Mapping the 2019-2020 New South Wales East Coast Bushfire Season using Landsat Multispectral Imagery Analysis

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Introduction

Landsat 8 (primarily) and Landsat 9 data is used to study the effect of the 2019-2020 bushfires in the East Coast forests of New South Wales, Australia.

Landsat scenes from path 90 were acquired, from row 83 in the north providing covering to the northern edge of the Wollemi World Heritage wilderness, to row 86 in the south covering the southern Australian coastline and the eastern Victorian forests.

Only Landsat Collection 2, Level 2 (Surface Reflectance/Bottom of Atmosphere) scenes were used.

Bushfires were active on the East Coast from October 2019 through to March 2020.

A raster dataset mapping the fire extent was obtained from the NSW Department of Planning and Environment, published December 2020. This is a 10m resolution raster mapping fire severity (a metric of the loss of biomass caused by fire) based on Sentinel 2 imagery. This dataset represents the 2019/2020 fire season including all bushfires greater than 10 hectares with a fire start date between July 2019 and June 2020.

The fire extent raster was converted to an MRR and a “Coverage Any” overview pyramid was built to represent a super-set of cells affected by fire. A copy of this raster was extracted at 640m resolution and converted to a polygon. This polygon is a superset of the area affected by fire.

Scenes

Scenes were downloaded to create datasets for 2018, 2019, 2020, 2021 and 2022. The scenes are listed below showing the path and row, the bird, the year/month/day of capture, and the percentage cloud cover.

The scenes in each mosaic are listed from highest to lowest cloud percentage. This mirrors the order in which the scenes were consumed in the virtual rasters. Consequently, each scene contributes data that may be overwritten by the scenes following it. This may be because the scenes overlap or because data was masked after being identified as water or cloud.

Mosaic 2018 (Pre fire)

90-85	L8	2018/05/02	1.04%
90-86	L8	2018/05/02	0.51%
90-84	L8	2018/05/02	0.13%
90-83	L8	2018/05/02	0.06%

Mosaic 2019 (Pre fire)

90-83	L8	2019/03/02	4.78%
90-84	L8	2019/04/19	3.4%
90-83	L8	2019/05/05	1.71%
90-84	L8	2019/03/02	1.61%
90-85	L8	2019/03/02	0.88%
90-86	L8	2019/03/02	0.65%

Mosaic 2020 (Immediately post fire)

90-86	L8	2020/04/21	14.28%
90-85	L8	2020/04/21	5.03%
90-85	L8	2020/08/27	4.22%
90-84	L8	2020/04/21	1.98%
90-86	L8	2020/06/08	1.55%
90-83	L8	2020/04/21	0.35%

Mosaic 2021 (Post fire)

90-84	L8	2021/02/19	3.82%
90-85	L8	2021/04/24	2.6%
90-83	L8	2021/05/26	1.54%
90-85	L8	2021/07/29	1.23%
90-86	L8	2021/07/29	0.32%
90-84	L8	2021/08/30	0.22%

Mosaic 2022 (Post fire)

90-83	L9	2022/02/14	10.74%
90-86	L9	2022/02/14	5.63%
90-84	L9	2022/02/14	2.87%
90-85	L9	2022/02/14	1.87%
90-86	L8	2022/03/10	0.42%
90-84	L8	2022/08/01	0.38%
90-83	L9	2022/05/05	0.15%

Virtual Raster Chain

Each scene is downloaded as a collection of cloud optimised geotiff (COG) format rasters, one raster per spectral band, with additional rasters for QA data and ancillary data.

Each scene is firstly represented by a “SceneData” virtual raster (MVR) which collates all the source rasters into a multi-field and multi-band raster. Digital Numbers are rescaled to Reflectance and Temperature. QA data is separated and reflected in mask bands.

The “SceneData” MVRs are consumed in the “SceneDataMask” MVR for each yearly mosaic. In this MVR the “SceneData” rasters are collected into a raster source. They are listed in order of increasing quality – corresponding to decreasing cloud cover. These are consumed in a “RasterMask” operation. The mask Boolean is acquired from the same raster source, using the “Mask” & “Land (Clear)” field and band. The field and band structure of the “SceneData” rasters are duplicated, but all masked pixels are removed.

