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Environmental Data Acquisition, Elaboration and Integration: Preliminary Application to a Vulnerable Mountain Landscape and Village (Novalesa, NW Italy)

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ABSTRACT

Climate conditions play a crucial role in the survival of mountain communities, whose survival already critically depends on socioeconomic factors. In the case of montane areas that are prone to natural hazards, such as alpine slope failure and debris flows, climatic factors exert a major influence that should be considered when creating appropriate sustainable scenarios. In fact, it has been shown that climate change alters the availability of ecosystem services (ES), thus increasing the risks of declining soil fertility and reduced water availability, as well as the loss of grassland, potential shifts in regulatory services (e.g., protection from natural hazards), and cultural services. This study offers a preliminary discussion on a case study of a region in the Italian Alps that is experiencing increased extreme precipitation and erosion, and where an isolated and historically resilient community directly depends on a natural resource economy. Preliminary results show that economic factors have influenced past population trends of the Novalesa community in the Piemonte Region in northwest Italy. However, the increasing number of rock fall and debris flow events, which are triggered by meteo-climatic factors, may further influence the livelihood and wellbeing of this community, and of other similar communities around the world. Therefore, environmental monitoring and data analysis will be important means of detecting trends in landscape and climate change and choosing appropriate planning options. Such analysis, in turn, would ensure the survival of about 10% of the global population, and would also represent a possibility for future economic development in critical areas prone to poverty conditions.

1. Introduction

Human-induced alterations of our planet across a range of scales are now detectable [1,2]. These alterations include land-use change and climate change, which can interact and lead to significant environmental degradation of our natural resources and vulnerability of the communities supported by those resources [3,4]. For example, an increase in extreme precipitation and a decrease in vegetative cover can intersect to create catastrophic erosion, landslides, and flooding that destroy lands used for agricultural production [5]. Alpine areas are particularly exposed to environmental degradation, due to their steep slopes, thin soils, and sparse vegetation, and rural isolated villages have few alternatives to natural-resources-based economies [6,7].

The consequences of environmental degradation are visible in the loss of ecosystem services (ES). ES in mountain areas include provisioning (food), regulating (climate), supporting (nutrient cycles), cultural (recreation), and other services [8]. The relation between climate change and the risk of ES loss has already been assessed in the literature [9,10]. In particular, for mountain regions, the risks of declining soil fertility and reduced water availability [11], the loss of grasslands in favor of forests [12], and potential shifts in regulatory services (e.g., protection from natural

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hazards) and cultural services [13] have been assessed. Communities dependent on ES must manage the challenges of spatial and temporal heterogeneity, along with trade-offs and synergies among different services [14]. With changes in services, the resilience of alpine human communities is at risk. Social systems and local institutions that are largely based on traditional ecological knowledge (TEK) could build an adaptive capacity to climate and landscape disruption [15]. However, a lack of resources, information, and political will are barriers to adaptation [16]. To address these issues, planning options should be developed that consider environmental change and its impact on human activities and wellbeing. In order to develop such planning options, environmental and socioeconomic data should be appropriately collected and processed at the local scale, since many regional differences exist and data may display a meaningful temporal variability.

This paper offers a preliminary discussion on a case study of a region in the Italian Alps that is experiencing increased extreme precipitation and erosion, and where an isolated and historically resilient community directly depends on a natural resource economy. In the past, a mountain village's continued existence, along with its ability to preserve its economic livelihood while coping with the dynamics of environmental factors, was considered to be guaranteed. Consequently, past studies focused on studying the hydrogeological risks in mountain areas, and disregarded the multiple impacts that such phenomena could exert on the stability of existing villages. The scarcity of available social and economic data indirectly influenced the contents of the performed research. However, the social and economic stability of the village of Novalesa, as well as those of other mountain villages, is far from sure. In fact, a large trend toward depopulation was recorded in several alpine areas in the 20th century, resulting in a reduction of services provision and a declining living standard for the local population [17]. In parallel, it is important to remark on the relevance of alpine regions for Europe. Although the Alps are one of the less-populated areas in central Europe, they are one of the most densely inhabited mountain regions worldwide [18].

This preliminary data analysis offers the opportunity to answer some scientific questions. The first question is whether geological and hydro-meteorological data can demonstrate a change in the frequency of catastrophic erosion. The second question is whether—if there is an increase in catastrophic erosion frequency—the use of social and economic data could increase the information that is required in order to take appropriate action to decrease the vulnerability of mountain communities. The ultimate goal of this research, which will be developed from this point onward in forthcoming years, is to understand the dynamics of the interactions between communities and natural hazards under changing climate conditions. Moreover, through the same long-term research, we will try to understand the influence of this interplay on the resilience and livelihood of remote villages, and particularly on those whose cultural and historical heritage is recognized as relevant, and which should therefore be preserved.

2. Methods

2.1. Study area

The larger area of interest for this study is known as the Cenischia Valley, and is located within the Piemonte Region of northwest Italy. The highest mountain in the area is Mt. Rocciamelone and its associated peaks, which reach 3538 m above sea level (a.s.l.). The main village of the area, Novalesa, is located at 900 m a.s.l.; it is separated by a 4 km distance from the mountain top, with slopes averaging 60%. Novalesa is located within the Torino metropolitan administrative area. The river basins draining this region include the Malo, Cenischia, Gioglio, Claretto, Marderello, and Crosiglione Rivers (in the left Cenischia stream). A minor stream, called Le Roncie, is located between the Gioglio and Claretto Rivers; however, it is not classified as a river. Above 2400 m a.s.l., there is no perennial vegetation or tree cover, although lower elevations have pasture grass and sparse shrub and tree cover, mainly comprising Swiss mountain pine (*Pinus mugo*) and European larch (*Larix decidua*). Other species have been introduced during reforestation efforts, but thin soil depths have limited vegetation cover. The Marderello River Basin has an area of 6.61 km^2 and was recorded to generate bulk debris flow volumes, estimated at $2.6 \times 10^6\ \mathrm{m}^3$ [19]. The same study reported the existence of a deep-seated gravitational slope deformation (GSD) of 15 km^2 in the Mt. Rocciamelone slopes.

