CHAPTER 7.

Using Tree Canopy Cover Data to Help Estimate Acres of Damage

Erin Berryman

Andrew McMahan

INTRODUCTION

Among other responsibilities, the Forest Health Assessment and Applied Sciences Team (FHAAST) of the U.S. Department of Agriculture Forest Service Forest Health Protection (FHP) program has spent the past several years developing the Digital Mobile Sketch Mapper (DMSM) for its aerial survey program. This is intended to replace the Digital Aerial Sketch Mapper (DASM) as the primary way that aerial survey data are collected, stored, accessed, and processed. The Insect and Disease Survey (IDS) program is currently transitioning from DASM to DMSM. The IDS database (DB) contains mostly DASM data, but some regions started using DMSM in 2015. By 2018, all regions were using DMSM, and DASM will soon be completely phased out. With DMSM comes a fully synchronized IDS DB, which will continue to represent the most updated, comprehensive, and authoritative dataset of forest health conditions in the United States. This dataset is essential for providing multiscale spatiotemporal summaries of forest pest outbreaks and informing the estimated impacts on forest resources. Insect and Disease Survey data have a wide variety of Forest Service users, including FHAAST and regional and forest entomologists, as well as academic researchers and State, industrial, and private landowners outside of the Forest Service. The end goals of each user likely vary, so it is important to make data accessible and meaningful for use by all parties as much as possible. While it is not the goal of FHAAST to conduct research, by encouraging research use of IDS we benefit by possibly adopting what the research community learns. This chapter helps address the goal of FHAAST's Quantitative Analysis program to support the development of DMSM and help users better interpret and use the new IDS data that are being collected with DMSM.

With the reconceptualization of aerial survey methods and the resulting DMSM, one goal was to better allow for accurate reporting of total damage across multiple regions and nationally, despite the variability in canopy density across and even within regions. For example, one might argue that, for a national report on bark beetle mortality, an area containing bark beetle mortality in dense lodgepole pine (*Pinus contorta*) forest results in more tree mortality than the same acreage of bark beetle mortality in sparse ponderosa pine (*P. ponderosa*) woodlands. This concept of "acres of," rather than "acres with," can be helpful when comparing damage summaries across different regions, hosts, or agents. Among some of the key changes in DMSM are the introduction of grid cells as a new data collection feature type in addition to polygons and points; replacing "trees per acre" and "number of trees" measures of mortality with a five-class rating system based on percent of trees affected; and replacing defoliation "severity" and "pattern" with three severity classes. In addition to streamlining and standardizing aerial survey reports, these changes will help FHAAST better integrate aerial survey data with remote sensing and ground survey data (FHAAST 2017).

In DMSM, damage is recorded based on the visual assessment of the percent of live and standing dead trees that are affected; therefore, tree cover, as defined by all standing live and dead trees detectable at a 30-m resolution as viewed from directly above, is inherently assessed during flights along with damage type, agent, host, and severity (FHAAST 2017). A key issue with obtaining accurate estimates of damage occurs when damage polygons include untreed area, such as meadows or farms, or when the forest is very sparse, resulting in significant gaps between trees. Often in cases of complex damage patterns on the landscape, surveyors have no choice but to draw large, general polygons or grid cells to indicate damage, yet these areas inevitably contain untreed area in all but the most densely stocked forests. Because of this reason, IDS polygons and grid cells are treated by FHAAST as representing more general "acres with" damage due to the nature of their collection. What are needed for data summaries, however, are "acres of" damage that take into account both percent of trees affected and overall treed versus untreed area. While this is still not a true representation of reality, it represents an improvement in accounting of damage that allows a more fair comparison of damage among different regions and damage-causing agents. Updated, accurate geospatial information about tree cover can serve as a critical data input to adjusting IDS polygons for more accurate estimates of acres of damage. For our purposes and continued use with DMSM, there are several key considerations when choosing a treed cover layer:

- Wall-to-wall national coverage;
- Updated at least once every 5 years to reflect an accurate depiction of conditions during the most recent aerial surveys;
- Appropriate spatial resolution to correspond with DMSM data (30 m to 240 m); and
- Consistent methods across product updates, or a measure of error introduced by using different methods.

The National Land Cover Database (NLCD) Tree Canopy Cover (TCC) product (Yang and others 2018) is a 30-m resolution, satellite-derived canopy cover layer. Some important considerations for the use of this layer for adjusting IDS data to "acres of" damage are:

- It relates ground-measured tree cover to satellite-measured spectral reflectance (i.e., greenness) from Landsat to identify signatures that delineate forested cover from nonforested cover.
- Burned areas with standing dead trees may register as tree canopy cover, albeit at lower canopy cover than surrounding unburned forest.
- To obtain the highest-quality data and imagery, data may be used from a range of years leading up to the product release. For example, the 2011 TCC product uses imagery from 2009–2011.
- Products from different years are difficult to directly compare to each other because they use slightly different methodology.

- The data layer reports percent canopy cover that can either be used raw or be converted to a binary treed/untreed layer by selecting a canopy cover threshold.

This chapter describes analyses for determining the potential of this data source to help adjust IDS polygons to better represent "acres of" damage rather than "acres with" damage. First, NLCD TCC was directly compared to FHAAST's in-house forested/nonforested layer that was developed in 2002 and last refined in 2012 using various thresholds for delineating forested versus nonforested. Next, the proportion of treed area inside actual IDS polygons was examined using the in-house forested/nonforested layer, and we then analyzed the sensitivity of IDS-derived acres of damage using different thresholds of NLCD TCC for use as a forested/nonforested layer. Finally, aerial surveyor assessments of treed area inside IDS polygons was compared to NLCD TCC-derived estimates of treed area, also at different NLCD TCC thresholds.

