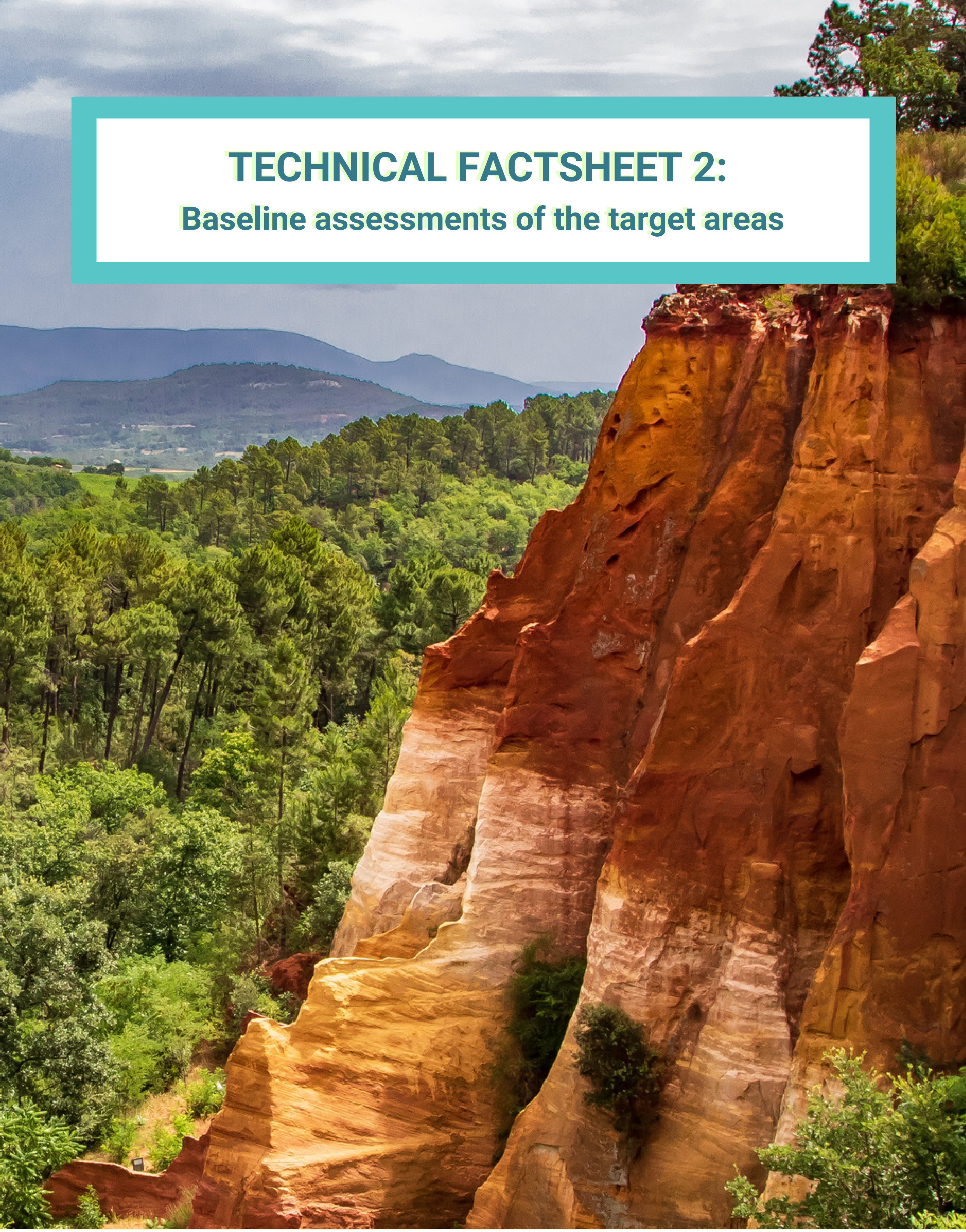
TECHNICAL FACTSHEET 2:
Baseline assessments of the target areas



MED ITER RE3

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1. Introduction

The **MediterRE3** project will provide projections of Burnt Area (BA) and associated Green House Gas (GHG) emissions, under different scenarios of future climate change and fire-smart landscape interventions, for different Mediterranean target landscapes. The project aims to support national climate change mitigation, and climate-resilient landscape planning policies & strategies.

The results of **Work package II** ("Development and application of a robust science-based methodology for estimating the reduction in fire-related GHG emissions under future climate change scenarios in fire-smart, mosaic-like resilient landscapes") are summarised in technical factsheets No's 1-3.

The **current technical factsheet** (No 2, WPII, activity AII.2) presents relevant base-line fire data for three target landscapes (Fig. 1). It details a novel, robust, methodology for estimating BA & GHG emission from climatic and fire indices. The methodology aims to be applicable throughout southern Europe, being able to use both open-access European data as input, as well as regional data.