This sub-area is relevant for hydrogeological research purposes. In fact, it may be a favorable space for observing geomorphologic transformations. These, in turn, depend on the existing steep slopes, tectonic activity, and immature hydrographic network, and on the degrading processes that periodically occur (i.e., rock falls, complex landslides, debris flows, etc.). These processes are also connected with climate dynamics. The rapid evolution of orographic perturbations is relevant for defining the importance of this sub-area. Gradients in atmospheric temperature, due to the different exposures and orientation of mountain slopes, support the generation of breezes, as well as the development of orographic precipitations and summer thunderstorms, which often trigger debris flows. Ice dynamics—which are now reduced to a small glacier located north of Mt. Rocciamelone—shaped the existing slopes. The generated debris is processed during major hydrogeological events (such as debris flows).

Debris flows are common processes in the Italian Alps and in other mountainous regions of the world. Several of these events have produced significant damage and fatalities during the last decades [20,21]. Understanding the behavior of debris flows (i.e., triggering conditions and downstream transfer rates) is essential for assessing their related risks. An important approach to improving the knowledge of debris flow processes is historical data [22] and real-time data accumulation by debris flow observation stations [20,23,24]. In order to study their triggering conditions and dynamics, the research personnel of the Institute for Hydro-Geological Protection Research (CNR-IRPI, which belongs to the Italian National Research Council) developed a historical database of frequent events [25]. In parallel, starting from 1994, an intensive monitoring campaign was developed in the area, using and updating available instrumental networks to allow the measurement of different meteorological and hydrological variables in the high mountain environment. Due to the extreme environmental conditions, a continuous process of technological updating and instrument intercalibration is obviously necessary in order to cope with the risk of data loss, which is still quite relevant during the winter season due to the high snow cover and limited accessibility of the sites during these months. Nonetheless, the number of monitored parameters has been growing over the years.

In the 7th century AD, a monastery was established in Novalesa to support the medieval pilgrim route, known as the Via Francigena, from Rome in Italy to Santiago de Compostela in Spain. The abbey was strategically positioned to provide support to pilgrims and military troops along the boundary with France. When the Saracens raided in 906 AD, the monastery was evacuated [26]. Around the end of the 12th century, commercial flows affected the area, due to the development of transalpine fairs and marketplaces. As a result, the fittest men in the nearby villages took on the job of alpine guides. In addition to carrying goods and removing the snow from tracks during the winter, they began to offer support to travelers crossing the most difficult parts of the mountain. Later, in the 18th century, Napoleon decided to open an entirely new carriage road, which largely determined all subsequent passage through that area (within a few years, the number of wagons passing through the area was quadrupled) [27]. Although it was isolated within the mountains, the Mount Cenis pass enabled cultural and ecotourism exchanges with the rest of Europe; this is evidenced by Saint Stephen Church in Novalesa, which contains a painting created by the world-renowned 17th century Flemish painter Peter Paul Rubens. Tourist visits to the nearby towering waterfalls have also been recorded. The main economic activities of the Novalesa residents are connected to farming, which involves working within the mountain environment, and to Italian–French transalpine tourism, which is linked to an extended artificial reservoir at the pass (the Lake of Moncenisio, which is 6.68 km^2 and has a total water capacity about 320×10^6 m^3). Thus, the chosen site has several favorable characteristics for evaluating the role of environmental factors in the livelihood of a small mountain community that has manifested a high degree of resilience throughout its millennial history.

2.2. Data sources

Basic data about effective surface, slope, exposition, and geolithology were previously determined for the areas of the Claretto, Marderello, and Crosiglione Rivers. These data are also reported in previously published papers. Basic data are reported in Table 1. The hydro-meteorological monitoring network, which was originally installed and operated to monitor meteorological parameters that might be able to trigger the development of slope instability phenomena, presently consists of seven different installations [23,25].

Each installation includes a precipitation gauge (Deltaohm model HD2013) with a sample area of 400 cm^2 and a sample size of 0.1 mm. The installation also includes sensors for relative humidity, air temperature, atmospheric pressure, and wind speed and direction. The locations of the seven installations range from 800 to 3100 m a.s.l., while a radiometer is located at 2850 m (at the Alpine Refuge Ca d'Asti) and a water level sensor is located at 820 m. The monitoring system was recently extended along an alluvial fan with one ultrasonic water level sensor, two video cameras, and four vertical geophones (10 Hz) separated by approximately 50 m [28]. A day/night video camera and two geophones are located in the Marderello Basin at 1850 m. In 2017, an X-band low-power continuous wave disdrometer (PLUDIX) was installed in the village of Novalesa. PLUDIX provides the drop size distribution (DSD) (i.e.: the raindrop number concentration with respect to 21 different equivalent-diameter drop class sizes) at a time resolution of 1 min. The precipitation gauges were installed in 1994, but due to weather and debris limiting their accessibility, there is an incomplete record. From 1994 to 2002, and for certain periods in 2003 and 2004, data are missing due to site inaccessibility. In addition, monitoring activities were suspended from 2008 to 2011 due to problems with the network. Improvements were made, and the network was restarted in June 2012.

Table 1
Summary of main geological and meteorological data.

Characterization	Claretto	Marderello	Crosiglione
Effective surface (km^2)	4.10	6.61	5.78
Slope (%)	74	75	65
Exposition	Southwest	Southwest	Southwest
Geo-lithology	Calcshist	Calcshist	Calcshist and phyllites
Mean annual precipitation (mm)[a]	–	850	–

[a] From the Pian Marderello rain gauge.

Mass wasting data were reported as rock falls [19]. Debris flow data were inferred from monitoring instruments in the three rivers of Claretto, Marderello, and Crosiglione, beginning in 1994. Flood data were derived from archives [29]. Community data were first recorded as part of the Novalesa Abbey in 726 AD, and were then formally collected as part of the Italian census efforts starting in 1861. In particular, census data were recorded and made available online by the Italian National Statistical Institute (ISTAT), which is in charge of collecting, performing, and validating all of the official statistical analyses in Italy.

