The effect of the 2019 eruption on the island of Stromboli (Aeolian Islands UNESCO Site, Italy)

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TEST SITE & METHODOLOGY

Test site: Stromboli Island

Hazards

- Volcanic risk
- Landslide risk
- Tsunami risk
- Wildfires risk
- Seismic risk

Total area

12,6 km² (circa)

Main elements at risk

- *Inhabitants:* n. 500
- *Buildings:* n. 2.315
- *Artifical areas:* 0,7 km²
- *Agricultural areas:* 3,1 km²
- *Semi-natural vegetated areas:* 4,6 km²

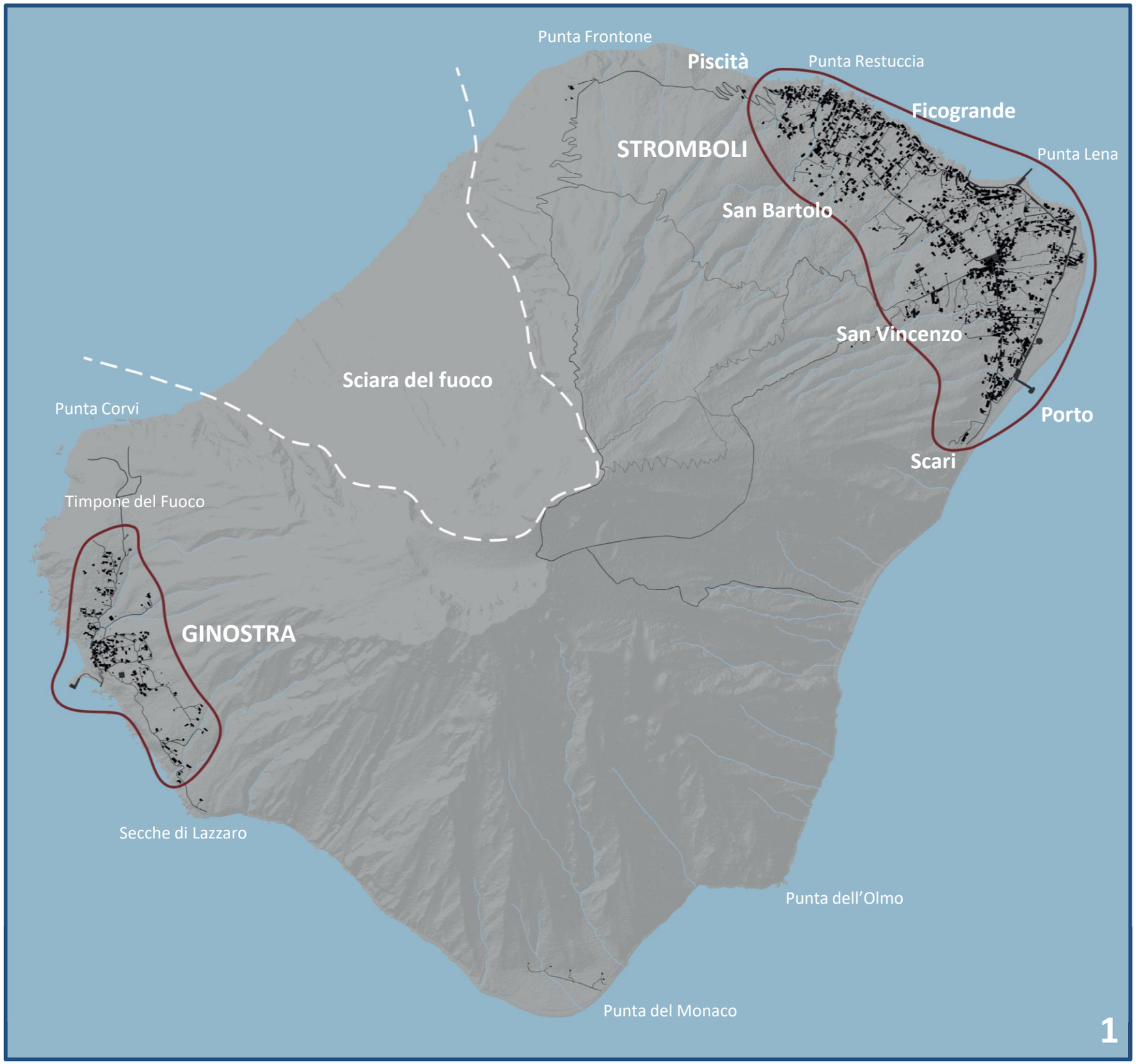


Figure 1 – ***Geographical framework of Stromboli Island***

Research methodology

3rd July & 28th August
STROMBOLIAN ERUPTIONS

LAND COVER & LAND USE ANALYSES

DATASET:
- Sentinel-2 MSI satellite imagery

Normalized Burn Ratio (NBR) Index
EVALUATION

Goals:
1) Identify wildfires impacted areas.
2) Produce preliminary LC and LU maps.
3) Evaluate wildfire severity.

DATASET:
- Sentinel-2 MSI satellite imagery

Revitalized Burn Ratio (RBR) Index
EVALUATION

DATASET:
- PLÉIADES-1 satellite imagery
- CORINE Land Cover

Multi-temporal
Land Cover (LC) & Land Use (LU)
EVALUATION

Goals:
1) Identify landascape patterns.
2) Produce detailed LC and LU maps.

EYEWITNESSES ACCOUNT

Semi-structured interviews

Goals:
1) Validate LC and LU analyses.
2) Obtain more information about eruption-induced damages.
3) Analyze transformation of land use managment.

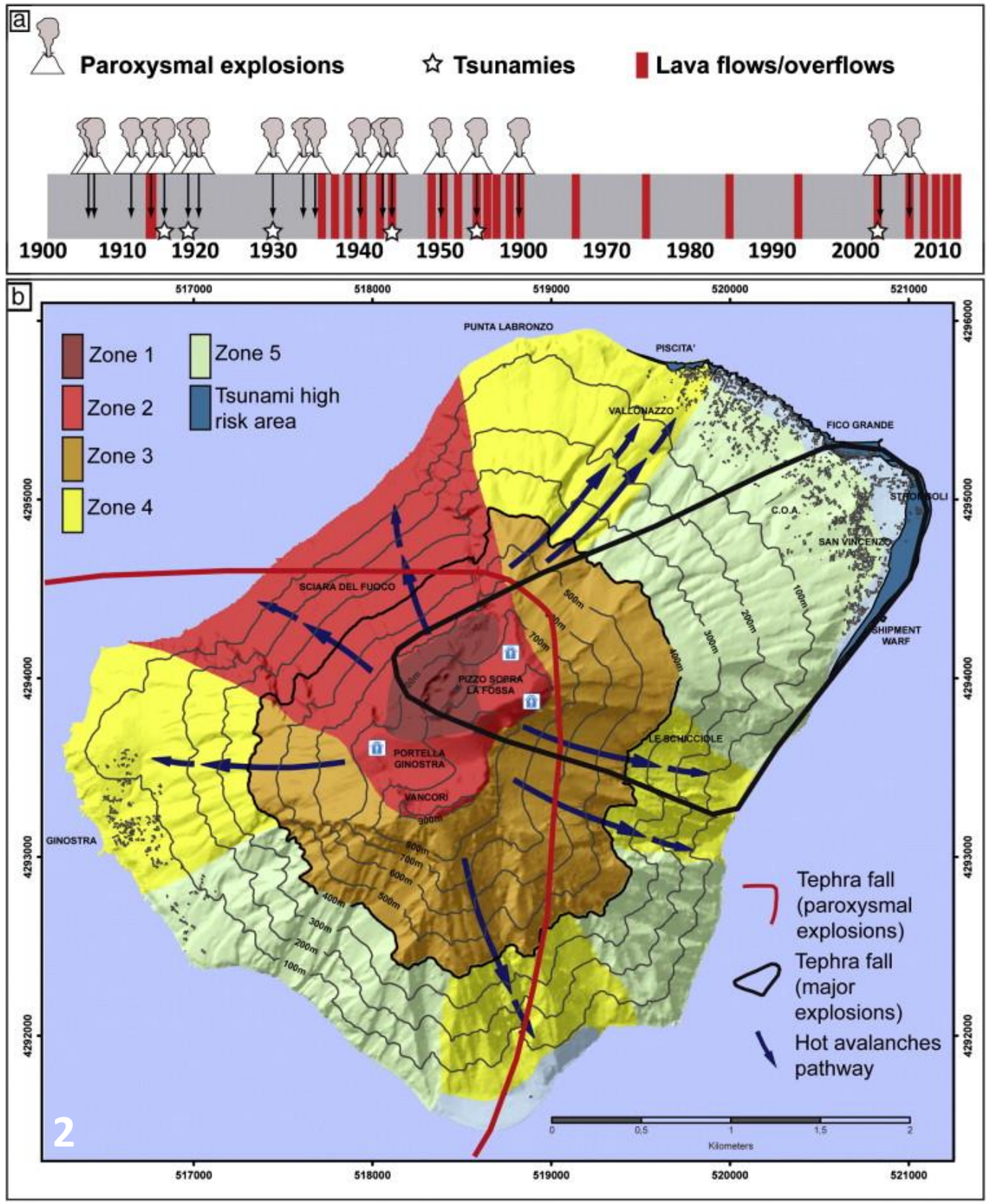
WILDFIRES IMPACTS

- Vegetation loss
- Damages to agricultural heritage
- Transformation to landscape patterns

