Participatory Scenario Development to Address Potential Impacts of Land Use Change: An Example from the Italian Alps

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Changes to land use such as the removal of natural vegetation and expansion of urban areas can result in degradation of the landscape and an increase in hydro-meteorological risk. This has led to higher interest by decision-makers and scientists in the future consequences of these drivers. Scenario development can be a useful tool for addressing the high uncertainty regarding modeling future land use changes. Scenarios are not exact forecasts, but images of plausible futures. When studying future land dynamics, emphasis should be given to areas experiencing high rates of socioeconomic change. We have focused on the eastern Italian Alps, which face increasing pressure from tourism development. Identified drivers of local land use change are mostly external and difficult to quantify. This area, characterized by a traditional Alpine landscape, is subject to high levels of hydro-meteorological risk, another reason to study potential future land use changes. We tested a scenario generation method based on existing decisions and assumptions about future tourism development. We aimed to develop a framework leading to plausible scenarios that can overcome data inaccessibility and address external drivers. We combined qualitative methods, such as stakeholder interviews and cognitive mapping, with geospatial methods, such as geographic information systems, geostatistics, and environmental modeling. We involved stakeholders from the beginning to support the steps of generating data, understanding the system of land use change, and developing a land use change model for scenario development. In this way, we generated spatio-temporal scenarios that can assist future spatial planning and improve preparedness for possible undesirable development.

Keywords: *Land use change; scenarios; tourism; hydro-meteorological hazards; spatial simulation; stakeholders; Alps; Italy.*

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Introduction

Land use changes can have significant consequences in mountainous environments that are characterized by high occurrence of hydro-meteorological hazards, vulnerable mountain societies, and slower ecosystem recovery rates (Körner et al 2005). They can affect hydro-meteorological risk, defined as the potential loss to a human–environment system exposed to hydro-meteorological hazards such as floods and landslides (Cardona 2004; Fuchs et al 2013). Land use changes can increase this risk by affecting the occurrence of hazards or changing the spatial pattern of exposure due to urban expansion (Bronstert et al 2002; Glade 2003; Glade and Crozier 2005). They can also have other negative consequences, such as habitat loss, degraded biodiversity levels, and a lower quality of the landscape image (Chemini and

Rizzoli 2003; Tasser et al 2005; Giupponi et al 2006). This acknowledged relationship between land use change and numerous impacts on mountain communities has recently led to increased attention by decision-makers to the drivers and consequences of such changes (Schneeberger et al 2007). Therefore, it is necessary to study how future land use changes might affect human–environment interactions (Rounsevell et al 2006).

A suitable method of planning for potential future land use changes is scenario development; it makes it possible to explore potential futures and their environmental consequences as well as potential solutions to environmental problems and thus supports decision-making (Kriegler et al 2012). A scenario is not an exact forecast, but an image of a plausible future (Abildtrup et al 2006). It is a creative, visionary tool that can support

planning for a desired future as well as preparation for possible undesirable events (Deshler 1987; Wollenberg et al 2000). Scenarios are best developed not by researchers alone but with stakeholder participation. Participatory approaches offer a chance to discuss, negotiate, and reach agreement (Patel et al 2007; Albert 2008). Participatory scenario development can thus be considered more reliable and relevant for stakeholders (Von Korff et al 2010; Bohunovsky et al 2011; Kok et al 2015; Haller and Einsiedler 2015).

Participatory scenario development has been applied to a variety of issues, including community forest management (Wollenberg et al 2000), rural funding policy in mountainous landscapes (Bayfield et al 2008), deforestation in Brazil (Soler et al 2012), forest management impacts on livelihoods (Kassa et al 2009), future environmental changes (Odada et al 2009), management of natural parks (Daconto and Sherpa 2010), and changes to freshwater resources (van Vliet et al 2010). Usually participatory scenario development does not generate spatially explicit results, but in some applications, participatory modeling has been combined with spatial simulation (Castella and Verburg 2007; Potvin et al 2007; Swetnam et al 2011; Berkel and Verburg 2012; Hoyer and Chang 2014).

Spatially explicit modeling is needed to identify critical areas that are likely to undergo change (Verburg et al 1999). This is of high importance in mountain areas, with specific biophysical (terrain, hydrology, soil, geology) and socioeconomic characteristics (accessibility, population, employment density). To further investigate the possibility of integrating participatory approaches with spatial simulation, we developed and applied a multistep scenario-generation framework in a regional-scale case study in the Italian Alps, where uncertainty regarding future drivers of land use change is high. We aimed to develop a framework that (1) enables the development of plausible scenarios, (2) can overcome lack of data, and (3) can address external drivers that are difficult to quantify. Moreover, our aim was to identify potential hot spots of land use change.

Study area

The Gemonese, Canal del Ferro e Val Canale Mountain Community is a local government entity (a so-called "Comunità montana" in Italian) consisting of 15 municipalities. It lies in northeastern Italy in the Autonomous Region of Friuli Venezia Giulia, bordering Austria and Slovenia (46°30′25″N, 13°26′25″E). The size of the area is 1150 km^2. It lies in the Carnian and Julian Alps, rising to 2754 m. The area (Figure 1) is defined by steep slopes, high relative relief (up to 1500 m), and a mean annual precipitation of 2000 mm (Cucchi et al 2000). The area is subject to various natural hazards, among them

flash floods and debris flows (Borga et al 2007). Around 33,000 people inhabit the area; however; only 2 settlements have more than 4000 inhabitants: Tarvisio and Gemona del Friuli. Since 1990 the area's population has decreased by 10% (ISTAT 2014). Despite depopulation and a dramatic decrease in economic activity since the 1980s, the area witnessed a 12% increase in built-up areas due to tourism development, real estate development, and infrastructure projects (Malek et al 2014). The area receives a lot of support from the regional and national government to maintain its population and landscape, mainly due to the growing tourism development and strategic importance of the area as an international energy and communication corridor. Interest in further development, and consequently sustainable land development and risk management, is therefore high.

