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Remote sensing reveals fire-driven facilitation of a C_4 rhizomatous alien grass on a small Mediterranean volcanic island

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Abstract. Volcanic islands are special ecosystems for studying biogeographical and evolutionary processes. Occasional disturbance events, such as eruptions, tsunami or big fires, can represent major drivers of such processes leading to biotic sterilisation or major changes in island biotas. In this study, through remotely sensed data, we investigated the intensity and the extent of a large fire event that occurred on the small volcanic island of Stromboli (Aeolian archipelago, Italy) on 25-26 May 2022, to assess the short-term effect of fire damages on local plant communities. For this purpose, two different spectrally sensitive indices, i. e. the differential Normalised Burned Index (dNBR) and the Normalised Difference Vegetation Index (NDVI), were used. The dNBR was also used to quantify the extent of early-stage vegetation recovery, dominated by *Saccharum biflorum* Forssk. (Poaceae), a rhizomatous C4 perennial grass of paleotropical origin. The burned area was estimated to have an extension of around 337.83 ha, corresponding to 27.7% of the island surface and to 49.8% of Stromboli's vegetated area. On the one hand, this event considerably damaged the native plant communities, hosting many species of high biogeographic interest. On the other hand, S*accharum biflorum* clearly benefited from arson. In fact, it showed a very high vegetative performance after burning, being able to exert unchallenged dominance in the early stages of the post-fire succession, reaching within a few months stem density values that are only slightly lower than those of the unburned stands. Our results confirm the complex and probably synergic impact of different human disturbances (recurrent fires, introduction of invasive alien plants) on the structure and the functioning of natural ecosystems on small volcanic islands. The natural dynamics of such ecosystems is dependent on the complex relation between successional processes and the intensity and frequency of natural or anthropogenic disturbance, which can regulate mid- and long-term response of *Saccharum*. In fact, although the expansion of *Saccharum* proves to be surprisingly fast, its decline may also be relatively rapid as well, if local vegetation is no more affected by fire. After the abandonment of the agricultural practices in the highest portion of the island, the rewilding process could lead to the replacement of the large beds dominated by this invasive grass by native woody vegetation within a few decades.

Keywords. Biological succession, Disturbance, Field monitoring, Satellite imagery, Sprouters, Vegetation dynamics.

Introduction

Wildfires are a main disturbance factor affecting the Mediterranean terrestrial ecosystems, whose vegetation patterns are largely influenced by interactions with fire. Fire frequency delineates landscape attributes (Pausas, 2006; Jouffroy-Bapicot et al., 2021), affects the structure and composition of the vegetation (Trabaud, 1994) and regulates speed and direction of ecological succession dynamics (Canelles et al., 2019). Also, fire causes sudden variations in the carbon and energy balance

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of ecosystems (Novara et al., 2013; Harris et al., 2016; Pausas & Millán, 2019) and in the soil microbial activity and functional diversity (Velasco et al., 2009; Goberna et al., 2012).

At the onset of human civilisations, Mediterranean landscapes have been deeply modified by anthropogenic fires that were used to expand the human habitat and facilitate a wide array of foraging activities (Pausas and Keeley, 2009). Throughout human history, demographic fluctuations, innovations and cultural exchanges have always been accompanied by changes in land use and thus in fire regimes, amount and patchiness of fuel (Guyette et al., 2002; Driscoll et al., 2021).

After the mid-20th century, land abandonment associated with an increase of scrub cover and the build-up of fuels (Mantero et al., 2020) chiefly contributed to the increased fire hazard in the Mediterranean Region (Le Houérou, 1993; Salis et al., 2022). Despite the occurrence of some natural factors favouring fires, most of them are due to arson, typically ignited through carelessness or voluntary action. Being the vegetation burning strongly related to plant water content (Bond and Wilgen, 1996), fires happen mostly during the warmest and driest months, i.e. during the Mediterranean summer (Bergmeier et al., 2021). Climate change scenarios indicate rising temperatures and decreasing amounts of precipitation, resulting in longer summer aridity, soil water shortages and increasing fire risk (Moriondo et al., 2006; Lozano et al., 2017; IPCC, 2021). Furthermore, typical Mediterranean scrublands are highly resilient to relatively frequent, high-intensity fires, but changes in the fire regime resulting in shorter fire intervals may make these communities susceptible to compositional changes and alien plant invasions (Keely and Brennan, 2012; Vallejo et al., 2012). The positive feedback between invasive species and fire can be a major cause of unidirectional change in invaded ecosystems (Brooks et al., 2004), and invasive species able to sustain an increased fire frequency and intensity may generate favourable conditions for their self-perpetuation (Pauchard et al., 2008). Small islands are particularly vulnerable to biological invasions (Bellard et al., 2016), due to the combined effect of the reduced species pool and the competitive traits of invasive species. This process has been reported for Mediterranean islands (Celesti-Grapow et al., 2016; Fois et al., 2020), particularly in the case of volcanic islands with ongoing or recent volcanic activity (Karadimou et al., 2015; Pasta et al., 2017; Chiarucci et al., 2021).