WILDFIRES IMPACT ANALYSES

HAZARD

Volcanic&Tsunami *Hazard Map*



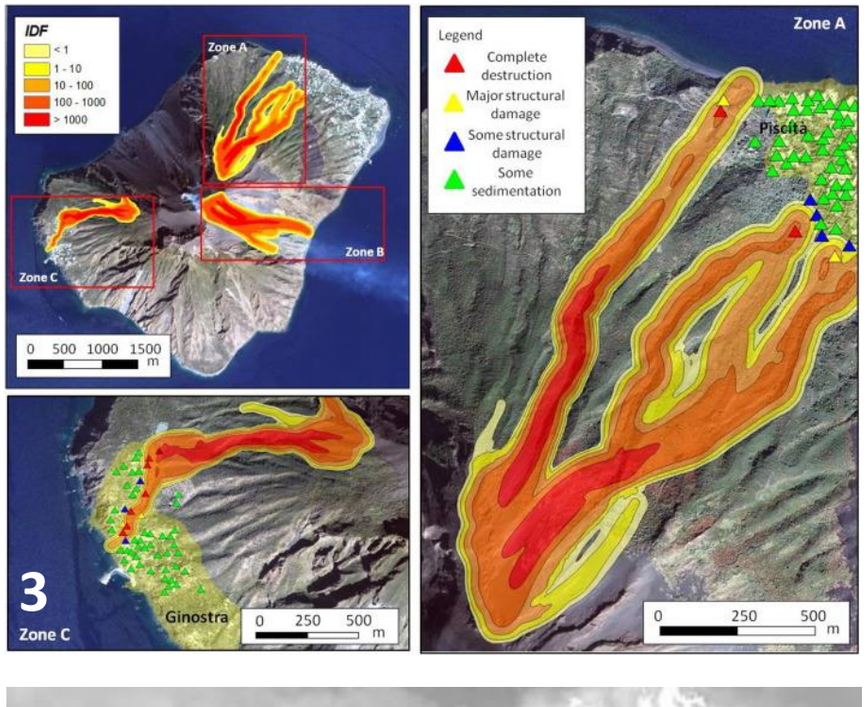
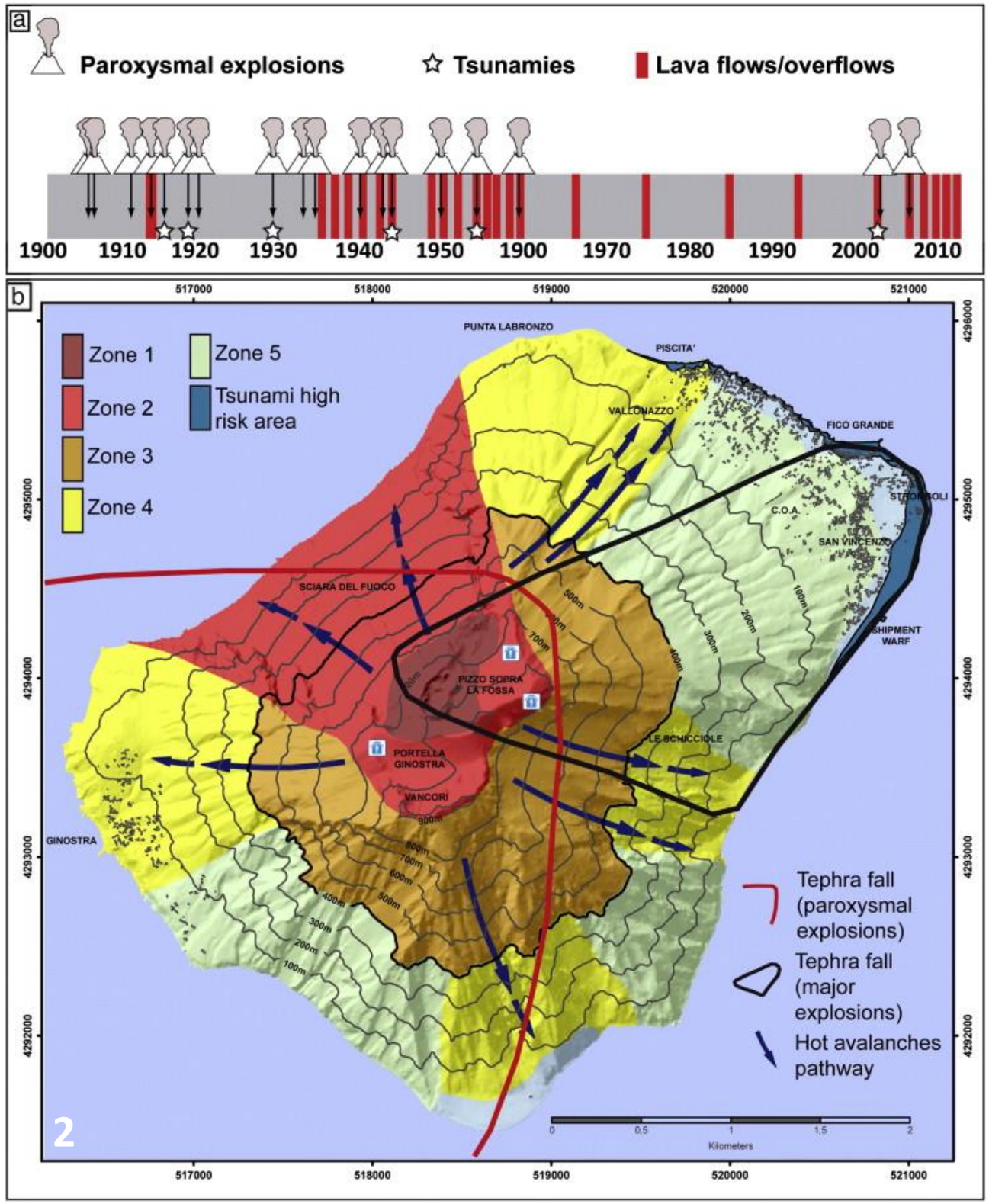


Figure 2 – ***Vlcanic & Tsunami hazard map***
(Nave et al., 2010)
Figure 3 – ***Hot rock avalanches hazard map***
(Salvatici et al., 2016)
Figure 4 – ***Wildefirese damages, caused by 2019 eruptions.***
(Turchi et al., 2020)

Volcanic&Tsunami *Hazard Map*



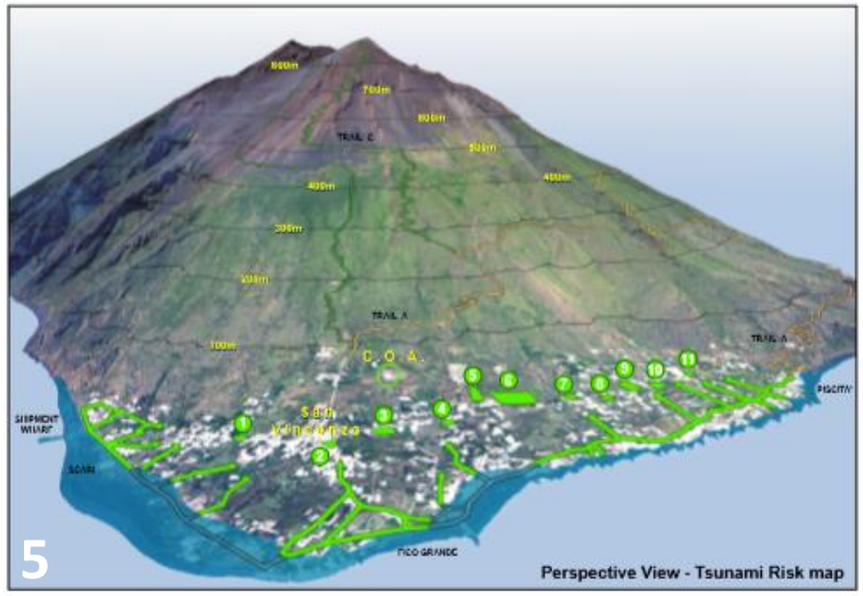


Figure 2 – *Vlcanic & Tsunami hazard map*
(Nave et al., 2010)
Figure 5 – *Tsunami hazard map*
(Salvatici et al., 2016)
Figure 6 – *Tsunami damages, caused by 2002 Sciara del Fuoco landslide.*
(Tinti et al., 2005)

