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Supplementary Material

Different approaches make comparing studies of burn severity challenging: a review of methods used to link remotely sensed data with the Composite Burn Index

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Supplemental Information 1 for:

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This supplementary information includes:

Supplementary tables S1-S7
Supplementary figures S1-S6
Supplementary references

Table S1. Typical post-fire change in spectral regions and their ecological causes.

Spectral region	Typical change after fire	Ecological cause	Studies
Red	Increases	Decrease in chlorophyll absorption	van Wagtendonk et al. (2004)
Near-infrared	Decreases	Consumption or damage of leaves	Epting et al. (2005), Key and Benson (2006), Miller and Thode (2007), van Wagtendonk et al. (2004)
		Reduction in leaf area index	Chuvieco et al. (2006)
Shortwave Infrared	Increases	Reduction of canopy shadow and moisture	Epting et al. (2005), van Wagtendonk et al. (2004), White et al. (1996)
		Canopy combustion, exposed ash and bare soil, charred large logs	Pereira et al. (1999), van Wagtendonk et al. (2004)
		Drying of vegetation and soil, decreased vegetation density, increased exposed substrate, and presence of charred fuels	Key and Benson (2006), Miller and Thode (2007)
Thermal	Increases	Decrease in transpirational cooling and exposure of lower emissivity soil	Cahoon Jr et al. (1994), García and Caselles (1991), Zheng et al. (2016)

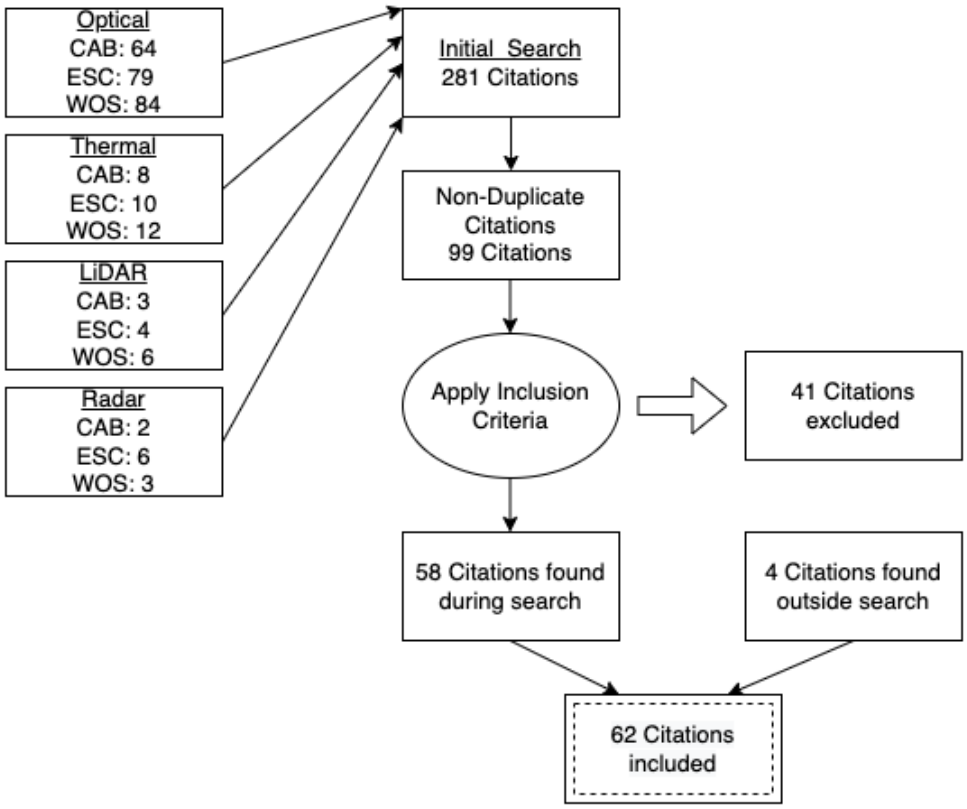

Figure S1. Flow chart showing systematic review process to identify 62 citations to include for review. CAB: CAB Direct; ESC: Environmental Science Collection; WOS: Web of Science.

Table S2. Article-level information extracted from each included citation.

