# Boxwood Blight Infection Risk Model
## A disease caused by *Calonectria pseudonaviculata* (Fungi: Ascomycota)

Infection Risk Model Documentation for USPEST.ORG
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**Model Access Links**

This model has been released and is available at the USPEST.ORG multi-pest modeling website:
https://uspest.org/risk/boxwood_app
(newer interface intended for mobile devices; latest version includes an option for "push" email notifications); find apps by searching for "boxwood blight" in the Apple App and Google Play stores, and:

https://uspest.org/risk/models?mdl=bxwd_s
(older interface integrated with 150+ other USPEST.ORG "MyPest Page" models. Note bxwd_s is the key standing for "boxwood blight – susceptible varieties")

The synoptic (N. America) version of this model, which uses Google maps and links current risk level color-coded pins to the full model (older interface) for each available weather station, is available at:
https://uspest.org/risk/boxwood_map

**Abstract**

The invasive pathogen, *Calonectria pseudonaviculata* (synonyn *Cylindrocladium buxicola*) causes boxwood blight on susceptible cultivars of boxwood, *Buxus sempervirens* and related species. Models to predict infection and severity of this disease are urgently needed. As part of the OIPMC/USPEST.ORG commitment to tools to mitigate the impact of IPM and invasive pests in the US, an infection risk model was developed in order to better predict environmental conditions conducive to infection. Version 2.1 of this model was developed from four main sources; 1) a presentation by Belgian researchers Gehesquiere, Huylenbroeck, and Heungens (Sept. 2012), for two varieties of *Buxus*; *B. sempervirens* (Common or American boxwood), which has been classified as susceptible, and *B. sempervirens var. Suffruticosa* (English or true dwarf boxwood), which was found to be among the most highly susceptible varieties assessed (see https://ext.vt.edu/content/dam/ext_vt_edu/boxwoodblighttaskforce/files/resistant_susceptible.pdf), 2) a publication by Avenot et al. 2017, 3) boxwood blight webinars available (Mar. 2012 & Mar. 2013) from http://www.anla.org, including presentations by Sharon Douglas (Conn. Agric. Exp. Sta.) and others, and 4) end-user feedback and incidence report analysis. The model will be revised as additional data become available.

In version 1.0 of the model, we developed a "degree-hours (DH) during periods of leaf wetness (LW)" infection risk model. Two lower temperature thresholds for infection risk were fit using the x-intercept regression method: 46ºF (7.78ºC), for first infections on young foliage; and 51ºF (10.56ºC), for first infections on mature foliage. First infection DH values (in Fahrenheit) were: Young leaves (Tlow=46ºF): B. s. var. Suff.: 56 DHs, B. s.: 160 DHs; Mature leaves (Tlow=51ºF): B. s. var. Suff.: 41

DHs, B. s.: 144 DHs.

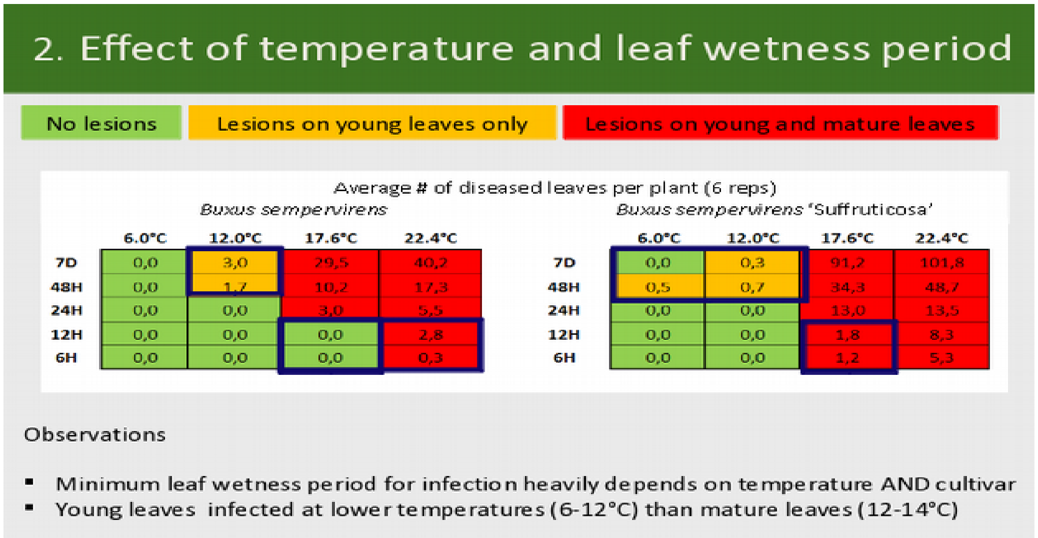
For version 2.0 (2018) of the model, a non-linear temperature response with lower, optimal, and upper threshold values established as 47ºF (8.3ºC), 76ºF (24.4ºC) and 89ºF (31.7ºC) based on Avenot et al. 2017 (Fig.s 3 and 4). This update was implemented using a non-linear table lookup approach to infection degree-hours. The dry period required to halt the infection process, based on Aventot et al. 2017, was shortened from 8 hours to 3 hours. This was later recalibrated to 5 hours based on end-user feedback and case-study analysis. The laboratory studies that established such a short dry period proved unrealistic, as leaf-dryoff after periods of rainfall or once dewpoint is reached can take longer in the plant canopy than under laboratory conditions.