Seismic *Hazard Map*

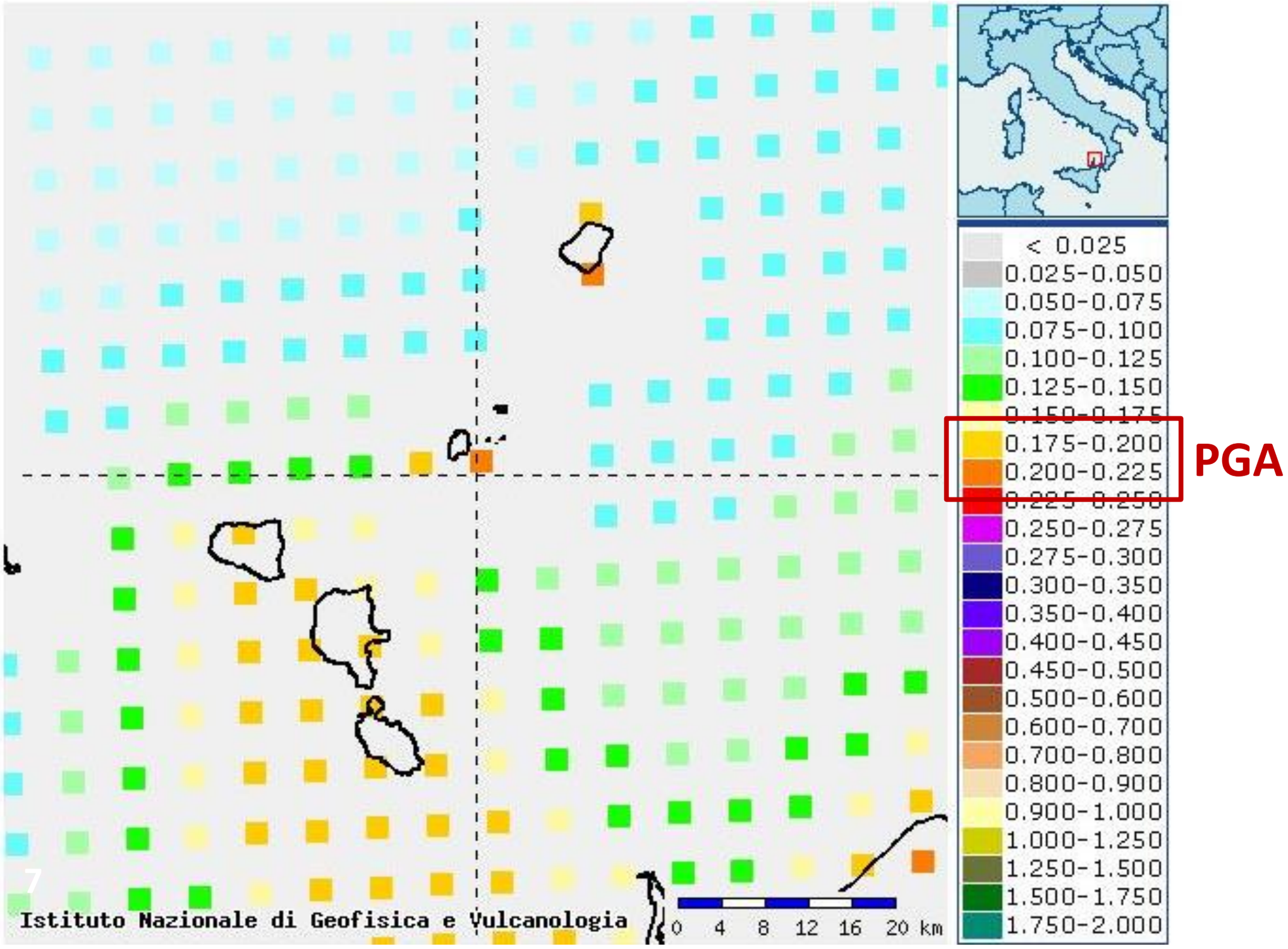
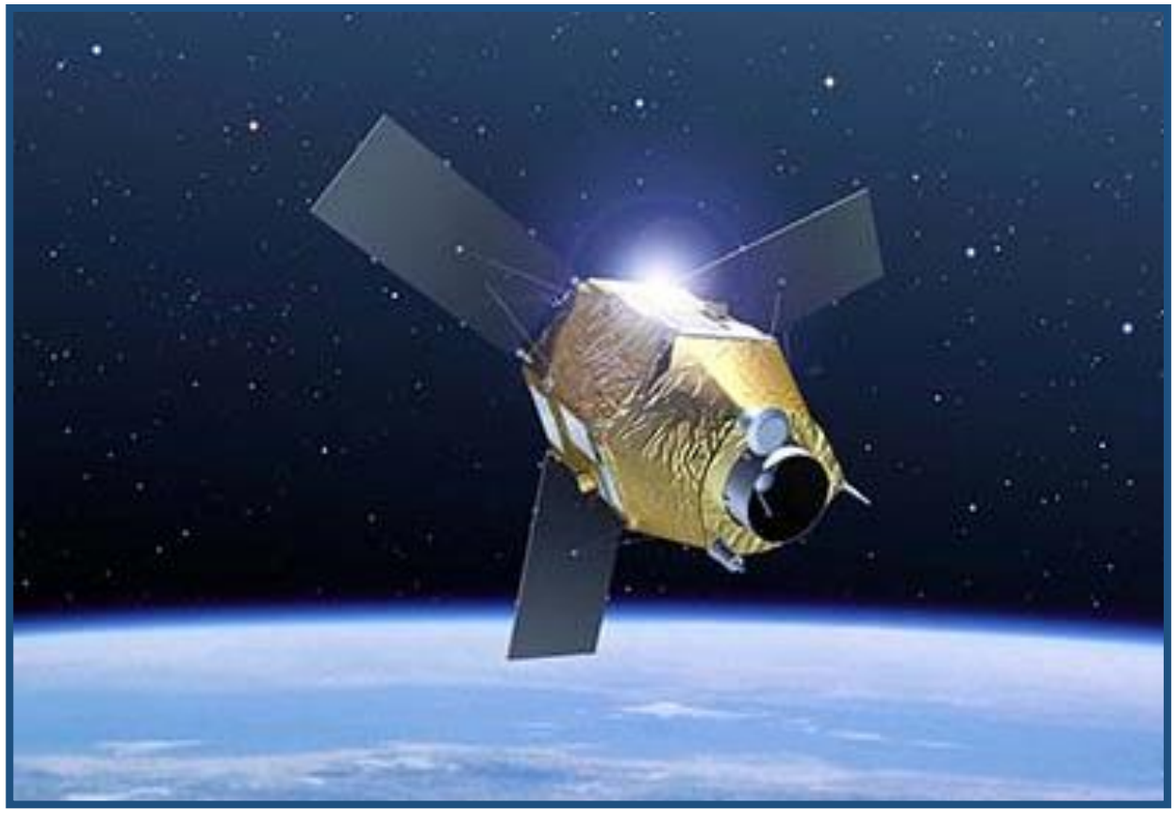


Figure 7 – ***Seismic hazard map.***
(http://esse1-gis.mi.ingv.it/)

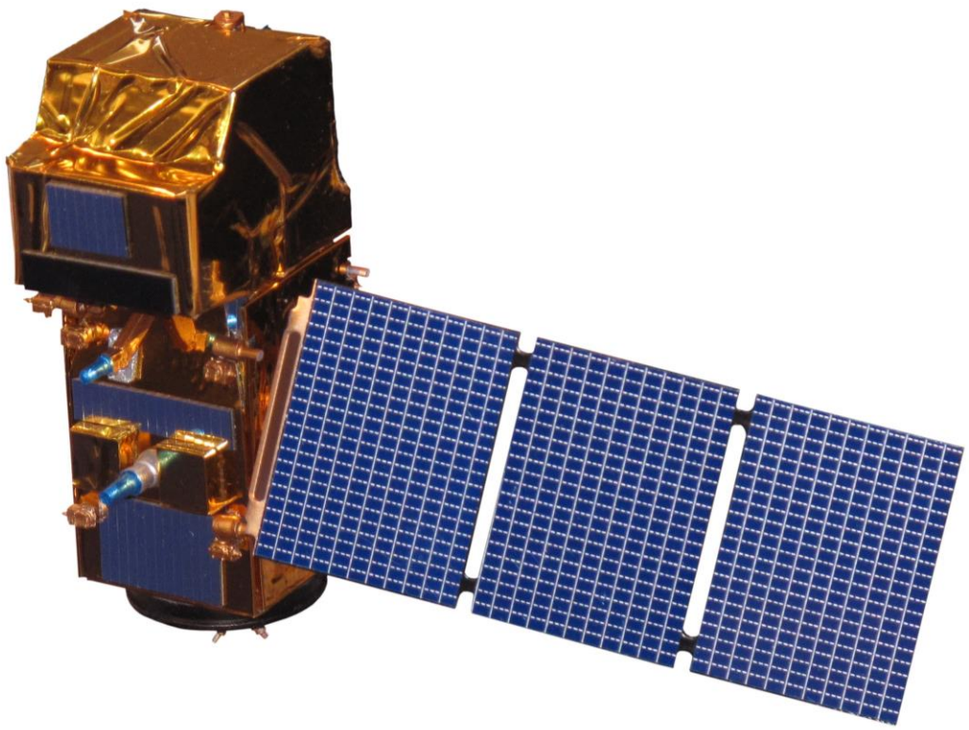
DATA

Remote sensing: data set



Optical imagery, PLÉIADES-1 satellite

- Very high spatial resolution
  (0.5m x 0.5m Pancromatic, 2m x 2m Multispectral data).
- Multispectral (RGB) and panchromatic.
- On-demand
  (1st September 2018, 13thJune 2019, 13th August 2019, 8th October 2019).