Field	Description and examples
Author(s)	study main authors
Year	year study published
Journal	journal where study published
Lat/Long	study latitude and longitude if provided
Location name	study location name, e.g. western North America
Ecosystem type	studied ecosystem type, e.g. Boreal forest
Sensor used	type of sensor, e.g. TM, ETM+, OLI
TOA or SR	whether top of atmosphere or surface reflectance imagery was used
Indices used	type of spectral indices used, e.g. dNBR, RdNBR
dNBR offset inclusion	whether study indicates offset was used in calculation of spectral indices (dNBR)
Single or bi-temporal imagery	whether single imagery or bitemporal imagery was used
Radiometric normalization	whether bitemporal imagery was radiometrically normalized before index calculation
Georeferencing/co-registration	
Smoothing	type of smoothing, if any, e.g. 3x3 mean, bilinear
Indices	indices used in analysis, e.g. dNBR, RdNBR
Absolute or relativized spectral indices	whether absolute or relativized indices were used
Field plot distribution (UB, L, M, H)	the distribution of field plots across severity classes, if given
Type of model/regression used	type of model/regression used, e.g. linear, quadratic
CBI predictor or response	whether CBI plots were used as a predictor or response variable in statistical analysis
Metric assessed	statistical metrics assessed, e.g. pearson correlation, R2, p
Comparison across strata	CBI strata assessed, e.g. overall, understory, overstory, both

Table S3. Fire-level information extracted from each included citation.

Field	Description and Examples
Fire name(s)	name(s) of fire(s)
Fire location(s)	fire location(s)
Fire date(s)	fire date(s) (month, year if available)
Fire type(s)	fire type(s), e.g. prescribed, wildland, wildland fire use
Fire size(s)	size of the fire(s)
Number of field plots	number of field plots used for each fire
Type of field plots	whether CBI, GeoCBI, or WCBI was used
Field plot size	size of the field plots
Field plot shape	circular or square
Field plot timing	timing of field plot collection (month, year if available)
Unburned field plots	whether unburned field plots were collected (yes/no)

Table S4. Comparison-level information extracted from each included citation.

Field	Description and Examples
Fire name(s)	name(s) of fire(s) studied
Fire location(s)	fire location(s)
Fire date(s)	fire date(s) (month, year if available)
Fire type(s)	fire type(s), e.g. prescribed, wildland, wildland fire use
Fire size(s)	size of the fire(s)
Number of field plots	number of field plots used for each fire
Type of field plots	whether CBI, GeoCBI, or WCBI was used
Field plot size	size of the field plots
Field plot shape	circular or square
Field plot timing	timing of field plot collection (month, year if available)
Pre-fire data	what sensor was used for pre-fire remotely sensed data e.g. TM/ETM+
Pre-fire timing	timing of pre-fire remotely sensed data collection (month, year if available)
Post-fire data	what sensor was used for post-fire remotely sensed data e.g. TM/ETM+
Post-fire timing	timing of post-fire remotely sensed data collection (month, year if available)
Spatial resolution	the spatial resolution of remotely sensed data

