



Ngorongoro WHS Conservation Area

Analysis of Vegetation Health as Indicator of Environmental Change
Using Landsat 7 ETM+ and Landsat 8 OLI,
with preliminary Sentinel-2 MSI data

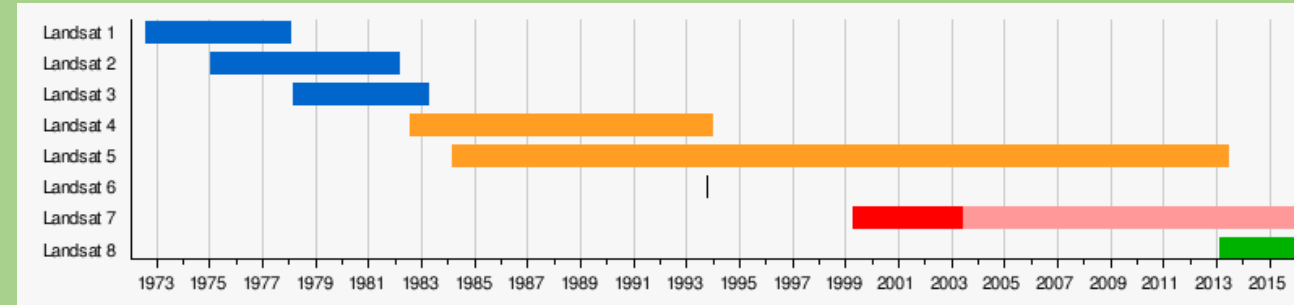
Douglas C. Comer, Ph.D., President, CSRM Foundation, President, US/ICOMOS
Joe Mazzariello, CSRM Foundation

1 November 2018
Huangshan Dialogue
Huangshan, China



Analyses presented here:

- *Normalized Difference Vegetation Index (NDVI)* — a measure of vegetation health. Most of this presentation deals with NDVI
- Making use of mature technology
 - Drawing upon
 - The historical record it provides
 - Temporal resolution
 - Landsat has been in use since 1972
 - We are interested in temporal resolution more than spatial resolution for this application
 - Utility depends upon **field verification**, matching NDVI results with **climatic records**, **demographic studies**, **consultation with subject matter experts**, a relationship with the Ngorongoro Conservation Area Authority (NCAA).



Landsat series launched 1972
Same year as World Heritage Convention ratified.

Precipitation: The NASA Integrated Multi-Satellite Retrievals for GPM (*IMERG*)

Population: Various, UNDP, NASA SEDAC POPGRID



What does NDVI tell us?

- Vegetation — health and vigor of vegetation, in some cases, type or general type of vegetation.
- Standing water — Locations of lakes, ponds, streams, rivers, etc.

The sensors used

Landsat 7: Enhanced Thematic Mapper Plus (ETM+)

- Temporal resolution: 16 days
- Spatial resolution: 30m
- Level-2 Surface Reflectance (BOA) products downloaded from USGS EarthExplorer

Landsat 8: Operational Land Imager (OLI)

- Temporal resolution: 16 days
- Spatial resolution: 60m
- Level-2 Surface Reflectance (BOA) products downloaded from USGS EarthExplorer

Sentinel-2A MultiSpectral Instrument

- Temporal resolution: 10 days
- Spatial resolution:
Bands 2-4, 8: 10m
Bands 5-7, 8a, 11, 12: 20m
Bands 1, 9, 10: 60m
- Surface Reflectance (BOA) products created using ESA Sen2Cor tool on our end



Overview of the Ngorongoro Conservation Area, plus the Surrounding Region





Background Image Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Craters



World Heritage Site Boundaries



Landsat Study Area



Paper maps provided by
Prof. Charles Musiba
University of Colorado, Denver



New map of

NGORONGORO

Conservation Area

The first original artwork was entirely hand-drawn • First Edition: 1996 • Adjuncted in 1999 and updated in 2003.
Copyrights © 1996 and 2003 by Giovanni Tombazzi (Author and Editor) • All Rights Reserved.
For suggestions or comments please contact the Author: E-mail: info@ngorongoro.com, web: www.ngorongoro.com.
Published in 2003 by MACO EDITIONS LLC • Printed in Italy • To Anita and Savanna.

0 2 4 6 8 10 12 14 16 18 20 km
Mercator Projection • Scale 1:250,000 • 1 cm on the map = 2.5 km in nature.
The reproduction of this map by any means, in whole or in part, is prohibited without the prior permission of the Author.
All distances in kilometers and all elevations in meters.



Basic land cover, roads, and
boma locations as of 2003



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NDVI

$$NDVI = (Near\ Infrared\ Band - Red\ Band) / (Near\ Infrared\ Band + Red\ Band),$$

to assess vegetative health and classify vegetative cover within and around the NCA.

The equation creates values generally ranging from 1 to -1:

- Values from 0.8 to 0.3 typically represent healthy vegetation (0.8 to 0.6 typically represents **forest cover**)
- Values from 0.3 to 0.2 represent **shrub and grassland**
- Values between 0.2 and 0.1 typically represent **bare soils**
- Values around 0.1 and below represent **rock, sand, or snow**
- Values under 0 are typically **standing water** and/or clouds

(See Weier and Herring 2000 for more:
<https://earthobservatory.nasa.gov/Features/MeasuringVegetation/>)



Satellites Used

For this series of slides, we used

- Landsat 8 Operational Land Imager (L8 OLI) and
- Landsat 7 Enhanced Thematic Mapper Plus (L7 ETM+)
- Sentinel-2 (one image)

to create NDVI images to assess vegetative health in and around Ngorongoro Conservation Area (NCA) during **2002 and 2017**.



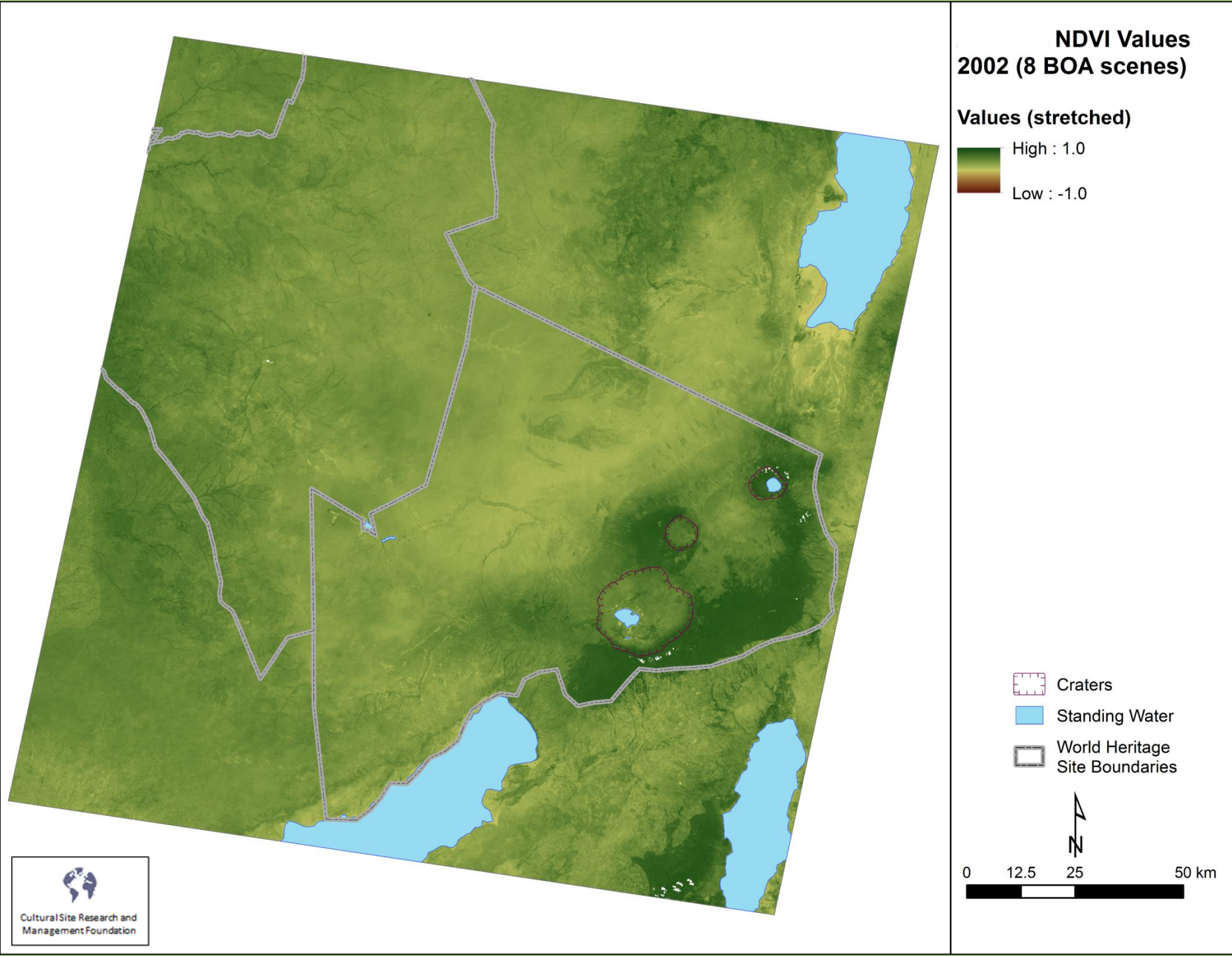
Methodology

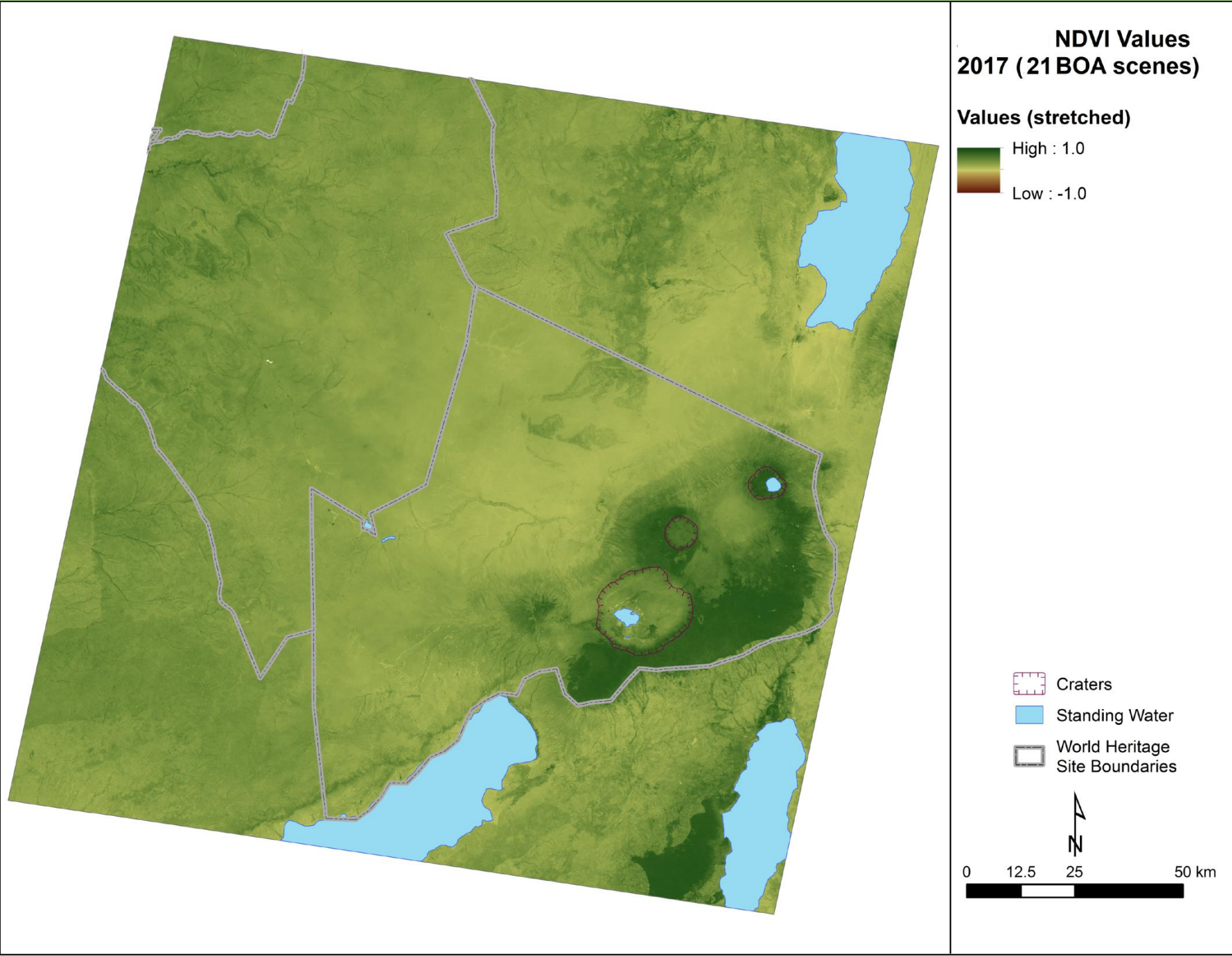
1. Download free and publicly available image scenes from USGS EarthExplorer (<https://earthexplorer.usgs.gov/>)
 - Eight Level-2 L7 ETM+ scenes were available for 2002
 - 21 L8 Level-2 OLI scenes were available for 2017
 - One S2A image from 2017
 - *All imagery is converted to surface reflectance (i.e., bottom of atmosphere, or BOA) values
2. Calculate NDVI
3. Remove cloud cover using Quality Assessment files in ArcMap/QGIS
4. Stack and calculate NDVI pixel statistics
 - Mean (μ)
 - Standard Deviation (σ)
 - Variance (σ^2)
 - Coefficient of Variance (σ/μ)