3. Results and discussion

3.1. Meteorological data

Table 1 provides a summary of the main geological and meteorological data in regard to the Claretto, Marderello, and Crosiglione Rivers. (Note that the annual mean precipitation amount refers to the Pian Marderello rain gauge—i.e., the oldest installation point, which is located in a central position with respect to the three monitored rivers.) The slopes are impacted by the fact that the lower areas of the rivers are associated with waterfalls.

The annual average precipitation in the study area is 850 mm, 62% of which is recorded during the spring and autumn seasons. In 2000, the greatest total seasonal rainfall was recorded in the autumn (710.6 mm), while in 2008, the greatest total seasonal rainfall was in the spring (678 mm). In October 2000, there was a total precipitation of 493.8 mm, which coincided with a major flood event [30]. The greatest total monthly precipitation occurred during March 2008, when 553.8 mm was recorded. The lowest seasonal precipitation was recorded during the summer of 2003, which was characterized as a major drought event [31]. Fig. 1 provides a graph of cumulated year-scale seasonal precipitations from 1994 to 2015. The seasons for which data were available are spring, summer, and autumn. The plot evidences an increasing trend for spring precipitations and a diminishing amount of autumn rainfalls. Summer rainfall records for the last two periods are lower than for the first one. However, the 2011–2015 summer precipitations are slightly higher than those of the previous decade.

Fig. 2 represents typical daily rainfall data, expressed in millimeters and calculated as the mean values of daily precipitation data for the same date over 24 years. Data were collected using the Pian Marderello rain gauge at 2100 m a.s.l. for the months of May to October from 1994 to 2017. These data were originally used to study the triggering effect of precipitation events on debris flows. Thus, winter data were excluded from storage since debris flows occur from late spring to autumn. The average daily precipitation value recorded during this period was 2.30 mm, with a

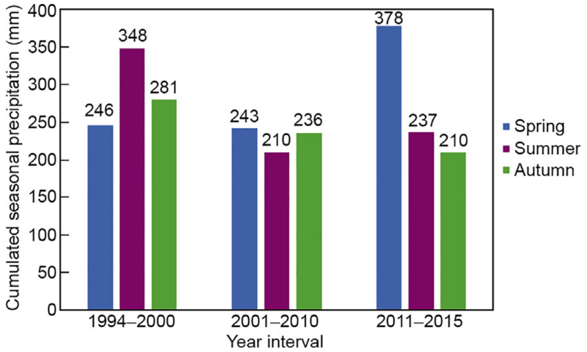

Fig. 1. Cumulated year-scale seasonal precipitations (mm) measured for the first installed rain gauge (Pian Marderello), which is associated with the Marderello River. Time periods (years) are grouped into 1994–2000, 2001–2010, and 2011–2015. Data values are reported above the bars.

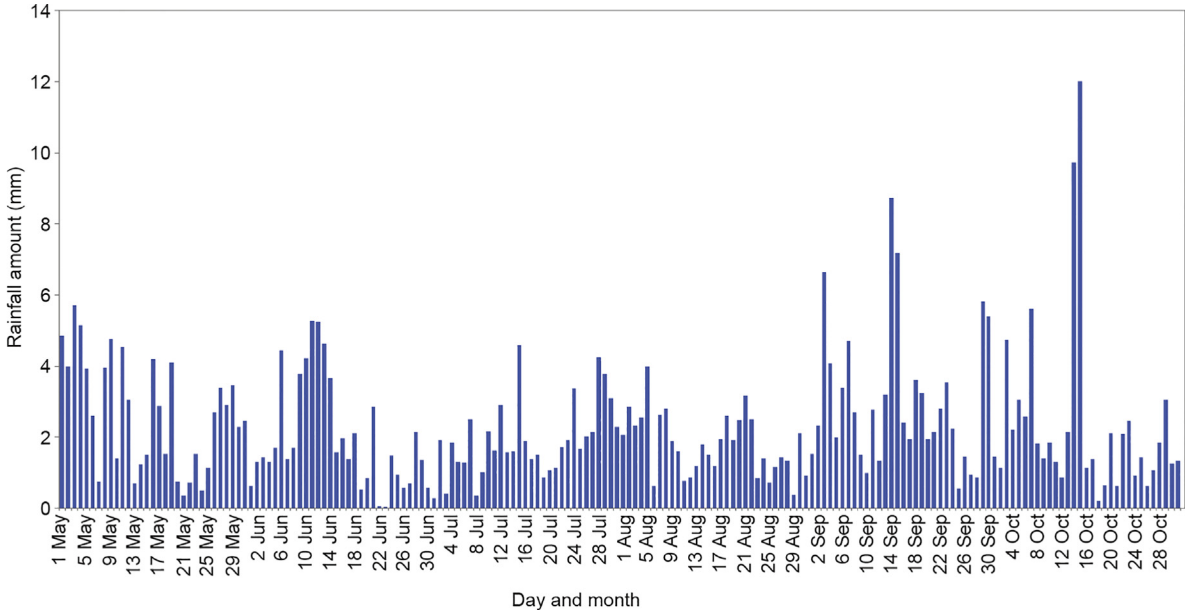

Fig. 2. Average daily rainfall (expressed in mm, ordinate), from 1 May to 31 October, belonging to the 24 year dataset (1994–2017) for the Pian Marderello rain gauge.

maximum of 12.03 mm and a minimum of 0.04 mm. Ranking the measured values in order of average daily precipitation amount, the days with lowest recorded rainfalls were June 22 and June 23, while those with highest recorded rainfalls were October 14 and October 15. Finally, the highest daily value recorded was in 2000, when 204.8 mm of rain was measured on October 15.

Because there are fewer than 30 years of record from the local monitoring network, it is not possible to further infer climatic trends. However, the broader network of rain gauges in the Piemonte Region of the Italian Alps experienced an increase in the number of extreme precipitation events, when comparing post-1990 and pre-1990 records [32]. As the intensity increased, the precipitation totals slightly increased [33], a trend that extends beyond the Italian Alps to the whole Euro-Mediterranean region [34]. This finding is also confirmed by the lower cumulative seasonal rainfall in autumn (Fig. 1), in contrast to the maximum values recorded during the measuring period, which occurred during the month of October (Fig. 2). A trend of increased winter droughts, with increased winter precipitation intensity, has been noted over several Italian regions [35]. In summary, the precipitation intensity has increased in this region, and periods of drought have become more frequent.

