Bio-evaluation: Dothistroma Needle Blight near Gustavus, AK, 2016

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Background

Nine 24ft-radius permanent plots were installed near Gustavus, AK June 20-22 2016 to monitor shore pine foliage disease severity and survival. Here, there has been an outbreak of Dothistroma needle blight disease ongoing since around 2010 that has resulted in crown discoloration, premature needle loss, and shore pine mortality. Associated Sitka spruce and black cottonwood remain healthy. The problem was originally investigated in 2012, when Gustavus community members and local ecologists contacted USFS Forest Health Protection staff about the poor condition of shore pine, and tree crown damage was observed and mapped during the July aerial survey.

In August 2012, the cause of the damage was preliminarily determined to be Dothistroma needle blight, and definitively confirmed in June 2013. A similar damage signature was observed on the main tree bole and lateral branches of many trees when temporary transects were installed at four sites in 2013: needle cohorts from 2008 and 2009 were present, needle cohorts from 2010 and 2011 had been prematurely cast, the 2012 needle cohort was discolored with abundant *Dothistroma* fungal fruiting structures, and the 2013 needle cohort was still in the bud or emerging. This pattern indicates that the outbreak began around 2009 and 2010. In the absence of a foliage disease outbreak, older needles are cast first. From 2013-2016, Dothistroma needle blight was aerially mapped on 3,400-4,800 acres per year and approximately 11,000 acres near Gustavus and Glacier Bay National Park. In 2015 and 2016, Dothistroma was also aerially mapped between Haines and Klukwan and north of Skagway. The increased acreage from 2012 (500 acres) to 2013 is probably partly due to increased sampling effort in addition to disease spread and intensification. In 2015, the species of Dothistroma present in Gustavus, Haines, and Juneau was molecularly confirmed as *Dothistroma septosporum* by Irene Barnes and Mike Wingfield at the University of Pretoria in South Africa. This is the same presumably native fungal species that occurs in neighboring British Columbia and has caused unprecedented damage to lodgepole pine plantations linked to climate change (Woods et al. 2005).

Transects Installed 2013, Remeasured 2014

In June 2013, four 15x100ft transects were installed to coincide with the 2012 aerially mapped damage polygons. Within transects, foliage disease severity ratings (1-5) and dominance class (sapling, suppressed intermediate, codominant, and dominant) were tallied for all shore pine trees (≥ 4.5ft tall), and counts of other tree species were recorded. Foliage disease severity ratings of 1-5 corresponded to the percentage of the tree crown affected by foliage disease (1=0-5%, 2=6-49%, 3=50-95%, 4=96-99%, 5=100%; Fig. 1). Shore pine trees with disease ratings 3 and 4 were flagged so that their survival could be assessed the following year. Fifty of the 112 flagged pines (46%, 40-57% of flagged pines per plot) were dead in August 2014, and 9 pines (8%, 5-15% of pines per plot) were almost dead. The ratings assigned to some pines had washed off flagging tape by 2014, but trees rated 4 were more likely to die than trees rated 3. Of 58 pines rated 4, the rating was still legible on 41, and 32 (78%) were dead and 2 (5%) almost dead. In contrast, of 54 pines rated 3, the rating was still legible on 38, and only 6 (16%) were dead and 4 (11%) almost dead. Although trees rated 3 were less likely to have died over the course of the year, 61% (23 of 38 with a visible rating) had a more severe disease rating when reassessed in 2014.

When we consider all 204 shore pine transect trees, 115 (56%) were dead in association with severe foliage disease in 2014, with mortality of at least another 4% (9 pines; 8% of flagged pines) expected by 2015. Since transects were non-randomly placed in areas of high disease severity, this level of mortality (61% of shore pine trees) is thought to represent areas with high disease severity and damage visible from the air.

Figure 1. Foliage disease severity ratings of 1-5 corresponded to the percentage of the tree crown affected by foliage disease (1=0-5%, 2=6-49%, 3=50-95%, 4=96-99%, 5=100% (not pictured)).