Overview of NDVI Scenes







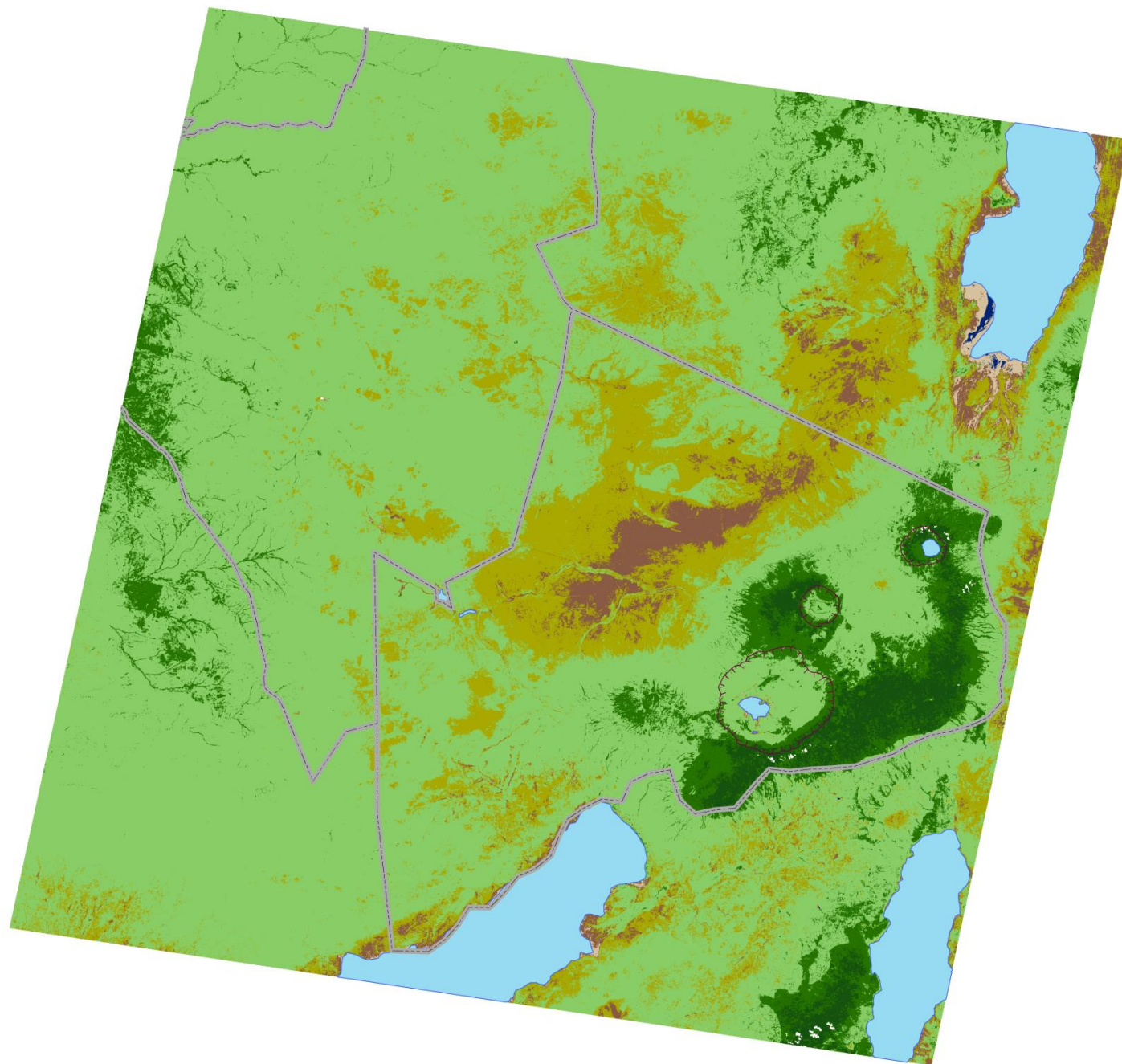
Vegetative cover Change Over 15 Years

Estimated classification of types of vegetation

Based on calculated NDVI values

2002 and 2017

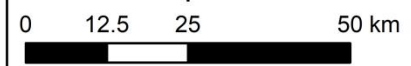




NDVI Values 2002: Classified Tiers

- Dense Forest (1.0 to 0.8)
- Forest (0.8 to 0.6)
- Savanna, small trees, and other foliage (0.6 to 0.3)
- Sparser grassland and shrubs (0.3 to 0.2)
- Very sparse vegetation and soils (0.2 to 0.1)
- Barren landscape (0.1 to ~0)
- Standing water (~0 to -1.0)

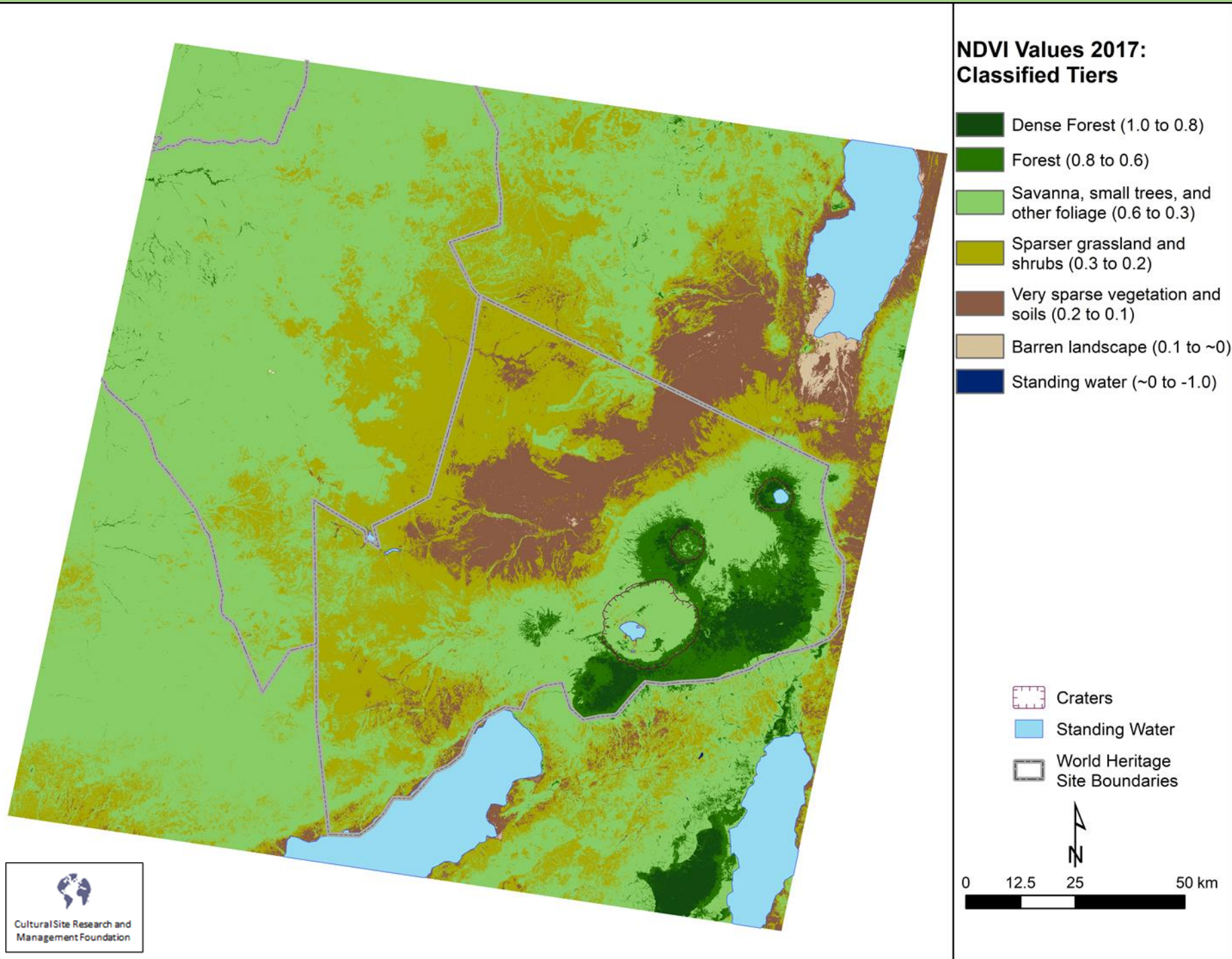
- Craters
- Standing Water
- World Heritage Site Boundaries



Less dense forest

Much more

- Sparse grassland
- Very sparse
- Vegetation
- Barren landscape



Change Detection

Percent Change:

Three five-year intervals between 2002 and 2017 (Top of Atmosphere, TOA, data)

Updated Percent Change: 15-year interval from 2002 to 2017 (BOA data)



We used a percent change algorithm to derive a simple measure of how the vegetation changed between each period:

$$(\text{NDVI}_{\text{year2}} - \text{NDVI}_{\text{year1}}) / |\text{NDVI}_{\text{year1}}|$$

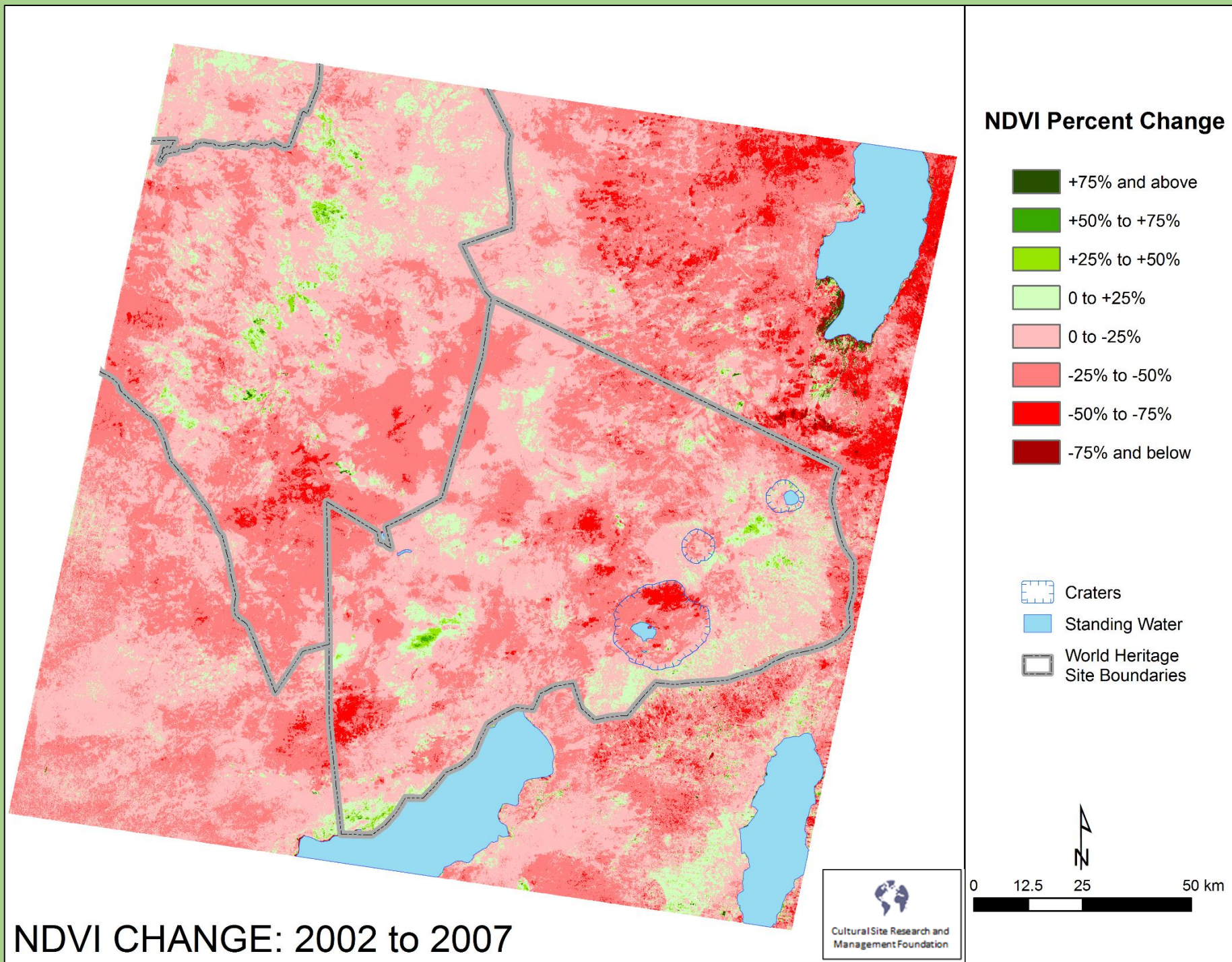
The following slides show a preliminary change detection at five-year intervals between 2002 and 2017 using five* top of atmosphere reflectance scenes per year (2002, 2007, 2012, and 2017). These are then followed by an overall trend between 2002 and 2017.

Note the difference between the overall trend and the five-year interval trends.

*These were five scenes with the least amount of cloud cover per year, which was typically less than 10% or 20%.