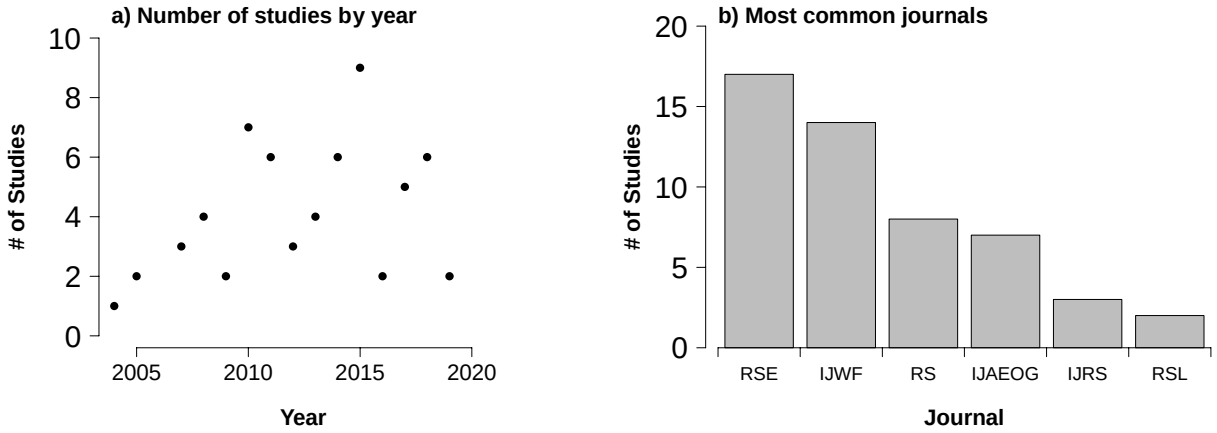

Figure S2. (a) Number of studies relating remotely sensed data to CBI as a continuous measure of burn severity by year (N = 62 studies). (b) Most common journals that published at least two studies in this review. RSE: *Remote Sensing of Environment*; IJWF: *International Journal of Wildland Fire*; RS: Remote Sensing; IJAEOG: *International Journal of Applied Earth Observation and Geoinformation*; IJRS: *International Journal of Remote Sensing*; RSL: *Remote Sensing Letters*. Eleven journals published one citation: *Arctic, Antarctic, and Alpine Research*; *Canadian Journal of Forest Research*; *Ecosphere*; *Environmental Management*; *Fire Ecology*; *Forests*; *GIScience and Remote Sensing*; *Journal of Arid Environments*; *Natural Hazards*; *Photogrammetric Engineering and Remote Sensing*; and *Rangeland Ecology and Management*.

Table S5. Thresholds for severity classification across studies where values were provided.

Unburned	Low	Moderate	High	Studies
0.0-0.29	0.30-1.75	1.76-2.23	2.24-3.0	Boucher et al. (2017)
0-1.04	1.04-1.16	1.16-1.85	1.85-3.0	Chang et al. (2016)
NA	0.00-0.99	1.00-1.99	2.00-3.00	Chen et al. (2011)
Not given				Epting et al. (2005)
0.00-0.09	0.10-1.24	1.25-2.24	2.25-3.00	Fernandez-Manso and Quintano (2015)
0	0-1	1-2	2-3	Karau and Keane (2010)
0-0.1	0.1-1.24	1.25-2.24	2.25-3.0	Karau et al. (2014)
0-0.1	0.1-1.24	1.25-2.24	2.25-3.0	Miller and Thode (2007)
0-0.1	0.1-1.24	1.25-2.24	2.25-3.0	Musyimi et al. (2017)
0.00-0.09	0.10-1.24	1.25-2.24	2.25-3.00	Parker et al. (2015)
NA	□1.25	1.26-2.25	>2.26	Stambaugh et al. (2015)
0	0.1-1.24	1.25-2.24	2.25-3	Quintano et al. (Quintano *et al.* 2015)
0	0< CBI <=1	1<CBI <=2	>2	Tanase et al. (2015a)
0-0.1	0.1-1.24	1.25-2.24	2.25-3.0	Cansler and McKenzie (2012)
0-0.75	0.75-1.25	1.25-1.75; 1.75-2.25	2.25-3	Picotte and Robertson (2011)
<=1.25	<=1.25	1.25<CBI<=2.25	>2.25	Parks et al. (2014)
0	0.1-1.25	1.26-2.25	2.26-3.0	Mallinis et al. (2018)
Unchanged to low 0-1.25	Unchanged to low 0-1.25	1.26-2.25	2.26-3.0	Miller et al. (2009)

Table S6. Remote sensing technologies used in the studies reviewed and the number of studies in which they were included. Sensor refers to the specific instrument used to acquire data. Spectral range is the wavelengths of the electromagnetic spectrum that the sensor samples. Wavelengths is the general regions of the electromagnetic spectrum sampled (VIS: *visible*; NIR: *near infrared*; SWIR: *short wave infrared*; TIR: *thermal infrared*; RGB: *red, green*, blue) Number of bands is the number of raster bands captured over the spectral range. Spatial resolution is the pixel size of remotely sensed imagery. Temporal resolution is the revisit period of the sensor over the same location. Citations used is the number of studies that included the specified sensor.