The model (since version 1.0) also calculates the relative degree of infection (measured as the number of lesions per plant reported by Gehesquiere et al.).  Selected additional predictions (in Fahrenheit) of this extended model include: at 250 DHs: B. s. var. Suff.: 6 lesions, B. s.: 1 lesion; at 400 DHs: B. s. var. Suff.: 12 lesions, B. s.: 3 lesions; at 550 DHs: B. s. var. Suff.: 18 lesions, B. s.: 5 lesions.

The model may need further updates as additional results are released, including covering a wider range of susceptibilities beyond the two boxwood varieties studied thus far.

**Models of First Infection**

Time of first symptoms of infection (lesions on leaves), (data from Gehesquiere et al. 2012, Fig. 1) were plotted vs. temperature (C) to determine potential lower thresholds, both for infection of young leaves and mature (less susceptible) leaves, for the two varieties of *Buxus* studied, *B. sempervirens* and *B. s. var. Suffruticosa* (Fig. 2).




*Buxus sempervirens*

| | 6.0°C | 12.0°C | 17.6°C | 22.4°C |
|---|---|---|---|---|
| 7D | 0,0 | 3,0 | 29,5 | 40,2 |
| 48H | 0,0 | 1,7 | 10,2 | 17,3 |
| 24H | 0,0 | 0,0 | 3,0 | 5,5 |
| 12H | 0,0 | 0,0 | 0,0 | 2,8 |
| 6H | 0,0 | 0,0 | 0,0 | 0,3 |

*Buxus sempervirens* 'Suffruticosa'

| | 6.0°C | 12.0°C | 17.6°C | 22.4°C |
|---|---|---|---|---|
| 7D | 0,0 | 0,3 | 91,2 | 101,8 |
| 48H | 0,5 | 0,7 | 34,3 | 48,7 |
| 24H | 0,0 | 0,0 | 13,0 | 13,5 |
| 12H | 0,0 | 0,0 | 1,8 | 8,3 |
| 6H | 0,0 | 0,0 | 1,2 | 5,3 |

Fig. 1. Data of Gehesquiere et al. 2012 used to develop vers. 1.0 *Buxus* infection risk models.