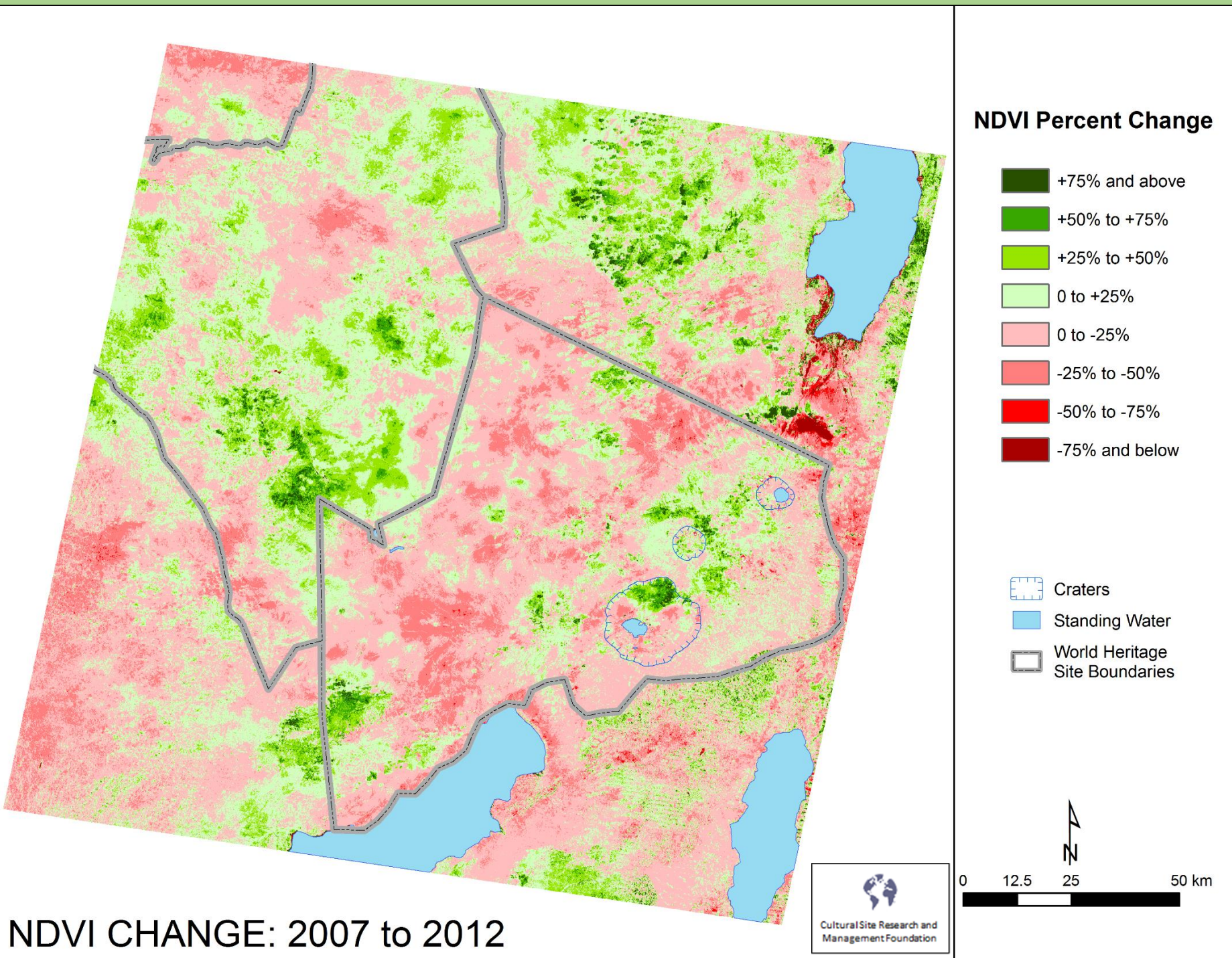
Drastic
reduction in
overall
vegetative
health



*Note: there was a significant drought during 2011-2012

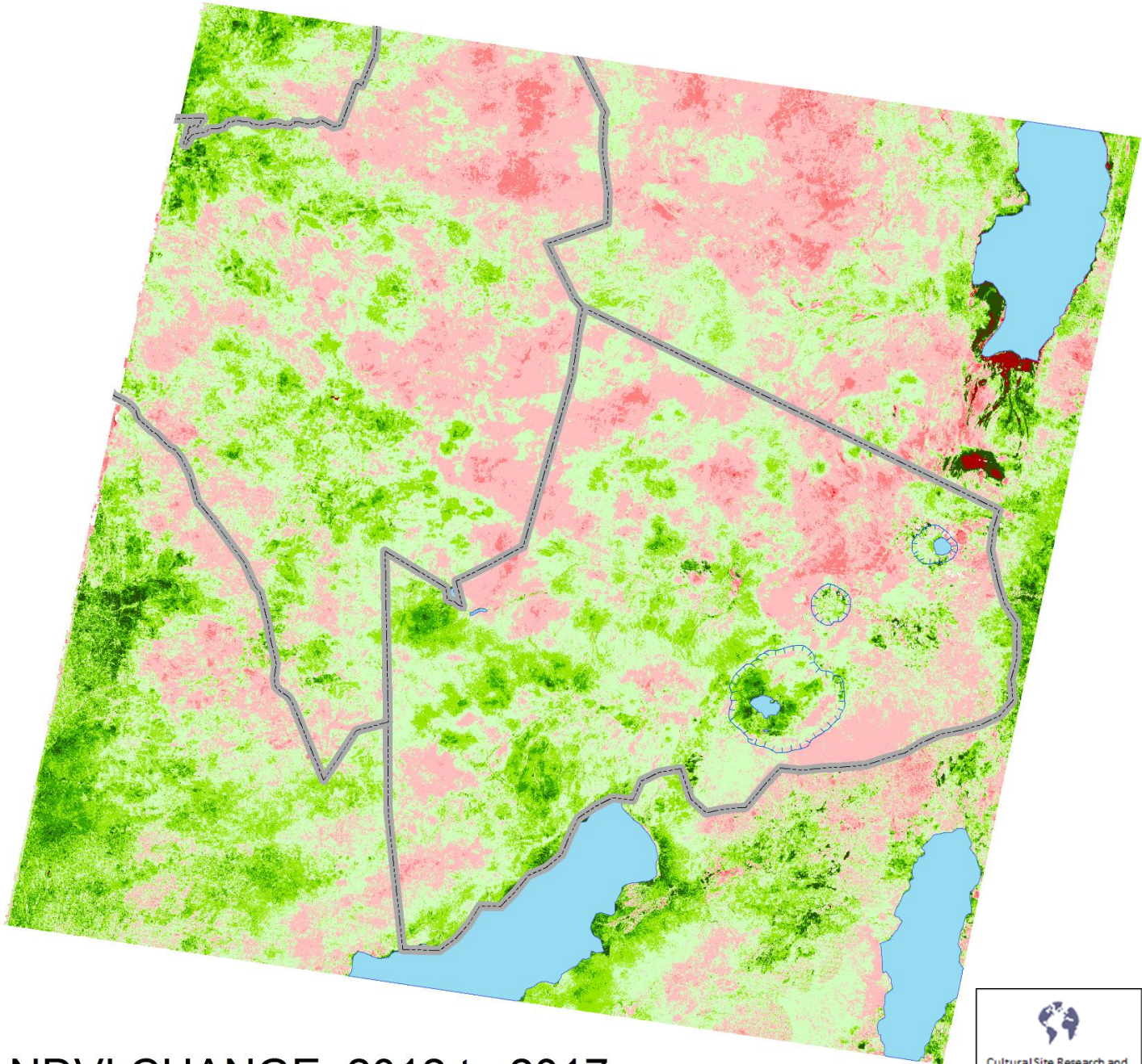
Recovery in some areas despite 2011-2012 drought

Further reduction in vegetative health elsewhere



*Note: there was a significant drought during 2011-2012

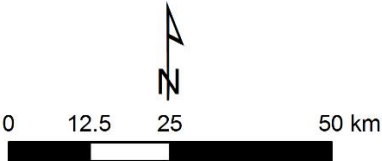
More widespread recovery, possibly from 2011-2012 drought



NDVI Percent Change

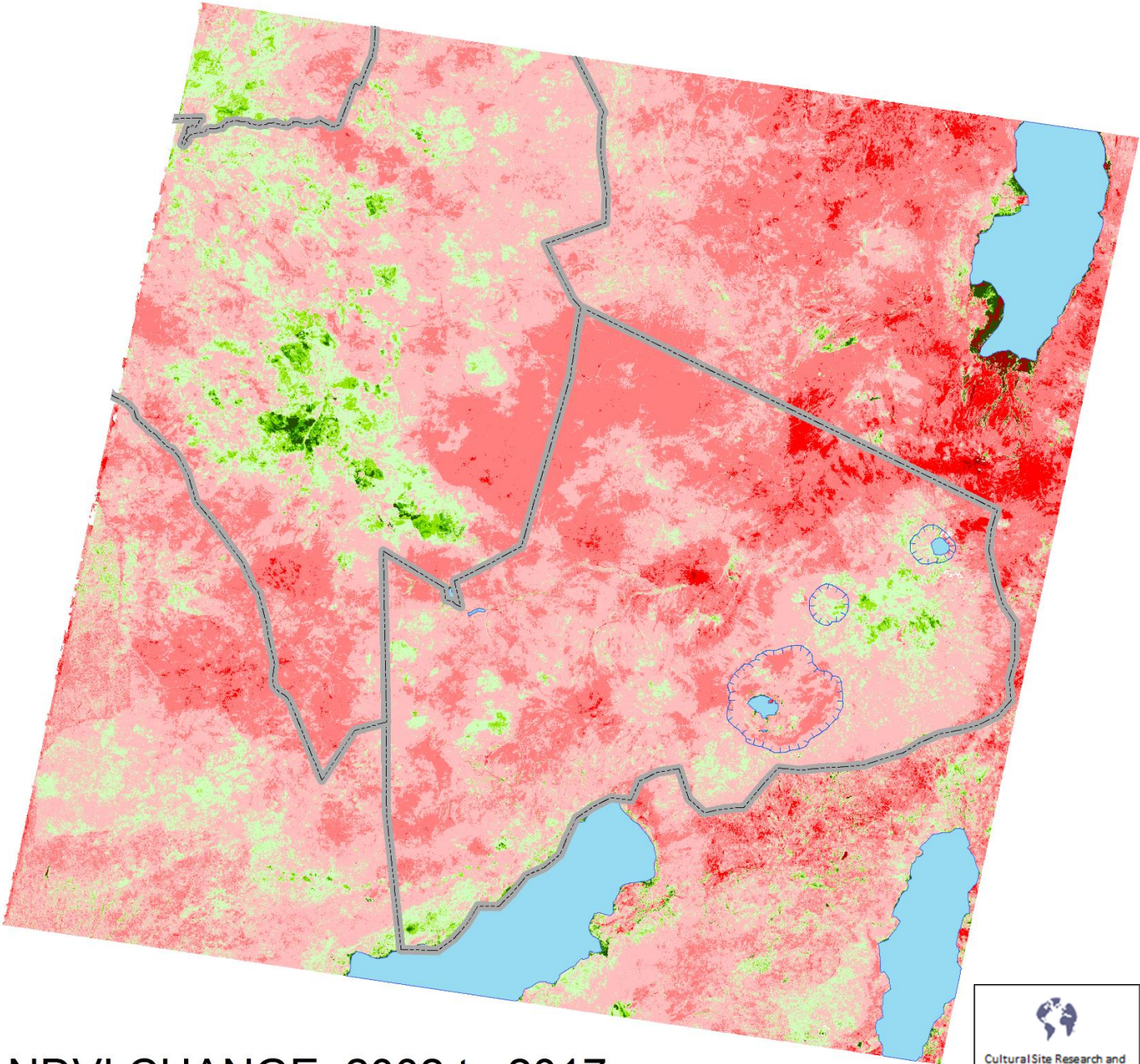
- +75% and above
- +50% to +75%
- +25% to +50%
- 0 to +25%
- 0 to -25%
- 25% to -50%
- 50% to -75%
- 75% and below

- Craters
- Standing Water
- World Heritage Site Boundaries



NDVI CHANGE: 2012 to 2017

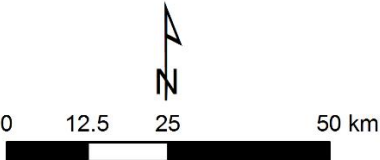
Overall
reduction in
vegetative
health over 15
years



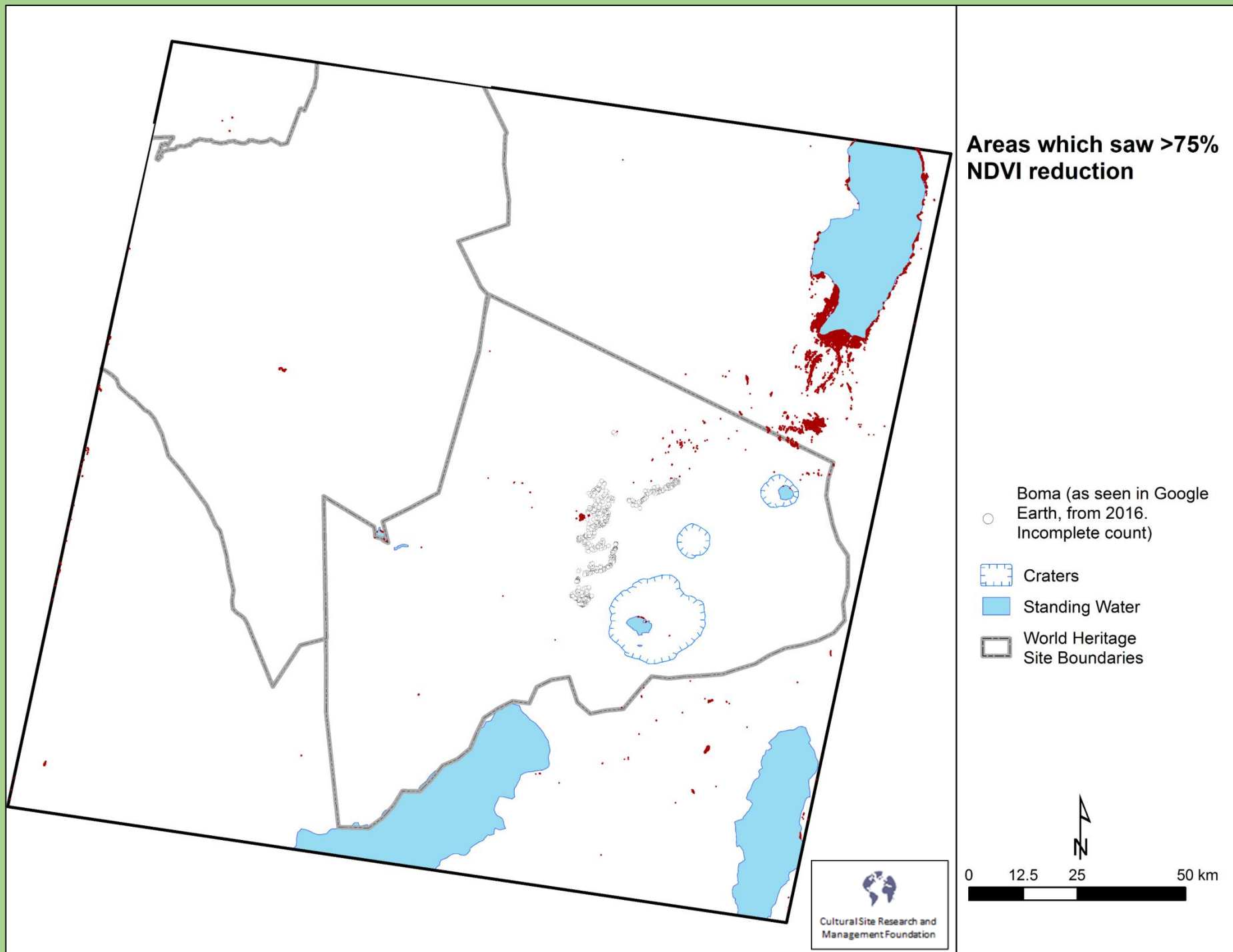
NDVI Percent Change

- +75% and above
- +50% to +75%
- +25% to +50%
- 0 to +25%
- 0 to -25%
- 25% to -50%
- 50% to -75%
- 75% and below