3.2. Historical list of recorded events: Rock falls, debris flows, and flooding events

Table 2 reports the frequency of historical rock falls, debris flows, and flooding events, as inferred from archival data and direct observations. Debris flows and flooding events are associated with the Claretto, Marderello, and Crosiglione Rivers. Rock falls from the Mt. Rocciamelone area, which create the availability of debris for these three rivers, are represented in the second column of the same table.

Overall, the available data indicate that the cumulative number of rock fall and debris flow events is higher during the last period (2001–2017) than the previous periods. Thus, the geological and hydro-meteorological data seem to indicate an increasing trend in the frequency of catastrophic erosion in the area. Small rock falls or debris collapses below the crest line take place almost annually as a result of melting ice or snow. The increasing frequency of records from 2001 and the observed events that occurred during the spring and summer of 2005 indicate the geological evolution of the degradation processes, which are leading to a continuous feeding of materials downslope [19].

The surface detrital cover on slopes often experiences wet conditions due to rainfall and snow cover, causing it to become prone to rill erosion or landslides. The months from April to September are particularly favorable for observing such phenomena. In fact, this is the part of the year during which thunderstorms develop in the Piemonte Region, with the highest peak of thunderstorm incidence occurring in the month of July [36]. The same study showed that the maximum number of recorded events occur around 13 coordinated universal time (UTC), and are thus associated with the effects of maximum incoming solar radiation (which normally occurs at noon in local time).

Within this meteorological context, the stream flow, which does not usually exceed 0.02–0.04 $m^3 \cdot s^{-1}$, can rise to 180 $m^3 \cdot s^{-1}$ (this is

Table 2
Historical frequency of recorded events (rock falls, debris flows, and flooding events) and the mean population of the Novalesa municipality grouped in different year intervals.

Years interval	Rock falls[a]	Debris flow[b]			Flooding events[b]			Novalesa mean population (inhabitants)
		Claretto	Marderello	Crosiglione	Claretto	Marderello	Crosiglione	
Prior to 1900	4	–	2	2	1	1	1	1243
1901–1920	1	–	–	–	1	1	0	1028
1921–1940	–	1	–	–	2	0	0	759
1941–1960	–	3	4	1	1	2	1	689
1961–1980	–	–	1	0	1	1	0	596
1981–2000	3	1	8	0	1	2	0	541
2001–2017	13	3	17	3	2	4	2	554

[a] Rock falls are associated with the Mt. Rocciamelone area and affect the three monitored rivers (Claretto, Marderello, and Crosiglione), creating debris availability.
[b] Debris flows and flooding events are associated with the three rivers.

the highest peak value, which was recorded on 14 August 2015). Consequently, flow mixtures sometimes develop, with the less-frequent transportation of large blocks (1000 m^3) downstream. The debris flow frequency in the area of the three small rivers (Claretto, Marderello, and Crosiglione) are also reported in Table 2. A global increase in the occurrence of debris flow events has been recorded in recent decades; in this case, Marderello River had the highest frequency peak in the period 2001–2017.

Flooding events have been documented over the centuries in the area of Novalesa, with the oldest observed flood dating back to 1664. Marderello River has the highest number of flood records, with a peak (eight floods) occurring during the period 1981–2000. A second relative maximum frequency (six events for Marderello and four events for Claretto) is reported for the period 1941–1960. Crosiglione River was the least affected by flooding.

3.3. The socioeconomic evolution of Novalesa and possible impacts of increased meteorological and hydrogeological risk factors

Population data since 1861 (i.e., the year of national Italian unification under the Reign of Italy) were grouped into different year classes (prior to 1900, 1901–1920, 1921–1940, 1941–1960, 1961–1980, 1981–2000, and 2001–2017). The mean number of inhabitants for each class is reported in the last column of Table 2. The Novalesa community exhibits a declining trend, with only small signs of increase in the last 20 years. The decline of the community began in the 20th century, in alignment with industrial development in the Torino area. The population numbers were significantly affected by the two world wars. The great economic crisis in 1929 was another important factor that impacted the Novalesa population, as it did many other areas of the world. The most recent national census database (in 2011) reported a population of 560 inhabitants, with a density of 20 inhabitants per square kilometer. Compared with the alpine region as a whole, which has an average population density of 74.6 inhabitants per square kilometer (as of 2013), the Novalesa area has a low population. Moreover, the alpine region, to which Novalesa belongs, is characterized by a decline in fertility rate and an increase in population aging, due to the depopulation of active working citizens [17].

This dataset suggests that population trends are mainly affected by macroeconomic factors. It is notable that flooding events and debris flows were already recorded in local chronicles before the 20th century. The only exception to the general trend of such events may be the interval from 1981 to 2000, when more frequent flooding events occurred in association with the Marderello River. Thus, the community appears to be more resilient to environmental factors than to economic ones. However, the small amount of socioeconomic data that have been collected over the years suggests a cautious approach to any such statement.

At present, it is not possible to perform any meaningful statistical analysis to compare the correlations of environmental and socioeconomic variables. Environmental data collection began quite recently (in 1994), and has encountered many difficulties due to the extreme conditions of the mountain environment. As noted earlier, population data have only been recorded every ten years since 1861, while historical data have been collected on the basis of chronicles. A systematic collection of economic data from other studies (which are not directly available, since they are owned by the Italian National Statistical Institute and are not available in any public form) only provides data collection for recent years (2003–2013). However, a broader data collection and analysis, that was applied to the whole alpine area (involving several countries, namely, France, Italy, Switzerland, Liechtenstein, Slovenia, Austria, and Germany), provided some clearer economic details for the last decade. In particular, the following socioeconomic variables were included in Ref. [17]: employment rate, change in employment rate (in ten years), unemployment rate, and population with tertiary education. Another recent study detailed the factors triggering socioeconomic decline (i.e., lack of access to resources, education, healthcare, and livelihood) [37]. That study analyzed the economic performance of the whole alpine area from 2003 to 2013. The research outcomes indicated three main problems for the regional area (including the municipality of Novalesa) that potentially trigger negative economic performance: a high proportion of elderly people within the population, a low employment rate, and a low proportion of people with a high level of education.

