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REVIEW PAPER

The influence of land abandonment on forest disturbance regimes: a global review

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Abstract

Context Since the nineteenth century, rural areas have experienced progressive abandonment mostly due to socioeconomic changes, with direct and indirect effects on forest disturbance regimes occurring in these human-dominated landscapes. The role of land abandonment in modifying disturbance regimes has been highlighted for some types of disturbances, albeit being still somewhat overlooked compared to climate change.

Objectives This literature review is aimed at highlighting the most relevant effects of land abandonment and land-use legacy on the regime of different types of forest disturbances, providing insight into land-use change/disturbances interactions.

Methods We searched in the Scopus and Web of Science databases for relevant studies at the global scale dealing with eight major natural disturbances: avalanche, flooding, herbivory, insect outbreak, landslide, rockfall, wildfire and windthrow. We classified papers into five relevance classes, with the highest score (4) assigned to studies quantitatively measuring the interactions between abandonment dynamics and disturbance regimes.

Results Most papers focused on wildfires in Mediterranean Europe in the twentieth century, where landscape homogenisation and fuel build-up contributed to worsening their frequency, size and severity. Dense forests developed following land abandonment instead exert inhibiting effects toward mass movements such as avalanches, rockfalls and landslides. Regarding the other investigated disturbances, we found only a few studies presenting site-specific and partly contrasting effects.

Conclusions Land abandonment triggers ecological processes at the landscape scale, altering land cover patterns and vegetation communities, which in turn affect disturbance regimes. Implications for land and resource management mostly depend on the stage at which post-abandonment secondary succession has developed.

Keywords Land-use change · Disturbance ecology · Wildfire · Landslide · Avalanche · Windthrow · Rockfall · Insect outbreak · Flooding · Herbivory

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Introduction

Land abandonment has recently been identified as the most important local-scale cause of landscape change in Europe (Ameztegui et al. 2016; Levers et al. 2016; Plieninger et al. 2016). Mountainous and marginalised areas of Europe have been being depopulated since the end of nineteenth century and mostly from the second half of twentieth century (Varga et al. 2018), leading to massive changes in land cover and land use (MacDonald et al. 2000; Tasser et al. 2007; Sitzia et al. 2010; San Roman Sanz et al. 2013). Only between 1990 and 2000, agricultural land abandonment involved over 9 Mha in 20 European countries (Pointereau et al. 2008). In Russia, after the fall of the Soviet Regime, more than 40 Mha of arable land had been abandoned within 20 years (Prishchepov et al. 2012).

The phenomenon of land abandonment is however strongly affecting several other regions around the world (Cramer et al. 2008; Munroe et al. 2013), with an exponential increase in rate and extent since the 1950s (Cramer et al. 2008). Ramankutty and Foley (1999) estimated 1.47 million km^2 of abandoned croplands worldwide between 1700 and 1992: according to this study, eastern North America experienced the earliest and largest cropland abandonment (starting from mid to late nineteenth century); the phenomenon then began to become widespread also in Eurasia, mostly from the 1960s. Aide et al. (2012) estimated more than 360,000 km^2 of recovered woody vegetation resulting from abandoned agricultural land in South America.

Despite the widespread and growing trend of global agricultural abandonment, its importance is often neglected compared to other two processes also significantly determining global environmental change, i.e. increasing competition for land (Smith et al. 2010; Sikor et al. 2013) and expansion of land use activities (Foley et al. 2005).

Land abandonment is defined as a process 'whereby human control over land (e.g. agriculture, forestry) is given up, and the land is left to nature' (FAO 2006). Several drivers are responsible for land abandonment and are typically classified into three main categories: (1) unadapted agricultural systems and land mismanagement (leading for example to overexploitation or soil degradation); (2) ecological or environmental drivers (including such factors as elevation, slope, aspect, soil erosion, climate); (3) socioeconomic drivers (including for instance migration and rural depopulation, market incentives, technology, industrialisation) (e.g. Rey Benayas et al. 2007; Haddaway et al. 2014; Lasanta et al. 2017). This latter category (and among its factors, rural–urban migration) has been suggested to be the most prominent globally (Rey Benayas et al. 2007). Marginal and mountain areas are often hotspots of change, where many of the drivers included in these three categories act simultaneously and can result in complex interactions.

Land abandonment reflects global trends and regional features, but it is mostly local socioecological conditions that guide its direction, pace and outcomes. The main result of land abandonment is commonly an uncontrolled colonisation by woody vegetation in the abandoned areas that leads to the establishment of shrublands, woodlands or forests, with various landscape, environmental and socioeconomic impacts (Lasanta et al. 2017).

In terms of societal trade-offs, positive, as well as negative consequences, whose relevance can differ in different parts of the world, may result from land abandonment. These consequences can also occur over varying temporal and spatial scales (Hall et al. 2012). Among the possible problems arising from the abandonment of agricultural land, Rey Benayas et al. (2007) identified five main ones: the reduction of landscape heterogeneity, soil erosion and desertification, reduction of water stocks, local biodiversity decrease and loss of cultural and aesthetic values. This is particularly true for those landscapes that were shaped by millennia of human intervention, where land cultivation resulted in complex and heterogeneous systems with a mosaic of diversified patches ensuring high levels of species and structural diversity. The Mediterranean basin and other dry regions of the world are more likely to experience the detrimental consequences of land abandonment, with increasing degradation processes. Conversely, in the absence of dispersal as well as abiotic and biotic limitations, revegetation can result in positive impacts on carbon sequestration, soil recovery, nutrient cycling, biodiversity (e.g. higher number of species typical of woodland or forest habitats), hydrological regulation, erosion reduction (Rey Benayas et al. 2007; Haddaway et al. 2014; Plieninger et al. 2014). Opportunities for ecosystem restoration can thus arise from abandonment, through both passive processes and active rewilding initiatives (Torres et al. 2018; Perino et al. 2019).

An increase in forest cover around the world has been associated with the cessation of agricultural activities and consequent land abandonment (Lambin and Geist 2006). Post-abandonment forest expansion has been commonly observed on steep slopes of mountainous regions all over the world (e.g. MacDonald et al. 2000; Fukamachi et al. 2001; Southworth and Tucker 2001; Gehrig-Fasel et al. 2007; Gellrich et al. 2007; Kuemmerle et al. 2008; Meyfroidt and Lambin 2008; Hartter et al. 2010; Cao et al. 2011; Aide et al. 2012; Brown et al. 2012; Garbarino et al. 2020). This 'forest transition' (a reversal from net deforestation to reforestation in a region; Munroe et al. 2013) may be favoured by national or international policies integrating environmental concerns and promoting ecosystem restoration (see for instance the Common Agricultural Policy (CAP) in the European Union; Pointereau et al. 2008).

Abandonment outcomes, either positive or negative, result in changes of landscape properties that could affect disturbance regimes, introducing novel disturbances within the system or modifying the characteristics of the existing ones. Land abandonment can thus be considered one of the most important drivers of regime shifts for several disturbances acting at different spatial scales. Abandonment of large areas can result in a more homogeneous landscape, change vegetation structure and composition (sometimes favouring the presence of invasive species), increase fuel load and/or vertical continuity or in general density and distribution of biomass. All of these modifications have potential impacts on the occurrence and characteristics of disturbances (e.g. landscape homogenisation can promote the spread of certain disturbances and increase their size and severity). However, possible effects on disturbance regimes are controversial and may vary locally, based on trajectories of land abandonment (e.g. time since abandonment, cultivation legacies, local climate and soil conditions).