- Craters
- Standing Water
- World Heritage Site Boundaries



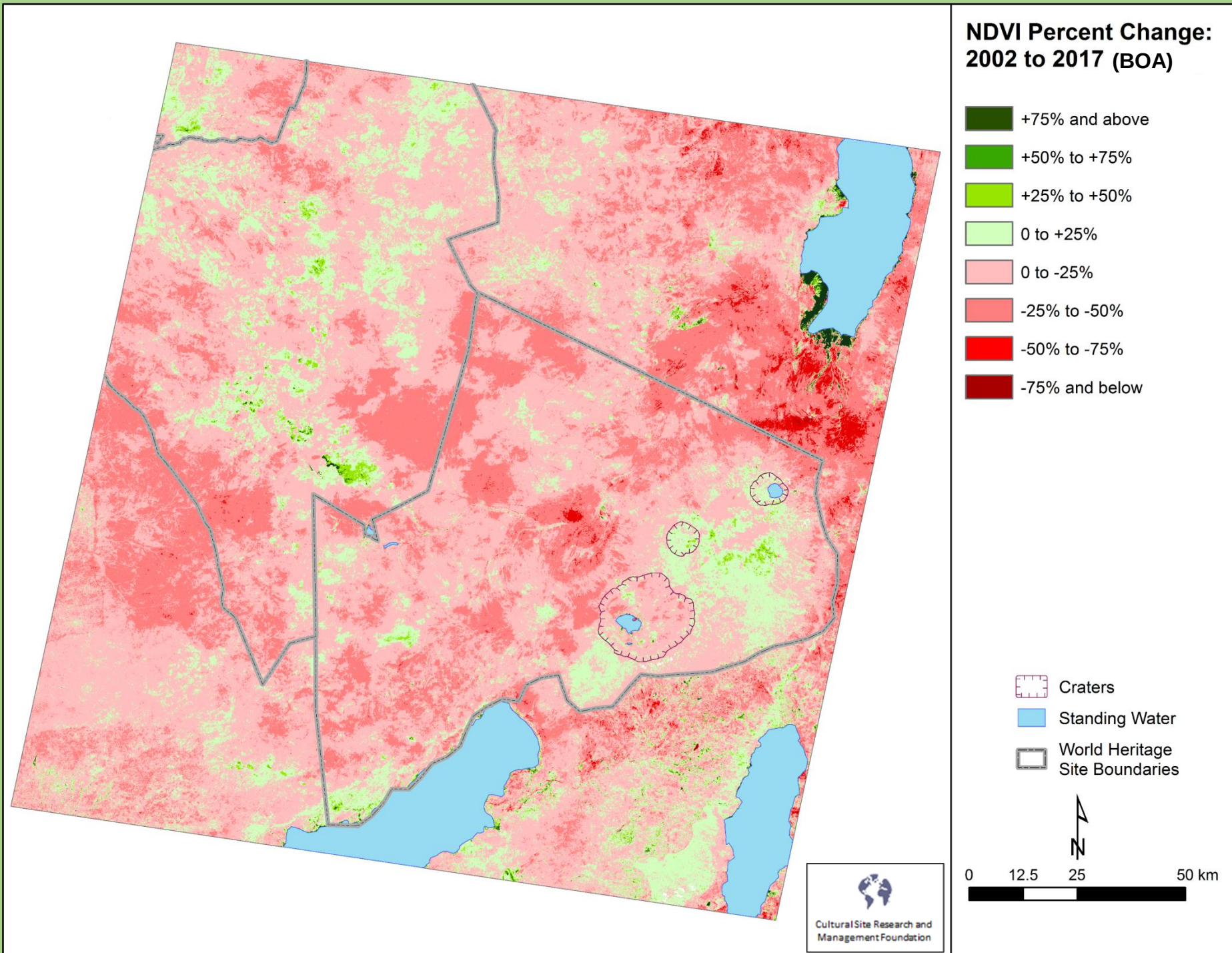
NDVI CHANGE: 2002 to 2017



The next scenes are level-2 surface reflectance (BOA) products that include all available scenes* from 2002 and 2017. These slides better account for seasonal changes within and between years. Please note the differences in results with the TOA products above. 2007 and 2012 data is forthcoming.

*Clouds were masked from each scene using the Landsat band quality assessment files, which classifies cloud and cloud shadow cover. Pixels with identified cloud or cloud shadow values were excluded from the algorithm used to make the yearly NDVI images.





NDVI Percent Change: 2002 to 2017 (BOA)

 -50% to -75%

 -75% and below

 Boma (as seen in Google
Earth, from 2016.
Incomplete Count)

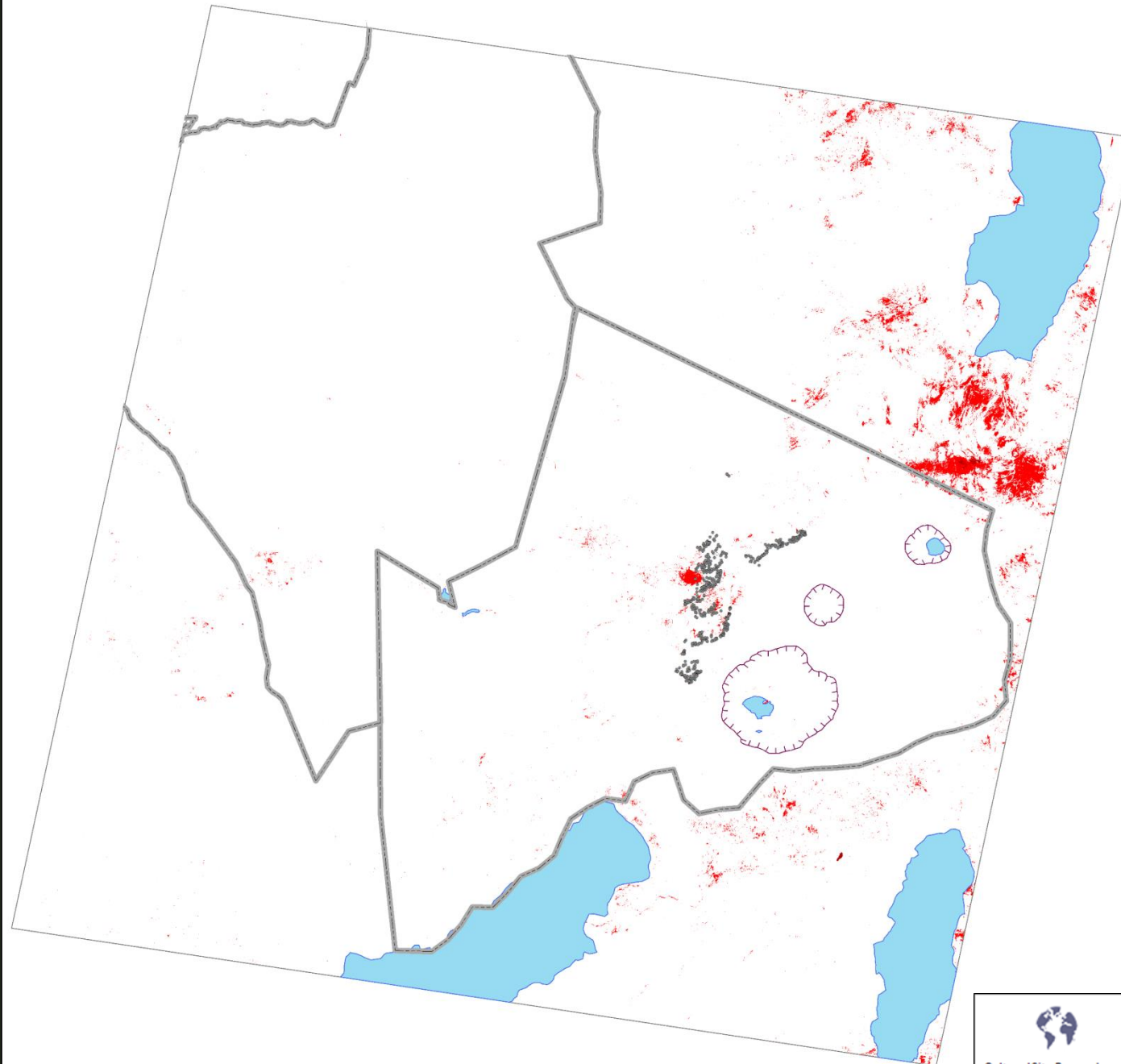
 Craters

 Standing Water

 World Heritage
Site Boundaries



0 12.5 25 50 km



Vegetative cover class change maps

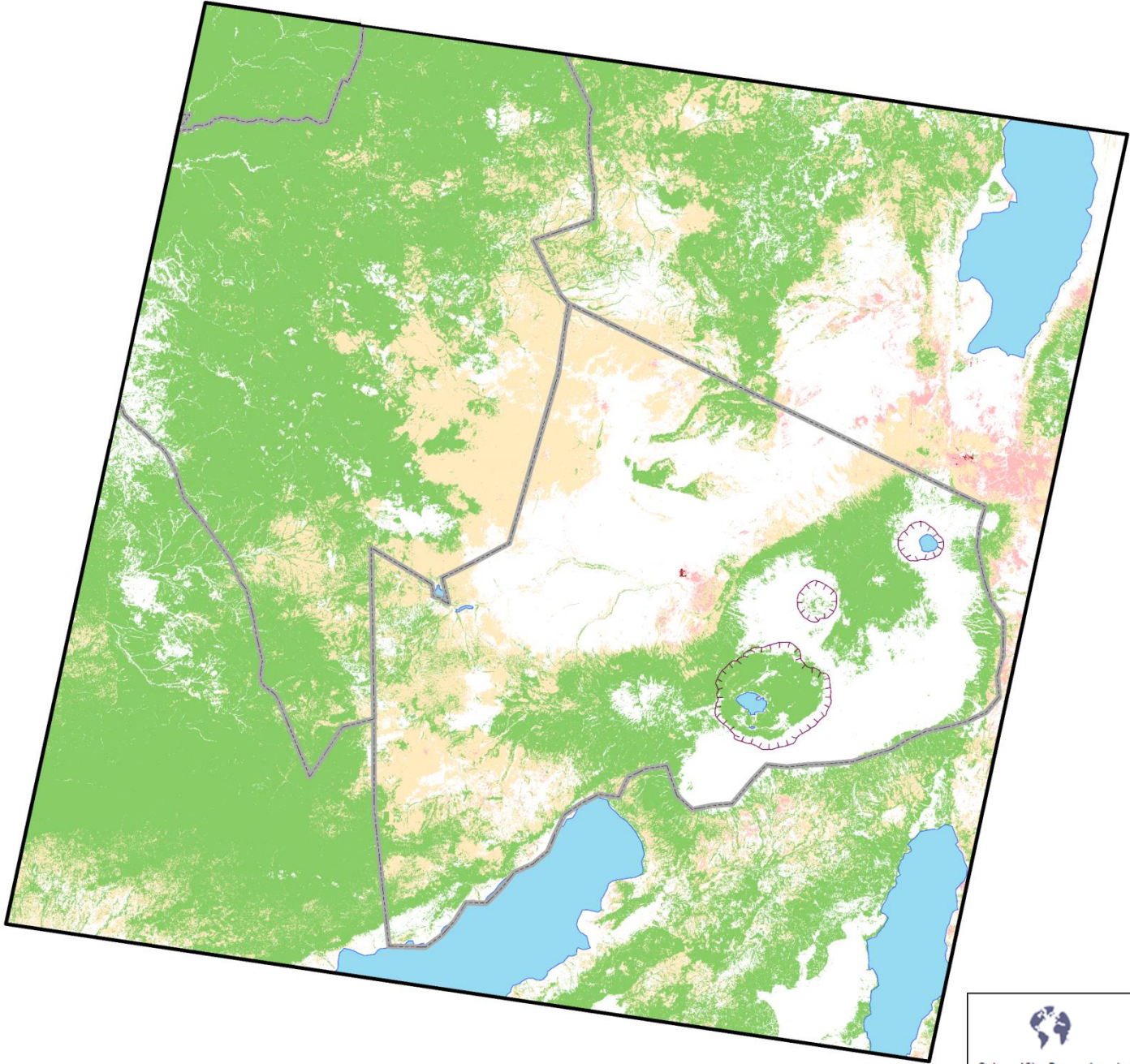
Estimated change in vegetative classification between 2002 and 2017

The following maps show where and what types of vegetative change occurred according to changes in NDVI values



Savanna
change

2002 to 2017



**Estimated changes in
savanna, etc. (NDVI
value 0.6 to 0.3)**

- Stable
- Change to sparser
grass/shrub
- Change to very sparse
foliage or soil
- Change to barren
landscape
- Change to water