Optical imagery, SENTINEL-2 satellite

- Moderate spatial resolution
  (10m x 10m or 60m x 60m, depending on the bands).
- Multispectral
  (13 visible and infrared bands, between 0.433µn and 2.19µn).
- 5 days
  (10 days on the whole island).

Remote sensing: data set

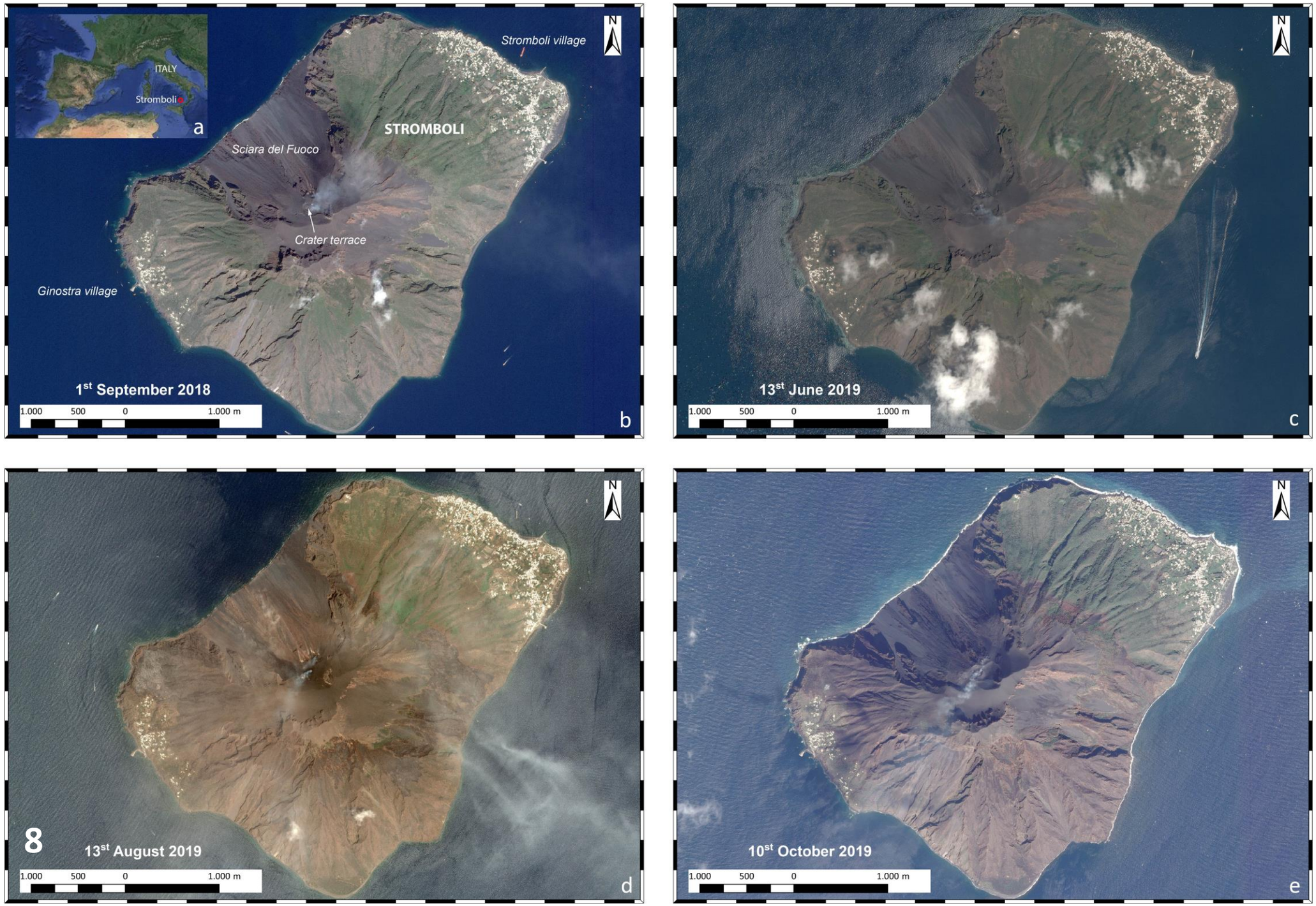


Figure 8 – ***(a) Geographic location of the Island of Stromboli (Google Earth image); PLÉIADES-1 images collected on (b) 1st September 2018; (c) 13th June 2019; (d) 13th August 2019; (e) 8th October 2019.***
(Turchi et al., 2020)

PLÉIADES-1

Remote sensing: data set

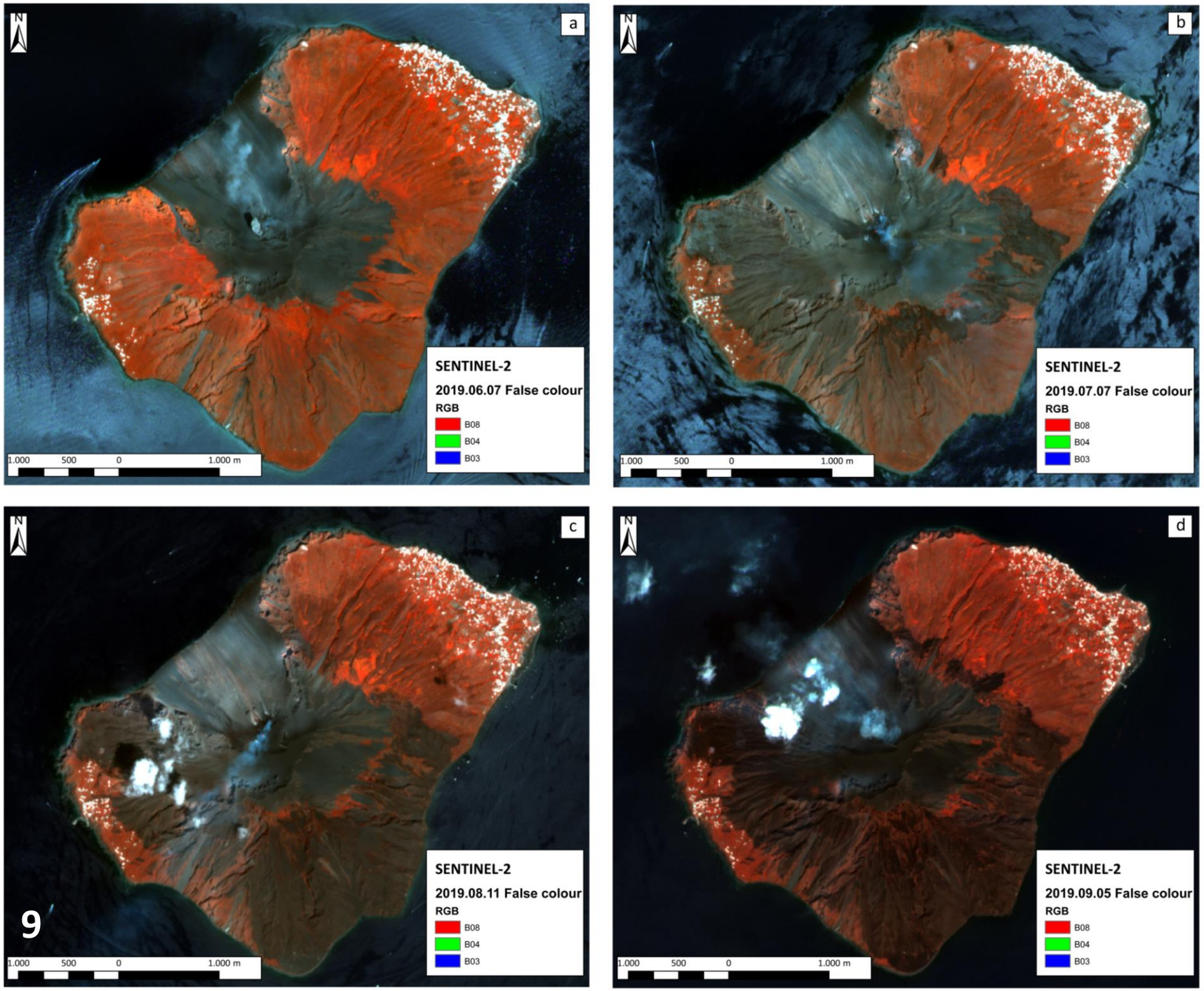


Figure 9 – ***Sentinel-2 image (false color) collected on: (a) 7th June 2019 (pre-eruption), (b) 7th July 2019, (c) 11th August 2019, (d) 5th September 2019.***
(Turchi et al., 2020)