The role of land abandonment on disturbance regimes in human-dominated landscapes has been recognised for some types of disturbances, particularly for those defined as natural hazards, due to the presence of people and human assets threatened by their occurrence, with potential negative impacts on society. Nevertheless, compared to land-use change, climate change is still more often described as the main driving force affecting disturbance regimes globally (Dale et al. 2000; Seidl et al. 2017). Gravity-driven disturbances (e.g. rockfalls, avalanches, landslides), whose occurrence is more frequent in mountain areas, where steeper slopes have a higher probability of being abandoned, could then be most affected by land abandonment. Indeed, in their systematic map on the environmental impacts of farmland abandonment in high altitude/mountainous regions, Haddaway et al. (2014) identified a knowledge gap in the area of natural disturbances.

This literature review is based on worldwide studies and explores the effects of land abandonment on natural forest disturbance regimes. Evidence existing on interactions between this form of land-use change (LUC) and the occurrence of different types of disturbances leading to short- or long-term shifts in their regimes could provide useful insights into resource management implications in marginal and abandoned areas.

Materials and methods

To explore the effects of land abandonment on disturbance regimes, we exploited the Scopus and Web of Science databases, conducting a literature search including only papers published in English. Using these online databases, we performed a preliminary scoping to identify the most relevant terms to include in the search string.

A disturbance is defined here according to the widespread definition by White and Pickett (1985) as "any relatively discrete event in time that disrupts ecosystem, community, or population structure, and changes resources, substrate availability or physical environment". After the preliminary scoping, we decided to also include the term natural hazard, defined as "a natural process or phenomenon that may have negative impacts on society" (UNISDR 2009), which is often applied to identify those disturbances affecting people or human assets.

The disturbance types considered for this research were (1) avalanche, (2) flooding, (3) herbivory, (4) insect outbreak, (5) landslide, (6) rockfall, (7) wildfire and (8) windthrow. We searched for interactions of land abandonment with disturbance regimes, possibly altering one or more of the main components of a regime (e.g. frequency, size, severity) and also with disturbance risk (danger x vulnerability). The terms were searched in titles, abstracts and keywords.

The final search string, reported here as applied in Scopus, includes the following key terms: "TITLE-ABS-KEY ("land-use" OR "land-cover" OR "land-use change" OR "land use change" AND abandonment OR "secondary succession" OR "forest development" OR "fallow land" OR "marginal land" OR "old-field succession" OR "forest expansion" OR "new forest" AND fire OR wildfire OR "forest fire" OR wind* OR storm OR "ice storm" OR flooding OR landslide OR rockfall OR "rock fall" OR avalanche OR "snow gliding" OR herbivory OR ungulates OR browsing OR insect OR "bark beetle" OR hazard* OR disturbance* AND forest* OR woodland* OR shrubland*)".

We ranked each paper based on its suitability for the aims of the review by giving a score from 0 to 4, corresponding to no or high relevance, respectively. We considered highly relevant (R4) those papers that quantitatively measured the interactions between abandonment dynamics and disturbance regimes. We classified papers as moderately-highly relevant (R3) when the abandonment phenomenon and disturbance regime characteristics were linked through a qualitative approach. We considered the relevance as moderate-low (R2) when the interactions between land abandonment and disturbance regime shifts were only mentioned. We gave a score of 1 (R1) to articles with low relevance, only citing land abandonment and/or disturbance regime shifts, or to the papers that only analysed other effects of land abandonment (e.g. soil erosion, increase or decrease in biodiversity, changes in C stock). Finally, we gave a score of 0 (R0) to those papers with no relevance (containing the queried words without focusing on the topic), which were therefore discarded.

The search was conducted by one of the authors (GM) on 18 May 2020, to include all studies published until 31 December 2019. Duplicate articles found on both databases were removed. The relevance of the resulting papers was then assessed following a step-wise classification procedure. All titles and abstracts (n = 900) were read in the first step by GM to attribute relevance 0 and 1. Introduction and discussion sections of the remaining papers (n = 194) were read in a second step by GM to attribute relevance 2 to 4. To assess the homogeneity of the evaluation and the absence of biased judgment, 100 randomly chosen articles were also checked by DM, and the resulting classification was compared with that obtained by GM.

The papers with high ranking ($\geq$ 3; n = 98) were then screened by MG, DM and RMa, and read in full by GM and RMa.

We assessed the abundance of papers on a yearly basis, standardising the number of articles found in our research by the total number of papers published for each year, containing both the keywords "land use" and "forest".

For papers with a relevance higher than 2 we examined the geographical distribution of the studies by disturbance type, based on available or derived coordinates, assigning the relative biome according to Olson et al. (2001). We also summarised the main effects of land abandonment on disturbance regime characteristics (e.g. size, frequency, severity) and risk, as reported in those papers.

For the papers with the highest relevance (4) we retrieved data on land use prior to abandonment, time since abandonment and effects on the main disturbance regime, in terms of increase or decrease in frequency or severity, and higher or lower risk.

On a subset of studies with relevance 4, quantitatively assessing land-use change and regime alterations following land abandonment, we further reported the percentage of change for each land-use class. We considered the following land use classes: forest, cropland (including grassland), shrubland and urban.

Results and discussion

Literature review

The results of the article selection and classification workflow are reported in Fig. 1.

The relative frequency of published papers per year (Fig. 2) shows a slight increase in the number of published works from 1985 to 2019, but without a clear trend. Prior to 2000, there are very few papers with relevance higher than 2. If we assess the abundance of papers on a yearly basis with two WOS-SCOPUS queries including, respectively, the key terms "land-use change" AND disturbance*, and "climate change" AND disturbance*, we find that,

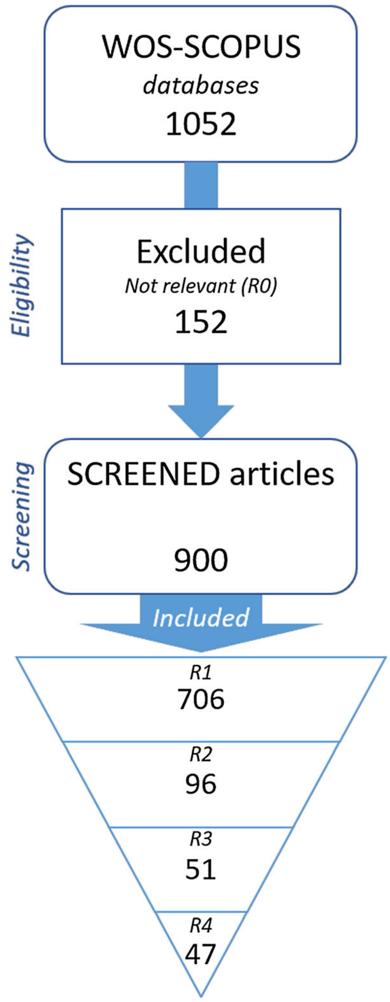

Fig. 1 Article selection and classification workflow of 1052 papers resulting from the WOS-SCOPUS query: "land-use" OR "land-cover" OR "land-use change" OR "land use change" AND abandonment OR "secondary succession" OR "forest development" OR "fallow land" OR "marginal land" OR "old-field succession" OR "forest expansion" OR "new forest" AND fire OR wildfire OR "forest fire" OR wind* OR storm OR "ice storm" OR flooding OR landslide OR rockfall OR "rock fall" OR avalanche OR "snow gliding" OR herbivory OR ungulates OR browsing OR insect OR "bark beetle" OR hazard* OR disturbance* AND forest* OR woodland* OR shrubland*. The article relevance (R) for the aims of the review ranges from 0 (not relevant) to 4 (highly relevant)