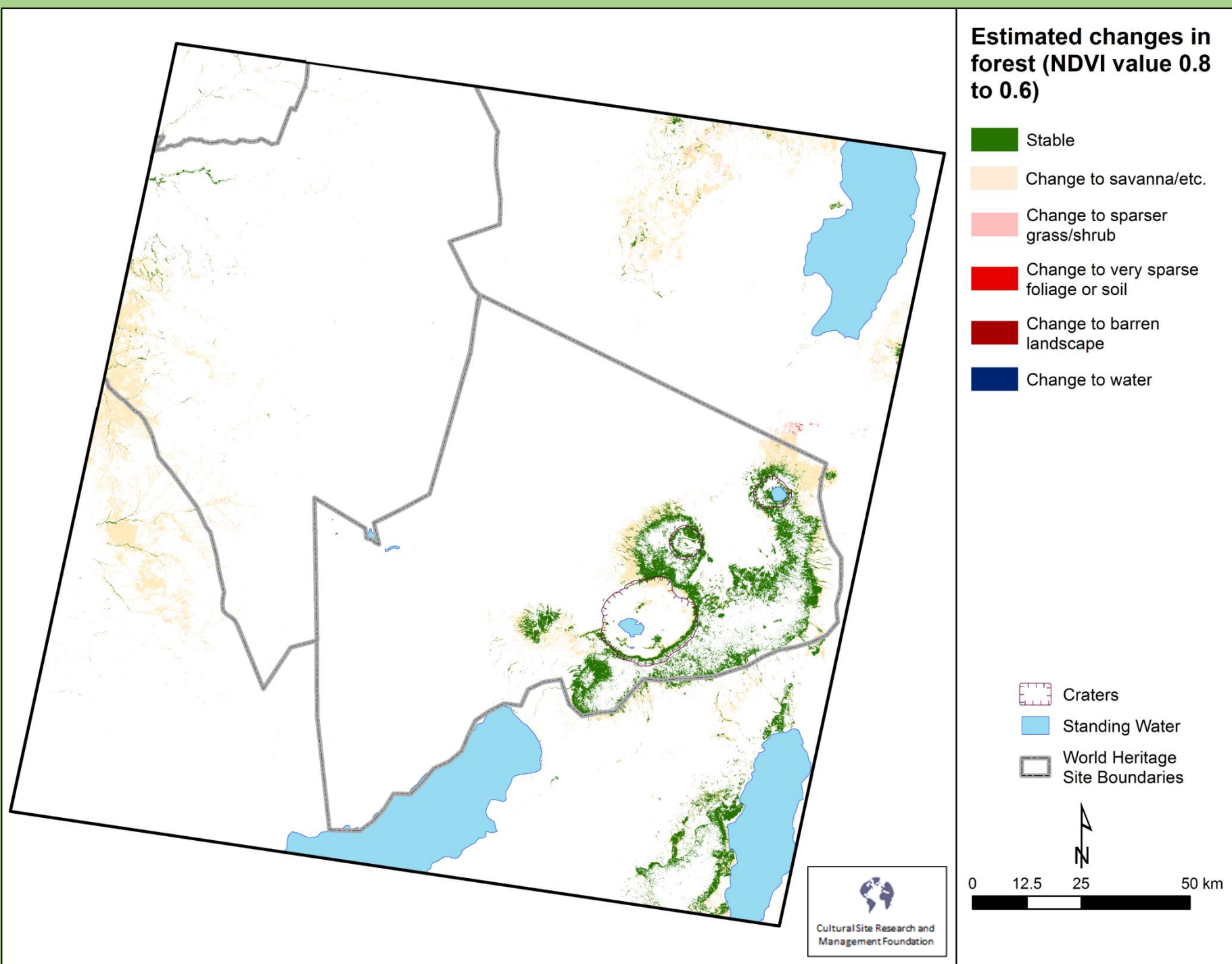
- Craters
- Standing Water
- World Heritage
Site Boundaries



0 12.5 25 50 km

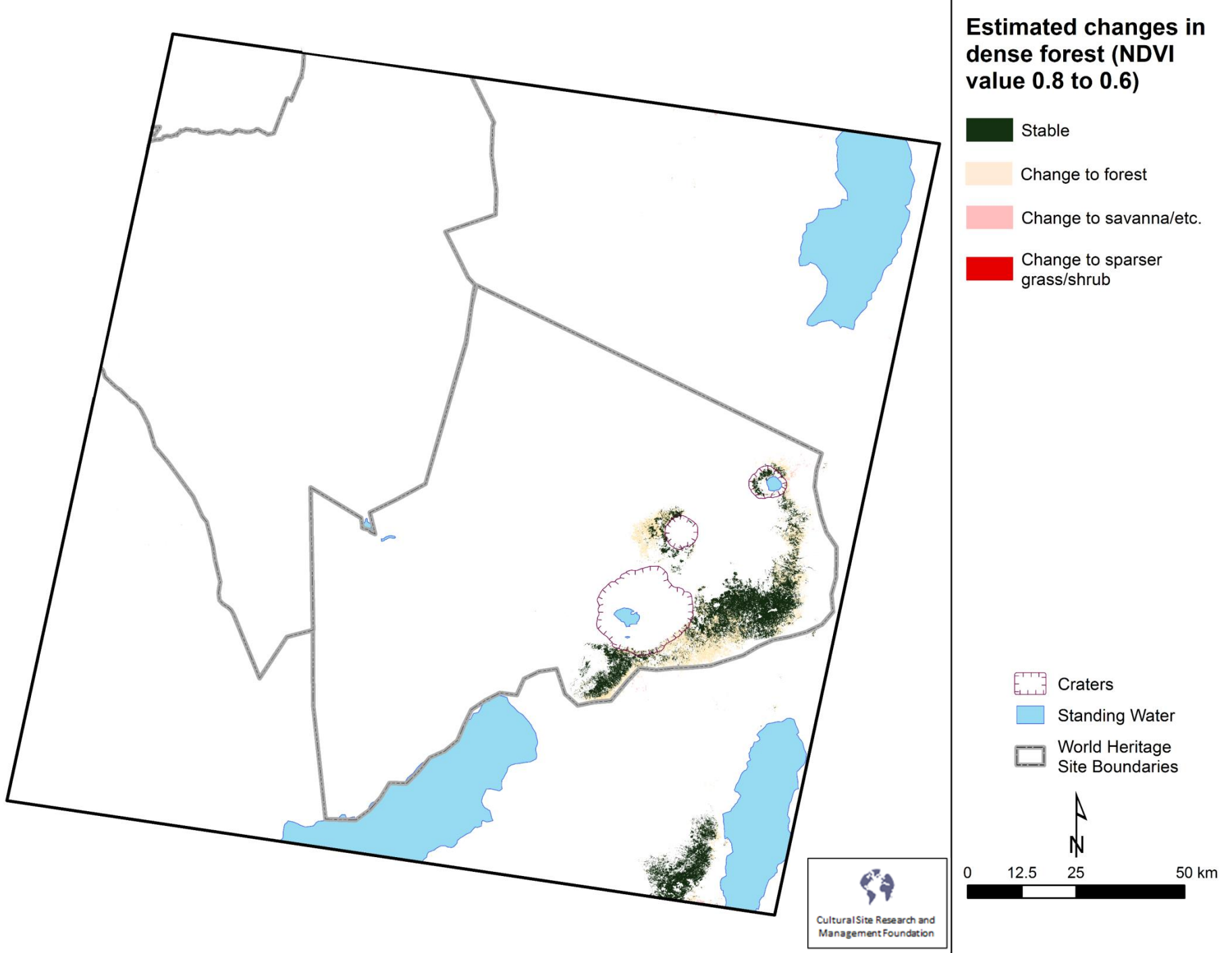


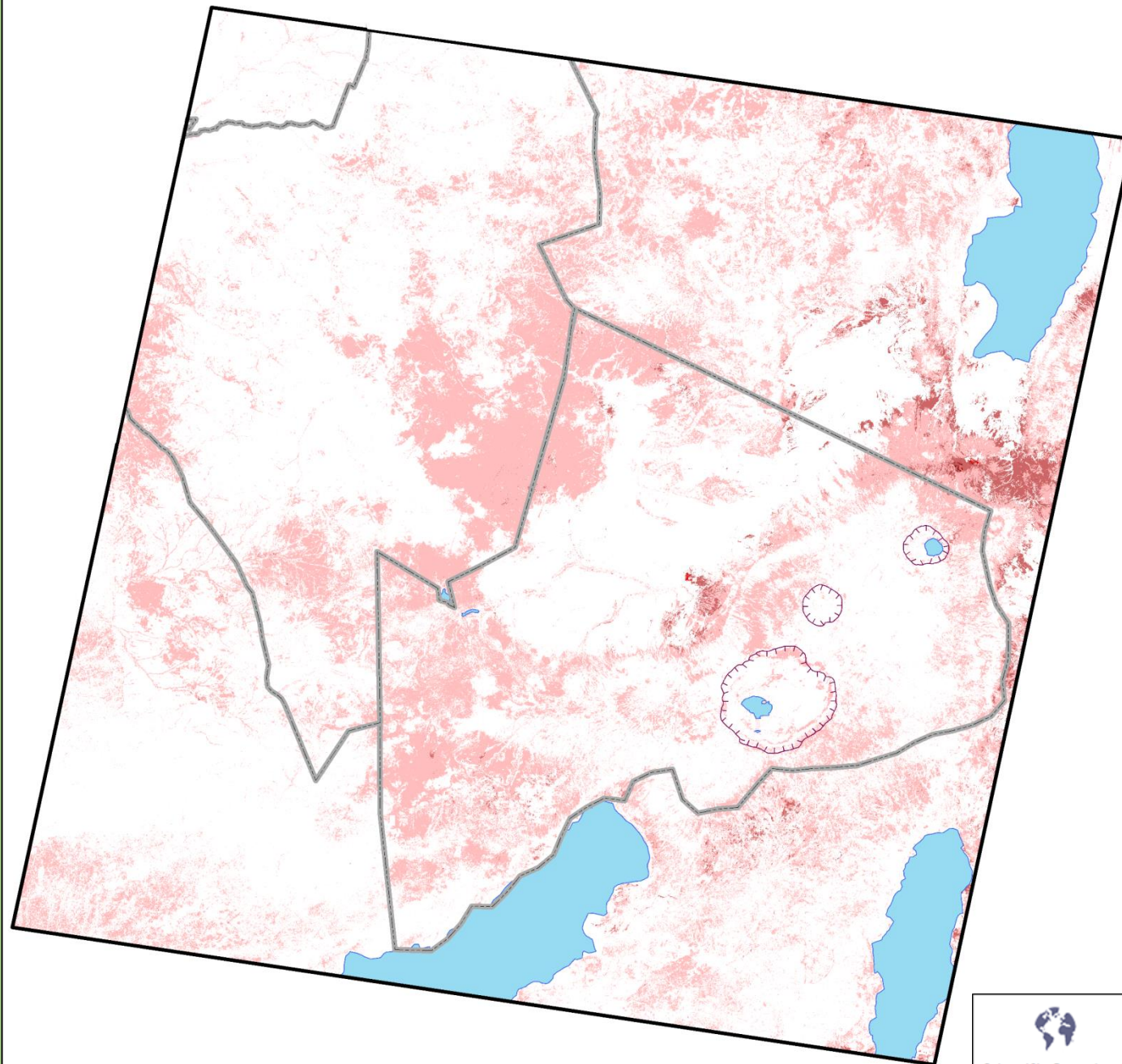
Forest change
2002 to 2017



Dense forest
change

2002 to 2017

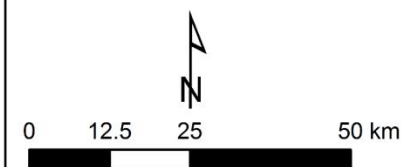




Generalized Class Change (2002-2017)

- One tier change
- Two tier change
- Three tier change
- Four tier change
- Change to water

- Craters
- Standing Water
- World Heritage Site Boundaries



Variance and Coefficient of Variance Study

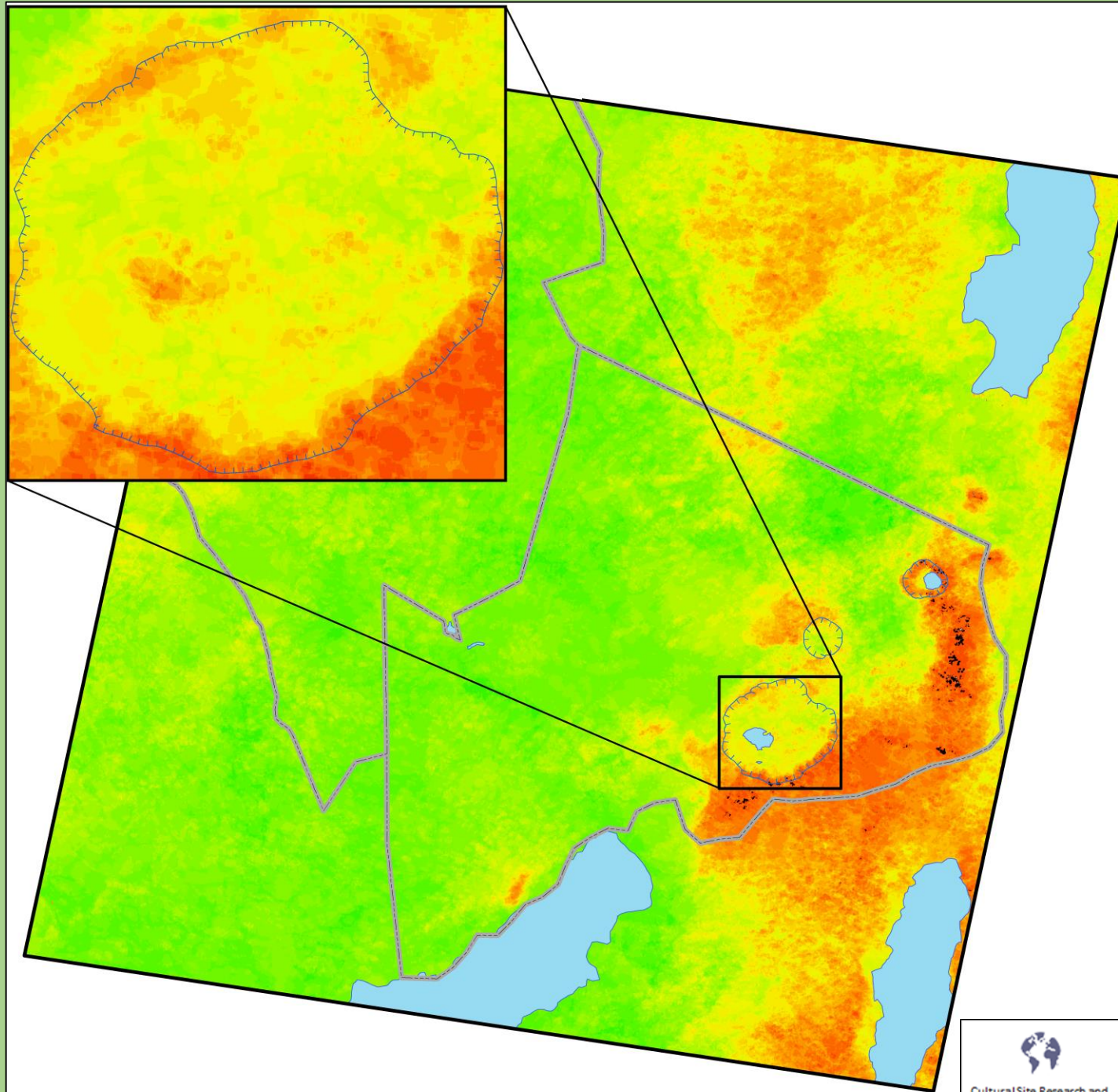
Variance and Coefficient of Variance of NDVI values within 2002 and
2017



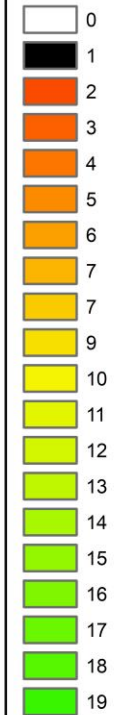
The variance shows the degree of variability of values. This is done by squaring the standard deviation (σ^2). For example, two areas can have the same average NDVI value, but the NDVI values might vary more in one area than the other.

