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Systematic Review

Wildland–Urban Interface: Definition and Physical Fire Risk Mitigation Measures, a Systematic Review

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Abstract: Due to the associated fire risk, the wildland–urban interface (WUI) has drawn the attention of researchers and managers from a range of backgrounds. From a land management point of view, it is important to identify the WUI to determine areas to prioritise for fire risk prevention. It is also important to know the fire risk mitigation measures available to select the most appropriate for each specific context. In this systematic review, definitions of the WUI were investigated and physical mitigation measures for reducing the risk of fire were examined from a land management perspective. The PRISMA 2020 Statement was applied to records published until 31 December 2022 and retrieved from the Web of Science, Scopus, and other research engines. A total of 162 publications from scientific journals and the grey literature were scrutinised and selected for analysis. Only publications providing an original definition of the WUI or proposing physical measures to reduce fire risk at the interface were retained, while those relating to emergency management and social perception were not considered. The risk of bias was reduced by internal cross-assessment by the research team. Definitions of the WUI (n = 40 publications) changed according to the research objective, varying broadly in identification of the anthropogenic and the wildland components of the interface. Terminology varied according to the definition, and the term wildland–human interface (WHI) was found to be more comprehensive than WUI. Methodological definitions of the interface ranged from using aggregated data through to identification of the buildings at risk in the interface with considerable precision. Five categories of physical fire risk mitigation measures (n = 128 publications) were identified: clearance distances, landscaping, wildland fuel management, land planning, and buildings design and materials. The most effective measures were those applied at early stages of urban development, and maintenance of assets and vegetation is crucial for preparedness. This review represents an analysis of scientific evidence on which land managers can base their actions to reduce the fire hazard risk in the WUI. The number of studies investigating the WUI is considerable, but experimental studies and quantitative results are scarce, and better communication and coordination among research groups and land management agencies is advisable. This systematic review was not registered.

Keywords: wildfire; bushfire; interface; WUI; WHI; land management

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1. Introduction

Wildland fires regularly gain public attention during the fire season, as dramatically observed in the last few years in California [1], Australia [2], and Southern Europe [3]. Much of this attention is because this is where many people reside, and businesses and community groups are established. This area, where human and natural environments meet, is most commonly referred to as the wildland–urban interface (WUI). This zone is of particular interest with regards to wildland fire due to its vulnerability to disturbance by fire and its tendency to act as a source of ignition [4].

The original concept of the WUI arose in California during the late 20th century, when a series of wildfires caused unexpected yet consistent losses in neighbourhoods dispersed in the chaparral [5,6]. Similar scenarios have then been observed in other fire-prone areas of the world: Canada, Chile, Australia, Southern Europe, and South Africa [7–12].

The reasons for such disasters cannot be ascribed only to wildland fire, a natural disturbance and ecological driver in many ecosystems [13,14], nor to the sole presence of human settlements, many of which have been present historically. New forms of inhabiting the rural landscape not based on the use of agro–sylvo–pastoral resources must also be considered [6,15]. Indeed, due to a series of socioeconomic and demographic trends in the last few decades, it has become feasible—and attractive—for people to move away from cities to take advantage of more space, lower costs, and better aesthetics [16,17], or for seasonal recreation [18]. This trend has pushed the creation of scattered settlements near or within wildland vegetation, with considerable consequences in the case of wildfire. The increasing number of high-value buildings that need to be defended and the accumulation of large amounts of plant biomass, which represents a stock of fuel for wildfire, have often overcome the resources available to fire crews [19,20].

In addition, the presence of humans in the interface represents the main source of fire ignitions. Given a predicted increase in number of houses in the WUI and the forecasted changes in climate, the risk of fire in the WUI is going to escalate if countermeasures are not taken [21]. For these reasons, the WUI has risen to the top of the agenda for institutions managing wildland fires [22].

The scientific community was first in pointing out the problem of the WUI [5,23], and, in the last 20 years, offices of public administrations have taken action by implementing policies for managing the WUI. In this sense, one of the first legal frameworks to appear was based on a notice in the Federal Register (66 FR 751) by five US government agencies to allocate funds for the fiscal year 2001 [24] and the introduction of an associated legal definition [4]. The proposed thresholds and WUI definition have, in turn, been used extensively in the US as a baseline for successive scientific studies [25–27]. Later, other similar legal frameworks were established in other fire-prone regions around the world, with definitions and legal requirements tailored to meet local needs [26,28–31].

Despite the relatively simple basis of the WUI—where human and natural environments meet—over time, the definition has become increasingly more complex. New aspects are continually being considered and incorporated. For example, some studies have focused on the role of the WUI in habitat fragmentation and facilitation of invasive species [26,32]. Other studies have considered the effects of human resources in the interface, such as built infrastructure and production facilities [33]. In addition, the augmented availability of ancillary information, such as population demographics and census data, increased computational power, and remote sensing capabilities have been used for systematic identification of the WUI and its geographical delineation [34].

Recognising the abundance of factors and agents involved that make the WUI a complex topic, public agencies have launched long-term awareness programmes [35–37] and have supported targeted research projects [38,39]. Academia has also responded by analysing the WUI from various points of view, including the social sciences, ecology, and engineering [40,41]. Some of this research has recently been summarised in noteworthy reviews [42–44], although this has not been carried out in a systematic manner, nor have other studies directly addressed land management issues in fire-prone areas (see Appendix A).

The objective of this systematic review is to analyse the current scientific and grey literature produced worldwide on the wildland–urban interface from a land management perspective. In particular, the definition of the WUI and the physical measures used to reduce the associated fire risk are investigated. To our knowledge, no such assessment currently exists (see Appendix A), and the outputs will be of use to decision-makers at any administrative level.

2. Materials and Methods

As the initial step, a thorough search for similar, already existing systematic reviews was performed (Appendix A). No equivalent reviews were found, so the current systematic review was initiated in accordance with the PRISMA 2020 Statement [45].

Studies including a definition of the WUI and/or physical measures to reduce fire risk [46] were selected as eligible, while studies related to emergency management and social sciences were excluded, because they are not directly related to land management. Studies concerning other topics, but from which useful information could be retrieved, were retained. An additional exclusion criterion was the document type: editorials, position papers, forewords, and similar commentary papers were not considered, as well as theses. Publications describing fire risk mitigation measures without inclusion of additional experimental or meta-analyses were also excluded, but, when possible and relevant, studies cited in these publications were retrieved.

The databases accessible through Scopus [47], Web of Science [48], Agris [49], Treesearch [50], arXiv [51], and bioRxiv [52] were searched with the keywords "*urban AND interface AND fire*" up to 31 December 2022. No filters were imposed with case-by-case selection after retrieval. External entries were obtained from other research engines (Google [53] and Google Scholar [54]), from bibliographies of retrieved publications, and from suggestions by colleagues. These publications were contextually checked for duplication and eligibility. Only full text, readily available publications were retained in the process. Data used for further analysis were retrieved by reading the full text of the publications collected at the final stage of the selection.

The objective of the review was determined using the question formulation framework of PerSPEcTiF [55] (Table 1), and was derived from both the outputs of previous research projects [38,39] and consultation among the authors. The results were presented using a narrative synthesis as defined in the SWiM guideline [56] as the scarcity of numerical results precluded a meta-analysis.