from 1985 to 2019, their number greatly increases (e.g. WOS TOPIC "land-use change" AND disturbance*: n = 0 in 1985, 25 in 2005 and 161 in 2019; WOS TOPIC "climate change" AND disturbance*: n = 0 in 1985, 95 in 2005 and 1094 in 2019). Papers dealing with climate change always exceed in number those

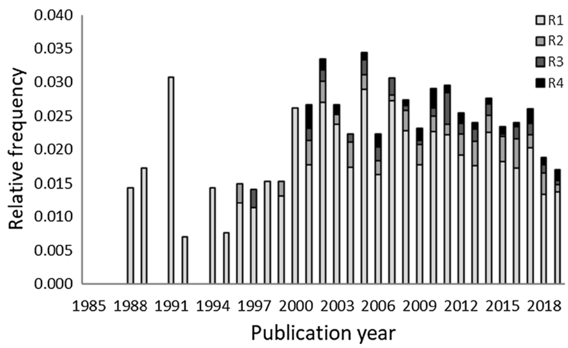

Fig. 2 Number of published papers per year standardised by the total number of papers published in the same year containing both the keywords "land use" and "forest", grouped by relevance score (1–4), for the period 1985–2019. Only papers with a relevance ≥ 1 (n = 900) are included

dealing with land-use change, being around 6 times more frequent in 2019. This result highlights the strong focus on climatic drivers compared to land-use change ones.

Among papers analysing a specific disturbance in relation to land abandonment (n = 287), wildfire is by far the most studied (65.8%) and has the largest number of studies in the higher relevance classes (R3 = 62.7%; R4 = 53.2%; Fig. 3), followed by flooding (10.5%) and landslide (8.4%).

From a map of the most relevant (R ≥ 2) papers of our literature search we observe that the majority (84%) of studies are located in Europe and among these, 60% are in the Mediterranean region (Fig. 4). This result appears to be mostly driven by the socioeconomic changes that occurred in this area during the twentieth century as a result of rural–urban migration (Rey Benayas et al. 2007) and the related scientific attention to this phenomenon.

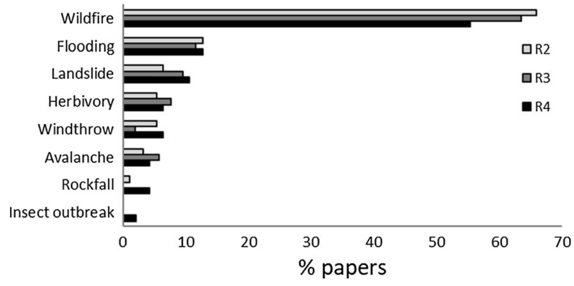

Fig. 3 Relevance (R) proportion by disturbance type among papers with relevance ≥ 2

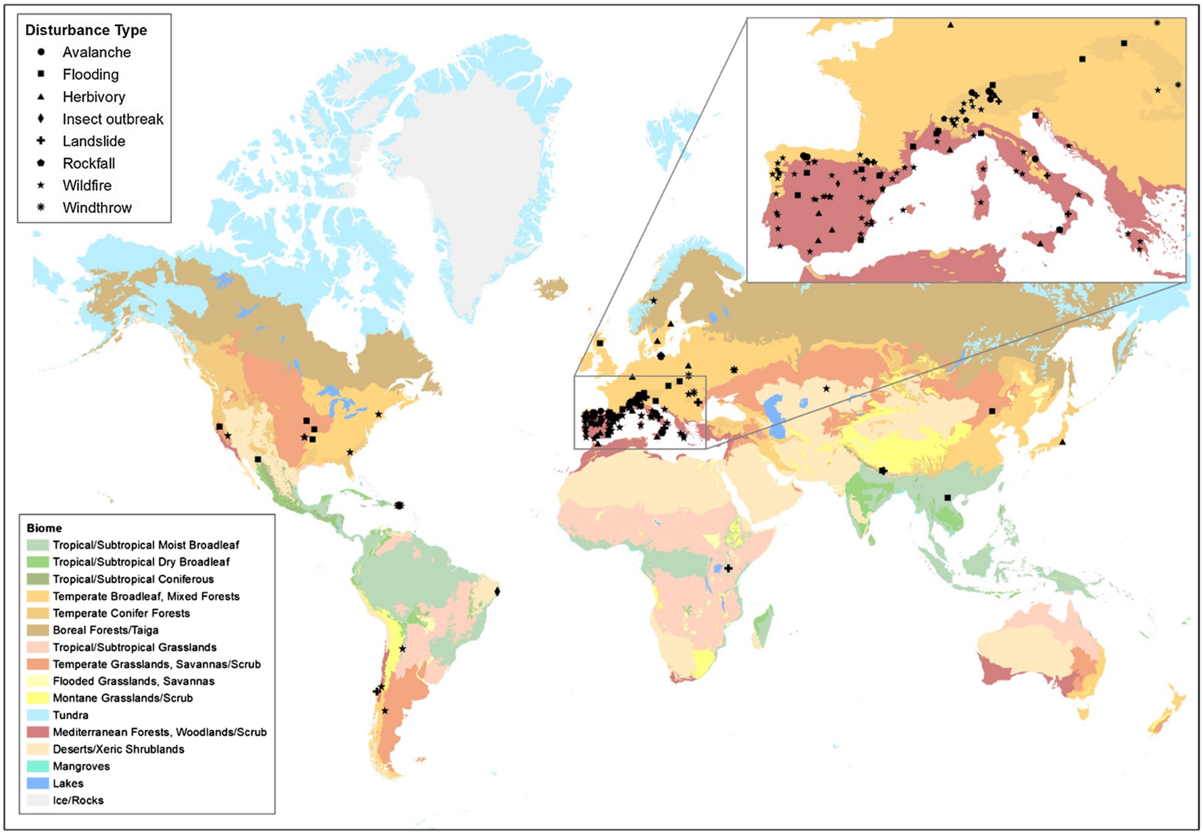

Fig. 4 Geographical distribution of papers with relevance ≥ 2 (n = 194) by disturbance type (avalanche, flooding, herbivory, insect outbreak, landslide, rockfall, wildfire and windthrow). Biome classification follows Olson et al. (2001)

Several of the papers with relevance 4 (40%) used spatial data derived from remote sensing sources. For example, Moreira et al. (2001) used aerial photographs of Northern Portugal from 1958 to 1995, whereas Lloret et al. (2002) employed land cover maps of 1956, 1978 and 1993 and wildfire occurrence maps of the 1975–1990 period in Catalonia. Models such as GLMM (e.g. Viedma et al. 2015) or GAM (e.g. Zumbrunnen et al. 2011) were also widely applied (38.3% of the studies), while only a few used historical archives (e.g. García-Hernández et al. 2017b), dendrochronology (e.g. Sarris et al. 2014) and chronosequences (e.g. García-Ruiz et al. 2015).