The masking process removes pixels in each scene that are either cloud affected or identified as water. Where scenes overlap, masked pixels may be replaced by valid pixels from another scene. The goal is to acquire a high percentage of valid pixels in the mosaic. It also “collapses” the raster collection to a single raster where there is a single unique value for each pixel.

The “SceneDataMask” MVR is then consumed in the “SceneDataMaskIndex” MVR. This generates the index formulas that are valid for the scenes. This is dependent on the spectral bands present. The index calculations use the scaled reflectance and temperature fields rather than the digital numbers.

The “SceneDataMaskIndex” MVR is then consumed by the “SceneDataMaskIndexClip10m” and “SceneDataMaskIndexClip640m” MVRs. This uses a raster mask operation to clip the mosaic to the 10m resolution fire severity raster, or the 640m resolution fire severity raster. The 640m cells are populated if any 10m cell is populated within their footprint, so they represent a broader superset polygonal region.

Each of these mosaic rasters can now be collated into a multi-event raster. The rasters “IndexCollate”, “IndexCollateClip10m”, and “IndexCollateClip640m” rasters each contain five events (2018 – 2022). The data links back to the unclipped masked scene mosaic, and to the clipped mosaics of the same at 10m and 640m resolution. From these rasters it is possible to compute statistics for each event.

An additional MVR was generated to compute Delta NBR (see definition below). Based on the index data for the 10m clipped scene mosaics, this MVR executes a calculator operation to compute the difference between the NBR index pre-fire and post-fire.

Index Calculations

Only those index calculations that are valid for Landsat 8 and 9 have been used. The formulas use the spectral band naming IDs followed in ProRaster Scientific. For reference, those ID’s map to the following bands in Landsat 8.

ID	Name	Wavelength range (um)
Coastal	Band 1 - Coastal Aerosol	0.43-0.45
Blue	Band 2 – Blue	0.45-0.51
Green	Band 3 – Green	0.53-0.59
Red	Band 4 – Red	0.64-0.67
NIR	Band 5 – NIR	0.85-0.88
SWIR1	Band 6 - SWIR1	1.57-1.65
SWIR2	Band 7 - SWIR2	2.11-2.29
Pan	Band 8 – Pan	0.50-0.68
Cirrus	Band 9 – Cirrus	1.36-1.38
TIRS1	Band 10 - TIRS1	10.6-11.19
TIRS2	Band 11 - TIRS2	11.50-12.51

Some of these index calculations can use digital numbers, but others require calibrated reflectance values as input. Thermal values are assumed to be brightness temperature in Kelvin. For this study, calibrated surface reflectance and calibrated surface temperature in Kelvin were used.

Normalized Burn Ratio
NBR = (NIR-SWIR2)/(NIR+SWIR2)

The Normalized Burn Ratio is an index that uses the differences in the way healthy green vegetation and burnt vegetation reflect light to find burnt area. Healthy green vegetation will have a high NBR value while burnt vegetation will have a low value. Areas of dry, brown vegetation or bare soil will also return lower NBR values than green vegetation.

NBR returns values between (but not limited to) -1 and 1. Lower values correspond with burnt areas and higher values correspond with healthy vegetation. A cut-off value of anywhere between 0.1 and 0.3 is suggested to differentiate between burned and unburned areas.

Normalized Burn Ratio 2
NBR2 = (SWIR1-SWIR2)/(SWIR1+SWIR2)

Normalized Burn Ratio SWIR
NBRSWIR = (SWIR2-SWIR1-0.02)/(SWIR2+SWIR1+0.1)

Normalized Burn Ratio Thermal 1
NBRT1 = (NIR-SWIR2*(TIRS1/1000))/(NIR+SWIR2*(TIRS1/1000))

Delta NBR
Pre-fire NBR – Post-fire NBR

The difference between the pre-fire and post-fire NBR indices is used to calculate the delta NBR, which then can be used to estimate the burn severity. Delta NBR can be more useful than NBR alone to determine what is burnt, as it shows change from the baseline state.

Burnt areas will have a positive value and higher values indicate more severe damage. Negative values may indicate regrowth following a fire.