Table 1. Review objective as defined with the PerSPEcTiF framework.

Per	Perspective	In scientific and grey literature
S	Setting	Worldwide
P	Phenomenon	The wildland–urban interface
E	Environment	From a land manager perspective
(C)	(Comparison)	(-)
Ti	Time	Until today (2022)
F	Findings	How is it defined, and what physical measures are suggested to reduce fire risk in it

To make the synthesis useful for land managers, two important aspects were considered: firstly, the definition of the WUI, and secondly, a collection of critical measures to reduce fire risk in the area defined. For the definition of the WUI, three questions were addressed: *conceptual* (what the WUI is), *semantic* (how people name it), and *methodological* (how it is identified and mapped). For investigation of preventive mitigation measures to reduce fire risk in the interface, five logical categories were developed based on the publications screened to search for similar existing reviews (as provided in Appendix A):

- Clearance distances (between buildings and plants, and amongst each of the constituents).
- Landscaping.
- Wildland fuel management.
- Land planning.
- Buildings design and materials.

Integrative information on the review process is presented in Appendix B.

3. Results

A total of 3578 publications were retrieved, 3583 using research keywords and 37 as external entries (Figure 1). After deletion of duplicates, screening, and selection for eligibility, 162 publications were used for the final stage of selection. All publications retained (subsequently referred to as *the publications*) were in English and at a published stage. To investigate the definition of the WUI, 40 publications were used, while 128 publications were used to collect mitigation measures for fire risk, with six publications serving both purposes.

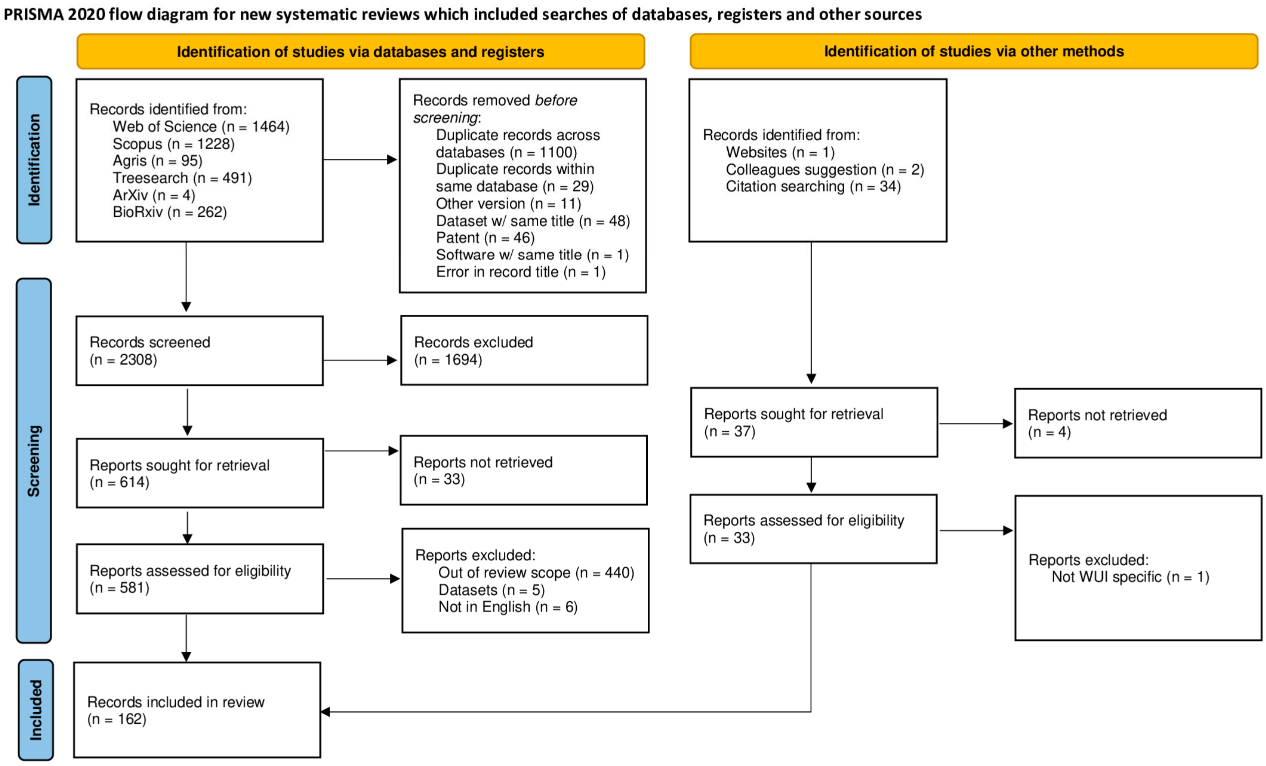

Figure 1. Flow diagram of the systematic review, from the PRISMA 2020 template [45].

The time range of publication was 1983–2022. There was a steady increase in the number of publications throughout the period, with a peak in 2022 (18 publications, Figure 2).

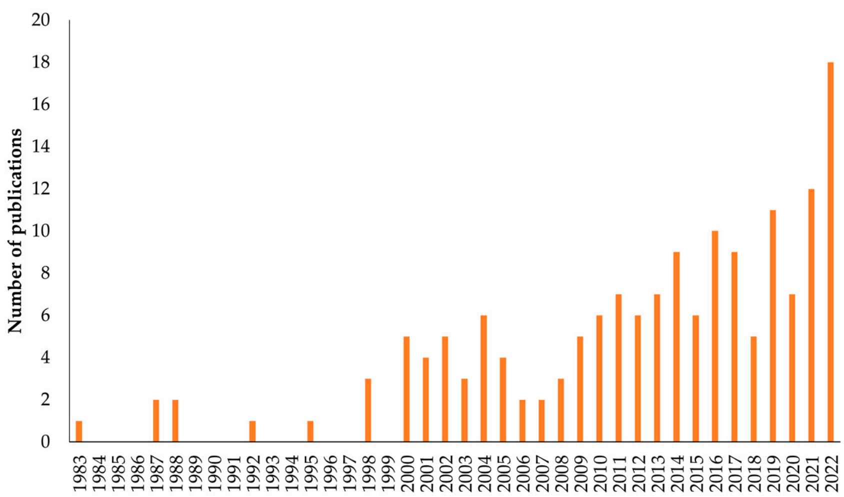

Figure 2. Number of selected publications per year.

Location of the studies presented in the publications was strongly concentrated in northern America (US, n = 44; Canada, n = 8), Oceania (Australia, n = 12; New Zealand, n = 1), and Europe (n = 37), with fewer studies from South America (n = 9) and Asia (n = 1). Nonetheless, a large number of publications were derived from laboratory or desk analyses (n = 37) or did not refer to a specific geographic region (n = 14).

Most publications were peer-reviewed (n = 141; 87%) based on their publication in a scientific journal or as part of a conference proceedings (peer-revision of proceedings was assumed for all conferences). The remaining publications were considered as grey literature (e.g., agencies publications, outreach material).

