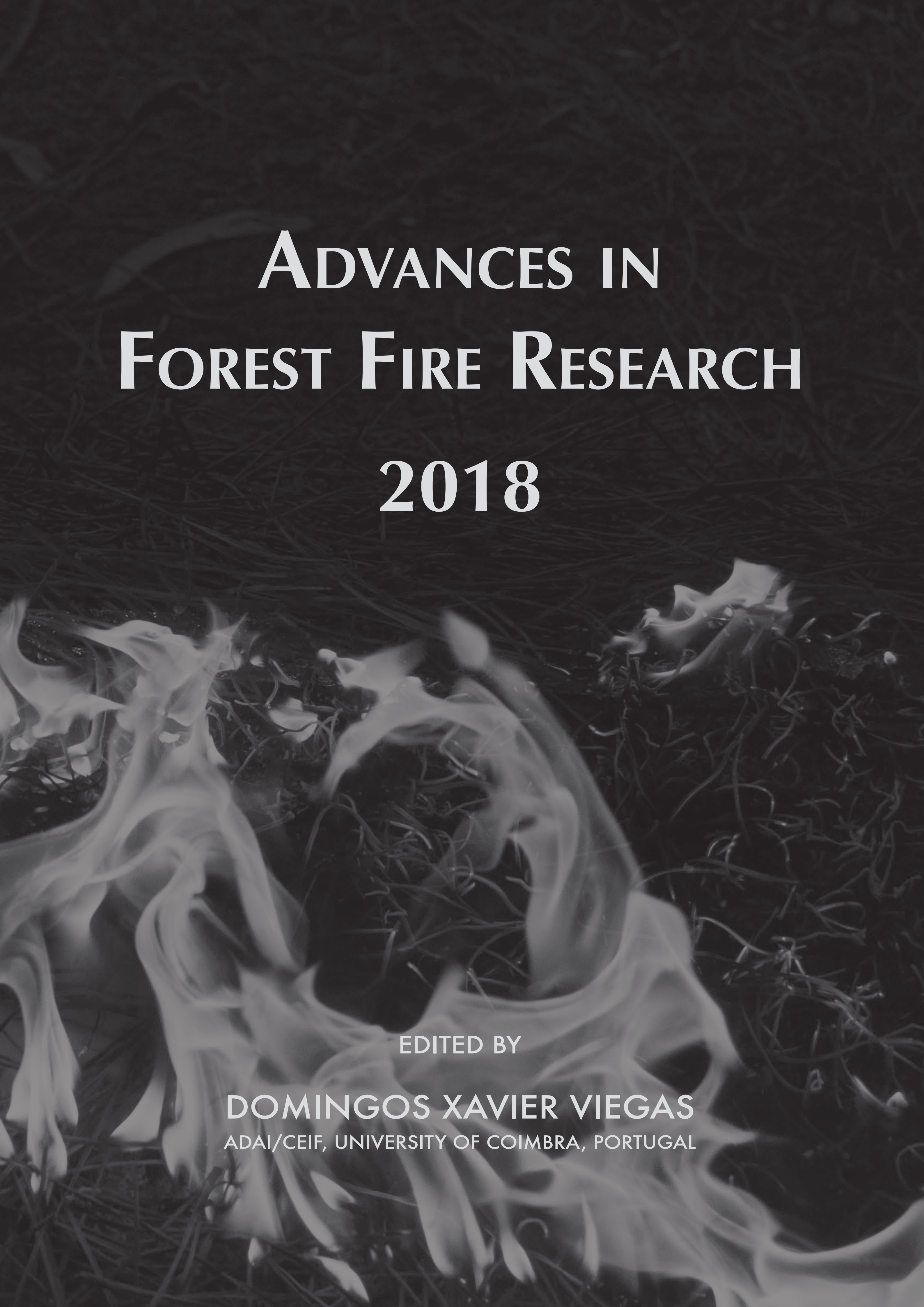

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Coupling multi-criteria analysis and GLM for modelling houses vulnerability to forest fires at WUI

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Abstract

In the French Mediterranean context, a quite low number of damages are caused by the forest fires on anthropogenic values. The usual statistical correlative approaches for vulnerability modelling, aimed at explaining the observed damages with some local variables, may lack of repetitions in comparable conditions. To overcome this constraint, we coupled an expert opinion based multi-criteria analysis and modelling (MCM) approach and some generalized linear models (GLM) techniques in order to specify a vulnerability model validated in different contexts. The method consists in first defining an opinion based model of vulnerability using a multi-criteria analysis. The specified model allows calculating some vulnerability indexes in relation to the value of some vulnerability criteria. The relationship between the vulnerability indexes provided by the MCM outputs and the observed damages is then tested by comparing indexes values in the samples of comparably exposed damaged and non-damaged houses. Non-parametric tests have to be used due to the relatively low number of observations and the uncertainty of the distributions normality.