Our literature search highlighted that the main land abandonment effects were an increase in the severity of wildfires, herbivory and windthrow. However, a decrease in frequency was observed for flooding, avalanches and rockfalls (Table 1).

Considering only the highly relevant papers (R4), we observe that the majority are located in the Mediterranean region and South America, that the most common former land use is cropland followed by pasture and the abandonment stage ranges between 20 and 100 years (Table 2).

Only a small sample of 14 papers among the highly relevant ones tried to quantitatively assess land cover change due to abandonment and its effect on disturbance regimes. All of them showed an increase of woody vegetation (trees and/or shrubs encroachment) with a consequent increase of disturbance risk, except for rockfall (Table 3).

Land abandonment and natural disturbances

Wildfire

Most of the retrieved papers (n = 189, Fig. 3) investigated the interactions between wildfires and land abandonment. Considering only papers with relevance ≥ 2, the Mediterranean Region is the most

Table 1 Summary of the main effects of land abandonment on disturbance regime characteristics and risk according to the articles with relevance ≥ 2

Disturbance type	Abandonment related effects	N
Wildfire	Increase in size	11
	Increase in frequency	25
	Increase in severity	10
	Increase in risk	50
	Decrease in frequency	1
Flooding	Increase in severity	1
	Increase in risk	1
	Decrease in frequency	3
	Decrease in severity	4
Landslide	Increase in frequency	2
	Increase in risk	6
	Decrease in frequency	1
	Decrease in risk	2
Herbivory	Increase in severity	6
	Decrease in severity	1
Windthrow	Increase in size	2
	Increase in severity	4
	Increase in risk	1
Avalanche	Decrease in frequency	2
	Decrease in severity	4
	Decrease in risk	1
Rockfall	Decrease in frequency	2
	Decrease in risk	1
Insect outbreak	Decrease in severity	1

studied area, with 75% of the studies. In the Mediterranean Region, most study sites were located on the Iberian Peninsula (70% of the Mediterranean studies).

There is a general agreement in the literature that land abandonment led to fuel build-up and higher landscape homogeneity, and both raised wildfire risk or altered the fire regime by increasing frequency, size and severity. In the Valencia province (eastern Spain), an increase in fire frequency and size has been observed since the 1970s due to the rural exodus and abandonment of traditional land use (Pausas and Fernández-Muñoz 2012). At the early stages of the secondary succession triggered by land abandonment, fire-prone vegetation is widespread and dominant (Bonet and Pausas 2007; Baeza et al. 2011) thus increasing fuel connectivity, e.g. allowing fires to spread further (Pausas and Fernández-Muñoz 2012).

Similar results regarding LUC and trends of wildfire regimes were reported in several highly relevant studies that compared different periods. Viedma et al. (2015) observed a twofold increase, from 26 to 42%, in the proportion of hazardous land cover types, due to agricultural land abandonment, when studying changes in fire risk from 1950 to 2000 in Spain. Notably, the main contribution to LUC came from the abandonment of agricultural land until 1986, while in subsequent years it was mainly driven both by fire occurrence and encroachment dynamics of natural vegetation (e.g. densification of open stands to conifer stands). Moreira et al. (2001) found that a considerable fuel build-up (20–40%) contributed to a threefold increase in the number of wildfires in the 1980–1996 period in Northern Portugal. This fuel accumulation was caused by a significant decrease in agricultural and low shrubland cover in favour of tall shrublands and forests. Similarly, Lloret et al. (2002) and Vega-García and Chuvieco (2006) assessed the strong effect of landscape homogeneity on wildfire propagation in Eastern Spain, which was caused by the expansion of shrublands to the detriment of forested areas and agricultural lands. Loepfe et al. (2010) also found that the loss of the traditional rural mosaic, resulting from a selective abandonment of marginal agricultural land, led to more homogeneous landscapes where an increase in the number of wildfires was observed. Moreover, these authors found two feedbacks in the fire-landscape relationship: a decrease in fire occurrence was created by fire through the transformation of dense forests into shrublands with a lower fuel load, while an increase in fire propagation was the result of further landscape homogenisation produced by fire. Recurrent wildfires, low resilience and poor dispersal abilities of forest species can instead sometimes favour the persistence of highly flammable shrublands (Mouillot et al. 2003). Frequent fires also reduce or temporarily remove the vegetation cover, exposing soil to erosion agents, and can alter the soil infiltration capacity, increasing soil hydrophobicity and thus inducing changes in the water cycle (Llovet et al. 2009; Calsamiglia et al. 2017). In Portugal, Gonçalves et al. (2011) found that the abandonment of traditional grazing activities led to fuel build-up. The frequent use of uncontrolled fires for pasture renovation emerged as the primary cause for wildfire occurrence outside the typical fire season (summer). Tonini et al. (2018) studied the effects of rural abandonment on the

Table 2 Effects of land abandonment on disturbance regime, in terms of increase (+) or decrease (−) in frequency and severity, and risk (H = higher; L = lower) according to the papers with the highest relevance (4)

ID	References	Location	Biome	Land use		Disturbance			
				Former Land Use	Years Since Abandonment	Type	Frequency	Severity	Risk
6	Viedma et al. (2015)	Spain (Central-Western)	Mediterranean Forests, Woodlands and Scrub	Cropland (trees and herbs), Agroforestry, Pasture	40	Wildfire			H
24	Loepfe et al. (2010)	Spain (Tivissa, Igualada, Ports)	Mediterranean Forests, Woodlands and Scrub	Cropland	40	Wildfire		+	H
27	Mouillot et al. (2003)	France (Venaco)	Mediterranean Forests, Woodlands and Scrub	Cropland, Pasture	100	Wildfire			H
43	Moreira et al. (2001)	Portugal (Minho)	Temperate Broadleaf and Mixed Forests	Cropland (herbs), Pasture	40	Wildfire	+		H
59	Tonini et al. (2018)	Portugal	Mediterranean Forests, Woodlands and Scrub	Cropland (trees and herbs), Agroforestry, Pasture	20	Wildfire	+		H
79	Lloret et al. (2002)	Spain (Tivissa)	Mediterranean Forests, Woodlands and Scrub	Cropland	30	Wildfire	+		H
93	Cervera et al. (2019)	Spain (Bages, Berguedà)	Mediterranean Forests, Woodlands and Scrub	Cropland (trees and herbs), Agroforestry	40	Wildfire			H
112	Martínez et al. (2009)	Spain	Mediterranean Forests, Woodlands and Scrub		40	Wildfire			H
119	Zumbrunnen et al. (2011)	Switzerland (Valais, Ticino)	Temperate Conifer Forests	Cropland, Forest	40	Wildfire	+		H
125	Martínez-Fernández et al. (2013)	Spain	Mediterranean Forests, Woodlands and Scrub		50	Wildfire	+		H
128	Vega-García and Chuvieco (2006)	Spain (Alto Mijares)	Mediterranean Forests, Woodlands and Scrub		40	Wildfire			H
129	Aragó et al. (2016)	Spain (Castellón)	Mediterranean Forests, Woodlands and Scrub			Wildfire			H
130	Fernandes et al. (2014)	Portugal (Northern and Central)	Mediterranean Forests, Woodlands and Scrub		70	Wildfire			H
134	Chas-Amil et al. (2015)	Spain (Galicia)	Temperate Broadleaf and Mixed Forests			Wildfire	+		H
137	Carmona et al. (2012)	Chile (Maule Region)	Mediterranean Forests, Woodlands and Scrub	Cropland, Agroforesty		Wildfire			H