3.1. Definition of the Wildland–Urban Interface

3.1.1. Conceptual Definition

Considering the conceptual definition, the WUI was always determined by at least two components: the wildland—a portion of land under low anthropogenic influence—and a human-altered part of the landscape. A number of studies considered residential buildings as the only anthropogenic component in the WUI (n = 7) [9,11,22,24,57–59], while others did not define which kind of human assets to consider (n = 8) [15,25,27,34,60–63]. Some studies clearly stated that both buildings and other infrastructure (n = 3) [64–66], or houses and industrial areas (n = 3) [67–69], were considered, while few studies (n = 2) accounted comprehensively for infrastructure, industrial, and residential areas [33,70]. Only one publication considered any human presence (*ecumene*) as the anthropogenic component of the interface [71]. In addition, a small number of publications focused on a specific human asset, as either infrastructure [72], industrial areas [73], or agrarian land [66,74].

Three studies added a third component to their definition of the WUI—the occurrence of wildland fire [60,75,76]. Another conceptual categorisation of the WUI was used to describe the grade of mingling of human and natural components: (i) wildland–urban interface *sensu stricto* if the human assets abut wildland, (ii) wildland–urban intermix if human assets are dispersed within the wildland, (iii) occluded WUI if an island of vegetation is surrounded by human assets, and (iv) rural WUI if clusters of assets are widely scattered across a landscape [4].

3.1.2. Semantic Definition

For the semantic definition of the interface, the majority of studies (n = 30 publications) referred to it as the *wildland–urban interface* (WUI), and in three studies it was called the *wildland–human interface* (WHI) [33,70,71]. The following definitions were used in one or two studies each: *urban–forest interface* [68], *wildfire interface zone* [60], *rural–forest interface (RUI)* [66], *road–forest interface* [72], *forest–settlement mixing zone* [77], *forest–agricultural interface (FAI)* [75], *forest–grassland interface (FGI)* [75], *wildland–anthropic interface (WA)* [63], *wildland–industrial interface (WUI–Ind, WII)* [71,73], *wildland–infrastructure interface (INF)* [71], and *wildland–agricultural interface* [74]. Three publications [60,61,78] gathered multiple definitions from other studies (Table 2). Some of these terms were used in other studies to refer to a specific condition of the WUI, including *fringe* [9], *peri-urban* [9], and *rural* [9,15,60,66].

Table 2. Collective terms used to define the interface. Some of the terms were used in other studies to address the wildland–urban interface (WUI) in specific conditions.

WUI Definition Terms	Publication
I-zone, rural–urban interface, urban interface, chaparral–urban interface.	[60]
I-zone, urban–rural interface, residential–wildland interface.	[61]
Urban–rural interface, residential–rural interface, urban–forest interface, peri-urban interface, urban–edge, urban proximate, urban–forest fringe, residential forest, urbanising landscape, urban sprawl, rural–urban fringe, residential–open land intermix, urban–proximate wilderness.	[78]

3.1.3. Methodological Definition

The two main classes of methodological definitions of the WUI were related to (i) the density of the assets (i.e., buildings) or (ii) inclusion of a buffer around the assets. A further class was (iii) a combination of asset density and buffer distances. Definitions including asset density were the most prevalent (n = 12 publications) [9,11,15,24,25,27,33,57,66,76,79], compared to definitions including a buffer (n = 7) [22,64,65,69,70,75,80] and a combination of the two (n = 8) [58,59,61–63,67,77,81]. The "density" definition was most commonly in the US (n = 5) [24,25,27,57,76] compared to the combined definition (n = 2) [59,61], but there was no clear pattern for methodological definitions in publications originating from other countries. There was no clear relation between the year of publication and the class of methodological definition used.

Eight of the studies examined used other methodological definitions. These were based on settlements morphology [68], population income [82], plant species communities [72], cadastral and LiDAR data [34,83], probability of wildfire occurrence [60], buffer from wildland areas [84], property rights and orthophotographs [12], and normative classification [74,85].

3.2. Fire Risk Mitigation Measures in the Wildland–Urban Interface

Mitigation measures for fire risk were searched according to five categories (i.e., clearance distances, landscaping, wildland fuel management, land planning, and building design and materials), which were further grouped as (i) measures acting on natural fuels and (ii) measures for protection of human assets. This rationale simplified data presentation and interpretation and better reflected the two physical components of the WUI. In addition, the two groups are directly related to two major components of fire risk: hazard and exposure, respectively [46]. Summary information relating to the five categories can be found in Appendix C.

3.2.1. Natural Fuels

Mitigation measures for natural fuels included the first three categories: clearance distances, landscaping, and wildland fuel management. The most common configuration of cleared spaces was the creation of concentric buffers stripes of managed vegetation around buildings with reduced management intervention further away. Four buffers could be delineated (Figure 3; Tables 2 and 3), although no publication considered all of them together, and their width was derived from experiments, simulations, retrospective case studies, or customary practices. The first three buffers are variously referred to as the home ignition zone (HIZ [86]) or house defensible space, and span the first tens of metres (Table 3) [62,78,86–96]. The HIZ is the zone where ornamental vegetation should be maintained to reduce the probability of building ignition by contact, convective, and radiative heat, and to reduce the creation of flying embers [5,12,36,64,86–89,91,93,95,97–103]. A multiplication factor is applied to buffer width in case of steep slopes or particularly high natural fuel load [98,100,104]. The fourth buffer zone is referred to as the community protection zone (CPZ [99]), and is similar to an HIZ, but protects groups of buildings. The CPZ spans hundreds of metres from infrastructure (Table 3) [59,64,97,99,105–110].

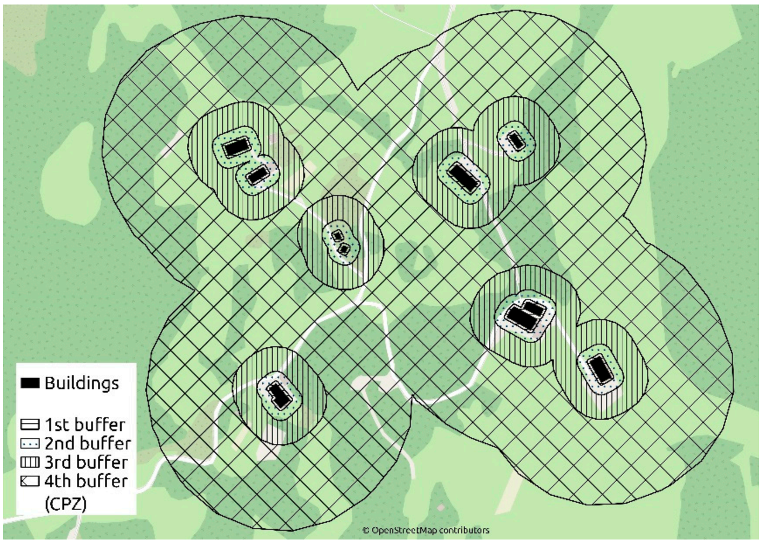

Figure 3. Illustrative example of buffer areas around buildings including an outer community protection zone (CPZ).

Table 3. Ranges of buffer distances recommended for home ignition zone (HIZ) and community protection zone (CPZ). Distances measured in imperial units have been converted to metric and rounded (2 feet = 0.5 m, 3 feet = 1.0 m, 30 feet = 10 m, 380 feet = 100 m); * indicates values obtained solely from simulation; † indicates values retrieved from publications that did not specify management actions (e.g., retrospective analyses). Values in square brackets are publications providing the information.

