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2.1 Introduction: The meaning of territory in Forest Fire and Drought cases

We have made the decision to deal with “state-of-the-art” territorial vulnerability approaches to droughts and forest fires in a common section because we felt that the parameters involved fully justify this choice. The following paragraphs, which make up the introduction, hopefully provide an idea of how “territory” is conceptualized, first in the case of droughts and then in the case of forest fires. Although the relevant papers on droughts and forest fires, which were used as contributions to this chapter, were produced independently, we attempted a synthesis, both in the introduction and in the following sections.

Definition of drought

According to WMO (1975) drought is defined as “a deficit of rainfall in respect to the long-term mean, affecting a large area for one or several seasons, that drastically reduces primary production in natural ecosystems and rained agriculture" (see Le Houérou, 1996). The definition of hydrologists is somewhat different: "drought means the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels causing hydrological imbalance that adversely affects land resource production systems" (ICCD, 1994; Williams and Balling, 1994).

The material on droughts included in this chapter focuses on *drylands*, i.e. areas having a ratio between precipitation (P) and potential evapo-transpiration (PET), i.e. P/PET < 1. Drylands represent a total of 47.2% of the earth's land area (Oldeman et al., 1990) and are inhabited by approximately one third of the world population. These areas experience essentially more frequent droughts comparing to other types of Earth lands. According to P/PET ratio, drylands can be further subdivided into hyper-arid, arid, semi-arid and dry sub-humid zones (Table 1). Excluding hyper-arid zones, which are actually represented most predominantly by the Saharan Desert, hyper-arid lands generally are unsuitable for growing crops and therefore have already reached the ultimate level of desertification. Consequently, the remaining 39.7% of the drylands are under threat of desertification (Table 1, Fig. 1).

Table 1: Regional distribution of the world climatic zones, 103 km2 (Oldeman et al., 1990).

Zone	Africa	Asia	Australia	Europe	N. America	S. America	Total	%
Drylands								
Dry sub-humid	2687	352	513	1835	2315	2070	12947	9.9
Semi-arid	5138	6934	3090	1052	4194	2645	23053	17.7
Arid	5035	6257	3030	110	815	445	15692	12.1
Hyper-arid	6720	2773	0	0	31	257	9781	7.5
Drylands total	**19580**	**16316**	**6633**	**2997**	**7355**	**5417**	**61473**	**47.2**

Other land types								
Cold	0	1082	0	279	6169	377	7650	13.6
Humid	10076	12243	2189	622	8385	11881	51004	39.2
Other total	**10076**	**13325**	**2189**	**901**	**14554**	**12258**	**58654**	**52.8**
Earth Total	**29656**	**42560**	**8822**	**9505**	**21909**	**17675**	**130127**	**100**

Generally, with an increase in the ineffective rain-aridity proportion (Le Houérou, 1984), i.e. with the decrease of P/PET ratio, the probability of droughts increases.

Land degradation and decrease in productivity of intensively exploited lands may also be the result of a temperature increase, not necessarily accompanied by a decrease in precipitation (see Emanuel et al., 1985; Manabe and Wetherald, 1986). As the pre 1950s conditions are considered as a benchmark for landscape change, humid regions may also experience some degree of desertification. Yet, the consequences of temperature increase *per se* as well as other changes that can be caused by global warming are beyond the scope of the present report.

In this review we address desertification stemming from frequent droughts in drylands. To provide a quantified definition, a drought year is defined as a year during which precipitation is at least 25% lower than the long-term annual mean or over 35% of the precipitation falls during the spring months (March-May for the Eastern Mediterranean). We consider spring rains as having only limited contribution to plants, especially to annuals and rain-fed crops. We ignore hyper-arid areas (less than 100 mm of precipitation per year), where the vegetation is extremely scattered and put special attention to arid (100 - 200 mm) and semi-arid (200-400 mm) zones, which e.g. characterize the southern part of Israel.

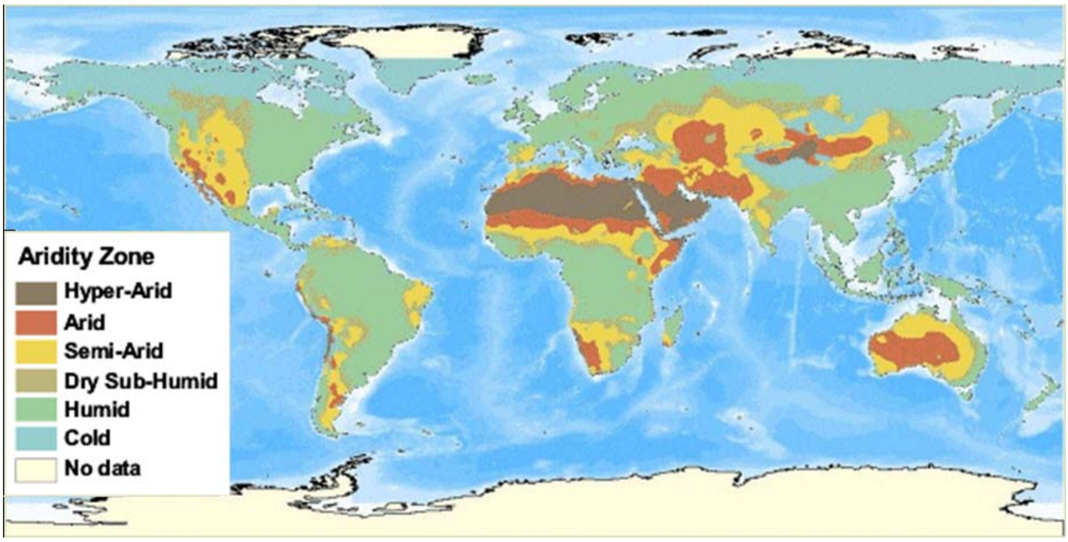


Figure 1: World aridity zones. Source: World Resources Institute. 2002. Available online at: http://www.wri.org.

This chapter presents the state-of-the-art of current knowledge on droughts' influence on ecosystem and man. At the next stages of ENSURE research, we can and will compare different scenarios of drought, including those reflecting long-term global warming and land-use changes, and their influence on selected ecosystems. The influence of drought is a part of a wider task of the partners who contributed the relevant report, which focuses on vulnerability of the Northern Negev region in Israel to natural and man-made hazards.

Drought and Desertification

During drought, the ecosystem approaches the threshold of sustainability and its ability to rehabilitate is damaged partially or even irreversibly. The longer is the drought the most probable is area's transition beyond sustainable state and entering the feedback that can finally lead to *desertification*. While some scientists distinguished between "aridization" caused by natural climate change and "desertification" caused by human impact (Tao et al., 2002; Le Houérou, 1996), we regard desertification as a general term regardless whether caused by natural or human causes.

Qualitatively, desertification is defined by its consequence - degradation of lands that might lead to minute production. As it is claimed at the UN Desertification Conference in Nairobi, Kenya, in 1977, desertification is: "A reduction of the land production potential in arid, semi-arid and dry sub-humid zones that may ultimately lead to desert-like conditions" (see Karrar and Stiles, 1984). The notion was broadened at the Earth Summit, the UN conference on Environment and Development (UNCED, Agenda 21) in Rio Janeiro (1992) and agreed upon at the International Convention to Combat Desertification (ICCD, 1994): "Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climate variation and human activities".

Land abuse by man is considered as a cardinal factor accelerating or even determining desertification. In Africa, for example, the main anthropogenic effects are overgrazing following by agriculture and forest clearing (Le Houérou, 1996). Positive linear relation between the density of rural human population, livestock and desertification was found not only in Africa, but in most developing countries (Le Houérou, 1996).

Whether frequent or infrequent, droughts exert a high burden on the ecosystem. The vulnerability to droughts is reflected at the organism and community levels and at the entire ecosystem (biotic and abiotic). As in the case of forest fires, *territorial* vulnerability to droughts refers either exclusively to natural ecosystems or to coupled human – ecological systems. This is illustrated in our discussion on the impacts of drought included later in the section on objectives.

Forest Fires

In contrast to droughts, wildfires start at a point in the landscape, but those that cause most damage often cover large areas. The 2007 fires in Greece and recent fires in California and Australia burnt hundreds of thousands of hectares, destroying farms and farm animals, thousands of homes and the associated infrastructure, and in the case of California causing hundreds of thousands of evacuees. Vast areas – in some cases large proportions of a country – may be threatened and the health of local people affected by smoke, local commerce suspended, towns put on alert and whole suburbs on the urban-rural interface destroyed in less than an hour. Hence, forest fires have a strong spatial and territorial character. As it will become clear later, they are associated with droughts and climate change.

The territorial impact of wildfires is more extensive than that of a major earthquake, although they do not burn into the central business areas of major cities. Uniquely – compared with other hazards – vast specialist resources are maintained and used to combat wildfires. When very large fires are involved, these resources are supplemented by those from other countries. However, there are questions over the cost-effectiveness of this approach.

A wildfire is usually synonymous with a forest fire, bushfire, grassfire and other terms that pertain to local contexts and are used locally to describe an unwanted fire burning across the landscape. The term “wildland fire” is also in use, even though wildfires occur frequently in rural rather than wilderness landscapes.

Such landscape fires are very common in rural areas largely as a result of deliberately lit fires used for land management – for example, related to agriculture in Europe, fuel management in many areas, and for ecological reasons, for example in parts of Australia. Fires also occur naturally as a result of lightning. Both these types of fires generally burn and spread slowly, cause little damage and are reasonably easy to control or extinguish. The risk of any given fire spreading and becoming uncontrollable depends on the weather conditions. Wind driven fires occurring on hot windy days are often uncontrollable. In addition to the flames, heat, embers and smoke possess a major health hazard and can make transport difficult by reducing visibility. Around human settlement, many fires are deliberately lit by arsonists, or result accidentally from careless use of machinery. Arsonists usually light up on extreme fire weather days, and because they generally operate near or within urban settlements, the resulting fires can be very dangerous with little or no warning for those at risk.

Territory in the case of forest land is used to represent in the main an eco-system; but when the forest fire phenomenon became usual in the case of mixed wildland-housing and wildland-urban interface areas the term *territory* came to approximate more or less a geographically embedded, human-ecological system, the vulnerability of which incorporates clearly a structural component (the vulnerability of building structures to fire), a socio-economic component (vulnerability of the potentially impacted communities) and an ecological / environmental component. Nevertheless in the case of forest fires, neither the use of the expression “territorial vulnerability” nor the concept of an interlinked chain of impacts when assessing the impact of fire are usually present. The focus is more on elaborating fire risk assessments by analyzing landscape, socio-economic and climate parameters.

At this point it is useful to refer to some other particularities of the terminology used by the forest fire research community. In particular, the most frequently used terms in forest fire literature and research carry the following meanings according to the California Governor's Office of Emergency Services (*Structural Fire Prevention Field Guide: For Mitigation of Wildland Fires,* 2000):

- *Hazard* means the resistance to control once a wildfire starts. Fuels, topographic features and weather conditions adversely affecting suppression efforts are hazard factors.
- *Fire Hazard* is dangerous accumulation of flammable fuels in wildland areas usually referring to vegetation; the flammable materials that may be ignited by the various fire risks or cause fires to increase in intensity or rate of spread.
- *Risk* is the likelihood of a wildfire ignition. This is normally a result of the activities of people.
- *Fire Risk* is a source of ignition of fire hazards.
- *Risk-Fire* is the potential for ignition of fuels or an ignition agent.
- *Wildland Fire* means any fire occurring on undeveloped land.
- *Urban-Wildland Interface* refers to the geographical point where flammable vegetation meets man-made structures.

According to the Climate Change Research Community when talking about the occurrence of forest fires the anthropogenic dimension of risk is determinant. Excluding the meteorological and geophysical conditions of hazard production, man plays a very important role on forest fire events as far as triggering and spreading is concerned. In fact, human action over territory has a decisive influence on forest fire risk, conditioning both the hazard probability of occurrence and its impacts over natural environments and populations living on the affected areas. There are several methodologies of forest fire risk assessment, adjusted to different objectives of forecast and management, to diverse time and space scales, as well as to varied territorial realities and climate contexts.

2.2 Objectives

Our purpose in this section is to place the objectives of our task in the context of impacts of droughts and forest fires. We take the view that the best way to convey our intention to explore territorial vulnerability is to refer to these impacts, which create the necessity not only to resolve conceptual issues but also to throw light on the need for appropriate methodologies of analysis and action. We made the point earlier that territorial vulnerability to droughts is evident either in the case of natural ecosystems or in the case of coupled human – ecological systems. This can be seen in the following discussion on the impacts of drought on these systems, which will be followed by a sub-section on the impacts of forest fires. Besides, climate change and droughts can directly lead to increased fire risks, as pointed out later in the section on the socio-economic impact of droughts.

2.2.1 The Impact of Drought on Ecosystems

During drought, additional clear days and consequent extra load of radiation affects a complex of abiotic and biotic processes in the ecosystem. The effects are both direct and indirect (Austin 2002). Despite some open questions, there is a wide agreement between the researchers regarding the critical role of droughts in shaping the ecosystem.

<u>The Impact on the Abiotic Components of the Ecosystem</u>

Increase in surface temperature and evaporation

First, drought causes a direct increase in surface temperatures, especially of the bare areas. According to Weaver and Albertson (1944), the severe droughts of the 1930s in the USA have resulted in an increase of several degrees in surface temperatures. As reported by Herbel et al. (1972), surface temperatures were by 3.5ºC higher during a drought than under normal conditions. The increase in surface temperature further results in increased evaporation. According to Gardner (1950) the latter can reach 130% of the normal level.

The reduction of vegetation cover during drought period, results in an increase in the extent of bare areas (Balling et al., 1998). Bare areas are characterized by lower soil organic matter (SOM) and less microorganism population (Kieft et al., 1998; Borken et al., 1999). Furthermore, bare areas are subjected to intensive rain drop impact during future rainstorms. The latter would lead to higher surface compaction and to the formation of a physical crust (Le Houérou, 1996), which, in turn, promotes runoff (Cammeraat, 2004; Assouline and Mualem, 1997). As a result, relatively short drought of few years can cause extensive bare areas covered by microbiotic crusts. These areas would be characterized by increased runoff yields and high sediment and nutrient loss during future rainstorms (Kidron and Yair, 1997, 2001; Kieft et al., 1998; Bestelmeyer et al., 2006).

Wind erosion

Another factor responsible for sediment and nutrient loss during and after a drought period is wind erosion; the reduction in plant cover during droughts results in an increase in the surface wind speed (Herbel et al., 1972) and thus, increased loss of soil nutrients (West et al., 1984). According to Gile (1999), three years of consecutive droughts sufficed to cause high erodibility in Southwestern United States, to expose hard subsoil horizons to the surface, and to decrease substantially the uppermost soil layer and hence soil fertility.

"Positive" side effect of the increase in bare areas is the reduction in fuel load and, thus, of fire risk and/or severity (Grover and Musick, 1990; Scholes and Archer, 1997; Peters et al., 2006). Yet, fire risk may increase due to the higher temperatures that characterize drought years.

Reduced precipitation and decrease of water table

At a global scale, the reduction in precipitation during drought decreases spring and river flow (Boulton, et al., 1992; Manga, 1999). It lowers the level of water table (Sophucleous and Perkins, 2000), and affects the chemical composition of rivers and lakes (Webster et al., 1996). Decreasing surface moisture and water table accelerate dune mobility (Gibbens et al., 1983) and consecutive land erodibility, bringing about sand and dust storms.

<u>The impact on flora</u>

Decrease in productivity and plant survival

In dry ecosystems, productivity depends on rain supply (Patten, 1978) while plant communities are essentially sensitive to rain pulses (Noy-Meir, 1973). Drought imposes an added challenge upon plants and thus, upon the entire ecosystem (Rietkerk et al. 2004), and may result in a decrease in above-ground phytomass. Net primary production may decrease between 3 and 10 times from wet to dry years (Huenneke and Schlesinger, 2006).

According to Le Houérou (1996), there is a linear relationship between the amount of rainy days and aridity. The author stresses that variability in rainfall results in a 20-50% increase in the subsequent variability of plant productivity. This is especially relevant for deserts where small fluctuations may result in extreme dry conditions (Tevis, 1958) and thus in a substantial decrease in plant productivity.

Rainfall amount is the most important productivity factor, which explains over 90% of the productivity variation (Sala et al., 1988). According to Noy-Meir (1973), a minimal quantity of water necessary for plant growth is 25-75 mm per season. A similar threshold of 50 mm per season was reported by Le Houérou (1986). It is very important whether this amount falls in winter, spring or summer. In areas characterized by winter precipitation, some of the rain falls also in spring. Yet, with high proportion of spring rain and consequently low proportion of winter rain, overall productivity may be severely affected, as it may hinder germination and impede the development and growth of rain-fed winter crops. Much higher evaporation during the spring may explain part of the limited contribution of spring rains. Similarly, regions that are characterized by summer rains are characterized by lower amount of moisture in the soil following the same amount of rain (R) in comparison to winter rains (Mott, 1972). As a result, productivity to rain ratio P/R is lower in summer than in winter (Noy-Meir, 1986). In addition, altitude may also have an important effect upon evaporation (Huntigford et al., 1998; Blyth, 1999) and precipitation (Yang and Lowe, 1956).

The timing of rain is also important in determining the length of the growing phase. Late rainstorms or a long hiatus between consecutive rains may substantially shorten the life cycle of annuals from typical 10-20 weeks to 6-10 weeks (Beatley, 1967), or even 5-6 weeks (Shreve, 1942). Furthermore, large rainstorms and long periods during which the soil remains wet increase plant survival.

To bypass the complex relations between season, altitude and other factors influencing R/P ratio and productivity, Beatley (1967, 1969) directly relates plant growth and soil moisture, and considers the top 7.5 cm soil layer as the most effective layer for plant survival. Higher soil moisture content and subsequent higher plant cover may thus characterize elevated areas within the same geographic zone (Shreve, 1942; Svoray et al. 2004).

