Eric,

I’m glad to hear progress is being made on this and am excited to see the final results.  Here are my thoughts regarding the questions raised by Brian.

dHost, I believe using only the tree species will work.  The trees likely represent the majority of the roots on many sites and information concerning *P. cinnamomi* susceptibility in shrubs and herbs is mostly lacking.

dWater, If we can added a variant of the epidemiological model you describe dWater in the ProbPresence equation might be used to describe where enough moisture is available for *P. cinnamomic* to survive.  Another option might be to remove dWater from the ProbPresence and assume anywhere chestnut can grow has enough moisture for *P. cinnamomi* to survive, but not necessarily cause significant disease.

ProbPresence = dTemp \* dHosts

The inclusion of the epidemiological model, or something similar, might be very helpful and able to handle what is generally seen, where under wet conditions *P. cinnamomi* reproduces, infects new hosts and disease symptoms develop.  When conditions become intermediate *P. cinnamomi* maintains preexisting infections but trees can replace or cope with the amount of roots lost to the pathogen, uptake enough water and new symptoms are generally less prevalent.  When conditions become dry, new infections do not occur but symptom development and tree death is high because of the root loss caused by *P. cinnamomi* and the trees inability to regenerate sufficient roots and uptake enough nutrients/water.

I would envision dWater values causing the following shifts in the epidemiological model:

high - shift from “Susceptible” to “Infected non-symptomatic” to “Diseased symptomatic”

intermediate – shift from “Diseased symptomatic” to “Infected non-symptomatic”

low – shift from “Infected non-symptomatic”  to “Diseased symptomatic”

Could this “epidemiological model” or maybe “conducive environment” be integrated into the Damage(*i*) equation?

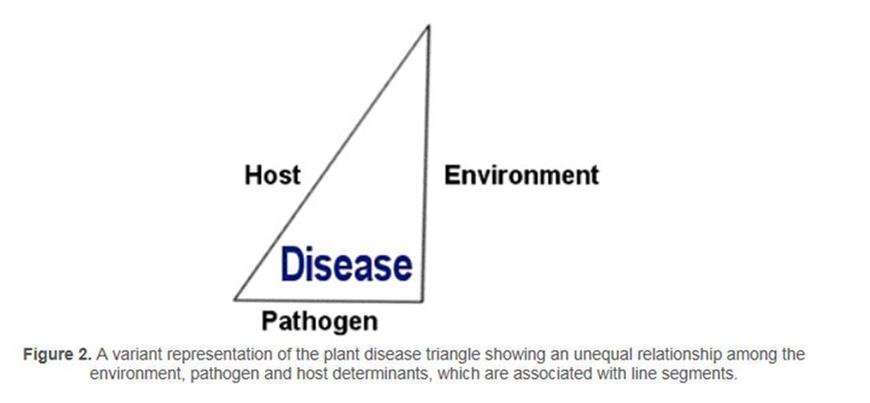
Damage(i) = Presence \* Susceptibility(i) \* Conducive Environment

If this is posable the equation would look similar to the disease triangle that is used in plant pathology, see figure below.  The amount of disease is the product of the susceptibility of the host, presence/virulence of the pathogen and conduciveness of the environment to disease development.

Please let me know if you have any questions or if I need to clarify anything.

Thanks,

Tyler



<https://www.apsnet.org/edcenter/instcomm/TeachingArticles/Pages/DiseaseTriangle.aspx>

**===========================================================**

**From:** Miranda, Brian R -FS   
**Sent:** Tuesday, February 26, 2019 11:41 AM  
**To:** Gustafson, Eric -FS <[egustafson@fs.fed.us](mailto:egustafson@fs.fed.us)>  
**Subject:** RE: Root rot question

Eric,

Here’s my recap of where we left off in the root rot discussion.

* dTemp appears to have good support, with literature to draw from for parameterization.
* dHosts may be challenging because there are many hosts that would not be simulated (not trees).  Is it okay to use tree species as indicators of host presence, even if the tree species themselves are not hosts?  We should also clarify whether the quantity of host relative to non-host is important in determining the presence of *P. cinnamomi*, or simply the presence of host is what is important.
* dWater sounds like it might need to be adjusted to better capture the environment factors.  Tyler stated that both flooding and drought can favor disease development.  I’m wondering if this implies a bi-modal function for dWater would be appropriate, where the value is high at both low and high pressure head values, and lower in between.  It’s not clear how we would determine the appropriate threshold values to define this function.

The above factors are part of the calculation to determine presence of the disease.  I have not seen any comments regarding the damage to tree cohorts.

