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# Haines Index in Sardinia, Italy

Salvatore Cabiddu; Marcello Casula; Franco Casula; Tiziana Pinna; Antonio Casula; Gian Carlo Muntoni; Leandro Usai; Maria Gabriella Cuccu; Bachisio Arca; Michele Salis
scabiddu@regione.sardegna.it, michele.salis@ibe.cnr.it

## Introduction

This paper deals with the predictive capacity of the Haines Index (HI) in relation to the development of large forest fires in Sardinia, Italy. The H I (Haines, 1988), also known as the Lower Atmosphere Severity Index, is a meteorological index that measures the atmosphere's potential to contribute to the development of large and severe forest fires, even in conditions of low wind, dry air, and unstable atmospheric stratigraphy. Although more studies are being conducted and there is an open, stimulating scientific debate to update its formulation, the HI is still widely used, especially in North America, to characterise atmospheric conditions that increase the likelihood of large fires (Potter, 2018; Artés et al., 2021). In this paper, the HI's predictive capacity in the Mediterranean environment was investigated by evaluating the relationship between the HI value and the occurrence of fires with a burnt area of more than 100 ha on the island of Sardinia, Italy.

## Methodology

The mathematical formula of the HI is as follows:

$$HI = (T_{p1} - T_{p2}) + (T_p - T_{dp})$$

in which two summands are recognisable:

— The first ($T_{p1}$ - $T_{p2}$) assesses the contribution to atmospheric stability/instability conditions utilising the temperature difference between two reference barometric altitudes. Under conditions of high atmospheric instability, i.e., with a higher thermal gradient along the height profile, there is usually a higher convective potential (Table 1).

— The second ($T_p$ – $T_{dp}$) assesses the proximity of the atmosphere to the state of condensation by comparing the temperature of the air with its saturation temperature at a reference barometric altitude. High saturation deficit conditions have a higher potential for high-intensity fire development. (Table 1).

The barometric reference heights at which to measure temperatures for calculating the HI are set as shown in Table 1, which illustrates the hPa values to be considered for the three altitudinal belts.

A standard table associates the ΔT of the first and second by adding numerical values ranging from 1 to 3 so that the HI falls between a minimum of 2, indicating a humid and stable air situation. In contrast, the maximum of 6 corresponds to a dangerous atmospheric stratigraphy due to the presence of dry and unstable air.

Herein, we present the results of a study on the predictive capacity of the HI in a central Mediterranean area where the relationship between the HI value and the occurrence of fires with a burnt area of greater than 100 ha, from June to September between 2008 and 2017, has been recorded. We set 10.00 a.m. to 6.00 p.m. as the period when approximately 95% of the total area was burned by the fire annually in Sardinia.

We used ECMWF-ERA5 reanalysis data at the native resolution of 0.28125° (approximately 31 × 31 km). To exclude events whose size could be related to strong winds from the analysis, only fires that occurred on days with little wind were considered. Since the maximum wind intensity in Sardinia is statistically registered in the central hours of the day, it was decided to include only fires larger than 100 ha that occurred on days with a wind intensity of less than 5 m/s at 2.00 p.m. Sardinia Island was divided into three nearly equivalent macro-areas (North, Centre and South; Fig. 1 and Table 2). From the atmospheric stratigraphy at 2.00 p.m. of the barycentric pixel of each macro-area, first, the days with little wind were selected, and then the two HIs were calculated for the low (<305 m) and medium (between 305 and 914 m) altitudinal belts.

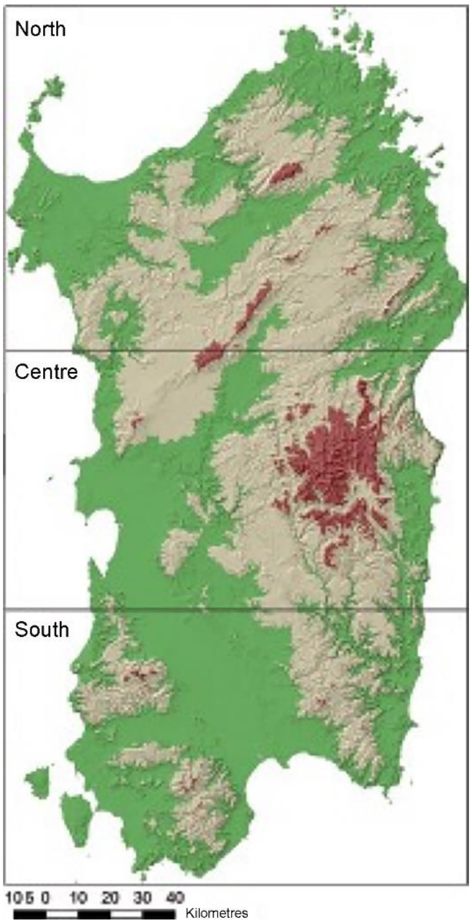
| Altitudinal belt from the ground above which the atmospheric column is situated [m] | Reference barometric altitude for the T of the first summand | | Reference barometric altitude for the T of the second summand |
|---|---|---|---|
| | P1 | P2 | |
| Low (<305) | 950 hPa | 850 hPa | 850 hPa |
| Medium (305-914) | 850 hPa | 700 hPa | 850 hPa |
| High (>914) | 700 hPa | 500 hPa | 700 hPa |