Soil moisture plays also a cardinal role in determining plant growth. The longer the soil remains wet, the denser and taller the vegetation (Shreve 1942). Conversely, following droughts seedling mortality may take place (Beatley, 1967; Tielbörger and Kadmon, 1995).

Decrease in diversity of plant community

Consecutive droughts may reduce plant species diversity (Gibbens and Beck, 1988) and also change species composition. Drought may result in the migration of plant communities further to the poles, where the environmental conditions are more favourable or may result in the penetration of alien invasive species into bare areas in forests. This was indeed the case with the invasive species *Acacia saligna* in the Judean Hills in Israel and in other parts of the world (Holmes and Cowling, 1997). Similarly, during the droughts of the 1930s, an increase in succulents and cacti took place in the mid and southwestern USA (Weaver and Albertson, 1944). Yet, the cacti population decreased again following wet years.

Decrease in germination

Soil moisture is cardinal for plant germination and growth and is a natural parameter that relates rains and plants (Snyder et al., 2006; Svoray et al. 2007). It is also determined by temperature (Kidron, in press) and lower temperatures at high altitudes will result in lower evaporation rates (Huntigford et al., 1998; Blyth, 1999). Similarly, strong winds may substantially increase evaporation (Le Houérou, 1996; Kidron, 2005) and may thus reduce soil moisture and hence plant cover.

Plants' moisture demand for germination is higher than for growth (MacMahon and Schimpf, 1981). Therefore, large rainstorm may result in a 3-4 fold increase in annuals' and even in perennials' germination (Went, 1942, 1949). While rainstorms of 25 mm and higher are necessary for maximal germination in deserts, rainstorms as small as 5-6 mm are considered minimal (Went, 1953; MacMahon and Schimpf 1981). These authors also stress the fact that higher amounts of rain are needed for the germination of summer annuals compared to winter annuals.

Wet years increase flower and seed production (Shreve, 1942; MacMahon and Schimpf, 1981) and high moisture in deserts may cause a 3-4 fold increase in flower yield and subsequent seed production (Tevis 1958).

Soil moisture is not the only factor to affect germination. Timing of the precipitation is also important (Paulsen and Ares, 1961). While a small rainstorm may not suffice for germination, two small rainstorms during less than 48 hours may compensate and provide total moisture that will suffice (Went, 1955). Timing is also crucial due to the temperature effect, with winter and summer plants requiring completely different range of temperatures for germination (Went, 1949). This is especially crucial for regulating the germination in regions having bi-seasonal precipitation, such as in the southwestern United States. High temperatures will also impede germination of winter annuals in regions such as the Eastern Mediterranean having winter rains. This may partially explain the limited contribution of spring rains.

Germination is also impeded by a physical crust, which results from the rain drop impact on the bare soil (MacMahon and Schimpf, 1981; Le Houérou, 1986). Physical crust is more likely to develop in deserts where plant cover is low (Assouline and Mualem, 2003). It is more so during droughts and then wider than usual areas become directly impacted by the rain drops. As a result of low precipitation and physical crusts, much lower fraction of plants successfully germinates during droughts. And thus, according to Went (1955), germination during droughts may be less than 1 percent of the amount that characterizes normal conditions.

Plant species coping capacity to droughts

Generally, plant species have developed physiological mechanisms to cope with variability in water supply. Annual plants compensate for low or even unavailability of water by inhibiting their growth until favourable moisture conditions improve. Shrubs overcome dry conditions by reaching more moisture at greater depth. Halophyte species are able to use high soil water potential, while cyanobacteria shift into a dormant state (MacMahon and Schimpf, 1981; Gutschick and Snyder, 2006).

Adaptation to drought can essentially increase the vulnerability of the plant community. Some plants have developed symbiotic relationships with fungi known as arbuscular mycorrhizal (AM), a symbiosis that increases soil water-holding capacity (Augé et al., 2001) and plant tolerance to low water availability during droughts (Ruiz-Lozano, 2003). Nevertheless, whether better adapted or less, drought results in a decreased above-ground phytomass. According to Huennecke and Schlesinger (2006) net primary production may decrease between 3 and 10 times from wet to drought years.

<u>The impact on fauna</u>

The influence of drought on natural fauna is beyond the focus of this review and will be considered in short. Drought has a strong impact upon animals, both directly and through reduction in plant productivity. Most important are two effects: *First*, the reduction of above-ground phytomass during drought affects the entire food chain. Affecting plant communities, drought thus affects species composition and diversity of the fauna (Noy-Meir, 1974) leading to animal migration towards more favourable regions. *Second*, many animal species tend to postpone mating until the first substantial rainstorm. In addition, many animal species are characterized by lower reproduction rate and higher mortality during droughts (Myers, 1968; Turner et al., 1970; Noy-Meir, 1974). Besides direct reduction of the amount of food, the reduced phytomass increases competition over food between faunal species. This is especially valid for species confined to specific plants in their diet.

Abiotic-biotic Relationships as Affected by Droughts

Simultaneous effects of droughts on biotic and abiotic components of the ecosystem

Droughts simultaneously affect the abiotic (physical) and biotic (organisms) conditions. For instance, the increase in bare areas (microphytic patches) during drought affects ecosystem water budget in two ways: by promoting runoff yield and by increasing evaporation. The runoff that leaves the ecosystem through arroyos reduces the amount of water that remains available within the ecosystem and the bare areas are subjected to higher radiation load, and increased water loss with increased evaporation. Runoff that remains within closed basins and concentrates in topographical depressions serves there to sustain a relatively lush vegetation and fauna (Kidron, 1999). Consequently, surface heterogeneity and species diversity increase (Shmida, 1986).

Another example of the interaction between biotic and a-biotic factors is the influence of drought on sand dunes and sandy landscapes. High surface temperatures during drought substantially increase evaporation (of up to 1/3, Gardner, 1950) and impede germination (Neilson, 1986). For sandy soils, high rates of erosion and/or deposition expose plant roots to high temperatures or alternatively bury the plants, resulting, in both cases, in high plant mortality (Weaver and Albertson, 1944; Herbel et al., 1972).

Droughts as the factor of vegetation shift

Complex relationships between physical and biotic components lead many authors to conclude that recent vegetation shift in the southwestern part of the USA may have resulted from consecutive droughts during the last 100 years (Lohmiller, 1963; Gibbens and Beck, 1988; Bestelmeyer et al., 2006). Frequent droughts during the last 100 years may have influenced the long-term succession processes and caused extreme vegetation shift in the Chihuahua Desert by changing the balance between winter (shrub) and summer (grass) vegetation. Indeed, being primarily a grassland ecosystem during the end of the 19th century and the beginning of the 20th century (Clements, 1934), the Chihuahua Desert experienced a drastic shift with winter shrubs encroaching northward, and replacing perennial grasses. The reasons for the shift are still under debate. Only few researchers have related it to CO_2 concentration increase that affects the efficiency in which summer and winter plants fix carbon (Cole and Monger, 1994). Several others explain the shift as a result of frequent summer droughts during the late 1890s, 1910s, 1930s and 1950s, that were favourable for winter shrubs (Lohmiller, 1963; Bestelmeyer et al., 2006). Being more resistant to droughts (Gibbens and Beck, 1988; Wainwright, 2006), shrubs are thus believed to be more adapted to drought than grasses.

Once established, a spatial rearrangement is taking place. According to the literature, nutrient translocation takes place by runoff and wind from the inter-shrub habitats (termed also microphytic patches) into the under-canopy habitat (termed macrophytic patches), resulting in higher concentration of nutrients under the shrubs (Schlesinger et al., 1990; Schlesinger and Pilmanis, 1998; Cross and Schlesinger, 1999). This is especially so in areas subjected to overgrazing which almost solely results in grass consumption, thus substantially reducing the grass capability to compete with shrubs (Schlesinger et al., 1990). Due to nutrient shortage, future grass re-establishment at the microphytic patches is thus extremely difficult (Grover and Musick, 1990; Schlesinger et al., 1990)

The above dynamics of plant spatial distribution during competition for nutrients (Neilson, 1986; Szarek, 1979) is conceived as the leading hypothesis in explaining the vegetation shift in the southwestern United States. Nevertheless, various aspects of the model are in dispute (Buffington and Herbel, 1965; Scholes and Archer, 1997; Abrahams et al., 2006; Bestelmeyer et al., 2006). Weaver and Albertson (1944) stress the resilience of the dominant grass, black gramma (*Bouteloua eriopoda*) to drought, and emphasize the importance of soil moisture for species diversity, while Went (1953) disregards competition for nutrients as a major factor controlling plant growth in deserts, and considers moisture as the prime factor. Indeed, lack of moisture following frequent droughts may substantially affect shrub cover. Guevara et al. (1997) report on 65% of shrub mortality following drought in southern Argentina and Ram and Yair (2007) report on after-droughts high shrub mortality observed in the past several years in the western Negev Desert in Israel.

2.2.2 The Socio-Economic Impact of Droughts

Arid and semi-arid zones as most vulnerable to droughts

Among the drylands, drought effects on the ecosystem are strongest in the arid and semiarid zones. Arid zones are usually sparsely populated, while semiarid zones are inhabited by approximately one billion people (Havstad and Schlesinger, 2006) and the social and economic effects of droughts there may be thus essentially wider. Unlike the hyper-arid zones, the arid and semiarid zones have dispersed geographical distribution (Fig. 1) that include countries with different development level (Fig. 2), and hence have differential social vulnerability. The main task is then to assess the implication of droughts with respect to social vulnerability in different geographical scales.

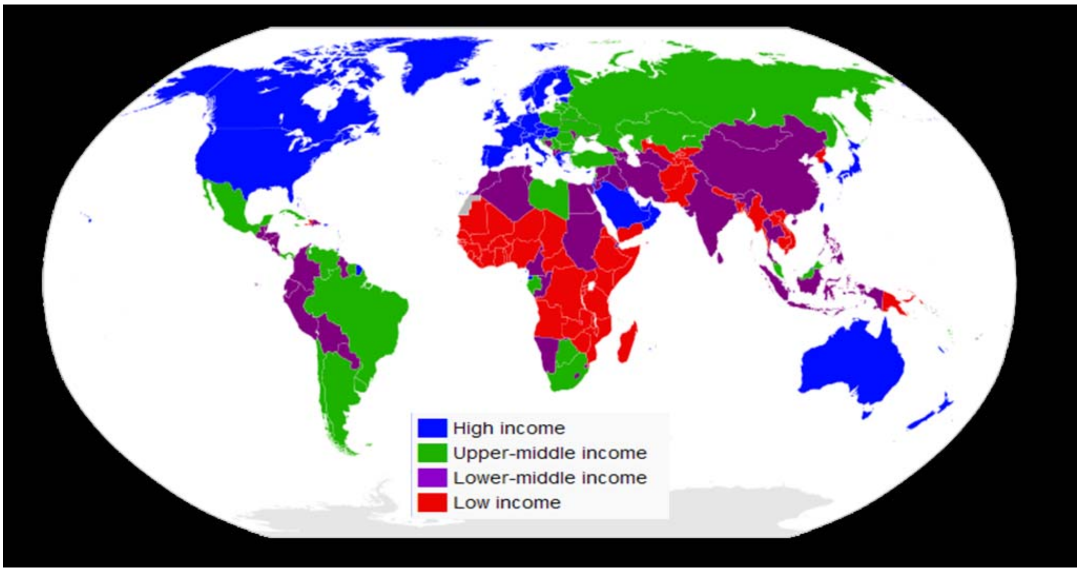


Figure 2: World income level. Source: World Bank income groupings for 2006 (calculated by GNI per capita)

Direct and indirect influence of drought on humans

The effect of droughts on human society is multi facetted. That is because the effects on ecosystems are passed further to humans: Increased surface erodibility and aridization risk economic status especially through agriculture and farming in arid and semiarid zones (Mitchell et al., 1998), dust storms affect air and water quality (Hagen and Woodruff, 1973; Stensland and Semorin, 1982), causing diseases (Bar-Ziv and Goldberg, 1974), and are hazardous to aviation and traffic (Pye, 1987).

Vulnerability of plant agriculture and farming to droughts

In economic milieu, drought-caused change in the carrying capacity of grazed areas leads to a decrease in cattle productivity (Noy-Meir, 1974; Evenari et al., 1971; HilleRisLambers et al., 2001). For instance, cattle stock of the semi-arid southwestern US, with 250-300 of annual precipitation, requires 30-60g more of the dry mass per square meter of the grassland than the ecosystem could supply during periods of droughts (Havstad and Schlesinger, 2006). The decrease in grassland productivity there resulted in substantial decrease in cattle heads (Grover and Musick, 1990; Conley et al., 1992) and steep economic losses of the cattle owners (Conley et al., 1992). In face of increased mortality many rangers transferred cattle outside the impacted zones (Gardner, 1950).

Generally, during drought, domesticated grazers demand essential outer source of food to reach the necessary level of the 2.5% of their weight per day (Guevara et al. 1997). As a result, during droughts the cows are replaced by goats that make do with lower amounts of food and are better adapted to consume shrubs (Lioubimtseva et al., 2005). This produces a switch to goat foraging on shrubs and a subsequent increase of the cover of microphytic patches.

Despite some advantage of nomadic farming during the years after droughts, droughts pose a severe burden upon cattle farming in the arid and semiarid zones. On the one hand, the raise of the livestock prices during droughts entails overgrazing (Fafchamps and Gavian, 1997), on the other, the lack of natural vegetation cause changes in the household structure (De Bruijn, 1997), and emigration of farmers from the drought area (Hampshire and Randall, 2000; De Haan et al., 2002). The stronger is farmers' dependence on the local foods the more severe are the consequences: Frequent droughts of 1970s and 1980s in the Sahel (Khalfaoui, 1991; Sumberg and Burke, 1991; Sivakumar, 1992) lead to emigration of family members or entire families (Le Houérou, 1996), changed traditional proportion between the rural and urban population there, and enforced drastic changes upon cities and infrastructure.

Droughts often lead to a major change in crops to those demanding less water and are more resilient to higher temperatures and drier conditions. For instance, alfalfa and citrus trees that demand large amounts of water can be substituted by barley, sorghum and olive trees for which less water suffices. Similarly, cotton can be substituted by sesame or pearl millet (Le Houérou, 1996).

Influence of droughts on life quality and socio-economic activity

Droughts have effects on quality of life and other socio-economic activity. Considering landscape changes in a longer term, let us note that while infrequent droughts primarily affect farmers and rangers, frequent droughts may affect the entire matrix of urban and rural life. Exhaustion of resources, shift to intensive agriculture and expansion of the urban centers are only some of the global effects that are expected.

Global warming can drastically affect all aspects of life in the arid and semiarid zones (Foley et al., 2005).

One of the main aspects is health and quality of life. Dust storms affect air and water quality (Hagen and Woodruff, 1973; Stensland and Semorin, 1982), cause diseases (Bar-Ziv and Goldberg, 1974), and are hazardous to aviation and traffic (Pye, 1987). Drought can decrease the water quality and contribute to a higher concentration of pollution in surface water (Collins and Bolin, 2007) which can lead to diseases and mortality. Bad water infrastructures aggravate these impacts of drought. In addition, reduced water level in the surface waters and reservoirs entails changes in water temperature which may cause fish populations to diminish. Another important aspect is fire risk. Reduced humidity and higher temperatures increases the risk of fires. Indeed, the risk of forest fires in many countries like Italy, France and Greece increased recently. Consequently, higher budgets are required for prevention and extinction of fires (Isendahl and Schmidt, 2006).

Reduced water availability creates conflicts between people as individuals, ethnic groups and countries. The Darfur tragedy is seen by some analysts as an actual example for natural and socio-political disaster that results from conflict between people that try to sustain their livelihoods. Water scarcity creates also conflicts between land uses which need water for their activity such as residence, agriculture and tourism. Reduced water supply can affect tourist activity which is based on water attractions and can also affect the ability to use rivers and lakes as transportation means.

Society adaptation to droughts

Humans always tried to adapt to droughts. Essential resources are being invested into checking dune movement (Mitchell et al., 1998), developing water-saving irrigation techniques, and utilizing additional water sources (Le Houérou, 1996), all crucially important for substituting extensive to intensive agriculture (Pandey et al., 2002). We shall discuss later the dynamics of the Northern Negev in Israel in drought conditions with respect to these aspects.

2.2.3 The Impact of Forest Fires

The case of forest fires presents particularities and differs in many respects from other hazard cases. Forest fires are not like earthquakes or floods that start basically as natural phenomena (i.e. as relatively uncontrollable natural processes) and it is only in the subsequent sequence of events that impacts and losses are accommodated and / or intensified by human action and manmade structures. In the case of forest fires, the ignition of the phenomenon is provoked by human action (in most cases) and only the subsequent destructive process is determined (largely) by natural forces. Hence, although we stressed earlier the effect of climate change and drought on fire risk, in the case of forest fires, hazard is not associated directly, but only indirectly, with the onset of the phenomenon and the underlying human causes but rather with the following stages of fire spread and intensification. It follows that exposure to fire hazard does not refer to the probability that a forest ecosystem will experience and suffer from forest fires within a specific time horizon. It refers rather to the duration of contact of the forest ecosystem with a fire of a specific intensity which will determine the degree of impact. It is in this perspective that vulnerability was until recently a rarely used term referring solely to forest ecosystems. It was only when forest fires in wildland-urban interface areas became a major problem that the term vulnerability acquired a socio-spatial component.

Since, in our days, forest fires represent a growing and direct threat for both the natural environment and human communities -due to climate change and multiple manmade pressures exerted on forest ecosystems- they cannot be left out of the present project.

Indeed a combination of trends in climate and demography is increasing the wildfire threat across Europe. Food and Agriculture Organization (FAO) data indicate that Europe is seeing a growing number of wildfires and an increasing wildfire risk. In 2003, Europe faced about 50,000 fires, with an annual average of 60,000 ha burnt, more than double that of the 1970s. Three quarters of all forest fires and almost all the annually burnt area are located in the Mediterranean region, with Greece having the most severe problem (Moriondo, Good et al., 2006). Nevertheless, all of Europe including the Ukraine and Russia is affected to some degree.