The island of Stromboli is the youngest and most active volcano in the Aeolian Archipelago (NE-Sicily); its subaerial activity began around 85 ka BP (Francalanci et al., 2013). Stromboli has the lowest number of species, as expected by the within archipelago species-area relationship among the seven largest islands of the Aeolian Archipelago, both for native and alien species (Chiarucci et al., 2021). By far the most common alien plant in Stromboli is a tall, vigorously growing rhizomatous grass, *Saccharum biflorum* Forssk., which was introduced in the 19th century as a windbreak. *Saccharum* has then spread on former cultivations, abandoned terraced fields and wherever there is accumulation of volcanic ash, where this grass species sinks its robust rhizomes. Local elder people recall a major spread of *Saccharum* soon after the arson caused by paroxysmal activity in 1930 and the subsequent abandonment of a large portion of the cultivated terraces along the eastern slopes of the island (Richter and Lingenhöhl, 2002). In following years, its spread has been somewhat reduced by the development of native scrub, which until recently was the most widespread vegetation type on the island. Another large fire event, ignited at the Punta Labronzo landfill site in 1978, promoted the recovery of *Saccharum* all over the gently sloping sites on the eastern side of Punta Labronzo.

On 25-26 May 2022, a large fire event burned much of the northern and eastern quadrants of Stromboli, upstream of the villages San Vincenzo, San Bartolo and Piscità. This study uses remotely sensed data to analyse the post-fire damage on local vegetation through the application of two spectrally sensitive indices, i.e. the differential Normalised Burned Index (dNBR) and the Normalised Difference Vegetation Index (NDVI). The dNBR has been used also to quantify the extent of the subsequent early-stage vegetation recovery, dominated by *Saccharum biflorum*.

Material & Methods

Study area. The island of Stromboli, 12.6 km^2, is the emerged part of a volcanic complex elongated in a N-E direction. It represents the northeastern end of the Aeolian Archipelago, in southeastern Tyrrhenian Sea, Mediterranean biogeographical

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region (Cervellini et al., 2020). The elevation of Stromboli is 926 m a.s.l., with quite a regular slope averaging 28° and two large horseshoe-shaped flank collapses named “Sciara del Fuoco”, on the northwestern-, and “Rina Grande - Le Mandre”, on the southeastern flank of the island.

Our study area covers an area of ca 3.4 km^2, between 50 m a.s.l. and 530 m a.s.l., on the northern and eastern sides of the volcano and can be roughly divided in two sectors. The northern sector is bounded by the "Fili del Fuoco" ridge, overlooking “Sciara del Fuoco”, to the west and by the Vallonazzo valley to the east; the eastern sector is bounded by the Vallonazzo valley to the north-west and by the “Rina Grande - Le Mandre” depression to the south-east. Both sectors are characterised by a smooth texture and medium to gentle slopes, with 80% of the area sloping less than 30° (Fornaciai et al., 2010).

The climate is typically Mediterranean. The first weather station in Stromboli recorded data from 1946 until 1980 and was located at an elevation of 4 m a.s.l. A new weather station (ID: ISICILIA191) was installed on the island in 2016, at the same elevation. Based on the available data, Stromboli villages experience an average yearly temperature of 18.2 °C, with an average mean temperature of 12.3 °C in the coldest (January) and 26 °C in the warmest month (August). The average annual rainfall amounts to 570 mm, while the relative humidity is 75.0% in winter and 60.8% in summer. Based on the WorldClim interpolated maps (Hijmans et al., 2005) and on the Rivas-Martínez bioclimatic classification (2004), the study area is characterised by an upper thermo-mediterranean thermotype and a dry to sub-humid ombrotype (Bazan et al., 2015).

The study area was dominated by a typical Mediterranean rockrose garrigue (*Cistus creticus* subsp. *eriocephalus*, *C. monspeliensis*, *C. salvifolius*) with scattered patches of maquis with *Genista tyrrhena*, *Spartium junceum*, *Olea europaea*, *Erica arborea* and *Pistacia lentiscus* (Richter, 1984; Cavallaro et al., 2009). The former cultivated land and the volcanic ash deposits were extensively colonised by *Saccharum biflorum*, while small holm-oak stands were occasionally found along the impluvium lines. Equally rare and scattered were the patches of *Euphorbia dendroides* scrub, limited to the rocky outcrops, especially along the south-facing rim of Vallonazzo valley (Ferro and Furnari, 1968; Richter and Lingenhöhl, 2002). The highest and southernmost end of the study area included part of the local population of *Cytisus aeolicus*, a narrow ranging endemic broom growing only on the islands of Vulcano, Alicudi and Stromboli (Zaia et al., 2020).