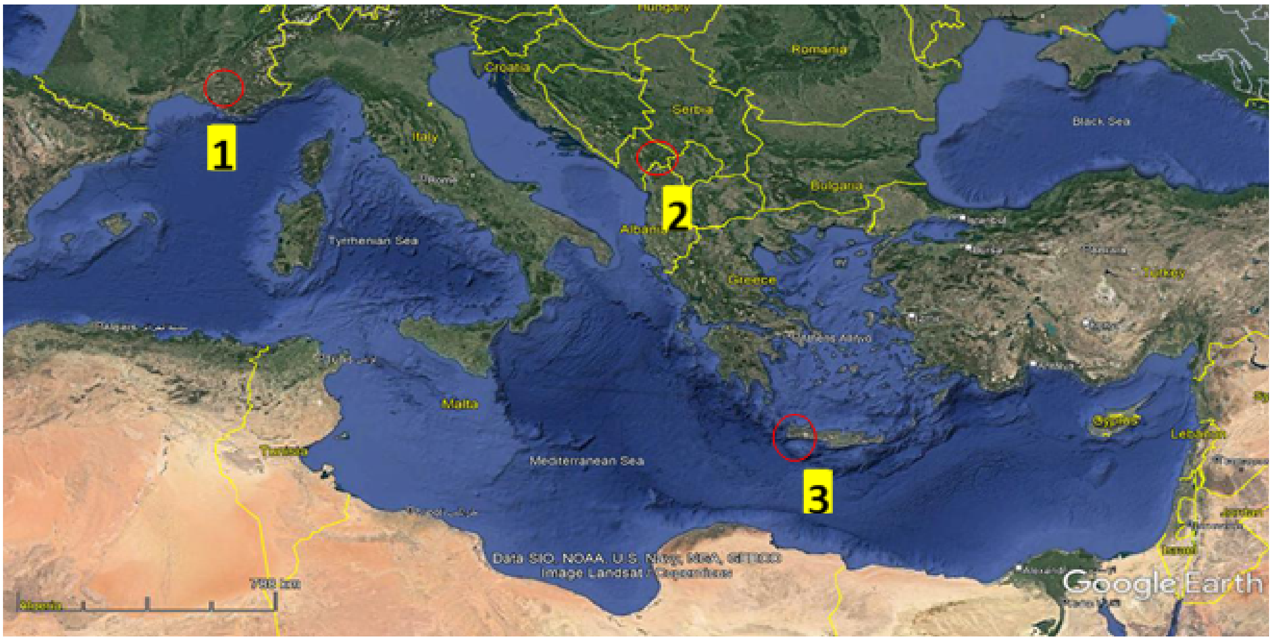

Figure 1. *Location of the target areas selected for fire-smart management interventions (1. Luberon-Lure NP, SE France; 2. Prokletije/Komovi NP, SE Montenegro; 3. Samaria NP, W Crete, Greece)*

1.1. Background & Approach

Mean BA by wildfires in the Mediterranean is projected to double or triple by 2070 under future climate change scenarios [**1-4** and references herein], assuming non-significant changes in external factors (i.e., land-use, fire suppression and human activities). Emissions of GHG by wildfires are strongly related to area-specific BA. However, there are large regional differences in projections of climate-driven BA changes, while no single method is used to estimate future BA changes across the Mediterranean due to climate change.

Here we present a method for estimating BA and associated GHG emissions, which is applicable throughout southern Europe, using a novel statistical model that is driven by selected climatic and fire-danger indices. The statistical model needs to be calibrated at each target site with observational data and is therefore area-specific.

We first present the available observational fire-data at each of the target areas (section 2), and then introduce the methodologies for calculating BA and related GHG emissions (section 3).

2. Baseline data from the target study areas

For meaningful statistical correlations of BA to climatic and fire-danger indices, study areas need to be sufficiently large. When focussing on small study areas, there are often no fires at all during days characterised by high fire danger. Only over large spatial areas there is a correspondence between high fire danger and fires/BA. This study (WPII, factsheets 1-3) used the following site-specific data-sets (all of which needed to cover >15 years): BA records, fire-emission data and meteorological data.

Burnt Area Records (more than 15 years long). When regional high-resolution BA records are available, study areas need to have a minimum surface area of about 50 x 50 km. Regional BA databases were available (and used) for W Crete (Chania Province) and the Luberon National Park (SE France). Larger study areas are required (minimum size of about 100 x 100 km) when European BA data are used from EFFIS (European Forest Fire Information System, https://effis.jrc.ec.europa.eu/), which are also used in GWIS (Global Wildfire Information System, https://gwis.jrc.ec.europa.eu/), as only large fires were registered up to 2017. The Rapid Damage Assessment provided the daily update of the perimeters of burnt areas in Europe for fires of about 30 ha or larger, since 2003 until 2017, twice every day. Since 2018, the use of Sentinel-2 imagery allows the detection of fires below the 30 ha threshold and it is estimated that the areas mapped in EFFIS represent about 95% of the total area that burns in the EU every year (https://effis.jrc.ec.europa.eu/about-effis/technical-background/rapid-damage-assessment).

This study accessed fire-emission data for all target areas from GWIS. Climate information was derived from the state-of-the-art ERA5-Land reanalysis dataset [**5**] and used in the statistical modelling procedure (section 3). Sections 2.1 to 2.3 below detail the information on BA and emissions (related to wildfires) that is available for each of the target study areas.

2.1. Crete

Regional fire and emission data for entire Crete (surface area: 8.450 km^2) used in this study, accessed from the Global Wildfire Information System (GWIS: https://gwis.jrc.ec.europa.eu/), are summarised in Figures 2.1-2.4 below. These data span the period from 2002 until 2019.

High-resolution BA data for Chania Province (W Crete; surface area: 2.376 km^2) have been provided by the fire department (Fig. 2.5). These data record total BA related to all fires from 2000 until 2021. This BA information is of a much higher resolution than BA data from the Global Wildfire Information System (see section 2, introduction). For the statistical model for Chania Province, only these high-resolution BA data were used (see section 3).
High resolution BA data for Chania province indicate that **0,63%** of its surface area is burned annually, on average. Annual emissions from wildfires are about **6 Gigagrams** [hereafter: Gg] over 2.376 km^2 (**0,25 Gg/km^2**).