The dramatic events in Greece during the 2007 wildfire season, with significant loss of life and assets, and resultant political fallout, highlight the European wildfire problem. This is similar to that in other wealthy regions such as the USA and Australia with the numbers, impacts and risk of large-scale wildfires increasing in spite of escalating expenditure on fire control. Climate change is leading to longer more severe fire seasons, socio-demographic and land-use changes result in a more extensive urban-rural interface and more fuel for wildfires. The fuel issue is exacerbated by the systematic exclusion of fire from areas where it was once used for land management. Historically, rural areas in Europe were relatively heavily populated with farm and timber workers and those that serviced their needs. Fire was often used as a farming tool, and rural people worked to protect their livelihoods from fire as one of many natural hazards of farming.

> *"..With industrial development, European Mediterranean countries have experienced: depopulation of rural areas, increases in agricultural mechanization, decreases in grazing pressure and wood gathering and increases in the urbanization of rural areas* (Dimitrakopoulos and Mitsopoulos, 2006).

These changes from traditional land use have led to the abandonment of large areas of farmland. In turn, vegetation has grown back and accumulated as fuel for wildfires. These factors along with the expanding urban edge and increasing tourist use have dramatically increased fire frequency in Southern Europe (Dimitrakopoulos and Mitsopoulos, 2006) – along with hotter drier summers. There are also important local and national factors. According to a FAO-IFFN report, in Greece one of the most important fire related trends -that started in the late 1970s- of building secondary summer housing along the coast accelerated in the 1980s:

> "*These housing areas were poorly planned, creating troublesome urban/wildland interfaces….The demand for such places exceeded supply, driving prices extremely high, and the lack of a land register and poor law enforcement allowed those burning forests to illegally occupy them. On more than one occasion, many years later, when the number of these people became great, it was practically impossible to evict them and the government legalised these occupied lands. In this way, a motive for arson was created*" (Xanthopoulos, 2000).

Our interest in the present project extends beyond the above reasons. Forest fires and droughts induce as secondary hazards desertification, floods, landslides, microclimatic changes etc which fall in the scope of our concern. Nevertheless, terminology divergences from other hazard cases and the historical existence of important scientific communities already pre-occupied with forest fires and droughts necessitate an independent consideration of *Vulnerability to Forest Fires and Droughts.*

2.3 Conceptual Approaches to Territorial Vulnerability

2.3.1 Vulnerability of Territorial System to Droughts

From the perspective of the analysis of droughts, we consider vulnerability as a basic notion of the complex system theory, a notion which is opposite to system's robustness. Conceptually, the system S is "vulnerable" to a drought D when its structure, parameters and way of functioning qualitatively change during D and cannot be restored afterward (Fig. 3).

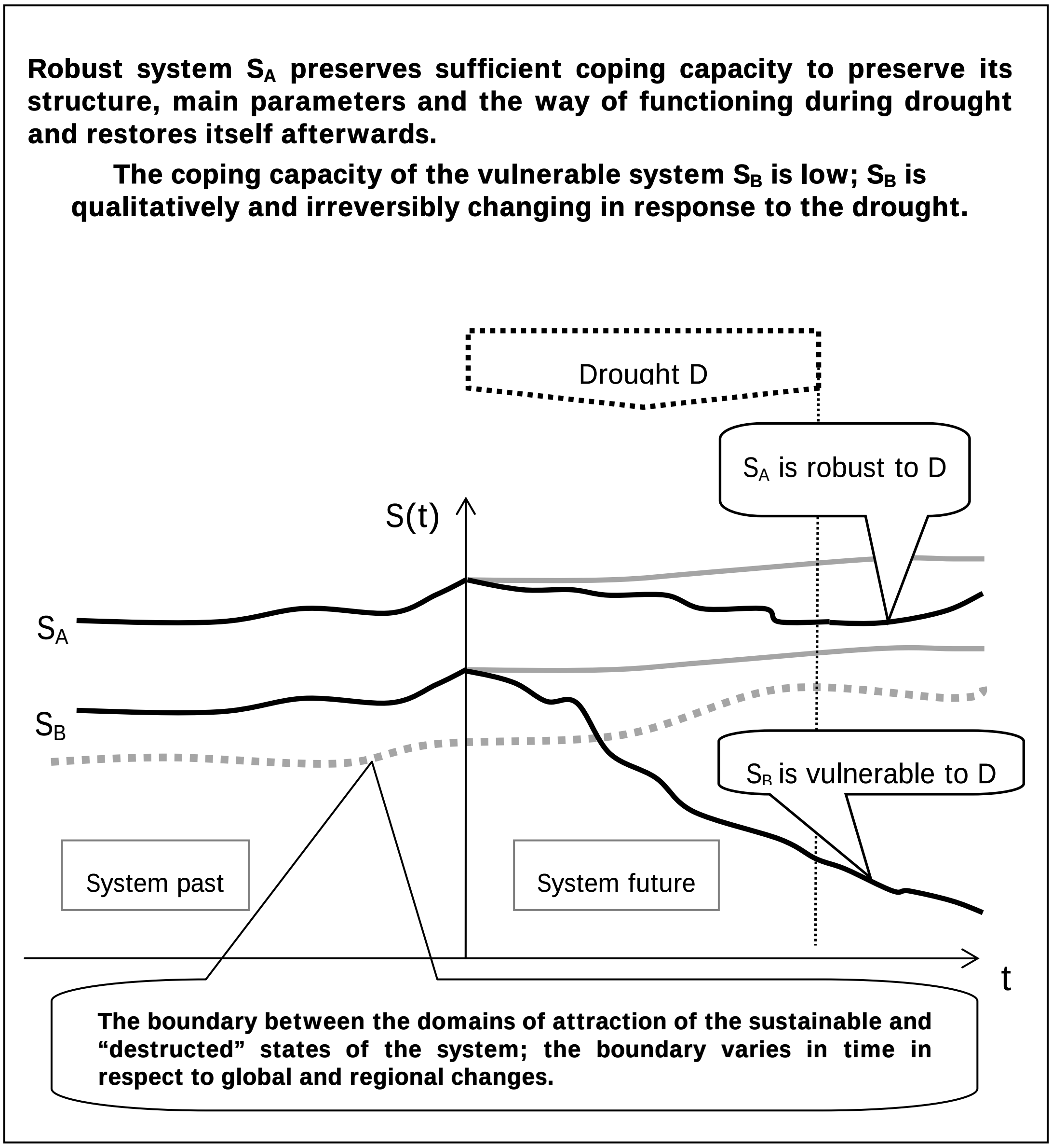


Figure 3: Schematic description of the possible course that can be taken by the system in respect to the damage. S(t) denotes the state of the system. The gray (continuous) line marks the system's dynamic in case of damage.

For a more educated preparation towards future threats, we need to tackle the following:

- Understanding system's S vulnerability to a drought D demands investigation of the entire system's life-span;
- Knowledge about the system past is critical for understanding system's preparedness and coping capacity to damage;
- Knowledge about the system present is critical for understanding immediate reaction of the system to a damage;
- To estimate this coping capacity of the system, knowledge about the dynamics of drought D is necessary;
- Projection of the system future is critical for understanding whether the system would be able to preserve its structure, parameters and the way of functioning in the future;
- The following aspects of vulnerability are critical for applying the notion to the real-world system:
    - The degree of system components' preparedness to the drought can vary;
    - The preparedness of the natural system is defined by its evolution and can be hardly managed;
    - The preparedness of the human system is determined by society's investment and varies greatly;
    - Vulnerability of a system S depends on the strength and duration of the drought; weak but long-term drought can be more dangerous for the system than strong but limited in time;
    - Characterizing of the vulnerability of spatially extended system is especially complex; the expression of drought and system's preparedness to drought vary in space; the connectivity between systems' spatial parts is especially critical in case of spatially heterogeneous system.

Here we specify the general definitions in regard to the damage that can be caused by drought, both in case of the drought caused by the local and / or temporal variation of weather during several sequential seasons and in case of drought caused by global change. Whatever the source, droughts always affect extended and heterogeneous areas. That is why territorial vulnerability is the most important aspect of vulnerability when drought is the source of damage.

It is important to note that the effects of short-term droughts are usually quantitative only. Natural systems usually adapt to the short-term drought impact during the course of evolution, while human systems usually possess the resources necessary to cope with the droughts that last one or two seasons. Global change poses a challenge to humanity as it implies, to a certain degree, more frequent and longer periods of drought.

As a test case we shall consider later the vulnerability of the semi-desert zone, which is potentially most vulnerable to droughts and may have a wider range of damages. As an operational example we classify the damage that the droughts can cause, the reaction of the system to these damages and the resulting vulnerability of the 50x50 km Northern Negev area in Israel. The future stages of the project, from which this analysis was borrowed, will include development of a simulation model for quantitative estimation of the Northern Negev territory vulnerability to droughts.

2.3.2 Territorial Vulnerability to Forest Fires

There are two major points of view or lines of thought with regard to Territorial Vulnerability to Forest Fires. The first is quite close to the notion of **ecological vulnerability**, while the second addresses indivisible **human – ecological systems**. There is here a parallel with our earlier analysis of vulnerability to droughts, in which we dealt initially with the impact of drought on ecosystems and then with socio-economic impact. The first approach to territorial vulnerability to forest fires refers to ecosystems and wildland territories and denotes the susceptibility of the ecosystem to change as a consequence of fire (Alloza et al., 2006). Vulnerability is perceived as a time-variant attribute and its analysis is structured in different stages: Short-term (focused on soil-degradation risk) and medium-term (focused on changes in plant composition and structure). Integrated vulnerability is then approached by coupling short and medium-term vulnerabilities.

The second version of territorial vulnerability to forest fires is more closely related to the notion of territory and territorial unit as we have defined it in the context of other hazard cases. However, this second version has not been studied adequately. While the existence and importance of vulnerability of mixed wildland-housing areas has been widely acknowledged, a territorial approach to vulnerability, in quantitative and qualitative terms, is lagging behind. Not surprisingly, this is exactly the object of a project proposal prepared by Oporto University and submitted for funding by the EU within the scope of the 7th Framework Programme in 2007. The proposal employs the term vulnerability as the degree of fragility of organized societies, economic structures, built environments and ecosystems in the face of negative consequences resulting from exposure to hazardous events such as forest fires. In this sense **exposure** is considered a precondition for vulnerability to manifest itself. However exposure is neither contained in vulnerability nor identical with it.

A somewhat different situation prevails in Mediterranean countries, albeit not exclusively. In certain regions of these countries, where mixed forest-housing areas and areas of wildland-urban interface pre-dominate, the respective human-ecological systems are highly exposed to fire ignition incidents due to land use dynamics, land ownership disputes, widespread human presence within forests etc. This exposure is related to the probability and frequency of occurrence of human causes of forest fires (i.e. by intention or negligence) and is usually described as Fire Risk Index. Kalabokidis et al. (2003) have attempted to evaluate this index quantitatively by using simple geographical parameters (basically the distances from critical manmade installations). This is exactly the object of research of a Greek project under the title *"Assessment of Forest Fire Risk and Spatial Planning for Forestland Protection against Forest Fires"* (NTUA, 1995). In particular, the project looked for interrelationships between:

- Locations of forest fire ignitions and locations of certain land use / land cover transformations;
- Rates of land use transformation and frequency of forest fire occurrences.

The above approach / methodology was tested in an area of the Region of Attica (the Greek Capital Region) which had suffered in the past a series of devastating forest fire events. Indeed, it was confirmed by the study that high frequency of forest fire occurrences could be correlated with one of the following three categories of land use dynamics (Fig. 17):

- Pressures by building development in cases of high demand for urban land (e.g. an expanding city) or for second home construction;

- Pressures by agricultural activities to compensate for agricultural land lost to urban expansion and building development;
- Pressures by grazing activities due to the increasing scarcity of pasture land.

In all the above cases the respective areas suffer from high fire-risk indices, i.e. exposure to forest fire human causes (connected to arson or negligence).

As already mentioned, to the Climate Change scientific community Forest Fire Risk represents a synthesis of both the socio-economic and bio-physical parameters that contribute jointly to the ignition and propagation of forest fires. Potsdam Institute for Climate Impact Research (PIK), representing the Climate Change community in the context of ENSURE, regards as appropriate the Joint Research Centre classification of risk assessment indexes according to their time coverage:

- Structural or long-term indexes, which consider only factors with low time variability;
- Dynamic or short-term indexes, resulting from factors with high time variability (in a scale of days or even hours);
- Integrated or advanced indexes, which combine structural and dynamic variables.

In PIK's view, forecasting fire risk probability (understood as the combination of ignition probability and propagation) should include dynamic variables, concerning the state of the vegetation and the local weather conditions described in fire weather indexes (relative humidity, air temperature, precipitation, wind), and structural factors the variability of which is lower compared to the geophysical characteristics of the territory (geomorphologic, ecological and land use). PIK refers to three methodologies which are used to assess this specific version of "fire risk" and which refer to different spatial and time scales: The Canadian Forest Fire Weather Index System (FWI), the RISICO system and the Spanish system for WUI areas.

PIK suggests that vulnerability of a territory to fire events is not static; it changes with respect to different temporal and spatial scales. Therefore, the factors aggravating territorial vulnerability are not the same across the different scales and should be differentiated accordingly. For instance, worldwide, up to 90% of fire ignitions have anthropogenic origin. This means that man alone, directly or indirectly, is responsible for the vast majority of fire ignitions. Usually, a territory is more vulnerable to forest fires if the population density in contact with the forest/urban interface is higher. Population density is a factor that aggravates the vulnerability of a territory in the early stage of a fire event (ignition); natural causes of fire ignition are very limited in Europe. On the other hand, once fire starts, the factors that determine its extent are different from the ones that determine its occurrence. The size of a forest fire, in this second stage, will be determined by climatic conditions, land use characteristics, type of vegetation patterns, species flammability and terrain slope. During fire spreading, population density is no longer a factor that aggravates vulnerability, but rather a factor that can contribute to an early detection of fire and therefore to quicker intervention and reduction of the burnt areas. Therefore, the factors that aggravate territorial vulnerability vary according to time and space; one and the same factor can play distinct roles depending on the stage of the fire event. Table 2 below displays the main factors that influence ignition and fire spread; X identifies those factors that influence both stages of a disaster process.

Table 2: Factors that influence the ignition and spread stages of a forest fire event

		Fire ignition				
		Population density	Wildland-urban interface	Climate	Vegetation type	Road network
Fire spread	Climate			**x**		
	Vegetation type				**x**	
	Vegetation distribution					
	Land morphology					
	Population density	**x**				
	Road network					**x**

Note:

- ✓ Vegetation type and distribution denotes that with respect to forest occupation there should be references to the density and distribution of forest species and the degree of flammability of shrub and sub-shrub vegetation;
- ✓ Land morphology refers to altitude, exposure and slope;
- ✓ Road network refers to proximity to main roads and density of forest and agricultural tracks.

The contribution of each factor to territorial vulnerability is not always towards one and the same direction. For example, road density promotes easy access of people to forests leading to higher probabilities of ignition. On the other hand, a dense road network allows for a fast intervention of the fire fighters, enhancing the chances for an effective fire control.

While there has been no progress as regards understanding and assessment of the overall vulnerability of human-ecological systems to forest fires, significant work has been carried out in relation to some of the distinct vulnerability components of the above systems, basically on the **vulnerability of building structures** and to a lesser degree on **socio-economic vulnerability** to forest fires. Furthermore, **institutional vulnerability**, i.e. vulnerability of the suppression mechanism, has also been considered as critical. We shall return to this subject later.

2.4 Examples of methodologies Assessing Territorial Vulnerability

2.4.1 Character and identity of the Methodologies

A number of examples were considered for the purposes of this task in order to review methodologies used to assess territorial vulnerability or, more generally, vulnerability with a territorial emphasis. In the case of droughts extensive reference is made to the case of the Northern Negev in Israel. As for forest fires, we have used the examples of the Canadian Forest Fire Weather Index (FWI) System, an Australian study of the vulnerability of structures, the Italian RISICO system employed by the Civil Protection Department, a Spanish study of wildland – urban interface (WUI) patterns and Greek research on a Fire Risk Index. We first take a broad view of the identity of these methodologies and we shall then provide more detailed information on all examples.

Droughts: A Land-Use Dynamics Model as a Tool for Assessing Vulnerability to Drought (The case of the Northern Negev)

In presenting the case of the Northern Negev project in Israel we considered it expedient to start with an outline of the tool used in it for the assessment of vulnerability and to leave the details of the case until later, when we provide more information on all case studies

Land-use change model as a tool for socio-economic investigation

Land-use change models offer the possibility to test the vulnerability sensitivity of land-use patterns to droughts through formulating the scenarios that explicitly describe the change in temperature, precipitation as well as the reaction of society to these changes, as it is partially done in Angelson and Kaimowitz (1999). The model used for the Northern Negev case enables testing of the robustness of the socio-economic-ecological system of the Negev. The study of the model aimed at predicting the rate and spatial extension of the quantitative and qualitative changes of the Northern Negev territory under the influence of droughts and at specifying the weak points and bottlenecks of the system.

High-resolution spatially-explicit dynamic modeling

The model is being developed by the Northern Negev study team as a spatially-explicit Cellular Automata, which cells will be associated with the (irregular) coverage of land parcels. Spatially explicit land-cover data are derived from aerial photographs with the help of Remote Sensing techniques and are directly linked to household survey data using GIS, as is demonstrated in Walsh et al. (2001), Serneels and Lambin (2001), and Kaufman and Seto (2001).