On 25-26 May 2022, due to recklessness during the filming of a television drama, a fire broke out in the upper outskirts of the village of San Vincenzo and, fuelled by a strong sirocco wind, burned the whole of our study area. While *Saccharum* stands were entirely burned, a very few small patches of garrigue and holm-oak stands escaped by chance from the fire.

Satellite imagery processing. In order to assess the extent of fire damage to the vegetation and the post-fire surface of the resprouted *Saccharum* patches, we used optical satellite images acquired by the spaceborne Sentinel-2 sensor, a multispectral mission launched in the frame of the European Space Agency (ESA) Copernicus program (Drusch, 2012).

Sentinel-2 measures globally the backscattered solar radiation from ground targets with a temporal resolution of around 5 days, across 13 spectral bands with different ground sampling distance (GSD) varying from 10 to 60 metres. In this work, we employed the four bands at 10 m GSD, namely in the visible range (blue, green, red) and near infrared (NIR). Additionally, we relied on Band 12 in the short wave infrared (SWIR) at 20 m GSD in order to detect burned areas. All other bands were not used in this analysis. The products used were at processing level 2A, which provides radiometrically corrected, georeferenced, orthorectified, atmospherically corrected, and converted to bottom of atmosphere reflectance data. The choice of using reflectance rather than radiance products is motivated by the following reasons: (1) overall brightness differences in different images due to different acquisition conditions are reduced in the level 2A products, (2) quantities estimated from single images through spectral indices result meaningful when applied to data in reflectance.

The data selection and processing was carried out on Google Earth Engine (GEE) (Amani et al., 2020), and at the same time a multi-petabyte repository of geo-referenced and harmonised Earth Observation raster, vector, and tabular datasets, which includes the whole Sentinel-2 archive.

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To quantify the damage caused by the above mentioned fire event on the vegetation, different Sentinel-2 scenes acquired in a relatively short time span were aggregated, in order to increase the robustness of the results by reducing noise, outliers, small clouds and cloud shadows which can affect single images. A snapshot of the island before the event was derived by considering images from 8 acquisition dates with cloud cover below 5% acquired before the fire event, from April 22 to May 22, 2022, considering the median reflectance for each image element. The post-fire reflectance was estimated by applying the same processing to 6 acquisition dates after the event, from June 1 to 16, 2022. The two image composites are reported in Fig. 1. Therein, pre- and post-event true colour images obtained from Sentinel-2 bands in the visible range (namely bands 4, 3, and 2) can be visually assessed, with damage caused by the fire in the northeastern part of the island already evident in this band combination.

In order to estimate vegetation loss and total burned area, we derived the Normalised Burn Ratio (NBR), defined for a multispectral image x as:

$$NBR(x) = \frac{NIR - SWIR}{NIR + SWIR},$$

where NIR and $SWIR$ represent for Sentinel-2 data the reflectance of x in bands 8 and 12, respectively. The NBR is a commonly used index to detect burned area and burn severity (Key and Benson, 1996), and is particularly sensitive to the changes in the amount of live green vegetation, moisture content, and some soil conditions which may occur after fire (Lentile et al., 2006).

Change detection relying on spectral indices from multitemporal pre- and post-fire images can be used to estimate biomass loss. Thanks to the availability of multitemporal images, we used the differenced NBR ($dNBR$) since it has the best performance in capturing the spatial severity within fire perimeters (Picotte and Robertson, 2010; Soverel et al., 2010).

The $dNBR$ related to pre- and post-event images, respectively x_{t0} acquired at time $t0$ and x_{t1} acquired at time $t1$, is the delta of the two measurements:

$$dNBR(x_{t0}, x_{t1}) = NBR(x_{t0}) - NBR(x_{t1})$$

This quantity has been used to estimate both damage severity and vegetation recovery after the fire event: a negative $dNBR$ is correlated to regrowth after fires, while a positive one indicates damages, whose severity is proportional to the $dNBR$ value.

Another approach to the estimation of damage in the area is by simply estimating the loss in live green vegetation, rather than the appearance of burned areas. The normalised difference vegetation index ($NDVI$; Gandhi et al., 2015) was derived as well for this purpose, and its values were compared before and after the event. $NDVI$ is defined as:

$$NDVI(x) = \frac{NIR - RED}{NIR + RED}.$$

$NDVI$ is usually less effective in detecting burned areas because the reflectance in the NIR region of the spectrum is usually higher than RED both in live vegetation and burned areas, although the difference is much reduced in the latter, while reflectance in the SWIR can be higher than NIR in burned areas.

To check whether the severity of the damage was related to geomorphological features, rather than to different vegetation units, the correlation between results of the $dNBR$ and a digital elevation model (DEM), also rendered in hillshade, was also evaluated.