METHODS

NLCD Comparison with FNF

An analysis was conducted to compare FHAAST's forested-nonforested layer (FNF) (Ellenwood and others 2015) to the TCC layer derived from NLCD. The FNF layer was developed at 30-m resolution using a similar approach as NLCD TCC: relating ground tree [≥1-inch diameter at breast height (d.b.h.)] survey measurements to spatial data on greenness, topography, and other environmental variables. The modeled product is a raster of live forested basal area (BA) at 30-m resolution which is then classified as forest or nonforest based on a threshold of 1.7 square feet of BA per 30-m pixel. This layer uses data collected around 2002, an important consideration when comparing it to TCC from 2011. Because analyses were done at 240-m resolution, the 240-m version of FNF was used. This layer contains values from 0–64, indicating how many of the component sixty-four 30 m-pixels are "treed" (i.e., have a modelled BA ≥1.7 square feet). This was reclassed into two classes: treed (1–64 treed 30-m pixels per 240 m) or untreed (0 treed 30-m pixels per each 240-m pixel). This 240-m treed/untreed layer was then compared to a similar layer produced using data from NLCD.

A treed/non-treed classification layer was established from NLCD TCC using a number of different thresholds of treed canopy cover to delineate treed pixels: 10, 20, 25, 30, 35, and 50 percent. It was first reclassed into a binary raster using these NLCD TCC thresholds, and then the 30-m cells were summed into 240-m resolution with values 0–64, similar to the FNF layer. These were reclassed into the same treed/untreed classes as the FNF 240-m layer.

Confusion matrices were created at both the national scale and for each Environmental Protection Agency (EPA) Level 3 Ecoregion. Kappa statistics were calculated from the confusion matrices as a measure of agreement between the FNF layer and the NLCD TCC layers at each threshold (Congalton and Green 2008).

Kappa was examined for trends by NLCD TCC threshold and ecoregion. It was hypothesized that classification based on NLCD TCC threshold would probably vary according to forest type and structure, such as what would be delineated by general aridity of the ecoregion. To assess this, we grouped ecoregions into six classes according to annual precipitation, obtained from spatially averaging [using "Zonal Statistics" in ArcGIS (ESRI 2011)] the 30-year mean of annual precipitation from the PRISM dataset (4-km resolution; PRISM Climate Group, Oregon State University 2017). Then, in each group, kappa was plotted against NLCD TCC threshold to determine which TCC threshold resulted in the greatest agreement between FNF and NLCD TCC for each precipitation class. The results of this analysis will help determine what range of NLCD TCC threshold to further examine for use as a treed layer.

To examine the variability in FNF treed cover in actual IDS polygons, treed cover was calculated for each IDS polygon >50 acres for 2 years: 2008 and 2015. Zonal Statistics in ArcGIS was used to calculate FNF treed cover as a proportion of each polygon. Histograms of proportion of treed area were generated for each year.

Sensitivity of IDS Polygons to Threshold

Our objective was to determine how selection of a particular NLCD TCC threshold would impact summary statistics computed in DMSM. We calculated treed area using different methods on a new subset of IDS polygons (grid cells were not yet being used in 2015) selected according to the following criteria:

1. Collected in 2008 and 2015 (to include both DASM and DMSM)
2. >100 acres (i.e., more likely to contain nonforested area)
3. General shape rather than specific (i.e., round; low circumference-to-area ratio)

This resulted in a total of 7,795 polygons in 2008 and 6,928 polygons in 2015. To limit the influence of polygon size on the results (i.e., tradeoff between specificity and size), we selected the same size area within each polygon within which to calculate statistics. We centered a 480-m "superpixel" within each selected IDS polygon and calculated treed area (using Zonal Statistics in ArcGIS) from different treed area products: FNF, three different NLCD TCC thresholds (10, 20, and 30 percent), and the raw NLCD TCC product (i.e., mean TCC within the superpixel). These treed area values were then averaged for each EPA Level 1 Ecoregion to detect general trends among FNF, different NLCD TCC thresholds, and raw NLCD TCC.

Consistency of Treed Layers with Aerial Survey Assessment

In addition, we randomly selected 60 of the above superpixels (30 from 2008 and 30 from 2015) for a manual exercise to compare NLCD TCC-derived treed area with aerial surveyor assessments. An equal number of images was selected from each year to avoid bias associated with switching from DASM to DMSM. Average treed cover for the superpixel was calculated using the three different NLCD TCC thresholds, raw NLCD TCC, and FNF. To assess which GIS layers of treed cover were most consistent with aerial surveyor assessment of treed cover during flights, high-resolution aerial imagery from NAIP (National Agriculture Imagery Program) was examined for each of the 60 superpixels by two experts in aerial survey techniques. Experts were asked to quickly visually estimate treed cover within each 480-m superpixel with the mindset of an aerial surveyor (i.e., what areas would they consider when making a damage severity assessment from a plane?). We calculated the degree of agreement between each NLCD TCC threshold layer and the observers' assessments using root mean squared error (RMSE):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(C_i - \hat{C}_i)^2}$$

where

C_i = for each superpixel *i*, the observed value (expert assessment of treed cover)

$\hat{C}_i$ = for each superpixel *i*, the predicted value (cover from treed layer)

n = the number of observations (60 for observer 1's assessment, 54 for observer 2's assessment)

Root mean squared error was calculated for each of three NLCD TCC thresholds (10, 20, and 30 percent) separately for polygons in the Western United States (west of the Mississippi River) and Eastern United States and for all polygons combined. Root mean squared error was also calculated for the same three TCC thresholds but aggregated to 60-m (four pixels) and 90-m (nine pixels) resolution to see if agreement depended on spatial resolution of the treed layer. All analyses are summarized in table 7.1.