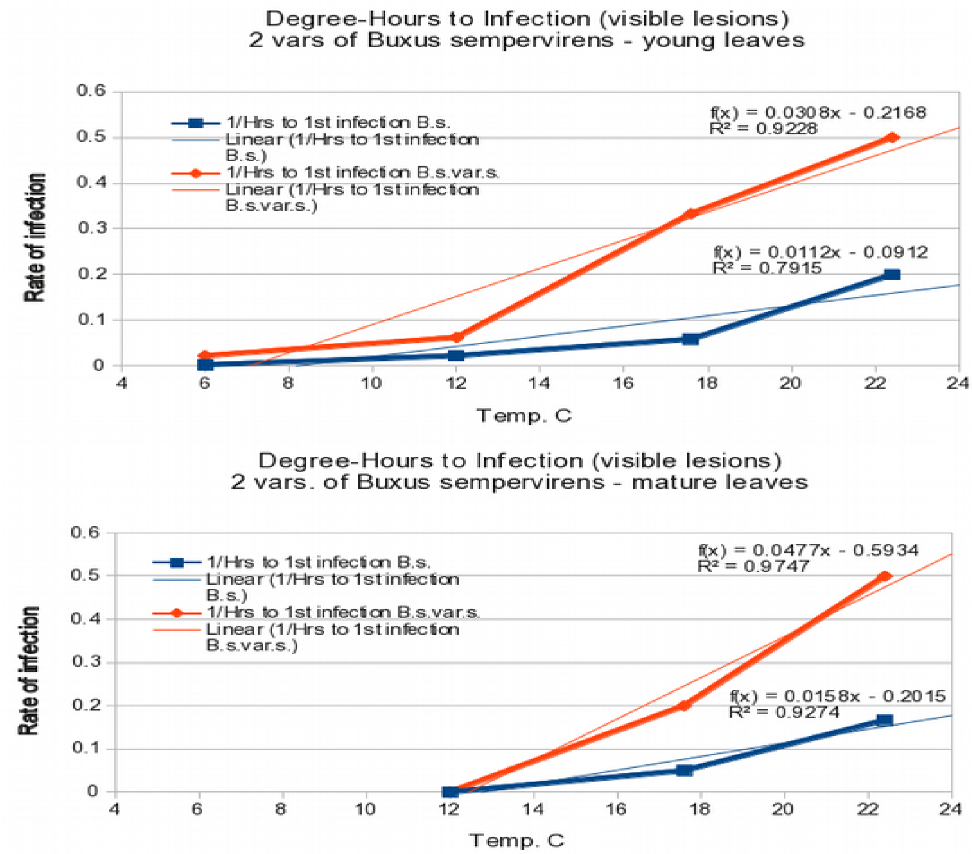



Fig. 2. Regression of rate of first lesion development (1/hours) vs. Temperature (C) for two varieties of boxwood, and for young leaves (Top), and mature leaves (Bottom).

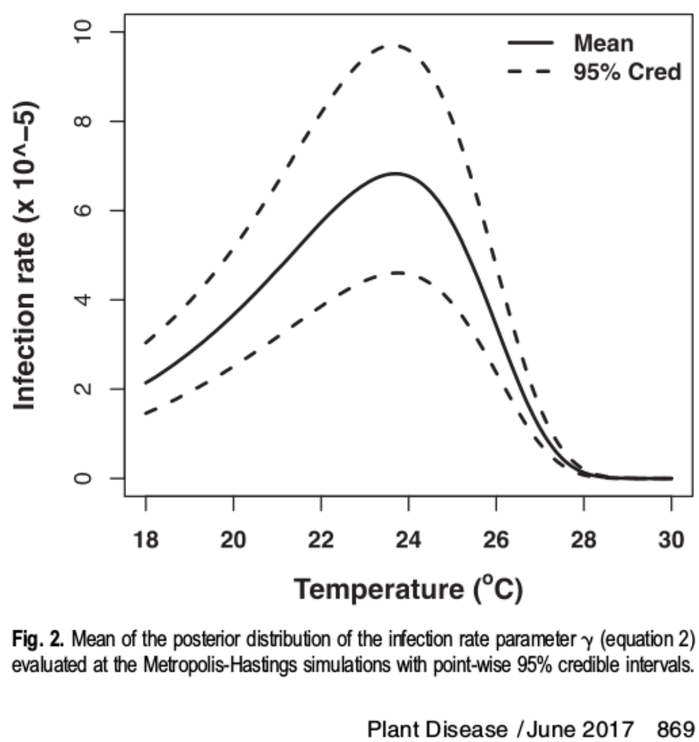



Fig 3. Infection rate vs. temperature response modeled in Avenot et al. 2017.