Finally, to assess the quality of the information derived from dNBR analysis, additional qualitative validation has been carried out by comparing dNBR results and very high resolution images acquired by a drone DJI Phantom 3 professional on 17 August 2022, i.e. around 3 months after the fire event and 5 days after the first intense rainstorm. Drone images were

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merged and geo-referenced through the software Agisoft Photoscan Professional (version 1.2.6). These images have 10 cm GSD, and have been mosaicked over the north-eastern part of the island, covering the inhabited area of San Bartolo and San Vincenzo (Fig. 2). The drone images did not cover the higher elevations of our study area, closer to the volcano's vents, nor the northernmost part, near Punta Labronzo.

Target species. *Saccharum biflorum* Forssk. [= *S. spontaneum* L. subsp. *aegyptiacum* (Willd.) Hack.] is a bushy grass of Palaeotropical origin (Amalra and Balasundaram, 2006) with herbaceous, erect, robust, full culms up to 1.5-2.5 m and flowering stems up to 3 m high. Its rhizomes can be up to 6 m long, with nodes every 10-15 cm, from which the culms and fascicled roots branch off (Supplement 1, Fig. S1). This grass bears curved leaves with up to 1.40 m long lamina, glabrous, rough, up to 1 cm wide, often convolute. This species has a C_4 metabolism, and thrives in sandy-silty, often alluvial soils (Pignatti et al., 2017-2019).

Gussone (1832) reported its occurrence (despite wrongly identifying it as *Saccharum ravennae* L.) on the islands of Stromboli, Panarea, Lipari and Vulcano, as "cultivated hedges in vineyards". The alien species was then properly identified by Ferro and Furnari (1968), who reported that "a large part of the north-eastern slope of the island, the very slope that Lojacono travelled through 'vineyards that produce beautiful wines', is covered by dense, almost monophytic *Saccharum* vegetation, from sea level up to the upper limit of the ancient crops (...). This slope could have been colonised in a different way by native floristic elements, but it is difficult to make predictions on the final outcome of the competition, given the compactness of the *Saccharum* rhizomatous apparatus".

However, photos published by Ferro and Furnari (1968) give the impression that 50 years ago *Saccharum* was somewhat more widespread than nowadays. In addition to cultivation abandonment, the establishment of this plant is favoured by fire, as observed by Richter (1984) and Richter and Lingenhöhl (2002). In order to collect useful information to better understand the interaction between *Saccharum*, fire and native vegetation, a comparative evaluation of stem density/m^2 in burned vs. unburned patches, ten replicates each, was carried out in the field. In the unburned patches, the relative percentage of dry stems compared to green stems was also assessed, in order to explain the ease of fire ignition due to the abundant presence of dry biomass, consisting mainly of the flowering stems of *Saccharum* which, once faded, dry out completely but remain standing, as they are supported by the green stems which have not yet flowered.

Results

The application of the *dNBR*, which was thresholded to values larger than 0.19 in order to detect the areas affected by fire, yielded a damage map which can be visually assessed against the difference between pre- and post-fire acquisitions (Fig. 1), showing how burned areas got very close to the inhabited area, and surrounded the Osservatorio Restaurant in the north of the island, near Punta Labronzo. *NDVI* values were strongly correlated with *dNBR* values. However, the pre- and post- event difference in *NDVI* showed less clear patterns with evident noise in the estimation of vegetation loss, and false positives scattered across the inhabited area, and are not reported further in this paper. This happens in spite of *NDVI* having a true resolution of 10 m in Sentinel-2 products, while *NBR* employs the SWIR band, which is originally at 20 m GSD and therefore interpolated. The higher sensitivity of *NBR* to spectral changes caused by the appearance of burned areas makes this index in our case study a better detector for damage, even when this is present at sub-pixel level only. We found no correlation between the *dNBR* and neither the elevation nor the slope (therefore not reported here).

In order to give an estimate of the total burned area, and its varying fire damage, we must take into account deviations due to the qualitative approximation introduced by the manual setting of the threshold adopted for *dNBR* to consider the presence of burned vegetation, and the spatial approximation due to the GSD at hand (10 m, resulting in each pixel covering an area of 100 m^2). Regarding the former aspect, the extension of the burned area and the exposure of the soil after the event allowed

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fine tuning of the threshold based on visual assessment from the experts. The approximation in spatial resolution should, on such a large and homogeneously burned surface, balance out small undetected damaged fractions of single pixel with partially unburned image elements. Taking into account the above-mentioned sources of uncertainty, we can quantify the burned area in 337.83 ha, corresponding to 27.7% of the island surface. Of these, 44.31 ha showed high severity burning, assigned to a *dNBR* value higher than 0.45 (Fig. 1).

To assess the quality of our results, we computed a new *dNBR* between the pre-event image and a mosaic of Sentinel-2 acquisitions from the time range 15-17 August 2022. The burned area detected in such way overlapped very well the burned area observable in the drone image acquired on August 17th, with areas with vegetation which was spared by the fire event correctly not included in *dNBR* results (Fig. 2). Other vegetated areas are correctly included in *dNBR* results, because even if they did not burn completely they were still affected by fire, exhibiting a steep decrease in the red edge portion of the spectrum around 700 nm, denoting decrease of vegetated area and strong vegetative stress.