Sensor	Spectral range (µm)	Wavelengths	Number of bands	Spatial resolution (m)	Temporal resolution (days)	Studies used
TM, ETM+	0.45 – 12.5	VIS, NIR, SWIR, TIR	7	30 (120 TIR)	16	60
OLI/TIRS	0.435 – 12.51	VIS, NIR, SWIR, TIR	10	30 (100 TIR)	16	8
Landsat (unspecified)	--	VIS, NIR, SWIR, TIR	--	--	--	5
AVIRIS	0.4 – 2.5	VIS, NIR, SWIR	224	20	--	4
MASTER	0.457 – 12.878	VIS, NIR, SWIR, TIR	50	5 – 50 (altitude dependent)	--	3
MODIS	Bands 1-19 from 0.405 to 2.155; Bands 20-36 from 3.66 to 14.28	VIS, NIR, SWIR, TIR	36	250 (bands 1-2) 500 (bands 3-7) 1000 (bands 8-36)	16	3
ALOS PALSAR	15 – 30 cm	Radio	--	10 and 100	42	2
Sentinel-2	0.4924 – 2.2024	VIS, NIR, SWIR		10, 20, 60 (band dependent)	10 days each for S2A and S2B (5 days combined)	2
APEX	0.38 – 2.5	VIS, NIR, SWIR	Up to 334 (default 114)	22.5 µm (VNIR) 30 µm (SWIR)	--	1
ASTER	0.52 – 11.65	VIS, NIR, SWIR, TIR	14	15 (VNIR) 30 (SWIR) 90 (TIR)	16	1
Deimos-1	0.52 – 0.90	VIS, NIR	3	22	1 – 3	1
QuickBird	0.45 – 0.90	VIS, NIR	4	2.62 m (nadir) to 2.90 m (20° off-nadir)	1 – 3.5	1
SPOT4	0.50 – 1.75	VIS, NIR, SWIR	4	10 (R) 20 (G, NIR, SWIR)	2 – 3	1
SPOT5	0.49 – 1.7	VIS, NIR, SWIR	4	10 (VNIR) 20 (SWIR)	2 – 3	1
WV-2	0.442 – 1.043	VIS, NIR	8	1.8	1.1 – 3.7	1
WV-3	0.40 – 2.365	VIS, NIR, SWIR	16	1.24 (VNIR) 3.70 (SWIR)	1 – 4.5	1
UAV*	RGB	VIS	3	~ 0.02	--	1

* UAV specifications given for imagery captured in study but platform highly adaptable to other sensors

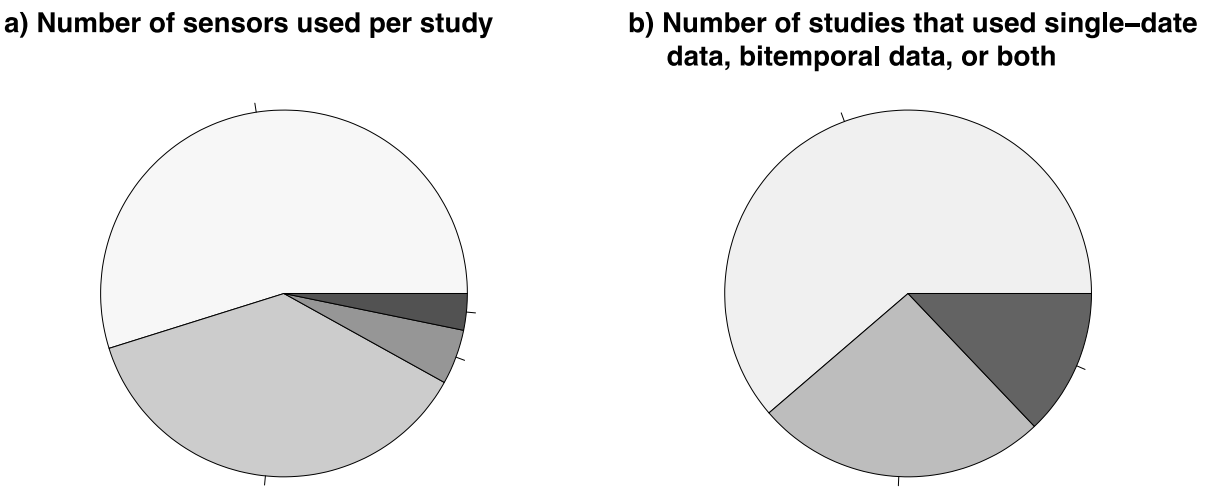

Figure S3. (a) Number of sensors used in each study (N = 62 studies). All Landsat sensors (TM, ETM+, OLI) were combined before analysis. (b) Number of studies that used single-date data, bitemporal data, or both (N = 62 studies). The number of studies for each criteria is shown in parentheses.