Table 7.1—Summaries of analyses for this report

Data layers	Spatial resolution	Subset	Analysis performed
NLCD TCC, FNF	240 m	All pixels from conterminous United States	Compared treed versus untreed classification accuracy and how accuracy varied by ecoregion and precipitation regime
IDS, FNF	30 m	>50 acres, 2008 and 2015 only	Calculated proportion of treed area in each polygon and examined distribution using histograms
IDS, NLCD TCC, NLCD10, NLCD20, NLCD30, FNF	30 m	>100 acres, 2008 and 2015, round polygons	Calculated proportion of treed area using each of five different treed or forest canopy cover layers inside a 480-m superpixel centered inside each polygon
Same as above	30 m	Same criteria as above; 30 randomly selected in 2008, 30 randomly selected in 2015	Added expert assessment of treed area within a 480-m superpixel centered inside each polygon; RMSE determined between each expert assessment and GIS treed area calculation

NLCD TCC: National Land Cover Database Tree Canopy Cover; FNF: forested-nonforested; IDS: Insect and Disease Survey; NLCD10: 10-percent NLCD TCC threshold; NLCD20: 20-percent NLCD TCC threshold; NLCD30: 30-percent NLCD TCC threshold.

RESULTS

NLCD Comparison with FNF

Applying a threshold of 10-percent TCC to delineate a pixel as "treed" results in roughly 20 percent more area of the contiguous United States being construed as "treed" relative to FNF. The distribution of canopy cover classes varies geographically, with more western and arid regions having most treed pixels classed into lower canopy cover classes; pixels are classed conversely in the wetter, eastern areas.

The kappa statistic, which reflects the overall classification accuracy of NLCD TCC-derived treed area compared to FNF, varied depending on both ecoregion and TCC threshold. In the Western United States, kappa was highest at canopy cover threshold of 10 to 20 percent (fig. 7.1). In eastern ecoregions, kappa was highest when 30- to 35-percent canopy cover threshold was used. In general, regardless of TCC threshold, agreement between TCC-derived treed area and FNF was highest for eastern, wetter ecoregions than for western, drier ecoregions (fig. 7.2). Based on these results, we chose to further examine the performance of 10-, 20-, and 30-percent NLCD TCC threshold layers with IDS data—these are denoted as NLCD10, NLCD20, and NLCD30 from here forward.

Sensitivity of IDS Polygons to Threshold

Within IDS polygons >50 acres, 70 percent of them were >90 percent treed in 2008, with 74 percent of them >90 percent treed in 2015 (fig. 7.3), according to the FNF treed layer.

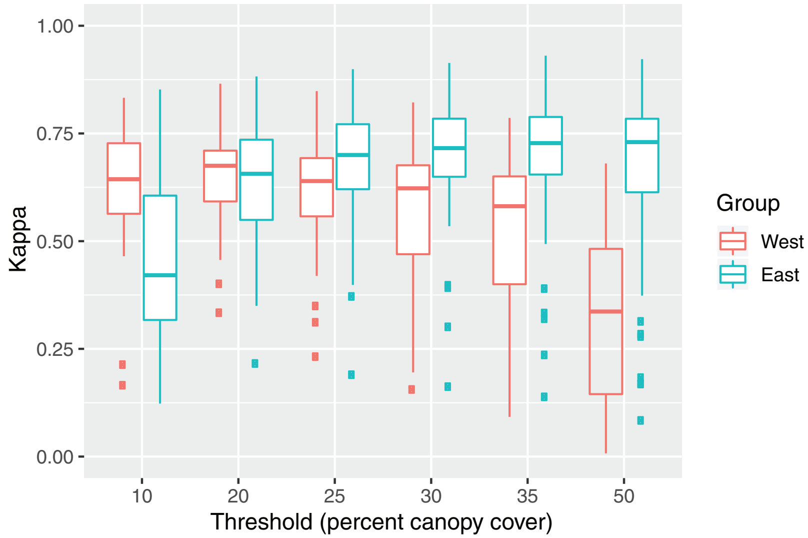


Figure 7.1—Kappa statistic (TCC versus FNF) for each Level 3 Ecoregion plotted against the canopy cover threshold, grouped into western U.S. ecoregions and eastern U.S. ecoregions. Boxplots approximate the distribution of the kappa values within each category, showing the median kappa as the horizontal line, bracketed by the first and third quantiles as the extent of the boxes. Outliers are outside 1.5 times the range indicated by the box height. This illustrates that (1) the best performing TCC threshold is higher for eastern ecoregions compared to western ecoregions; and (2) western ecoregions overall show a poorer fit of TCC with FNF.