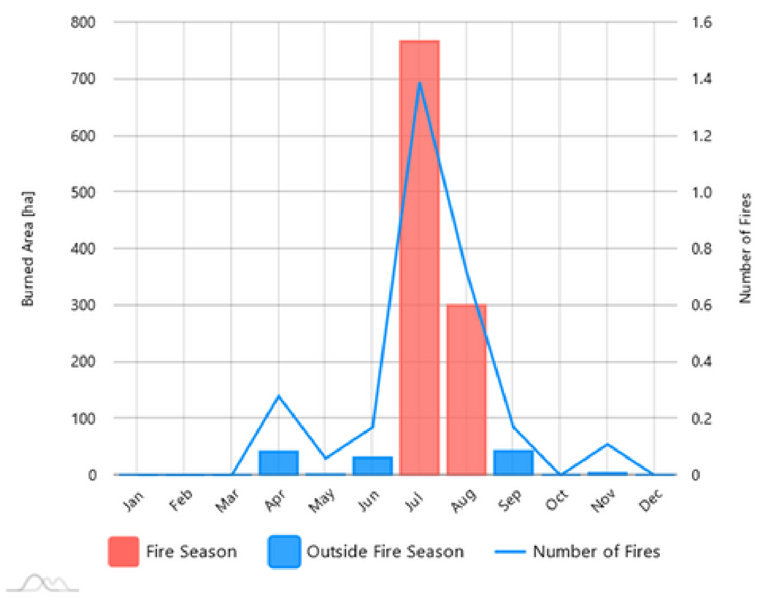

***Figure 2.1**: Burnt Area and No of fires per month, for Crete (2002-2019). The main fire season is in July and August, although large fires do occur from April to November (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/).*

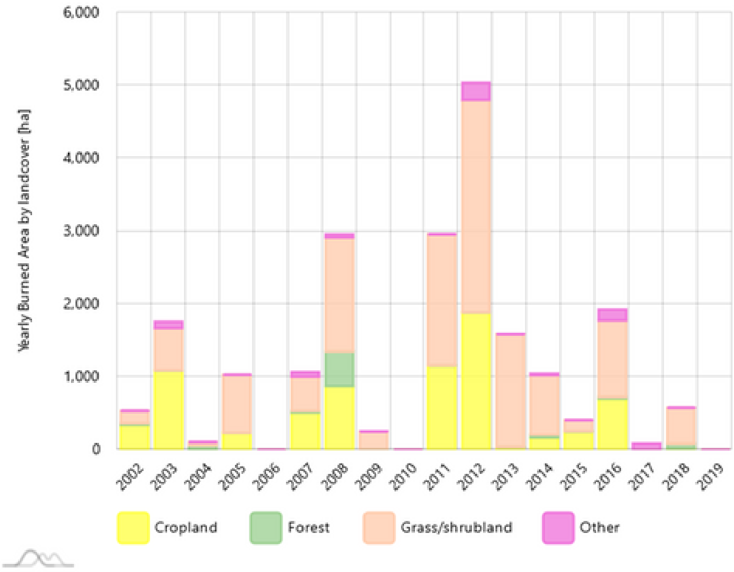

Figure 2.2: *Annual Burned Area by landcover for Crete, over the period 2002-2019 (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/). Note that overall, only a limited amount of forest burns.*

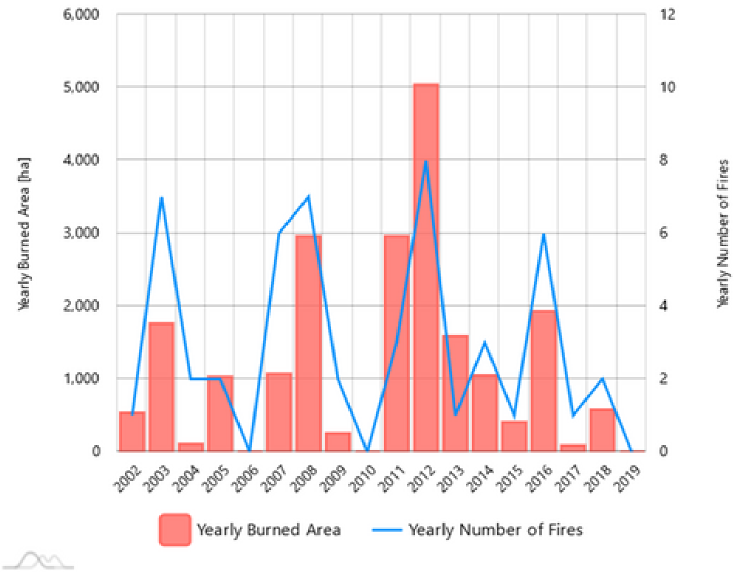

Figure 2.3: *Yearly Burned Area and Yearly No of fires for Crete over the period 2002-2019. The Yearly Burned Area is highly variable from year to year, and does not directly correspond to the number of fires (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/).*

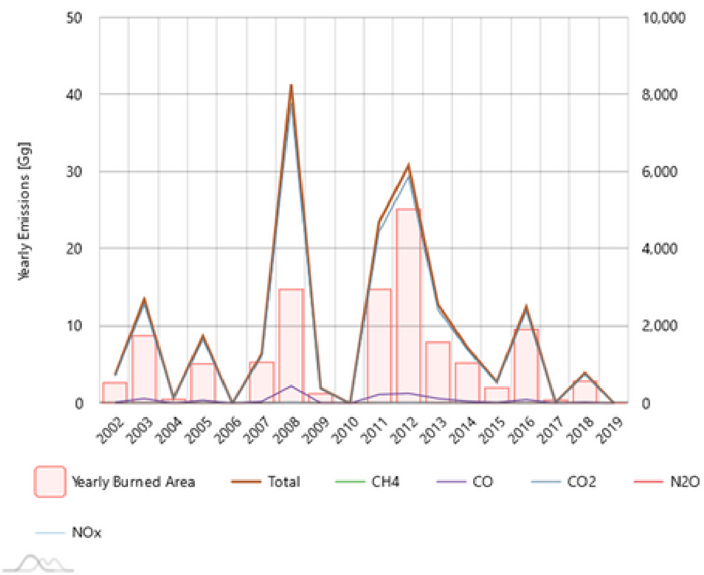

Figure 2.4: *Yearly Emissions and Yearly Burned Area for Crete over the period 2002-2019. The Yearly Emissions are not only related to Yearly Burned Area, but also to type of landcover being burned (see Fig. 2.2). Forest is characterised by the highest emissions, as can be seen for 2008 compared to 2012. In 2012 the yearly burned area was much larger, but emissions lower than in 2008 as hardly any forest burned (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/).*