Some care should also be taken as false positives can return a positive result:

- A lot of smoke in the post burn image can interfere with the Delta NBR value
- Areas that have been cleared of vegetation by some other means (logging, harvesting, and landslides) towards the end of the baseline period may incorrectly show up as burnt
- Drying out of bright green vegetation such as grasses. If a fire event has been preceded by a rapid drying out of vegetation this can result in low positive Delta NBR values in areas that have not burnt.

The following table of burn severity levels, corresponding to delta NBR, is proposed by the USGS. Note the error in the dNBR range (not scaled) for "Unburned".

	Severity Level	dNBR Range (scaled by 10^3)	dNBR Range (not scaled)
	Enhanced Regrowth, high (post-fire)	-500 to -251	-0.500 to -0.251
	Enhanced Regrowth, low (post-fire)	-250 to -101	-0.250 to -0.101
	Unburned	-100 to +99	-0.100 to +0.99
	Low Severity	+100 to +269	+0.100 to +0.269
	Moderate-low Severity	+270 to +439	+0.270 to +0.439
	Miderate-high Severity	+440 to +659	+0.440 to +0.659
	High Severity	+660 to +1300	+0.660 to +1.300

Mid-Infrared Burn Index
MIRBI = 10*SWIR2-9.8*SWIR1+2

Burnt Area Index
BAI = 1/(pow(0.1-Red,2)+pow(0.06-NIR,2))

This index highlights burned land in the red to near-infrared spectrum, by emphasizing the charcoal signal in post-fire images. The index is computed from the spectral distance from each pixel to a reference spectral point, where recently burned areas converge. Higher values indicate burned areas.

Normalized Difference Vegetation Index
NDVI = (NIR-Red)/(NIR+Red)

NDVI returns values between (but not limited to) -1 and 1. Values between -1 and 0 indicate dead plants, or inorganic objects such as stones, roads, and houses. Values for live plants range between 0 to 1, with 1 being the healthiest and 0 being the least healthy.

Statistics

Statistics were computed for each event in "IndexCollateClip10m.mvr" for a selection of computed indies. Recall that this raster is masked, collated from multiple scenes and duplicated scenes observed at similar times, and clipped to the 10m resolution fire mask raster. Statistics were computed at the base resolution level, which has a cell size of 30m.

Statistics were also computed for the Delta NBR index, looking at the difference between NBR between 2018 and the following four years from 2019 to 2022.

For each event (year) there is a different number of cells in each dataset due to the masking. This is summarised in the following table. It shows the number of cells in total, the number of valid and invalid cells, the number of invalid cells that were empty, the area of the valid cells in square kilometres, and the percentage this area is of the maximum area (measured in 2021). Note that the total burnt area in New South Wales, derived from the burnt area mask, is 50071.2 square kilometres. This includes substantial fires to the north and west of the study area.

Year	Total	Valid	Invalid	Empty	Area	Percentage
2018	349700096	29107572	320592524	271702668	26196.81	0.9922
2019	349700096	28999936	320700160	299007744	26099.94	0.9885
2020	349700096	28400270	321299826	290891122	25560.24	0.9681
2021	349700096	29337569	320362527	271472671	26403.81	1.0000
2022	349700096	29156782	320543314	304814674	26241.10	0.9938

In the following summary statistics, I have recorded the minimum value, maximum value, mean, median, and mode values, standard deviation, lower quartile threshold, upper quartile threshold, and interquartile range. Each index is listed with the spectral components contributing to that index. I have chosen indices that use a different combination of spectral bands.

NBR (NIR,SWIR2)

Year	Min	Max	Mean	Median	Mode	St Dev	LQ	UQ	IQR
2018	-1.3605	3.1085	0.6354	0.6699	0.7389	0.1515	0.5570	0.7475	0.1905
2019	-2.1255	13.2717	0.6292	0.6659	0.7303	0.1501	0.5578	0.7379	0.1801
2020	-2362.3096	1854.0490	0.2772	0.2901	0.3817	0.6821	0.0410	0.5227	0.4817
2021	-206.6440	208.1026	0.5252	0.5508	0.6460	0.2032	0.4042	0.6696	0.2653
2022	-9.2590	18.7290	0.5971	0.6272	0.6869	0.1440	0.5180	0.7022	0.1842

The median NBR shows a drop of 56.7% in 2020, recovering to 6.4% in 2022.