Logistic binary regressions with a logit link function are then defined with the aim to explain damaged or non-damaged comparably exposed houses to fire by the MCM vulnerability indexes. . In order to avoid autocorrelation effects, a shifted vulnerability index is integrated to the model as an additional explanatory variable, the auto-correlation having been previously assessed with the Moran index. If the binary regression is significant, a polytomic logistic regression is tested in order to assess the effect of the calculated vulnerability indexes on damage level. This latest is assessed using a six levels scale of damages on objects, the main dwelling building or the whole site.

Although the very high variance in both damages occurrence contexts and scenarios, results show the possibility to validate a general model of vulnerability by coupling the MCM approach and statistical analysis of observed damages. One of the most constraining requirement is to find some damaged and non-damaged sites that were equally exposed during the event. Physical modelling of fire behavior is often used to assess the exposure. However, the systematic data collection of damages on anthropogenic values using a normalized protocol, and its dissemination in a shared data base would be a great progress for decision support in land management and planning for WUI vulnerability mitigation.

Keywords: vulnerability, damages, multicriteria analysis, generalized linear models

1. Introduction

Due to global change, vulnerability more and more becomes a key concept in wild fire risk assessment together with hazard and exposure (Zscheischler & al., 2018). Climate change impacts mainly hazard, defined as the likelyhood of occurrence of fires of a given range of intensity levels. But it may also incease vulnerability of forest ecosystems, by decreasing thier resilience and recovering potential, even if fire regimes do not change. Other components of global change, including land cover change, also increase both hazard and anthropogenic vulnerability (FUME, 2013). Large wildland urban interface resulting from the extend process of discontinous urban areas within wildlands are areas of both great ignition rate (Ganteaume 2013) and great vulnerability level (Maillé & al. 2015). While for wildland fires the key factor for risk mitigation is hazard, vulnerability of houses and other anthropogenic stakes must also be reduce in order to limit the probability of damages in case of WUI fires disaster (Cohen 2003, Lampin-Maillet & al., 2009). With this objective, vulnerability of anthropogenic stakes should first be objectively assessed with validated models (Blanchi & al. 2011, Caballero & al. 2003). Statistical approaches for modelling vulnerability are the only one to be able to bring the proof of model validity, based on data collection of damages on anthropogenic stakes caused by past fires. However, in the contexts of relatively low number of damages occurred in comparable conditions, the statistical approach may lack of repetitions. Alternative approaches, including multi-criteria analysis of expert opinions (MCA) (Saaty 1980, Saaty 1993), bring some more information aimed at contributing to vulnerability modelling.

We coupled a multi-criteria analysis approach and some generalized linear models (GLM) techniques in order to specify a vulnerability model validated in different contexts (Hedan 2017). Given the wide variety of definition found in the litteratude, we develop de conceptuel framework chosen in the methodological section 2. Then we describe de method principles and the study fires. We present some early bird results in section 3 and discuss about the appraisal and perspective of this work in section 4.

2. Method

2.1. The conceptual framework

A wide variety of definitions is found in the literature for the concept of vulnerability (Zscheischler & al. 2018, Zeng & al. 2003, D'Ercole & Metzger 2009, Carrega 2008). In this work, we define vulnerability as the potential consequences in terms of damages of a hazard occurrence, i.e. a fire event with a given intensity, threatening anthropogenic stakes. A stake is defined as any valuable element of the territory that might be damaged by the fire, i.e. any valuable element with a vulnerability level different from zero. This includes anthropogenic stakes (buildings, infrastructures and also human populations themselves), and natural stakes (notably forest ecosystems themselves, and notably their biodiversity). A "value" is assigned to the stakes in order to hierarchize different classes of stakes. Econometrical methods aimed as assessing such values should be able to take into account many kinds of values, including production, patrimonial, heritage, hedonic, living environment, etc. and also to provide assessment of human being life, what is ethically unsustainable.