In order to estimate the biomass loss, the *NDVI* was used to calculate the total vegetated area on the island before the event. An *NDVI* calculated with a threshold of 0.08 identified all pixels having at least 8% covered by photosynthetically active vegetation, and quantified the area of the island covered by vegetation before the fire as 678.73 ha. Considering the described correlation between *dNBR* and NDVI, and the above reported area affected by the fire as computed by *dNBR*, it can be concluded that 49.8% of the vegetated area of Stromboli has been burned during the fire event.

Regarding the type of vegetation affected, most of the areas with higher *dNBR* (high severity burning) correspond to patches dominated by *S. biflorum*, while patches with lower associated *dNBR* value correspond to the local native plant communities described in the 'study area' section (see above).

The fast recovery of the *Saccharum* patches, with their soft green colour standing out against the surrounding black, caught everyone's attention as early as a few weeks after the fire, due to the obvious contrast to the harsh environmental conditions imposed by a particularly hot and dry summer (Supplement 1, Fig. S3-5). Until first rains, which occurred on the night of 12 August 2022, *Saccharum* was the only green spot in the fire-affected areas.

In the Sentinel2 images of 22 September 2022, previous damage from the fire event appears mitigated. More in detail, a total of 110 ha of the previously burned area (roughly one third) exhibits a *dNBR* value below -0.1, which represents a strong indicator of vegetation regrowth. This regrowth is mostly occupied by *Saccharum*, demonstrating that this species is able to exert unchallenged dominance in the early stages of the post-fire dynamics (succession), reaching vegetative stem densities slightly lower than those of the unburned stands in a short time (Fig. 3).

Indeed, the high resolution drone images on August 17th 2022 clearly show all *Saccharum* patches in their regrowth phase.

Discussion

Although we applied a permissive threshold (8%) in the NDVI for our quantitative analysis, our conclusion that the fire occurred on 25-26 May 2022 destroyed roughly half of Stromboli's vegetated area appears reasonably accurate, when considering all the available data we used for validation. First, visual assessment of the satellite data clearly shows even at a resolution of 10 m the burned area, due to its size, partial homogeneity, and to its ground being exposed. These observations match the *dNBR* results. Furthermore, a qualitative validation for the accuracy of detected damage using high resolution data acquired by drones yielded a favourable outcome and our field observations were in line to the remotely sensed observations described in this paper.

Fire is a major driving force for Mediterranean insular ecosystem dynamics since the emergence of the Mediterranean climate (Médail, 2021) and also a major driver of degradation in volcanic island ecosystems (Irl et al., 2014). This paper provides the first report of how a single fire event significantly affected Stromboli island, burning 50% of the vegetated island surface. This clearly affected the island biota, in particular destroying the spontaneous vegetation, which is rich in species of relevant biogeographic interest, such as *Centaurea aeolica*, *Genista tyrrhena*, *Dianthus rupicola* subsp. *aeolicus*, *Jacobaea maritima* subsp. *bicolor* (Pasta et al., submitted). In addition, the highest and southernmost end of the study area included part of the *Cytisus aeolicus* population, one of the rarest and most emblematic endemic plant species of the Aeolian Archipelago (Zaia et al., 2020).

Our study confirms that the establishment of *Saccharum* is certainly favoured by fire, as already observed by Richter (1984) and Richter and Lingenhöhl (2002). Fire spreads very easily across *Saccharum* vegetation, due to the abundant presence of standing dry biomass (Supplement 1, Fig. S2, S4, S6). This result agrees with many recent studies focused on the role of fire as promoter of C_4 grasses (Scheiter et al., 2012; Hoetzel et al., 2013; Ripley et al., 2015). Although the native rockrose garrigue vegetation is also adapted to - and favoured by - periodical fires (Pausas, 1999), its survival derives from the ability of *Cistus* to develop a long-lasting soil seed bank (Soy and Sonie, 1992; Scuderi et al., 2010). Too frequent fire events and runoff caused by heavy rainfall on sandy and incoherent soils may cause a critical depletion of soil seed bank and favour sprouters against obligate seeders. On this purpose, we must point out that the autochthonous sprouters (such as *Erica arborea*, *Pistacia lentiscus*, *Olea europaea*) have slower growth rate than *Saccharum* and need longer time to become established.

After the fire, our study area was exposed to full solar radiation; dark sandy surfaces were subject to extreme microclimatic (surface temperatures up to 80 °C; see Richter, 1984) and extremely dry conditions. These were not favourable for the germination of the soil seed bank, whilst sprouters faced almost no competition until first rains, which occurred on 12 August 2022. The first and most important beneficiary of these contrasting conditions was *S. biflorum*, which over time was able to colonise large surfaces of tephra in the northern and eastern parts of the island, likely due to a positive interaction between land abandonment, recurrent fires and volcanic ash deposition.