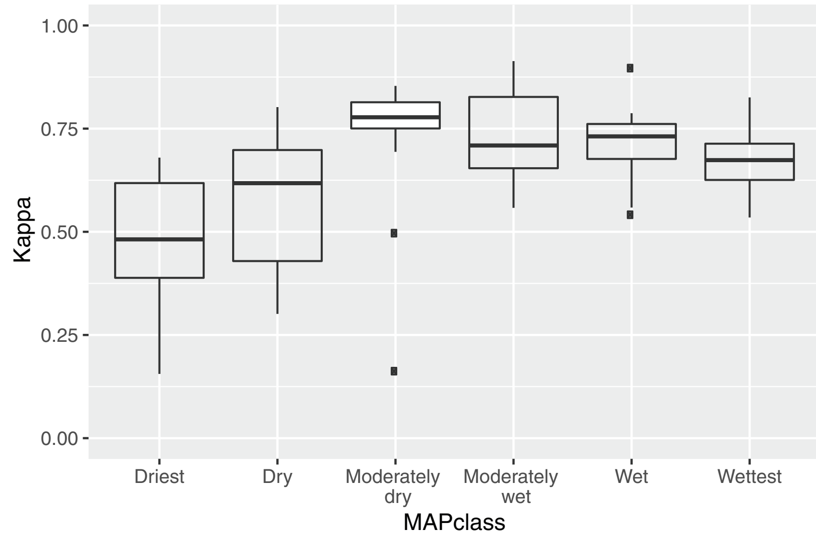


Figure 7.2—Kappa statistic (TCC at 30-percent threshold versus FNF) for each Level 3 Ecoregion plotted against the mean annual precipitation class (MAPclass) of the ecoregion. Boxplots approximate the distribution of the kappa values within each category, showing the median kappa as the horizontal line, bracketed by the first and third quantiles as the extent of the boxes. Outliers are outside 1.5 times the range indicated by the box height. This illustrates TCC forested cover compares better to FNF forested cover in wetter ecoregions than in drier ecoregions. Therefore, caution should be used when using TCC to delineate forested cover in dry forests.

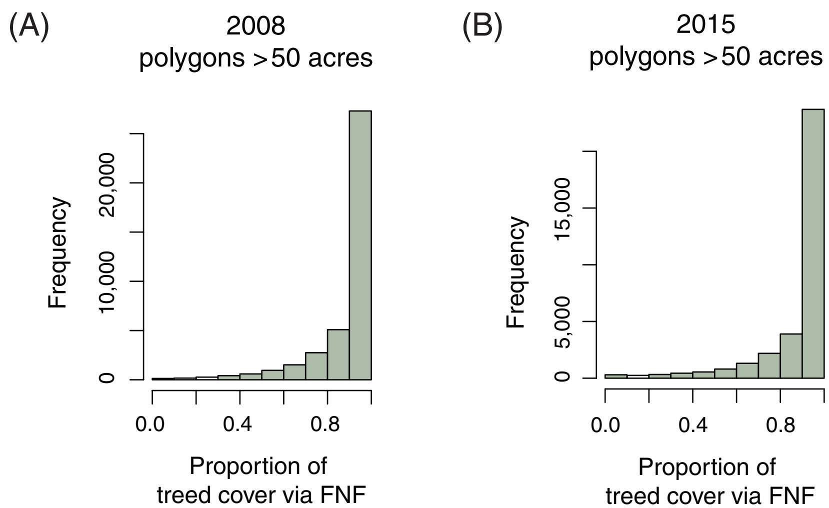


Figure 7.3—Histogram of (A) 2008 and (B) 2015 IDS polygon treed proportion (according to FNF) only including polygons >50 acres.

Within 480-m superpixels inside IDS polygons, the largest discrepancies in treed area between different layers occurred in drier Level 1 Ecoregions, i.e., Great Plains, Mediterranean California, North American Deserts, and Temperate Sierras (fig. 7.4). Averaged across Level 1 Ecoregions, NLCD TCC was always the lowest out of all measures. NLCD10 consistently resulted in the highest mean treed cover in the IDS superpixels, although in many ecoregions it was similar to measures from NLCD20 and NLCD30.

In 2015, about 2 percent of the total area contained within IDS polygons was (arbitrarily) considered highly sensitive to the placement of the NLCD TCC threshold; that is, there was a >30-percent difference between treed cover estimates within IDS polygons moving from NLCD10 to NLCD30. In other words, in 98 percent of the area covered by damage polygons in 2015, the calculated treed acres did not vary much depending on what TCC threshold was used: 10, 20, or 30 percent. The remaining polygons that were sensitive to TCC threshold tended to be concentrated in the Western United States (Intermountain West and Inland Northwest) (fig. 7.5).

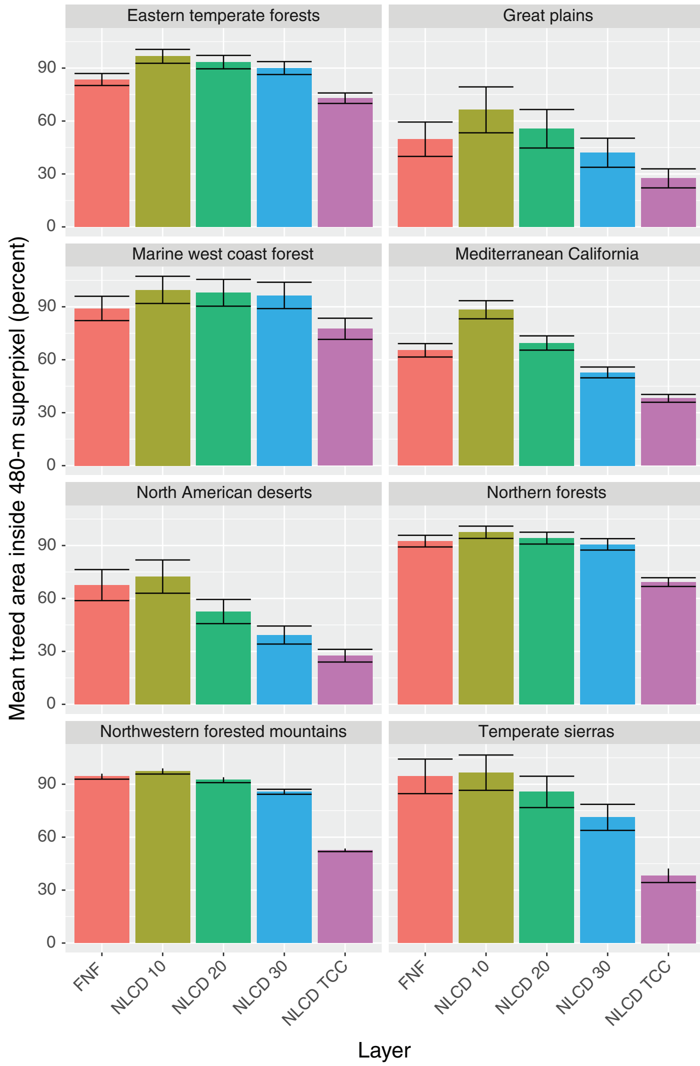


Figure 7.4—Mean treed area by Level 1 Ecoregion within 480-m superpixels centered inside large, round 2015 IDS polygons using five different treed cover or canopy cover layers: FNF (FHAAST native); NLCD 2011 with a 10-, 20-, and 30-percent canopy cover threshold; and NLCD TCC. Error bars represent +/- standard error.