Participatory approach and spatial modeling

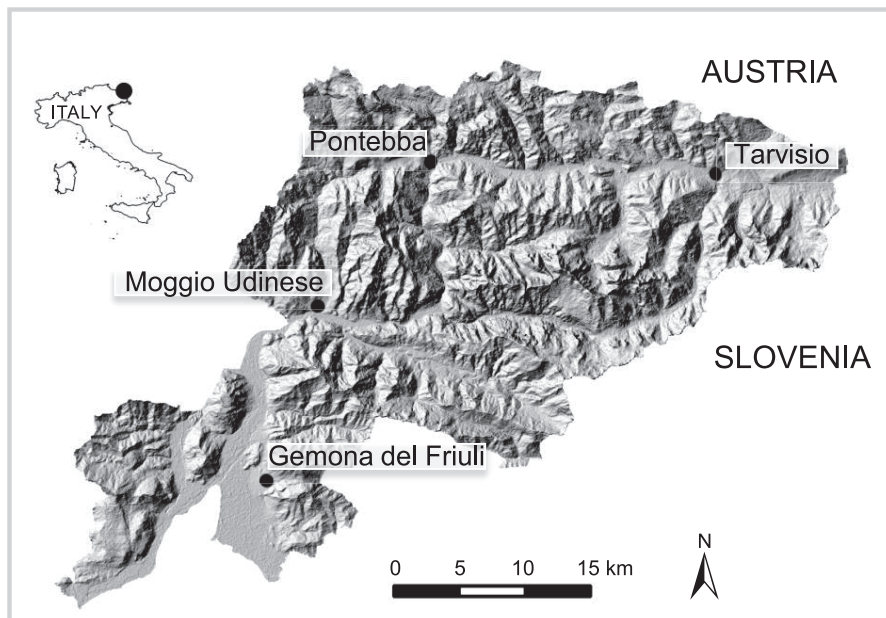### Cognitive mapping of local land use change

We began our analysis by developing cognitive maps of local land use change. Cognitive mapping is a qualitative method in which numerous concepts are interconnected in a graphic representing an expert-based mental model (Axelrod 1976). Through involvement of experts, significant knowledge about the system can be encoded and visualized, thus compensating for inaccessible data or intangible drivers (Eden 1992). We held group discussions with 10 expert stakeholders from the study area, actors at local and regional levels of decision-making and research on land use and risk management, in October and November 2012 (Table 1).

Participants were first asked to discuss demographic, institutional, economic, cultural, and environmental aspects of past, present, and future land use change. They identified the most relevant causes and consequences of land use change in the area and their perceived relative importance; special emphasis was given to identifying possible external and other intangible drivers. Together with the participants, we then connected the causes and consequences to each other, again based on participants' expert knowledge. The final relationships were then visualized in the form of a cognitive map using Gephi, software for visualizing and analyzing networks (Bastian et al 2009). The map is presented in Figure S1 in the Supplemental Material (*Supplemental data*, Figure S1: http://dx.doi.org/10.1659/MRD-JOURNAL-D-14-00082.S1).

Developing a conceptual model

There are many applications of conceptual models in land systems science, especially to bridge the gap between biophysical and socioeconomic variables (Bürgi et al 2004; Verburg 2006; Voinov and Bousquet 2010; Kok and van

FIGURE 1　Location of the study area. (Data source: Regione FVG 2013; map by the authors)

Vliet 2011; van Vliet et al 2012). We adopted a cause–response framework known as DPSIR—drivers, pressure, state, impact, response (EEA 1999). A *driver* is a scenario element that influences land use change. *Pressure* is a land use change that emerges as a consequence of the driver. *State* is land use at a given time. *Impact* is change to the landscape. *Response* is the choice of land use management option.

We worked with participants in a group discussion to apply this framework to their land use issues and expectations for future change (Figure 2). All the concepts of the DPSIR framework presented in Figure 2 were defined by the participants. This enabled us—both the researchers and the participants—to derive indicators for spatial simulations and identify management objectives and preferences. Moreover, it served as a framework for scenario development. Indicators were chosen according to the following criteria: (1) significance to and understandability by stakeholders, (2) relevance for land change processes, (3) data accessibility, and (4) possibility of expression in quantitative, spatial terms. They are summarized in Table 2.

The values for the drivers and response concepts were defined by the participants or the data. For example, the participants identified the growth values for the main driver "tourism accommodation," while the data defined the values and locations for nature and landscape conservation and risk policy. The values for pressure, state, and impact were generated later by the researchers using statistical, geographic information system (GIS), and spatial allocation models. Each participant then evaluated whether the final DPSIR model and indicators provided

a logical symbolic representation of real-life decision-making on land use.

Developing scenarios

This conceptual land use change model helped both stakeholders and researchers to develop future scenarios. We conducted additional interviews with stakeholders involved in planning economic activities at the local level—a mayor and a spatial planner. The scenarios were based on different logics of and assumptions about future development, and not just described as different increase or decrease rates—for example, low and high growth scenarios (Ogilvy and Schwartz 1998).

Having identified tourism development as a main driver of land use change in the area, study participants no longer considered possible future scenarios abstract, because they could associate them with a tangible indicator of tourism accommodation.