Table 2 continued

ID	References	Location	Biome	Land use		Disturbance			
				Former Land Use	Years Since Abandonment	Type	Frequency	Severity	Risk
257	Lopez Iglesias et al. (2013)	Spain (Galicia)	Temperate Broadleaf and Mixed Forests		50	Wildfire			
393	Moreira et al. (2010)	Portugal	Mediterranean Forests, Woodlands and Scrub		40	Wildfire	+		H
403	Aráoz and Grau (2010)	Argentina (North-Western)	Tropical and Subtropical Grasslands, Savannas and Shrublands	Pasture	40	Wildfire			
415	Azevedo et al. (2011)	Portugal (Franca parish)	Mediterranean Forests, Woodlands and Scrub	Cropland	50	Wildfire	+	+	H
437	Zumbrunnen et al. (2012)	Switzerland (Canton Valais)	Temperate Conifer Forests	Cropland, Forest	50	Wildfire	+		H
447	Koutsias et al. (2012)	Greece (Peloponnisos)	Mediterranean Forests, Woodlands and Scrub		50	Wildfire			H
538	Vilar et al. (2016)	Mediterranean Basin	Mediterranean Forests, Woodlands and Scrub		56	Wildfire	+		
621	Quintero et al. (2019)	Spain (Central-Western)	Mediterranean Forests, Woodlands and Scrub			Wildfire	+		
633	Bajocco et al. (2019)	Italy (Sardinia)	Mediterranean Forests, Woodlands and Scrub	Cropland, Pasture		Wildfire	–		
647	Jajtic et al. (2019)	Croazia (Dalmatia)	Mediterranean Forests, Woodlands and Scrub		50	Wildfire	+		H
334	Keesstra et al. (2005)	Slovenia (Dragonja)	Mediterranean Forests, Woodlands and Scrub	Cropland	50	Flooding	–	–	
369	García-Ruiz et al. (2008)	San Salvador (Arnas)	Mediterranean Forests, Woodlands and Scrub	Cropland (herbs)	50	Flooding	–	–	
577	Faccini et al. (2017)	Italy (Sturla basin)	Mediterranean Forests, Woodlands and Scrub	Cropland, Pasture	50	Flooding			H
579	Martínez-Fernández et al. (2017)	Spain (Upper Esla)	Mediterranean Forests, Woodlands and Scrub	Cropland, Pasture	50	Flooding		–	
598	Szwagrzyk et al. (2018)	Poland (Ropa basin)	Temperate Conifer Forests			Flooding		–	
671	Ortega et al. (2014)	Spain (Rivillas, Azohía rivers)	Mediterranean Forests, Woodlands and Scrub			Flooding		+	

Table 2 continued

ID	References	Location	Biome	Land use		Disturbance			
				Former Land Use	Years Since Abandonment	Type	Frequency	Severity	Risk
248	Gariano et al. (2017)	Italy (Calabria)	Mediterranean Forests, Woodlands and Scrub	Cropland (trees and herbs)	40	Landslide	+		
276	Beguería (2006)	Spain (Ijuez Valley)	Temperate Broadleaf and Mixed Forests	Cropland, Pasture	40	Landslide	–		
525	Malek et al. (2015)	Romania (Buzau Subcarpathians)	Temperate Grasslands, Savannas and Shrublands	Cropland, Pasture	20	Landslide			L
570	Pisano et al. (2017)	Italy (Rivo basin)	Mediterranean Forests, Woodlands and Scrub	Cropland, Pasture	40	Landslide			H
577	Faccini et al. (2017)	Italy (Sturla basin)	Mediterranean Forests, Woodlands and Scrub	Cropland, Pasture	50	Landslide			H
618	Malek et al. (2018)	Romania (Carpathians)	Temperate Grasslands, Savannas and Shrublands		30	Landslide			L
372	Delibes-Mateos et al. (2009)	Spain (Andalusia)	Mediterranean Forests, Woodlands and Scrub		30	Herbivory		+	
378	Silva et al. (2009)	Brasil (Coimbra forest)	Tropical and Subtropical Moist Broadleaf Forests	Cropland	47	Herbivory		–	
642	Petersson et al. (2019)	Sweden (Southern)	Temperate Broadleaf and Mixed Forests	Cropland, Pasture, Forest	100	Herbivory		+	
104	Schelhaas et al. (2010)	Europe	na		50	Windthrow		+	H
160	Flynn et al. (2010)	Puerto Rico (Luquillo, Carite, Ciales)	Tropical and Subtropical Moist Broadleaf Forests	Cropland, Pasture	80	Windthrow		+	
242	Lomascolo and Aide (2001)	Puerto Rico (Luquillo, Carite, Ciales, Utuado)	Tropical and Subtropical Moist Broadleaf Forests	Cropland, Pasture	60	Windthrow		+	
199	García-Hernández et al. (2017b)	Spain (Asturian Massif)	Temperate Broadleaf and Mixed Forests	Pasture	60	Avalanche		–	
277	García-Hernández et al. (2017a)	Spain (Asturian Massif)	Temperate Broadleaf and Mixed Forests	Pasture	60	Avalanche		–	
256	Farvacque et al. (2019)	France (Crolles)	Temperate Broadleaf and Mixed Forests	Cropland (trees and herbs)	160	Rockfall	–		H
1051	Lopez-Saez et al. (2016)	France (Crolles)	Temperate Broadleaf and Mixed Forests	Cropland (trees and herbs)	160	Rockfall	–		H

Table 2 continued

ID	References	Location	Biome	Land use		Disturbance			
				Former Land Use	Years Since Abandonment	Type	Frequency	Severity	Risk
165	Rodríguez-García et al. (2017)	Spain (Guadalajara, Segovia, Soria)	Mediterranean Forests, Woodlands and Scrub	Cropland, Pasture		Insect outbreak		–	

Biome classification follows Olson et al. (2001). Article IDs refer to the complete list of papers provided in the supplementary material

relationship between the extent of the rural–urban interface (RUI) and that of wildfires in Portugal. RUI, defined as the area where structures and other human developments meet or intermingle with semi-natural forests and agricultural areas (Tonini et al. 2018), is an alternative to the concept of wildland-urban interface (WUI) and has been identified as the most fire-prone area in the Mediterranean region. From 1990 to 2012, the RUI in Portugal increased by about 70% and the area affected by fire within it doubled, despite a 35% decrease in the total burned area.