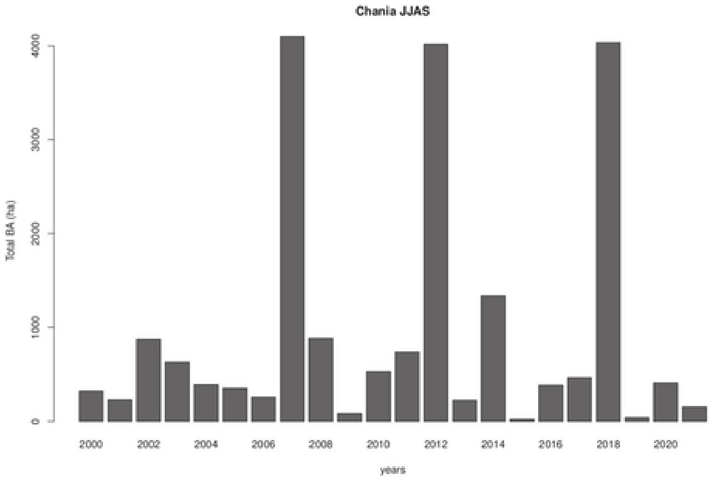

Figure 2.5: *Yearly Burned Area for Chania Province (W Crete) based on annual burned area by all fires as registered by the fire department, spanning 2000 until 2019. Please note the difference in the timing of the peaks, when compared to large fires registered by GWIS (https://gwis.jrc.ec.europa.eu/) over the whole of Crete (Fig. 2.4). This difference shows the variability between regions within the island of Crete, related to different climate conditions as well as different local ignition rates and causes.*

2.2. Montenegro

Fire and emission data for entire Montenegro (surface area: 13.812 km^2), accessed from the Global Wildfire Information System (GWIS: https://gwis.jrc.ec.europa.eu/), are summarised in Figures 2.6-2.9 below. These data span the period from 2002 until 2019. These data, related to the entire surface area of Montenegro, are used for analyses, as high-resolution local BA data for Prokletije/Komovi NP in SE Montenegro are not available. However, annual BA for Montenegro was taken from the EFFIS database (European Forest Fire Information System, https://effis.jrc.ec.europa.eu/), spanning 2010-2020 (11 years), as these data appear more detailed.

The EFFIS database shows that **1,23%** of the total surface area is burned annually, on average. Annual emissions from wildfires are relatively high and amount to **116 Gg** over 13.812 km^2 (**0,84 Gg/km^2**).

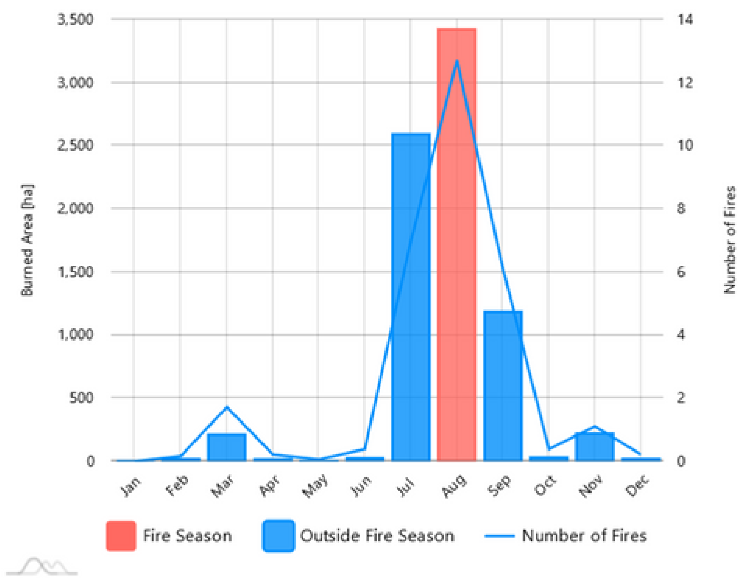

Figure 2.6: *Burnt Area and No of fires per month for Montenegro (based on data spanning 2002-2019). The main fire season is from July to September, although large fires do occur from February to December (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/).*

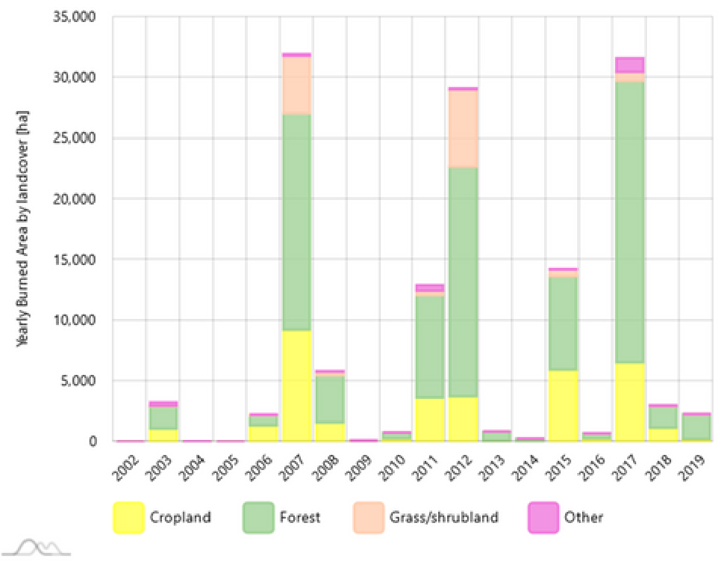

Figure 2.7*: Annual Burned Area by landcover for Montenegro from 2002 until 2019 (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/).*
Note that during years with large BA's (2007, 2012, 2017) significant amounts of forest burn.