Sentinel-2 MSI false color

LAND COVER & LAND USE ANALYSES

Wildfire impact & Severity recognition

Pre-event Sentinel-2	S2A_MSIL2A_20190607T095031_N0212_R079_T33SWD_20190607T113731
Post-event Sentinel-2	S2A_MSIL2A_20190707T095031_N0212_R079_T33SWD_20190707T114200
	S2B_MSIL2A_20190811T095039_N0213_R079_T33SWD_20190811T125524
	S2A_MSIL2A_20190905T095031_N0213_R079_T33SWD_20190905T114758
Calibration	Images reflectance evaluation.
Resample	Resampling of all images at a resolution of 10 meters.
Stack	Bands of a certain period are processed in a single file.
Subset	Images were cut out on the study area.
Indices calculation	NBR (Normalized Burn Ratio),
	NDVI (Normalized Difference Vegetation Index)
	RBR (Relativized Burn Ratio) as the difference between the index before and after the normalized event.
Wildfire areas identification	
Land Cover/Land Use maps	

Figure 10 – ***Flowchart summarizes the image processing procedure for the wildfire impact and severity mapping.***
(Turchi et al., 2020)

Wildfire impact & Severity recognition

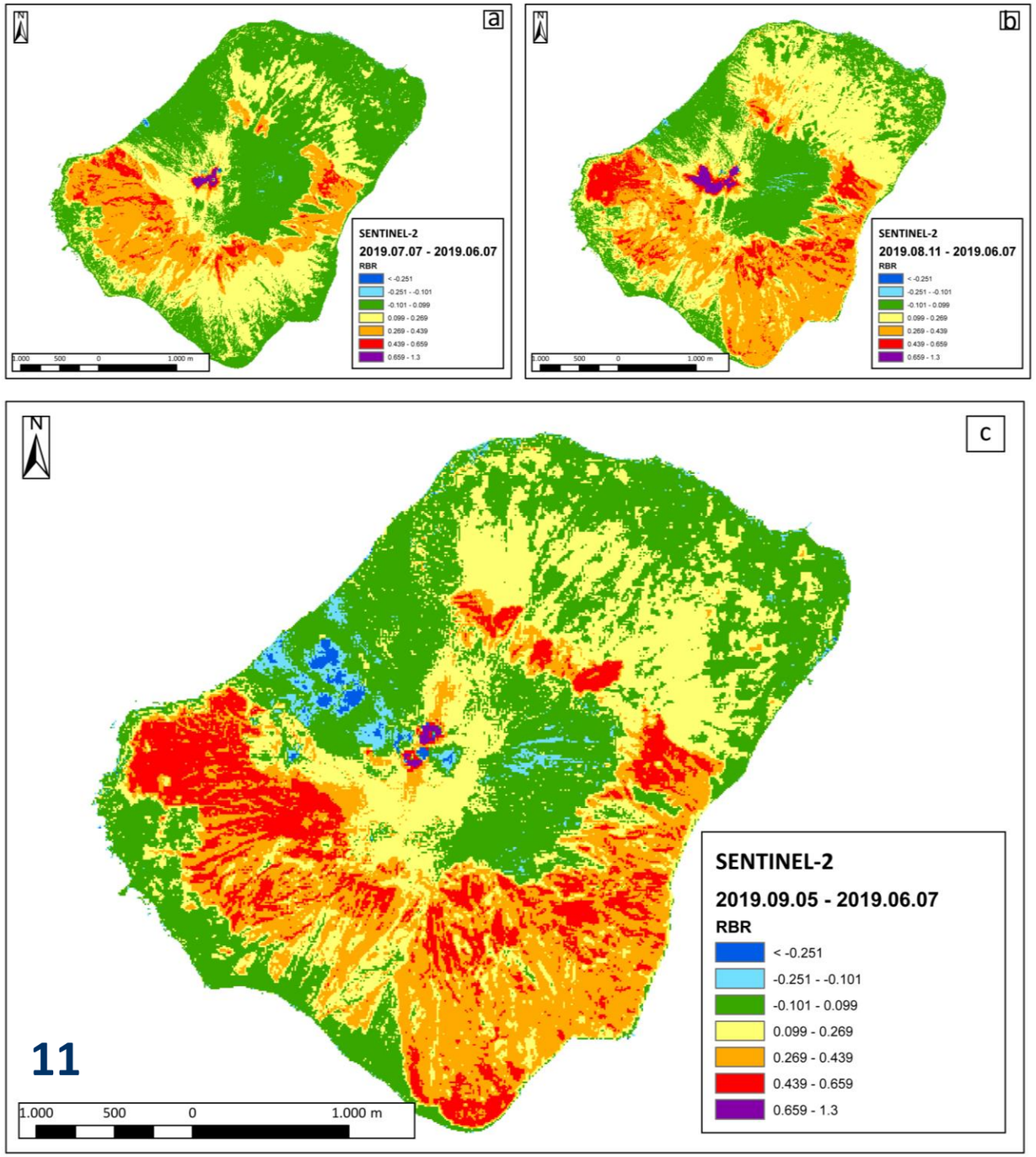


Figure 11 – ***Sentinel-2 images-derived Relativized Burn Ratio (RBR) on: (a) 7th June 2019 – 7th July 2019, (b) 7th June 2019 – 11th August 2019, (c) 7th June 2019 – 5th September 2019.***
(Turchi et al., 2020)

NBR index

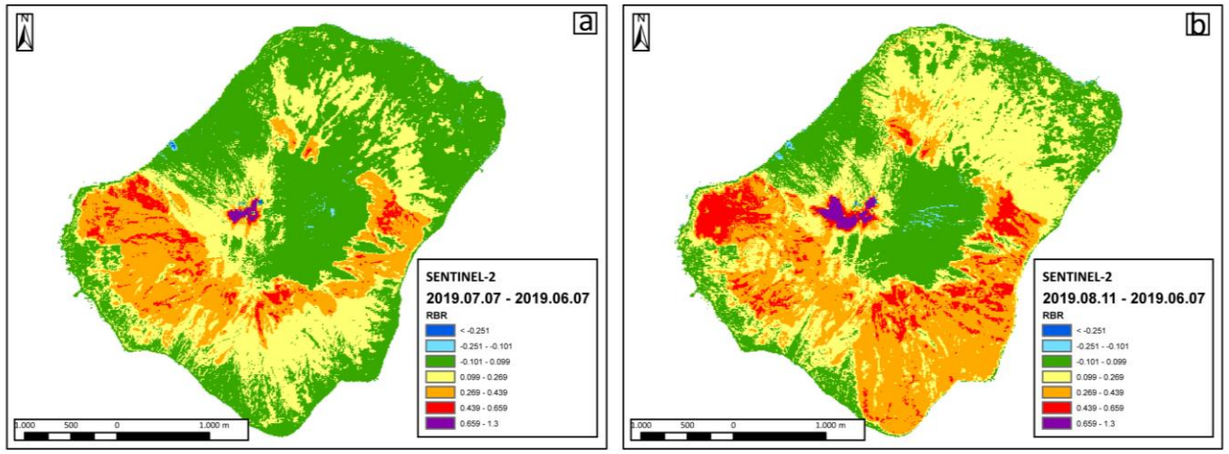
Used to easily identify wildfire affacted areas and fire severity.
Calculated on two Sentinel-2 imagery (bands 8 and 12), acquired on different dates before and after wildfires.

$$NBR = \frac{NIR(B8) - SWIR(B12)}{NIR(B8) + SWIR(B12)}$$

NIR: Near InfraRed region reflectance value
SWIR: ShortWave InfraRed region reflectance value

Recently burned areas have relatively low near infrared reflectance and high reflectance in the short wave infrared band.
A high NBR value generally indicates healthy vegetation, while a low NBR value indicates that the soil has no plant cover (bare soil) and that the areas have recently been burnt.