Table 1: Barometric quotas in hPa at which to measure the temperature values for the calculation of HI differentiated by altimetric range.

| Altitudinal belts | <305m (%) | 305-914m (%) | >914 m (%) |
|---|---|---|---|
| NORTH | 52.3 | 46.6 | 1.1 |
| CENTRE | 40.6 | 49.7 | 9.8 |
| SOUTH | 70.5 | 29.1 | 0.4 |

Table 2. Percentage of surfaces in the three macro-areas according to their altitudinal belts.

The HI values calculated only for days without wind were considered representative of the whole macro-area during the whole day and were related to all fires occurring in the macro-area during the same day.



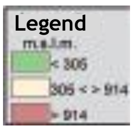




Figure 1: Distribution of altimetric belts in Sardinia.

## Results

The six graphs of the three macro-areas and the two altimetric belts of the soil are presented in Figs. 2-7. These results illustrate the relationships between the HI values and the fires. Along the horizontal axis, we measure the HI, while on the primary vertical axis, we report the average values of burnt area in km2 (BA) per day. Moreover, the average number of fires per day (IP) is displayed on the secondary vertical axis.

The data demonstrates a general increase in the area burnt as the HI increases. There are also some differences in the three macro-areas of the island. The data for the central macro-area of Sardinia are interesting because the relationship between the increase in HI and large fire events seems clearer and deserves further statistical analysis. At the same time, there are limits to the predictive capabilities of HI, especially in the North macro-area of Sardinia. Although the preliminary study indicates a relationship between HI and large fires, it is evident that more parameters need to be integrated. Indeed, variables including the type, amount and humidity of fuels, the orography of the territory or others that interfere with the atmosphere's convective phenomena could reveal synergistic effects that may increase the probability of large forest fires (LFF).

This is probably what happened during the Montiferru fire in the province of Oristano, which started on 24 July 2021 and covered an area of about 13,000 ha. On the night of 24-25 July, a transiting storm cell probably interacted with the convective column produced by the fire, generating downdrafts (outflow boundary) that contributed to increase the flame propagation speed (Fig. 8). In fact, during the night of 24-25 July, the personnel of the Montiferru forest fire-fighting unit observed sudden strong winds.

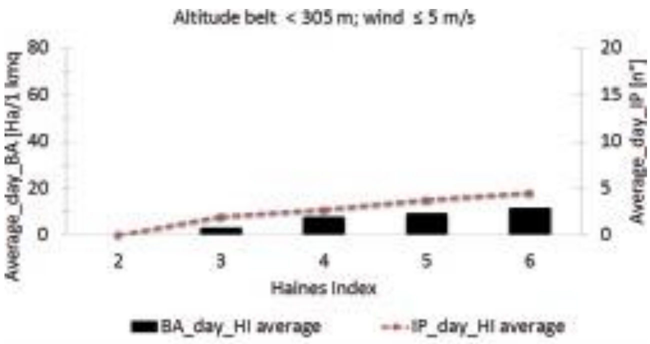



Figure 2: Northern macro-area, low altitude belt.

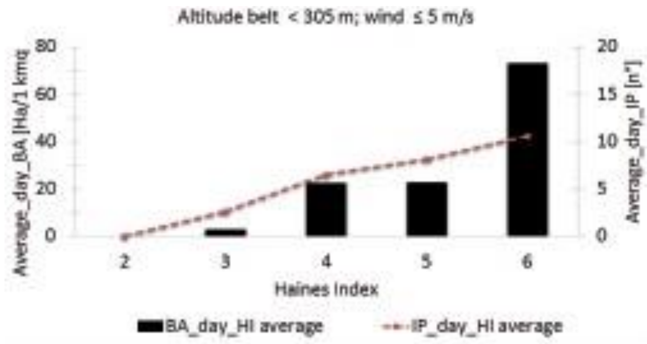



Figure 3: Central macro-area, low altitude belt.