HIZ			CPZ
1st Buffer (m)	**2nd Buffer (m)**	**3rd Buffer (m)**	**4th Buffer (m/km)**
0.5–1.0 [88]	3 [96]	28 [111] *	30–70 m [12]
1.5 [103]	10 [88,98,111]	30 [89,98]	100 [96]
5 [91,93]	15 [112] *	40 [113] *, [96]	200 m [108]
10 [5,31,97]	30 [5,97]	50 [31]	250–300 m [107] †
10–35 [114]	40 [109]	60 [5,86,99]	500 m [64,99,106,109]
50 [95] *	20–80 [114]	70 [114]	400–700 m [10] †
60–120 [101]	50–100 [62]	100 [97,100,109]	850 m [110]
			0.8–2.4 km [105]
			0.8–1.6–3.2 km [59]
			1.2 km [115]
			2.5 km [116]
			10 km [97]

In instances where landscaping was proposed as a method for fire risk mitigation, appropriate design and maintenance were considered to be more important than plant species selection [92,117]. Herbaceous and woody ornamental vegetation (shrubs, trees) should be discontinuous, both horizontally (i.e., between plants) and vertically (i.e., between trees canopies and understorey) to reduce fire spread and, for the same reason, trees should not be planted too close to buildings [5,89,98,103,113,118–120]. Periodical maintenance in the form of trimming, mowing, and removing residues is needed to maintain this discontinuity and avoid buildup of combustible fuel (Table 4) [5,31,88,89,94,98,109,114,116,120–122]. Additional recommendations included watering plants and mulching against weeds [5,40,88,89,98,101,109,117,120,123–125]. For selection of plant species, preference is given to plants that retain a high amount of water in their tissues, such as deciduous broadleaves, succulents, and drought-tolerant species. Plants rich in resins, oils, and volatile organic compounds should be avoided as they can potentially increase flammability, as should plants with needle-shaped leaves, such as conifers, as these structures have high surface area/volume ratios that facilitate combustion (Table 4) [5,36,88,111,119,120,126–143].

Wildland fuel management comprises various practices implemented beyond the HIZ to reduce fire risk near assets. Most of the management practices mentioned were aimed at hampering crown fires by removing ladder fuels (fuels between the ground and trees canopy), thus reducing the probability of crown fire [100,119,144,145]. Another recommended management practice was thinning trees to reduce the probability of crown-to-crown fire spread [36,89,98,100,108,144–150]. Specific management practices included disposal of debris from forest operations [36,98,144,146], and fuel management appropriate for grasslands or shrublands [5,89,151–154]. At a broader scale, fuel discontinuity is achieved by clearing strips of vegetation. These areas are called *firebreaks* if all vegetation is removed to impede the spread of fire [155–158]; *fuelbreaks* if vegetation is reduced for firefighters deployment [154,156,159]; and *greenbelts* if vegetation is managed along linear infrastructures or boundaries [5,89,90,101,108,143,160].

At a landscape level, fuel discontinuity was proposed for risk mitigation with land cover fragmentation, favouring land cover with low fuel load (e.g., cultivated land) amid fire-prone vegetation (e.g., coniferous forest) [8,119,129,135–137,152,154,161–169]. As for landscaping measures, conservation of a target fuel load requires periodical maintenance [89,98,108,109,147,149,167]. This is often achieved with prescribed burning (PB)—the practice of reducing wildland fuel by burning under controlled conditions. A series of precautions to reduce smoke emissions and to minimise environmental harm have been suggested in relation to PB [98,101,108,109,119,167]. For other treatments of wildland vegetation, such as forest thinning, advice was provided to reduce negative ecological impacts, for example, on forest regeneration [31,36,89,98,144,170]. While there was no consensus on what human assets to prioritise with landscape treatments (e.g., buildings, roads, or the most fire-prone areas [25,69,100,104,106]), it is clear that it is more efficient to protect communities instead of single buildings, to coordinate among communities, and to treat big areas instead of small patches. In addition, treatments should be implemented first in the interface sensu stricto, then in the wildland–urban intermix, and lastly around isolated houses in the wildland (Table 4) [20,99,161,171,172].

3.2.2. Anthropic Assets

Fire risk mitigation measures for anthropic assets concern the last two categories: land planning, and buildings design and materials.

Land planning was found to be more influential on fire effects than topography and vegetation in the WUI [102,173–175]. The main recommendation was to build in compact settlements which can be better defended in case of fire because of smaller exposed perimeter and better access for fire crews [64,108,116,137,175–177]. In addition, constructions on certain topographical features (e.g., ridge tops) were discouraged as they are more exposed to heat and smoke, although those locations are preferred by residents for aesthetic qualities [5,89,92,101,102,120,175,176]. Special mention was given to the road network, considered as a source of ignitions [160,168,169,178–180] but also an obstacle to fire propagation [108,159,179].

Mitigation actions for single buildings can be performed by the owner, and often to already existing structures (i.e., retrofitting). In response to building design, the main recommendation was to avoid spaces where firebrands can accumulate (e.g., corners, wooden decks), and to adapt existing ones (e.g., chimney, gutters) [5,102,120,122,181–188]. With reference to building materials, inert materials were suggested for roofs and walls [5,89,92,94,101–103,120,122,175,185,185,187–191], and specialised materials should be used for windows and frames [5,103,122,175,187]. Proper maintenance of buildings is also crucial: old houses have a higher probability of burning, and all types of roofs become ignitable with ageing [94,103,175,182,192]. Simple maintenance actions, such as removing debris from gutters, roofs, and at the base of exterior walls, can result in effective reduction of ignition [5,87,120,122,182,188,192]. The measures proposed for buildings also apply to temporal dwellings, such as mobile homes and tents [122,193]. Additional measures can increase building survivability during a fire, such as keeping fuel (e.g., wood piles, LPG tanks) away from buildings [5,92,103,188,194–198], and taking measures to facilitate rescue operations during a fire [5,89,120,188].

Table 4. Synthesis of fire risk reduction measures collected in the present systematic review with selected reference publications.

Measure	Publication
Natural fuel management	
Reduction of vegetation in concentric buffers around assets, with greater clearing efforts near assets.	[20,59,97]
Periodical management of vegetation by trimming, pruning, watering, and removal of debris.	[31,89]
Avoidance of fire-prone plant species in gardens and parks.	[88,130]
Increase trees canopy/crown base height and reduction of canopy continuity.	[98,145]
Creation of fuelbreaks/firebreaks in wildland vegetation to reduce fire spread and facilitate fire suppression.	[155,159]
Land cover fragmentation and some types of land cover hinder fire spread.	[8,152,162]
Configuration of human assets	
Compact settlements are more easily protected by fire crews and with less perimeter exposed to fire.	[64]
No building on steep slopes or ridges.	[176]
Road network design should facilitate egress and fire suppression operations.	[90,108]
Roof and walls built of inert material.	[189,192]
Windows with tempered, double-pane glass.	[175]
Avoid creating spaces where embers can accumulate.	[5]
Store domestic fuel (LPG, firewood) away from buildings and vegetation.	[92,195]
Maintenance of buildings, and removal of leaves from roofs, gutters, and near walls to prevent ignitions.	[87,94]

4. Discussion

The studies selected for this systematic review were published over the last four decades and across most of the world, with an expected increase in number of publications in recent years [199], and a focus on Western countries [200]. Grey literature formed a minor share of the selected publications, but some documents in this category were used throughout much of this review [5,31,89,97,188]. This can be ascribed to the scope of grey literature, to collect the information acquired with scientific research, and to synthesise it for the general public, both in the form of outreach material [5,89,188] and as prescription [31,97].