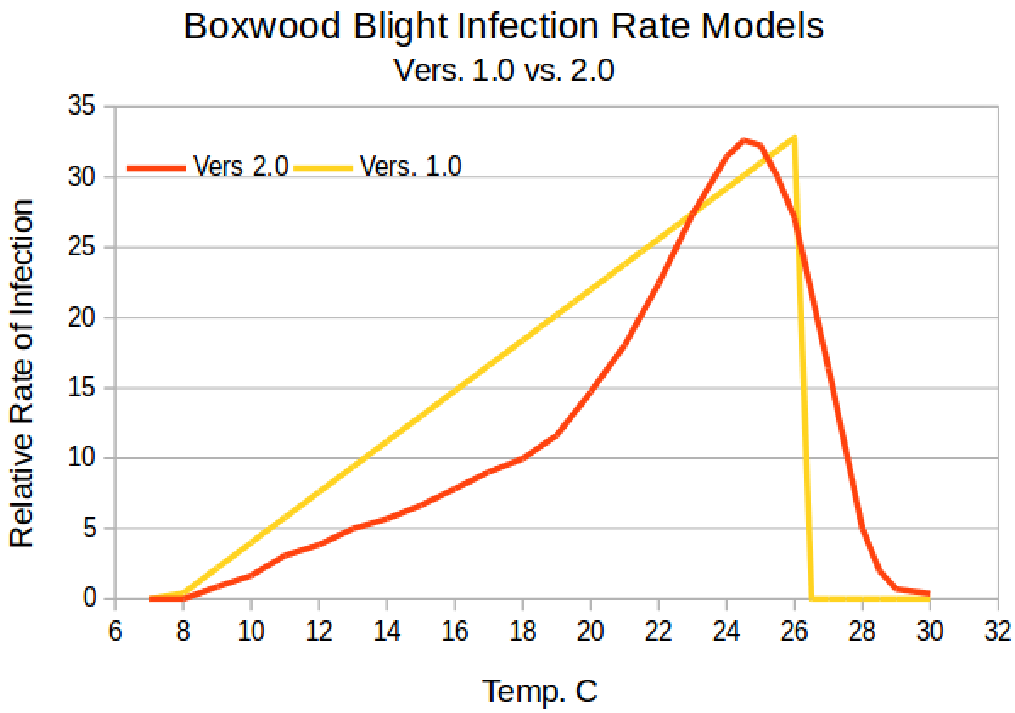



Fig. 4. Infection rate vs. temperature response used in vers. 1.0 and 2.0 in current model.

These models indicated low temperature thresholds (using the x-intercept method) for first lesions of between 7.0 and 8.1ºC for young leaves, and 12.4 and 12.8ºC for mature leaves for the two varieties of boxwood. When combined, and forced to the nearest whole integer (in ºF) and extended past initial infections (see below), these models were modified to a low threshold of 7.78ºC (46ºF) for young leaves, and to 10.56ºC (51ºF) for mature leaves. The resulting regression equations retained a reasonably good fit to the data for first infection models ($r^2$ = 0.92 and 0.79, young leaves; 0.93 and 0.97, mature leaves). The resulting DHs to first lesions were: Young leaves (Tlow=46ºF): B. s. var. Suff.: 56 DHs, B. s.: 160 DHs; Mature leaves (Tlow=51ºF): B. s. var. Suff.: 41 DHs, B. s.: 144 DHs. This version 1.0 temperature response is shown vs. 2.0 in Fig. 4.

**Updated Temperature Response**

When new information on infection rate vs. temperature was published by Avenot et al. (2017), these new results (Fig. 3 above) were combined with the earlier data to form the combined curve depicted in Fig. 4 (Vers. 2.0). This response curve retained the low temperature response range covereded by Gehesquire (2014), plus the higher temperature nonlinear response range reported by Avenot et al. (2017). The combined model was scaled to match the approximate linear curve that was the degree-hour relationship basis for version 1.0, and implemented as a table lookup. The revised model, while no longer a simple DH-LW model, behaves nearly the same as one. Other changes made for version 2.0 included: 1) the temperature response curve was shifted to 1 degree C warmer, to account for some of the cooling effect of the plant canopy vs. a recording weather station shelter, which does not benefit from any evaporative cooling or other canopy effects, which has been estimated to average ca. 1.8 C. under typical daytime conditions, and 2) the dry reset value was reduced from 4.3 hr to 3.3 hr to more literally match laboratory results. In comparisons of model performance this shift initially made little difference to model results. However, upon receiving feedback that the model was now too conservative (overpredicts infection risk), and with case-study analysis, this value was changed back to 5.3 hours. Current feedback (anecdotal but from scientists) is that this value may be about right for more arid regions, but disease risk is under-predicted in highly humid regions. We await data to potentially add a relative humidity threshold to the model to suppliment the LW threshold currently in use.