NBR2 (SWIR1,SWIR2)

Year	Min	Max	Mean	Median	Mode	St Dev	LQ	UQ	IQR
2018	-1.3920	6.6000	0.3871	0.3952	0.4171	0.0654	0.3462	0.4351	0.0889
2019	-77.0000	2.9206	0.3859	0.3952	0.4189	0.0688	0.3444	0.4347	0.0903
2020	-15.7529	148.7894	0.2323	0.2302	0.2164	0.1131	0.1528	0.3135	0.1607
2021	-440.0035	825.0168	0.3099	0.3087	0.2830	0.2165	0.2497	0.3735	0.1237
2022	-1.5346	2.2254	0.3471	0.3522	0.3691	0.0696	0.3008	0.3982	0.0974

The mode NBR2 shows a dop of 48.4% in 2020, recovering to 11.9% in 2022.

NBRT1 (NIR,SWIR2,TIRS)

Year	Min	Max	Mean	Median	Mode	St Dev	LQ	UQ	IQR
2018	-3.3254	1.3411	0.8736	0.8909	0.9180	0.0649	0.8465	0.9190	0.0726
2019	-0.5757	10.7165	0.8696	0.8882	0.9181	0.0667	0.8450	0.9150	0.0700
2020	-144.8412	1929.1912	0.6943	0.7239	0.8820	0.4454	0.5770	0.8330	0.2560
2021	-262.7292	33.5519	0.8309	0.8477	0.8909	0.0976	0.7847	0.8933	0.1086
2022	-12.4490	18.6314	0.8600	0.8757	0.9005	0.0627	0.8314	0.9038	0.0724

The mean NBRT1 shows a drop of 20.5% in 2020, recovering to 1.6% in 2022.

BAI (Red,NIR)

Year	Min	Max	Mean	Median	Mode	St Dev	LQ	UQ	IQR
2018	0.8573	805.2611	47.8258	39.8434	26.7966	28.3161	26.6536	61.8936	35.2401
2019	2.1313	7197.7739	42.8101	36.4152	28.1868	23.2007	26.7959	51.6397	24.8439
2020	0.8069	1925.9966	99.1136	85.6467	37.2210	64.1647	47.7004	135.9204	88.2200
2021	0.9669	1968.4965	61.0633	51.7374	29.2653	36.7277	31.5921	87.0537	55.4616
2022	1.3378	8938.5078	49.1302	40.8937	27.4970	29.8391	26.9720	64.2911	37.3191

The mean BAI shows an increase of 131.5% in 2020, recovering to 14.8% in 2022.

Delta NBR (NIR,SWIR2)

Year	Min	Max	Mean	Median	Mode	St Dev	LQ	UQ	IQR
2019	-1.9311	2.4731	0.0060	0.0065	0.0169	0.0754	-0.039	0.0475	0.0859
2020	-1853.5002	802.3613	0.3592	0.3215	0.0909	0.5060	0.1339	0.5734	0.4395
2021	-207.4024	207.3760	0.1086	0.0797	0.0121	0.1758	0.0041	0.1936	0.1896
2022	-18.0497	10.0616	0.0393	0.0292	0.0095	0.1286	-0.036	0.1076	0.1432

The mean dNBR peaks at 0.36 in 2020, recovering to 0.04 in 2022.

NDVI (Red,NIR)

Year	Min	Max	Mean	Median	Mode	St Dev	LQ	UQ	IQR
2018	-130.3742	33.9135	0.7808	0.7966	0.8208	0.0952	0.7385	0.8423	0.1038
2019	-65.1412	532.2299	0.7853	0.8062	0.8395	0.1385	0.7470	0.8461	0.0991
2020	-1834.3214	10469.7168	0.6076	0.6269	0.7934	2.3572	0.4773	0.7499	0.2726
2021	-2705.8535	3439.3606	0.7369	0.7605	0.8286	0.8889	0.6780	0.8191	0.1412
2022	-211.9503	155.8971	0.7793	0.8019	0.8375	0.1041	0.7390	0.8405	0.1014

The mean NDVI shows a drop of 22.6% in 2020, recovering to 0.77% in 2022.