To summarise, almost all the studies retrieved from the literature search assessed an increase in all the components of wildfire regimes (mostly frequency) and risk in the last decades.

Flooding

Studies regarding flooding and land abandonment are located mainly in Europe and the USA. Changes in land-use and land cover determine modifications in many of the factors affecting both flooding risk and severity. However, while many studies observed the effects of urbanisation in flood-prone areas, leading to an increase in flood peak discharge and, therefore, to flood damage (e.g. Huong and Pathirana 2013), fewer focused on the consequences of land abandonment on this disturbance (Szwagrzyk et al. 2018). The expansion of vegetation cover following land abandonment often alters hydraulic flow and water balance (Szwagrzyk et al. 2018), increasing water interception and reducing erosion, runoff and sediment supply to the stream (García-Ruiz et al. 2011; Martínez-Fernández et al. 2017; Szwagrzyk et al. 2018). Increased forest cover may also induce channel narrowing and further vegetation encroachment (Martínez-Fernández et al. 2017). Szwagrzyk et al. (2018) modelled the effects of forest expansion in the Polish Carpathians, finding out that the increase in forest cover would likely reduce the adverse effects due to urbanisation, leading to a decrease in flood peak discharge. Similarly, Martínez-Fernández et al. (2017) registered a decrease in the average mean annual discharge and median annual maximum flow after the colonisation of woody vegetation.

Conversely, the development of woody cover on old abandoned terraces might increase hydrogeological instability and worsen the soil drainage (Faccini et al. 2017). Other negative effects are caused by an

Table 3 Land-use changes and effects on disturbance regime, in terms of increase (+) or decrease (−) in frequency and severity, and risk (H = higher; L = lower), resulting from land abandonment according to the papers with the highest relevance (4; n = 14) quantitatively assessing land-use changes

ID	References	Location	Land use change				Disturbance			
			Forest	Shrubland	Cropland	Urban	Type	Frequency	Severity	Risk
6	Viedma et al. (2015)	Spain (Central-Western)	+ 5%	+ 2%	− 13%	na	Wildfire			H
24	Loepfe et al. (2010)	Spain (Tivissa)	− 17%	+ 21%	− 8%	+ 2%	Wildfire		+	H
24	Loepfe et al. (2010)	Spain (Igualada)	− 22%	+ 19%	+ 2%	+ 2%	Wildfire		+	H
24	Loepfe et al. (2010)	Spain (Ports)	− 1%	+ 7%	− 6%	+ 1%	Wildfire		+	H
43	Moreira et al. (2001)	Portugal (Minho)	+ 20%	+ 9%	− 13%	− 1%	Wildfire	+		H
59	Tonini et al. (2018)	Portugal	− 23%	+ 24%	− 20%	na	Wildfire	+		H
79	Lloret et al. (2002)	Spain (Tivissa)	− 25%	+ 30%	− 7%	+ 0%	Wildfire	+		H
93	Cervera et al. (2019)	Spain (Bages, Berguedà)	+ 10%	+ 0%	− 7%	na	Wildfire			H
128	Vega-García and Chuvieco (2006)	Spain (Alto Mijares)	+ 11%	+ 1%	− 8%	− 14%	Wildfire			H
415	Azevedo et al. (2011)	Portugal (Franca parish)	+ 7%	+ 7%	+ 6%	+ 0,5%	Wildfire	+	+	H
577	Faccini et al. (2017)	Italy (Sturla basin)	+ 37%	− 7%	− 31%	+ 1%	Flooding			H
248	Gariano et al. (2017)	Italy (Calabria)	+ 11%	na	− 22%	+ 2%	Landslide	+		
276	Beguería (2006)	Spain (Ijuez Valley)	− 17%	+ 18%	− 14%	− 1%	Landslide	−		
570	Pisano et al. (2017)	Italy (Rivo basin)	+ 17%	− 3%	+ 2%	na	Landslide			H
256	Farvacque et al. (2019)	France (Crolles)	+ 22%	na	− 51%	na	Rockfall	−		L
1051	Lopez-Saez et al. (2016)	France (Crolles)	+ 25%	na	− 55%	+ 22%	Rockfall	−		L

Article IDs refer to the complete list of papers provided in the supplementary material

increase in solid transport in the streams, caused by soil erosion in the collapsed terraces and increased frequency of shallow landslides (Faccini et al. 2017).

There is still an open debate on the effectiveness of forest cover changes in mitigating floods (Bradshaw et al. 2007; Laurance et al. 2007); consequently, impacts on this disturbance regime have not yet been distinctly identified. The effects of land abandonment on flooding are not linear, and differences between studies may be due to the stage of secondary succession, for instance because of the lower interception of rain by shrubs and small trees compared to large trees, as well as to the characteristics of the site (García-Ruiz et al. 2008). However, in their global-scale study on developing countries, Bradshaw et al. (2007) demonstrated the correlation between forests and flood regimes and suggested that reforestation could determine a reduction in flood occurrence and severity. It is worth mentioning that to mitigate the impact of floods, several nations, particularly the more flood-prone ones, are investing in reforestation projects or trying to reduce the loss of native forests (Mather et al. 1999; Bradshaw et al. 2007).

Landslide

Most studies regarding the interactions between landslide and land abandonment have been conducted in the Mediterranean region. Land abandonment can affect soil characteristics in several ways, leading to an improvement in soil quality or a worsening of land degradation processes. Colonisation by shrubs and trees generally increases interception, infiltration and water uptake by vegetation, improving soil protection against rain splash, particles detachment and runoff (Symeonakis et al. 2007; García-Ruiz and Lana-Renault 2011; García-Ruiz et al. 2013). Positive effects on soil characteristics comprise an increase in soil organic matter (SOM) content, aggregates stability, hydraulic connectivity and water holding capacity, causing a decrease in soil erosion, streamflow and sediment discharge (García-Ruiz and Lana-Renault 2011; García-Ruiz et al. 2013; Lana-Renault et al. 2018). Instead, the abandonment of agricultural terraces or forest degradation caused by wildfires emerged as the most relevant factors enhancing runoff and soil erosion (Symeonakis et al. 2004). Contrasting effects of land abandonment on landslides were highlighted, depending on site properties and vegetation characteristics. A slightly negative effect on the occurrence rate was observed in the Pyrenees (Spain) in the second half of the twentieth century, where the re-vegetation of former agricultural lands was able to erase scars of previous landslides but had limited capacity in preventing landslide occurrence on hillslopes covered by dense shrubs or young forest cover (Beguería 2006). Similarly, in Southern Italy (Calabria region), the number of rainfall-induced landslides increased in heterogeneous agricultural areas and forests during recent (1966–2010), compared to previous years (1921–1965) (Gariano et al. 2017). This is likely due to the presence of early stages of vegetation and young forests in these land cover classes, as LUC was characterised by a decrease of arable land (− 3261 Km^2) and an increase of heterogeneous agricultural areas (+ 2464 Km^2) and forests (+ 1658 Km^2). Abandoned croplands transformed into shrublands or pastures appear to be very susceptible to landslides, according to Pisano et al. (2017), probably because of the lack of management triggering soil erosion and the consequent instability. The abandonment of bench-terraced fields, formerly used to ease cropping and avoid soil degradation, often caused their collapse due to the occurrence of small landslides (Lasanta et al. 2001; García-Ruiz and Lana-Renault 2011; García-Ruiz et al. 2013). This created concentrated runoff and sediment flows along preferential pathways (Lana-Renault et al. 2018) that could evolve into gullies (Lasanta et al. 2001).