Two main limitations are present in this review: the heterogeneity within selected studies, and the scarcity of numerical outcomes. For these reasons, no formal assessment of the risk of bias, within and across studies, was possible, and no meta-analysis was performed. Homogeneity in definitions, methodologies, and recommendations was mostly only found in studies produced by the same research group. With regard to the scarcity of direct measurements, several studies did not perform empirical experiments, but instead retrieved numerical inputs from the few seminal works containing data. Related to this last point, some publications (excluded in the selection process) used "WUI" or similar terms without actually addressing this topic, using them only as keywords to attract the attention of the readers.

4.1. WUI Definition

The analysis of definitions used for the WUI examined concepts, terms, and methods used over time and tried to clarify their usage. The conceptual, semantic, and methodological aspects of WUI definition are interdependent; therefore, an ultimate definition is probably not achievable. Given a specific aim, appropriate terms are selected, and a method (e.g., mapping) is chosen [201]. The relationship between concepts and semantics were evident in some studies, for example, those describing the influence of road networks or agrarian land on wildland fires in which new terms were created to define the interface [66,72].

Apart from some exceptions, "wildland–urban interface" was the most used expression. There are two obvious reasons for this: (i) use in legislation [24], and by early [202] or seminal studies [20,25,202], and (ii) in most studies, the human component of the interface was a residential area where the term "urban" is appropriate. However, there is emerging evidence of forest fires threatening industrial areas, becoming natural hazards triggering technological disasters (NATECH) [203]. In addition, the negative consequences of new settlements on ecosystems are rarely considered and exceed land cover modification (i.e., increase in ignitions, change in fire regime) [26,32,169,204]. To account for nonresidential assets and to rebalance the importance of both sides of the interface, new terms such as the wildland–human interface (WHI) [33,71] or the wildland–anthropic interface (WA) [63] have been proposed and can be used as a general substitute for the WUI.

The interdependence of the three aspects of the definition of WUI is also evident in mapping methods. In the US, the predominance of methods based on aggregated data may be derived from local legal definitions based on asset density [24] and the computational power available at the time of the law enactment. This scenario creates a natural baseline for local research [25]. In the rest of the world, in the absence of similar legislation, novel mapping methods have been explored. Density-based methods are resource-efficient, especially for estimates and for large areas, and can benefit from data already acquired (e.g., periodical censuses, demographics) [25]. Even today, when temporal trends are investigated, new maps are created incorporating past methods [27,205]. However, as computational power and accessibility to remote sensing data are continuously increasing, finer-scale definitions of the interface based on vegetation and buffer distances are both feasible and desirable, even at a national level [84]. In reality, the retention of the topographic location of assets can better represent the real extent of the interface [57,70,110,205] and can translate to better allocation of resources for fire risk mitigation. In this sense, methods based on LiDAR and cadastral data appear to be the current state of the art for interface mapping [34,83].

Fine-scale mapping can also permit additional analyses to better characterise the fire risk: in fact, all studies considered the interface as the geographical intersection between a natural area and an anthropic one [44], but few publications explicitly considered the presence of wildland fires, the third and necessary component of interface fire risk [60,75,76]. Mapping the probability or the simulated intensity of fire, as already performed for wildland fires, may enhance the categorisation of the risk throughout populated landscapes [206].

In summary, although the most commonly used term was *wildland–urban interface* (WUI) and the most commonly used mapping methodologies were based on density criteria, we suggest adopting the expression *wildland–human interface*, because it better encompasses a range of anthropogenic influences on the interface, and to use nonaggregated topographic data, such as LiDAR, to define the interface with greater precision and, consequently, the areas to prioritise for management.

4.2. Fire Risk Mitigation Measures in the WUI

The analysis of measures to reduce fire risk in the interface divided them into those acting on natural fuel and those targeting human assets. The ones acting on natural fuels were related to distances for clearing vegetation, landscaping practices, and managing wildland fuel. Those targeting human assets relied mainly on land planning practices and construction of buildings.

Regarding clearing distances, only one study validated data obtained from simulation [20,112] with a field experiment [111], showing a general lack of studies using direct measurements [95,207]. Simulations are often used because they are relatively inexpensive, but estimated data required to run models may lead to inaccurate outputs [95,157]. Retrospective case studies, especially post-incident surveys, are valuable sources of information, but the knowledge of the prefire situation represents a bottleneck, especially in the case of remote sensing analyses [10,102,110,116,119,180,208–210]. "Common sense" distances are widespread, especially in legislation [28–31], and are easily accepted because they reflect local experience of fire behaviour, but may underestimate fire risk in the case of unprecedented conditions. Clearing distances depend on local climate and vegetation and may be inapplicable out of context [62,97,116]. Realistically, one-size-fit-all distances for clearing cannot be suggested, but management of vegetation in concentric buffers around assets with the maintenance of good aesthetical and ecological levels of the surroundings can be balanced to protect buildings and other assets.

Landscaping in the interface, or *firescaping*, as the practice is occasionally called [211], follows the same concentric rule, with more attention required close to assets. It relies on two key concepts, to break fuel continuity within assets and between assets and vegetation, and to reduce the amount of combustible biomass. Periodical maintenance was the main action for both objectives, and garden design or measures to contain plant growth, such as mulching, can reduce the frequency of maintenance. Most of these publications were set in a US context, changing the effectiveness of such methods in other countries. Proposed thresholds (i.e., distances, type, and frequency of maintenance) would need to be tailored to specific settings to be useful.

Plant species selection was found to be secondary [89] in landscaping and relies on plant traits that influence combustion, not solely on species. Moisture in plants is a heat sink and needs to be vaporised before the dry mass can burn. In contrast, oils and resins are energy reservoirs for combustion, and needle-shaped leaves burn intensely because the biomass is in optimal contact with oxygen due to the high surface-to-volume ratio [88]. Consequently, global lists of fireproof plant species waned in popularity in the early 2000s and listings are now only recommended locally [89,212]. In addition, rankings of species flammability developed though laboratory analysis vary considerably depending on the protocol applied [139]. Another historic landscaping trend was the substitution of native vegetation with putatively less flammable exotic ones, but an increasing awareness of biodiversity conservation and alien species has made this strategy far less popular [213].

Wildland fuel management is designed to disrupt fuel continuity as in landscaping, but forestry-related measures are generally carried out over large areas. The focus is to avoid crown fires because they produce large quantities of flying embers, the main source of interface ignitions [181]. Removal of ladder fuels and reduction of the bulk density of tree canopies can create a park-like forest structure and mimics regions characterised by low-severity fire regimes [36,188]. By far, the most popular management tool to achieve this is prescribed burning, but production of smoke in the WUI creates resistance in urban populations [214]. Regardless of the type of management method used, all fuel treatments need to be applied periodically; otherwise, untreated landscapes can represent unacceptably high fire risk, as in the case of abandoned agrarian fields in Europe [119].