Farming, agriculture, handcraft, and tourism, which are supported by ES, are the main economic activities for Novalesa. In particular, farming is a well-rooted economic practice in the area, in association with the culture of transhumance (i.e., moving livestock from one grazing ground to another in a seasonal cycle—typically moving to the lowlands in winter and to the highlands in summer). (It is important to remark here that 39% of Italian dairy products and 11% of Italian meat come from the alpine regions located in the northern part of Italy [38].) In fact, summer farms can be found in the area surrounding the village of Novalesa. A preliminary mapping of existing farms (46 active farms and 13 that have been abandoned for many decades) shows that the farms are concentrated over the southern mountainside, due to more favorable exposure to solar radiation and higher surface water availability. In addition, 29 simple houses used by farmers were identified. Thus, the total number of houses (29) and farms (59, of which 46 are active) is 88. Fig. 3 reports the location of the groups of farms and simple houses using black points. Finally, 20 economic activities (mainly shops) associated with farming are present in the main area of the village.

Farming is influenced by climatic conditions. If the droughts that have been affecting several regions in northern Italy in recent years continue, grazing persistence may come under discussion in the future. An increasing frequency of debris flows in the area where the mountain farms are found may create long-lasting damage, which will lower the resilience of the Novalesa mountain community. Moreover, a GSD is affecting the Mt. Rocciamelone area, creating a higher availability of debris. Thus, increased extreme precipitation events could negatively affect all of the ES that support economic activities in the area. In fact, a study demonstrates that intense rainfalls reduce the supply of ES in different ways that persist for several years, requiring huge economic investments to recover from damages [39].

Agricultural data (i.e., products and economic flows) are not presently available, although the local municipal administration informally reports the existence of agricultural activities in the Novalesa area. However, past research indicates that heat-related risks may be more relevant for the lower cropland and pasture sites, whereas water-related issues may become increasingly important for more elevated locations [40]. It is important to note that climate change is the only factor impacting agriculture in this region. An integrated analysis that was conducted for the Italian Alps and extended to the European alpine region showed that changes to land use and changes to land cover may be equally severe given the projected temperature increases, which depend on climatic trends [41].

Data on handcraft activities are also missing. However, the possibility of gaining economic support from selling traditional handcraft products is often related to tourism fluxes. Therefore, the tourism sector should be carefully considered when planning the socioeconomic livelihood of a montane community. In our case study, mountain tours are not associated with skiing, but with trekking activities and with cultural and historical sites. Previous studies showed that an increase in the frequency and intensity of natural hazards could have tremendous consequences on the

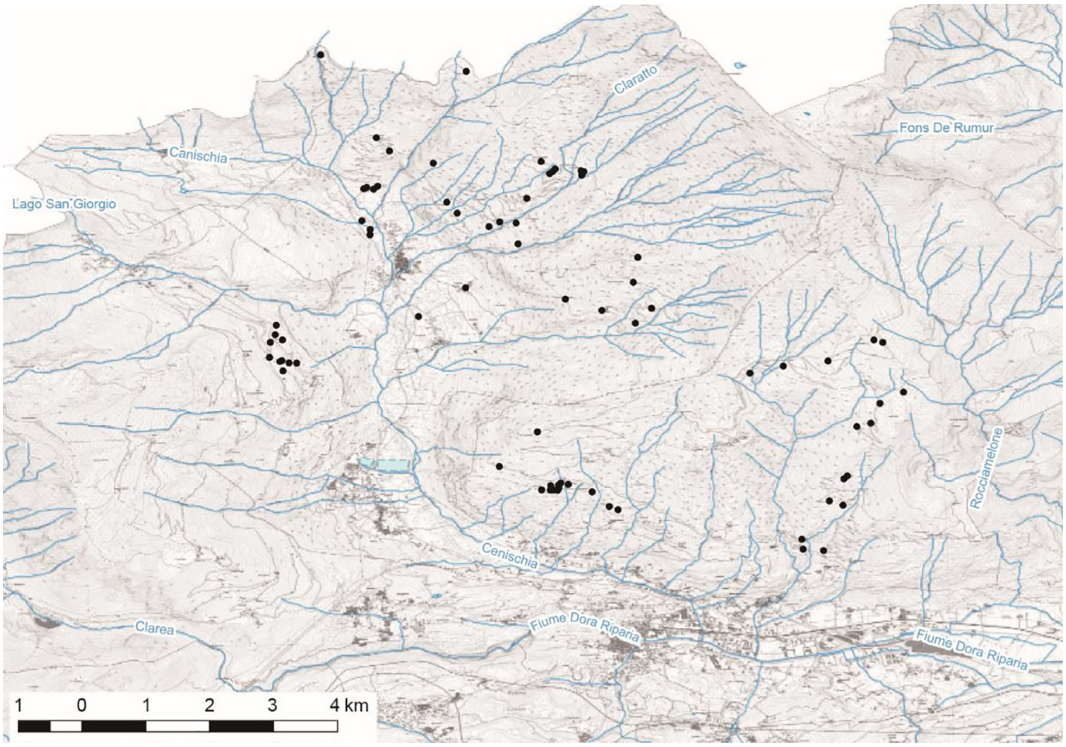

Fig. 3. A map of the locations of mountain farms (59, of which 46 are active) and mountain houses (29) around the municipality of Novalesa.

tourism industry, particularly when the costs of adaptation strategies are too high [42]. Moreover, tourist fluxes are associated with several climate indexes, and are particularly associated with temperature [43]. In fact, a negative outcome has been detected in association with warmer destinations, whereas a possible attraction for cooler countries has been observed. An integrated use of participatory processes and modeling outputs could increase the effectiveness of decision-making processes aimed at obtaining sustainable solutions to climate-change-related scenarios in a mountain context [44].