According to Lojacono (1878), *Saccharum* was planted along the vineyards to shelter them from the northerly winds (Fig. 4). This condition lasted until the eruption of 11 September 1930, so far considered the most violent and destructive event in the historical records of Stromboli's activity (Rittmann, 1931). Facilitated by the winter rains and by a rapid expansion via rhizomes, *Saccharum* first benefited from the emigration of most inhabitants and subsequent abandonment of terraced fields, which in a very short time lapse were almost completely sealed off by a dense monospecific bed, which made it difficult for other species to establish themselves (Ferro and Furnari, 1968; Richter, 1984). Since then, competition for space between local native vegetation and *Saccharum* beds has been regulated mainly by the periodical occurrence of fires. Further studies are needed to understand the duration of the *Saccharum* expansion phases. Our preliminary results suggest that the expansion of *Saccharum* is surprisingly fast, but the decline may also be relatively rapid. There is no data on the longevity of *Saccharum* rhizomes and related senescence processes, nor on the effects of volcanic ash deposition on rhizome burial. However, there are reasonable indications that, if the vegetation is not affected by fire, *Saccharum* could be gradually replaced by native vegetation within a few decades, as captured in the maps published as "Fig. 4" by Richter and Lingenhöhl (2002).

Saccharum beds have over time become an important secondary habitat for many animal species. In fact, they represent the main breeding site for at least 70% of breeding bird species on Stromboli (Massa et al., 2015) and host conspicuous populations of almost all terrestrial vertebrates occurring on the island (especially *Tarentola mauritanica*, *Podarcis siculus* and *Hierophis viridiflavus*). Some of the invertebrates that occurs in the *Saccharum* beds are of considerable biogeographic interest, such as *Caulostrophus zancleanus*, a regional endemic (Lo Cascio et al., 2022), and the recently described *Catomus aeolicus*, endemic of the northeastern sector of the Aeolian archipelago (Ponel et al., 2020). Although not specialised on *Saccharum*, the rhizophagous larvae of the melolonthid *Anoxia orientalis*, a species considered rare at national scale in Italy, feed on its rhizomes. Surprisingly enough, *S. biflorum* does not seem to be an attractive fodder for the mammals introduced in historical (*Oryctolagus cuniculus*) or more recent (*Capra hircus*) times, nor significant infestations of phytophagous insects have ever been observed. Thus, herbivory does not seem to be a limiting factor to the expansion of *Saccharum* on Stromboli.

Conclusions

Remotely sensed data provide fast, accurate and reliable information for post-fire damage analysis, being spectrally sensitive to vegetation features and structure. Multi-temporal data acquisition allows observations on early stage vegetation dynamics which, in our case, point out the outstanding pioneer role played by *Saccharum biflorum*.

On 12 August 2022, a severe thunderstorm triggered disastrous erosion processes over the entire area affected by the fire on May 25-26. Large quantities of mud, stones and volcanic ashes flooded the streets of the villages Piscità, San Bartolo and San Vincenzo (Supplement 1, Fig. S7). In the burned area, the traces of runoff and surface rill erosion were still very evident during our inspections on 18-19 September 2022. However, just as evident was the ambivalent role of *Saccharum*, which, while on the one hand clearly prevails on native species, on the other hand, thanks to its dense mat of rhizomes, proves to be much more efficient than the burned native vegetation in counteracting hydrogeological instability. The latter is a very relevant aspect in a volcanic island, whose soils are largely made up of loose tephra ashes.

Therefore, while considering the fragility of the context, given that *Saccharum* is already present and widespread on the island, it is believed that its rhizomes could be usefully employed for targeted interventions, burying them where it is deemed necessary to contain the disastrous effects of erosion caused by rainfall as much as possible, and then later supporting the biological succession through manual thinning of *Saccharum* culms and sowing of the native woody species typical of local garrigue and maquis communities. A recovery process of natural vegetation, a true rewilding of the upper part of the island, is expected in absence of major anthropogenic disturbance which has favoured the establishment and spread of the alien-dominated vegetation.

Author contribution. RG and DC developed the research idea, DC processed satellite and drone imagery, RG and RZ conducted the field work, RG led the writing process, all authors discussed the results and contributed to the manuscript.