The preferred type of treatments for management of wildland fuel over landscapes differed across studies, reflecting local socioenvironmental conditions. For example, in residential areas, the WUI was found to be managed to protect the greatest number of houses [109], while in rural areas with dispersed buildings, the road network was the primary area treated to reduce ignitions and fire spread [178]. In communities where lightning ignitions were frequent, the most fire-prone areas were prioritised to halt fire penetration into the WUI [215]. A risk mitigation measure found to be effective for slowing the spread of fire across a landscape was land cover fragmentation, for example, achieved by alternating wildland parcels with agrarian fields [154,162]. This pattern is easy to maintain if it is already present in the landscape, whereas if it requires land use change, it is unlikely to be accepted by stakeholders or by the society as a whole [168].

Land planning during development of new settlements is the most efficacious measure for building safety, by reducing both the exposure of buildings to wildfire and creating safe conditions in which to operate in case of fire. Despite this, community-based measures were not recurrent in the publications examined, although they were more efficient than single-properties interventions [103,171,208]. This is possibly due to difficulties in reaching a consensus among residents. Redesigning existing settlements is also contentious due to the cost of retrofitting whole communities and expectations of stakeholders in the WUI, especially a recreational community with residents having little appetite for altered landscapes, changes of scenic views, and reducing distance from other houses.

As a confirmation of the difficulty to intervene at the community level, single building construction and maintenance were the most common topics in the publications examined to reduce WUI fire risk. A large number of publications addressed cleaning and maintaining premises and repairing broken or aged parts, which are common activities for homeowners regardless of location. One reason for this may be the—sometimes large—proportion of owners with second houses in the WUI, who may be less keen than residents to divert leisure time into fire risk reduction activities [18], or who may be absent for most of the year [216]. Another reason for inadequate property maintenance can be underestimation of risk [217]. Such sociological or psychological aspects were not investigated in this systematic review, but have emerged frequently, suggesting an influence on the more tangible aspects of WUI fire risk reduction.

Considering building design and materials, the focus of much of the relevant literature was on reducing the risk posed by the weakest points of a structure, the roof, and the glazing system. Logically, the roof is where most of the flying embers land and smoulder. To some extent, the occurrence of embers can be reduced if other risk mitigation measures are applied [20]. Windows failure allowing egress of embers was often cited as the cause of house destruction [175]. Inert materials are the preferred choice for reducing this fire risk; however, the choice may be overridden by regional habits or availability. For example, common building materials used in Mediterranean countries are concrete or masonry, but in other countries, including the US, Canada, and Australia, they are predominantly wood or composite. In this sense, houses in the Mediterranean are places of shelter [186,216], instead of sources of house-to-house ignitions [103,177]. Nonetheless, flammable materials are common in the Mediterranean for minor structures (sheds, garages [186]) or in campsites [193], indicating that a collection of best practices can be useful worldwide, regardless of local differences in wildland vegetation, fire regimes, and urban settings.

5. Conclusions

This systematic review of the WUI was a much-needed global and comprehensive search for a clearer understanding of what the WUI represents in fire-prone areas around the world, and in examining mitigation measures of fire risk. Regardless of location, the WUI has become the focus of attention for wildland fire management due to the existence of wildland fuel, increasing human presence, and high-value assets.

The definition of the WUI has changed over time and with purpose. Today, the interconnection between human habitation and wildland vegetation is recognised, and precise identification of anthropic assets is both possible and desirable with available technology. The most effective fire risk mitigation measures were those carried out at the planning level and, for established locales, those describing maintenance of vegetation and structures. While some recommendations only have local value, the concepts examined hold true worldwide, signalling that collaborations among land managers and researchers, the latter from different fields, may be beneficial to all. Collaborative research would be best served by designing comprehensive experiments to give quantitative, objective indications on the best configuration of structures and their surroundings to withstand wildland fire at the interface.

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Appendix A

The existence of similar reviews on the wildland–urban interface was assessed before the start of the work using a systematic approach.

The string of keywords "**land–urban interface fire review*" (the asterisk acts as a wild card) were used for the first time on 15 March 2019 in Web of Science (WoS), Scopus, and Agris to search for reviews up to that date. The keyword "**land*" was used because synonyms of the broad term *wildland* are frequently used (e.g., *bushland* in Australia). In addition, this keyword also encompassed other types of land cover, such as *grassland*, *rangeland* and *brushland* [152,162,167], that were deemed relevant for the current study. The research parameters were the most inclusive as possible were selected:

- WoS—"all years", "topic", and "all databases".
- Scopus—"article title, abstract, keywords".
- Agris—"all languages" and records from aggregators.

Collectively, 115 records were found (59 from WoS, 41 from Scopus, 15 from Agris), which was reduced to 79 after duplicates were removed, and further reduced to 63 after screening the titles. To manage these records, items from Scopus and WoS were exported, respectively, to CSV/.xls files with the designated function, keeping information on title, authors, source, and abstract (and year, for Scopus). The items were then merged into a single spreadsheet, retaining information on the original database (Scopus or WoS) by adding another attribute. Selection of duplicates was performed by hand by ordering entries by title and authors. Screening of titles and abstracts were also performed by hand. For Agris, it was not possible to export records; therefore, removal of duplicates and screening was performed online. After having read some of the publications, it was evident that the keyword **land* was not inclusive enough for our purpose [5,33], and was therefore deleted from the search string.

A second search was carried out on 18 March 2019 using the keyword string "*urban interface fire review*", with the other options unchanged. Once the 129 publications (65 from WoS, 49 from Scopus, 15 from Agris) were checked for duplicates, 89 records remained. This number was reduced to 42 after title screening, and to three after reading the abstract. Excluded publications were conference proceedings or were concerned with other fields of knowledge (e.g., social sciences, civil protection, hydrology), or were site-limited in scope. Full-text versions of the remaining articles were obtained and read. It was evident that these studies were not overlapping with our proposed research. One of the three remaining publications gathered information on fire behaviour and fire modelling [42]; the second focused on human caused fires [218]; and the third was a foreword of a journal [219].

On 23 January 2020, a similar search was carried out to account for studies published while our review was in progress. In Scopus, two new records were found, but they were only partially relevant and therefore were excluded. One was centred on policies and land planning in Spain [220], and the other examined building codes in the US and Australia [221]. In WoS, five new records were found, again not matching our in-progress review. These concentrated on spotting during uncontained fires [222], policies and mapping methodologies [44], fire ecosystem (dis)services [223], databases for evacuations [224], and evacuation procedures [225]. No new records were found using Agris.

A last search was performed immediately before submission (9 August 2023), for the sole period 2020–2022. In WoS, 43 publications were retrieved, in Scopus there were 21 publications, and 1 in Agris. After deletion of duplicates (n = 24) and reviews published in January 2020 (and therefore already considered, n = 4), titles and abstracts were screened. Only one publication [209] was assessed for eligibility, but it was a methodological study on post-incident surveys.

The preliminary search for similar previous reviews was carried out to identify a key gap in research. This was achieved and, additionally, provided valuable sources of information and improved our review process by refining the underlying research question, eligibility criteria, and the publication selection process.

Appendix B

Integrative information on the review process is presented in this appendix instead of registering a formal research protocol.