Yet, apart from drought, the contribution of additional driving forces of territorial development, such as cultural, economical, political and technological (see Bürgi et al. 2004) to landscape change are also being analyzed and the interrelations between the droughts and these forces will be incorporated into the model (Krausmann et al., 2003; Lambin et al., 2003). GIS and Remote Sensing data will serve for model parameterization, calibration and verification and, further, for comparing the model output to the real system. Following Wear and Boldstad (1998) and Pahari and Murai (1999) demography will be treated as an independent driving force. This is essentially important due to the substantial differences in the birth rates of the Jewish and Bedouin populations in the Northern Negev. In addition, the ecological and economical impacts will be considered (Dale et al., 2000; Costanza et al., 2002).

The Northern Negev territorial system as an example of complexity

One may however note that not all consequences following droughts are necessarily negative. The challenge in confronting droughts may result in positive consequences. Thus for instance, water desalination, improvement of brackish and sewage water, all may take place as an inevitable necessity to cope with water shortage. Fig. 4 shows a possible specific scenario of drought in conjunction with population growth in the cities and settlements and forestation. While only minor changes may take place following medium droughts, substantial changes are expected following severe droughts. Thus, immigration of the Bedouin population will take place. Whereas some will immigrate to the city periphery or concentrate in settlements as a result of the decrease in open spaces and the growing opportunities for work in the city/settlement, others will take over the territories that were left behind thus increasing the available forage for the remaining goat and sheep. Consequently, more land per household will be needed in order to maintain the same amount of goats and sheep leading eventually to a decrease in the amounts of goats and sheep.

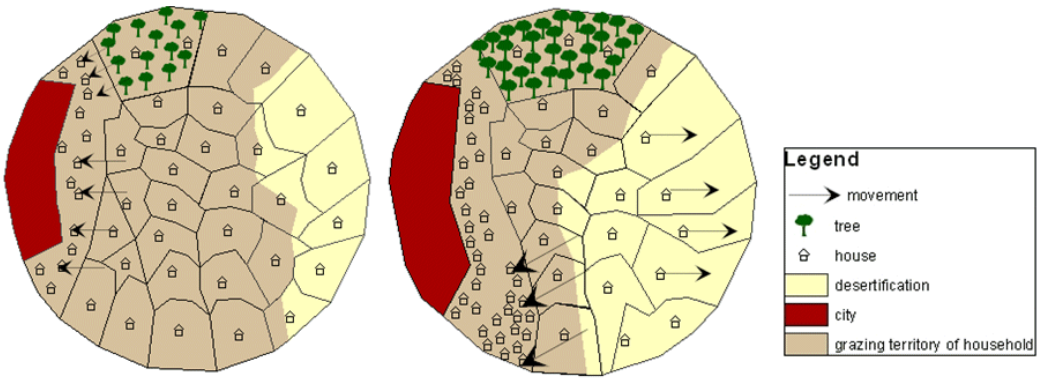


Figure 4: Land-use changes as affected by medium (left) and severe (right) droughts.

To conclude, the aim of the Negev study team is to develop a spatially explicit high-resolution dynamic socio-economic model (Parton et al., 1988; Costanza et al. 2002), which would capture the feedbacks between social, ecological and economic components of the system and serve as a tool in a systematic analysis of the territory vulnerability to droughts. In the model, the processes and mechanisms that govern the interconnected dynamics of water and plant cover and their linkage to human population, agriculture and settlement pattern will be addressed. The model approach will also serve as a tool for ecosystem-based and watershed-based management of the area, thus facilitating a better preparedness to droughts.

Further information on the Northern Negev case is provided later in the section containing the examples, where a diagram is included which illustrates the consequences of drought and forms the basis of the model.

<u>Assessment methodologies of forest fire vulnerability</u>

Let us repeat here that with regard to forest fires, we have used the examples of the Canadian Forest Fire Weather Index (FWI) System, an Australian study of the vulnerability of structures, the Italian RISICO system employed by the Civil Protection Department, a Spanish study of wildland – urban interface (WUI) patterns and Greek research on a Fire Risk Index. As mentioned earlier, we first take a broad view of the identity of these methodologies. At a later point we shall provide more detailed information on all examples.

In the case of assessment of Vulnerability of natural territories to Forest Fires (i.e. ecological vulnerability) methodologies are mostly qualitative. The sensitivity degree of the factors under consideration is usually divided in three or more categories: High

(H), medium (M) and low (L). In the case of the Spanish model evaluating **ecological vulnerability** to F.F. in Mediterranean ecosystems (Alloza et al., 2006) the environmental factors considered for short term vulnerability (focused on soil degradation risk) are the following: rainfall aggressiveness (categories based on maximum rainfall intensity in 24 hours, return period 10 years), slope steepness and a soil erodibility factor (integrating lithological maps with organic matter estimations, the latter based on vegetation maps and remote sensing). The time of exposure of the soil surface is also taken into account and the integration of environmental factors is supplemented by an estimation of the response capacity of the vegetation (based on the dominant reproduction strategy –frequency of seeder and resprouter species-, on water constraints and fire frequency –that can influence the soil seed bank and resprouting capacity). Medium term ecological vulnerability is determined by the capacity of the community to return after fire to pre-fire conditions without significant changes in composition and structure (resilience). This capacity is associated with the presence / dominance of species with different reproductive strategies, structure of the community and fire frequency.

In the case of **territorial vulnerability** to forest fires most approaches focus interest on mixed wildland-housing territories; in the respective examples **vulnerability of housing buildings** and their surroundings is assessed separately by taking into account the following parameters: (a) material and design of housing buildings and their surroundings (Blanchi et al. 2006) and (b) personal and institutional responses before, during and after the fire. These parameters reflect damage and coping capacity potential, i.e. two aspects of vulnerability familiar to us from general studies of vulnerability (vd. ESPON Hazards project 2005, Adger 2006).

Indeed, following the wide recognition of the Wildland-Urban Interface problem in the 1980s a lot of work has been produced in this direction in the United States, while similar work has been carried out in Canada and Australia; also in Southern Europe. One of the main objectives of this work has been the development of guidelines aiming to reduce the vulnerability of structures. The number of scientific or technical publications listing the factors that affect house vulnerability to forest fires is really great. Sometimes, it is unclear which ones draw upon the others, but some examples of substantial contributions, at least in the USA, can be found in a guide by the California Department of Forestry (1980), in the work of J. Cohen (Cohen 1995, 2000) and more recently in De Jong (2003). The most commonly identified factors in general are presented in Table 3 (basic source: Xanthopoulos 2003).

Each of the categories of factors presented in Table 3 has been examined in the context of Mediterranean Europe, to identify in detail features of vulnerability to wildland fires in WUI areas. The conclusion is that there are significant differences in the vulnerability of houses and the wider mixed use and mixed landcover territories in the Mediterranean in comparison to the USA, Canada and Australia (Xanthopoulos 2003). Therefore, already existing guidelines should not be adopted unquestioningly and adjustments supported by scientific and technical research are indispensable. In the paragraphs following the drought case study of the Northern Negev reference will be made to relevant research findings or models of applied methodologies for policy-making purposes in Canada, Australia, Spain, Italy and Greece. These references reveal notable differences in analysis and policy making against vulnerability of mixed territories to forest fires.

Table 3: Factors affecting vulnerability of buildings in WUI to wildland fires (Xanthopoulos 2003)

1. Fire behavior to which a house is exposed, as affected by fuels, weather and topography

House location, in relation to the effect of topography on fire (house sitting in relation to fire behaviour)

2. House design and construction materials

The design of houses and the construction materials are also two important elements.
Moreover, it is quite common in the Mediterranean to see residences which appear quite safe, to catch on fire during a WUI fire, because of specific weaknesses that make them especially vulnerable. Examples of such weaknesses are:

- Use of tar paper under the roof tiles, because this paper is easily ignited
- Lack of non-flammable window shutters that will protect window glasses, the curtains and the interior of the house from radiation.
- External use of flammable materials such as PVC rain-gutters, which are flammable. Concentration of dead needles and leaves in them aggravates the situation.

3. Flammable materials outside but close to the house

Nearly all the international literature on the subject makes reference to these elements that can be found outside a WUI house:

- Wooden decks (or made of other flammable materials)
- Wood piles
- Flammable liquid and gas storage (gas tanks.)
- Dead vegetation which has not been cleared (such as cured grasses, leaves and needles mainly on the roof)
- Flammable live vegetation close to, or in contact with, the house.
- Positioning of flammable materials, such as firewood piles, outside the house but at a short distance from it or under it.

4. Flammable materials inside the house

Whereas in the United States, in Canada and in Australia ignition of the external parts of a house is a major concern, in Mediterranean Europe, ignition of materials inside a house is a much more common source of disaster. Some of the most obvious and common examples are:

- Nylon curtains
- Rugs
- Upholstery
- Polyurethane furniture

5. Fire protection infrastructure and firefighting capacity by firefighters and the owner

Proximity to roads, escape routes, inclusion in a settlement or not, affect the possibility of accessing and defending a WUI house.
The new well-planned settlements described in the US publications make effective firefighting possible. The guides for development of WUI areas, always refer to a number of points that when observed carefully, will allow good fire protection and, if needed, quick and safe evacuation of the public. These points, at a minimum, include:

- Accessibility
- Road network condition (width, turnarounds, street signs, …)
- Water (tanks, hydrants,..)

There is also need for availability of good firefighting resources. Considerations are expressed about if and when homeowners should stay and protect their homes during a fire episode.

2.4.2 Examples of empirical studies

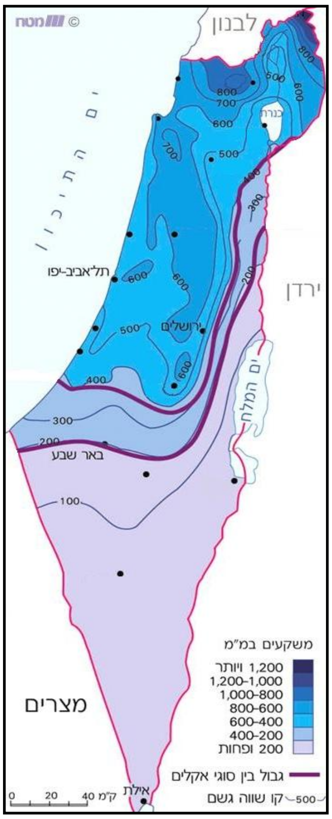
2.4.2.1 Assessing Vulnerability to Droughts in the Northern Negev Territory

Very few studies focus on assessing vulnerability to droughts. Many of them took place in Africa where long-term droughts affected the matrix of life. Out of these models, the models constructed by Stéphenne and Lambin (2001) and Tews et al. (2006) deserve special attention. Both address the dynamic of land-use changes in the Sudano-sahelian countries following extended droughts. We have already presented the modeling approach of the Northern Negev study, but in this section we provide detailed information about the case, drawn from the work carried out in the context of the Negev project.

Presentation of Northern Negev

As the Negev Desert is one of the experimental areas for the ENSURE research, let us consider the concept of landscape vulnerability and sustainability there at various levels from organism to the ecosystem as a whole.

General characteristics of the area



Extending in the southern half of Israel, the dry sub-humid climate of northern Israel is changing to semi-arid and arid climate within a short distance of tens of kilometers characterized by dense isohyets (Fig. 5). While the arid Negev Desert is defined as having less than 200 mm, one may also include the semi-arid regions of Israel as areas prone to droughts and will subsequently be dealt herein as areas vulnerable to droughts. In the process of the project development, the northern Negev will include all areas extending between 100 to 400 mm.

Figure 5: Israel borders and isohyets. Note the 100 to 400 mm isohyets which bound the Northern Negev area that will be investigated within the ENSURE project (see closer zoom of the area in Figures 6-10).

The Northern Negev territorial GIS

The database of the Northern Negev, which is currently under construction, contains very high-resolution layers of land-uses, roads, population, vegetation, soils and other components. The majority of the layers are updated towards 2008 Israeli population census and accompanied by the temporal data which enable reconstruction of the area land-use and population dynamics during the last two decades. In addition, starting from 1960s, the complete coverage of the aerial photos is available at temporal resolution of 1-3 years. From 1980s aerial photos can be combined with the satellite photos of the area.

Combining temporal GIS data and aerial photos of the previous years, the influence of the natural droughts that happened in the last two decades in the Northern Negev territory can be estimated and the model of the Northern Negev vulnerability to droughts can be validated. The model will be developed during the next stages of the project. The maps presented in this report are constructed on the basis of the Northern Negev territorial GIS.

<u>The effects of droughts on the Northern Negev</u>

Droughts affect all types of zone of the Northern Negev area – natural, agricultural, and urban. Urbanized areas of the Negev consist of large cities with mixed population and small settlements. Many of the latter are populated by Bedouins. In essence, droughts may affect the entire matrix of life, having a variable impact on the natural as well as man-affected environment. As such, they may influence, modify and even change the socio-economic conditions of many of the region's inhabitants. In the following paragraphs, different drought-affected aspects will be described.

Figure 6 presents Negev's settlements and road network and Figure 7 presents the map of the main land-uses in the northern Negev.

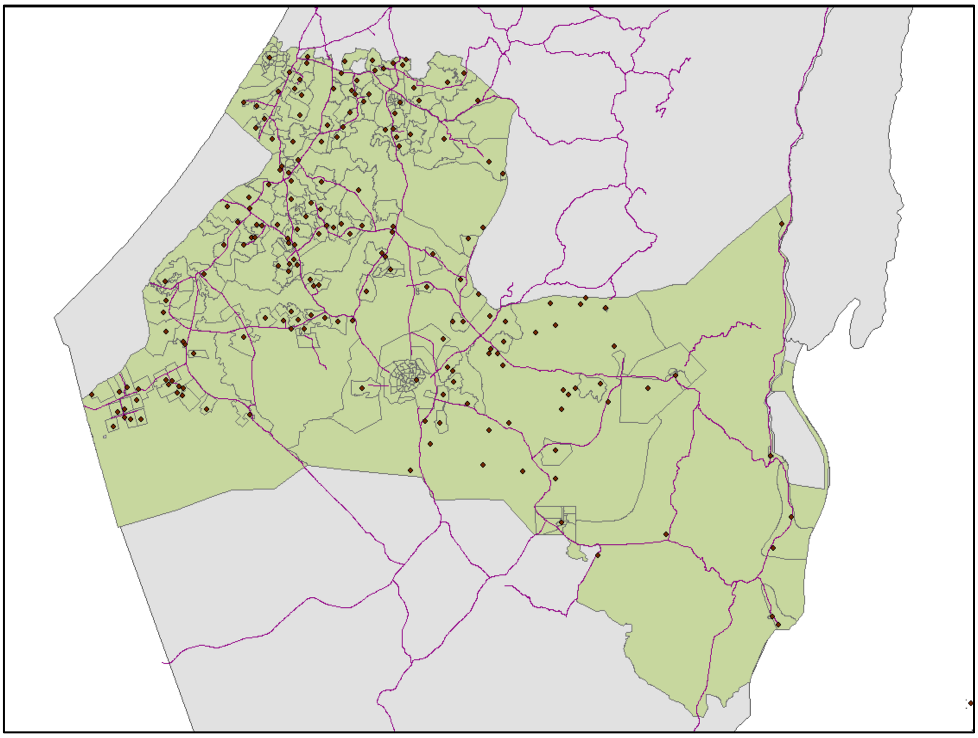


Figure 6: Roads and settlements in the northern Negev.

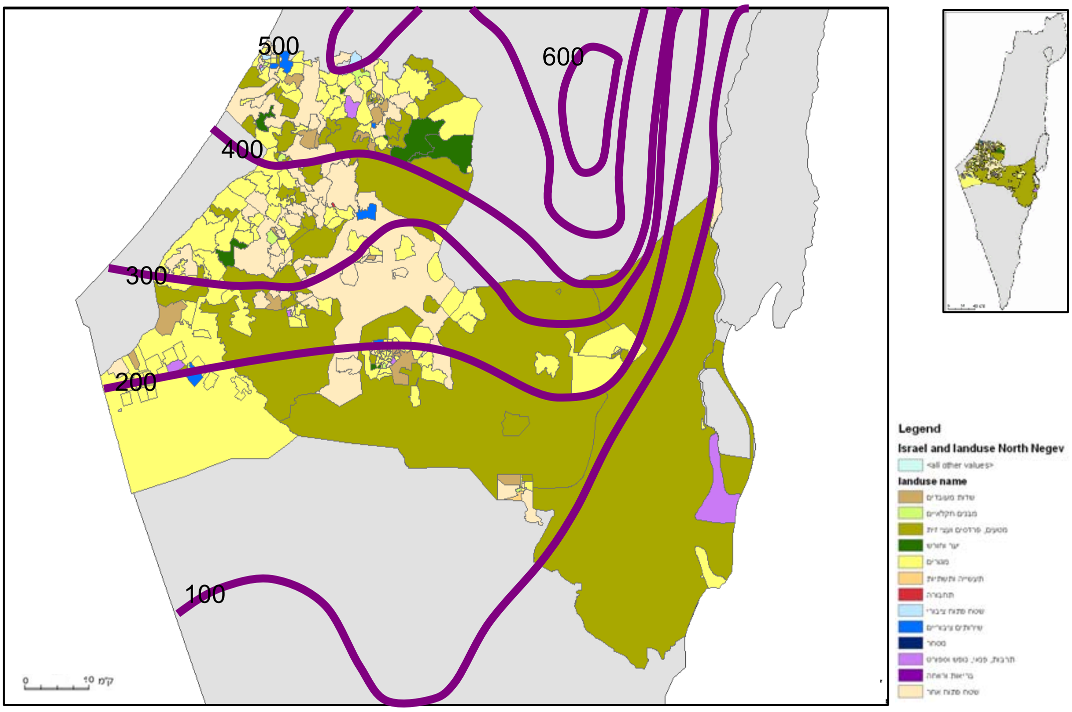


Figure 7: Northern Negev land-use map with and rain isohyets superimposed

The effect of droughts on the natural ecosystems of Northern Negev

In the natural ecosystems droughts may affect the entire food chain, including primary producers such as microorganisms. Among the microorganisms that may be affected are lichens (Insarov and Insarova, 2002), sometimes termed as lower plants. According to Kappen et al (1979), a slight change in the environmental condition of *Ramalina maciformis*, one of the fruticose lichens abounding in the Negev Desert, may result in enhanced transpiration and negative net carbon balance that may eventually lead to the death of a species.