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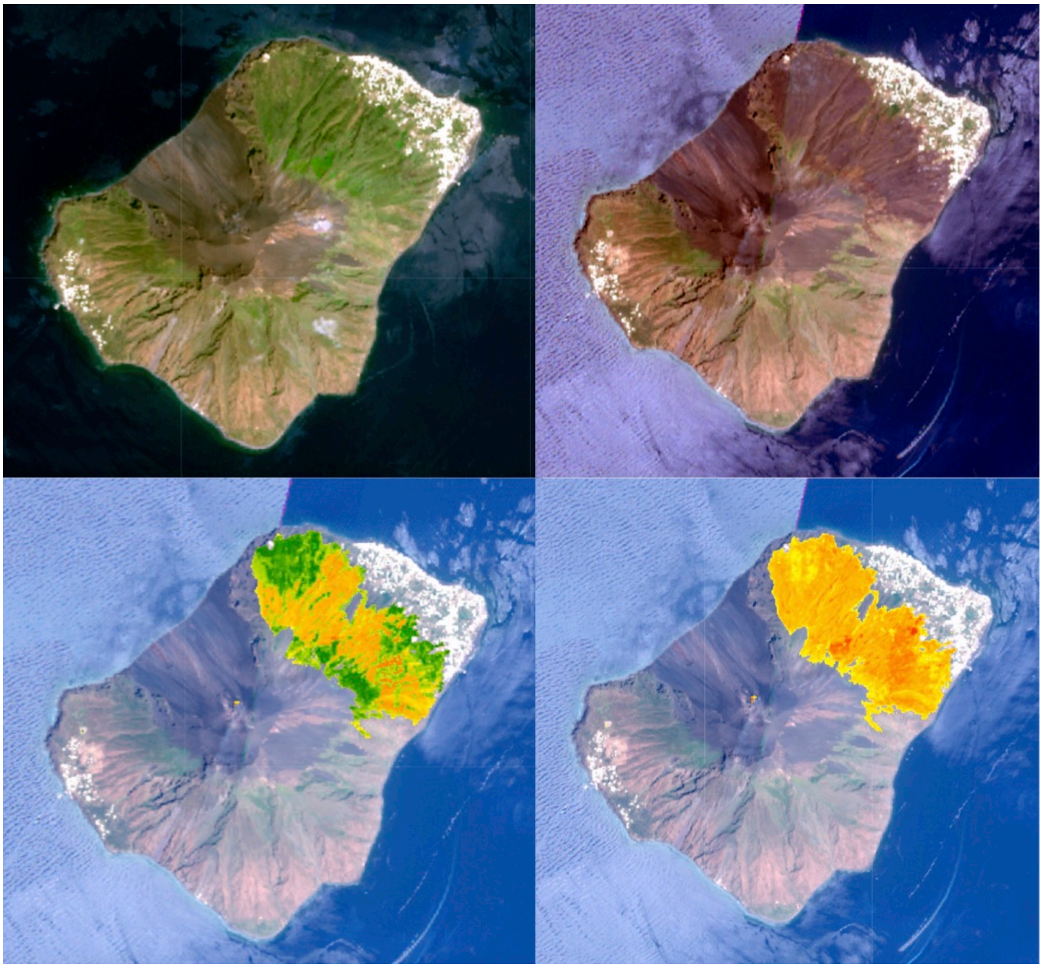

Figure 1: (clockwise from the top left corner) Sentinel 2 image before fire event (composite of acquisitions in the time period 22/04 - 22/05/2022); Sentinel 2 image after fire (composite of acquisitions in the time period 1-16/06/2022); *dNBR*-assessed burned area (yellow: low-, orange: middle-, red: high-severity damage); *dNBR*-assessed vegetation recover (dark green: high-, pale green moderate vegetation recover; Sentinel 2 image, 22 September 2022).