The regional government had concrete plans for future tourism development, with a goal of a 30% increase in accommodation facilities by 2035. Currently there are 5731 guest beds in the area, 2334 in hotels, and 3397 in other tourism facilities such as chalets and individual room providers (ISTAT 2014). We based our scenarios only on this proposed increase and did not include a lower or higher growth rate. We wanted to simulate the decision-making process and evaluate different decisions in order to achieve a goal seen as desirable and plausible by the stakeholders. This goal is relatively high, due to competition between the study area and other, more successful Italian Alpine tourist areas, such as the neighboring Carnia in South Tyrol and

TABLE 1 Study participants and their priority concerns in relation to land use change.

Level	Participant	Demographic changes	Changes to agriculture or forestry	Environmental (agriculture, forestry, risk) policy	Economic development	Consequences of land use changes
Local	Mayor	X	X		X	
	Local historian	X	X			
	Forestry technician		X	X		X
	Spatial planner			X	X	X
	Civil protection officer		X			X
	Human geography researcher	X			X	X
Regional	Forestry official		X	X		X
	Geologist			X		X
	Regional civil protection agents			X		X
	Rural economy researcher	X	X		X	

Carinthia in Austria. The study area is falling behind these areas in terms of accommodation facilities and tourism infrastructure (ISTAT 2014).

In order to achieve the desired higher tourism revenue, participants said that it was necessary to increase the number of accommodation facilities, because only increasing the number of beds within the current lodging properties or increasing prices would not suffice. They described 2 options for achieving this goal: the "business as usual" approach, in which tourism accommodation is mostly based on individual incentive and small-scale tourism properties, and an alternative pathway in which tourism development is based on larger properties such as hotel or chalet resorts. These 2 options have different consequences in terms of demand for space and the spatial pattern of land use change.
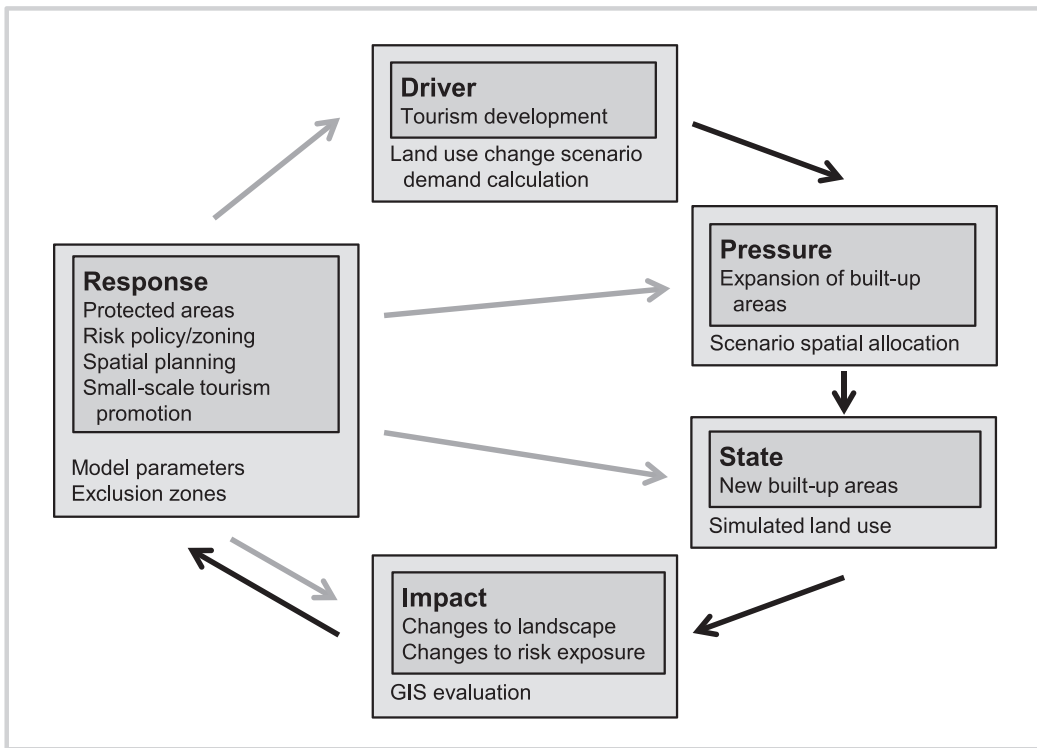
Spatial allocation and evaluating impact
Based on the conceptual model and quantitative indicators (Figure 2; Table 2), we developed a spatial allocation model in Dinamica EGO (Soares-Filho et al

2002), an environmental modeling platform that has already been applied in modeling urban dynamics, agricultural expansion, and forest cover change (de Almeida et al 2003; Maeda et al 2011; Kamusoko et al 2013). We projected the demand for urban expansion based on the 2 scenarios described above, from 2013 to 2035 in 5-year intervals, according to spatial transition rules explained below. We modeled the transitions from agricultural land, forest, and grassland to new urban areas, either "large hotels and resort complexes" or "smaller inns and hostels."

The transitions were calibrated in Dinamica EGO using land cover data from 1990, 2000, and 2013 (Malek et al 2014), and a variety of spatial factors: elevation, slope, aspect, and distance to roads, ski and other recreational areas, service areas (towns), and water bodies. This was done by applying the weights-of-evidence technique, a Bayesian probability method of identifying the influence of spatial factors on land change transitions using historic observations of that transition (Bonham-Carter 1994; Hosseinali and Alesheikh 2008). The result

FIGURE 2   Land use change framework used in the study: key elements of the framework, local examples of those elements, and indicators used to measure them. The framework starts with the Drivers (black arrows depicting the steps of the framework). The gray arrows present how the Response options influence each step of the framework during the simulation.

was a probability map showing the areas where urban expansion is more likely.