As for higher plants, germination in the Negev Desert is extremely low during drought years. Following a 46.9 mm rainfall in the western Negev Desert during 1993/94, annual germination was below 10% of the level characteristic of a year of average precipitation of 95 mm (Tielbörger and Kadmon, 1997). High mortality of perennials was also reported in the Negev for the years that follow droughts of the second half of the 1990s and first half of the 2000s (Ram and Yair, 2007).

Going along the trophic chain, the reduction in plant production causes a decrease in rodent population in the Central Negev. The survivors intensified their activity and intensive porcupine digging in search for subsurface bulbs of *Erodium hirtum* was observed, causing intensive damage to this species (Kidron, unpub.).

Coping capacity of Northern Negev ecosystems

In parallel to reduction in all components of plant species productivity, one has to account for the adaptation mechanisms developed by the desert species, first of all the ability of the desert plants' seeds to keep viability for several years until sufficient rain arrives (Noy-Meir, 1973; Svoray et al., 2008).

Adaptation to drought at the population level is accompanied in the Negev Desert by the mechanisms that act at the level of the community and ecosystem as a whole. As an example, porcupine diggings serve as important microhabitats for seed accumulation and germination, thus contributing to higher species diversity at the ecosystem level (Gutterman et al., 1990). Another example can be microbiotic crusts established on the bare areas. The crust prevents wind erosion (McKenna Neuman et al. 1996, Marticorena et al. 1997) thus impeding nutrient loss. This phenomenon is especially important in the western Negev, where intense dune migrations are characteristic during drought periods. Following sufficient precipitation, these new dunes will be rapidly covered by microbiotic crusts thus enabling further recovering of the dune ecosystem (Kidron, 2008).

Runoff concentration is also a factor of ecosystem robustness in the Negev. Concentrating in low-lying areas, runon zones (i.e., areas where runoff concentrate in) enables the formation of "islands of fertility" that serve as preferential sites for moss (Herrnstadt and Kidron, 2005) and annual (Tielbörger and Kadmon, 1995; Svoray et al., 2008) growth and reproduction. While not evenly distributed, these sites act to preserve the ecosystem richness in terms of species diversity and composition (Svoray et al. 2007).

While on a local scale rainfall-runoff relationship may act to minimize the drought effect, the overall result is a substantial decrease in the ecosystem biomass, rain-fed crops and grazing capacity, all of which may result in land-use modifications and socio-economic change. In the section on the identity of methodologies we outlined the approach of the Negev study for the construction of a spatial-temporal model that may describe and predict vulnerability to droughts. Here however we present the effect of droughts on the area.

The effect of droughts on grazing

Significant areas in the Northern Negev are assigned for army training purposes. The entry of civilians to these areas is prohibited. Therefore they may reflect, at least in the parts that are not used by army vehicles, the natural status of vegetation. The rest of the Northern Negev areas are all used for grazing, over 95% by the Bedouins' herds.

Two grazing species, goats and sheep are raised for milk, meat and wool/hair. The economic benefit of the third grazing species - camels - is limited. Camels are merely used as a status symbol. Following droughts, a reduction in camel heads is expected in spite of their capability of grazing on thorny shrubs, which are not grazed by sheep or goats. Yet, following reduction of vegetation, the competition for the grazing areas will strengthen and economic or status benefits for maintaining camel herds will decrease. Consequently, a reduction in the camel population can be expected.

A reduction in sheep population is also expected, however, for totally different reasons. Being more "delicate" and "sensitive" than camels or goats, the reduction in vegetation production will require larger grazing area for the herds or the purchase of hay.

Contrary to camels and sheep, goats are better adapted to consume shrubs (Lioubimtseva et al., 2005) and the number of goats may remain constant for longer time before a decrease in their number will take place. Proportionally, the number of goats is expected to increase at the expense of camels and sheep.

The effect of droughts on the Northern Negev plant agriculture

Agriculture is a main water consumer and as such, the first to be affected by water shortage. It may be severely impacted by droughts. Domesticated plants are also known to be more vulnerable to droughts than native species.

Droughts may affect plant agriculture at three levels:

(a) On a broader scale, intensive agriculture would shift to industrialized agriculture. Open fields, used for growing vegetables or flowers will be replaced by green houses in which a much better control of water use is secured, and the cost-benefit ratio is lower.

(b) On a meso scale, rain-fed agriculture, such as that of wheat and grains may decrease, turning these areas into grazing areas. Following a water cut imposed by droughts, a shift between the different agricultural domains is expected. The number of groves (fruit trees) and irrigated crops (such as vegetables) may decrease in favour of rain-fed crops in areas where the mean rain precipitation is expected to suffice for this type of agriculture. Year-long green groves and fields, subjected to intense agriculture, may turn into rain-fed winter crops.

(c) On a micro scale, crops known as heavy consumers of water will be replaced by crops better adapted to dry conditions. Citrus trees may be replaced by olives, while cotton fields may be replaced by corn. Alfalfa will be replaced by sunflowers, sesame or chick peas.

The Northern Negev database contains detailed data on the agriculture land-uses at resolution of land parcels and vegetation types (Fig. 8).

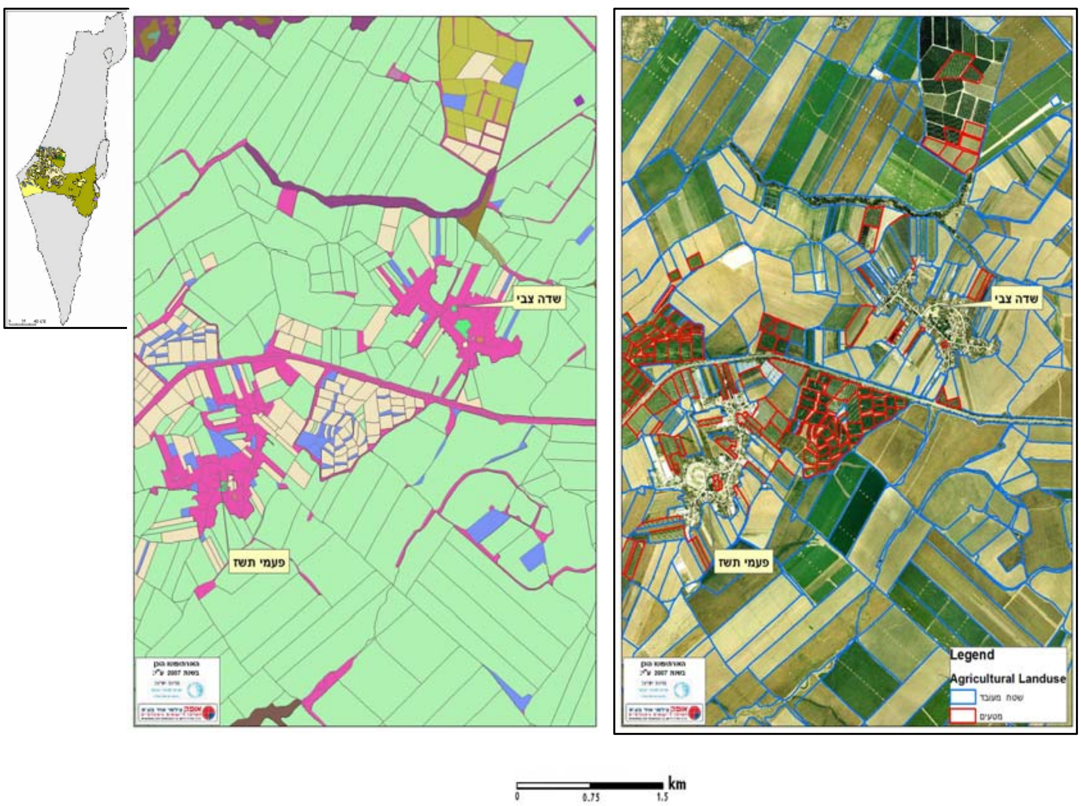


Figure 8: A close view of the northern Negev agriculture land-use.

The effect of droughts on the urban areas of the Northern Negev

Drought may also affect urban areas. First, Bedouin immigration to the city periphery may significantly increase following reduction of the traditional grazing and agriculture areas. Reduction in traditional occupations, such as that of shepherds and farmers, will be balanced by the Bedouins' occupation in more industrial professions. In the long run, Bedouin concentration near urban centers may pay off by their participation in better education system and a wider range of professions.

On a finer scale, droughts would cause changes in the use of open space and house gardening. Limited water supply would restrict planting of trees along sidewalks and change the prevailing view of urban park design. Lawn areas will be restricted and replaced either by "arid land design" or by artificial materials that either mimic lawn or provide soft substrate as a playground. Arid land design entails the use of pebbles which serve as mulch (and thus preserve soil moisture for long) and in addition play a decorative role. This design, frequently used in the arid parts of Arizona and New Mexico, is usually combined with the growth of scattered succulent and cacti vegetation, which consume very little water. This "arid land design" is expected in private gardening in the Northern Negev thus replacing the water-consuming lawns.

The Northern Negev database contains detailed data on the urban land-uses at all necessary resolutions (Figs. 9 and 10).

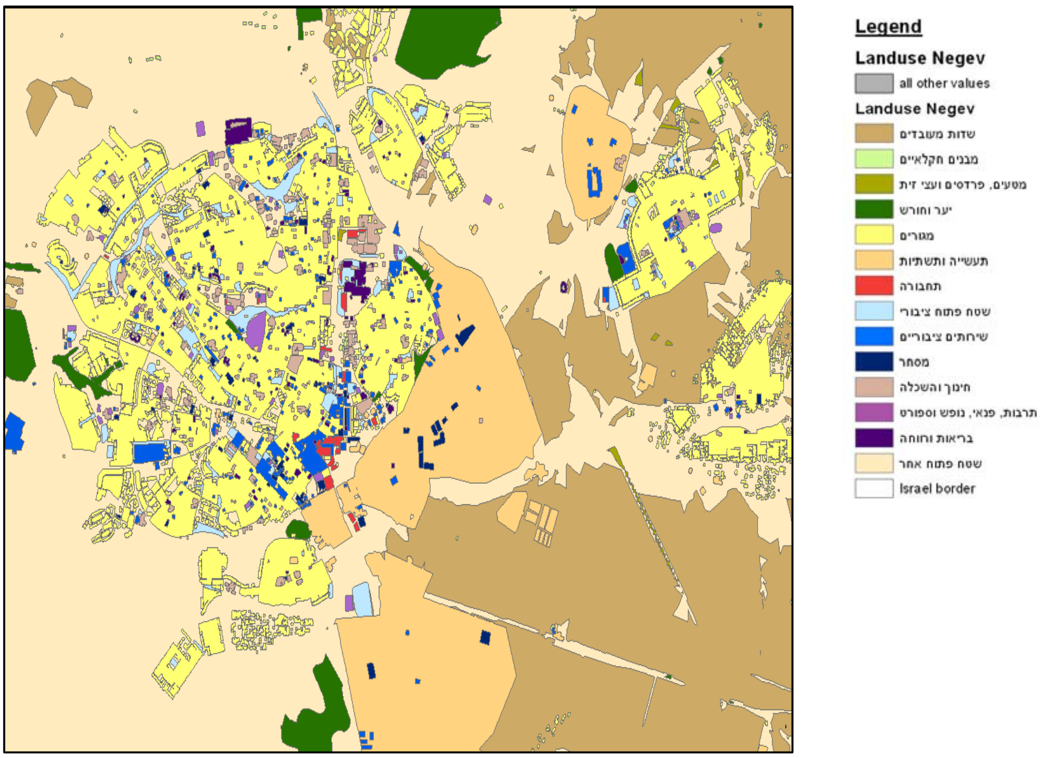


Figure 9: Urban settlements: Beer Sheba and surroundings.

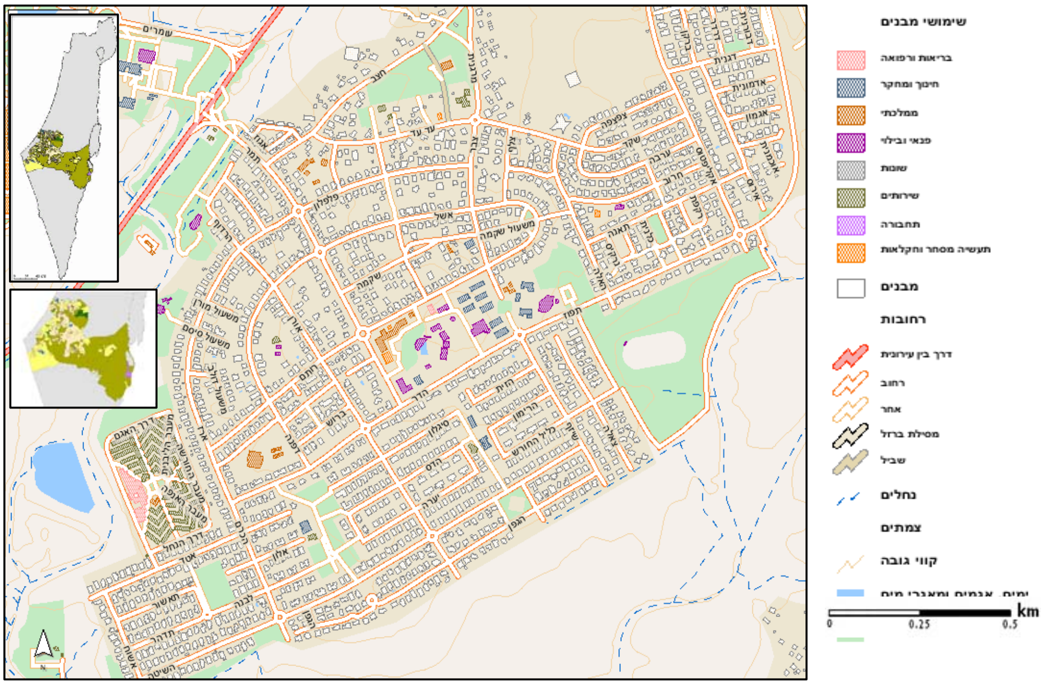


Figure 10: Infrastructure in Omer, a Jewish settlement next to Beer Sheba.

The main threats of droughts to the Northern Negev and the flow of drought consequences

The main threats of droughts to the Northern Negev territory are summarized in Table 4 and Figure 11, which is constructed on the base of the review contained in preceding paragraphs and presents the basic sequence of events that are caused by drought:

Table 4: Drought threats and their social economic consequences in the Northern Negev

Threats	Consequences
Decrease in water supply	Rangelands for modern and nomadic herds; Reduction of the water supply following shortage of water in Israel; Decrease in soil fertility and crop production
Overexploitation Overpopulation/lands overuse	Increase in urban areas at the expense of open areas; Goat and sheep overgrazing; Erosion and land degradation
Accumulation of environmental hazards in groundwater and air	Direct influence on the nomadic Bedouin and settler population including large cities such as Beer Sheba

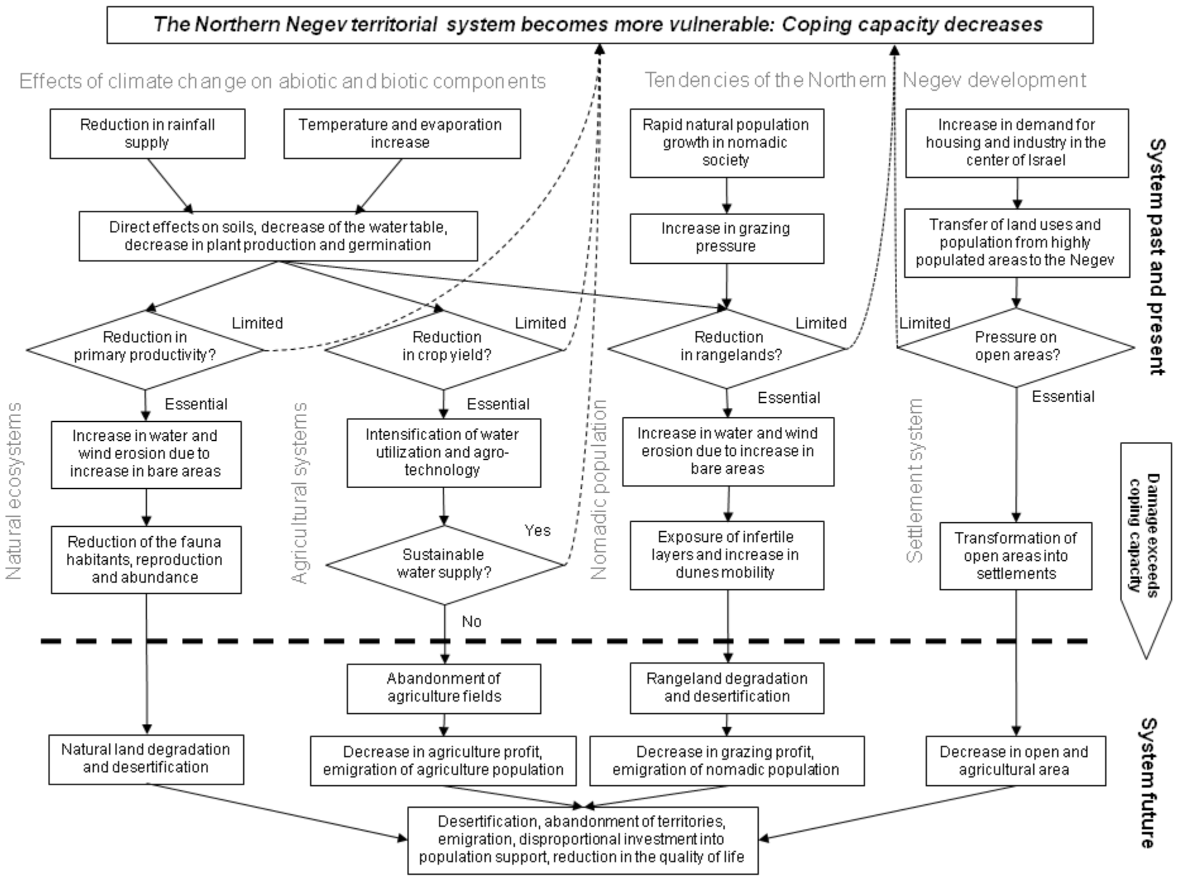


Figure 11: The main consequences of drought in Northern Negev.