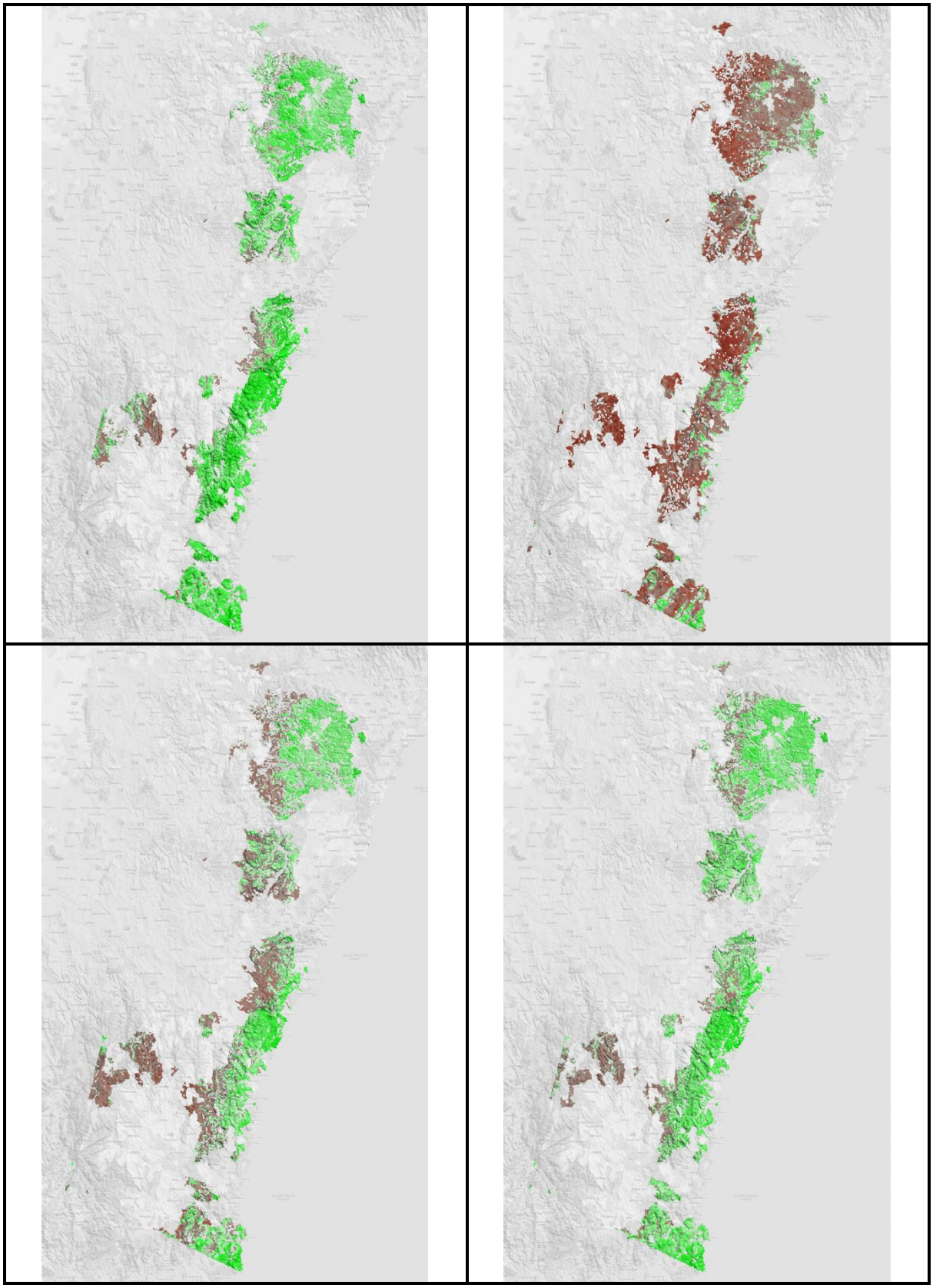
In summary:

- The most useful indices for mapping fire events are NBR, NBR2 and BAI.
- BAI and NBR are most sensitive to fire events.
- NBR2 and BAI are best for evaluating the long-term recovery from a fire event.