The transitions were then allocated across the landscape on a 30 m spatial resolution using a cellular automata model. Cellular automata models are bottom-up models, consisting of a grid-based landscape where every cell is associated with a state, in this case land cover types (Engelen et al 1995). Cells change their states according to transition rules and cell neighborhood (Mitsova et al 2011). All areas where it is legally forbidden to develop built-up areas were excluded from a possible transition in our model. These were nature-protection areas and areas of high hydro-meteorological risk as defined by the regional government (Regione FVG 2013). Additional areas were also excluded from a possible transition: areas characterized by steep slopes, erosion, or direct proximity to water bodies. The participants defined these exclusions earlier as response options in our land-use change framework (Figure 2).

The change allocation followed different rules for "large hotels and resort complexes" and for "smaller inns and hostels," described by the mean urban patch size of the simulated urban expansion. Both the demand per tourist bed and its spatial pattern of allocation (the mean size of a new built-up patch) were calibrated by relating statistical data on tourism between 1990 and 2013 with observed tourism-related urban expansion in the same period. Spatial allocation in the business-as-usual scenario allowed the expansion of existing urban areas, as

well as the formation of new, smaller urban patches (such as individual houses). In the alternative scenario, spatial allocation promoted the formation of new hotel areas near existing settlements.

The impact of both scenarios was assessed in a GIS (Quantum GIS Development Team 2013). To identify the extent of built-up areas in risk zones, we measured all new built-up areas in zones with possible geological restrictions or moderate flood risk as defined by the regional government. Within these areas, new buildings are allowed if they comply with the general risk regulations of the spatial plan, such as additional risk mitigation measures (Regione FVG 2013). We also assessed potential changes to the landscape. We identified the areal extent of lost natural and seminatural areas by measuring the loss of forests, grasslands, and agricultural areas.

Land use change and resulting impacts

The urban expansion probability map shows the most likely areas for urban expansion (*Supplemental data*, Figure S2: http://dx.doi.org/10.1659/MRD-JOURNAL-D-14-00082.S1). Preference is given to flatter areas on the valley floor near existing settlements, water bodies, and roads. Although we did not deliberately exclude high-altitude areas, the weights-of-evidence model produced a very low probability of expansion in most of these areas, based on analysis of land use changes between 1990 and 2013. Some areas at

TABLE 2 Framework elements and their key indicators.

Component	Indicator	Quantification
Driver		
Tourism development	Tourist accommodation	Number of beds
Pressure		
Expansion of built-up areas	Demand for built-up land	Bed density per ha
State		
Changed landscape New elements at risk	New built-up areas	Ha of new built-up areas
Impact		
Landscape degradation	Lost "green" areas	Ha of forest, grassland, and agricultural land lost
Increased risk	Built-up areas in risk zones	Ha of built-up areas in high-risk zones
Response		
Nature/landscape conservation	Protected areas	Restriction zones (locations and area within zones)
Risk policy	Excluded areas (zoning, slopes)	Restriction zones (locations and area within zones)
Green field expansion regulation	Promotion of intensive hotel resorts	Allocation of built-up demand in form of fewer larger built-up patches (scenario related)
Small-scale tourism promotion	Promotion of individual small tourism facilities	Allocation of built-up demand in form of numerous smaller built-up patches (scenario related)

higher altitudes and on steeper slopes were also identified as having a higher probability of urban expansion because higher-altitude areas or areas near the ski resorts were popular sites for tourism and secondary home development in the past and are likely to be in the future.

The scenarios differ in terms of both the amount of projected expansion (Table 3) and the spatial distribution of the expansion (Figure 3). The business-as-usual scenario results in a greater increase in urban areas than the alternative scenario because its accommodation density (beds per ha) is lower. The results become more obvious when focusing in more detail on particular areas, like the surroundings of Tarvisio, where the projected urban expansion is 3.7 times greater than the average regional expansion for the business-as-usual scenario and 3.3 times greater for the alternative scenario.

The impact of urban expansion on the landscape and on risk levels cannot be quantified solely by looking at the increase in built-up area. It must also be assessed in terms of the loss of particular natural and seminatural land cover types (Figure 4), and of the potential exposure to hydro-meteorological hazards of new built-up areas (Figure 5). The business-as-usual scenario results in

greater loss of forests, grasslands, and agricultural areas and exposure of more areas to geological hazards. The alternative scenario, however, results in greater flood exposure of new built-up areas—mostly because urban expansion in this scenario is characterized by larger homogeneous areas. If situated in areas with moderate flood hazard, these larger urban patches cover more hazard-prone area, and the smaller urban patches of the business-as-usual scenario are more evenly scattered across the landscape.

Besides the scenarios and maps of future land use, participants also shared their views on potential impacts of land use change. Whereas views on future development were similar among all participants, they differed on its potential consequences. All participants associated expansion of urban areas due to tourism development with a potential increase in hydro-meteorological risk. However, participants who worked at the local level also considered intangible consequences, such as the degradation of the traditional Alpine landscape image, very important. The alternative scenario, describing future tourism development in the form of new hotel resorts, was especially associated with negative

TABLE 3 Projected results of the two study scenarios.