2.4.2.2 Forest Fires: Examples of methodology

As we mentioned earlier, in the paragraphs that follow we present relevant research findings or models of applied methodologies for policy-making purposes in Canada, Australia, Spain, Italy and Greece.

i) The Canadian Forest Fire Weather Index (FWI) System: The missing aspect of vulnerability and exposure to manmade causes

The Canadian Forest Fire Weather Index (FWI) System in its current form has been in use across Canada for the past 30 years. In practice it tells us how easy it is to ignite vegetation, how difficult a fire may be to control and how much damage a fire may cause.

It uses daily weather observations to estimate moisture content of three different fuel classes in order to generate a set of relative indicators of potential rate of fire spread, fire intensity, and fuel combustion. The first three components are numeric ratings of moisture content of the fuel loads, the remaining three components are fire behavior indices, which represent the rate of fire spread, the fuel available for combustion, and the frontal fire intensity; their values rise as the fire danger increases. A schematic structure of the FWI is presented in Figure 12.

Some studies have attempted to assess the relationship between FWI and its components with observed data of number of ignitions and areas burnt in the Mediterranean geographical context. In the case of 14 Portuguese districts that have been studied high significant relationships were found among forest fires and the FWI system. More specifically, a stepwise regression showed that for the average conditions of 11 Portuguese districts under analysis, 81% of the variance in area burnt was explained by the monthly mean value of relative humidity (input data of the FWI) and drought code (DC in the FWI structure) and the monthly maximum FWI *(Carvalho, Flannigan et al. 2008)*. Due to its dynamic characteristics (the index facilitates estimation of current fire risk as well as future fire risk by using the weather forecast data) the FWI can be a very important tool in coordinating fire fighting policies.

The FWI provides information on on-site conditions as regards fire trend to spread and also the amount of available fuel for combustion. The FWI is used during the fire season (an annual time period where historically most forest fire ignitions occur); this somehow reflects a statistical approach to the probability of forest fire ignitions. Nevertheless, in the FWI structure itself, there is no component referring to the probability of ignition of a forest fire. Although one can state that a fire is more likely to occur in a place were weather and fuel conditions are appropriate, the FWI does not take into account factors like population density, road network or density and visibility of fire watch towers, factors that are important when determining the territorial vulnerability to forest fires.

Although the FWI is widely used, the method is adapted to the Canadian fire regime. The use of FWI in other regions of the world should be made with care.

The FWI System requires observed temperature, relative humidity, and wind speed at noon local standard time, as well as 24-hour precipitation. Various other observations, such as those concerning wind direction, dew point and atmospheric pressure are also saved in the database to be used for interpolation. Temperature and relative humidity values are corrected according to an elevation grid. The spring start-up dates and starting fuel moisture code values are calculated according to Turner and Lawson (1978).

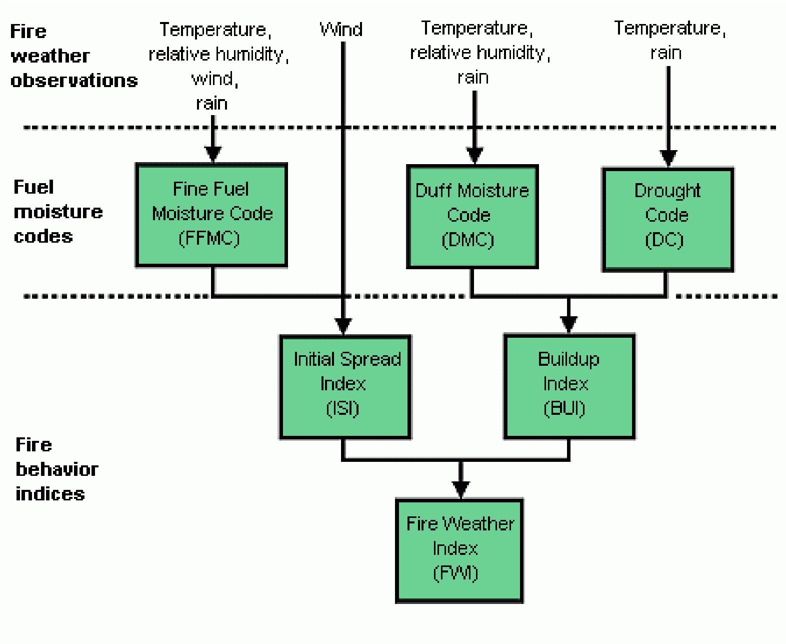


Figure 12: Structure of the FWI system

ii) The Australian Case: Vulnerability of structures
(This section is drawn largely from Leicester and Handmer, 2008)

Fires generally burn in rural or wildland areas outside urban areas. Structures are threatened when they lie within the path of the fire, either as isolated buildings or as part of a town or city. The rural-suburban interfaces of major cities are of particular concern because of their location by fire prone land and the extent of exposed assets and people, but recreation and tourist developments may be at even greater risk if located in isolated areas naturally prone to frequent wildfires.

Houses generally burn down from ember attack, with Australian data showing that almost all house destruction occurs this way. Relatively few houses burn down as a result of heat radiation or direct flame attack (Blanchi et al 2006). “Exploding houses” often referred to in media reports are usually the result of many ember fires gaining hold and then flaring up dramatically with a sudden burst of oxygen from for example a broken window.

One important issue concerns how far embers can penetrate urban areas and set fire to houses. The exact distance will depend on many factors, and a critical factor will be the prevalence of house-to-house ignition. This can greatly increase penetration as the houses become the main source of both fuel and embers for further ignitions. This appears to sometimes be the case in California. In situations where this is not the case, and where embers from the main fire front in the forest or rural lands are the main source of house ignition, Australian data suggests that maximum penetration will be about 500 meters as shown in Figure 13 (Chen and McAneney, 2004).

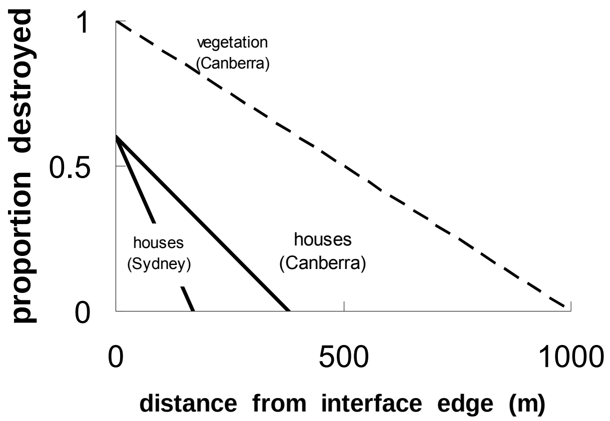


Figure 13: Proportion of houses and vegetation destroyed by wildfire
(source: Chen and McAneney, 2004).

Recent work reported in Blanchi et al (2006) confirms earlier research that the critical factor in house survival is the presence of an able bodied person who can defend the house from ember attack (also see Handmer and Tibbits 2005). Blanchi et al report:
:

- No human intervention: 30% survive.
- Occupant or neighbour present: 90% survive.
- Attention by fire brigade: 80% survive.

In summary, about 85% of the destruction of houses has been associated with ember attacks, and almost all of these are within 500m from the interface edge. The entry of embers causes a house to burn from the inside and so the presence of an alert person can be highly effective in saving houses.

The above research results apply to Australian conditions and buildings. It has been found that houses in some locations such as California may be much more flammable due to the use of untreated wooded roofs. Houses in rural Australia have generally been hardwood timber with corrugated iron or clay tile roofing. Most modern housing is brick veneer with tile or metal roofing. Verandas are normal with hardwood decking. Household gardens vary enormously, but in interface areas, eucalyptus trees are ever present and Australian bushfires are characterized by ember showers preceding the arrival of the fire front, and often continuing long after it has passed. Construction details can be very important in survival, for example the use of fine metal mesh can prevent embers from entering, and gardens can be arranged to minimize their contribution to the risk.

iii)The RISICO System

The system RISchio Incendi e Coordinamento (RISICO) provides Italian Civil Protection Department (DPC) with detailed wildland fire risk forecasts relevant to the whole national territory. The system is composed by two main modules, each of which represents a specific model, namely the fuel moisture model and the potential fire spread model.

The objective of the system is to evaluate the physical characteristics that a fire could assume, on the basis of the variables that condition locally the possibility of a successful ignition and fire propagation (Fiorucci, Gaetani et al. 2008). A schematic structure of the RISICO is presented below.

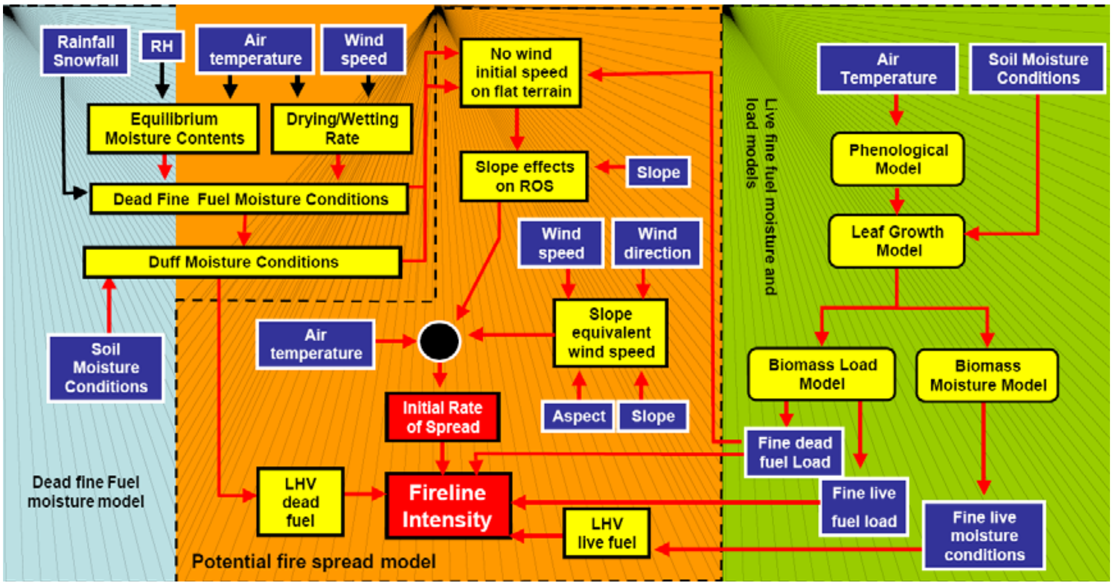


Figure 14: Structure of the RISICO system

The information that feeds the various modules represented in Fig. 14 is partly static and partly dynamic. Static information that is used in the present implementation of RISICO system refers to topographic (Digital Elevation Model -DEM) produced by the Italian SGN (Servizio Geologico Nazionale) and vegetation cover data drawn from CLC (CORINE Land Cover). Dynamic information is provided in time steps of 3 hours over a time horizon of 72 hours and includes information on rainfall, air temperature, relative humidity and wind speed/direction.

For each seasonal period five parameters have been drawn from the literature (Anderson 1982; Nuñez-Regueira et al. 1999): live fuel, load [kgm-2], HHV [kJkg-1], and moisture [%], b) for fine dead fuel, load and HHV. Thus, on the basis of the information provided by CLC map, above parameters are specified for each of the cells; these vary from one cell to another.

iv) The Spanish Case: Vulnerability of Houses and Fire Risk of W-UI areas

Among the Mediterranean countries Spain has paved the way for the application of a methodology for risk assessment and mapping, which has been tested in the Spanish areas of Wildland Urban Interface. A two-year study was funded by the Spanish Ministry of Environment, Directorate General for Biodiversity, for the identification, characterization and mapping of wildland-urban interface (WUI) patterns in Spain, and their associated risk distribution in each province due to forest fires. The methodology applied is based on the results of the WARM (Wildland-urban Area fire Risk Management) European project (2001-2004).

The general objective was to characterize direct and indirect risks associated with forest fires those that affect the W-UI and to provide a methodology and an information system for the minimization of losses and impacts on houses, society, economy and environment. The procedure for vulnerability evaluation is based on the convolution (product) of vulnerability of each of the existing elements and their exposure to the expected level of fire danger in the surroundings. The danger levels are characterized by the factors governing the behavior of the potential fire and the mode of heat transfer (contact, radiation, convection and firebrands) (Caballero et al. 2007). The geographic context of the methodology has been the territory of Spain (Fig. 15).

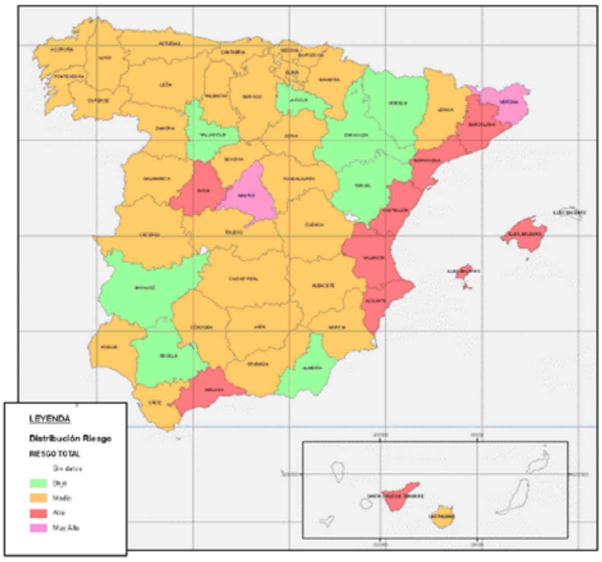


Figure 15: Risk distribution of the wildland-urban interface in Spain

For the identification of the different situations of WUI, and determination of associated level of risk, a number of aspects have been considered, namely:
· Potential progress of the fire in the vicinity, in the border and inside the settlement;
· Existing options for fire defense and civil protection operations;
· Exposure of houses to the potential fire within the interface;
· Level of vulnerability of houses;

The final outcome of the project is risk distribution across the wildland-urban interface areas in Spain, presented in four levels: low, moderate, high and very high. The type of vulnerability considered in the specific Spanish model has been that of houses exclusively; it is understood as the unwanted effects of fire on buildings, i.e. the degree of destruction expected when exposed to a certain level of danger (fire). The estimation of vulnerability of houses, i.e. the calculation of the potential damage when exposed to a certain level of danger, focused on the factors that entail the survival, partial effect on or destruction of a house. This is judged through the study of individual house situations.

As already mentioned vulnerability assessment of housing units has been part of the methodology developed for the assessment of W-UI fire risk in Spain based on interface zoning, typology and frequency. At W-UI scale, the first analytical step was to study the overall potential distribution, type and density of the urban settlements and housing areas in the forested areas of Spain. A set of typical interface situations was identified. This catalogue of interface situations aimed at facilitating the quick but accurate identification of the most frequent situations by applying an intuitive key, and at placing any real interface situations within one of the class-types, hence estimating the associated risk. The catalogue of interface situations is closely related to the catalogue of house situations, from which the average vulnerability is estimated.

The potential progress of the fire was considered to depend to a large extent on the structure and typology of forest fuel. Also, the slope and special topographic situations, such as shafts, saddles and canyons were considered. Additional information on hydrant network, water take points, the presence of safe and defensible areas, the presence and adequacy of signals and, lastly, the presence of buildings or other structures that could serve as refuge places were also taken into account.

Final exposure to the potential fire was obtained according to the clustering of houses and the pattern formed by the existing vegetation; also the *specific interface length index* has been computed (Caballero & Beltran, 2003). This represented the accumulated length of housing façades exposed to vegetation or other sources of heat in relation to the total developed area.

The ratings of Spanish provinces according to the levels of forest fire risk characterizing W-UI areas have been used as input to maps displaying the risk distribution across the Spanish administrative regions (Figure 4). This output formulates the basis for discussion and planning of action to confront the interface problem in Spain, particularly in those provinces in which the risk has been scored high and very high.

To identify house situations within a specific interface scenario, two main criteria have been applied:
· Position of the house in the settlement or housing area, in relation to sources of heat, and measured through exposure criteria (for example, the specific interface length index)
· Type of building and its elements, according to vulnerability criteria.

Consequently by looking into the interface situation classes, the house situations are categorized by ticking the following criteria:

√ Position of building

· Isolated house
· Small cluster of houses
· House placed in a mixed-use area
· House placed in a compact settlement
· House of rural town
· House in a large city
· Industrial installation in an industrial area interface

√ Type of building

· Modern house buildings made of stone, concrete or steel, i.e. fire-resistant
· Solid buildings mostly fire resistant, with burnable elements in the exterior
· Industrial building, warehouse, presence of flammable materials
· Rural houses, with old wood structure and clay stone or tile roofing
· House of average quality with noticeable presence of plastic, wood and other burnable material
· Poor-construction house, temporary warehouse with abundance of flammable and burnable elements

The final risk accounting for each province has been obtained then by simply deriving the importance (frequency) of each type by the associated risk as mentioned above. The resulting synthetic map of all provinces provides a first view of the risk attributed to forest fires in the WUI areas in Spain.

v) The Greek Case

In the Greek context, we consider of special interest in the case of human-ecological systems the effort of several authors and researchers to evaluate the so called **Fire Risk Index** which is in essence the exposure of the above systems or territories to human/social causes of forest fires. Kalabokidis et al (2003) associated this exposure with the following spatial and temporal parameters (Table 5):

- Distance from main roads and secondary roads
- Distance from power lines
- Distance from urban areas
- Distance from waste disposal sites
- Distance from railways
- Distance from open-air recreation areas
- Distance from agricultural works and grazing land
- Distance from military shooting range
- Month, day and hour of consideration.