**Degree of Infection Models**

From the data of Gehesquiere et al. (2012), we regressed the number of leaf lesions per plant (reflecting the number of infections) vs. DH during leaf wetness periods. Varying the low temperature threshold (Tlow) for DH calculation and recording $r^2$ values to indicate best fit indicated that a Tlow in the range of 10.5-11ºC was best for the data when the young leaves, shown above to be more susceptible at lower temperatures, were included in the analysis, and 11.5-12ºC when young leaves were excluded. This degree-of-fit analysis was repeated after dropping the 3 data points with highest number of lesions (due to a leveling off/non-linear effect). Highest $r^2$ values were obtained for Tlows of 11-11.5ºC when including young leaves, and 12ºC excluding young leaves.

Using the original Gehesquire data, two models of disease build up were then fit to the data (Fig. 5):

**B. semp.: Degree of infection (#lesions/plant) = 0.0243 x DH – 2.228; $r^2$ = 0.946**
**B. s. v. Suff.: Degree of infection (#lesions/plant) = 0.0706 x DH – 4.045; $r^2$ = 0.877**

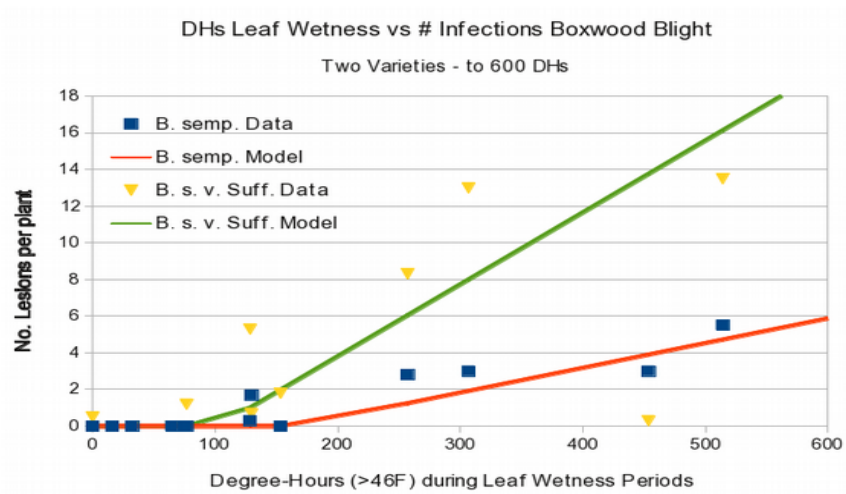



Fig. 5. Degree of infection models (converted to Fahrenheit) and data out to 600 DH.

**Model Description – USPEST.ORG "MyPest Page"**

A single low threshold temperature of 47ºF is used for both young and mature leaves. This temperature is 1ºF higher than 46ºF – the initial threshold temperature for young leaves. We implemented a nonlinear determination of Degree-Hours (DH) (Fig. 4) with optimum at 76ºF and maximum at 89ºF, using a look-up table rather than by fitting a formula (Appendix 1). First lesion (risk) is predicted at 56 DH during leaf wetness periods to infection thresholds while additional infection (degree of infection is predicted through two formulas:

| | |
|---|---|
| For American boxwood: | no. lesions per plant = 0.0243 x DH – 2.228 |
| For English boxwood: | no. lesions per plant = 0.0706 x DH - 4.045 |

These models describe the relative degree of infection have been implemented at the multi-pest modeling website http://uspest.org/risk/models?mdl=bxwd_s. The degree of infection model is subject to interpretation of events relevant to management needs, and therefore should be reviewed especially by potential end-users of the model. The combined model currently uses the following selected events and parameters drawn from the two degree of infection models:

**Summary of Parameters for Modeling Boxwood Blight :**
**Name of model:** Boxwood blight infection risk
**Model type:** Non-linear degree-hours (DHs) during leaf wetness periods
**Lower temp. threshold:** 47ºF (8.3ºC)
**Topt (optimal temperature):** 76ºF (24.4ºC)
**Upper temp. threshold:** 89ºF (31.7ºC)
**No. of dry hours to stop the infection cycle:**
more than 5.0 (this current value is based on both recent work and from end-user feedback)
DHs less than first infection of young leaves (low risk of new infections)
0 - color code 50FF80 (lt. green)
**DHs to first infection of young leaves (highly susc. Var.):**
56 - color hex code 00FF00 (green)
**DHs to first infection of young leaves (susc. Var.):**
160 - color hex code D0FF50 (yellow-green)
**DHs for infection resulting in: 6 lesions, highly susc. Var., 1 lesion, susc. Var:**
250 - color hex code FFC000 (yellow-orange)
**DHs for infection resulting in: 12 lesions, highly susc. Var., 3 lesions, susc. Var:**
400 - color hex code FF7850 (orange-red)
**DHs for infection resulting in: 18 lesions, highly susc. Var., 5 lesions, susc. Var:**
550 - color hex code FF50A0 (lt. red)
**Model assumptions:**
1. Spores from microsclerotia generally require rainfall to spread and initiate the infection process, thus the model conservatively does not require rainfall events, as spores may also be present from existing lesions.
2. The model assumes that infectious pathogen spores (inoculum) are present.
3. The model reflects a range of infection conditions most likely to occur in typical N. America climates; it was adjusted to reflect needs in the humid mid-latitudes (such as NC, VA, WV, PA, and MD). 4. These results reflect work performed on one highly susceptible (English boxwood) and one susceptible (American boxwood) cultivars; lower infection risk levels would be expected for less susceptible cultivars.

**Use of the model at https://uspest.org/risk/boxwood_app (latest mobile-friendly version)**
In Fig. 6., We display the model app with four tabs along the top: Intro, Inputs, Graph (Output), and Table (Output). The Intro tab includes more detailed suggestions on how to run and interpret the model. The Inputs tab includes a search for weather stations including an optional Google map, a start date, time span, and link to register for email push notifications. The Graph tab displays model output in graphical form. New for 2020 is a side-by-side comparison of the selected year vs. the prior year model results. The Table tab shows the same information in tabular form. It is suggested that you run the model for several nearby stations to obtain model consensus on whether environmental conditions are conducive for infection. If so, contact your local Extension personnel for advisement on appropriate management activities.