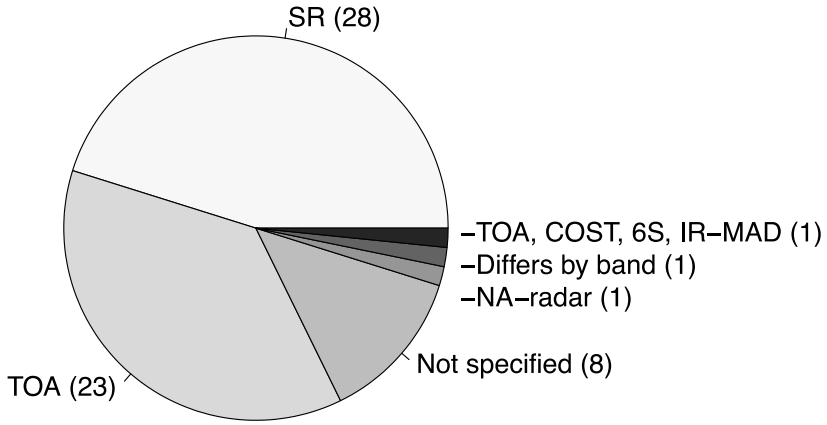

Figure S4. Atmospheric correction methods used by studies (N = 62 studies). The number of studies for each method is shown in parentheses. SR: *surface reflectance*; TOA: *top-of-atmosphere*; COST: *cosine of the solar zenith angle correction*; 6S: *second simulation of the satellite signal in the solar*; IR-MAD: *iteratively re-weighted multivariate alteration detection*.

Table S7. Indices used in studies with abbreviation, temporal and radiometric type, frequency in studies of this review, and key study reference.

Index	Abbreviation	Temporal	Radiometric	Frequency	Key studies
% black or brown trees	%BlorBr	Single	Spectral	1	Vereverbeke and Hook (2013)
Burned area index	BAI	Single	Spectral	1	Chuvieco et al. (2002)
burned fraction	BF/BurnF	Single	Spectral	2	Veraverbeke et al. (2014)
Char fraction	CF/CHAR	Single	Spectral	3	Veraverbeke et al. (2014)
Char soil index	CSI	Single	Spectral	1	Smith et al. (2007)
Enhanced vegetation index	EVI	Single	Spectral	4	Liu and Huete (1995)
green crown veg	GCV	Single	Spectral	1	Fraser et al. (2017)
Global environmental monitoring index	GEMI	Single	Spectral	1	Pinty et al. (1992)
Neighborhood texture	GEOTEX	Single	Spectral	1	Chen et al. (2011)
Green fraction/Green tree fraction	GF/GV/GTF	Single	Spectral	2	Fraser et al. (2017); Tane et al. (2018)
Hue	H	Single	Spectral	1	Koutsias et al. (2000)
Intensity	I	Single	Spectral	1	Koutsias et al. (2000)
Kauth-Thomas Brightness Transform	KTB	Single	Spectral	4	Kauth and Thomas (1976)
Kauth-Thomas Greenness Transform	KTG	Single	Spectral	4	Kauth and Thomas (1976)
Kauth-Thomas Wetness Transform	KTW	Single	Spectral	4	Kauth and Thomas (1976)
	LST/EVI	Single	Spectral	3	Zheng et al. (2016)
Mid-infrared burn index	MIRBI	Single	Spectral	2	Trigg and Flasse (2001)
modified soil-adjusted vegetation index	MSAVI	Single	Spectral	2	Qi et al. (1994)
modified soil-adjusted vegetation index 2	MSAVI2	Single	Spectral	1	Qi et al. (1994)
Normalized burn ratio	NBR	Single	Spectral	19	García and Lopez (1991)
Normalized difference SWIR index	NDSWIR	Single	Spectral	1	Gerard et al. (2003)
Normalized difference vegetation index	NDVI	Single	Spectral	12	Rouse et al. (1974)
Non-photosynthetic fraction of SMA	NPV	Single	Spectral	1	Tane et al. (2018)