	Business-as-usual scenario	Alternative scenario
Driver		
Increase of accommodation facilities (number of beds)	1769	1769
Pressure		
Demand for built-up areas (and spatial pattern)	180 beds per ha 0.10 mean urban patch size Spatial allocation trough expands existing areas and forming new urban patches	281 beds per ha 0.66 mean urban patch size Spatial allocation promotes the forming of hotel areas near existing urban areas
State		
New built-up areas (ha)	73.4	53.5
Relative increase in built-up area (%)	2.7	2.0
Relative increase in the most touristic area of Tarvisio (%)	9.9	6.6
Impact		
Landscape degradation		
Forest loss (ha)	28.9	22.4
Grassland loss (ha)	29.3	18.2
Agricultural loss (ha)	13.9	11.5
Risk increase		
Expansion on areas with high geological risk (ha)	18.0	13.9
Expansion on areas with moderate flood risk (ha)	4.4	5.9

consequences for the landscape. On the other hand, participants active at the regional level or in research emphasized the wide variety of consequences of future land use change. They focused also on the degradation of important ecosystems, such as forests and mountain grasslands.
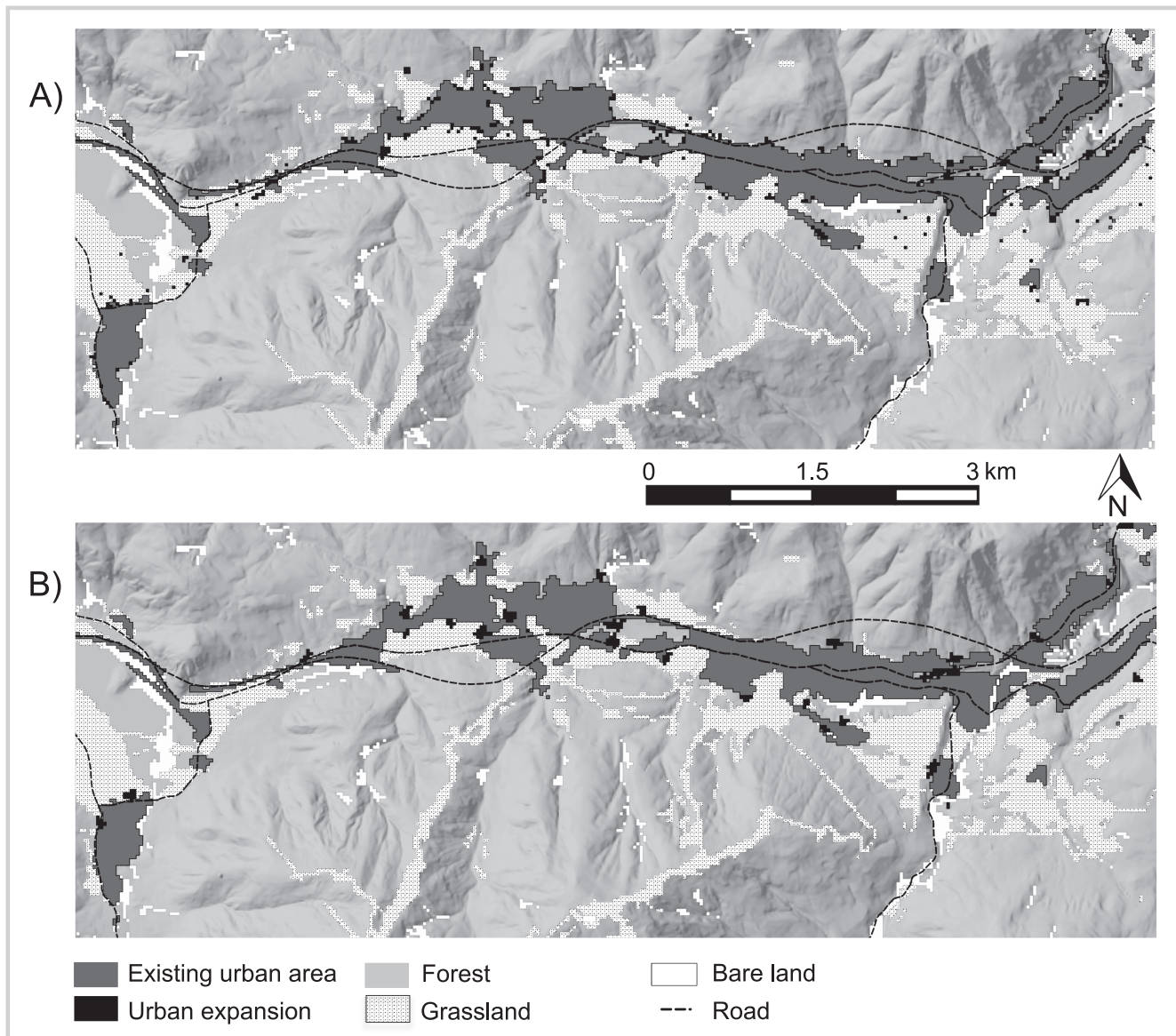
Discussion

This study developed a method of generating scenarios of future land change in mountainous regions, using the example of an Alpine region in Italy. Based on stakeholder participation and analysis of past trends, we simulated 2 scenarios for urban expansion due to tourism development. We tried to identify possible consequences of both scenarios in terms of changes to the landscape and exposure to hydro-meteorological hazards.