The coefficient of variation is another way to quantifying this value by comparing it to the average, or mean. This is done by dividing the standard deviation by the mean (σ/μ). The coefficient of variation is a useful measure when the conditions of measurement change, as it does here between the dry and wet seasons.

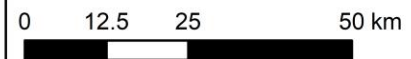


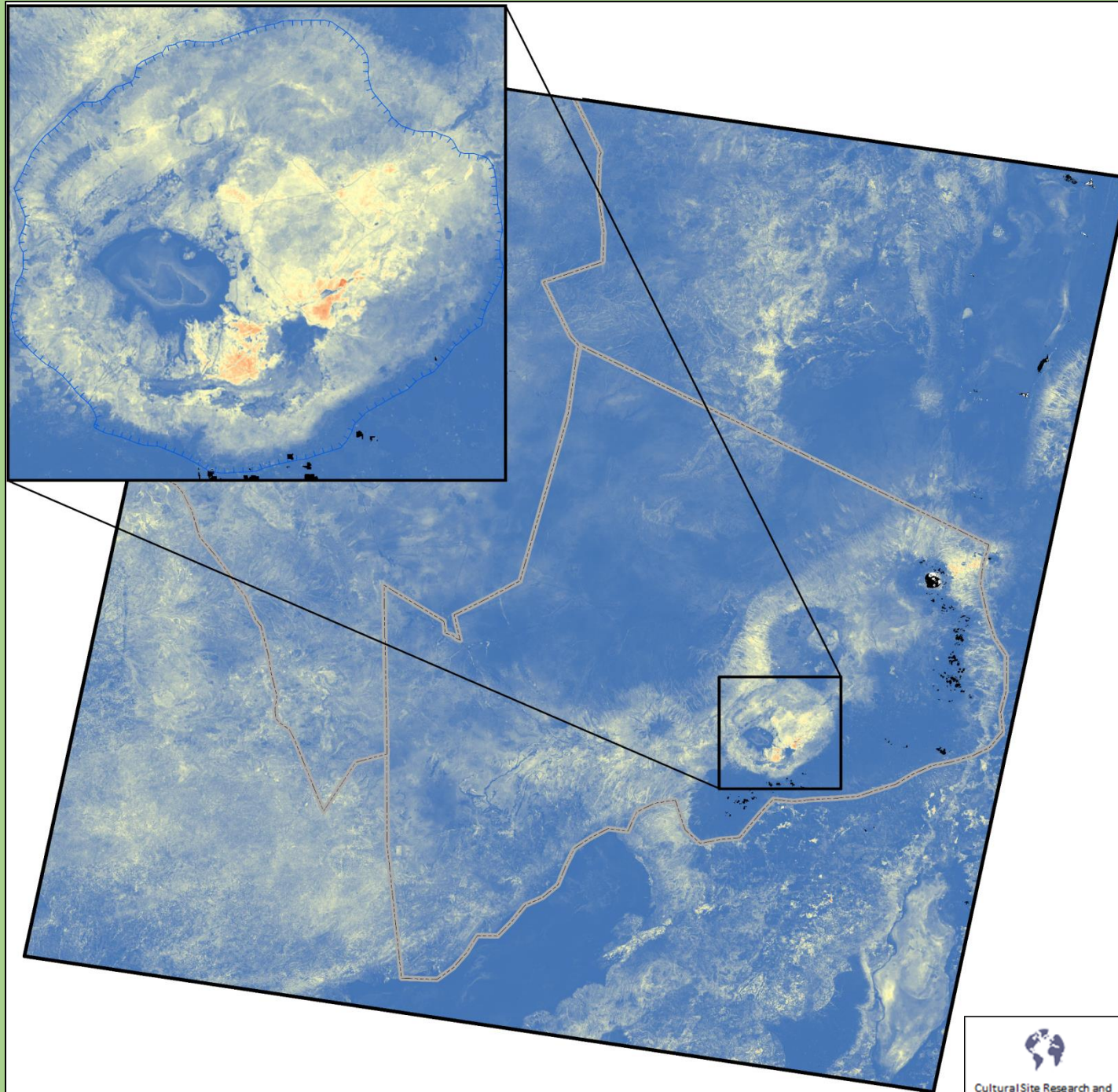


2017 Number of Cloudless Level 2 Scenes



-  Craters
-  Standing Water
-  World Heritage Site Boundaries





2017 NDVI Value Variance (20 BOA scenes from Jan-Dec)

Value

High : 0.0976009

Low : > 0.0*

*Values of 0 are blacked out



Craters



Standing Water



World Heritage
Site Boundaries



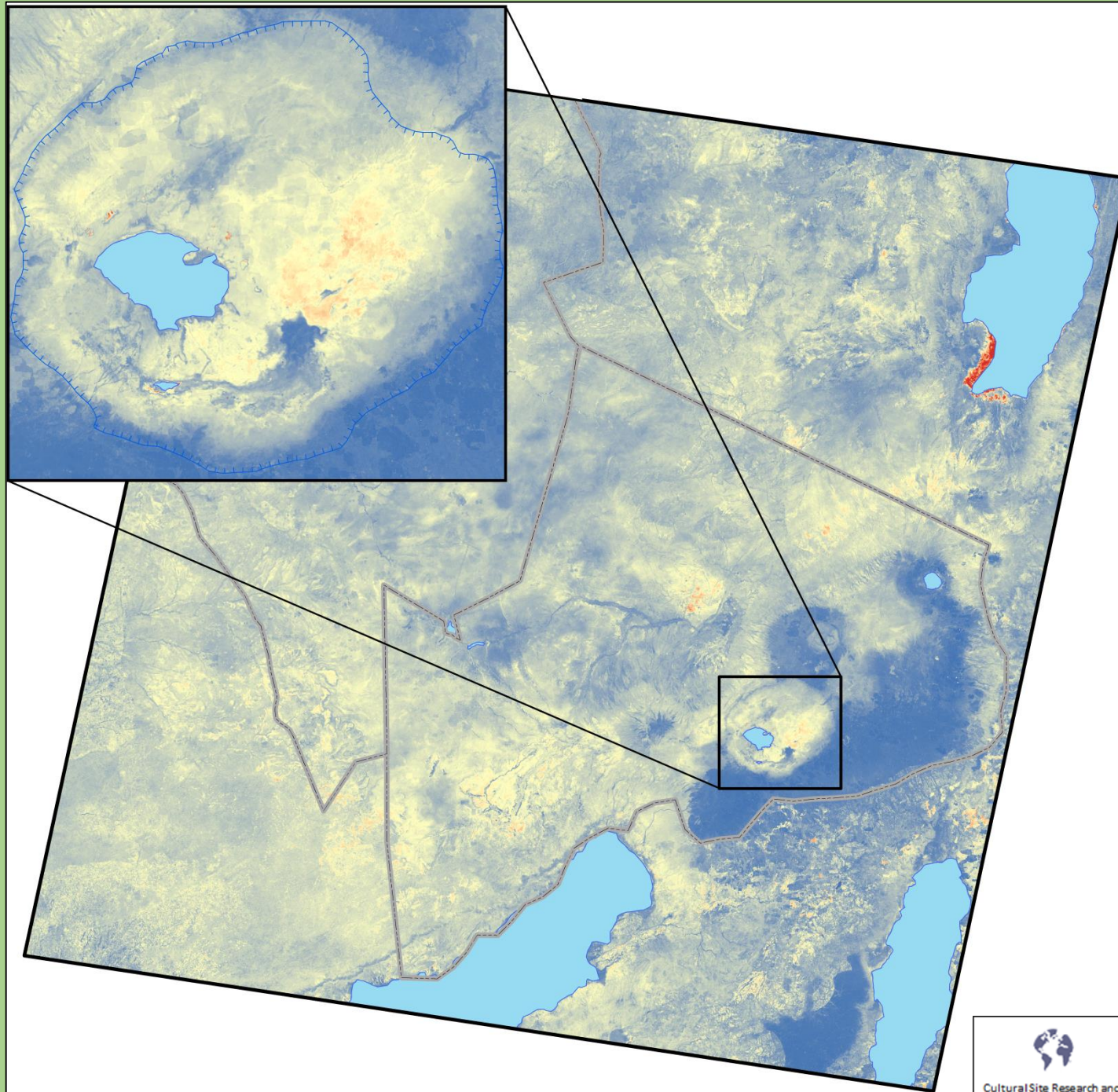
0 12.5 25 50 km



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2017 NDVI Coefficient of Variance (20 BOA scenes from Jan-Dec)

Value

High : 1 and greater



Low : 0 and lower



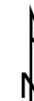
Craters



Standing Water



World Heritage Site Boundaries



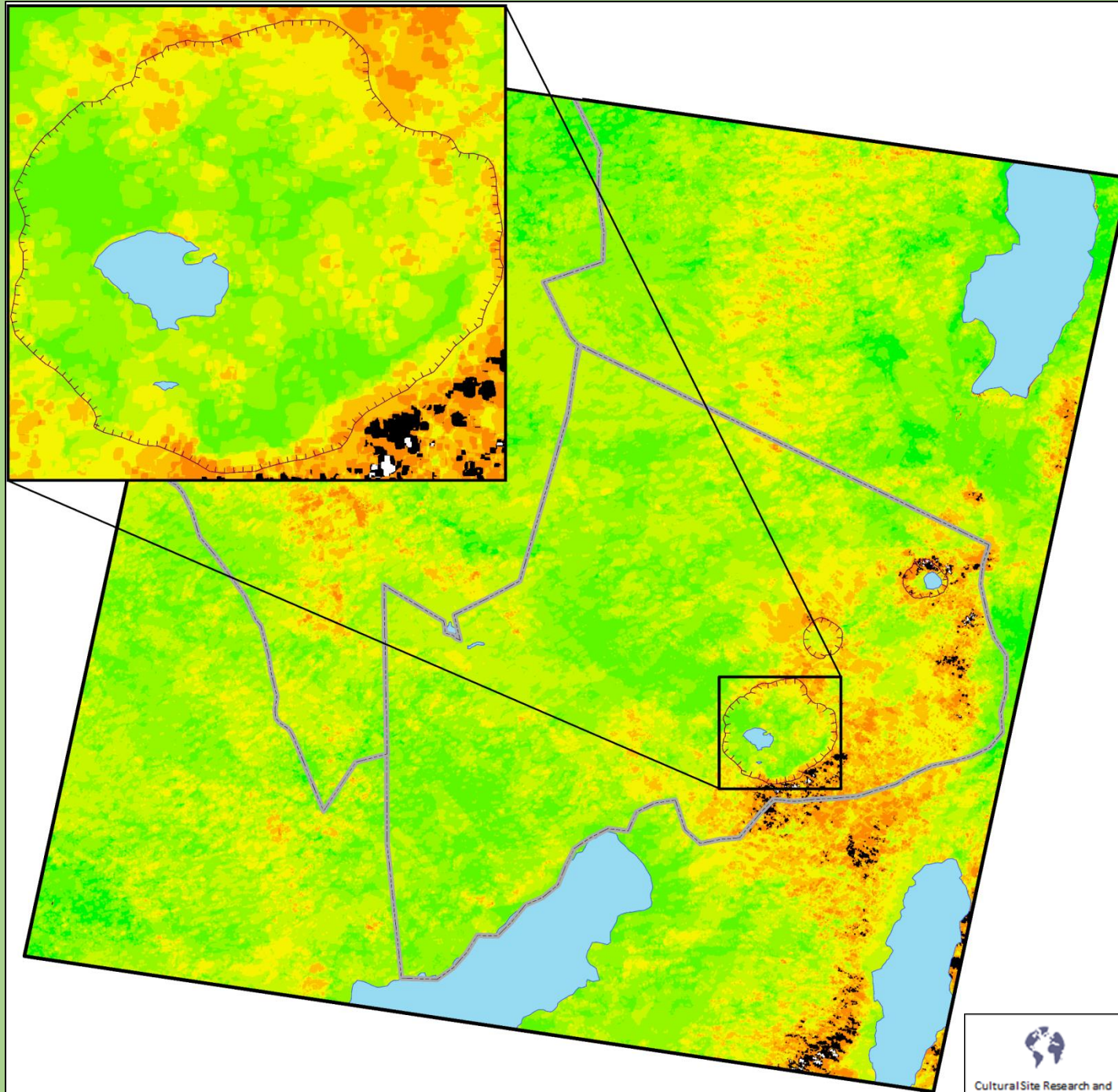
0 12.5 25 50 km



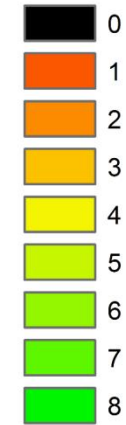
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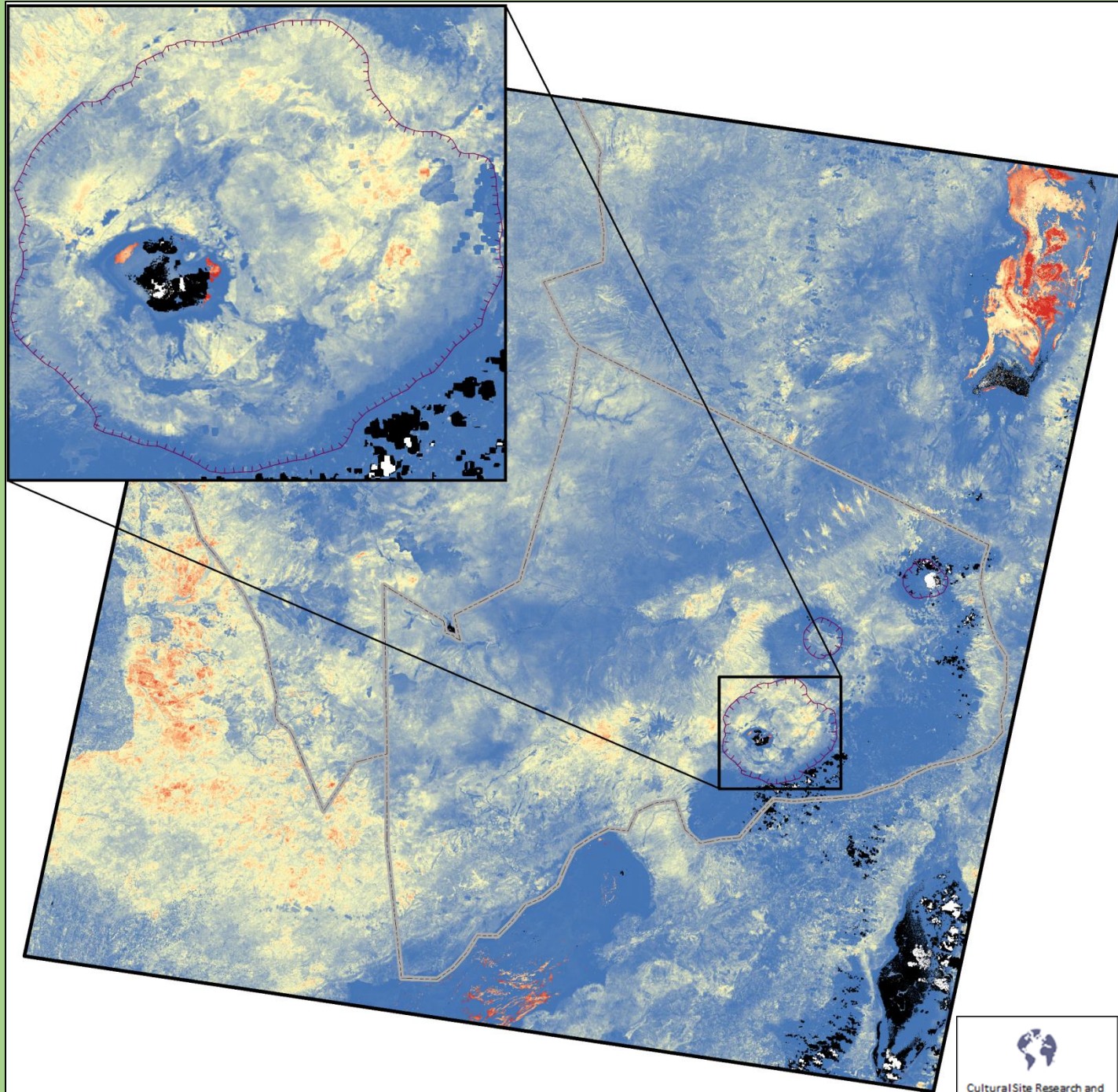