The choice of the research engines derived from their popularity in environmental sciences (Web of Science, Scopus) and life sciences (arXiv, bioRxiv), or from the important role of their maintaining agency in providing guidance for land management (Agris, Treesearch). The databases were first accessed on 19 March 2019 and lastly on 7 March 2023, to also include documents published before 31 December 2022.

The keywords used and the eligibility criteria were discussed in Materials and Methods and are presented again here: "*urban AND interface AND fire*" was used as a search string without imposing other search filters than the date limit. For each research engine, additional research options were selected:

- In Scopus, keywords were searched for in "article title, abstract, keywords".
- In Web of Science (WoS), keywords were searched for in "all databases", "all collections", "topic", and by enabling the "exact search" option.
- In Agris, a multilingual search was enabled and records that contained explicit link to the full text were considered, while records from aggregators were excluded.
- In arXiv, keywords were searched for in "all fields", including "cross-listed papers".
- In bioRxiv, keywords were searched for in "all sections" of "all collections", excluding the medRxiv database.
- In Treesearch, the search string was "urban interface fire", removing the logical operator "AND" as it appears to reduce the number of available records.

There were no barriers to accessing information, but in Agris, arXiv, and Treesearch it was not possible to download the list of the records (95, 4, and 491 publications, respectively), while for bioRxiv it was not possible to download records (n = 262) in a spreadsheet format. For this reason, results from these webpages were printed in PDF for examination offline.

In Scopus and WoS, records were exported and organised in spreadsheets, as explained in Appendix A. Totals of 1228 and 1464 publications were retrieved, respectively. These two spreadsheets were later used as a basis to remove duplicates from the printed PDF files.

Additional records were obtained from Google, from bibliographies of retrieved publications, and from suggestions by colleagues. These publications were contextually checked for duplication and eligibility. These records were marked as "external" as they were not obtained in a systematic manner.

Only full-text, readily available publications were retained in the process. Data used for the analyses were retrieved by reading the full text of the publications at final stage of the selection. Eligible studies were those including a definition of the WUI and/or physical measures to reduce fire risk. Ineligible studies were those related to emergency management and social sciences unless useful information could be retrieved from them. Eligibility was also assessed by document type: editorials, position papers, forewords, and presentation papers in general were not considered. Publications presenting fire risk mitigation measures without experimental data or meta-analyses were excluded, but, when possible and relevant, studies cited in these publications were retrieved as external entries.

Appendix C

This appendix aims at reporting more in detail the findings of this systematic review on WUI fire risk mitigation measures.

Appendix C.1. Measures for Natural Fuels: Clearance Distances

The most common recommendation to reduce fire risk in the WUI was the creation of concentric buffers around assets to design and implement fire risk mitigation actions.

Four buffers were identified: the first three protecting individual buildings and spanning tens of metres, and the fourth protecting groups of buildings and spanning hundreds of metres.

The first buffer immediately around a building (0.6–120 m from walls, median 10 m) should be inert to stop ignition by flame contact [5,87,91,93,95,100,103,114,125]. This area can be created with noncombustible materials such as concrete paths, paving blocks, and broken stone, and the width should be at least 3–5 times the height of surrounding grass when uncut [89,99,102,125,188].

The second buffer (range 3–100 m from walls, median 15 m) can be vegetated, but fuel load should be very low to reduce the amount of radiative heat emitted. Mowed herbaceous vegetation is preferred to trees and shrubs, and if these are present, they need to be widely distanced [12,36,99,100,114]. Fire-prone shrubs are discouraged here [5].

The third buffer (28–100 m from walls, median 60 m) can have shrubs and trees, but they need to be maintained with pruning and trimming, and residual biomass must be removed to reduce the amount of convective heat and flying embers impacting buildings [5,12,36,64,86,88,98–100,104,114].

The first three buffers can be widened near plantations [97], where natural vegetation has a high fuel load [98], or in case of steep slopes [99].

The fourth buffer zone is intended to protect groups of buildings. It spans for the first hundreds of metres from structures, often 500 m (mode) but ranging from 25 m to 10 km, with a median of 700 m [64,100,104–110]. One study further divided the fourth buffer into five concentric bands to organise the fuel management treatments (e.g., thinning, prescribed burning) [59].

Appendix C.2. Measures for Natural Fuels: Landscaping

Landscaping can contribute to reduce fire risk in the WUI by reducing available fuel near buildings.

When designing a new garden, the preferred arrangement for herbaceous plants is in raised beds, and in groups or widely spaced for shrubs and trees. A distance of five times their height between shrubs and 4–7 m between trees is advised [5,89,98,113,114,118,120,188].

In already-existing gardens, mulching helps containing weeds growth, but coarse mulch like pine nuggets, pine bark, and hardwood mulch are preferred over pine straw and grass mulch because they are less flammable [40,88,123–125,149].

If possible, watering plants, and especially turf, during the dry season reduces their flammability. To reduce the amount of fuel, turf needs to be mowed before the dry season [5,89,98,109,117,120,122]. Likewise, all dead plant material, on the ground or hanging, should be removed, especially litter under hedges [5,88,89,109,120].

To prevent fire transmission between vegetation and buildings, overhanging branches that are touching or near buildings should be removed, as well as branches within 3 m from chimneys. Trees around buildings should be removed for a distance of 10 m or one to two times the height of the trees [5,31,94,98,102].

Trees crown base height has to be raised to 2–9 m above the ground via pruning to avoid torching during wildfire [88,89,98,114,121,188]. To reduce fire spread between crowns, canopy ground cover needs to be low (35–40%) and crowns have to be widely spaced (3–6 m). A rule of thumb is to prune half of the tree canopy by volume every maintenance cycle [89,94,98,103,114,188].

For selection of plant species, preference is given to vegetation that retains a high amount of water in its tissues, such as deciduous broadleaves, succulents, and drought-tolerant species. Plants rich in resins, oils, and volatile organic compounds should be avoided as they can potentially increase flammability. Trees with needle-shaped leaves, such as conifers, have high surface area/volume ratios that facilitate drying and should also be avoided [5,36,88,111,120,126,140–142,188]. According to the publications interrogated, species commonly cited to avoid planting in the WUI are *Eucalyptus* spp., *Pinus* spp., *Juniperus* spp., *Erica* spp., and gorse (*Ulex europaeus*) [88,126–134,139–141]. For some species, such as Mediterranean Cypress (*Cupressus sempervirens*) and Oleander (*Nerium oleander*), there is no consensus on their hazard level [130,135–139]. If native vegetation is fire-prone, substitution with fire resistant species was recommended [5,98,101,109,117].

Appendix C.3. Measures for Natural Fuels: Wildland Fuel Management

Wildland fuel management applies the same concepts proposed for landscaping to vegetation beyond the home ignition zone.

To avoid vertical fire transmission, from ground to tree canopy, two interventions were proposed: selective thinning, leaving only the biggest trees (>30–50 cm diameter at breast height (DBH)) [36,98,144,146,147,150], and pruning, to raise canopy base height to 4–11 m above ground [100,144,145]. If understorey is retained for regeneration, habitat, or structural diversity, saplings have to be spaced (>4 m) and trees above them removed [36,98,188].

Thinning can also impair horizontal spread of crown fires, without reducing ecosystem services. Proposed targets were 75–400 trees/ha, two-thirds of forest canopy cover, 50% of basal area (BA), 11–27 m^2/ha of BA, and 3–6 m between crowns [89,108,144–150]. For the same reason, a target canopy bulk density of $\leq$0.1 kg/m^3 is advised [100,144].