Thus far, socioeconomic factors seem to have been predominant in shaping the dynamics of Novalesa population. However, in future, the dependency on environmental factors (which mainly depend on the regional effects of climate change) may increase, as such factors affect the availability of ES. In fact, as noted earlier, precipitation events are decreasing in number yet increasing in intensity, while hydrogeological processes (i.e., rock falls and debris flows) seem to be accelerated. In the case of such environmental alterations, labor migration could become the only possible solution for survival, as hypothesized by a recent study [45]. The availability of more social and economic data could increase the information that is needed in order to take appropriate action to decrease the vulnerability of mountain communities. In particular, new information could unveil further correlations between economic activities or general livelihood and the variability of environmental conditions. Quantitative detail could be extremely useful in this respect. Useful data might include more detailed demographics (e.g., population distribution per age); individual income with respect to population age distribution; local disaggregated monetary flows, grouped according to economic activity codes; employment rates; and access to services (e.g., education, healthcare, etc.).

The interchange of geospatial workflows and provenance information in environmental monitoring and other geographic information system (GIS) applications, together with GIS cyberinfrastructure, will be fundamental in the development of future landscape planning under a climate change scenario in which the vulnerability of Novalesa community may be strongly triggered by environmental factors. For this reason, data collection, elaboration, and integration are important in detecting trends in landscape and climate change and in choosing appropriate planning options for the future livelihood of mountain communities. Innovative monitoring approaches should be adopted in an appropriate way, in order to infer ongoing landscape transformations. In particular, the mixed use of aerial and satellite platforms as a hierarchical monitoring technique has already been shown to be effective for such a purpose [46–50]. A better use of cyberinfrastructure might allow the development of future multiuser workflows, which should incorporate provenance-interchange Internet standards that can augment transparency, trust, and reproducibility in environmental monitoring activities that involve multiple collaborating organizations.

The importance of data collection and sharing goes beyond the main purpose of this research, as it is relevant for creating a common shared base of discussion for sustainable planning. In fact, collaboration among different organizations in developing regional sustainability plans is important in order to increase the understanding of the environmental and socioeconomic drivers of local/regional sustainability [51]. Moreover, the sharing of experience among regional sustainability research networks has demonstrated the capability to boost policy outcomes [52].

Temperature and precipitation data appear to be the most relevant meteorological variables, and will require more detailed analyses. In particular, with respect to precipitation measurement, PLUDIX can provide more detailed precipitation records and nowcasting (i.e., present weather sensor (PWS) functions) [53]; furthermore, it can operate during extreme events and in high mountain environments [54]. DSD data can be integrated with radar or satellite remote-sensing data of storms in order to infer the dynamics and microphysical properties of precipitation. It can also be applied to hydrogeology studies in order to define the kinetic energy and erosive power of the precipitation [55]. Moreover, nivometric and ice cover data should be collected. A characterization of permafrost will be possible in the future due to a concurrent monitoring campaign that was recently begun by other research groups.

A deeper knowledge about water stress and water quality should be developed. It is known that a strong coupling exists between anthropogenic activities and water resources in mountainous areas [56]. Continuous measurement of water levels and flows in the surface rivers would be desirable, along with the quantification of available groundwater. Water quality, which was not previously considered for our study area, should be included in future investigations. Basic water quality parameters (e.g., biochemical oxygen demand (BOD), turbidity, eutrophication, etc.) and geochemical water characteristics (e.g., pH, ion concentrations, etc.) would be relevant, as shown in a previous study [57], in determining whether anthropogenic activities are altering water bodies. The impacts of farming activities on water quality, the potential transport of pollutants and nutrients along water bodies, and the impacts of pollution transfer from other areas and other environmental matrices (e.g., from air to water or from water to soil) should be defined and modeled [58,59].

Relevant policies should be developed to cope with the vulnerability of montane socioecological systems to climate change. A study has shown that mountain communities and environments are particularly endangered if strong globalization is assumed [60]. Early landscape and economic planning have been suggested as an appropriate answer to the present scenario. Finally, with respect to economic activities, the traditional positive attitude of montane communities toward resource reuse and recycling, which are the pillars of circular economy, should be appropriately exploited. The development of traditional sectors, such as agriculture, in new forms, such as leisure agriculture, may represent a future alternative to promote the development of the area, while simultaneously encouraging the growth of local ecotourism [61].

4. Conclusions

The livelihood of montane communities critically depends on environmental conditions. In future, the availability of ES may be reduced due to climatic change, which will likely affect the biodiversity status and the occurrence of natural hazards, such as flooding events and slope instability phenomena. This article discussed a case study of a region in the Italian Alps that is experiencing increased extreme precipitation and erosion, and where the survival of a historically resilient community directly depends on a natural resource economy.

A preliminary analysis indicates a change in the frequency of catastrophic erosion, which may be further triggered under a climate change scenario characterized by increased intense precipitation events, even if the total precipitation is diminishing. An analysis of the social data led to two apparently contrasting findings: The first, which seems to be somewhat trivial, is that the montane community under study is vulnerable to external socioeconomic conditions. The second finding, which should be investigated further, is that its strong dependence on ES, which is driven by climatic factors, increases the community's dependence on external economic factors. In any case, the results show that in future, problematic economic conditions may be further triggered by climate factors. For this reason, a careful planning of scenarios based on environmental data collection and elaboration is necessary.

However, this conclusion is not only true for the Novalesa community. Mountainous areas, which constitute about 20% of the earth's surface, support about half of the global population through water, energy, minerals, forests, and agricultural products [45]. Moreover, the preservation of indigenous TEK is precious for developing appropriate adaptive processes toward changing environmental conditions, as recently stated in the text of the Paris Agreement.[†]

Therefore, future research will involve collecting more complete local data and, possibly, comparing data from different communities around the world. In fact, the resilience of montane settlements would ensure the survival of about 10% of the global population, and would also represent a possibility for future economic development in critical areas that are prone to poverty conditions. However, appropriate policies can only be planned if the current limited availability of specific multidisciplinary research can be overcome with timely research and development roadmaps and actions.

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Compliance with ethics guidelines

Massimiliano Lega, Marco Casazza, Laura Turconi, Fabio Luino, Domenico Tropeano, Gabriele Savio, Sergio Ulgiati, and Theodore Endreny declare that they have no conflict of interest or financial conflicts to disclose.