Conversely, forest expansion due to land abandonment can decrease the extent of areas subjected to landslide susceptibility because of the increased slope stability generated by roots aggregation effects and the regulation of soil moisture, thanks to evapotranspiration processes (Beguería 2006; Malek et al. 2015, 2018; Pisano et al. 2017). Woody vegetation does not always exert positive effects on soil stability since dense shrubs and tree cover on abandoned terraces can increase flood and landslide risk, as observed using the Curve Number (CN) registered on these land use categories in Sturla Valley (Genoa, Italy) (Faccini et al. 2017). The CN is the parameter used to forecast direct runoff or infiltration from rainfall excess (United States Department of Agriculture 1986) and its increase corresponds to a faster runoff for the lower time of concentration, proving that the development of woody vegetation worsens the previous condition of hydrogeological stability and soil drainage (Faccini et al. 2017). In general, the effects of land abandonment on landslides are strictly connected to soil properties and site characteristics affecting vegetation structure and its ability to stabilise the slopes and prevent shallow landslides.

Herbivory

Studies assessing relationships among land abandonment and herbivory that were retrieved from the literature search did not show any specific geographical cluster but were heterogeneously spread across continents. Both mammal and insect species were investigated as disturbance agents. Although the magnitude of herbivore impact on plant colonisation is not completely clear (Edenius et al. 2011; Bobiec et al. 2011), land abandonment generally leads to an increase in the number of herbivorous mammals, which mostly affects tree regeneration. Edenius et al. (2011) provided some insight into how land abandonment influenced aspen density in Sweden: land-use changes were identified as an important driver of change in aspen abundance, while moose browsing had a limited role in the investigated aspen dynamics. Oak regeneration in the Białowieża National Park was found to occur successfully in abandoned agricultural fields without being associated with other less preferred woody species as protection against herbivory, despite the presence of wild (mostly browsing) ungulate species (Bobiec et al. 2011). The abundance of big-game species (e.g. Iberian wild goat, red deer, roe deer and wild boar) in Andalusia (Spain) has been affected by recent land-use changes, and a considerable increase in both density and geographical range has been observed due to the expansion of Mediterranean scrubland and woodland cover (Delibes-Mateos et al. 2009). In the same area, landscape homogenisation has been proved to lead to segregation between big-game (in mountain areas) and small-game species (in agricultural areas) (Delibes-Mateos et al. 2009). In tropical ecosystems, the expansion of cultivated lands, deforestation and landscape fragmentation has increased the abundance of leaf-cutting ants (e.g. Fowler et al. 1986; Jaffe 1986; Vasconcelos and Cherrett 1995; Terborgh et al. 2001), while land abandonment can cause their decrease (Silva et al. 2009). In the Coimbra forest (Brazil) a decrease in the number of nests of *Atta cephalotes* (a leaf-cutting ant) after land abandonment was registered, due to a pronounced decline in the provision of palatable plants in natural secondary succession and maybe because of the increased abundance of predator or parasite communities (Silva et al. 2009). The effects of land abandonment on herbivores depend on the species considered and on their optimal habitats. For those herbivores which thrive on croplands, abandonment means a decrease in palatable species and, as a consequence, a decrease in the population. In contrast, for those species typical of shrublands and woodland, land abandonment means an increase in size and connection of patches of suitable habitat.

Windthrow

Trends of increasing wind damage to European forests have been reported for the last decades (Schelhaas et al. 2003; Seidl et al. 2014; Bebi et al. 2017); they partially reflect an improvement in the reporting of windthrow data over time, but are mostly related to the increased forest cover and associated changes in stand structure (Schelhaas et al. 2003, 2010; Kulakowski et al. 2017), with taller and older stands being generally more prone to windthrow. Conversely, changes in the landscape pattern leading to a reduced fragmentation can make it less susceptible to windthrow (Laurance and Curran 2008; Zeng et al. 2009).

Despite some evidence reporting an increase in frequency and intensity of wind storms due to climate change, the higher windthrow severity (measured in terms of damaged timber) registered in European forests has been mostly attributed to a higher susceptibility related to the increase in growing stock and average stand age (Schelhaas 2008; Kulakowski et al. 2011; Schuck and Schelhaas 2013; Lindner and Rummukainen 2013; Mason and Valinger 2013).

Structural and compositional characteristics of post-abandonment secondary forests, shaped by time since abandonment and legacies of previous land use, thus strongly influence stand vulnerability.

Similar patterns to European forests were also found in tropical regions, with stand age affecting the response to hurricane force wind disturbance (Lomascolo and Aide 2001; Flynn et al. 2010). In these studies, early stages of succession were less affected compared to old secondary forests, due to trees being smaller in diameter and height.

If current trends of increasing forest area, growing stocks and share of old forests continue, as projections for the future suggest, vulnerability to storm damage will thus probably further increase (Schelhaas et al. 2010). Forest management goals aiming at mixed stands (increasing the share of deciduous tree species) and higher harvest removals could contribute to slowing down this tendency (Gardiner et al. 2010; Schelhaas et al. 2010).

Avalanche

According to the relevant studies found in the literature, mainly located in the Alps, the effects of land abandonment on avalanche regime are contrasting and mostly depend on the development stage of the secondary succession. Several authors (e.g. Bebi et al. 2009; Kulakowski et al. 2011; García-Hernández et al. 2017a, b) observed a decrease in damage (severity) and frequency due to forest expansion following land abandonment. García-Hernández et al. (2017b) underlined the close relationship existing between damage caused by avalanches and socioeconomic changes, analysing over 126 events that occurred between 1800 and 2015 in NW Spain. While the highest damage rate co-occurred with the peak demand for wood, population growth and intensive grazing (mostly between 1850 and 1950), a clear reduction in the damage rate due to natural reforestation was observed after the rural exodus during the second half of the twentieth century. However, natural reforestation of slopes is spatially heterogeneous and strongly depends on avalanche frequency, which inhibits the development of tree cover (Tasser et al. 2007; Bebi et al. 2017; Beato Bergua et al. 2019). When the avalanche release zone is placed hundreds of metres above the tree line, even the development of a new forest would not be able to counteract this disturbance (Bebi et al. 2017; Beato Bergua et al. 2019). The primary function of the forest in counteracting avalanches is both to prevent their release and to slow down the small ones, but it has a limited effect on those with massive dimensions and that have already reached a high speed (Bebi et al. 2009). Newesely et al. (2000) assessed that the colonisation of abandoned land by shrubs has a limited protective function against avalanches and erosion, but it could instead trigger gliding avalanches. What emerges from the reviewed studies is that the development stage of the secondary succession strongly influences the avalanche phenomenon, acting either as a limiting or exacerbating factor. The probability of avalanche release is reduced in areas characterised by the development of a dense forest, whereas it can be heightened in the initial/intermediate development stages of the secondary succession when a compact layer of low and flexible dwarf shrubs is present (Newesely et al. 2000; Bebi et al. 2009). Early successional vegetation can also be dominated by long grasses that can favour glide-snow avalanches release (Feistl et al. 2014).