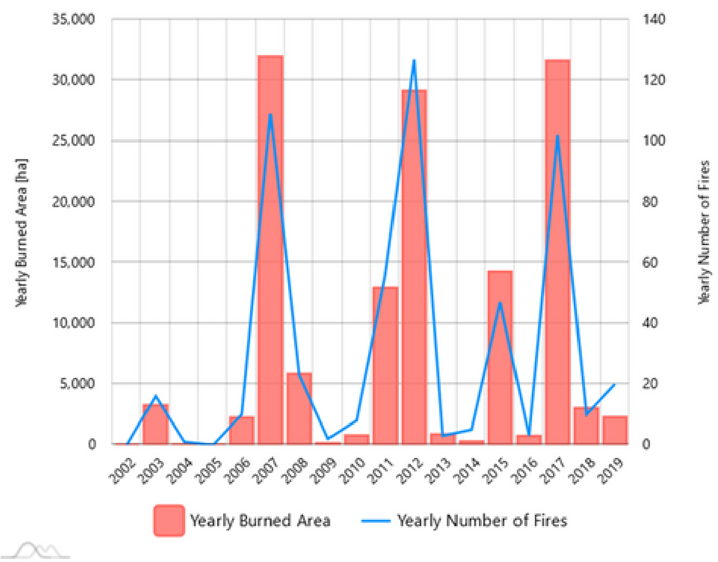

Figure 2.8*: Yearly Burned Area and Yearly No of fires for Montenegro over the period from 2002 until 2019. The Yearly Burned Area is highly variable from year to year, but does appear to relate to the number of fires (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/).*

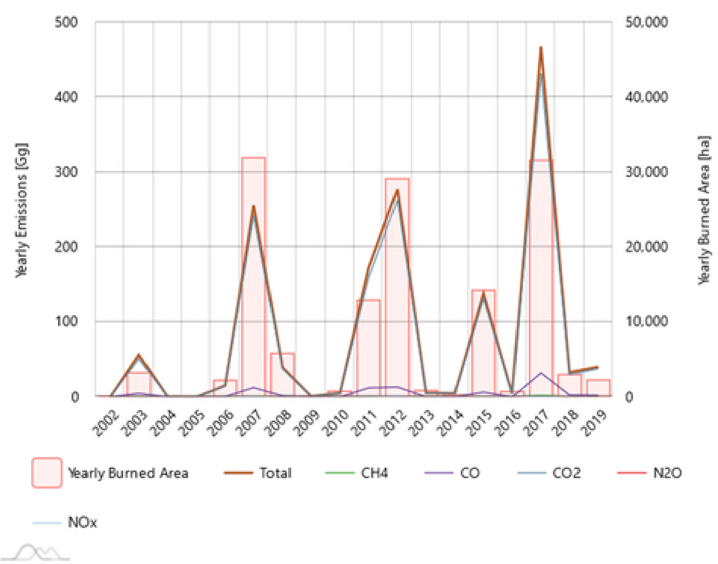

Figure 2.9*: Yearly Emissions and Yearly Burned Area for Montenegro from 2002 until 2019. The Yearly Emissions are not only related to Yearly Burned Area, but also to type of landcover being burned (see Fig. 2.6). Forest is characterised by the highest emissions, as can be seen for 2017 compared to the years 2007 and 2012. In the latter two years, the yearly burned area was similar, but emissions lower than in 2017 as less forest burned (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/).*

2.3. Luberon-Lure

Regional fire and emission data for entire region of Provence-Alpes-Côte d'Azur (surface area: 31.400 km2), accessed from the Global Wildfire Information System (GWIS: https://gwis.jrc.ec.europa.eu/), are summarised in Figures 2.10-2.13 below. These data span the period from 2002 until 2019.

High-resolution BA data for the Luberon Lure UNESCO Biosphere Reserve (SE France; surface area: 2.308 km2) have been provided by our partners (Fig. 2.14). This study used total BA related to all fires from 1998 until 2021 (24 yrs). This information is of a much higher resolution than the BA data from GWIS (see section 2, introduction). For the statistical model for Luberon Lure Biosphere Reserve, only these high-resolution BA data were used (see section 3).

The high-resolution BA data indicate that up to **0,08%** of the total surface area is burned annually, on average. Annual emissions from wildfires amount to **1 Gg** over 2.308 km2 (**0,04 Gg/km2**).

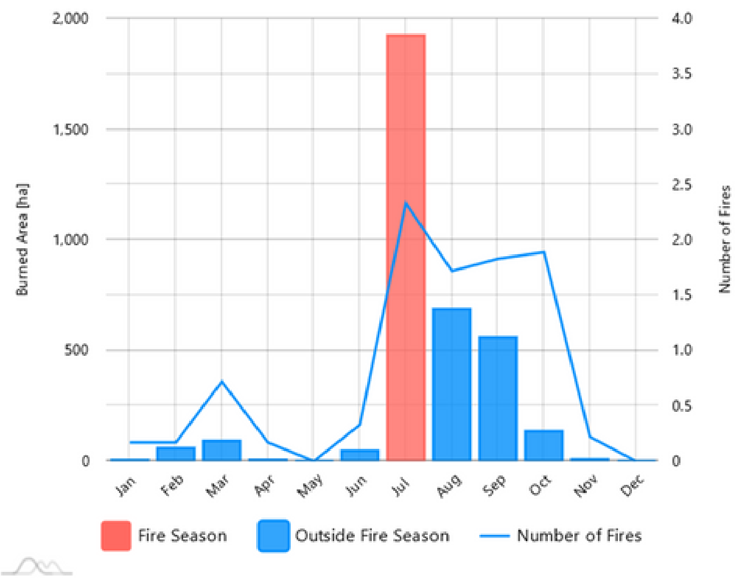

Figure 2.10*: Burnt Area and No of fires per month for Provence-Alpes-Côte d'Azur (based on data spanning 2002-2019). The main fire season is from July to September, although large fires do occur from February to November (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/).*