2002 Number of Cloudless
Level 2 Scenes



-  Craters
-  Standing Water
-  World Heritage Site Boundaries





2002 NDVI Value Variance (8 BOA scenes from Jan-Dec)

Value

High : 0.1 and higher



Low : > 0.0*

*Values of 0 are blacked out



Craters



Standing Water

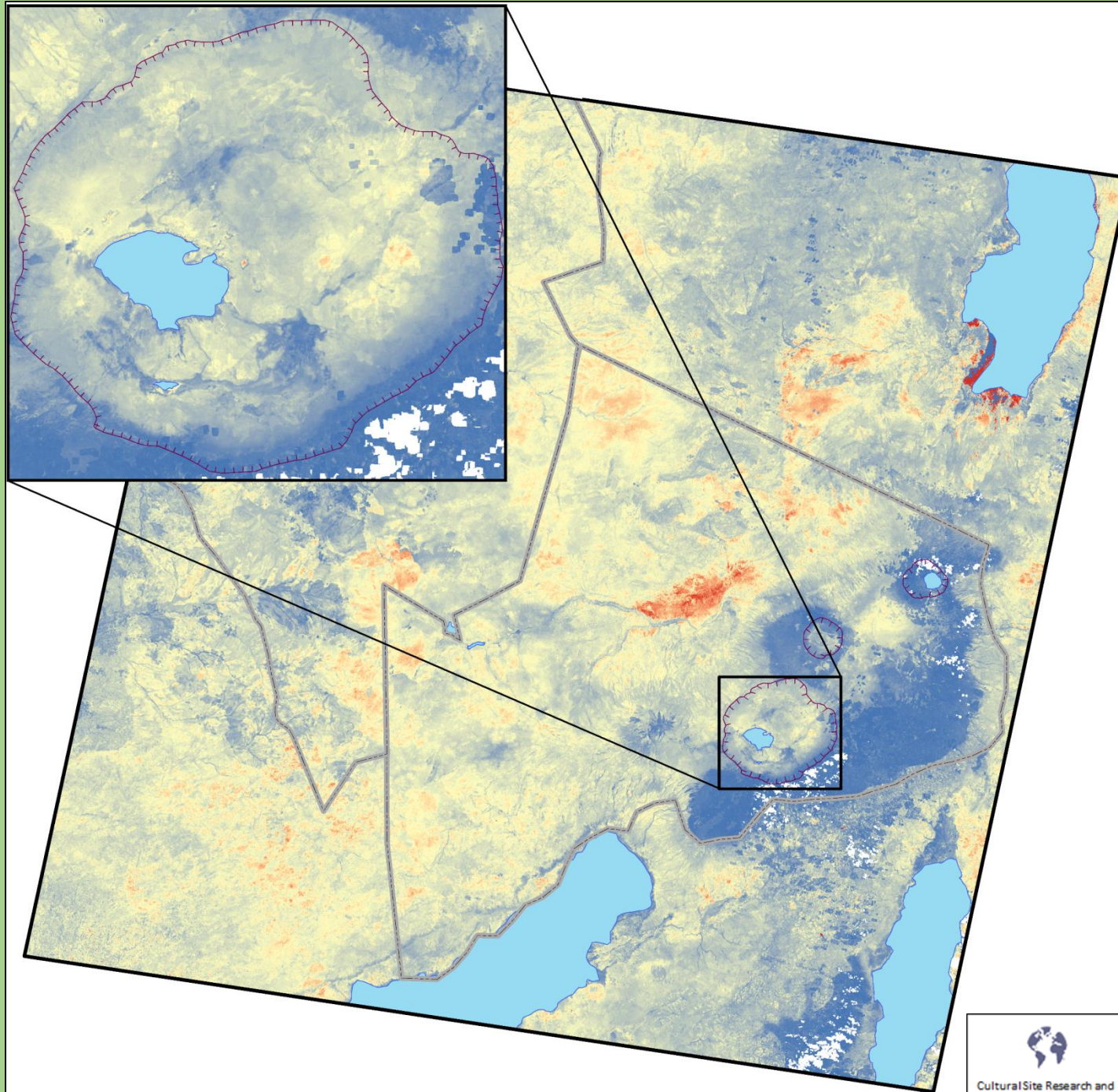


World Heritage
Site Boundaries

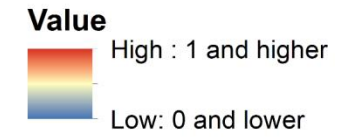


0 12.5 25 50 km

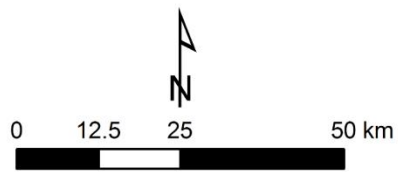




2002 NDVI Coefficient of Variance (8 BOA scenes from Jan-Dec)



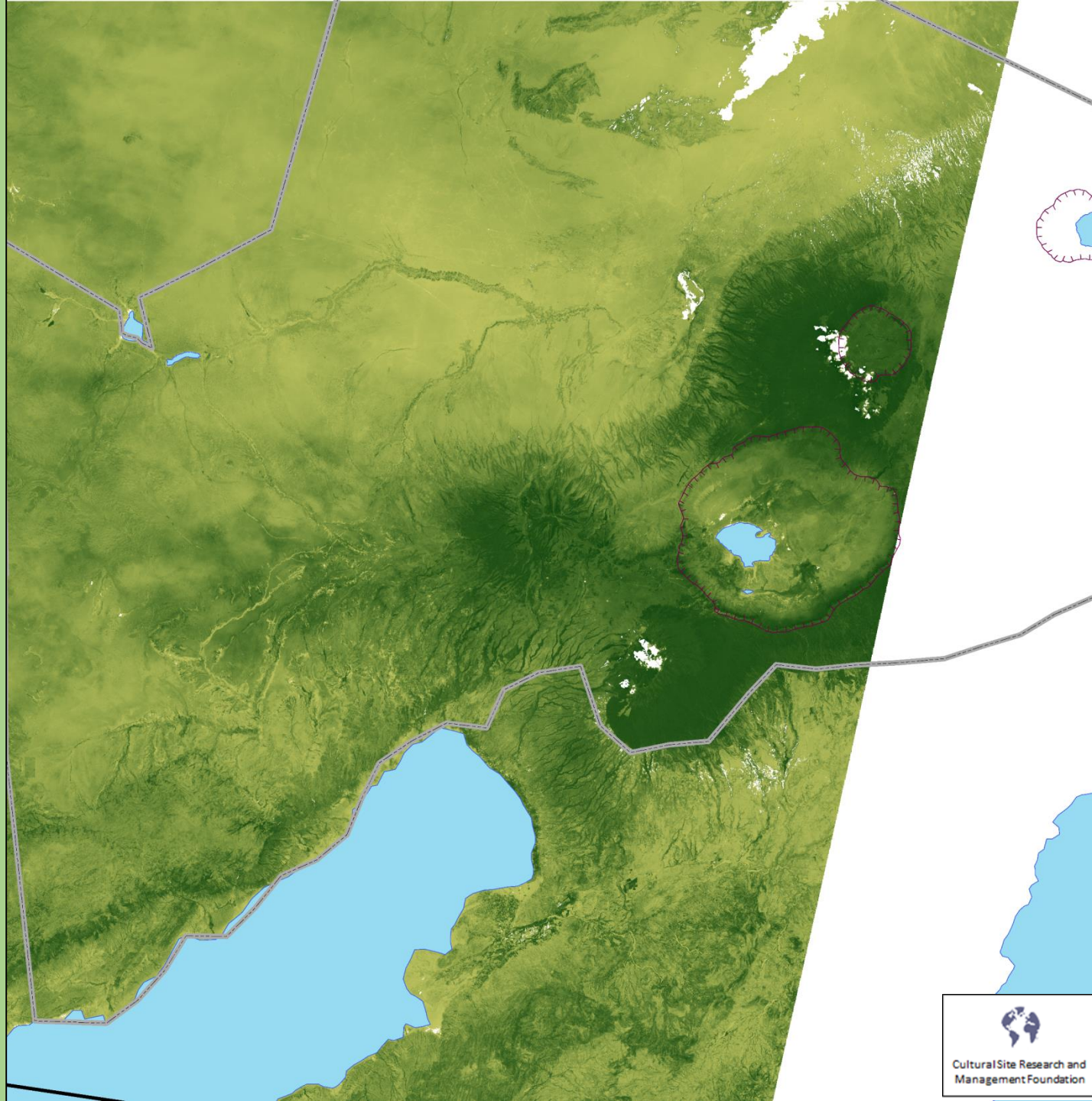
- Craters
- Standing Water
- World Heritage Site Boundaries



Processing of Sentinel-2 MSI is Currently in Progress

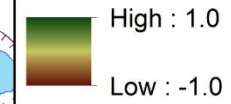
Sentinel-2 imagery is higher resolution than Landsat 7 and Landsat 8 sensors, but as a consequence the swath width is smaller, so the satellite requires two passes to cover the NCA.



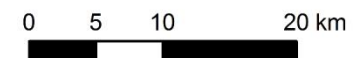


Average NDVI Values Jan 2017 (S2A BOA)

Values (stretched)



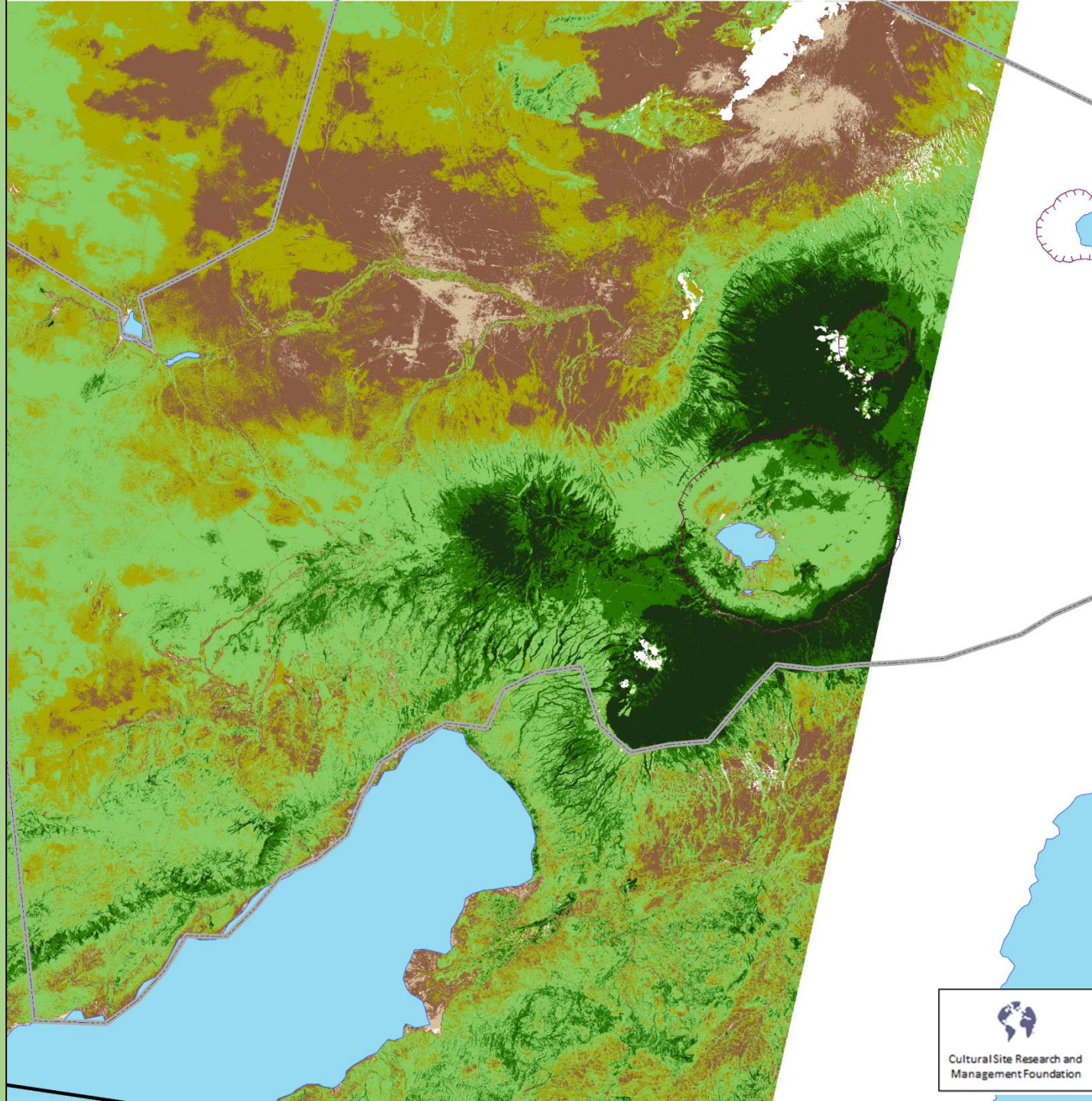
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-  Standing Water
-  World Heritage Site Boundaries



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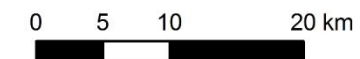
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NDVI Values Jan 2017: Classified Tiers

-  Dense Forest (1.0 to 0.8)
-  Forest (0.8 to 0.6)
-  Savanna, small trees, and other foliage (0.6 to 0.3)
-  Sparser grassland and shrubs (0.3 to 0.2)
-  Very sparse vegetation and soils (0.2 to 0.1)
-  Barren landscape (0.1 to ~0)
-  Standing water (~0 to -1.0)

-  Craters
-  Standing Water
-  World Heritage Site Boundaries



Preliminary study of vegetative health around Maasai settlements

Location of a major concentration of *boma* are estimated from 2016 Google Earth imagery. A comprehensive coverage is forthcoming.