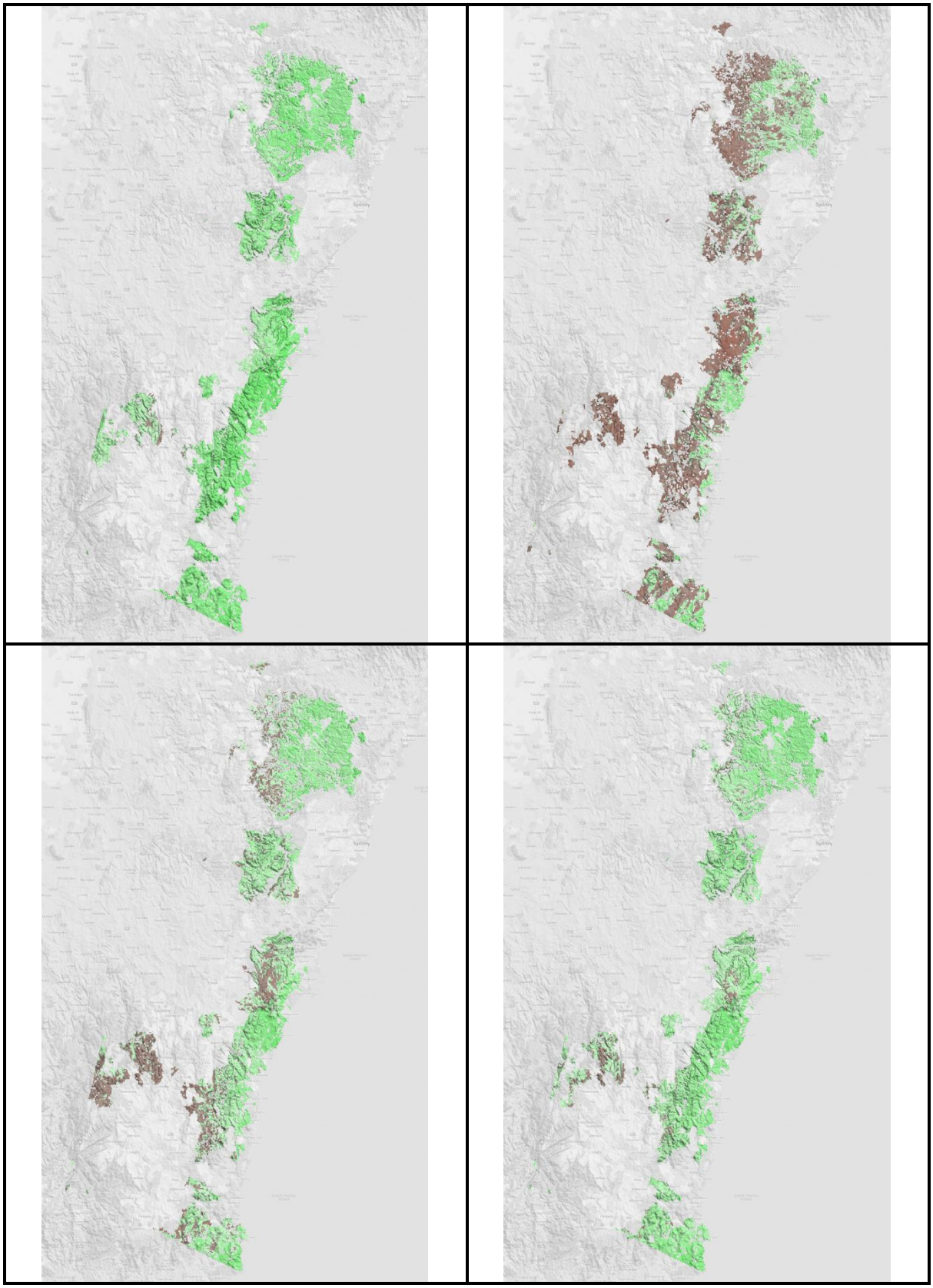
One of the surprising take-aways from this analysis is how quickly the burn signature disappears from the satellite data. Some of these indices, for example NDVI, show no evidence of fire activity within just two years post-fire.

In the following pages of imagery, I present the Index values for the burnt area over the years 2019 (pre-fire), 2020 (immediately post-fire), 2021 (1 year post fire), and 2022 (2 years post-fire). In 2019 the East Coast was experiencing drought conditions, leading up to the fires in 2019-20. However, these weather conditions then changed to record breaking high rainfall in 2021 and 2022. The imagery is draped on terrain and Google Maps as a background.