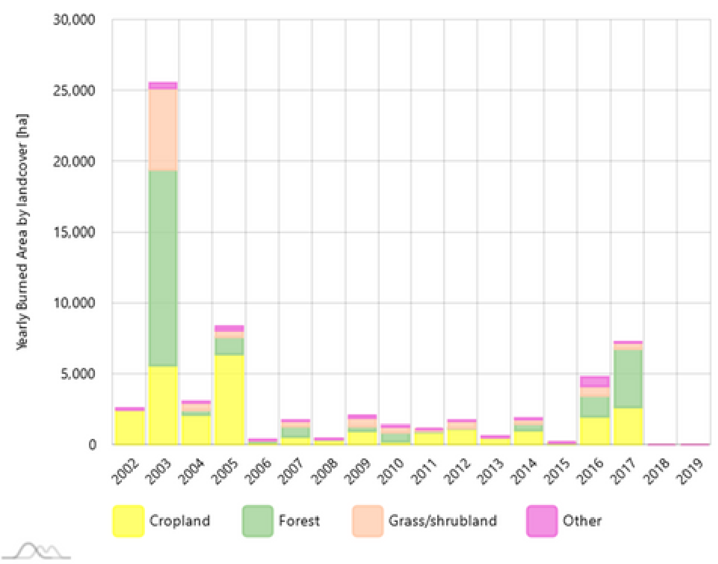

Figure 2.11*: Annual Burned Area by landcover for Provence-Alpes-Côte d'Azur from 2002 until 2019 (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/).*

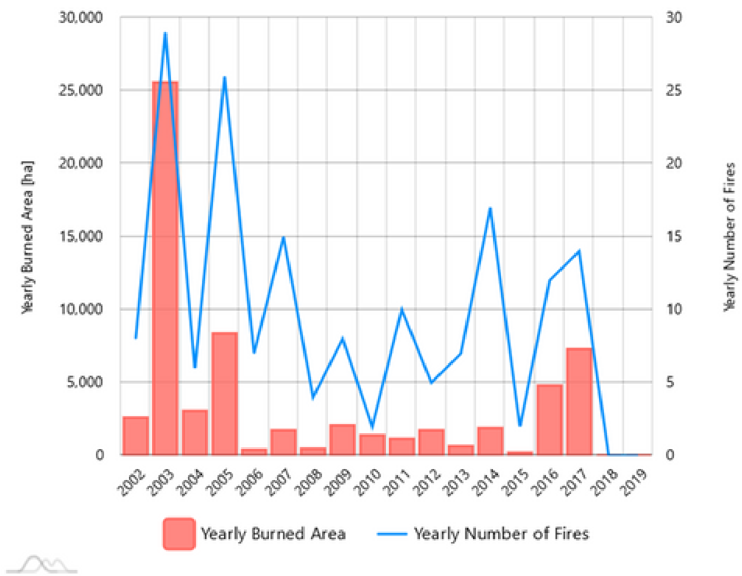

***Figure 2.12**: Yearly Burned Area and Yearly No of fires for Provence-Alpes-Côte d'Azur from 2002 until 2019. The Yearly Burned Area is highly variable from year to year, and does not appear to relate to the number of fires (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/).*

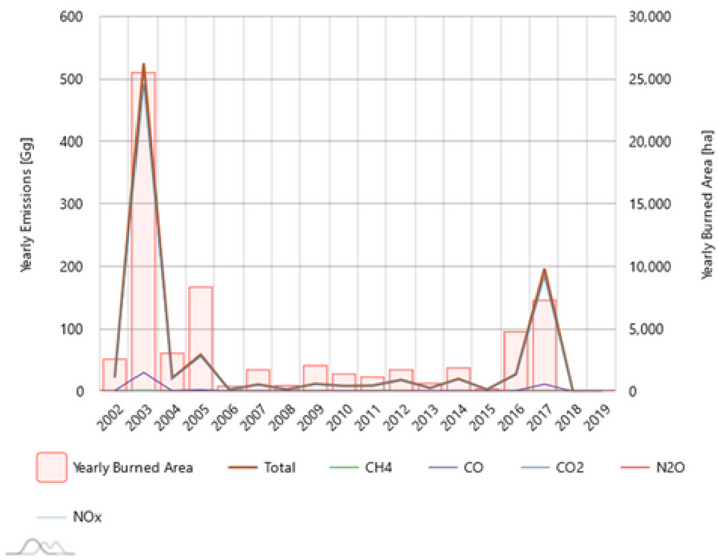

***Figure 2.13**: Yearly Emissions and Yearly Burned Area for Provence-Alpes-Côte d'Azur from 2002 until 2019. The Yearly Emissions are not only related to Yearly Burned Area, but also to type of landcover being burned (see Fig. 2.10). Forest is characterised by the highest emissions, as can be seen for 2003 and 2017, compared to the years 2005 and 2016. In the latter two years, the emissions were comparably low, as less forest was burned (after GWIS, accessed 20/12/2022 at https://gwis.jrc.ec.europa.eu/).*

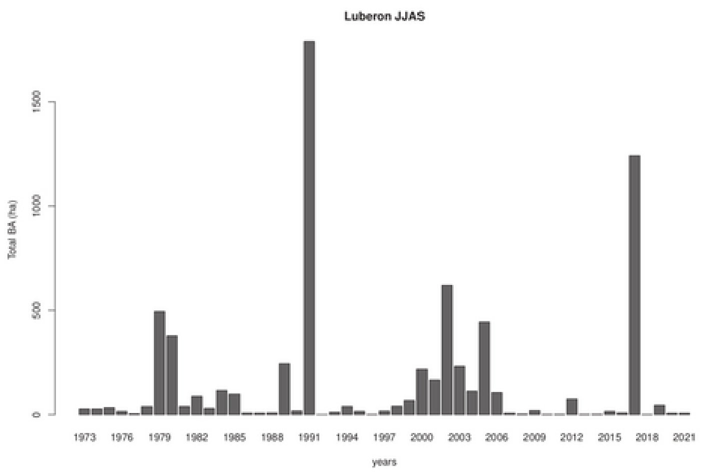

***Figure 2.14:** Yearly Burned Area for the Luberon Lure Biosphere Reserve based on total annual burned area by all fires as registered by the park authorities (spanning 1973 until 2021). Please note some difference in the timing of the peaks, when compared to large fires registered by GWIS (https://gwis.jrc.ec.europa.eu/) over the whole of the region Provence-Alpes-Côte d'Azur (Fig. 2.13). These are related to regional differences in, for example, climate, vegetation, fire-ignition (rates / causes) and fire-spread.*