While it is possible that overgrazing has caused an adverse effect on vegetative health around this region, a more comprehensive comparison to precipitation and temperature data will be needed to determine what degree the change is actually anthropogenic.





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Boma seen in Google Earth Imagery



Google Earth

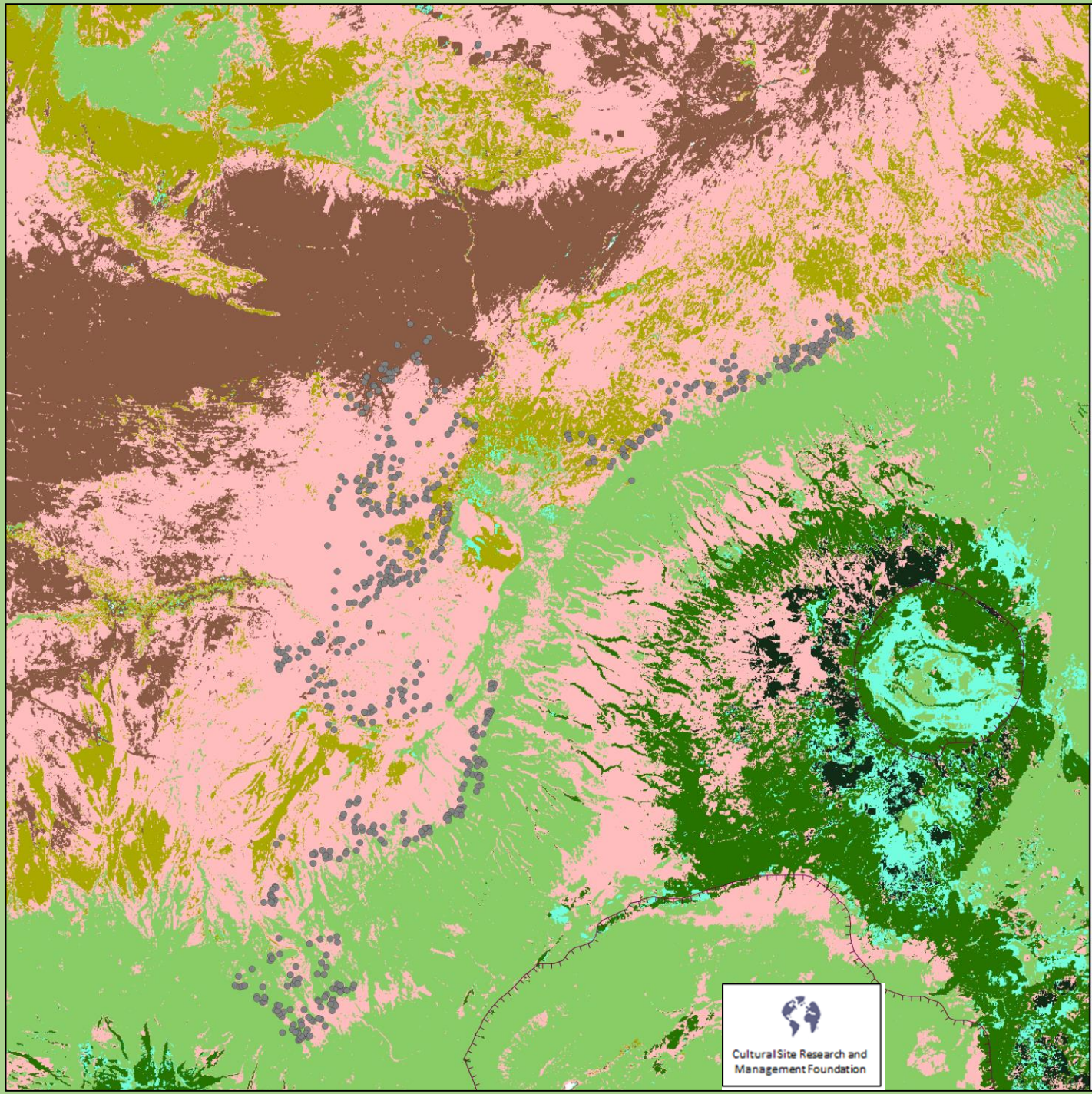
Image © 2018 CNES / Airbus
Image Landsat / Copernicus
© 2017 Google



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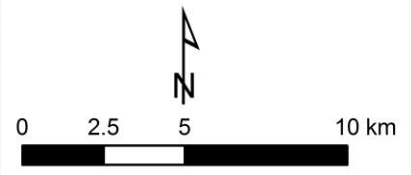


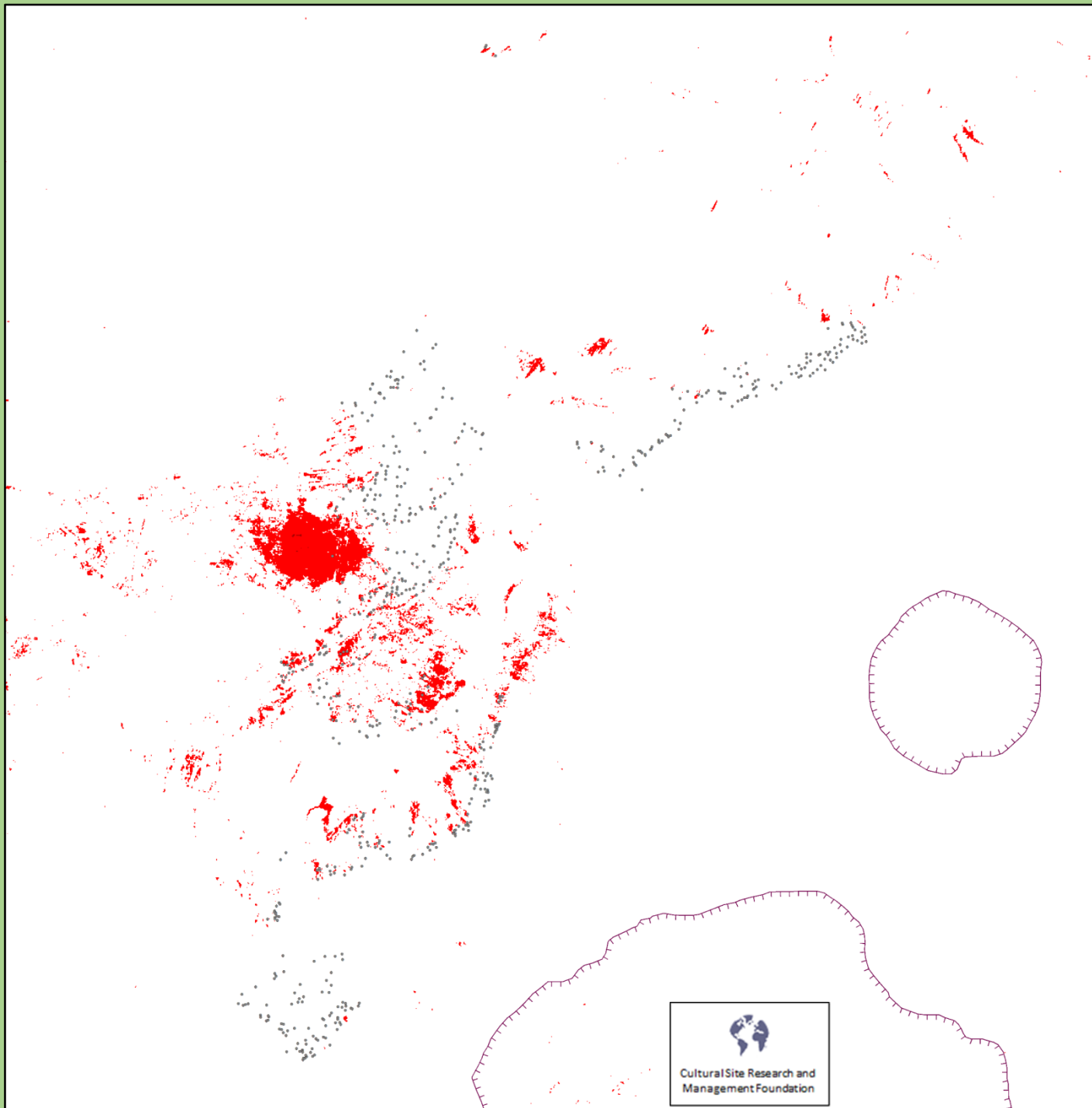
10 km



Estimated vegetation changes near Maasai 2002-2017

- Stable dense forest
- Stable forest
- Stable savanna/etc.
- Stable sparser grass/shrub
- Stable very sparse foliage or soil
- Areas seeing general reduction in vegetative density/health
- Areas seeing general increase in vegetative density/health
- Boma (as seen in Google Earth, from 2016. Incomplete Count)
- Craters
- Standing Water
- World Heritage Site Boundaries





NDVI Percent Change: 2002 to 2017 (Level 2)

 -50% to -75%

 -75% and below

 Boma (as seen in Google
Earth, from 2016.
Incomplete Count)

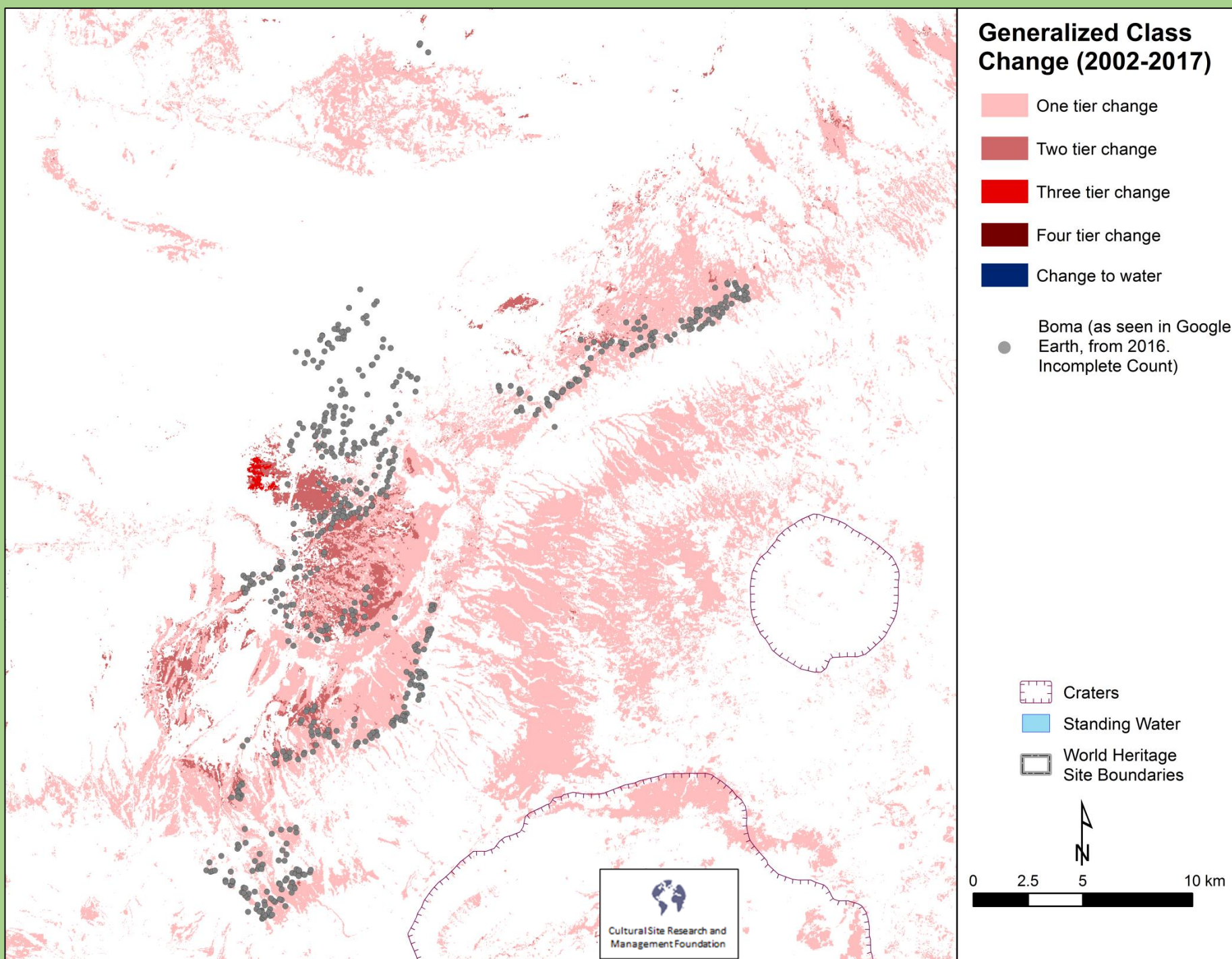
 Craters

 Standing Water

 World Heritage
Site Boundaries



0 2.5 5 10 km



Future studies:

- Continue Sentinel-2 multispectral analysis, including red-edge analysis
- Combining Landsat and Sentinel-2 multispectral analyses
- Sentinel-1 SAR analysis. This analysis will show where and when landscape disturbance takes place within intervals of about six days.