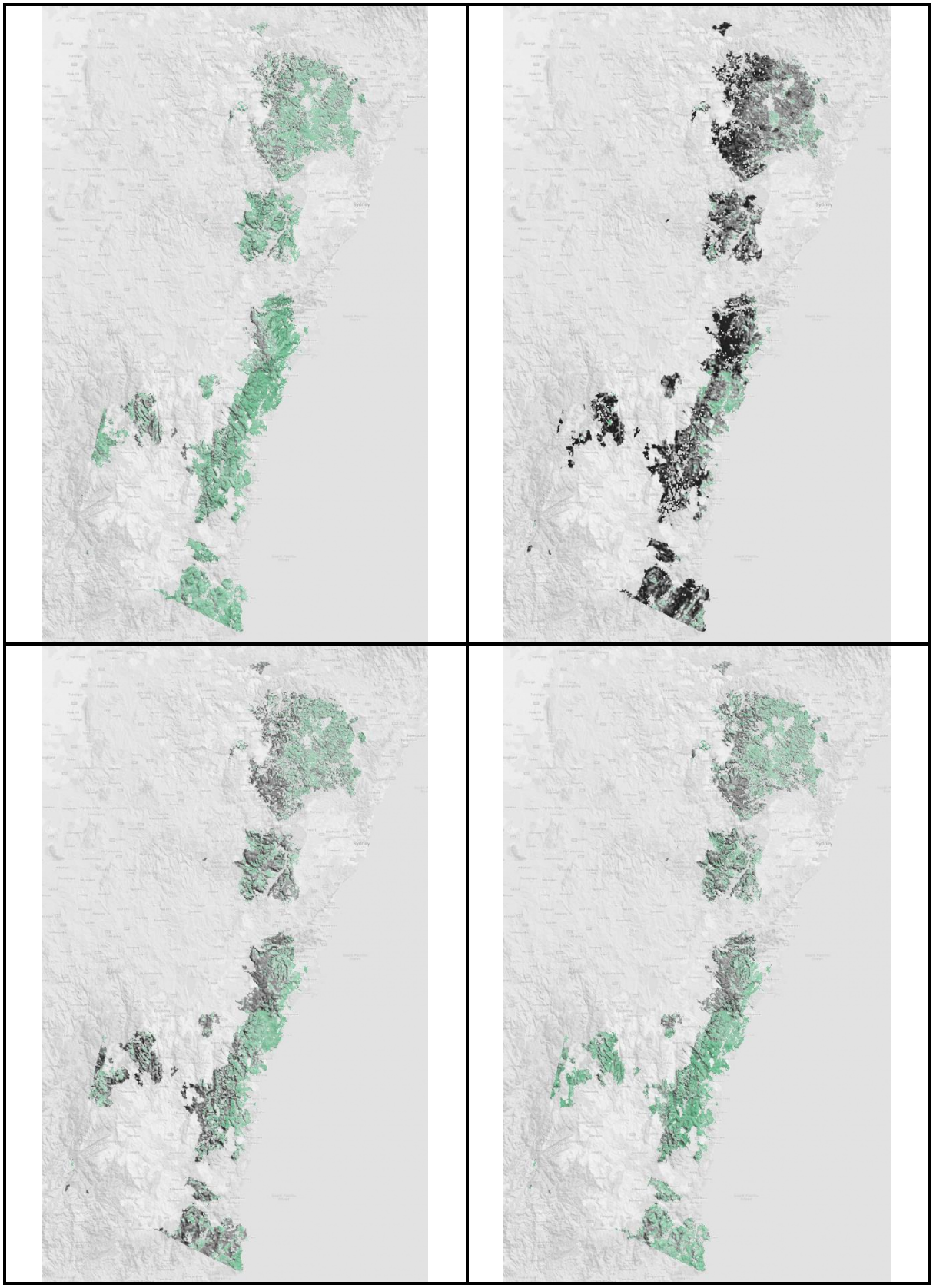
NBR – 2019, 2020, 2021, 2022



NBR2 – 2019, 2020, 2021, 2022



BAI – 2019, 2020, 2021, 2022



NDVI – 2019, 2020, 2021, 2022