3. Methodology for estimating BA from climate- and fire-indices

Here we introduce a methodology for estimating BA & GHG emission from climatic and fire indices. Firstly, we developed a statistical model, calibrated for each study area, that correlates Burned Area (BA) against fire-danger (FWI) & drought (SPEI) indices, as well as temperature. Published studies indicate that these variables are strongly correlated to BA in the Mediterranean area [**1-4**]. Secondly, GHG emission data from past wildfires in the target areas were downloaded from GWIS (https://gwis.jrc.ec.europa.eu/) and related to BA.

Empirical BA data for each study area are described in section 2, above. Meteorological data were obtained from ERA5-Land for each of the target areas. Fire-danger (FWI) and drought (SPEI) indices were calculated from the meteorological data. The FWI and SPEI indices are briefly explained in sections 3.1 and 3.2. Section 3.3 discusses the statistical model, its construction and required input variables. Furthermore, the calculation of GHG emissions related to wildfire BA is described.

3.1. What is the Fire Weather Index (FWI)?

The FWI is a daily meteorologically based index used worldwide to estimate fire danger in a generalised fuel type (mature pine stands).

It consists of different components that account for the effects of fuel moisture and wind on fire behaviour and spread.

The meteorological inputs to the FWI are daily noon values of temperature, air relative humidity, 10m wind speed and precipitation during the previous 24 h.

Since 2007, the FWI has been adopted at the EU level by the European Forest Fire Information System (EFFIS) of the Copernicus Emergency Management Service (CEMS) the to assess fire danger level in a harmonized way.

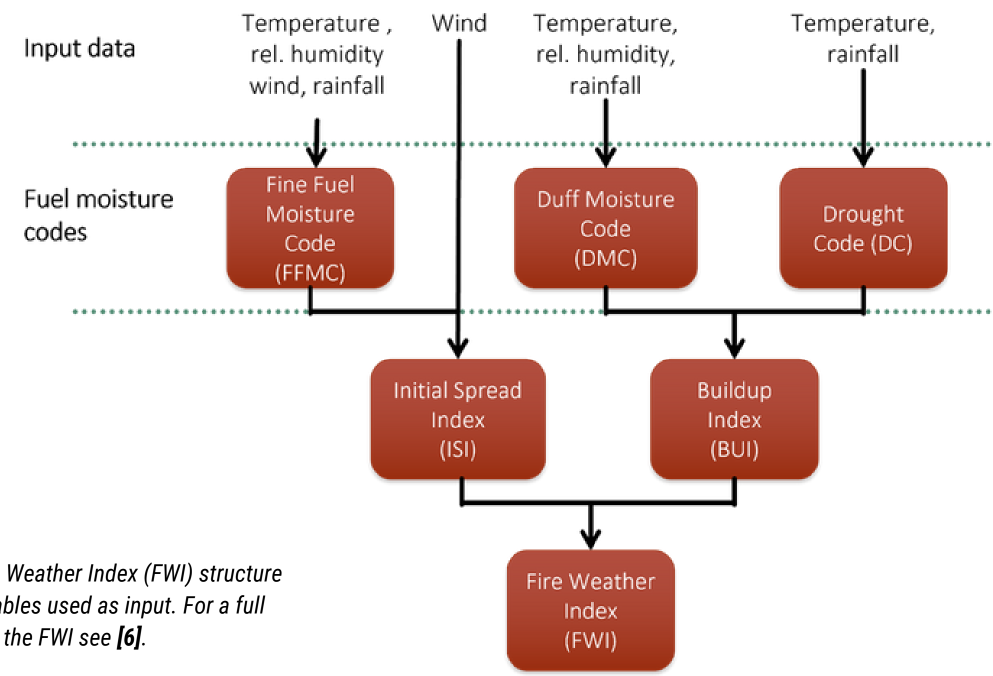

Table 3.1: *Fire Weather Index (FWI) structure & climate variables used as input. For a full explanation of the FWI see* ***[6]***.

This study used the monthly FWI values that are calculated over the fire season (June to September). The FWI of other months cannot be reliably related to either fire frequency or BA, as no significant correlation coefficients were found in our analysis.

3.2. What is the Standardized Precipitation Evapotranspiration Index (SPEI)?

The Standardized Precipitation Evaporation Index (hereafter: SPEI) is a drought index that needs monthly temperature and precipitation data for its calculation. The index is standardized against the long-term climatic data of an area; the required variables should span at least a 15-year period.

The SPEI is a multi-scalar drought index based on climatic data. It can be used for determining the onset, duration and magnitude of drought conditions with respect to normal conditions in a variety of natural and managed systems such as crops, ecosystems, rivers, water resources, etc.
SPEI has an intensity scale in which both positive and negative values are calculated, identifying wet and dry events. It can be calculated for time steps of as little as 1 month up to 48 months or more.
It needs monthly temperature and precipitation data for its calculation. The inclusion of temperature along with precipitation data allows SPEI to account for the impact of temperature on a drought situation.
The output is applicable for all climate regimes, with the results being comparable because they are standardized. With the use of temperature data, SPEI is an ideal index when looking at the impact of climate change in model output under various future scenarios.