Wildfire impact & Severity recognition



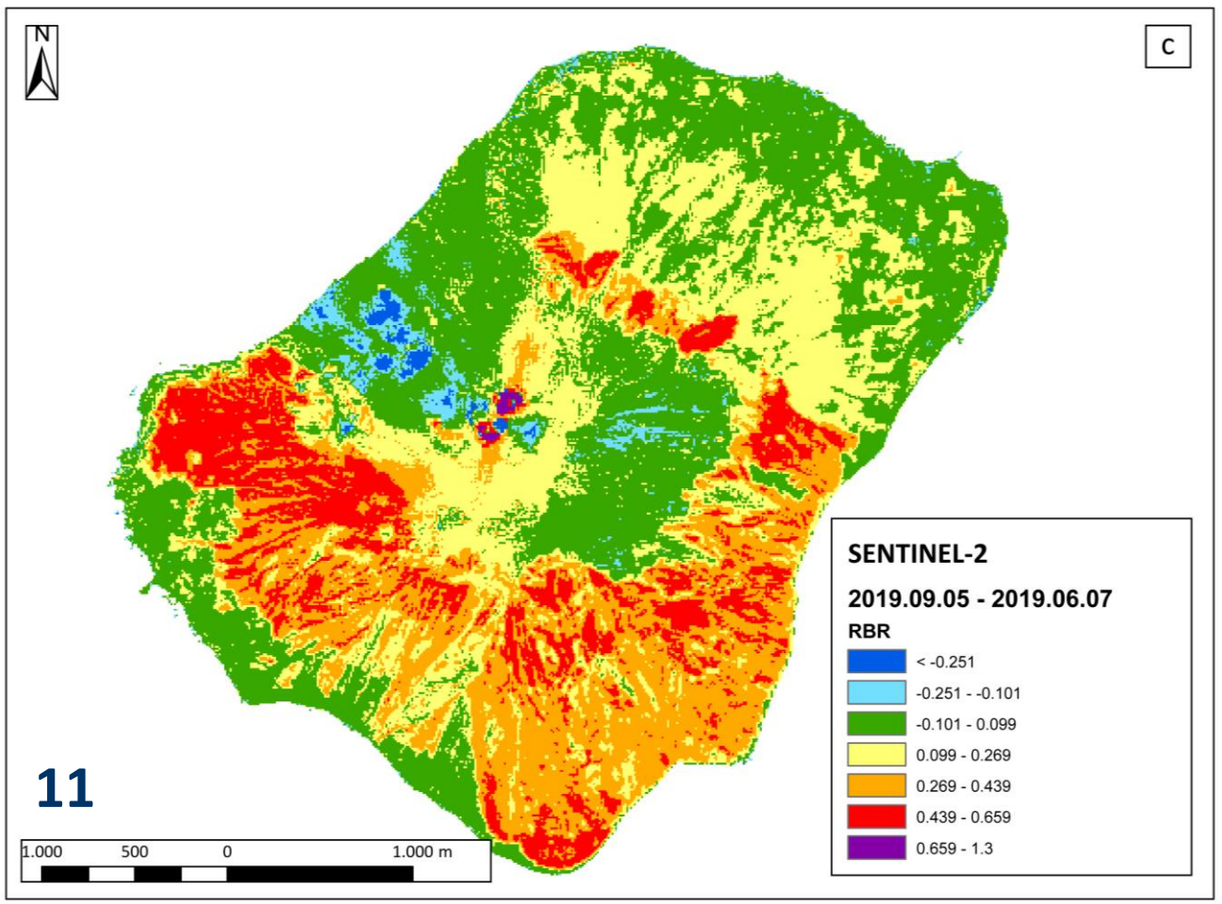


Figure 11 – ***Sentinel-2 images-derived Relativized Burn Ratio (RBR) on: (a) 7th June 2019 – 7th July 2019, (b) 7th June 2019 – 11th August 2019, (c) 7th June 2019 – 5th September 2019.***
(Turchi et al., 2020)

RBR index

Used to easily identify wildfire affacted areas and fire severity.
Obtained as the differece between the NBR index of the images acquired before and after the paroxysmal explosion.

$$RBR = \frac{dNIR}{NIRpre + 1{,}001}$$

$$dRBR = NBR_{pre} - NBR_{post}$$

NBR_{pre}: NBR calculated on the image before the wildfire
NBR_{post}: NBR calculated on the image post the wildfire

Multi-temporal LC & LU evaluation

Figure 12 – ***Examples of land uses at Stromboli Island: (a) urbanized areas at Stromboli village, (b) vegetable gardens at Ginostra village, (c) ancient olive groves mixed with shrubberies and Mediterranean bushes at Vallonazzo (Piscità, Stromboli village), (d) costal dunes between Punta Lena ad Porto (Stromboli village).***

LaMMA
III order
(CLC) reclassification

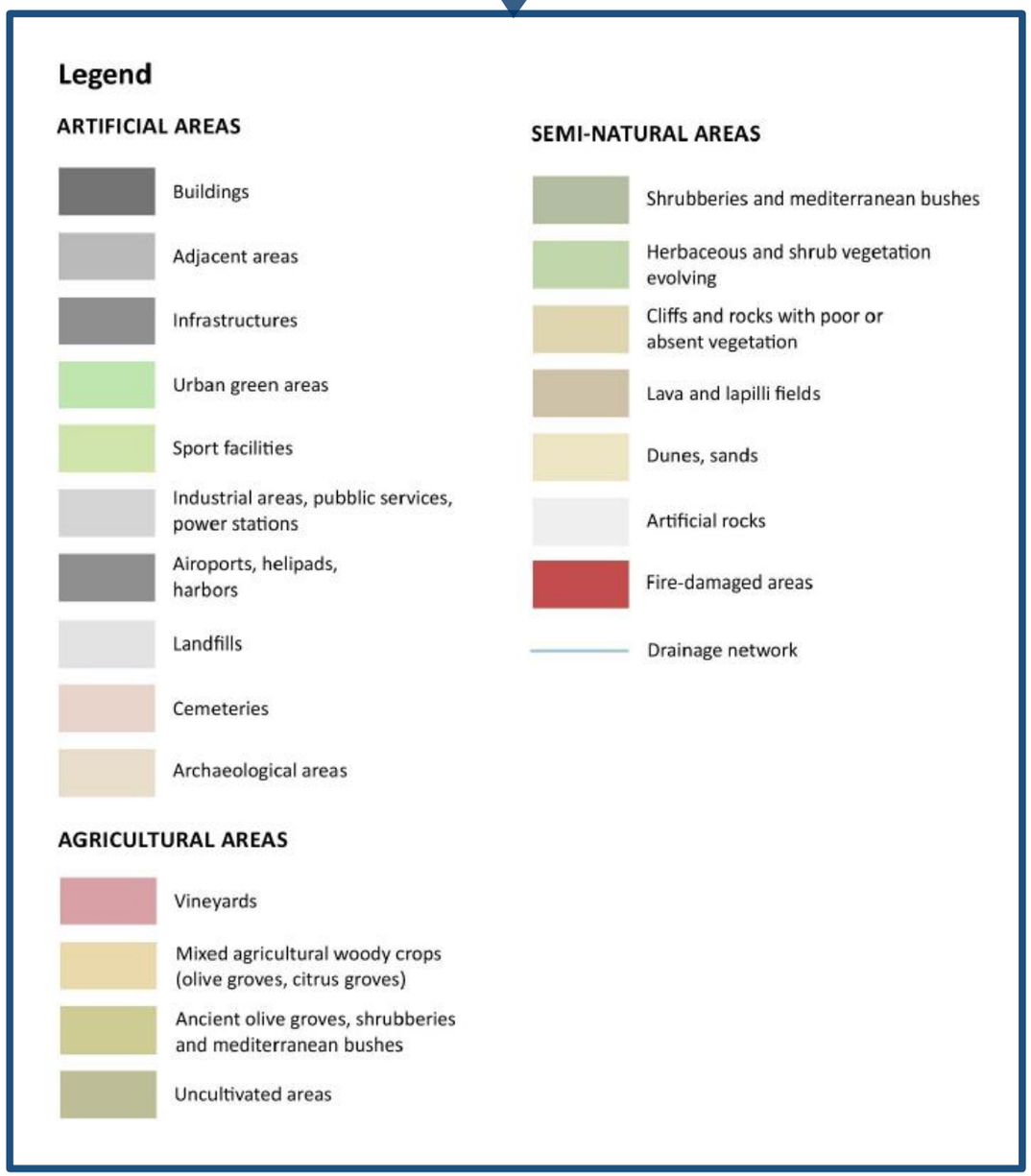
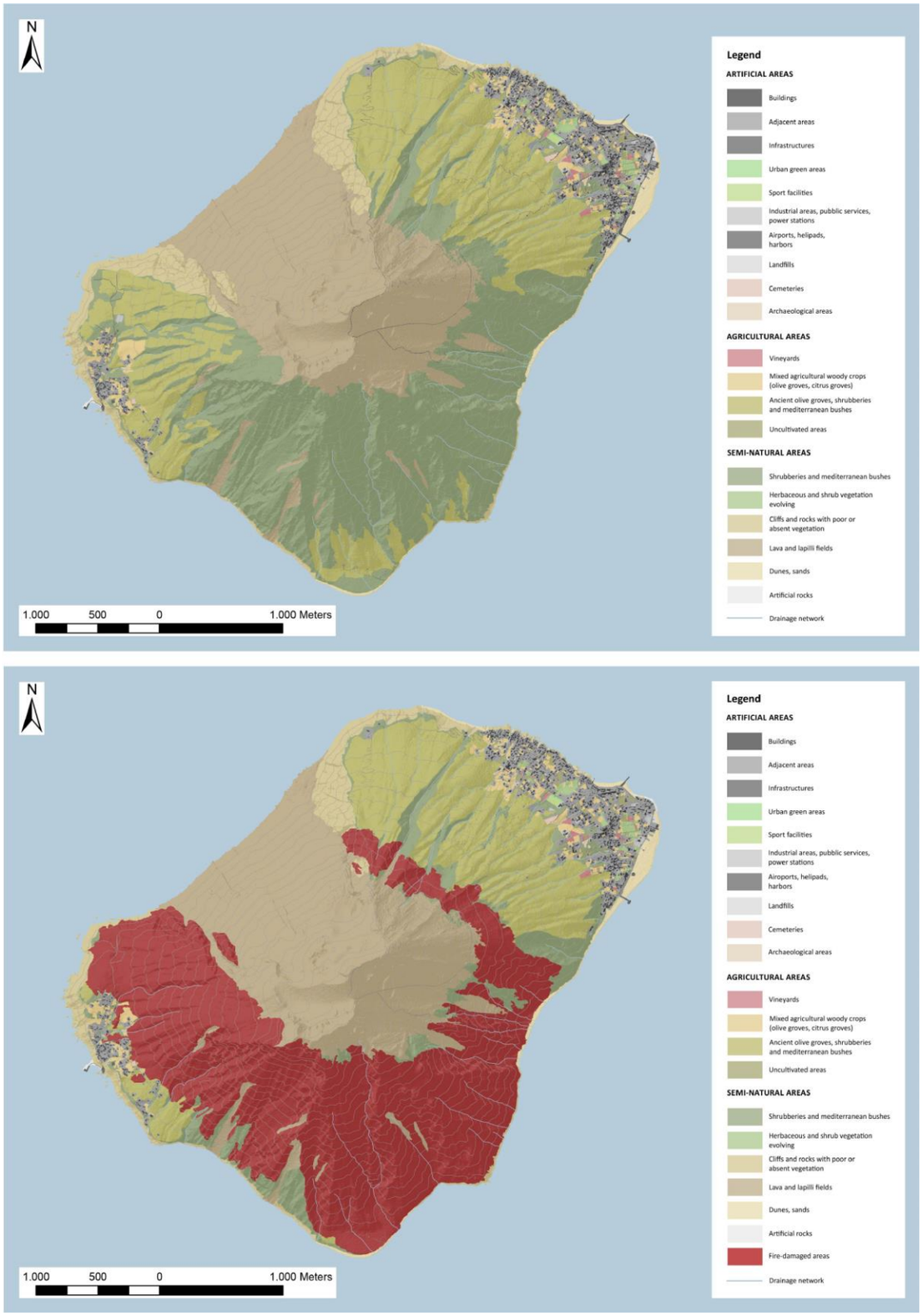