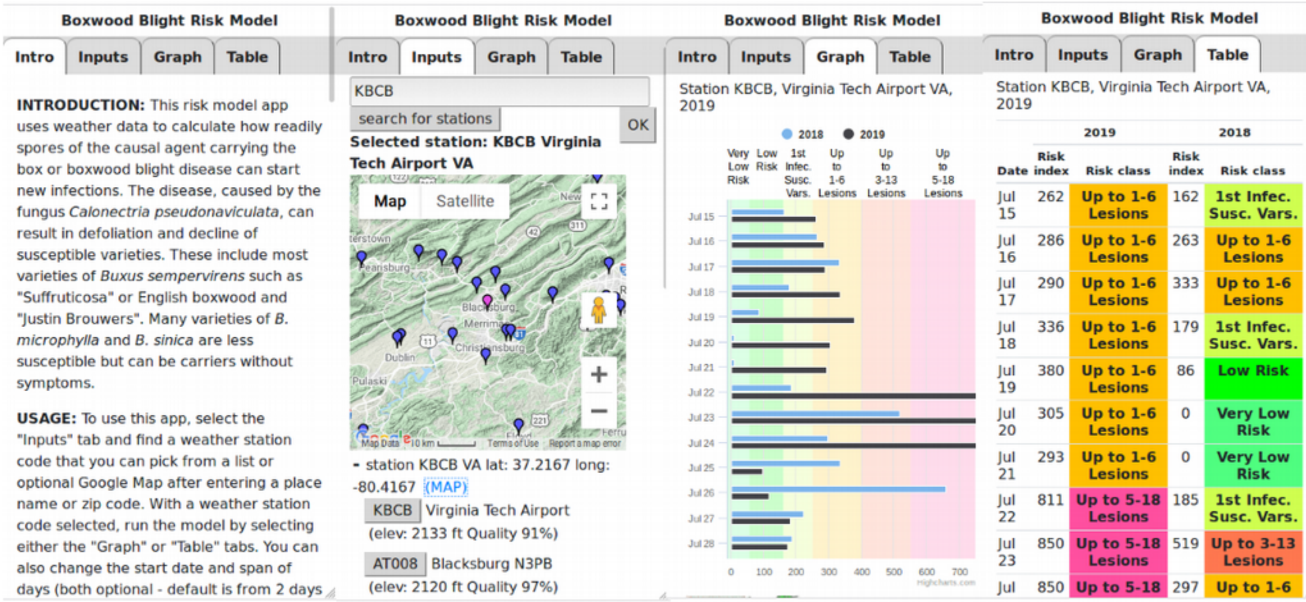



Fig. 6. The four tabs for navigating the boxwood_app are illustrated to show: 1) intro material, 2) model inputs, including weather station selection as aided by Google maps, 3) infection risk forecasts in graph format, and 4) the same results in table form.