Permanent Plots Installed 2016

Site selection and methods

The trees in four transects installed in 2013 and remeasured in 2014 were not permanently tagged. Although these transects were quick to install and allowed us to examine relationships between disease severity, dominance class and mortality rate, they did not facilitate long-term monitoring of individual tree damage and survival or changes in species composition and basal area. Therefore, we installed 24ft-radius permanent plots at nine locations. This included the four transect locations (plots 1-4 correspond to transects 1-4), and five more plots distributed across the area of known damage (from damage polygons mapped 2012-2016; Fig. 2). We installed plots on accessible sites with symptomatic shore pine trees for which we could determine ownership and obtain permissions. In some locations, it was important to locate portions of the forest with enough remaining live shore pine to warrant long-term monitoring, balanced with the goal of representing the composition and condition of the surrounding forest. A research permit was not acquired for Glacier Bay National Park prior to our visit, precluding us from installing plots on NPS land. Two plots were installed immediately east of the park boundary.

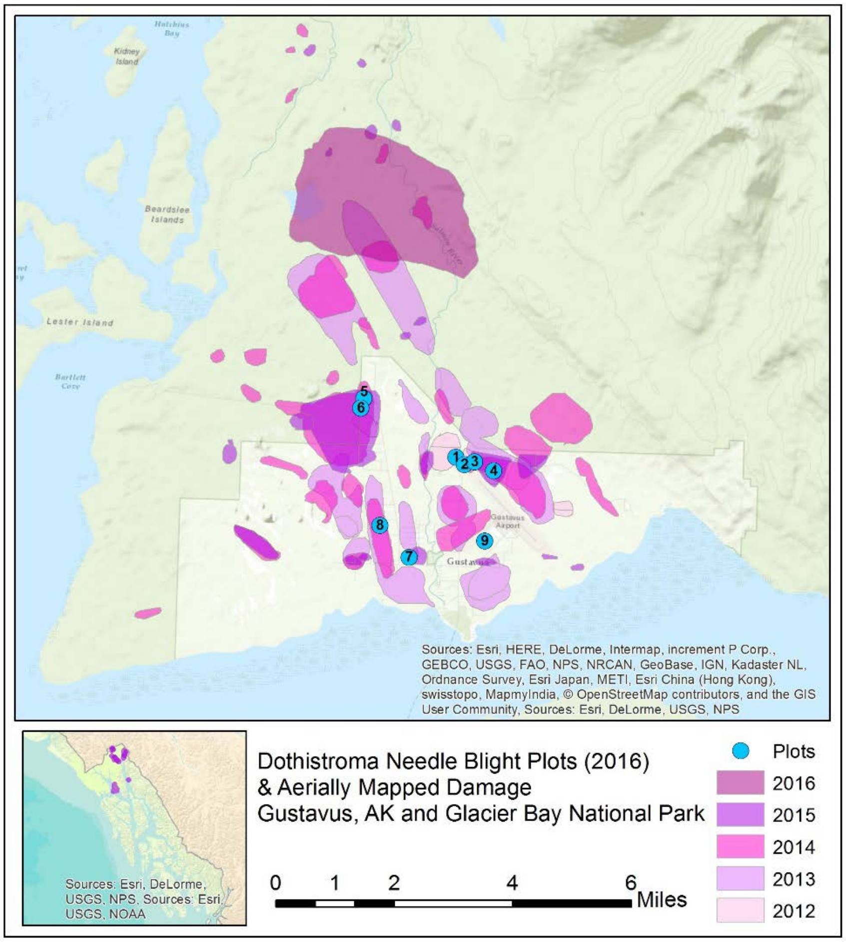

Figure 2. Dothistroma plot locations and Dothistroma damage polygons aerially mapped from 2012-2016.