In particular, Fire Risk Index was estimated in the context of Fire Danger Rating System (FDRS), an innovative model in terms of both research and practice which was first delivered by the EU programme AUTO HAZARD-PRO (RTD programme in the field of Energy, Environment and Sustainable Development). The system was applied on a pilot basis in the Greek island of Lesvos. The system formulated a basis for better planning, management and decision-making in the fields of pro-active measures and emergency action.

The main output of the proposed Fire Danger Rating System (FDRS) is the Fire Danger Index which is based on four other indices: the fire weather index (FWI), the fire hazard index (FHI) the fire risk index (FRI) and the fire behaviour index. The parameters have been chosen in a way that makes them easy to be defined and measured in order to be included in an operational system versus basic research methods (see table following). The parameters are retrieved through the analysis of remote sensing data, namely Landsat TM and Quick-Bird, as well as maps of a scale 1:50000 and the operational meteorological model SKIRON. Remote automatic weather stations (RAWS) and the operational weather forecasting system provide real-time and forecasted meteorological data respectively. Geographical Information Systems have been used for management and spatial analyses of the input parameters and the relations between wildfire occurrence and the input parameters are investigated by neural networks the training of which is based on historical data (Kalabokidis et al., 2003).

The function mapping of FWI, FHI and FRI is accomplished with Artificial Neural Network (NN) methodologies. The training of NN is based on fire history. Indeed, 420 historical fire events have been identified and mapped (1970-2001) in Lesvos island and historical data for the input variables have been collected for each event. This database is used for training, testing and validation of the NN (Kalabokidis et al., 2003).

Final results are classified in five levels of fire danger (see map in Fig. 16).The AUTO-HAZARD PRO and the final outcome of its application, that is the decision-support system has been a research initiative undertaken by the University of Aegean. The team has been constituted by geographers, civil engineers and environmentalists.

The General Secretariat of Civil Protection has been denominated as the user of the above project. For the whole summer period of 2004 and for pilot testing purposes the fire-danger map produced by AUTO-HAZARD PRO has been released to the local fire brigade and the General Secretariat of Civil Protection on a daily basis.

Table 5: Parameters of the proposed FDRS (Source: Kalabokidis et al. 2003)

FIRE WEATHER INDEX	FIRE HAZARD INDEX	FIRE RISK INDEX
Next day air temperature at 12.00 or real time air temperature from RAWS	Fuel models	Distance to main roads
Wind velocity	10-hour dead fuel moisture content	Distance to secondary roads
Relative humidity	Elevation	Distance to livestock and other similar significant buildings
Precipitation	Aspect	Distance to power lines
		Distance to urban areas
		Distance to waste disposal sites
		Distance to railways
		Distance to recreation areas and other suchlike areas of high population density
		Distance to grazing lands / agricultural cultivations
		Distance to forestry works
		Distance to military firegrounds
		Month
		Day

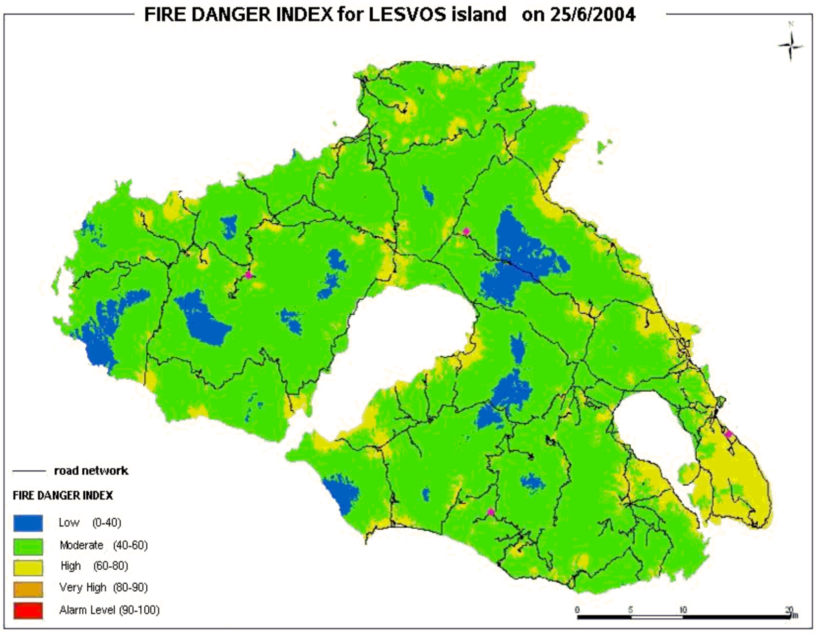


Figure 16: Fire Danger Index for the Island of Lesvos

However, the socio-economic dynamics that produce the manmade causes of forest fires are far more complicated and exposure assessment presupposes a more sophisticated analysis of the pressures exerted by socio-economic activities on forestland. In this sense the dynamics of real estate market, land ownership, decline of inner city areas and the environmental degradation and unplanned character of the peri-urban zones as well as other spatial and economic issues influence the exposure potential of regions to a large number of manmade causes of forest fires. A more sound solution to the problem of assessing such dynamics is through assessment of rates of land use and land cover transformation (e.g. rate of transformation of agricultural land to building development land) in the fragile and threatened by fires territories under examination. In the three following maps we can observe land cover transformations during the period 1969-1992 that occurred with the help of forest fires in a forest fire prone area of the Attica Region (i.e. the Greek capital region). The observer can notice in particular the gradual increase of housing developments represented by shades of red (Fig. 17).

2.4.3 Appropriateness of Parameters / Indicators Used in Assessment Methodologies

Droughts and wildfires are closely linked phenomena, which, in addition, are both related to climate change and global warming. This is so, notwithstanding the importance of the human factor as a triggering mechanism in the case of fires.

Droughts impact on both ecosystems (biotic and abiotic) and socio-economic systems, as indeed do forest fires, with the impacts being linked in a chain fashion affecting the full system. Hence, as we have seen, studying a system's vulnerability requires investigation of the entire system's life span (past, present and future) to understand its immediate reaction, preparedness, coping capacity and ability to preserve its systemic characteristics in the face of damage.

Analytical viewpoints and studies of Vulnerability to Forest Fires fall into two major groups:

1) Those zooming on natural areas and examining **ecological vulnerability** alone and
2) Those referring to human-ecological systems' or **territorial vulnerability** to forest fires.

In the first case vulnerability is acknowledged as a time variant attribute causing environmental changes (and degradation) diversified in time and space, after fire events. Ecological vulnerability in the short term is considered as the combined outcome of *erosive susceptibility* and *vegetation response ability*; besides it is a function of fire intensity, hence hazard dependent (Alloza et al., 2006). Ecological vulnerability in the long term is considered as determined by the ability of the vegetation community to persist in the long run with no substantial changes. The assumptions lying behind the above approach are:

- Short-term vulnerability after fires is a function of *environmental damage potential* (erosion) on the one hand and resistance or *ability for self- shielding* (i.e. self-protection) of burnt vegetation on the other.
- Long-term vulnerability is identical to lack of resilience on the part of vegetation community (which is assessed in terms of community structure, specific composition, relative presence of diverse species).
- Exposure is taken as the condition that transforms vulnerability into losses and coping incapacity.

The problem with the above approach is the fact that human presence and behaviour that modifies (increases or lowers) ecological vulnerability is totally ignored. The natural areas exposed to forest fire hazards are considered –falsely - to have been built by nature laws alone. Therefore some of the basic roots, the manmade causes of vulnerability, i.e. either harmful human interventions or neglect of forest ecosystems) are set aside.

On the other hand territorial vulnerability to forest fires (referring to human-ecological systems) is a more integral and inclusive notion because it addresses both natural and manmade causes of vulnerability of those territories that are a mixture of nature's and man's work and where a constant interaction occurs between human communities and the natural surroundings. In the case of droughts the force of natural causes is dominant, but here again human action intervenes either at the global level of contributing to climate change or at a more local scale, and this is very important, of securing or neglecting appropriate land and economic activity management.

Although this composite version of vulnerability has been acknowledged the respective determinant factors and parameters for its assessment have not been consolidated yet. Advancement has been achieved basically in the case of the component of vulnerability to forest fires that concerns housing building and complexes within forest environments. However, the basic vulnerability component of such mixed territorial units refers to interactions between the forest ecosystems and human activities and this element is totally ignored.

Finally, significant advancement has occurred in the field of the Fire Risk Index taken as the probability and frequency of occurrence of intentional or other (due to negligence) causes of forest fires.

The **socio-economic component** of territorial vulnerability to forest fires is a critical issue, almost untouched by research. However, the impact of a wildfire can affect the community well beyond those whose properties were burnt out. On farms it is often impossible to protect all assets and losses of stock, equipment and infrastructure can be extensive. These may be uninsured, underinsured or irreplaceable. After the fire there may be reduced employment opportunities in the area. On the other hand insurance or other sources of compensation replacing destroyed assets may stimulate the local economy (see also Handmer and Hillman, 2004).

Furthermore, wildfires do not usually happen gradually; therefore, timely information provision and the physical and mental capacity to act quickly are important - especially if people are to either evacuate safely or actively defend their properties. The willingness, resources and capacity to prepare and maintain a property for fire requires more than information. It requires money and commitment which may not be there for example with rental properties, or with those physically unable to defend the house. The ability to relocate if necessary requires social networks, transport and access to refuge or crisis support.

Table 6 summarizes a number of factors which are important in vulnerability to wildfires. These are among those identified in a major project into vulnerability and bushfires in Australia in rural Victoria (Handmer et al., 2007). In arriving at the classification published material in research and practice on vulnerability has been drawn on. This literature is very large and assessment has been supplemented by discussions with other researchers in the field. The result is eight categories which are fundamental to vulnerability assessment in rural locations. Each category describes a key component of vulnerability for which, in most cases, there is a substantial supporting literature in terms of both conceptual development and practical application

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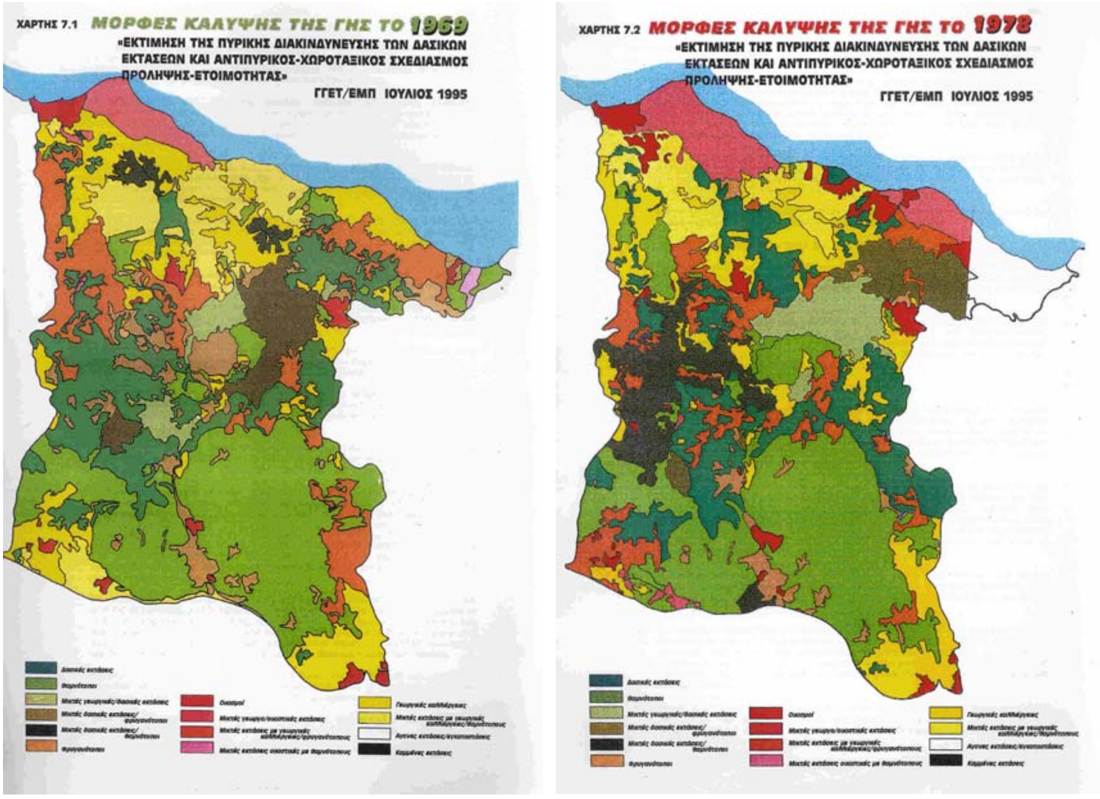
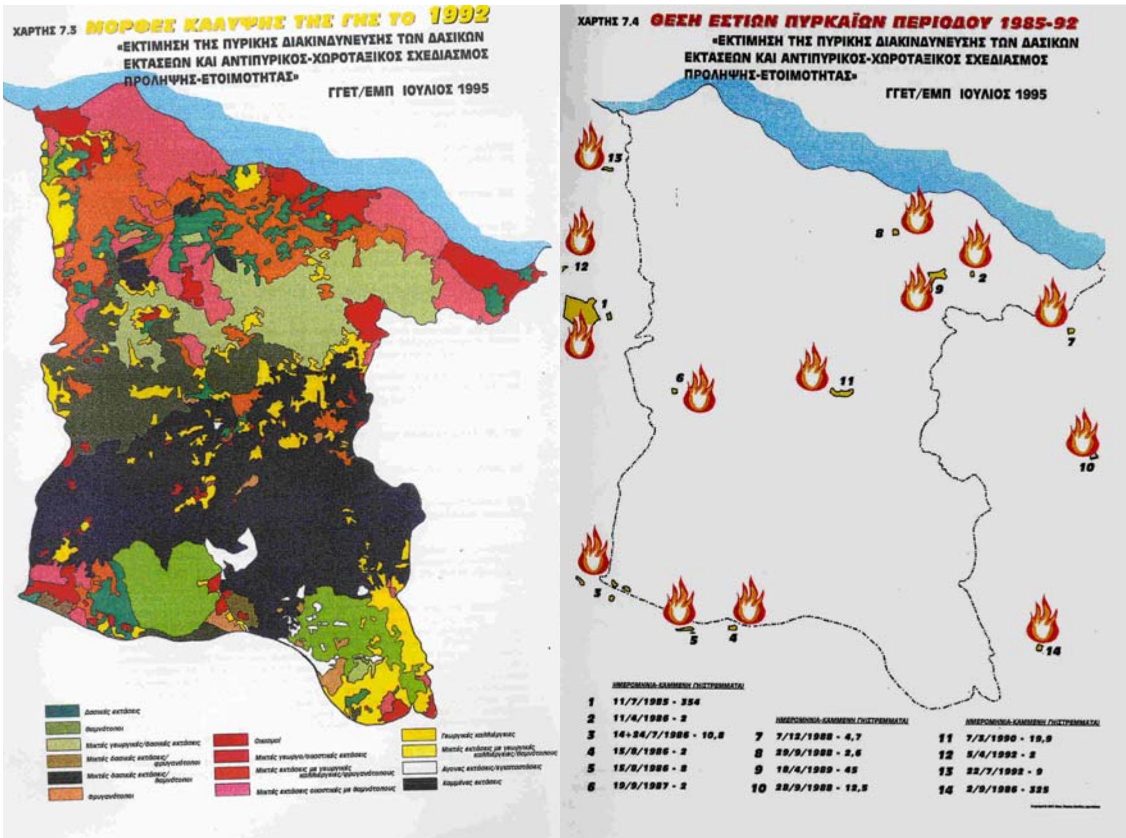


Figure 17: Land cover changes in a fire-prone area (within Attica Region) between the national road from Athens to Thessaloniki and Evoikos Bay during the period 1969-1992 – Major forest fires of the same period (NTUA 1995)



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The categories are listed below using well-established labels that inevitably obscure some of the detail. However, there are many other ways of categorizing and labelling areas of vulnerability. Areas of vulnerability that appear to be missing are bio-physical factors and political marginality or power analysis and governance. However, political issues are implicit in other factors such as social disadvantage, isolation and access to services and economic attributes. Governance issues are related to service access, distributional issues, security and social well-being. The broad areas or categories of vulnerability assessment are:

- Health and well being;
- Access to resources;
- Livelihood security;
- Social disadvantage;
- Accessibility/remoteness;
- Social capital;
- Self-assessment - which acts both as a bottom-up form of vulnerability assessment and a tool for application in many other areas of assessment;
- Climate change – is included as a separate area because it is becoming the focus of a rapidly expanding literature on vulnerability and adaptation to climatic hazards. It is also a major driver of change in natural and human systems.

Climate change is central in the process of drought generation as it is affecting rainfall, in terms of volume, frequency and duration. Policy responses to the problem are bound to have a long-term horizon. When however drought conditions provide a favourable framework for fire ignition the time horizon is accordingly shortened. Thus, in the case of fires, a major policy issue concerns vulnerability and response to wildfire: Are people and property less vulnerable when evacuated or when they stay at home as the fire passes? Australia has generally taken the view that people are at their most vulnerable during last-minute evacuations. So safety is maximized and vulnerability reduced if people at risk either leave well before the fire front arrives, or stay and defend their properties. Of course, the real options may be quite different for those in rural or otherwise isolated settings such as tourists, and those on the edge of major cities.

It is to be noted that most of the components of vulnerability identified in table 6, in spite of their socio-economic emphasis, apply to drought vulnerability as well. As stressed already an important feature of drought impact is the chain sequence of effects, from those attacking abiotic components of an ecosystem, such as surface temperature or wind erosion, to effects on biotic processes, such as plant survival or diversity, then to effects on abiotic – biotic relationships, e.g. through water availability, and, finally, to socio-economic impacts, e.g. on farming, immigration and urbanization.

