—SLE (for records reporting one landslide) and ALE (multiple landslides triggered by the same cause in the same geographic area)—and three human life consequence categories—C1 very severe (victims and/or missing people), C2 severe (injured persons and/or evacuations), and C3 minor (no physical harm to people). A single set of geographic coordinates is assigned to each record of the database, both for single and areal landslide events. The uncertainty related to the position of SLEs is specified by means of three confidence descriptors, while the coordinates attributed to ALEs

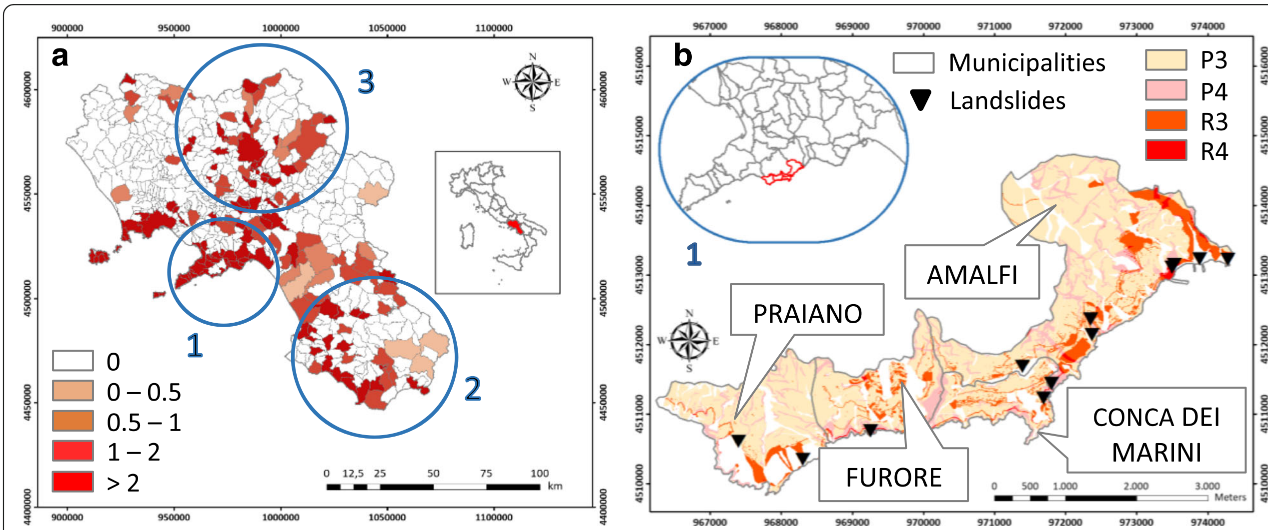

Fig. 11 (**a**) Values of the Landslide Index (LI) in the Campania region, per municipality; (**b**) four municipalities of the Lattari mountains (zone 1 in Figure **a**): landslides recorded in the FraneItalia catalog and areas zoned by the river basin Authority at high/very high landslide hazard (P3/P4) or risk (R3/R4)

are always indicative and are meant to approximately identify the geographical region affected by the mentioned landslides. The temporal uncertainty related to the occurrence of the landslide events is specified by means of two confidence descriptors.

From January 2010 to 2017 "FraneItalia" reports a total of 8931 landslides, recorded in 4231 SLEs and 938 ALEs. About 2% of the events had very severe consequences (C1), 14% severe consequences (C2), and the rest only minor consequences (C3). The areas affected by landslides are not equally distributed in Italy. As expected, there is a clear evidence of a correlation between an increasing density of landslide events and the location of the main Italian mountain chains, the Alps and the Apennines. The highest number of landslides reported in the inventory occurred in Toscana, mainly as a consequence of a series of major areal events triggered by heavy rainstorms. The lowest number of events is recorded in Puglia, whose territory mainly comprises plains. The monthly distribution of the SLEs and ALEs suggests similar trends in different years. In most parts of central and southern Italy a considerable number of landslides occurred during the autumn and winter seasons. In several regions in northern Italy, a non-negligible number of events also occurred in the summer, mainly in relation to extreme rainfall or snowmelt processes in the Alpine environment.