The aim of the first, qualitative part of this study was to address the uncertain future, lack of data, intangibility of drivers of change, and abstractness when relating future socioeconomic development with land use change with the help of local and regional stakeholders. The conceptual model used in this study (DPSIR) helped clarify participants' belief and knowledge systems and served as a starting point in the development of a spatial simulation model. This participatory approach differs from that used in other studies, which had a lower level of stakeholder participation, usually limited to providing their views on future land use trends, not helping to develop the model (Giupponi et al 2006; Schirpke et al 2012; Promper et al 2014). In our approach we were also able to identify different values and views relevant for future decision-making. For example, participants' views on future development were similar, which can be explained by the regional government's efforts to promote tourism in this region. Moreover, the acknowledgment of the potential negative consequences in terms of increased hydro-meteorological risk can be explained by numerous catastrophic flood and landslide events in the past decades. Differences in how

FIGURE 3 Projected 2035 spatial distribution scenarios for the tourism area near Tarvisio. (A) Business-as-usual scenario; (B) alternative scenario. The black patches show urban expansion.
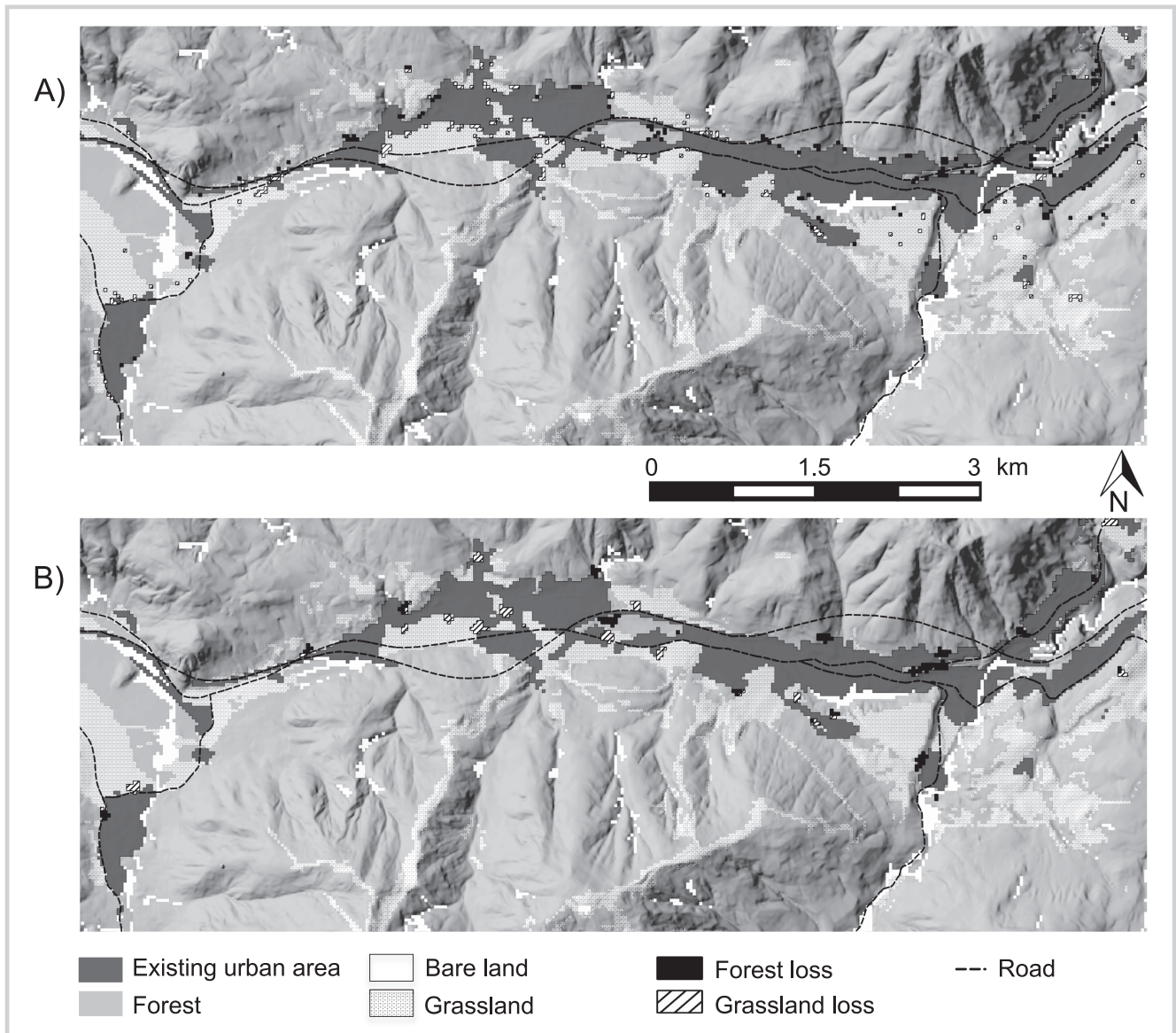

participants with local and regional perspectives identified other significant consequences of land use change can, however, be explained by their involvement in different aspects of land use management and spatial planning.

Other studies using cognitive mapping in environmental modeling have shown that increasing the number of participants can improve the results and produce a higher number of concepts (Özesmi and Özesmi 2004). Whereas the number of participants in our study might seem low, it still included experts and decision-makers working on the local, regional, and even national level. Nevertheless, performing the same

procedure focusing on only one locality in the study area, or on the regional level only, could result in identification of different future drivers and consequent scenarios.