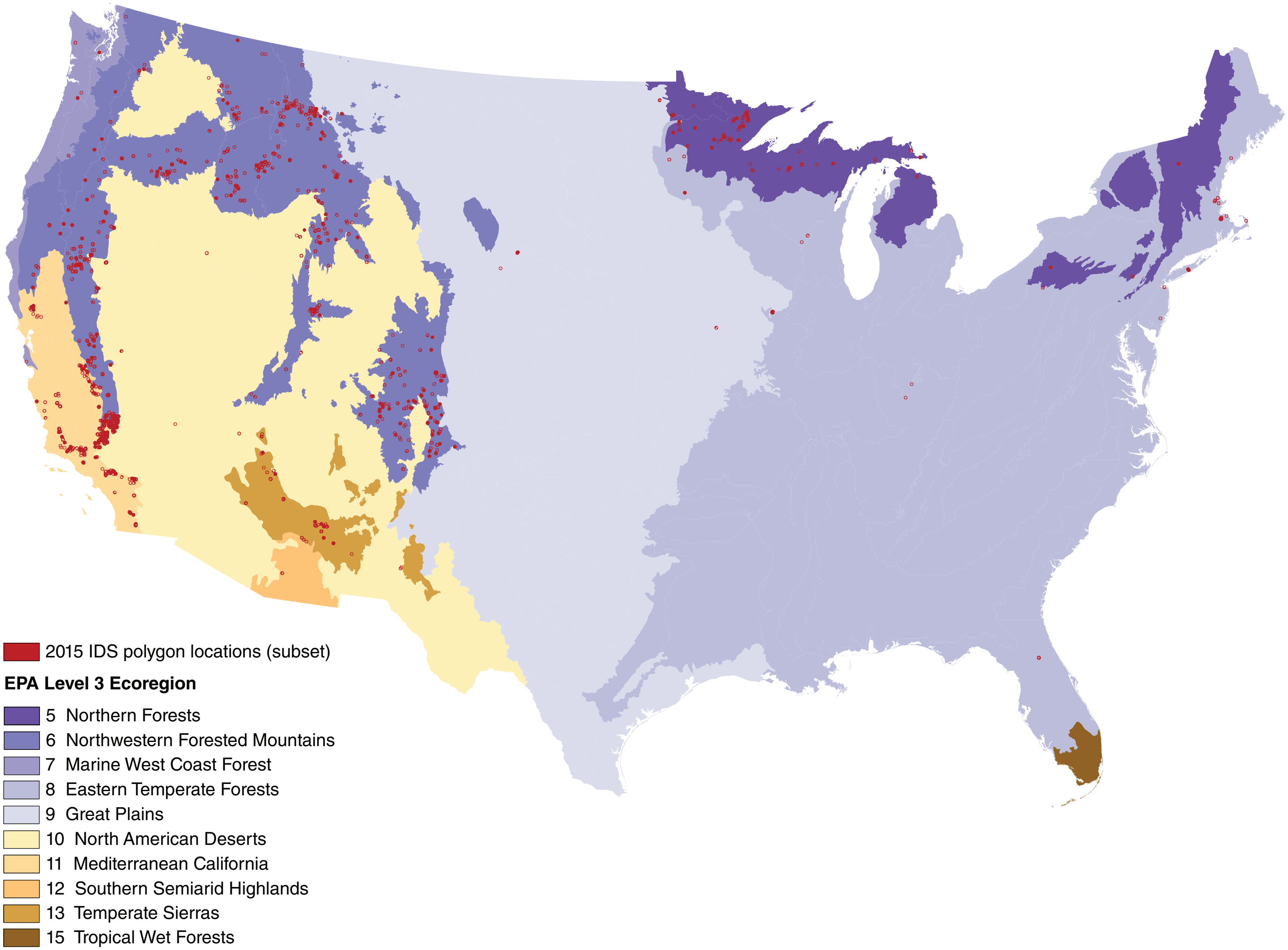


Figure 7.5—2015 IDS polygons where there was at least a 30-percent difference in treed area between using a 10-percent TCC threshold for NLCD and a 30-percent threshold for NLCD. This represents 2 percent of the total damage acreage mapped via polygons in 2015. Note that, because not all land was surveyed in 2015, this figure only indicates presence of damage and not absence of damage and may include false negatives.

Consistency of Treed Area with Aerial Survey Assessment

Aerial survey experts noted a few challenges with assessing treed cover. First, observer 2 noted that determining a percent treed cover is not consciously done when conducting an aerial survey. Both of the observers noted that the assessment of severity is done very quickly concurrently with other assessments of host, agent, and size of area.