Plot tree attributes recorded included: tree tag number, species, diameter, dominance class, live/dead status, decay class of snags (1-5), and observed damage. For shore pine, we also recorded foliage disease severity (1-5), foliated branch length (in) and foliage retention (yrs) (current year foliage not included), western gall rust (WGR) rating (0-6), presence and location of WGR bole galls, and an estimate of the height of crown with more than 1 year of foliage retention (ft, measured from top of tree). We also recorded whether the tree had been flagged in a 2013/14 transect (trees with severity ratings 3 and 4 were flagged) and the rating, if still legible. Decay classes were assigned following Forest Inventory Analysis definitions: 1-fine branches and needles present, 2- few fine branches no needles, 3- coarse branches only, losing bark, 4- losing bark, top broken, and 5- no bark, broken top, obviously decayed sapwood. Consistent with previous surveys, foliage disease severity ratings of 1-5 corresponded to the percentage of the tree crown affected by foliage disease (1=0-5%, 2=6-49%, 3=50-95%, 4=96-99%, 5=100%). WGR is caused by the fungus *Peridermium harknessii*. WGR rating was determined by vertically dividing the live tree crown into three equal sections, and assigning each section a rating of 0 (no galls), 1 (galls present, affecting < 50% of branches), or 2 (galls present, affecting ≥ 50% of branches or bole gall present). The ratings for each portion of the crown were then summed. This WGR rating system was modeled after the Hawksworth (1977) dwarf mistletoe rating system and was used in a broader assessment of shore pine health throughout SE Alaska (46 plots installed 2012-2013; Mulvey and Bisbing 2016). Temperature dataloggers were installed in each plot, attached to the north side of one tree bole near plot center at breast height, recording hourly.

Results summary

We collected data from 327 shore pine trees (188 snags), and 406 total trees greater than 4.5ft tall (Table 1). Of 140 dominant and codominant trees, 127 were shore pine (91%; including 39 snags), 11 were spruce and 2 were cottonwood (data not shown). Shore pine was the dominant tree species in all plots, with relative composition ranging from 56-100% of trees (Table 1). In all but two plots (7 and 9), > 50% of pines were dead. In contrast, very few associated trees were dead (2/70 spruce, both were suppressed trees). In some plots (1 and 2), pine mortality has already resulted in species composition shifts from pine-dominated to spruce-dominated forest. In other plots, there are relatively few trees of other species and the stand trajectories are less certain. In all plots, a high percentage of snags were very recently dead (retained needles and fine branches; Table 1), indicating that their death coincided with the foliage disease outbreak ongoing since 2010. It is unknown how long it takes shore pine to progress through snag decay classes following mortality; smaller dominance class pines in decay class 3 may have also been killed during this outbreak.

Composition and percentage dead based on basal area showed different trends than percentages of trees alone (Table 2). The percentage of shore pine dead by basal area tended to be lower (9-69% by plot, 34% overall) than by percent of trees (25-76%, 57% overall; Table 1). Dominant and codominant pines had lower overall mortality rates compared to other dominance classes, but dead dominant and codominant were also more likely to have died very recently (decay classes 1 and 2; Table 3).

Foliage disease severity ratings of 1-5 corresponded to the percentage of the tree crown affected by foliage disease (1=0-5%, 2=6-49%, 3=50-95%, 4= 96-99%). All live shore pine in plots had disease severity ratings of 2 or higher; the average rating was 3.4 and average needle retention was < 1 year (Table 4). By plot, average disease severity ranged from 3.1 to 3.9 and foliage retention ranged from 0.3 to 1.3 years (data not shown). As observed in the 2013/14 transects, there was an inverse relationship between both disease severity and foliage retention and dominance class (Table 4). In 2014, 61% of surviving tagged trees had more severe disease ratings than assigned in 2013. More severe disease was also noted in 2016: only 43% of dominant trees were rated disease severity 3 and 4 in 2013 compared to 84% in 2016 (Fig. 3).

Similar to our shore pine plot network in SE Alaska, 89% of live shore pine were infected with western gall rust, but severity ratings were lower: 50% were rated 1 and 2, 35% were rated 3 and 4, and 4% were rated 5 and 6 (data not shown). Western gall rust bole galls affected 14% of shore pine and associated topkill was also rare; this contrasts with the permanent shore pine plot network, in which 35% of pines had bole galls and 25% suffered associated topkill (Mulvey and Bisbing 2016).