This study focused on only one driver of land use change, tourism development, rather than on multiple drivers as other studies have (Verburg et al 2006; Castella et al 2007; Claessens et al 2009; Houet et al 2010). We chose this focus for 3 reasons. First, it was recognized by participants as the most significant driver. Second, local and regional development plans emphasize tourism as a prevailing economic activity in the study area. Third, the concept of future land change was abstract and sometimes difficult for participants to understand. Also,

FIGURE 4   Projected losses of different land cover types in the tourism area near Tarvisio. (A) Business-as-usual scenario; (B) alternative scenario.
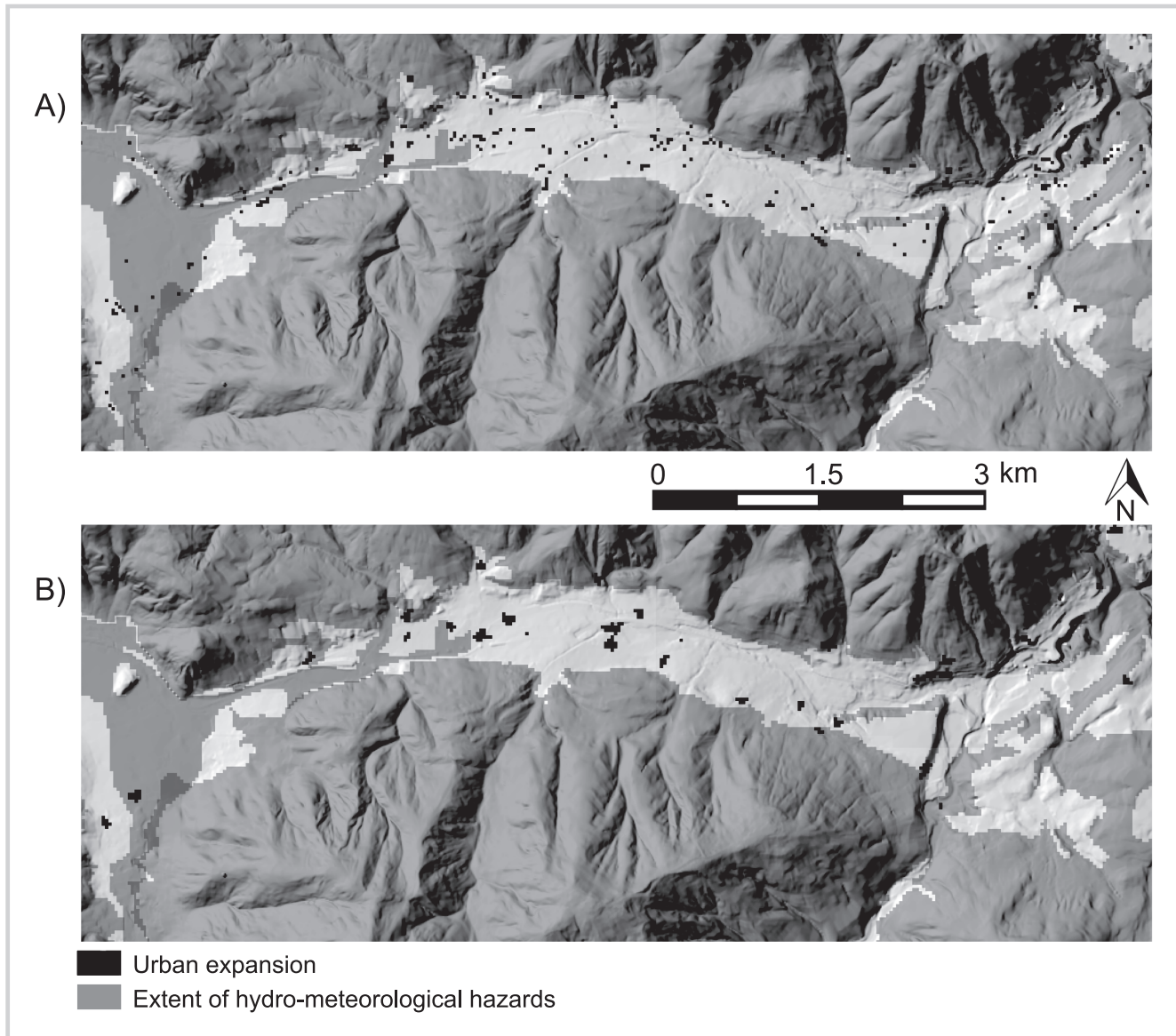

once the role of tourism in the future of the area was defined, it was difficult for participants to relate future urban expansion as a consequence of tourism development to any other land use change (eg pasture abandonment or forest expansion).

Other studies with stakeholder participation have modeled multiple land use transitions or taken market mechanisms into account; however, they did not generate spatially explicit results suitable for analyzing changes to risk exposure (Bayfield et al 2008; Balbi et al 2012). Moreover, studies have shown how difficult it is to assess even past land use change in mountain areas because of the number and complexity of its drivers (Rutherford et al

2008). Taking into account multiple land use transitions as well as urban expansion due to other economic activities would mean incorporating a different set of transition rules. These would also need to be differentiated across the different parts of the study area, as the spatial pattern of economic activities differs significantly between the lowland and upland parts of the area.

The spatial demand for accommodation (tourist beds) and the allocation of future scenarios based on this demand was calculated by relating tourism accommodation data from 1990–2013 to the spatial extent of tourism facilities (eg hotels with accompanying

FIGURE 5 Projected impact of expansion on exposure to hydro-meteorological hazards in the tourism area near Tarvisio. (A) Business-as-usual scenario; (B) alternative scenario.

parking spaces and green areas). The same goes for the spatial pattern (eg mean patch size). In this way we aimed to capture a more realistic spatial pattern of tourism facilities, instead of a pattern independent of study-area–specific characteristics. Nevertheless, extreme values for spatial demand and patterns from other regions could be considered in another future scenario. For example, Cammerer et al (2013) studied the impact of potential extreme scenarios. They included a scenario that disregards all risk information and policy, thus resulting in a dramatic increase in exposure to floods. We did not, however, identify potential dramatic changes to existing tourism patterns when discussing future scenarios with

participants. Our aim was to study potential spatial consequences of likely scenarios; therefore, this served our objectives completely. Moreover, our model assumed future urban expansion will occur only in areas where the law permits it. Study participants insisted that spatial planning in this region properly manages and controls urban expansion in hazard zones. After flood and debris flow events in 2003, the law changed, among other things introducing new hazard maps and restriction zones. These were seen as more beneficial for consideration of risk in spatial planning.