Principle component 1	PC1	Single	Spectral	1	Patterson and Yool (1998)
Principle component 2	PC2	Single	Spectral	2	Patterson and Yool (1998)
Principle component 2	PC3	Single	Spectral	1	Patterson and Yool (1998)
Ratio TM band 4 / TM band 5	Ratio 4/5	Single	Spectral	2	Malthus et al. (1993)
Ratio TM band 7 / TM band 4	Ratio 7/4	Single	Spectral	2	Kushla and Ripple (1998)
Ratio TM band 7 / TM band 5	Ratio 7/5	Single	Spectral	2	Epting et al. (2005)
Saturation	S	Single	Spectral	1	Koutsias et al. (2000)
Soil-adjusted vegetation index	SAVI	Single	Spectral	5	Heuete et al. (1988)
SWIR-MIR index	SMI	Single	Spectral	3	Veraverbeke et al. (2012)
Spectral reflectance of individual bands (MODIS)	SR_MODIS	Single	Spectral	1	--
Spectral reflectance of individual bands 1-50 (MASTER)	SR_MASTER	Single	Spectral	1	--
Thematic Mapper band 1 reflectance	TM1	Single	Spectral	4	--
Thematic Mapper band 2 reflectance	TM2	Single	Spectral	4	--
Thematic Mapper band 3 reflectance	TM3	Single	Spectral	4	--
Thematic Mapper band 4 reflectance	TM4	Single	Spectral	6	--
Thematic Mapper band 5 reflectance	TM5	Single	Spectral	6	--
Thematic Mapper band 6 reflectance	TM6	Single	Spectral	1	--
Thematic Mapper band 7 reflectance	TM7	Single	Spectral	5	--
Internal texture	TXIT	Single	Spectral	1	Hultquist et al. (2014)
Vegetation index 3	VI3	Single	Spectral	1	Kaufman and Remer (1994)
Land surface temperature	LST	Single	Thermal	4	Yu et al. (2014)
LSE-enhanced NBR version 1	ENBRv1	Single	Mixed	1	Veraverbeke et al. (2011)
LSE-enhanced NBR version 2	ENBRv2	Single	Mixed	1	Veraverbeke et al. (2011)
LSE-enhanced NDVI version 1	ENDVIv1	Single	Mixed	1	Fernández-Manso and Quintano (2015)
LSE-enhanced NDVI version 2	ENDVIv2	Single	Mixed	1	Fernández-Manso and Quintano (2015)
Ratio of LST to EVI	LST/EVI	Single	Mixed	3	Zheng e tal. (2016)
Normalized difference	NDVIT	Single	Mixed	1	Smith et al. (2007)

vegetaion index - Thermal					
NIR-SWIR-Emmissivity version 1	NSEv1	Single	Mixed	2	Veraverbeke et al. (2011)
NIR-SWIR-emissivity version 2	NSEv2	Single	Spectral	1	Veraverbeke et al. (2011)
Soil adjusted vegetation index - Thermal	SAVIT	Single	Mixed	1	Smith et al. (2007)
pixel and object-based canopy loss	CLobject	Bi-temporal	Spectral	1	Wu et al. (2015)
pixel and object-based canopy loss	CLpixel	Bi-temporal	Spectral	1	Wu et al. (2015)
SWIR1 to NIR ratio difference	d7/4	Bi-temporal	Spectral	1	Kushla and Ripple (1998)
SWIR2 to NIR ratio difference	d7/5	Bi-temporal	Spectral	1	Vogelmann (1990)
Difference in scene components char	dCHAR	Bi-temporal	Spectral	1	Kolden and Rogan (2013)
Chlorophyll index red-edge	dCIre1	Bi-temporal	Spectral	1	Gitelson et al. (2005)
differenced enhanced vegetation index	dEVI	Bi-temporal	Spectral	8	Zheng et al. (2016)
green normalized difference vegetation index	dGNDVI	Bi-temporal	Spectral	1	Mallinis et al. (2018)
Change in GV fraction	dGV	Bi-temporal	Spectral	1	Kolden and Rogan (2013)
differenced integrated forest index	dIFI	Bi-temporal	Spectral	1	Huang et al. (2008)
Differenced tassled-cap brightness	dKTB	Bi-temporal	Spectral	2	Meddens et al. (2016); McCarley et al. (2017)
Differenced tassled-cap greenness	dKTG	Bi-temporal	Spectral	2	Meddens et al. (2016); McCarley et al. (2017)
Differenced tassled-cap wetness	dKTW	Bi-temporal	Spectral	2	Meddens et al. (2016); McCarley et al. (2017)
Modified simple ratio red-edge	dMSRre1	Bi-temporal	Spectral	1	Datt (1999)
Modified simple ratio red-edge narrow	dMSRre1n	Bi-temporal	Spectral	1	Datt (1999)
differenced normalized burn index	dNBR	Bi-temporal	Spectral	50	Key and Benson (2006)
differenced normalized burn ratio narrow	dNBRn	Bi-temporal	Spectral	1	Mallinis et al. (2018)