Table 1. Plot information, including location, tree composition by species (number of trees with the number dead in parentheses), percent shore pine composition and snag information based on number of trees.

Plot	Latitude	Longitude	Shore pine	Sitka spruce	Black cottonwood	Western hemlock	Total Trees	Shore Pine Composition (% of trees)	Shore Pine Snags (%) in decay class 1-2	Shore Pine Dead (%)
1	58.43915	135.7302	27 (18)	19 (1)	2	-	48	56%	89%	67%
2	58.43747	135.7261	31 (18)	20 (1)	-	-	51	61%	72%	58%
3	58.43814	135.7214	35 (20)	7	-	6	48	73%	55%	57%
4	58.43615	135.7124	17 (13)	3	-	1	21	81%	62%	76%
5	58.45285	135.7737	72 (54)	2	-	-	74	97%	54%	75%
6	58.45048	135.7751	45 (29)	5	-	-	50	90%	69%	64%
7	58.41447	135.7504	40 (10)	11	-	-	51	78%	90%	25%
8	58.42202	135.7646	33 (17)	-	-	-	33	100%	53%	52%
9	58.41893	135.7156	27 (9)	3	-	-	30	90%	67%	33%
Total/ Avg.	--	--	327 (188)	70 (2)	2	7	406	81%	64%	57%

Table 2. Basal area (BA) by plot and species (in square feet per acre with dead basal area in parentheses), and percent shore pine composition and snag information based on basal area.

Plot	Shore pine	Sitka spruce	Black cottonwood	Western hemlock	Total	Shore Pine Composition (% of BA)	Shore Pine Dead (% of BA)
1	28.31 (12.81)	15.54 (0.13)	4.73	-	48.57	58%	45%
2	63.80 (22.97)	13.32 (1.18)	-	-	77.11	83%	36%
3	144.89 (42.25)	4.18	-	6.40	155.47	93%	29%
4	118.89 (81.77)	10.81	-	1.10	130.80	91%	69%
5	153.79 (66.05)	0.44	-	-	154.22	100%	43%
6	98.01 (40.77)	0.88	-	-	98.89	99%	42%
7	81.16 (7.65)	6.09	-	-	87.24	93%	9%
8	116.34 (19.91)	-	-	-	116.34	100%	17%
9	125.43 (26.27)	47.54	-	-	172.96	73%	21%
Total	930.60 (320.44)	98.78 (1.31)	4.73	7.51	1041.62	89%	34%

Table 3. The dominance and snag classes of 188 shore pine snags, with percentage dead and percentage of dead trees in decay classes 1 and 2.

Dominance Class	Decay Class 1	Decay Class 2	Decay Class 3	Decay Class 4	Decay Class 5	Dead	Live	% Dead	% Class 1 and 2
Dominant	4	-	-	-	-	4	36	10%	100%
Codominant	20	8	1	5	1	35	52	40%	80%
Intermediate	45	19	25	12	2	103	34	75%	62%
Suppressed	7	3	3	4	-	17	5	77%	59%
Sapling	10	5	5	9	-	29	12	71%	52%
Total Trees or Percent of Trees	86	35	34	30	3	188	139	57%	64%

Table 4. The dominance class and foliage disease severity rating of 139 live shore pine trees with the percentage of trees of each dominance class in parentheses. Average foliage retention (yrs) is shown with standard deviation in parentheses followed by the observed range.