I took a quick look back at the Epidemiological Disturbance Agent extension, and I don’t think we want to try to fit this into how that model specifically operates.  But I am wondering if we might want to adopt part of the structure of that model as it may help us more clearly define the condition of a site and to use the appropriate factors along the way.  Here’s a snippet from the User’s Guide:

Epidemiological disturbances in LANDIS are probabilistic at the cell (site) scale, where each site is assigned a probability of being in one of the following states: **Susceptible** (S), **Infected** (infectious non-symptomatic) (I), **Diseased** (infectious and symptomatic) (D) (Fig. 1).  Probabilities are compared with a uniform random number to determine whether the site becomes infected or, if already infected, to become diseased. Disease causes species- and cohort-specific mortality in the cell.

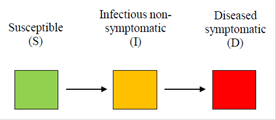


Figure 1. Compartmental structure of the epidemiological model (see equations in Section 2.4)

I’m wondering if this intermediate stage of infectious non-symptomatic might address some of the examples that Tyler provided of survival of the pathogen, but disease only appearing under favorable conditions.  So there might be different environment factors that lead to each stage and we’re trying to squeeze them into a single factor which is causing the difficulty.

I think we could use some additional feedback from those with knowledge of this disease before we get too far along.  Feel free to share my thoughts above with others if it will help the discussion.  I have also attached the design document that I have been working from for verification that I have the most current version, and if you have a more current version please share that.  Thanks!

Cheers,

-Brian

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Eric,

Thanks for the explanation.

Regarding the disease triangle yes the pathogen factor refers to the necessity of the pathogen being on the site.  As I understand it your algorithm for pathogen presence describes where P. cinnamomi can survive.  ProbPresence = dTemp \* dWater \* dHosts

I have a few questions and comments.

dTemp - I think we have a good understanding of the lower temperature limits that P. cinnamomi can survive and this will be what mainly controls the pathogens distribution.

dWater – Seems like a very powerful variable but I’m not aware of research that has looked at dWater and P. cinnamomi survival.  Have I missed something or are you able to glean enough from published studies to determine the dWater values that P. cinnamomi cannot survive?  For example P. cinnamomi causes a root rot in sand pine in FL, is found on oaks in the Ozarks and OH, chestnut in KY, and shortleaf in western NC.  These are very different environments and likely to have very different dWater values.

dHosts – This will be somewhat challenging because P. cinnamomi has over 1000 known host (including trees, scrubs, and herbaceous plants) and has been isolated from asymptomatic herbaceous plants.

I agree that the pathogen factor is a function of the environment and host factors.  But, the environment where P. cinnamomi can survive and where and when disease develop are two different things.  For example P. cinnamomi can survive in soil for more than 6 years without hosts and in studies in Australia can survive in and slowly grow in infected roots during unfavorable conditions (cold and/or dry) but only after the environment becomes favorable for disease development(warm and wet)  does P. cinnamomi aggressively grow in the infected roots, reproduce and infect new hosts.  A second example is littleleaf disease.  P. cinnamomi is found throughout the SE along with its many susceptible hosts but the disease is only a problem in a small portion of the SE, see the figure below.  P. cinnamomi also cases a very damaging root rot on sand pine in FL on drier and very sandy environments.  This might not be important as we are concerned with areas north of where sand pine is found but is an example of very different environments being favorable to P. cinnamomi disease development.

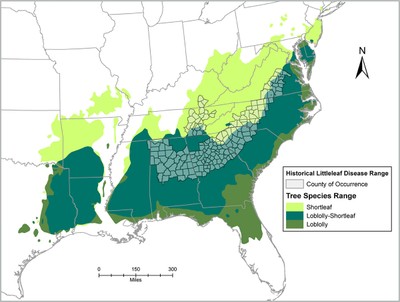
[](http://shortleafpine.net/growing-shortleaf-pine/forest-health/diseases-and-pests/littleleaf-disease/page-1/figure-1.jpg)

Figure 1. Native range of two commercial, southern pine species affected by littleleaf disease.

<http://shortleafpine.net/growing-shortleaf-pine/forest-health/diseases-and-pests/littleleaf-disease>

dWater might be useful in determining environments suitable for disease development and/or pathogen survival but it combines many different factors into one value that might cause problems.  I believe it would be possible to find sites that are very suppressive and favorable to disease development that have similar dWater values.  For example I assume (please let me know if I’m way off here) dWater values in some parts of FL and NC with shortleaf pine could be similar and would be higher than dWater values for areas with sand pine in FL.  But diseases caused by P. cinnamomi are only a problem in western NC and in sand pine in FL.  Are both high and low dWater values favorable for disease development?  Flooding, drought and particularly cycles of flooding and drought have been shown to favor disease development.  Depending on how dWater is calculated it might be hard to capture this in a single variable.