differenced normalized difference moisture index	dNDMI	Bi-temporal	Spectral	3	Meddens et al. (2016); McCarley et al. (2017)
Normalized difference SWIR index	dNDSWIR	Bi-temporal	Spectral	1	Gerard et al. (2003)
differenced normalized difference vegetation index	dNDVI	Bi-temporal	Spectral	18	Xiao et al. (2002)
normalized difference vegetation index red edge1	dNDVIre1	Bi-temporal	Spectral	1	Gitelson and Merzlyak (1994)
normalized difference vegetation index red edge1 narrow	dNDVIre1n	Bi-temporal	Spectral	1	Gitelson and Merzlyak (1994)
Change in NPV fraction	dNPV	Bi-temporal	Spectral	1	Kolden and Rogan (2013)
differences of pixel to pixel in each band (TM1-7)	dSR	Bi-temporal	Spectral	1	McCarley et al. (2017)
ratios of pixel to pixel in each band	image ratioing	Bi-temporal	Spectral	1	Nelson (1983)
differenced LST	dLST	Bi-temporal	Thermal	3	García-Llamas et al. (2019)
Differenced ratio of LST to EVI	d(LST/EVI)	Bi-temporal	Mixed	2	Zheng et al. (2016)
Radar Burn Ratio	Radar Burn Ratio (RBR)	Bi-temporal ratio	Radar	2	Tanase et al. (2015b)
Relative burn ratio	RBR	Relativized	Spectral	7	Parks et al. (2014)
Relative differenced normalized burn ratio	RdNBR	Relativized	Spectral	25	Miller and Thode (2007)
Relativized differenced normalized differenced moisture index	RdNDMI	Relativized	Spectral	1	Veraverbeke et al. (2011)
Relativized differenced normalized differenced vegetation index	RdNDVI	Relativized	Spectral	1	Veraverbeke et al. (2011)

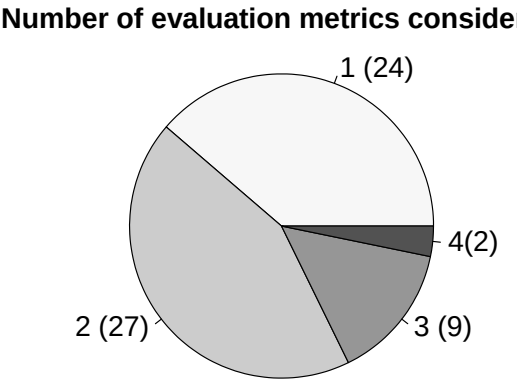

Figure S5. Number of evaluation metrics considered by each study (N = 62 studies). The number of studies that used each number of metrics is shown in parentheses.

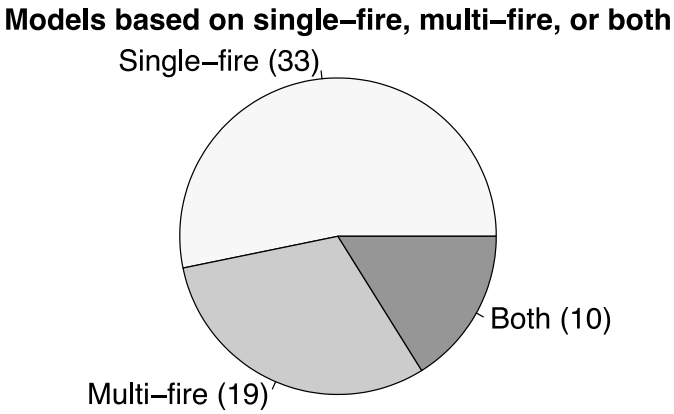

Figure S6. Use of models based on a single-fire, multiple fires or combination (N = 62 studies). The number of studies that used each type of model is shown in parentheses.

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Supplemental Information 2 for:

Different approaches make comparing studies of burn severity challenging: a review of methods used to link remotely sensed data with the Composite Burn Index

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International Journal of Wildland Fire

This supplementary information includes:

Citations included in this study for review as well as the number of comparisons of field observations and remotely sensed data extracted for analysis. Further information regarding the data that support this study will be shared upon reasonable request to the corresponding author.

Citation	Number of comparisons
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