References

[1] Steffen W, Persson A, Deutsch L, Zalasiewicz J, Williams M, Richardson K, et al. The Anthropocene: from global change to planetary stewardship. Ambio 2011;40(7):739–61.
[2] Intergovernmental Panel on Climate Change. Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, editors. Working group II contribution to the fifth assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press; 2014. p. 688.
[3] Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, et al. Planetary boundaries: guiding human development on a changing planet. Science 2015;347(6223):1259855.
[4] Casazza M, Liu G, Ulgiati S. The tenth planetary boundary: to what extent energy constraints matter. J Environ Account Manage 2016;4(4):399–411.
[5] Palomo I. Climate change impacts on ecosystem services in high mountain areas: a literature review. Mt Res Dev 2017;37(2):179–87.
[6] Kohler T, Wehrli A, Jurek M, editors. Sustainable mountain development series. Bern: Center for Development and Environment, Swiss Agency for Development and Cooperation, and Geographica Bernensia; 2014.
[7] Mountain Research Initiative EDW Working Group. Elevation-dependent warming in mountain regions of the world. Nat Clim Chang 2015;5(5):424–30.
[8] Haida C, Rüdisser J, Tappeiner U. Ecosystem services in mountain regions: experts' perceptions and research intensity. Reg Environ Change 2016;16(7):1989–2004.
[9] Rodríguez-Labajos B. Climate change, ecosystem services, and costs of action and inaction: scoping the interface. Wiley Interdiscip Rev Clim Chang 2013;4(6):555–73.
[10] Wang H, Zhou S, Li X, Liu H, Chi D, Xu K. The influence of climate change and human activities on ecosystem service value. Ecol Eng 2016;87:224–39.
[11] Schröter D, Cramer W, Leemans R, Prentice IC, Araújo MB, Arnell NW, et al. Ecosystem service supply and vulnerability to global change in Europe. Science 2005;310(5752):1333–7.
[12] Schirpke U, Kohler M, Leitinger G, Fontana V, Tasser E, Tappeiner U. Future impacts of changing land-use and climate on ecosystem services of mountain grassland and their resilience. Ecosyst Serv 2017;26:79–94.

[†] http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf.

[13] Mina M, Bugmann H, Cordonnier T, Irauschek F, Klopcic M, Pardos M, et al. Future ecosystem services from European mountain forests under climate change. J Appl Ecol 2017;54(2):389–401.

[14] Briner S, Huber R, Bebi P, Elkin C, Schmatz D, Grêt-Regamey A. Trade-offs between ecosystem services in a mountain region. Ecol Soc 2013;18(3):35.

[15] Ingty T. High mountain communities and climate change: adaptation, traditional ecological knowledge, and institutions. Clim Change 2017;145(1–2):41–55.

[16] Archie KM. Mountain communities and climate change adaptation: barriers to planning and hurdles to implementation in the Southern Rocky Mountain Region of North America. Mitig Adapt Strategies Glob Change 2014;19(5):569–87.

[17] Permanent Secretariat of the Alpine Convention. Demographic changes in the Alps Report on the state of the Alps. 5th ed. Innsbruck: Permanent Secretariat of the Alpine Convention; 2015.

[18] Permanent Secretariat of the Alpine Convention. Transport and mobility in the Alps Report on the state of the Alps. Innsbruck: Permanent Secretariat of the Alpine Convention; 2007.

[19] Turconi L, De SK, Tropeano D, Savio G. Slope failure and related processes in the Mt. Rocciamelone area (Cenischia Valley, Western Italian Alps). Geomorphology 2010;114(3):115–28.

[20] Guzzetti F, Peruccacci S, Rossi M, Stark CP. The rainfall intensity-duration control of shallow landslides and debris flows: an update. Landslides 2008;5(1):3–17.

[21] Salvati P, Petrucci O, Rossi M, Bianchi C, Pasqua AA, Guzzetti F. Gender, age and circumstances analysis of flood and landslide fatalities in Italy. Sci Total Environ 2018;610–611:867–79.

[22] Tropeano D, Turconi L. Using historical documents for landslide, debris flow and stream flood prevention. Applications in Northern Italy. Nat Hazards 2004;31(3):663–79.

[23] Turconi L, Coviello V, Arattano M, Savio G, Tropeano D. Monitoring mud-flows for investigative and warning purposes: the instrumented catchment of Rio Marderello (North–Western Italy). In: Lollino G, Arattano M, Rinaldi M, Giustolisi O, Marechal JC, Grant GE, editors. Engineering geology for society and territory. Switzerland: Springer; 2015. p. 85–90.

[24] Theule J, Crema S, Marchi M, Cavalli M, Comiti F. Exploiting LSPIV to assess debris-flow velocities in the field. Nat Hazards Earth Syst Sci 2018;18(1):1–13.

[25] Turconi L, Tropeano D, Savio G. Debris flows in the Marderello catchment in summer 2005 (Cenischia Valley, Western Italian Alps): a critical rainfall-process analysis. Wildbach und Lawinenverbau 2008;72:42–61. German.

[26] Versteegh K. The Arab presence in France and Switzerland in the 10th century. Arabica 1990;37(3):359–88.

[27] Grilletto R. Brief note: the "Crânes cloués" of the abbey of Novalesa (Turin, Italy). Bull Mem Soc Anthropol Paris 1986;3(1):47–50. French.

[28] Coviello V, Arattano M, Turconi L. Detecting torrential processes from a distance with a seismic monitoring network. Nat Hazards 2015;78(3):2055–80.

[29] Tropeano D, Turconi L. Evaluation of debris potential in small basins of western and central Alps. Rome: CNR-IRPI/GNDCI; 1999. Italian.

[30] Llasat MC, Llasat-Botija M, Prat MA, Porcu F, Price C, Mugnai A, et al. High-impact floods and flash floods in Mediterranean countries: the FLASH preliminary database. Adv Geosci 2010;23:47–55.

[31] Boschetti M, Stroppiana D, Brivio PA, Bocchi S. Multi-year monitoring of rice crop phenology through time series analysis of MODIS images. Int J Remote Sens 2009;30(18):4643–62.