In this work, we consider only one class of stake, the "interface dwelling site", and we assume an equal *"value"* assigned to all of them. An "interface dwelling site" is a system composed of one (or exceptionally several) dwelling house(s) and its (their) immediate surrounding environment, usually including a garden and some recreational elements (swimming pool, other leisure equipment) and annexes buildings. It is generally endowed with a vegetal biomass load, composed of ornamental and semi-natural vegetation. It is often enclosed with a fence, and is managed by one unique main actor (the owner or tenant): it usually corresponds to a tenure unit. Inhabitants themselves are also considered to be part of the site. Considering that human being life (and health) always has an "over-determining" value, we assume that attributes of persons leaving on the dwelling site (number, age, state of health…) do not change the stake *value* but only its vulnerability.

Three components of vulnerability are considered: *i)* internal vulnerability (sometimes defined as the susceptibility to damages – Carrega 2008), *ii)* external (or contextual) vulnerability, and *iii)* response capabilities. Internal vulnerability is mainly determined by building materials and building options. Contextual vulnerability is mainly determined by local potential exposure and the mechanisms of transfer of energy from the wildland fire to the stake, including notably local propagation by contact, brands projections in convective flows, and radiation possibly intercepted by opaque or semi-opaque elements. Finally, response capabilities concern the proactive behaviors of people during the event that may increase or decrease the global damages, including escape capabilities, self defense, risk The purpose of this work is to specify a model aimed at calculating *a priori* the vulnerability of interface dwelling sites. According to our definition, the model should be based on damages measuring, knowing the exposure conditions, notably the threatening fire local intensity. Local measures of fire intensity are very rare. Moreover, number of damages on anthropogenic stakes in similar conditions is very low on our case study area. In order to specify a valid model of vulnerability, tested the relationship between observed damades and the vulnerability indexes calculated by an expert oponions based vulnerability model.

2.2. Method pinciples and study fires

We based our modelling approach on expert opinions multi-criteria analysis and we used observations and measures of damages to check the validity of the multi-criteria model (*fig 1*).

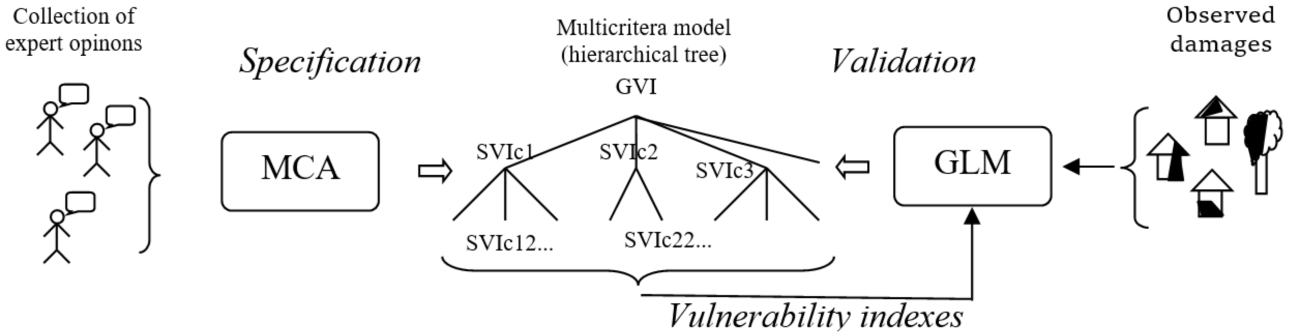

Figure 1 - The modelling approach

The first step is to specify an expert opinion based model of vulnerability using Multi-Criteria Modelling. This one allows calculating a global vulnerability index (GVI) and some indexes of vulnerability specific to criteria or to criteria families (SVIc1 to SVIc6, table 1). These latest represent the contribution of one criterion or criteria family to the global vulnerability.

The second step consists in relating the calculated indexes to some observed damages on WUI built up sites. Damages on houses in WUI of two main fires were described: the Rognac 2016 fire (10-12th of August 2016, 2663ha, 181 sites damaged, 117 buildings affected, 39 seriously and 26 totally destroyed) and the Cavaillon 2012 fire (21st of July 2012, 33ha, 20 sites affected, 13 dwelling houses damaged). The damages are described, based on three 6 levels scales of damages (0: not damaged, 5: totally destroyed/disappeared), related respectively to objects, main buildings and the whole damaged site, including usually a house and its environment. All the damaged houses could not be analyzed due to the required direct interview with the resident, who may not accept. Vulnerability indexes of non damaged but comparably exposed sites are also calculated. Given the low number of observations in the samples (20 observations for the Cavaillon fire and 36 observations for the Rognac 2016 fire, both including damaged and non damaged sites), and the uncertainty concerning the normality of the distributions, the relationship between damages and the different global and specific vulnerability indexes were tested using non parametric tests, mainly the Kruskal-Wallis test.