We might want to run the model as is or however it ends up using shortleaf pine and see how the results compare to Figure 1 and the Shortleaf Pine Initiative’s Site Suitability & Decision Support Tool (<http://shortleafpine.net/tools/site-suitability-and-decision-support-tool>).  If the results are similar the model might be realistic enough and we would have supporting evidence the model works reasonably well.  This is only a suggestion and if I’m completely missing something please let me know, this is not my area of expertise.

This type of work is all very new to me and I’m afraid I have more questions than answers.  Sorry if all of the questions are not helpful.

Thanks,

Tyler

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| --- | --- | --- | --- | --- | --- | --- |
| Forest Service Shield | |  | | --- | | **Tyler Dreaden, PhD  Research Plant Pathologist** | | **Forest Service**  **Southern Research Station, SRS-4160 Forest Health Research and Education Center** | | **p: 859-257-5969  c: 828-620-1997** [**tdreaden@fs.fed.us**](mailto:tdreaden@fs.fed.us) | | 1405 Veterans Drive Lexington, KY 40546 [www.fs.fed.us](http://www.fs.fed.us/)  [USDA Logo](http://usda.gov/)[Forest Service Twitter](https://twitter.com/forestservice)[USDA Facebook](https://www.facebook.com/pages/US-Forest-Service/1431984283714112) | | **Caring for the land and serving people** | |

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**From:** Gustafson, Eric -FS   
**Sent:** Thursday, October 18, 2018 2:17 PM  
**To:** Dreaden, Tyler - FS <[tdreaden@fs.fed.us](mailto:tdreaden@fs.fed.us)>  
**Cc:** Pinchot, Cornelia C -FS <[corneliapinchot@fs.fed.us](mailto:corneliapinchot@fs.fed.us)>; Sturtevant, Brian R -FS <[bsturtevant@fs.fed.us](mailto:bsturtevant@fs.fed.us)>; Douglass Jacobs ([djacobs@purdue.edu](mailto:djacobs@purdue.edu)) <[djacobs@purdue.edu](mailto:djacobs@purdue.edu)>; Miranda, Brian R -FS <[brmiranda@fs.fed.us](mailto:brmiranda@fs.fed.us)>  
**Subject:** RE: Root rot question

This is helpful, Tyler.

In studying the Disease Triangle a little more closely, it appears to me that the Pathogen factor refers to the necessity of the pathogen being at the site.  In my algorithm, we assume that the pathogen can disperse everywhere and anywhere except where at least one of the limiting factors is zero.  dTemp and dWater represent the Environment factor, and dHosts the Host factor. Thus the Pathogen factor is actually a function of the Environment and host factors because it is basically ubiquitous where Environment is conducive.  Let me know if this perspective is not consistent with your understanding of the triangle.  If we have to simulate dispersal of the pathogen, things get much more complicated because that is a spatial process.

The model carries no information about soil erosion, soil fertility or pH, but the dWater term integrates soil drainage, water logging, water shortage, soil depth and saturation.  We are working on an algorithm to estimate monthly soil temperature (for permafrost purposes), but maybe it would be adequate to use air temperature as a proxy.  We can probably come up with an algorithm to crudely estimate soil temperature in the surface meter of the profile.

Thoughts?

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| |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | | |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | Forest Service Shield | |  | | --- | | **Eric J. Gustafson, PhD  Research Ecologist** | | **Forest Service**  **Northern Research Station, Institute for Applied Ecosystem Studies** | | **p: 715-362-1152  f: 715-362-1166** [**egustafson@fs.fed.us**](mailto:egustafson@fs.fed.us) | | 5985 Highway K  Rhinelander, WI 54501 [www.fs.fed.us](http://www.fs.fed.us)  [http://wwwstatic.fs.usda.gov/images/email/usda-logo.png](http://usda.gov/)[Twitter Logo](https://twitter.com/forestservice)[Facebook Logo](http://facebook.com/USDA) | | **Caring for the land and serving people** | | | |