Table 3.2: *Explanation of the Standardized Precipitation Evaporation Index (hereafter: SPEI).*

This drought index may be calculated over one or multiple preceding months. The number of months incorporated in the index is reflected in the number behind "SPEI". For example, SPEI-6 is the drought index calculated over the previous 6 months at a given area, and compared to the long term average (over the same period) at this area.

3.3. Statistical modelling

3.3.1. Selection of Statistical Model Variables

Correlation coefficients between total monthly Burned Area (BA) and a number of variables for the fire season (June-July-Aug-Sep) over the years 2000-2021 (2002-2019 for Montenegro) were calculated to establish the best matches. This was done for all target areas.

BU												
0.29	FWI											
0.03	−0.41	SPEI3H										
0.30	0.96	−0.33	ISI									
−0.01	−0.23	0.48	−0.17	SPEI6H								
0.04	−0.40	1.00	−0.32	0.48	SPI3							
−0.01	−0.22	0.47	−0.16	1.00	0.47	SPI6						
0.36	0.75	−0.07	0.75	−0.08	−0.06	−0.07	TX					
0.36	0.63	0.01	0.60	−0.04	0.02	−0.04	0.94	TN				
0.35	0.72	−0.03	0.71	−0.05	−0.02	−0.05	0.99	0.97	TG			
−0.16	−0.68	0.46	−0.67	0.28	0.45	0.27	−0.48	−0.30	−0.44	RR		
0.02	−0.41	1.00	−0.33	0.49	1.00	0.47	−0.08	[illegible]	−0.05	0.45	SPEI3T	
−0.02	−0.22	0.47	−0.16	1.00	0.47	1.00	−0.08	−0.04	−0.05	0.27	0.47	SPEI6T

Table 3.3: *Correlation matrix between Burnt Area and a number of variables (BU: Build Up Index, FWI: Fire Weather Index, SPEI3H/T: 3-month averaged Standardized Precipitation Evaporation Index – Hargreaves / Thornwait, ISI: Initial Spread Index, SPEI6H: 6-month averaged Standardized Precipitation Evaporation Index – Hargreaves / Thornwait, SPI3: 3-month averaged Standardized Precipitation Index, SPI6: 6-month averaged Standardized Precipitation Index, TX: averaged maximum temperature for the fire season, TN: averaged minimum temperature for the fire season, TG: averaged temperature for the fire season, RR: Rainfall Rate).*

FWI, TX (maximum temperature) and SPEI6H (H for Hargreaves, T for Thornwait) were the selected variables, the first two from the matrix (Table 3.2) and the third from trial-and-error while modeling BA. Optimum variables were the same for all target areas.

Climate indices of the months (JFMAM and OND) **outside the JJAS fire season** cannot be reliably related to BA as **no significant correlation coefficients** were found in our analyses. To calculate the **total annual** BA, we will assume that the relative percentage (%) of BA over the fire season vs the other months (JFMAM and OND) **is stable** for each of the target areas.

The percentage BA over the fire season is above 90% for all target areas. Specifically, the relative amount of BA over the fire season (JJAS) and outside the season (JFMAM and OND) are: 96% vs 4% for Chania Province, 93% vs 7% for Montenegro, and 91% vs 9% for the Luberon NP.

3.3.2 Modelling the response variable

GAMs (Generalized Additive Models) were used to model the response variable (total BA) by selected independent variables (FWI, TX, SPEI6H), which are in the form of some smooth functions [e.g., $\log_{10}(BA) = s(FWI) + s(SPEI6H) + s(TX)$]. The statistical model based on the ERA5-Land was optimized using leave-one-out cross validation.
To assess climate change impacts, input data from Regional Climate Models were used to drive the statistical models for each of the target areas, to estimate BA under climate change conditions (see factsheet 3).

3.3.3. Green House Gas (GHG) emissions by wildfires

GHG emissions data from past wildfires (processed using the FAOSTAT methodology [**7**]) were downloaded from GWIS (https://gwis.jrc.ec.europa.eu/).
For this study, the relationship between the cumulative BA of the respective target study areas and the cumulative GHC, was assessed using the Reduced Major Axis regression. This area-specific relationship will subsequently be used to derive future estimations of GHG emissions related to wildfire BA.

4. Conclusions

Only up to **0,08%** of the total surface area (2.308 km^2) of the Luberon-Lure area is burned annually, on average, compared to **0,63%** of the surface area (2.376 km^2) of Chania Province and **1,23%** of the total surface area (13.812 km^2) of Montenegro. Differences in BA rates are most likely related to the area-specific rates of fire ignition & spread, and fire suppression efforts.

Annual emissions from wildfires amount to **0,4 Gg per km^2 of BA** for Chania Province (annual fire emissions: 6Gg) and to **0,5 Gg per km^2 of BA** for Luberon-Lure Biosphere Park (annual fire emissions: 1Gg). The emission per km^2 of BA is similar, indicating a comparable Mediterranean land cover. The absolute difference in emissions between these two areas, which have virtually the same surface area, is related to their different total BA.

Annual emissions from wildfires in Montenegro amount to **0,68 Gg per km^2 of BA** (annual fire emissions: 116Gg). The surface area of Montenegro is almost six times that of Chania or Luberon-Lure (annual fire emissions over a similar surface area as the two regions is about 19.7 Gg). The very high emissions in Montenegro are related to the high total BA and large amount of mature forest burning.

Our statistical model is quite accurate in projecting Burned Area based on input of the FWI fire danger index, the SPEI6 drought index, and the maximum averaged temperatures over the fire season (JJAS). It has reasonable outcomes for all three target areas, with the best results when using regional high-resolution BA data (Chania Province and Luberon-Lure Biosphere Park).

The case study from Montenegro shows that EU Copernicus data on BA may be used if no regional data are available, thus ensuring that key input data are publicly available. The approach is transferable to other Mediterranean regions ("upscaling"), which is a key aspect of the MediterRE3 project.

5. References

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