For significant identified relationships, an approach based on binary logistic regression, with the "logit" link function, is used to model damage occurrence (damaged/non damaged) in relation to vulnerability indexes values. Finally, in case the binary logistic regression was significant, ordinal (polytomic) logistic regression (Christensen, 2013) have been tested in order to propose a valid model able to preview damages levels in case of exposure (Cardona, 2012) in relation to vulnerability indexes values. In order to avoid autocorrelation effects, a shifted vulnerability index is integrated to the model as an additional explanatory variable, the auto-correlation having been previously assessed with the Moran index (Anselin, 1995).

3. Early bird results

The following table (table 1) compares the P-value of the Kruskal-Wallis test comparing the vulnerability indexes specific to the different criteria families and the vulnerability global index of samples of damaged or not damaged houses on comparably exposed sites.

Table 1 - P-values of the Kruskal-Wallis test of the effect of different vulnerability indexes on measured damages for fires Cavaillon 2012 and Rognac 2016

	Rognac 2016	Cavaillon 2012
SVIc1 (local infrastructures and equipments)	0,608	0,052
SVIc2 (Topography)	0,252	0,551
SVIc3 (Vegetation)	0,1228	0,063
SVIc4 (Building arragements in WUI)	0,061	0,197
SVIc5 (Construction techniques and materials)	0,529	0,781
SVIc6 (Human factors)	0,065	0,426
Global Vunerability Index (GVI)	0,3828	0,016

The global vulnerability index separates significantly the samples of damaged sites and non-damaged for the Cavaillon fire, but not for the Rognac fire. Vulnerability indexes specific to the criteria families do not significantly differs between these two samples, although some P-values are quite close to the 5% significance threshold. The non parametric Kruskal-Wallis test (ordinal test) is of course quite weak and some more observations of damaged building are required.

A logistic regression with the GVI and the shifted GVIs as explanatory variables of the damage occurrence (damaged/non-damaged) is then tested. The significance of the effect of each explanatory variable is tested with both the test of Wald and the likelihood ratio test (LR, Agresti 2002), while the global regression is tested by the likelihood ratio test only.

Unsurprisingly, the regression is not significant for the Rognac 2016 fire but highly significant for the Cavaillon 2012 fire (table 2).

Table 2 - Results of the binary logisitic regression on the Rognac 2016 fire and the Cavaillon 2012 fire

Rognac 2016 (DOM ~GVI + GVIs)				
Variable	**Coefficient**	**Test of Wald**	**LR test**	**Global LR test**
GVI	2,724	0,415	0,396	0,151
GVIs	-1,296	0,085	0,056	
Cavaillon 2012 (DOM ~GVI + GVIs)				
Variable	**Coefficient**	**Test of Wald**	**LR test**	**Global LR test**
GVI	8,060	0,079	0,020	0,001
GVIs	11,130	0,041	0,003	

4. Conclusion/Discussion

We proposed a contextualised explicative model of vunerability to forest fire of houses in WUI, by coupling a MCM and a GLM approaches. The obtained model is not general, and should be re-specify in different contexts. It is however explicative as it identifies the weight of the main variables (criteria) contributing to the global vulnerability of such anthropogenic values. Beside the operational results, this work brings some methodological lessons learned.

4.1. The multicriteria analysis as a modelling tool

Multi-criteria analysis (MCA) is a powerful approach of complex decision support tools implementation, but the use of expert opinion based multi-criteria analysis for a modelling purpose, known as multi-criteria modelling (MCM) is so a second level of use of MCA (Pugnet & Maillé 2013). MCM can only model the expert knowledge about a phenomenon, and not the phenomenon itself. However MCM is a way to identify and assess the main variables (criteria) involved in vulnerability of built up sites within WUI, in situations where experimental data is missing.

Usual statistical approaches are however required in order to bring the proof of the MCM model validity. Lack of homogeneous data constrains to use non parametric tests, usually weaker than parametric ones. Generalized Linear Models, and more specifically logistic models, also require homogeneous data, but the level of significance raise quickly as soon as either the variance decrease (homogeneity of the context) or the number of observations rises.

4.2. The need of a damages database for vulnerability modelling

In the contexts where damages on anthropogenic values (and specially dwelling houses) remain fortunatly rare (case of Southern France), an exhautive share data collection about damages should be carried out in order to have a comprehensive approach of damage occurence. An shared protocol for this data collection should be normalize at national or international level, and a shared database implemented.

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