**From:** Dreaden, Tyler - FS [<mailto:tdreaden@fs.fed.us>]   
**Sent:** Thursday, October 18, 2018 12:44 PM  
**To:** Gustafson, Eric -FS <[egustafson@fs.fed.us](mailto:egustafson@fs.fed.us)>  
**Cc:** Pinchot, Cornelia C -FS <[corneliapinchot@fs.fed.us](mailto:corneliapinchot@fs.fed.us)>; Sturtevant, Brian R -FS <[bsturtevant@fs.fed.us](mailto:bsturtevant@fs.fed.us)>; Douglass Jacobs ([djacobs@purdue.edu](mailto:djacobs@purdue.edu)) <[djacobs@purdue.edu](mailto:djacobs@purdue.edu)>; Miranda, Brian R -FS <[brmiranda@fs.fed.us](mailto:brmiranda@fs.fed.us)>  
**Subject:** RE: Root rot question

Eric,

I believe it is more complicated then soil water potential as periodic flooding and drought have been shown to increase mortality.  The known environmental factors that contribute to disease development vary somewhat between systems.  Generally soils with poor drainage, saturated during parts of the year, low permeability, and shallow rooting zones increase disease severity.

Here are site characteristics for two US systems.

Littleleaf disease - High amount of soil erosion, low fertility, low internal soil drainage, periodic water logging, periodic water shortages, shallow soils with areas of reduced permeability close to the surface, saturated soils close to the surface.

North Carolina Christmas tree plantations - Extreme hazard sites – extremely poor drainage, warm soil temps (>50F), average soil pH 4.5-6, and saturated soils

I think disease severity on a site has less to do with its history of infection and more to do with the properties of the site.  But if a site has a history of disease then it has soil properties conducive for disease development and the site is likely to have problems with disease development in the future.  Given this, I think increasing mortality on areas with a history of disease caused by P. cinnamomi would be an option if the very general conducive soil properties are difficult to use in your model.

If I’m not being clear please let me know.

Thanks,

Tyler

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| --- | --- | --- | --- | --- | --- | --- |
| Forest Service Shield | |  | | --- | | **Tyler Dreaden, PhD  Research Plant Pathologist** | | **Forest Service**  **Southern Research Station, SRS-4160 Forest Health Research and Education Center** | | **p: 859-257-5969  c: 828-620-1997** [**tdreaden@fs.fed.us**](mailto:tdreaden@fs.fed.us) | | 1405 Veterans Drive Lexington, KY 40546 [www.fs.fed.us](http://www.fs.fed.us/)  [USDA Logo](http://usda.gov/)[Forest Service Twitter](https://twitter.com/forestservice)[USDA Facebook](https://www.facebook.com/pages/US-Forest-Service/1431984283714112) | | **Caring for the land and serving people** | |

**From:** Gustafson, Eric -FS   
**Sent:** Thursday, October 18, 2018 12:00 PM  
**To:** Dreaden, Tyler - FS <[tdreaden@fs.fed.us](mailto:tdreaden@fs.fed.us)>  
**Cc:** Pinchot, Cornelia C -FS <[corneliapinchot@fs.fed.us](mailto:corneliapinchot@fs.fed.us)>; Sturtevant, Brian R -FS <[bsturtevant@fs.fed.us](mailto:bsturtevant@fs.fed.us)>; Douglass Jacobs ([djacobs@purdue.edu](mailto:djacobs@purdue.edu)) <[djacobs@purdue.edu](mailto:djacobs@purdue.edu)>; Miranda, Brian R -FS <[brmiranda@fs.fed.us](mailto:brmiranda@fs.fed.us)>  
**Subject:** RE: Root rot question

Tyler,

This is a great thought!  I am wondering exactly what soil properties are captured by the concept of Conducive Environment.  If it is soil moisture, this is already captured by the dWater term in the calculation of ProbPresence because soil water potential is a function of both precipitation inputs and soil texture (water holding capacity to be exact).  I don’t think we need to include this property twice, but perhaps there is some other attribute of the soil series that we should include.  It would help me to understand what property of the soil make it conducive or not.  Is it the history of infection?

Thanks!