Figure 13 – ***Land cover (LC) and land use (LU) classes.***
(Turchi et al., 2020)

Multi-temporal LC & LU evaluation

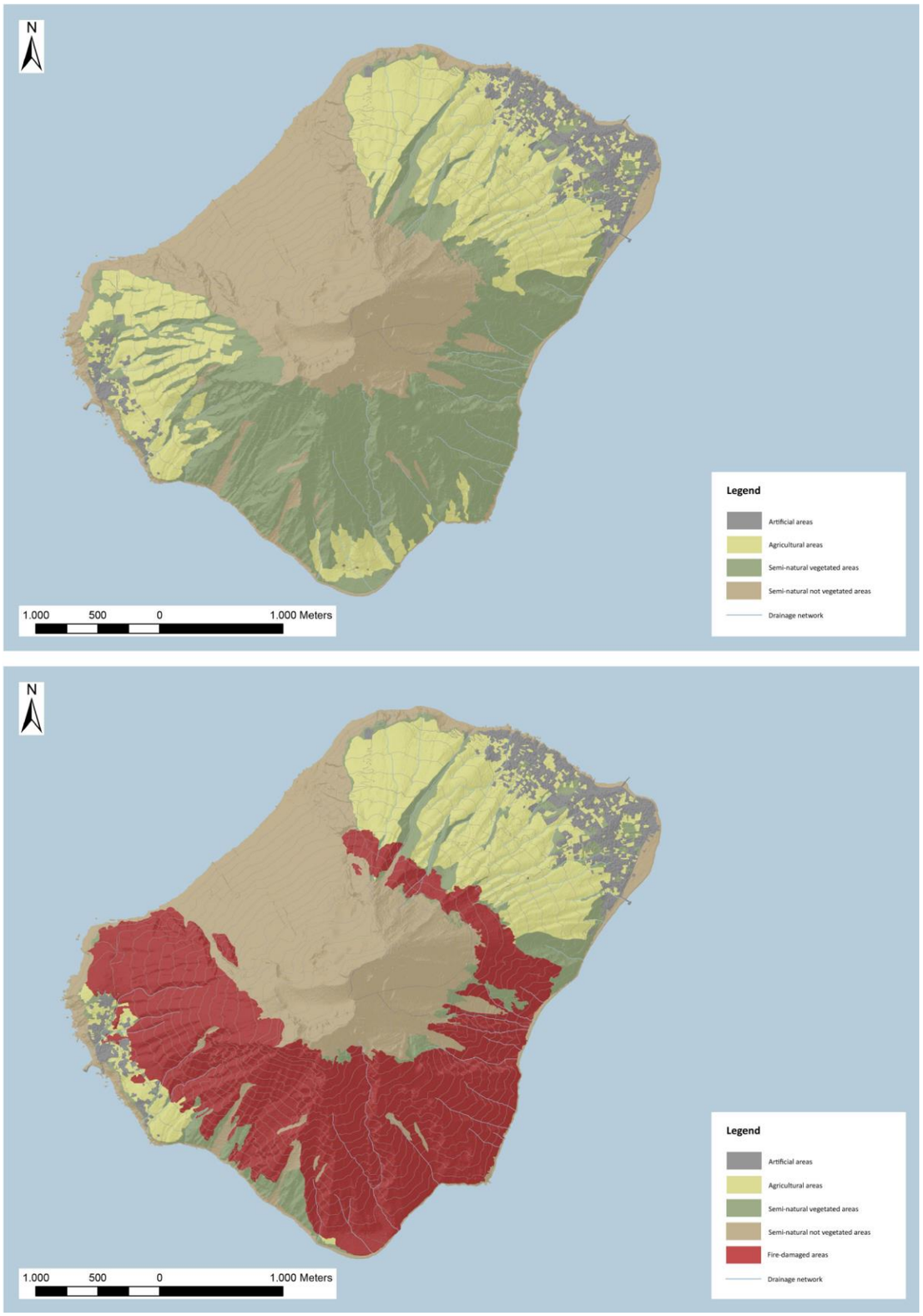


Land Use

is referred to the type of management/use of soil resources, in relation to the peculiarities of the local socio-economic system.

Figure 14 – ***Land cover map (LC) pre-eruption (2018) and post-eruption (2019).*** (Turchi et al., 2020)

Multi-temporal LC & LU evaluation



Land Cover

Is type of coverage of anthropic and non-anthropic surfaces, characterized by different degrees of ecological complexity.\