[32] Casazza M, Piano A. Intense events of rainfalls in Piemonte. Ann Geophys 2003;46(2):235–40.

[33] Brunetti M, Maugeri M, Monti F, Nanni T. Temperature and precipitation variability in Italy in the last two centuries from homogenised instrumental time series. Int J Climatol 2006;26(3):345–81.

[34] Norrant C, Douguédroit A. Monthly and daily precipitation trends in the Mediterranean (1950–2000). Theor Appl Climatol 2006;83(1–4):89–106.

[35] Brunetti M, Maugeri M, Nanni T, Navarra A. Droughts and extreme events in regional daily Italian precipitation series. Int J Climatol 2002;22(5):543–58.

[36] Davini P, Bechini R, Cremonini R, Cassardo C. Radar-based analysis of convective storms over northwestern Italy. Atmosphere 2012;3(1):33–58.

[37] Barua A, Katyaini S, Mili B, Gooch P. Climate change and poverty: building resilience of rural mountain communities in South Sikkim, Eastern Himalaya, India. Reg Environ Change 2014;14(1):267–80.

[38] Permanent Secretariat of the Alpine Convention. Alpine agriculture. Innsbruck: Permanent Secretariat of the Alpine Convention; 2017.

[39] Tomczyk AM, White PC, Ewertowski MW. Effects of extreme natural events on the provision of ecosystem services in a mountain environment: the importance of trail design in delivering system resilience and ecosystem service co-benefits. J Environ Manage 2016;166:156–67.

[40] Fuhrer J, Smith P, Gobiet A. Implications of climate change scenarios for agriculture in alpine regions—a case study in the Swiss Rhone catchment. Sci Total Environ 2014;493:1232–41.

[41] Tasser E, Leitinger G, Tappeiner U. Climate change versus land-use change—what affects the mountain landscapes more? Land Use Policy 2017;60:60–72.

[42] Nepal SK. Mountain tourism and climate change: implications for the Nepal Himalaya. Nepal Tour Develop Rev 2011;1(1):1–14.

[43] Rosselló-Nadal J. How to evaluate the effects of climate change on tourism. Tour Manage 2014;42:334–40.

[44] Bonzanigo L, Giupponi C, Balbi S. Sustainable tourism planning and climate change adaptation in the Alps: a case study of winter tourism in mountain communities in the Dolomites. J Sustain Tour 2016;24(4):637–52.

[45] Milan A, Gioli G, Afifi T. Migration and global environmental change: methodological lessons from mountain areas of the global South. Earth Syst Dynamics 2015;6(1):375–88.

[46] Lega M, d'Antonio L, Napoli RMA. Cultural heritage and waste heritage: advanced techniques to preserve cultural heritage, exploring just in time the ruins produced by disasters and natural calamities. In: Popov V, Itoh H, Mander U, Brebbia CA, editors. Management and the environment V. Ashurst Lodge: WIT Press; 2010. p. 123–34.

[47] Gargiulo F, Persechino G, Lega M, Errico A. IDES project: a new effective tool for safety and security in the environment. In: Wang G, Zomaya AY, Martinez Perez G, Li K, editors. Algorithms and architectures for parallel processing. Cham: Springer; 2013. p. 201–8.

[48] Lega M, Persechino G. GIS and IR aerial view: advanced tools for the early detection of environmental violations. In: Brebbia CA, Passerini G, Itoh H, editors. Management and the environment VII. Ashurst Lodge: WIT Press; 2014. p. 225–35.

[49] Errico A, Angelino CV, Cicala L, Persechino G, Ferrara C, Lega M, et al. Detection of environmental hazards through the feature-based fusion of optical and SAR data: a case study in southern Italy. Int J Remote Sens 2015;36(13):3345–67.

[50] Wang SY, Zhang XX, Zhu D, Yang W, Zhao JY. Assessment of ecological environment quality in the Changbai Mountain Nature Reserve based on remote sensing technology. Prog Geog 2016;35:1269–78. Chinese.

[51] Sharma A, Kearins K. Interorganizational collaboration for regional sustainability: what happens when organizational representatives come together? J Appl Behav Sci 2011;47(2):168–203.

[52] Mukhopadhyay P, Nepal M, Shyamsundar P. Building skills for sustainability: a role for regional research networks. Ecol Soc 2014;19(4):45.

[53] Prodi F, Caracciolo C, D'Adderio LP, Gnuffi M, Lanzinger E. Comparative investigation of Pludix disdrometer capability as present weather sensor (PWS) during the Wasserkuppe campaign. Atmos Res 2011;99(1):162–73.

[54] Porcù F, D'Adderio LP, Prodi F, Caracciolo C. Rain drop size distribution over the Tibetan Plateau. Atmos Res 2014;150:21–30.

[55] Casazza M. Some metrological limitations to rain impact computation in storm erosivity as defined in the Revised Universal Soil Loss Equation, version 2 (RUSLE2). J Environ Acc Manage 2016;4(1):37–44.

[56] Ling H, Xu H, Fu J. Changes in intra-annual runoff and its response to climate change and human activities in the headstream areas of the Tarim River Basin, China. Quat Int 2014;336:158–70.

[57] Casazza M, Maraga F, Liu G, Lega M, Turconi L, Ulgiati S. River water quality and its relation with air quality: a long-term case study in a remote and pristine NW Italian headwater catchment. J Environ Acc Manage 2017;5(1):35–47.

[58] Lega M, Endreny T. Quantifying the environmental impact of pollutant plumes from coastal rivers with remote sensing and river basin modelling. Int J Sustain Dev Plan 2016;11(5):651–62.

[59] Li H, Yang Z, Liu G, Casazza M, Yin X. Analyzing virtual water pollution transfer embodied in economic activities based on gray water footprint: a case study. J Clean Prod 2017;161:1064–73.

[60] Brunner SH, Grêt-Regamey A. Policy strategies to foster the resilience of mountain social-ecological systems under uncertain global change. Environ Sci Policy 2016;66:129–39.

[61] Jia Z, Qin A, Jia H. Research on the development of leisure agriculture tourism in Yi County based on circular economy. Manage Eng 2014;15:72–6.