Since vegetation structure, coupled with snow characteristics and topography, has a significant impact on the frequency and magnitude of avalanches, proper and active silvicultural management can influence avalanche regime and increase the protective function of the forest (Bebi et al. 2009).

Rockfall

Very few papers (n = 4) were found dealing with this disturbance and land abandonment, whereas several studies dealt with the impact of climate change on rock instability and rockfall hazard (Lopez-Saez et al. 2016; Berger et al. 2017; Lingua et al. 2020). An increase in rockfall occurrences has already been observed in years with weather anomalies (Berger et al. 2017); triggering factors (e.g. long and high-intensity precipitations, freeze–thaw processes, high-temperature variations over a short period) are related to weather conditions (Lingua et al. 2020). If climate change will most likely lead to an increase in rockfall occurrence (Berger et al. 2017), possible interactions with land-use and land cover changes should be also taken into account (Lopez-Saez et al. 2016), in order to better understand changes in rockfall regimes. The rockfall process requires the presence of steep slopes (usually exceeding 30°) where rock blocks can be released, so this phenomenon is often confined to mountain areas. In these areas, the widespread increase in forest cover since the abandonment of marginal crops and pastures should provide increased protection against rockfall propagations (Berger et al. 2017). If trees in the release zone can sometimes influence the start of a rockfall event (by speeding up weathering and cracking processes with their roots), in the path of the rocks rolling down the slope their mitigation effect can be significant and particularly effective if the rock size is smaller than 5 m^3 (Lingua et al. 2020).

Rockfall is a site-specific phenomenon, but interactive effects of climate and land-use change bring about a general reduction at least in its severity, mostly due to the increased protective effects of forests, resulting from longer forested slopes, larger basal area and higher density of stands, and higher broadleaves proportion (Lingua et al. 2020).

The agropastoral decline in mountain valleys is often accompanied by a higher demand for protection against gravity-driven hazards due to intense peri-urban expansion and increased human transit for recreational purposes. There is thus a need for a spatially precise characterisation of risk and adequate forest management to guarantee the protection function over time.

In the French Alps, Lopez-Saez et al. (2016) and Farvacque et al. (2019) documented that land abandonment was followed by a rapid natural afforestation and intense peri urbanisation from the second half of the nineteenth century. Lopez-Saez et al. (2016) demonstrated that these changes in landscape pattern affected the rockfall regime in the area by gradually reducing frequency and severity (resulting from a gradual decrease of the mean kinetic energy of rocks) as the forest cover of the slopes increased since 1850. The authors attributed these results mostly to the increase in forest density, particularly for those stands located on the upper part of the slopes. Effects on rockfall regimes thus depend on the speed of natural afforestation processes since abandonment. Moreover, since all forests are subject to stand dynamics that can modify their protection effectiveness, active forest management is often required to maintain a stand in this efficiency window. In the absence of adequate silvicultural interventions, older stands may offer reduced protection, and when tall trees collapse or are uprooted by windthrow and snowbreak, they can release the rocks they were anchoring. On the other hand, it has been demonstrated that an important residual protective function is still provided by deadwood on the ground for a long period (several decades) through an increase in surface roughness (Wohlgemuth et al. 2017).

Farvacque et al. (2019) obtained similar results to Lopez-Saez et al. (2016), where a strong decrease in rockfall risk (particularly for low-volume/high-frequency classes) resulted from the tree-rock interactions, allowing a reduction in both the reach probability and energy of rockfalls.

Although the limited number of papers found on this topic does not allow general statements to be made, the increase of forest cover following land abandonment can reduce rockfall risk and severity due to the capacity of trees to intercept rocks along slopes. The magnitude of these effects is amplified by the increase in size and/or density of trees with lengthening time since abandonment, as long as site conditions are favourable for tree growth and until senescence dynamics reduce tree resistance.

Insect outbreak

Only one study, although highly relevant, was found relating insect outbreak and land abandonment. Rodríguez-García et al. (2017) discussed the positive effects of changes in forest structure and composition caused by land abandonment in Spain. In particular, the abandonment of traditional land-use led to a transition from pure *Juniperus thurifera* forests to mixed forest, which experienced lower levels of cone damage, due to the increased difficulty for arthropods to find host plants. The authors also observed that the damage level depended on the arthropod group and cone abundance.

One possible reason for the current lack of studies dealing with insect outbreaks is related to the amount of time since abandonment: most forest stands developed after land abandonment in the twentieth century may often not yet be susceptible to insect outbreaks. When certain structural characteristics (e.g. large diameters for bark beetles) are reached, those stands could become vulnerable due to the presence of suitable host trees.

Conclusions

Several interactions were highlighted between land abandonment and disturbance regimes. The analysis of the existing literature revealed a noticeable imbalance regarding the number of studies per type of disturbance and evidenced specific hotspots where most studies were performed, with the great majority of study sites being located in Europe. Specific reasons for these differences should be further investigated. Despite preliminary scoping and a large number of key terms included, our search may have failed to identify all of the available literature on this topic.

While the effects of land abandonment on wildfires have often been studied, particularly in the Mediterranean Region, a much lower number of articles focused on interactions with other disturbances. This is not unexpected considering that land abandonment and rural depopulation occurred at a high rate in countries of Southern Europe, where wildfires are one of the most frequent disturbances and typically have a high impact on both the human population and vegetation communities.

For disturbances other than wildfire, opposite effects of land abandonment on their regime were observed, and regarding the same disturbance type, these effects were sometimes contrasting. Differences among studies could be attributed to differences in site characteristics or legacies of prior land use.

Another limitation of the available literature, particularly regarding under-represented disturbances, is the scarcity of quantitative assessments, truly measuring the process of abandonment and the resulting changes on disturbances.

When addressing abandonment-related impacts on disturbances, a key issue is represented by time since abandonment and the relative vegetation successional dynamics. There is still a lack of knowledge on the longer-term effects of land abandonment based on forest succession over time. Current changes in disturbance regimes attributed to changes in land use may thus be fluctuating according to long-term successional trajectories of forests, which are by their nature dynamic systems (Sebald et al. 2019). This calls for monitoring of land abandonment evolution over time, particularly when land and resource management are involved.

Moreover, land abandonment alone is only one possible factor of the whole equation. Interactions with climate change or feedbacks resulting from interactions among disturbances should also be taken into account (e.g. Schelhaas et al. 2010; Doblas-Miranda et al. 2017; Kulakowski et al. 2017; Potterf and Bone 2017; Beato Bergua et al. 2019).

At a global scale, the phenomenon of land abandonment can result in opportunities for restoring natural communities and enhancing the provision of important ecosystem services. There are situations where land abandonment could produce, at least in the short- or medium-term, an increase in disturbance size, frequency or severity, sometimes mostly because of the resulting increase in forested areas, and this should raise concern about potential consequences for human society. However, natural disturbances are an integral component of forest dynamics, and this process can be viewed as part of a path towards conditions more similar to those characterising some ecosystems prior to intense human exploitation.

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