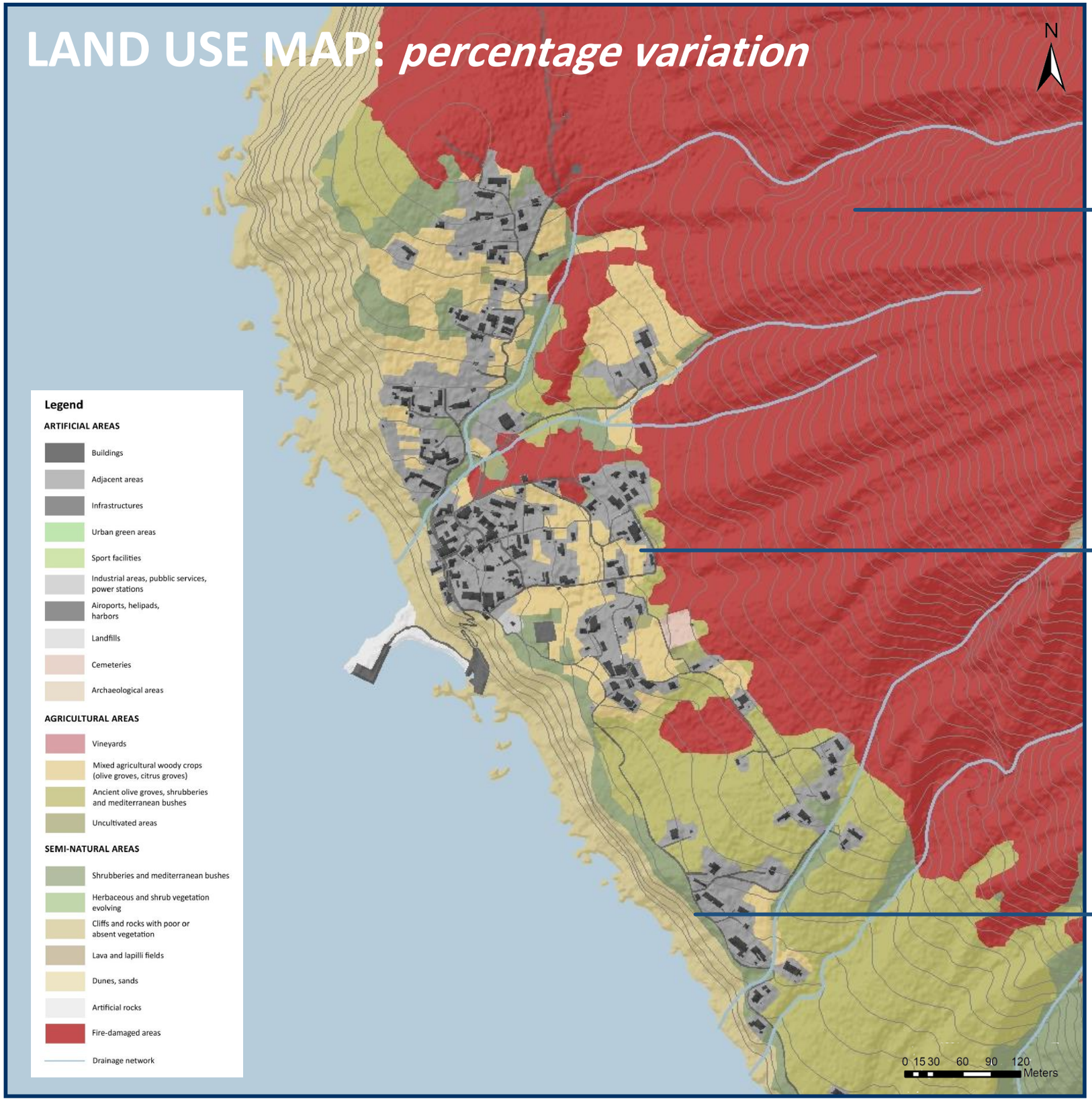
Figure 15 – ***Land use map (LU) pre-eruption (2018) and post-eruption (2019).***
(Turchi et al., 2020)

Multi-temporal LC & LU evaluation

Legend class LAND COVER	Legend class LAND USE	Pre-eruption 2019 Area m²	%	Post-eruption 2019 Area m²	%	Percentage variation (%)
Artificial areas	*Buildings*	160741	1.27	160741	1.27	0
	Adjacent areas	412005	3.27	409919	3.25	- 0.5
	Infrastructures	101009	0.80	101009	0.80	0
	Urban green areas	1418	0.01	1418	0.01	0
	Sport facilities	5345	0.04	5345	0.04	0
	Industrial areas, public services, power stations	21883	0.17	18802	0.15	-14.1
	Airports, helipads, harbors	7341	0.06	7341	0.06	0
	Landfills	1512	0.01	1512	0.01	0
	Cemeteries	5579	0.04	5579	0.04	0
	Archaeological areas	2191	0.02	2191	0.02	0
Agricultural areas	*Vineyards*	21822	0.17	21822	0.17	0
	Mixed agricultural woody crops (olive groves, citrus groves)	223145	1.77	202151	1.60	- 9.4
	Ancient olive groves, shrubberies and Mediterranean bushes	2875753	22.79	1893250	15.01	- 34.2
Semi-natural vegetated areas	*Uncultivated areas*	63749	0.51	63182	0.50	- 0.9
	Shrubberies and Mediterranean bushes	4561225	36.15	860617	6.82	- 81.1
	Herbaceous and shrub vegetation evolving	46031	0.36	46031	0.36	0%
Semi-natural not vegetated areas	*Cliffs and rocks with poor or absent vegetation*	774354	6.14	519454	4.12	- 32.9
	Lava and lapilli fields	3182509	25.23	3182506	25.23	0
	Dunes, sands	142661	1.13	142661	1.13	0
	Artificial rocks	6196	0.05	6196	0.05	0
Fire-damaged areas	*Fire-damaged areas*	0.0	0,00	4964742	39.35	--
Total area		**12616477**	**100%**	**12616477**	**100%**	--

Figure 16 – *Percentage variation of land cover/land use classes pre-eruption, sin- and post.*
(Turchi et al., 2020)

Multi-temporal LC & LU evaluation



wildfire areas

+...%

abandoned olive groves

-34,2%

shrubbery and bushes

-81,1%

Land cover damages: 3rd July 2019

Figure 17 – ***Damages to the adjacent area of the photovoltaic power station (a), damages to the ancient terraced olive groves (b), tephra accumulation on the roofs (c) and damages to the canopies (d) at Ginostra, following the 3rd July 2019 explosion.***
(Turchi et al., 2020)

SOCIAL ANALYSIS

Eyewitnesses account

FRAMEWORK

Eyewitnesses: n. 20
Age: 24-76 years old
Location: Stromboli & Ginostra villages
Time: 10-10 min.

SEMI-STRUCTURED INTERVIEWS

List of questions to guide the interviewer.
Open and flexible questions to investigate as much as possible.

Social research

Social research was crucial to:

1) validate LC and LU analysis results;
2) reconstruct of the 2019 paroxysms;
3) define people perception of two paroxysms, from Stromboli and Ginostra villages;
4) evaluate damages to the urbanized and non-urbanized areas (agricultural and semi-natural lands), following each explosion;
5) analyze transformations of the land use management;
6) analyze transformation of the landscape patterns.

Eyewitnesses account

3rd July 2019 explosion				
Eyewitnesses	*Age*	*Location*	*Event description*	*Damages description*
1	26	--	--	1 casualty
2	46	Stromboli (San Vincenzo)	1) Violent explosion, ash column upwards. 2) Ash/lapilli fall at Ginostra.	1 casualty; Wildfires on vegetated areas at Ginostra; Ash/lapilli accumulation on the roofs (obstruction of rainwater harvest cisterns and dirty water) at Ginostra.
3	49	Stromboli (San Vincenzo)	1) Explosion, ash column upwards.; 2) Pyroclastic flow towards Sciara del Fuoco.	1 casualty
4	≈ 75	Stromboli (San Vincenzo)	n.d.	1 casualty
5	68	Stromboli (San Vincenzo)	n.d.	Ash/lapilli accumulation on the roofs (obstruction of rainwater harvest cisterns and dirty water) at Ginostra.
6	51	Stromboli (Pizzillo)	1) Violent explosion, ash column upwards; 2) Lava flows; 3) Ash/lapilli fall at Ginostra.	Ash/lapilli accumulation on the roofs (obstruction of rainwater harvest cisterns and dirty water) at Ginostra.

Figure 18 – ***An extract from the summary of semi-structured interviews to the inhabitants of Stromboli island, after the 3rd July 2019 explosion.***
(Turchi et al., 2020)

Conclusions

The 3rd July 2019 explosion demonstrate that a moderate intensity explosion has impacted severely on the island (1 casualty, wide-spread wildfire).

The causes of the vastness of fires are due to ***natural factors*** and ***anthropogenic factors*** like agricultural land abandonment. The most affected areas by wildfires, located near Ginostra village (the south-western part of the island), have been those ones characterized by wild terraced olive groves and Mediterranean shrubberies and bushes, with an overproduction of highly flammable fuel indeed.

Multi-temporal LC and LU analyses and ***Semi-structured interviews*** have allowed to estimate not only damages (loss of Aeolian endemic vegetation and agricultural heritage), but also transformations of landscape patterns related to the land management changes.

From the 1930, the abandonment process has caused:

- physical impoverishment of terraces;
- reduction of hydraulic land management, in terms of outflow water drainage;
- increase of hydrogeological risk factors;
- reduction of crop diversity;
- reduction of landscape variety;
- loss of cultural heritage, in terms of material and immaterial settlings;
- loss of agricultural knowledges, techniques and practices.

Therefore LC and LU analyses are crucial to define the best strategies and policies that could be adopted to encourage a sustainable site-specific land management, taking into account the probability of occurrences of wildfires at Stromboli island.

References

Nave, R.; Isaia, R; Vilardo, G.; Barclay, J. *Volcanic and Tsunami Risk Map of Stromboli Island (Italy).* Journal of Maps 2009, 6:1, 260 – 269.

Salvatici, T.; Di Roberto, A.; Di Traglia, F.; Bisson, M.; Morelli, S.; Fidolini, F.; Bertagnini, A.; Pompilio, M.; Hungr, O.; Casagli, N. *From hot rocks to glowing avalanches: Numerical modelling of gravity-induced pyroclastic density currents and hazard maps at the Stromboli Volcano (Italy).* Geomorphology 2016, 273, 93 – 106.

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