



1	Supplementary Materials: The following are available online at <u>www.mdpi.com/link</u>
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3	Detecting drought-induced tree mortality in Sierra Nevada forests
4	with time series of satellite data
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9	MODIS Time Series Processing:
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25	The QA/QC process was informed by the MODIS Land Products Quality Assurance Tutorial. We determined VI quality for each pixel based on the quality of each band used to calculate the VI (e.g. red and near-infrared for NDVI). The MCD43A2 BRDF Albedo Band Quality product provides a 32-bit unsigned integer for each pixel, whose values represent the quality of the 7 bands. We parsed these values and flagged pixels with reflectance bands with less than "good" quality. We retained only pixels with good quality or better for each VI and removed low quality VI values from the calculation of the health metrics. The smoothing and filtering process was only applied if a VI time series had at least 158 quality data points and is illustrated by Figure S5. Polynomial interpolation is first applied, and then remaining gaps are filled in with linear interpolated time series. We prioritized higher VI values at each date, as natural occurrences that lower the quality of MODIS data (e.g. clouds, aerosols) will result in an underestimate of VI values. A final Savitzky-Golay filter is applied to this time series to reduce the amount of fluctuation in the time series curve. We used the values in this curve to calculate our VI health metrics.
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Table S1. Total flown areas during each annual Aerial Detection Survey (ADS) from 2011 – 2016. The total
areas of observed tree mortality from polygons with TPA > 1 are also reported for each year in both total
acres and a percentage of the flown area.

Survey Year	2001	2012	2013	2014	2015	2016
Flown Area (acres)	7,122,734	7,259,008	7,936,384	6,892,168	6,510,826	7,880,107
Observed Tree Mortality Area (acres)	69,272	44,948	85,019	139,383	1,216,497	1,589,207
Proportion Observed Mortality (%)	0.97	0.62	1.07	2.02	18.68	20.17

Table S2. Confusion matrix for the one-stage CRF based on the validation data.

Predicted Mortality	Reference Mortality				Consumer's Accuracy (%)	Comission Error (%)
	Background	Low	High	Severe		
Background	414044	8121	7519	4220	95.4	4.6
Low	201	1274	110	84	76.3	23.7
High	687	221	2884	431	68.3	31.7
Severe	449	161	422	2339	69.4	30.6
Producer's Accuracy (%)	99.7	13.0	26.4	33.0		
Omission Error (%)	0.3	87.0	73.6	67.0		
Overall Accuracy (%)	94.9					

Table S3. Confusion matrix for the one-stage CRF based on the 2016 map data.

Predicted Mortality	Reference Mortality				Consumer's Accuracy (%)	Comission Error (%)
, ,	Background	Low	High	Severe		
Background	347855	3357	4036	3290	97.0	3.0
Low	88	10506	81	76	97.7	2.3
High	466	173	17207	405	94.3	5.7
Severe	363	144	401	16048	94.6	5.6
Producer's Accuracy (%)	99.7	74.1	79.2	81.0		
Omission Error (%)	0.3	25.9	20.8	19.0		
Overall Accuracy (%)	96.8					
Area Weighted Overall Accuracy (%)	96.7					



Figure S1. Expanding tree mortality (red) within ADS flight extents (yellow) over time as the drought progressed from 2011 to 2016. Total flown acres and observed mortality acres from the ADS are reported for each year.



Figure S2. Distribution of tree mortality polygon sizes from the Aerial Detection Survey (ADS) dataset during 2011- 2016. The median polygon size is marked by the central horizontal black line, and mean size is marked by the blue dashed line. The lower and upper boundaries of each box mark the first and third quantile of the polygon size distribution, respectively.



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Figure S3. Cumulative areas in acres (top) and numbers (bottom) of observed mortality polygons
dominated by various host tree species based on annual Aerial Detection Survey .



Figure S4. Cumulative areas in acres (top) and number of polygons (bottom) of tree mortality polygons
by various mortality agents based on annual Aerial Detection Survey during 2011 - 2016.





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Figure S5. NDVI time series displaying the QA/QC and smoothing process. (a) Raw data points in red with high quality data points in blue. (b) The quality data time series in black after applying data interpolation and a Savitzky-Golay filter to the quality time series in blue. (c) Comparing the final time series product in black to the raw and unfiltered time series.





Trend in Summer NDWI (2012 - 2016)

0.02

0.01

0.00

₽ -0.01 ₽ -0.02

-0.02

-0.03

-0.04

-0.05

Background





Trend in Summer NDVI (2012 - 2016)

Summer NDVI Z-score



TPA Class

High

Severe

Low



Summer EVI Z-score















High

TPA Class

Severe

Background

Low

80 81

Figure S6 (cont.). Boxplots showing regional statistics of individual variables summarized over each mortality class based on the ADS records, similar to those in Figure 5.

- 83 84
- 85
- 86
- 87
- 88
- 89
- 90



Figure S7. Mapped 2016 tree mortality classes from the Reference ADS layer **(left)**, with model classification differences from the two-stage CRF **(middle)** and one-stage CRF **(right)** across the whole study region and within two zoomed extents. The difference maps show where the CRF models underestimate the tree mortality class in red, overestimate the tree mortality class in blue, and agree with the classified reference mortality map in tan.



between model estimates from the two-stage RRF (middle) and one-stage RRF (right) and the reference data across the whole study region and within two zoomed extents. The difference maps show where the RRF models underestimate the number of dead trees per acre in red, overestimate the number of dead trees per acre in blue, and agree with the reference mortality map in tan.