Despite the high preference for urban expansion in the southwestern part of the study area, where the valley

opens (*Supplemental data,* Figure S2: http://dx.doi.org/10.1659/MRD-JOURNAL-D-14-00082.S1), most of the urban expansion due to the increase in accommodations is projected to occur in the northeast around Tarvisio (Figures 3–5), because this area already serves as a tourism center. Participants confirmed that further development will based on winter and Alpine tourism and will be promoted in areas with existing tourism facilities (Tarvisio and surroundings) and not around the lowland Gemona del Friuli, which serves as a residential, commercial, and industrial center for the area.

Developing more land in order to increase tourism facilities could result in the increased well-being of the local population through new jobs and increased revenue. On the other hand, it could also result in a degraded landscape or increased risk. We tried to analyze these consequences under both scenarios. The indicators we used to quantify impact measured only the areal extent of possible future changes.

We found the indicators describing the loss of forests, grasslands, and agricultural areas sufficient. Still, in order to fully study changes to the landscape aesthetics, additional research should be conducted to take into account the architectural type and height of new buildings. Our business-as-usual scenario resulted in more urban expansion, but only in the form of smaller buildings, which might have less effect on the landscape image. The large hotels and chalet resorts envisioned under the alternate scenario could affect the landscape more.

Our indicators for risk exposure might not be sufficient to analyze the full extent of hydro-meteorological risk resulting from expansion, primarily because we used only proxy spatial data. For example, the data used for exposure to geological hazards only define areas where additional surveys should be performed before a plot is developed. The flood exposure data only describe the extent of urban expansion on areas with moderate risk. In order to determine all potential changes to the risk, additional studies should therefore be conducted of possible changes to hydro-meteorological hazards (including expected climate changes) and changes to the value of elements at risk, and not only their new spatial extent.

The influence of mitigation measures such as dams and reservoirs should be taken into account as well. Studies from other Alpine regions have shown that such measures can decrease risk exposure despite urban expansion (Fuchs and Bründl 2005). One way to achieve this is to develop risk scenarios in which land use change would be one constituent of the risk system (Mazzorana and Fuchs 2010; Mazzorana et al 2012). Finally, additional mitigation options of the developed scenarios could be evaluated as well. The alternative scenario resulted in higher exposure to floods; however, this exposure may also be easier to manage than that of the business-as-usual

scenario because its more concentrated expansion would require fewer and more concentrated technical measures.

Future land use scenarios have been recognized as a vital contribution to studying potential changes to hydro-meteorological risk (Promper et al 2014). Studies have shown that spatially explicit models of land use change in mountain areas can achieve a high rate of accuracy (Schirpke et al 2012). Assessing the performance of such spatial simulations is difficult, especially as the research focus is on the location of these changes and not only their quantity (Veldkamp and Lambin 2001). The uncertainty of the data used should be taken into account as well. Simulated future urban expansion should therefore be discussed with care. Instead of considering the projected scenarios as exact locations of future change, we suggest they be considered as potential hotspots for future development. Nevertheless, we consider the approach particularly useful for evaluating possible decision options through the use of scenarios.

Conclusion

The aim of this study was to identify potential drivers of land use change, develop scenarios of future land use change, and study their potential consequences, based on an Alpine example. Based on input from local and regional experts and stakeholders who participated in the study, we identified drivers of future land use change and developed a cognitive map representing participants' knowledge and beliefs. Then, based on a set of assumption regarding tourism development and actual development plans, we explored 2 urban expansion scenarios using a spatially explicit land change model. Finally, we analyzed possible consequences of these changes in terms of changes to the landscape and exposure to hydro-meteorological hazards.

The 2 identified scenarios were based only on potential future development and did not consider other drivers of change. Both scenarios assumed a 30% increase in accommodation facilities, but they differed in the amount and spatial distribution of land required for expansion. The business-as-usual scenario, which assumed expansion in the form of small-scale individual properties, resulted in a 2.7% increase in urban area. The alternative scenario, which assumed expansion would occur in the form of new hotels and other properties with a higher accommodation density, resulted in a 2% increase in area.

The business-as-usual scenario had, as expected, a larger effect on the loss of grasslands, forests, and agricultural areas, as well as possible exposure to geological hazards. The alternative scenario, however, resulted in a higher potential increase in flood exposure because of its more concentrated expansion. In order to fully study the effect on hydro-meteorological risk, however, we propose additional research taking into

account expected climate changes and changes to hazard patterns and occurrence.

This study presents an innovative method that combined participatory modeling with spatial simulation in order to address lack of data and intangibility of drivers. Scenarios generated in a participatory way have greater likelihood, as they incorporate local expert knowledge that is not available in published statistical data. Moreover, the spatial explicitness of this approach makes it possible to identify possible critical areas and spatial patterns of future changes. Therefore, this study contributes to the understanding of potential future environmental changes that take place in Alpine areas but have external drivers.

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Supplemental data

FIGURE S1 Unstructured cognitive map of expected land use changes.
FIGURE S2 Urban expansion probability map.

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