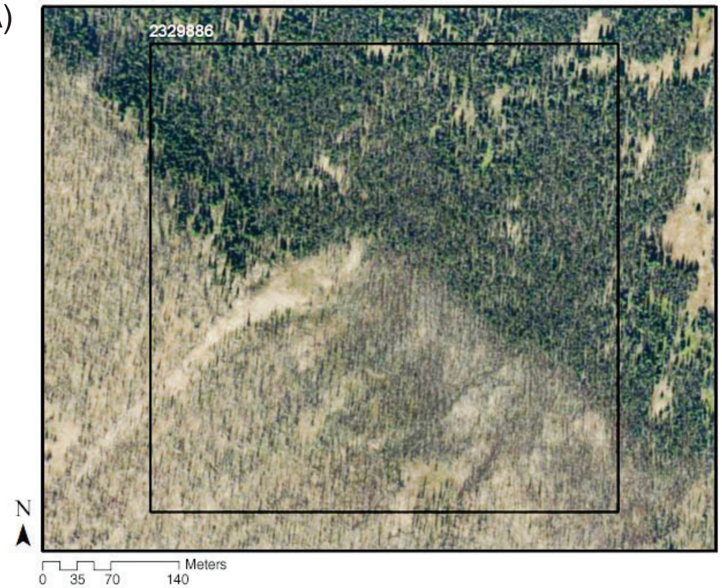
Aerial surveyors' assessment of treed area in NAIP imagery was overall closest to the NLCD30 threshold versus NLCD10 or NLCD20 (table 7.2). Agreement was similar among 30-, 60-, and 90-m resolution, with slightly worse agreement at larger spatial resolution; only the NLCD10 aggregated to 60-m resolution had lower RMSE than its 30-m counterpart (19.4 percent and 21.1 percent for observer 1's and observer 2's assessments, respectively). Error was higher for polygons in the Western United States compared to the Eastern United States (table 7.2). The two different experts had similar RMSE with each other, suggesting consistency among aerial surveyors from different regions, although it is difficult to conclude this based on only two surveyors. The exercise revealed two key issues with determining canopy cover using NLCD (fig. 7.6). First, aerial surveyors are trained to read areas containing standing dead trees as "treed," whereas NLCD would classify them as low canopy cover due to its reliance on spectral data and lack of live canopy in those areas. Second, in NLCD, sparse forests and woodlands may register as low canopy cover, making these places particularly sensitive to the placement of the canopy cover threshold for NLCD data. Expert assessment revealed that there may be large differences between different surveyors' treatment of a sparse woodland as treed or untreed when making a damage rating.

Table 7.2—Root mean squared error (RMSE) between treed cover estimates from expert assessment and from canopy cover layers derived from NLCD for 480-m superpixels randomly selected from large, round polygons located west of the Great Plains ("West") and east of the Great Plains ("East") in 2008 and 2015

	NLCD10[a]			NLCD20[b]			NLCD30[c]		
Expert	West	East	All	West	East	All	West	East	All
	percent treed cover								
Observer 1	21.6	13.9	19.7	20.6	9.3	18.1	17.8	9.1	15.8
Observer 2	22.4	18.5	21.6	20.5	7.5	18.9	17.1	4.9	15.4

[a] NLCD TCC-derived treed area using a 10-percent TCC threshold.
[b] NLCD TCC-derived treed area using a 20-percent TCC threshold.
[c] NLCD TCC-derived treed area using a 30-percent TCC threshold.

(A)

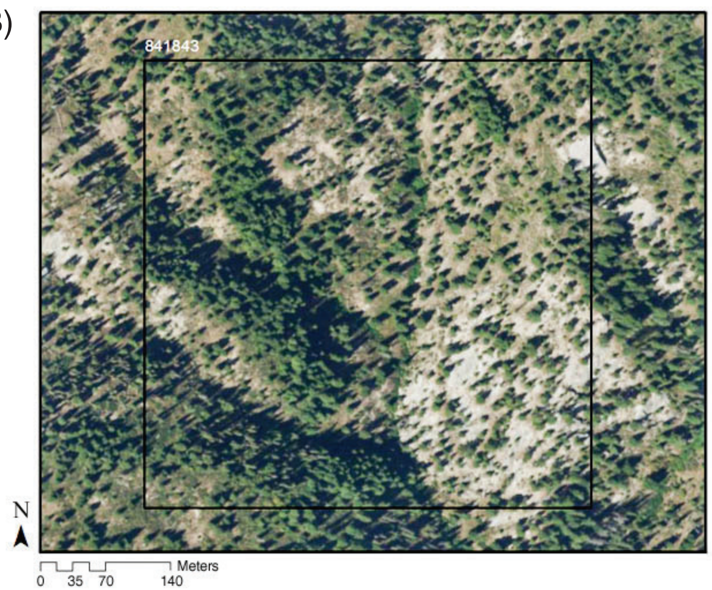


NLCD10: 78%
NLCD20: 50%
NLCD30: 45%

FNF: 98%

O1: 95%
O2: 95%

(B)



NLCD10: 71%
NLCD20: 41%
NLCD30: 30%

FNF: 80%

O1: 65%
O2: 40%

Figure 7.6—NAIP imagery from selected 480-m superpixels randomly sampled from large, round IDS polygons in 2008 and 2015 and different estimates of the percentage of treed area within the superpixel. (A) An area containing standing dead trees from a wildfire, which are read as "untreed" by NLCD. (B) An area where complex terrain results in spatial heterogeneity of forest density and widely varying assessments of treed cover depending on canopy cover threshold and expert. The red text indicates the layer that came closest to the expert assessment of treed cover. NLCD10 = treed cover from NLCD using a 10-percent canopy cover threshold; NLCD20 = treed cover from NLCD using a 20-percent canopy cover threshold; NLCD30 = treed cover from NLCD using a 30-percent canopy cover threshold; FNF = FHAAST native treed layer (Ellenwood and others 2015); O1 = observer 1's visual assessment from NAIP imagery; O2 = observer 2's visual assessment from NAIP imagery.