The acquisition and analysis of historic data of landslide events is essential for evaluating and managing landslide risk at small scales. Many initiatives have been carried out to compile global and national landslide catalogs searching news archives, and one can expect that many more will be developed in the future. The Italian landslides reported in the available global catalogs (14 from 2004 to 2010 according to Petley et al., 2012; 45 landslides from 2008 to 2013 according to Kirschbaum et al., 2015; 72 landslides from 2005 to 2014 according to Haque et al., 2016) are always much lower than the number of events reported in national databases. The first example of such initiatives is the AVI archive, which includes 22,346 landslides in the period 1009–2001. More recently, yearly reports on landslide events are being published by ISPRA (1033 landslides from 2010 to 2016) and CNR-IRPI (138 landslides from 2011 to 2017). A comparison between FraneItalia (8931 landslides from 2010 to December 2017) and the ISPRA and CNR-IRPI databases highlights that the FraneItalia database reports many more events per year.

In conclusion, the FraneItalia catalog should be seen as a useful source of information on recent landslide events occurring in the Italian territory that complements other resources already available to the Italian technical community evaluating and managing landslide risk at regional/national scale. The methodology adopted to define and populate FraneItalia is deemed to be general and can be used to develop similar initiatives in other countries.

Abbreviations

ALE: Areal Landslide Event; C1: Very severe consequences class; C2: Severe consequences class; C3: Minor consequences class; CP: Civil Protection press review; GA: Google Alert; L: Landslides; Nd1: Numerousness confidence descriptor "reported"; Nd2: Numerousness confidence descriptor "estimation"; R3: Areas zoned at high landslide risk; R4: Areas zoned at very high landslide risk; Sd1: Spatial confidence descriptor "certain"; Sd2: Spatial confidence descriptor "approximated"; Sd3: Spatial confidence descriptor "municipality"; Sd4: Spatial confidence descriptor "areal event"; SLE: Single Landslide Event; Td1: Temporal confidence descriptor "certain"; Td2: Temporal confidence descriptor "estimation"

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Preliminary results of the FraneItalia catalog, with data covering landslide events from January 2011 to June 2013, have been published (in Italian) by Calvello et al. (2013). We gratefully thank the two co-Authors of that paper, Prof. Settimio Ferlisi and Anna Ruggiero, for their important contribution in the initial phase of this project.

Over the years, a significant number of bachelor and master students, enrolled in one of the degrees offered by the Civil Engineering Department of the University of Salerno, has been working at populating the FraneItalia catalog. The contribution of the following people to the success of the project is herein acknowledged: Maria Ferrigno; Luciana Gioia; students of the "Landslides" and "Landslide risk" courses offered within the Master Degree in Environmental and Land Management Engineering, academic years 2013/2014, 2014/2015, 2015/2016, 2016/2017, and 2017/2018.

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Availability of data and materials

The FraneItalia catalog structure is available as a binary dump file of the PostgreSQL® DBMS at the following link: https://landsliderisk.wordpress.com/dissemination/franeitalia. A PostgreSQL® server must be running on the computer where the structure is restored. PostgreSQL® server is open source, and is available for different operative systems (https://www.postgresql.org). Post-GIS®, the spatial database extender for PostgreSQL®, is also required and can be installed using the StackBuilder, a package manager that can be used to download and install additional PostgreSQL® tools and drivers. Once all the software is installed, the following procedure for the restoration of the catalog can be executed from the pgAdmin® client (an open source software for the management of PostgreSQL® inventories):

1. double click on the 'Server' node icon;
2. right-click on 'Databases' and choose 'Create …' item;
3. in the 'New Database' dialog window the user can conveniently choose the name 'FraneItalia' to exploit immediately the QGIS® interface described at the end of this section;
4. once the new database has been created, a right-click allows to choose the 'Restore' item, and to access the corresponding item to restore the dump file of the catalog structure.

The current version of FraneItalia has been tested using PostgreSQL® 9.6.8, pgAdmin4 and PostgGIS® 2.3.7. To facilitate the use and the spatial analysis of the FraneItalia catalog, a QGIS® (https://qgis.org/it/site/) project for the visualization of the tables and maps is also provided. The QGIS® project is provided together with the dump file. It assumes that the new PostgreSQL® inventory is named 'FraneItalia', and is running on the 'localhost' server available through the standard 5432 port. To use directly the QGIS® project, QGIS® must be installed on the same computer running the PostgreSQL® server. The QGIS® project has been tested using the QGIS® releases 2.18 and 3.03.

Authors' contributions

MC and GP contributed equally to this work. MC designed and planned the research, supervised the analyses and wrote the main sections of the paper.

GP collected and analyzed the data and wrote the supplementary information. Both the authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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