Table 6: Summary of key factors in socio-economic vulnerability to wildfires. The factors were developed for rural communities, but most apply to urban interface communities as well. (Handmer et al., 2007, *Mappable Vulnerability Indicators for Victorian Communities*)

Components of Vulnerability	Definition in context of project	Rationale	Evidence & Examples
1. Health. **Wellbeing includes health and many other factors covered in this table.**	Health Well being indicators are a range of measures and evidence designed to identify and communicate economic; social; environmental; cultural and governance trends; and outcomes at local, regional and national levels.	Physical and mental health will directly affect vulnerability to wildfire. Life expectancy is the end point of many factors in lifestyle, health services & occupations.	• ABS National Health Survey • ABS Measures of Well Being and Progress • Rural and remote people have significantly lower life expectancy than city dwellers.
2. Access to resources. Access to legal resources is included here.	Indicators would reflect people's capacity to access financial resources to prepare for, respond to or recover from wildfires. Access to the law. For completeness aspects of social capital are included here as well as in 6 below.	Without resources people will have trouble coping with fires and other hazards. Those already carrying debt may find that access to additional credit is denied, or that further debt becomes a serious problem for their families and livelihoods. Legal access for building codes, OH&S and employment issues are connected with wildfire safety, and linked with health and thereby capacity for coping with fires and other hazards.	Closely linked with 3 below. Many rural people have high levels of debt and uncertain incomes with limited options for diversification.

Components of Vulnerability	Definition in context of project	Rationale	Evidence & Examples
3. Livelihood security / diversity. Security of tenure is included here.	(i) individual/household Risk of reducing existing income, and of reallocating income to debt and replacing assets. (ii) Community/region Risk of disturbing the economic activities that provide livelihood for community members. (iii) Tenure Secure tenure is seen as underpinning farming livelihoods, and constraints on eviction are key to household security.	(i) Change of current income or its reallocation may have a negative impact on the household extending to generational impacts through education. The result is a lower level of capacity in terms of expertise and funds. Fire may also destroy income producing tree crops. (ii) Continuation of economic flows from commerce or other sources is central to the sustainability of a community of a region. Any decline is reflected in withdrawal of govt and commercial services, and lower local capacities. Rural areas undiversified economically will be more vulnerable to fires, droughts and other weather phenomena. Tenure: Different types of tenure involve different debt loads, ability to obtain credit, and importantly security which impacts directly on investment in fire and drought protection, and on ability to recover, especially in either a long drought or drawn out recovery.	Agricultural Producers' perception of drought vulnerability and mitigation-Howard Country, Nebraska; -ABS, 1995. - Reducing Disaster Risk: A Challenge for Development. Dependence on undiversified agriculture, tourism, forestry.
4.Social disadvantage	A measure of relative social and economic disadvantage; typically associated with low income, high unemployment and low levels of education.	High levels of social disadvantage means that individuals and groups are excluded from much of what modern society and economy have to offer. Such groups are less likely to have the information, expertise and material resources to deal with wildfire.	• ABS Socio-Economic Indexes for Areas (SEIFA), in particular the index of relative socio-economic disadvantage. • Dropping Off the Edge; The distribution of disadvantage in Australia (Jesuit Social Services) • Rural indigenous communities are often seen as particularly disadvantaged.
5. Accessibility / remoteness	A geographical measure of the accessibility of goods and services from a populated locality.	Accessibility of services (health, education, welfare, banking, postal etc.) is vital to social and economic viability of rural towns and regions. More remote communities: may receive limited or delayed warnings and support during a crisis; often dependent on communication systems that may be disrupted during a crisis. Access to mental health services particularly important during drought and after bushfires. Service accessibility crucial in speedy recovery. More remote communities may have a strong sense of coping, self-efficacy and self-reliance.	• Rural, Remote and Metropolitan Areas (RRMA) classification (Australia). • Accessibility / Remoteness Index of Australia (ARIA and ARIA+) • Australian Standard Geographical Classification (ASGC) Remoteness Areas (based on ARIA+)

Components of Vulnerability	Definition in context of project	Rationale	Evidence & Examples
6. Social capital and networks	Social capital is seen as vital to individual and community resilience. It is a particular asset in remote or resource poor areas. 'Bonding' refers to the value assigned to social networks between relatively homogeneous groups of people and 'Bridging' refers to that of social networks between socially diverse groups.	Strong networks help people deal with fire and drought by mobilising collective expertise and psychological and material and resources. Bridging capital is likely to be more use during a major disaster or prolonged drought as it links to those not affected, whereas all those in a bonding network might be seriously impacted by an extensive disaster. Social capital is not equally available to all; geographic and social isolation limit access to this resource. Although it should be considered that high social capital does not necessarily indicate a resilient community (and vice versa), much research has investigated the importance of social cohesion in amplifying or attenuating stresses that are placed upon communities.	• ABS 'Measuring social capital: an Australian framework and indicators'
7. Self-assessment. Also a tool for use across most other areas.	Self assessment is a 'bottom-up' indicator, which would reflect people's perception of their own level of vulnerability or coping capacity.	Communities are aware of their own needs and concerns. Taking these into account is the basis of community engagement in all fields. Identify local concerns & priorities, & deal with them. Incorporation of local knowledge is called for in many post wildfire reports. (Improvements in people's day-to-day circumstances will do much to improve resilience and coping capacity.)	Self-efficacy, feelings of control are powerful factors in coping ability cf "helplessness". Without them people may not take adaptive action. (Handmer & Penning-Rowsell, 1990).
8. Climate change. A major driver of change.	Climate change is set to exacerbate existing vulnerabilities (Lowe and Lorenzoni, 2006; IPCC, 2007). Vulnerability indicators must therefore be identified in terms of current and future vulnerabilities. Understanding future vulnerability involves the use of scenarios, with adaptive capacity arrived at by identifying the options available to a community or region.	It has been widely accepted since the IPCCs Third Assessment Report in 2003 that issues related to climate change should play a defining role in the design of development and sustainability objectives. There are likely to be more severe wildfires and droughts with the possibility of a lower rainfall regime. Reducing vulnerability through adaptation may involve much more than recovery after an event through insurance for example.	• Bureau of Meteorology models of areas of increased fire danger under a series of climate change scenarios.

Components of Vulnerability	Definition in context of project	Rationale	Evidence & Examples
CROSS-CUTTING ISSUE: **Demographic characteristics. Also a source of information for other areas.**	Demographics are general characteristics used to segregate a population. They are useful in creating general descriptions and trends in population.	1. Standard data for whole country comparable over space and time. 2. provide a snapshot and can be used to create trends 3. They can be used to identify potential levels of vulnerability, eg non-English speaking people may be excluded from information and warnings; households with small children may not want to defend their properties against wildfire. 4. The literature often asserts that older people and women are especially vulnerable.	ABS reports

2.5 The Impact of the Pattern of Spatial Development on Territorial Vulnerability

Spatial planning aims at influencing the distribution of people and activities in space to serve socio-economic development and environmental protection and is pre-occupied with all administrative levels and spatial scales (urban plans, regional plans, national spatial plans, cross-border multi-regional plans etc).

In theoretical terms forestland plans should be integrated in the spatial planning system (Montiel and Galiana 2005). However, actual forest policy is not connected to spatial planning and this is a real handicap of both policies. Forestland planning and regulation is usually done from the forestry perspective; particularly in connection to the problem of large fires. However, two of the principal structural causes of large forest fires are relevant to building development and socio-economic changes which normally fall into the scope of spatial and development planning. The first of these causes refers to a settlement model with a sharp trend towards dispersion, that increases risk of ignition; the second cause relates to the uncontrolled evolution of forest vegetation towards a growing continuity of masses favouring wildland fire propagation (Montiel and Galiana 2005).

In the Mediterranean Region, land abandonment has led to increase of the fuel load available for burning. The abandonment of agriculture allowed the conversion of agricultural land to woodland. This resulted in increase of fuel loads available for potential fires and subsequently the creation of a more continuous vegetation cover. With more people moving to urban areas, the chances for early fire detection in the rural areas are seriously reduced. The conditions arising from the rural exodus facilitate the transformation of an initially controllable forest fire to a mega fire.

Preservation and maintenance of rural activities (such as use of forest fuel, establishment of agro-forestry systems or the harvesting of non-wood forest products such as mushrooms or hunting activities) in forested areas favours discontinuities in forest vegetation and lowers the fuel load. In the long term such policies become the best defense against the increasingly frequent mega fire events.

Urban sprawl and dispersed territorial development in areas touching or mixing with forested lands as well as changes in the use and occupation of rural houses pose a real challenge to the management of forest fires. Factors, such as geomorphology, vegetation, building development aggregations, tourism development patterns and population transfers, have entailed different land use and land cover patterns each of which is associated with a distinct level of risk and vulnerability (Aguilar et al., 2007).

The spatial dimension is critical in the case of droughts, which, as remarked earlier, always affect extended and heterogeneous areas. For this reason, territorial vulnerability is considered as the most critical aspect of vulnerability to drought. It is of course dependent on the duration of drought. Exposure to prolonged drought does not permit the adaptation of natural systems, which may be possible in the case of short periods of drought, and may lead ultimately to desertification. Human systems too may not possess the resources required to cope with long and repeated spells of drought. Given the sequence of drought impacts, spatial management is first required at the level of natural and agricultural landscapes. At a second stage however the consequences of drought reach urbanized zones, such as towns, cities, industrial areas and tourist zones because of problems of water supply, migratory movements, land occupation, housing and employment demands, natural environmental degradation etc. Here, long term spatial planning policies become mandatory.

2.6 Institutional and Territorial Vulnerability

Institutional and territorial vulnerabilities are intimately linked because “territory” is frequently defined in terms of administrative boundaries, a practice which often causes severe dysfunctionalities. Flexibility of response, vertical and horizontal cooperation, and citizen involvement are critical factors necessary for efficient action. This is particularly evident when impacts on natural ecosystems have a cause originating in manmade systems, e.g. in urbanized areas, or when a natural process leads to serious consequences for socio-economic systems.

The example of fire propagation shows the importance of institutional capacity, which may determine suppression capability. The rate of spread of a wildfire depends on weather and fuel factors. Weather is assessed in terms of a FDI index (Fire Danger Index) which is a function of temperature, wind-speed, relative humidity and fuel moisture (Noble et al., 1980). The fuel is essentially characterized in terms of the weight of fine fuel less than 6mm diameter. On hot windy days with very low humidity (down to 4% RH in the 2003 Canberra fire) days with an FDI>50, extremely dangerous fires can develop, even when there is aerial suppression support (Pluchinski et al., 2007). Under such conditions, once developed, even a fire travelling as slowly as 2.0 km/hr through 8-year old fuels cannot be stopped (Koperberg, 2003).

Another aspect that needs to be appreciated by suppression plans and mechanisms is the effects of radiation. At a distance of 1.0 times the flame height away from the fire, the radiation level is about 30 kw/m^2 regardless of the height of flame (assuming the flame shape is that of a semicircular disc of fire). At a distance of 5 times the flame height is about 2 kw/m^2. The significance of radiation levels is illustrated by the following examples. Depending on their detail and whether they are in contact with glowing embers, wood objects will ignite and windows can fail at radiation levels in the range 10-40 kw/m^2 – note that different types of wood perform very differently with hardwood generally being more resistant. In contrast, the safe operational level for people is only 2 kw/m^2.

Fire control or suppression capability is an issue of fire intensity (or energy) and size (Table 7). Unless they are very small, medium intensity fires are usually beyond control at least by direct attempts to simply stop the fire. The capability of suppression action is generally argued to have an upper limit around the 4kW m $^{-1}$ when direct attack becomes ineffective in forest fuels (Loane and Gould, 1986). The purveyors of some aerial fire-fighting appliances claim higher figures of around 8kW/m. However, Australian research has shown that aerial suppression is about as effective in stopping a fire’s forward spread as ground crews with tankers and bulldozers (e.g. Loane and Gould 1986, McCarthy 2003). It is important to appreciate that a forest fire may exceed 80kW/m, with fire intensity during the 1983 Ash Wednesday fires in Victoria, Australia peaking at more than 100,000 kW m $^{-1}$. The strong winds typically accompanying such fires increase the difficulty of control by making fuel breaks ineffective and starting spot fires well ahead (hundreds of metres or more) of the main fire front. Such spotting often makes direct control impossible even with relatively low fuel loads (Incoll, 1994; Cheney 1994).

Table 7: Limits of different fire suppression methods (Handmer and Bosmomworth in press)

Suppression Method	**Fire Intensity (kW/m)** The intensity at which suppressions are likely to fail on a 10ha fire in dry eucalyptus (stringy bark) forest
Hand tools (crew of seven)	800
Bulldozer (2Xd6)	2000
Airtanker (DC6)	2500
Ground tankers on a 40m fire break	3500

Source: Loane and Gould (1986)

Naturally, given the difficulties in controlling fires, effort during very severe fire weather is dedicated to preventing ignitions, by for example banning all outside sources of flames and use of equipment and tools likely to cause sparks, and in the event of an ignition, putting maximum effort into extinguishing it. If a fire gets away – and this can occur within minutes to hours – the chances of controlling it are very small.

Institutional vulnerability at a time of a hazardous event may limit or even eliminate the coping capacity of the administration and of the entire societal system to act and bounce back after the event, e.g. that of a fire in a mixed use area. But equally debilitating can be the inability of institutions to face slow and protracted developments, such as the increasing frequency of prolonged drought periods, in a territorially systemic manner. In this case the effects may be slow to appear, unless a disaster is triggered by human action (e.g. a fire), but are very large in cumulative magnitude. The issues of limited institutional capacity and institutional vulnerability are thus closely related to territorial dimensions.

2.7 Interdependencies and Overlaps among Territorial and Systemic, Socio-economic, Physical Vulnerabilities.

Systemic vulnerability characterizes *par excellence* the spread of drought – affected areas and activities. But it is also a term that befits fragility of territorial systems to forest fires and the sequential character of the respective losses. Indeed, it does denote the propensity of a territorial element to endure functional damages owing not only to the effects of a stress on its physical structure, but also to its connections to other elements belonging to the same territorial system. In other words, systemic vulnerability to forest fires is an appropriate term as it takes into account the functional dependence of one element on the other elements of a territorial unit (Minciardi et al. 2005). The occurrence of a forest fire exposes the fragilities and vulnerabilities of a particular territory those owing to the several linkages among the physical and socio-economic dimensions of this territory.

The impact of a major fire increases considerably by the loss of vegetation which helps landslide prevention. Flood risk is also affected since vegetation controlling run off cease to exist, leaving the bare soil susceptible to the erosive action of rainfall. Additional losses relate to wildlife habitat in natural areas; these can be severely reduced or affected after a forest fire posing a threat to local biodiversity, especially when fires become more frequent. Fire frequency is a powerful selection force, and although some vegetation is capable to cope with fire, when the life time of tree species exceeds fire return interval, the species that are unable to survive or reproduce after fire will eventually be extinct (Fernandes and Rigolot 2007).

Besides forest fires cause direct socio-economic losses, such as losses to property owners and the logging industry. Government intervention (similar to that taken by the Portuguese Government after the large forest fires of 2003) would be necessary in order to regulate the market and avoid very low wood prices. As to the systemic character of the effects of drought we have repeatedly stressed the sequence which may start at a level of natural abiotic components and end with severe stress in towns and cities. Systemic effects are already complex, even unpredictable, at the level of natural ecosystems, but they may become even more complex when they extend to human habitats at an enormous cost for life quality and resources.

2. 8 General Conclusions

The territorial aspect of vulnerability in both cases of drought and forest fires is critical and essential. However "territory" in the above cases may connote either a purely ecological territory or a human-ecological system. Hence territorial vulnerability (to droughts and forest fires) is split to ecological vulnerability and vulnerability of complex human-ecological systems.

Ecological vulnerability to forest fires denotes susceptibility of the ecosystem to change as a consequence to fire, the rather in an irreversible fashion. Ecological vulnerability changes with respect to the phases of the forest fire disastrous event. Short term ecological vulnerability refers to the soil degradation risk (hence its locus is on topsoil) and it is determined by pre-event parameters as well as exposure to the same the fire event. Medium term ecological vulnerability refers to probable changes in plant composition and structure that are not curable. Exposure to the fire event and resilience of the plant community are the basic components of this second type of ecological vulnerability. It is noteworthy that unlike hydro-geological hazards the meaning of exposure in ecological vulnerability is connected to the span of time during which the ecosystem suffers the damaging influence of the fire event.

The researchers dealing with territorial vulnerability of human-ecological systems to forest fires consider exposure and vulnerability from a different point of view. At a pre-event stage exposed and vulnerable territories are those suffering a high probability of fire ignition, i.e. those that are stressed and pressed by mass presence and expansionary trends of human population and socio-economic activities. At the stage of event manifestation (i.e. once fire starts) vulnerability is determined by climatic conditions, land use characteristics, vegetation patterns, species flammability and terrain slope. In this second stage population presence may decrease vulnerability. Hence exposure may carry two meanings, either a socioeconomic / institutional /ecological system that produces fire ignition incidences or a system that is exposed rarely or often, for short or for long to fire episodes.

In the case of droughts vulnerability of a human-ecological system is perceived as opposite to system's robustness. More specifically a system is vulnerable to a drought when its structure, parameters and way of functioning qualitatively change under the effect of drought and cannot be restored afterwards. It is interesting to note that vulnerability is related to a threshold of losses after which damage is irreversible. As in the case of forest fires vulnerability is tightly connected to exposure to the hazard of drought. According to aforementioned definition “vulnerability of a system depends on the strength and duration of the drought”, meaning exposure. As regards vulnerability assessment this is based on the damage potential and the coping capacity potential of the system under drought pressure. It ensues then that the approach of territorial vulnerability to droughts does not differ much from the cases of hydro-geological hazards. The difference lies in that in the latter cases damage and coping capacity refers to principally pure manmade systems. Besides the capacity to cope with hydro-geological risks originates basically from the threatened (possibly vulnerable) human-territorial system while the capacity to cope with droughts is a function of both the dynamics of the drought (i.e. hazard) and the capabilities of the exposed human-ecological system (its past, present and future).

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