DISCUSSION

A key calculation needed for inclusion in the DMSM Desktop and Reporting Tools is adjustment for untreed area included in polygons or grid cells reported by surveyors. To accomplish this in a GIS setting, a raster denoting treed versus untreed area could be used in post-survey processing. For example, the user could view the intersection of IDS feature classes (polygons or grid cells) with treed cover and perhaps aerial imagery, such as NAIP, giving the surveyor the option to calculate treed acres for each feature. An important requirement for the continued use of a treed layer by FHAAST is that the layer is updated frequently to remain representative of conditions during the survey. Since 2002, FHAAST has developed the FNF treed cover layer at 30-m and 240-m resolutions. However, the latest vintage of the FNF layer represents 2011 conditions, considered outdated during the writing of this report. Thus, there is a need for a new, updated treed cover layer available for use with IDS data. Our analysis found that the NLCD TCC can be a feasible option to use for adjusting IDS polygons to represent only treed area for use in IDS summaries, but with caveats. Due to overall lower percent canopy cover in arid, western forests compared to eastern forests, using the unadjusted raw NLCD TCC product to determine canopy cover may underestimate western U.S. forest damage compared to the Eastern United States. Instead, NLCD TCC should be converted to a binary treed/untreed layer based on a canopy cover threshold, similar to FHAAST's ca. 2011 FNF layer.

The results from this analysis could be useful to inform decisionmaking that uses NLCD TCC thresholds to define a treed/untreed mask for the area of interest (AOI). Considering variability in forest cover across the AOI may aid in selecting a NLCD TCC threshold for delineating treed area. For example, if one decides to use NLCD30 to define "treed area," then it is important to recognize that such a threshold will cut off a larger proportion of the tails of the distributions in more arid ecosystems than in others. Our results suggest that there can be greater inaccuracies in assigning treed cover to IDS data in the Western United States than in the Eastern United States, where sparser forests and woodlands may cloud the distinction between calling something "treed" versus "untreed." At the national scale, when errors in these large polygons are considered in the context of all IDS data for a given year, the overall error is low. This is because most polygons drawn in any given year are small and specific enough to contain mostly treed area, and the problem is largely restricted to certain regions, like arid, sparse forests. Ultimately, the decision of what NLCD TCC threshold to use might be a choice between under- or over-estimation of acres of damage in western forests compared to eastern forests. Differences in survey intensity and accuracy between western and eastern regions may play a factor in this decision; for example, it is arguably more challenging to accurately map tree damage in many eastern areas compared to western, so it may make sense to err on the side of an eastern-appropriate threshold than western.

To decide what TCC threshold to use for delineating forested area within the polygons, one consideration could be that whatever threshold is used should have results that are consistent with how the aerial surveyor assesses forested area when deciding what the mortality severity is. According to the experts we contacted, this is difficult to quantify, because aerial surveyors work quickly and subconsciously when making a judgment about how much of the forest is impacted. What is deemed "untreed" may differ by surveyor and region. Despite this, the two aerial surveyors with whom we worked on this analysis had assessments of treed area from aerial imagery that were very similar to each other, with the exception of areas that were very sparsely wooded. The NLCD TCC threshold that compared best to aerial surveyors' assessments was 30 percent, although the accuracy did not decrease very much for 20- or 10-percent TCC thresholds. Accuracy was noticeably higher for polygons located in the Eastern United States compared to the Western United States (table 7.2).

In this work, we only considered the use of NLCD TCC layer to distinguish treed cover. It may be worthwhile to seek out and test other products given some other key limitations of TCC. For example, NLCD uses different methodologies for its 2006, 2011, 2016, and planned 2021 products. This would make it difficult to compare measured "acres of" damage across consecutive years that overlap with these transitions from one product to the next. Another major issue with using NLCD as a treed layer for our purposes is that any spectral-derived layer of forested cover will have large errors in burned areas. Aerial surveyors consider standing dead trees as "treed," whereas the lack of vegetation would result in a reflectance-derived layer (like TCC) to call burned areas "untreed." This could be overcome by using a burned area layer to correct for these areas, such as Monitoring Trends in Burn Severity (MTBS), the newer U.S. Geological Survey Burned Area product (Hawbaker and others 2017), or the forest cover layer updated annually by Hansen and others (2013).

In cases where forests are fairly continuous or where damage is concentrated and easily contained within a general polygon shape or grid cell, use of a treed layer may not provide much advantage. However, many regions, especially those in the Eastern United States, are characterized by non-continuous forest due to farms, meadows, and urban infrastructure on the landscape. With the change in how mortality severity is recorded in DMSM compared to DASM, it is important to consider how uncertainty inherent in using mortality classes (rather than trees per acre) compares to uncertainty added by the use of a treed layer that may under- or over-estimate treed area in a given feature class. As an example, consider an aerial surveyor who makes an assessment of a 1920-m grid cell in an urban area as having Light (4–10 percent) mortality severity due to emerald ash borer (*Agrilus planipennis*) (fig. 7.7, grid cell A). To adjust the grid cell acreage to "acres of" damage, one approach would be to multiply the midpoint of the mortality range (7 percent) by the size of the grid cell (911 acres) = 64 acres of damage. However, the grid cell includes farmland and roads and thus only 80 percent of the cell is treed. Applying this treed area adjustment would result in 64 acres x 0.80 = 51 acres of damage. This is the same "acres of" damage value as we would get with NO treed area correction and estimating 6 percent mortality instead of 7 percent mortality, still falling within the Light mortality severity category. In contrast, grid cell B in figure 7.7 is only 25 percent treed and was also assessed