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**From:** Dreaden, Tyler - FS [<mailto:tdreaden@fs.fed.us>]   
**Sent:** Thursday, October 18, 2018 9:34 AM  
**To:** Gustafson, Eric -FS <[egustafson@fs.fed.us](mailto:egustafson@fs.fed.us)>  
**Cc:** Pinchot, Cornelia C -FS <[corneliapinchot@fs.fed.us](mailto:corneliapinchot@fs.fed.us)>; Sturtevant, Brian R -FS <[bsturtevant@fs.fed.us](mailto:bsturtevant@fs.fed.us)>; Douglass Jacobs ([djacobs@purdue.edu](mailto:djacobs@purdue.edu)) <[djacobs@purdue.edu](mailto:djacobs@purdue.edu)>; Miranda, Brian R -FS <[brmiranda@fs.fed.us](mailto:brmiranda@fs.fed.us)>  
**Subject:** RE: Root rot question

Eric,

I have one though/question.  Can we account for the environment in the Damage(*i*) equations?  The equation would then look very similar to the disease triangle used by plant pathologists to explain the amount of disease development.  Maybe something like

Damage(*i*) = Presence \* Susceptibility(*i*) \* Conducive Environment

We do not have much information on the environments that are conducive to chestnut damage by *P. cinnamomi* but could use environmental factors that increase risk of littleleaf disease until chestnut specific information is available.  We could give users the option to include or omit the Conducive Environment term or perhaps choose how the term is calculated.  Including the Conducive Environment term and the option to exclude it should give us more flexibility and might help during the peer review process.  Including the Conducive Environment term now might make it easier to update the model as more information becomes available.

I’m not sure of the best way to define the Conducive Environment term, but here are a few thoughts.

We could give users the option to increase mortality on sites with a history of littleleaf disease, see the figure below.

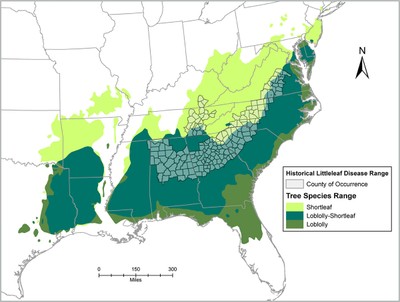
[](http://shortleafpine.net/growing-shortleaf-pine/forest-health/diseases-and-pests/littleleaf-disease/page-1/figure-1.jpg)

Figure 1. Native range of two commercial, southern pine species affected by littleleaf disease.

<http://shortleafpine.net/growing-shortleaf-pine/forest-health/diseases-and-pests/littleleaf-disease>

Depending on what soil information is available we might be able to use soil characteristics, Table 3 on page 6 at the below link, or soil series, Table 4 on page 8 at the below link, to define the Conducive Environment term.

**Table 4. Littleleaf disease risk level by Natural Resource Conservation Service (NRCS) soil series.7**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Risk Level** | | |
|  | **Low** | **Moderate** | **High** |
| Soil Series | Alamance, Ailey, Altavista, Armenia, Blanton, Buncombe, Cecil, Chewacla, Congaree, Davidson, Durham, Enoree, Giwnett, Georgeville, Hiwassee, Lakeland, Louisburg, Lloyd, Lockhart, Nason, Norfolk, Orangeburg, Pacolet, Red Bay, Rion, Starr, Tirzah, Toccoa, Wateree, Rion, Wehadkee, Wickham, Worsham | Albertville, Appling, Barfield, Bladen, Bonnie, Colfax, Decatur, Dewey, Fullerton, Gilead, Helena, Louisa, Luverne, Lyerly, Madison, Mayodan, Meggett, Ora, Pacolet, Sequoia, Sweatman, Talbott, Tallapoosa, Townley, Vaucluse, Waynesboro, Wolftever, Zion | Boswell, Cataula, Catawba, Colbert, Conasauga, Creedmoor, Cunningham, Enders, Enon, Firestone, Goldston, Herndon, Iredell, Latham, Lignum, Manteo, Mecklenburg, Orange, Susquehanna, Tatum, Vance, White Store, Wilkes, Winnsboro |

<http://shortleafpine.net/growing-shortleaf-pine/forest-health/diseases-and-pests/littleleaf-disease>

Please let me know what you think or if you have any questions.

Thanks,

Tyler

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| --- | --- | --- | --- | --- | --- | --- |
| Forest Service Shield | |  | | --- | | **Tyler Dreaden, PhD  Research Plant Pathologist** | | **Forest Service**  **Southern Research Station, SRS-4160 Forest Health Research and Education Center** | | **p: 859-257-5969  c: 828-620-1997** [**tdreaden@fs.fed.us**](mailto:tdreaden@fs.fed.us) | | 1405 Veterans Drive Lexington, KY 40546 [www.fs.fed.us](http://www.fs.fed.us/)  [USDA Logo](http://usda.gov/)[Forest Service Twitter](https://twitter.com/forestservice)[USDA Facebook](https://www.facebook.com/pages/US-Forest-Service/1431984283714112) | | **Caring for the land and serving people** | |