Dominance Class	Disease Severity Rating 2	Disease Severity Rating 3	Disease Severity Rating 4	No Rating	Avg. Rating	Avg. Foliage Retention (Yrs)	Number of Trees
Dominant	6 (17%)	19 (53%)	11 (31%)	-	3.11	1.2 (0.8), 0.1-4.0	36
Codominant	3 (6%)	26 (50%)	23 (44%)	-	3.35	0.8 (0.5), 0.1-2.2	52
Intermediate	1 (3%)	7 (21%)	24 (71%)	2 (6%)	3.72	0.7 (0.5), 0.1-2.0	34
Suppressed	-	-	5 (100%)	-	4.00	0.4 (0.2), 0.2-0.8	5
Sapling	1 (8%)	4 (33%)	7 (58%)	-	3.50	0.6 (0.6), 0.1-1.8	12
Total Trees (% in parentheses)	11 (8%)	56 (40%)	70 (50%)	2 (1%)	3.41	0.9 (0.6), 0.1-4.0	139

Discussion

The installation of a permanent plot network in forests affected by Dothistroma needle blight near Gustavus will allow us to track disease progression, tree survival, and important shifts in forest composition over time. A similar plot system has been established near Haines, AK, where an outbreak began around 2014/15. The degree of pine mortality observed in this localized outbreak is unprecedented for SE Alaska. Overall, 57% of shore pine trees and 34% of the pine basal area in our pine-dominated plots is dead. Two plots already appear to be transitioning from pine-dominated to spruce-dominated as a direct result of this outbreak. The outbreak is continuing, with worsening disease severity ratings (average rating 3.4) recorded among the remaining live pines, and further mortality is expected.

Relatively smaller shore pine trees may progress through the snag decay classes faster than larger trees, as has been shown in other pine species and ecosystem types (Dunn and Bailey 2012, Corace et al. 2010). Our observations suggest that smaller pines are more likely to have succumbed to foliage disease earlier in the outbreak, given their tendency to have higher disease severity ratings as live trees and greater percentages of trees dead (71-77% dead for intermediate, sapling, and suppressed trees). Smaller trees are more susceptible to suppression mortality, and this could also help to explain the broader range of decay classes observed among these dominance classes compared to codominant and dominant trees.

Similarly unprecedented pine mortality from Dothistroma needle blight has been reported in northwestern British Columbia (Woods et al. 2005). A dendrochronology study of affected plantations in BC identified August minimum air temperature as the best predictor of historical outbreaks, while above normal precipitation emerged as another important predictive variable (Welsh et al. 2014). Temperature data loggers taking hourly readings in each of our permanent plots will help us to determine whether important temperature thresholds for the pathogen may have been surpassed in the outbreak area. In the future, it may also be beneficial to track leaf wetness with specialized sensors, and to compare temperature and leaf wetness in areas of severe disease to nearby healthier forests of similar composition and structure. The interaction between temperature and leaf wetness strongly influences Dothistroma needle blight disease dynamics: infection can occur anytime during the growing season when needles are wet and temperature is favorable (15-20°C) (Peterson 1967, Gadgil 1974, Harrington and Wingfield 1998, Woods et al. 2005). The ideal temperature combination was found to be a daytime temperature of 20°C and a nighttime temperature of 12°C (Gadgil 1974). Careful analysis of weather variables before and after outbreak initiation in 2009/10 is also warranted.

There was a much lower incidence of damaging WGR bole infections and associated topkill near Gustavus, AK compared to our broader shore pine plot network, suggesting that there are biologically significant climate differences with our other plot locations. It is unclear why severe outbreaks have begun to occur in northerly and relatively drier portions of the range of shore pine in the panhandle (near Gustavus, Klukwan, Skagway and Haines) compared to wetter locations in SE Alaska. One theory is that higher rates of precipitation might actually wash spores off of needles, reducing successful infection. Peterson (1967) found that even small amounts of precipitation were sufficient for *Dothistroma* spore dispersal; it is possible that slight increases in summer moisture and temperature have created conditions far more conducive to Dothistroma needle blight disease development. Examples of climate change impacts on forest disturbance are mounting (Hennon et al. 2012, Woods et al. 2005). All suspected interactions between climate change and novel forest stressors require thorough investigation linking directional climate change (not isolated weather events) to individual tree health and survival, and long-term forest change.

Figure 3. Thin-crowned and dying codominant and dominant plot trees affected by Dothistroma needle blight near Gustavus, AK (2016).

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