To reduce the risk of windthrows and environmental disturbance, thinning is best performed in two steps separated by 5–10 years, or on clusters of trees, [36,98,144]. Wood debris from operations must be removed to reduce fire risk. Proposed alternatives were to pile and burn the debris, or to spread it in a shallow (<30 cm) layer [36,98,144,146,154].

In some countries prescribed burning (PB) is used along with thinning, or as its alternative, to maintain the desired forest structure. Before applying PB, debris should be removed or masticated to reduce smoke production, fire severity, and risk of uncontrolled fire. Prescribed burning can be performed up to 250–550 m from houses [98,101,108,109,167,188].

Care should be taken around wetland areas and waterbodies (lakes, rivers, sea) to reduce ecological disturbance and safeguard against wildfire [31,36]. Other means to combine fire risk reduction with environmental protection are to retain old trees, coarse woody debris (stumps, snags, and logs), and ecological corridors, because these habitat features do not appreciably increase fire risk and provide important environmental services [36,89,170].

Wildland fuel management has to be implemented periodically because of fuel buildup. Recommended intervals for thinning are 10–15 years, 2–7 years for PB, and annually for clearing shrubs [69,89,98,108,109,147,149,167]. In grasslands, fuel load can be kept low by mowing and leaving the grass in place, or by grazing livestock [5,89,151–153].

At a broader scale, fuel discontinuity can be achieved by clearing strips of vegetation (firebreaks) to stop the spread of fire [155–158].

For fuelbreaks, some vegetation is retained because the aim is to provide access and a safe defending zone to fire crews. Fuelbreaks should be positioned against fire barriers such as roads, creeks, outcrops, or on top of ridges. In fuelbreaks, tree crowns should be spaced (>3 m, canopy cover < 25%) and lower branches pruned. Only large trees (DBH > 35 cm) should be retained, and dead snags removed. If groups of trees are retained, they must be managed to keep the fuel load low [154,156,159].

Green belts are used to protect linear infrastructures and consist of buffers of managed, less ignitable vegetation on each side of roads (3–10 m) or power lines (5 m) [5,89,90,101,108,142,160]. The side below the road should have a wider buffer to reduce heat transfer by convection [159].

At the landscape level, maintenance of a fragmented land cover reduces wildfire severity in the same way as fuel discontinuity around assets. Agrarian fields, grasslands, and deciduous forests are less prone to fire than grasslands, plantations, or coniferous forests [8,119,129,136,152,154,161–166,168,169,188]. Mixed broadleaf–conifer forests may have a lower risk of fire than pure forests [135]. Some studies assign a high risk of fires to shrublands, while others do not [119,137,152,154,162,164–167,188,225]. One study suggested the conversion of plantations and agrarian fields to fire-adapted native forest [162].

Appendix C.4. Measures for Anthropic Assets: Land Planning

Land planning for new constructions in the WUI has an even greater role than topography or vegetation in risk mitigation [102,173–175].

Compact settlements (circular, square) can be better defended in case of wildfire. The perimeter adjacent to neighbouring vegetation, and thus to fire, is smaller and fire crews have quicker access to buildings [64,108,116,137,175–177]. Only two studies speculate that the buildings themselves can be a source of ignition if not spaced widely apart [103,177].

Buildings on steep slopes (>20% gradient) and close to ridges (<45 m) are more exposed to anabatic winds and convective heat transfer during fires, and should not be built there, although these locations are preferred by residents for aesthetic views [5,89,92,101,102,120,175,176].

In relation to infrastructure, burying power lines can avoid accidental ignitions during storms [89] and, presumably, during wildfire. The road network can be a source of ignitions [160,169,178–180], but can also hinder fire propagation [108,159,179]. Roads need to be multifunctional: wide enough to stop surface fires [108,176], designed to allow fire engines transit [89,90,108,120,176], without dead ends [89,90,92,120], and with cleared buffer stripes (2–30 m) [89,108].

Appendix C.5. Measures for Anthropic Assets: Building Design and Materials

For a single building, mitigation actions can be carried out directly by the owner, at a fraction of the cost of community mitigation actions, and often to already-existing structures (retrofitting).

With reference to building design, roofs are a critical point in relation to wildland fire risk [5,181]. Roofs designed with valley angles greater than 135° showed no ignition when subject to firebrands, because they could not deposit and smoulder [182]. Spaces where firebrands can accumulate should be avoided, such as overhanging roofs, corners, eaves, and post-and-beam foundations [5,102,120,122,181,185,187,188]. Vents, chimneys, and spaces under decks should be covered with metal mesh (5 mm) [5,120,186–188].

Other features of houses are a potential entry point for fire [92,103,120] and their safe design should be considered. For example, fences should have a lattice design to allow permeability of heat and wooden fences should be treated with fire retardant [91]. Properly constructed wooden decks can withstand burning under a continuous shower of firebrands [183], do not transmit fire to the adjoining structures [184], and, in some circumstances, may deflect heat and be regarded as a safe area [5].

Preferred building materials for roofs are ceramic, concrete, slate, metal, asphalt, or composite, while wood should be avoided unless treated with retardant [5,89,92,94,101–103,120,122,185,187,188,190,191]. Nonetheless, even intact ceramic and concrete tiles may be permeable to flying embers [186,190], and degraded ceramic and asphalt covers can present the same problem [175,182].

Walls should be of inert materials like fibre cement, bricks, stone, and stucco [5,89,92,102,103,120,122,175,185,187–189]. Timber buildings can withstand a grass fire if they contain enough moisture [91].

Windows are exposed to high thermal differences during wildfire. Glass should be tempered [5,122,175,187] and preferably in multiple panes [103,122,175,187]. Large windows should be avoided, or at least equipped with fire-resistant shutters [5,102].

Temporary dwellings such as tents and caravans, which are often used for leisure, are particularly vulnerable during wildland fire. Mobile homes burn more readily than permanent ones [102,122,181], and camping tents should be made of fire-resistant material and need to be placed in fuel-free areas [193].

Additional miscellaneous measures can increase building survivability, for example, presenting the house address on a visible reflective sign can facilitate rescue operations [89,120,188]; maintaining a portable gasoline pump to activate roof sprinklers and water pumps in the event of loss of power; keeping a (noncombustible) ladder at hand to reach the roof; installing outdoor taps with rubber hoses to wet building surfaces and surrounding vegetation; allowing swimming pools to be used as a water resource for firefighters [5,120,188].

All sources of fuel should be removed from buildings walls. This includes outdoor furniture, which can transmit fire to structures or other material [103,120,188,197]. Wood piles should be kept away (>10 m) from the house [5,92,103,120,188]. Fuel tanks (e.g., LPG) should be surrounded by bare ground (3 m) and they should be placed well away (30–50 m) from wildland fuel. Protective shelters specific for LPG tanks are currently being developed [194–196,198].

Finally, proper maintenance of buildings is crucial. Old houses have a higher probability of burning [103,175], and all types of roofs become ignitable with ageing [94,182,192]. Simple maintenance actions such as removing debris from gutters and roofs and away from exterior walls have resulted in effective reduction of ignitions from flying embers and surface fires [5,87,120,122,182,188,192].

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