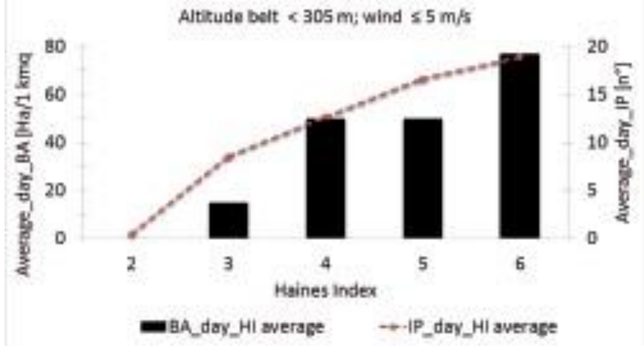



Figure 4: Southern macro-area, low-altitude belt.

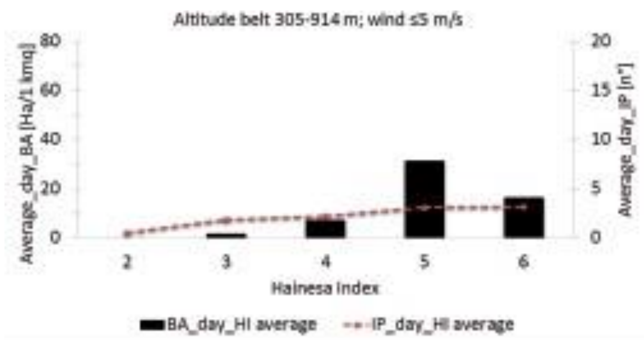



Figure 5: Northern macro-area, medium-altitude belt.

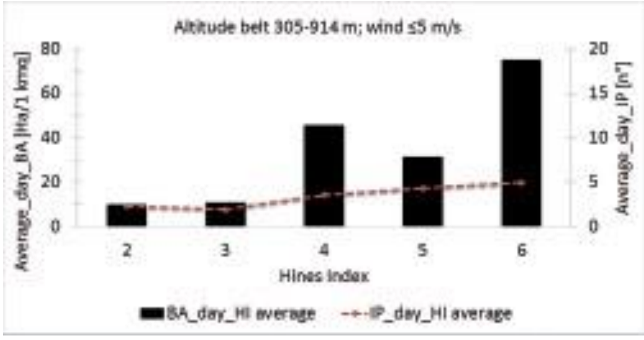



Figure 6: Central macro-area, medium-altitude belt.

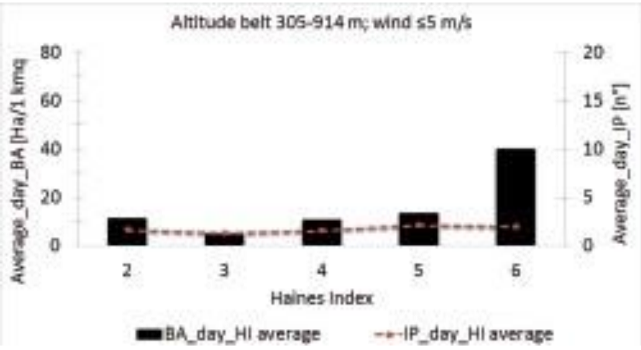



Figure 7: Southern macro-area, medium-altitude belt.

The particular atmospheric situation seems compatible with the Decimomannu (CA) atmospheric radiosonde located 200 km south of the island and referred to at midnight on 24-25 July (Fig. 9).

The HI calculated with the Decimomannu radiosonde for the medium-altitude belt (the area covered by the Montiferru fire falls within this belt) has a maximum value of 6.

From the radiosonde reading shown in Figure 9, it is noted that:

Above 3000 m altitude, there was a hygrometric condition close to saturation which could have generated precipitating phenomena facilitated by the water vapour introduced into the atmosphere due to the intense combustion of the fire.

Below 3000 m, the atmosphere was particularly dry.

As shown in Figure 10, this scenario continued with some differences throughout 25 July, when the Decimomannu radiosonde was reported at 2.00 p.m. A convective thermodynamic profile of the atmosphere was also confirmed, with a maximum HI of 6 in the medium-altitude belt.