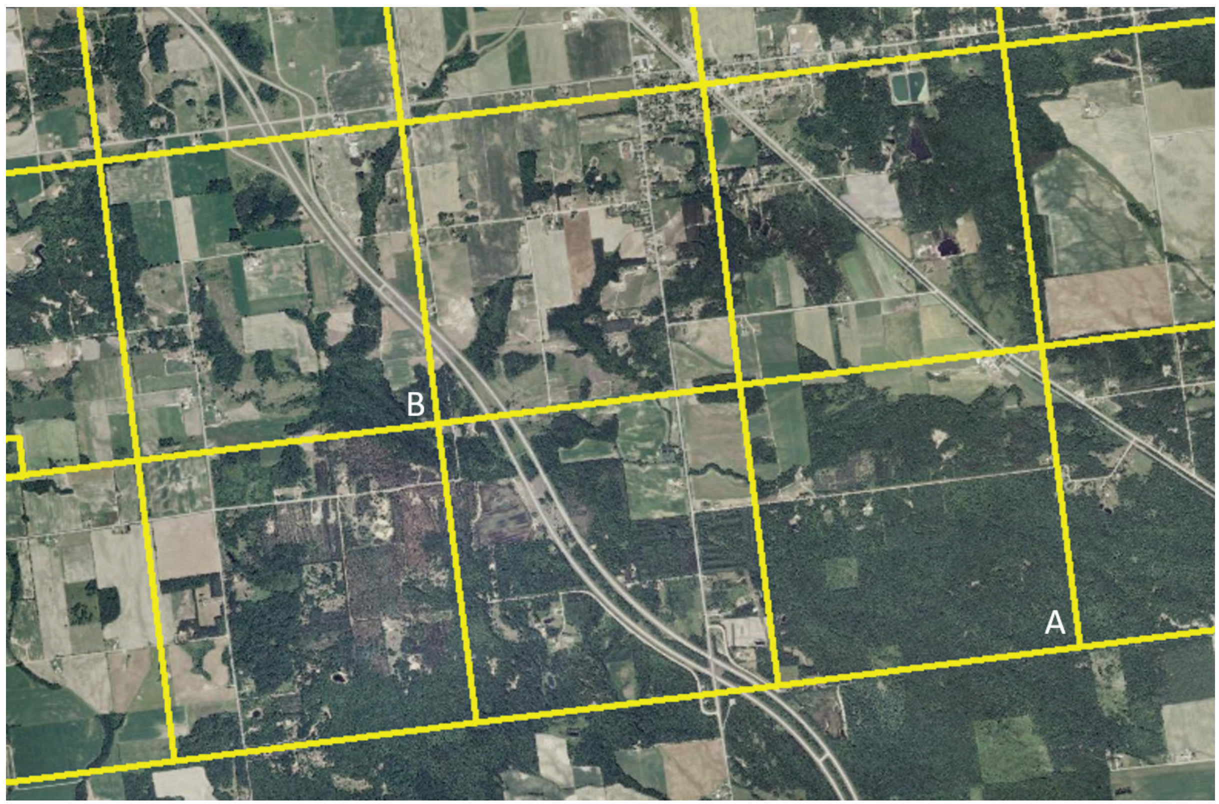


Figure 7.7—IDS data from 2015 showing 1920-m grid cells used to map emerald ash borer mortality in Michigan. Grid cell A has higher tree cover than grid cell B, and both cells were mapped at the same mortality severity (Light).

as having Light (4–10 percent) emerald ash borer mortality severity. Again, multiplying the mortality midpoint times the grid cell acreage results in 64 acres of mortality. Further adjusting this to only consider treed area results in 16 acres of damage. This same acreage of damage is equivalent to about 2 percent mortality if we do not account for untreed area, which would be considered Very Light mortality severity. Therefore, considering treed versus untreed area can make a difference in damage assessments when treed area is relatively low. This demonstrates the utility of using grid cells along with treed area for improving estimates of "acres of" damage, especially in areas with farms and urban development mixed in with forest which may not be feasible to distinguish by drawing polygons.

In our analysis, we found that NLCD30 agreed more often than NLCD10 or NLCD20 with aerial surveyors' assessments of treed cover contained within large, round IDS polygons. However, the uncertainty (RMSE) was not very different across the thresholds (a range of 15- to 22-percent error). Based on our analyses, national-scale IDS summaries on widespread pests may be largely insensitive to differences in treed cover layers that may be used to adjust polygons or grid cells for "acres of" damage. However, for analyses at scales smaller than the continental United States and for restricted-range pests and diseases, this error could be substantial depending on the region and pest of interest. The error associated with using one canopy cover threshold over another for a treed layer will often be smaller than the uncertainty inherent in the damage severity classes, although lower damage severity classes, with narrower ranges of error than moderate or high severity, could be most affected by error in tree canopy cover threshold. A bigger concern might be the possibility for large errors in treed cover in burned areas where standing dead trees remain, because NLCD will have much lower treed area than aerial surveyors would consider when assigning a mortality severity class. In such cases, using data derived locally that are more accurate than national products such as NLCD TCC would be desirable. Ultimately, the need for adjusting IDS polygons for treed area to improve "acres of" damage estimates must be decided on a case-by-case basis, depending on the region of interest, the goals of the summary, and the damage severity categories that have been mapped.

Overall conclusions:

- The use of severity classes in DMSM allows for an initial estimate of "acres of" damage by multiplying polygon or grid "acres with" damage by the midpoint of the assigned mortality class.
- Further adjustments for treed cover will have a lesser impact on "acres of" damage but may be necessary for large, general polygons and grid cells. A binary treed cover layer derived from the NLCD TCC product can feasibly delineate treed area inside IDS polygons and grid cells with a threshold of 20- or 30-percent TCC. Key uncertainties lie with delineating treed area in western, arid forests and where wildfires recently burned, and with using NLCD from different years (e.g., 2006 and 2011) due to changing methodologies.
- Crosswalking legacy measures of damage severity with DMSM will be challenging. Further analysis and testing are recommended to determine the appropriate methodology for representing cumulative "acre of" damage in an outbreak that spans both DASM and DMSM.

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