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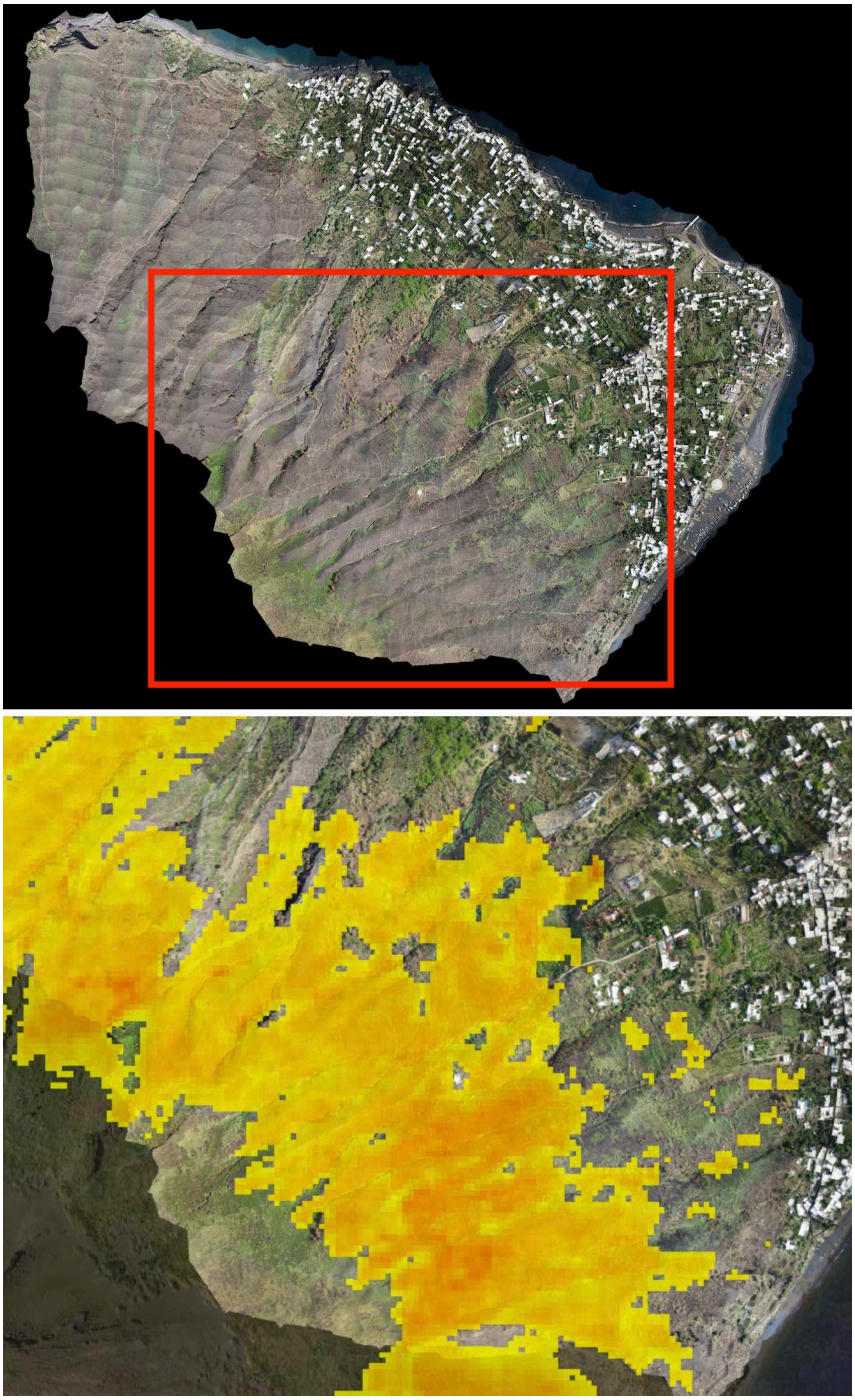

482
483 **Figure 2: (above) high resolution drone image acquired on 17 August 2022 to assess the quality of the information derived**
484 **from*dNBR*analysis; (bottom) detail of drone image with overlaid*dNBR*results for visual comparison (yellow: low-, orange: middle-**
485 **, red: high- severity damage). Credits of drone images: Antonio Zimbone.**

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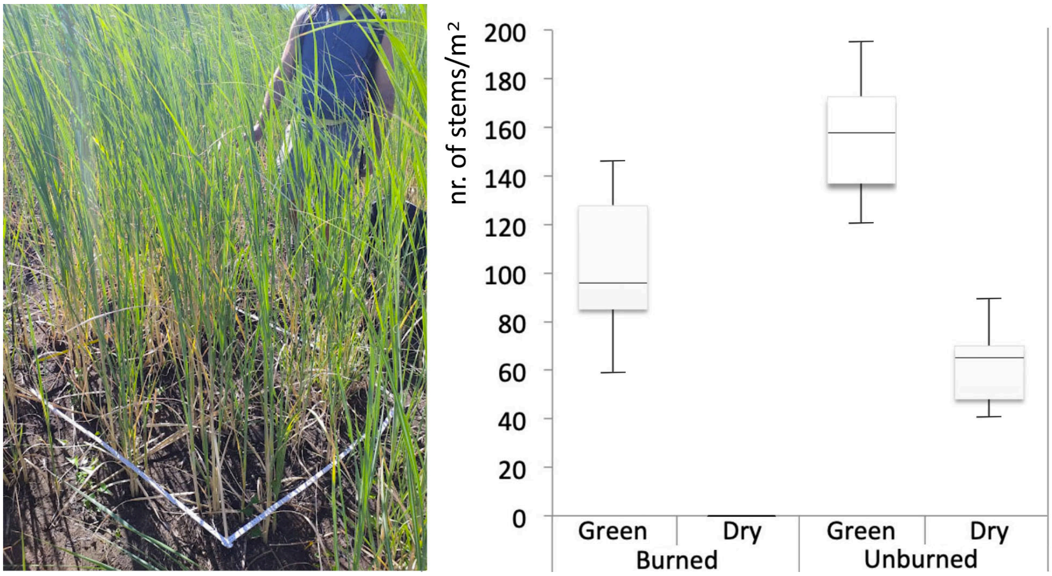

Figure 3: (left) measuring resprouted *Saccharum biflorum* stem density in one of the plots within the burned area (18 Sept. 2022, photo by R. Guarino); (right) boxplots of the stem density of *Saccharum* in burned and unburned patches.

Figure 4: (left) historical photo of terraced vineyards on Stromboli (year: 1891, anonymous), with rows of *Saccharum biflorum* used as windbreaks; (right) same view, 130 years later (16 July 2021, photo by P. Lo Cascio).