The thermodynamic profile of the atmosphere in Figure 10 is very similar to that of the Yernelll Hillfire scenario in Arizona (USA) on 30 June 2013, where the outflow boundary had a major impact on the spread of flames, resulting in the deaths of 19 members of the Granite Mountain Interagency Hotshots Crew (Wildland Fire Associates, 2013).

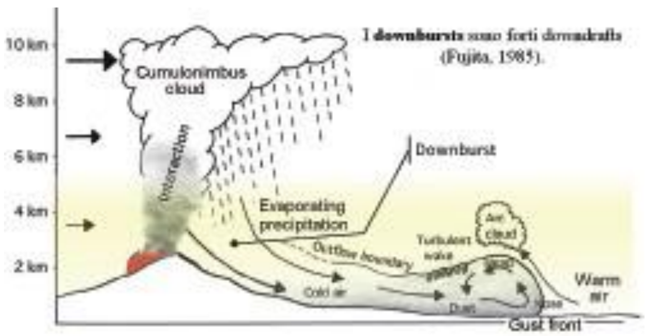



Figure 8. Simplified diagram of the interaction between the smoke plume and a storm cell. Water droplets that form at high altitudes by condensation of atmospheric vapour precipitate downwards. However, upon encountering a layer of very dry and warm air, they evaporate, cooling the air and creating strong downdrafts that reach the ground and propagate in all directions (adapted by Cabiddu from Knippertz et al., 2007).

In Sardinia, some light rainfall was recorded in the Montiferru area during the night, but there was probably evaporation of precipitation during the passage of droplets in the dry air layer from 0-3000 m, which also receives the heat released by combustion. It should be pointed out that evaporation of the precipitation cools the air and may have created the downdrafts observed by the fire crews.

Although further studies are needed on the appropriateness and usefulness of integrating the HI into fire hazard prediction tools in the Mediterranean environment, preliminary data for Sardinia seem to confirm a relationship between the HI and large fires.

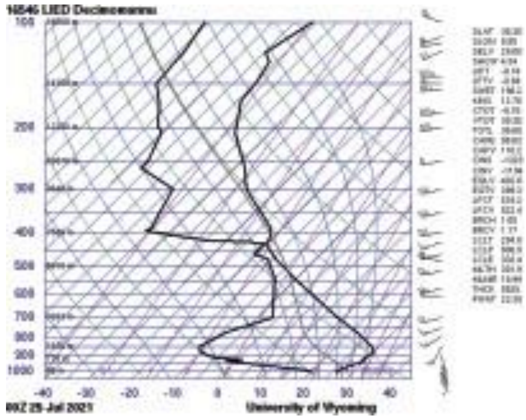



Figure 9: Atmospheric radiosonde at Decimomannu (CA) at midnight between 24 and 25 July 2021. A significant saturation deficit is evident, especially below 3000 metres, i.e., 700 hPa, where there is a large gap between the state curve on the right and the dew point curve on the left.

This relationship shows spatial variability and is less marked in the northern part of the island but is clearer in the central area.

It is also interesting to analyse and catalogue the thermodynamic per-files of the atmosphere, which, together with other factors, in the presence of a forest fire can already create favourable conditions for the development and spread of flames with extreme and sometimes unpredictable or less predictable behaviour.

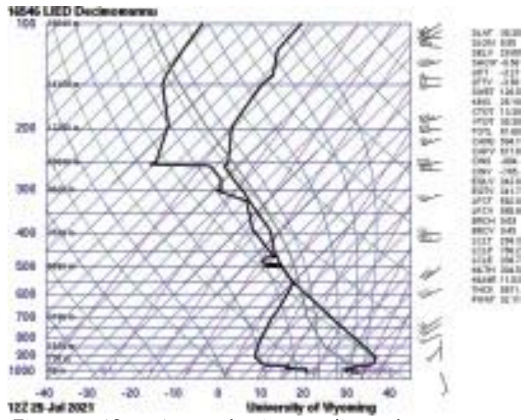



Figure 10. Atmospheric radiosonde at Decimomannu (CA) at 2.00 p.m. on 25 July 2021. A significant saturation deficit is still evident, especially below 3000 m or 700 hPa. In addition, there is an imposing layer of near saturation air above 4000 m altitude.

**References**

Salvatore Cabiddu
Forestry Engineer, Master in Sciences in "Wildfire Planning, Prevention and. Fighting in Mediterranean Areas (PIROS)", Forestry Corps Officer in Sardinia (Italy).