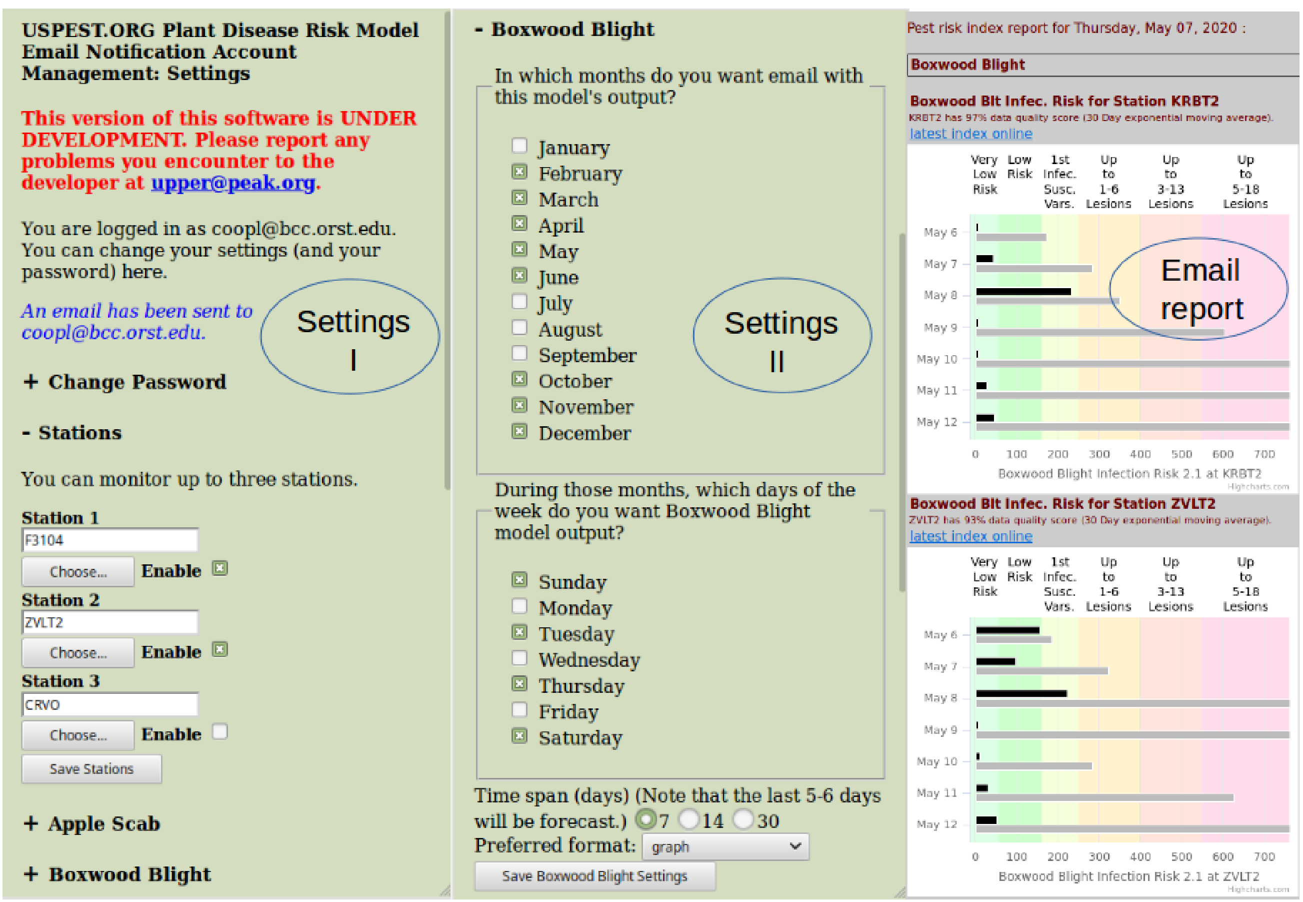



Fig. 7. Email "push" notification system now being tested in version 2.1 of the boxwood_app version of the model. Settings I (left) shows change of password and weather station selection (up to 3 weather stations currently allowed; it is recommended to use the model to find reliable stations and note the

station codes). Settings II (middle) shows selection of the schedule of months and days of the week for sending out the email reports, with time span and output format (graph, table or both). Example email report (right) will be received automatically on the days selected by the user. This system has been grower-tested for a hop powdery mildew model and is being replicated and tested for several other plant disease infection risk models at uspest.org.

**Model Changes and Areas for Potential Model Improvement**

Versions 1.0 and 1.1 have been in use since 2013, with revision to 2.0 in use since July 2018. Version 2.1 includes changes added during 2019 (modify dry period to reset degree-hour accumulations from >3 hr to >5hr) and during 2020 (new beta version of email "push" notifications technology, compare results to previous year). The model has been partly validated by comparing model predictions prior to observed outbreaks in several instances. In nearly all cases, the model gave sufficient warning that infection could spread if inoculum is present. We do have reports from areas of the humid southeastern U.S. which may indicate that leaf wetness is sometimes insufficient to predict infection, possibly due to periods very high humidity. With more research results or sufficient case study analysis, we expect to include a relative humidity threshold in the model to supplement the leaf wetness threshold approach. In a future release, the model is expected to be updated to include the residual effects of fungicides, and splitting forecast predictions into several categories of boxwood cultivar susceptibility, such as moderately tolerant, moderately susceptible, and susceptible cultivars.

If you would like to contribute to validation, please send reports of outbreaks to: coopl@science.oregonstate.edu. Please include in your posting: 1) the cultivars of boxwood affected and symptoms noted, 2) the time when symptoms were first observed/noted to rapidly expand, 3) the location and a description of the setting: park or other public space, nursery, private home, etc, and 4) relevant management activities including the usage of fungicides (active ingredients, rates and timing).

**Disclaimer**

All data and products are provided "as is" and users assume all risk in their use. No claims are made as to the correctness or appropriateness of this information for your particular needs. No specific pest control products are intended for endorsement or use. These responsibilities and all associated liabilities rest solely with the people who interpret and implement information from this and other sources. Use all predictive information with caution - errors occur, and predictive models do not replace the need for proper monitoring in the field. If you observe conditions that differ substantially from model predictions, please contact us to determine if the model inputs were incorrect, if the model functioning or weather data are in error, or if the model is inappropriate for your conditions.

**Acknowledgements**

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**References**

Avenot, H.F., C. King, T.P. Edwards, A. Baudoin andC. X. Hong. 2017. Effects of inoculum dose, temperature, cultivar, and interrupted leaf wetness period on infection of boxwood by *Calonectria pseudonaviculata*. Plant Disease 101:866-873.

Gehesquière, B. 2014. *Cylindrocladium buxicola* nom. cons. prop.(syn. *Calonectria pseudonaviculata*) on Buxus: Molecular characterization, epidemiology, host resistance and fungicide control. Ph.D. dissertation, Ghent University, Ghent, Belgium.

**Appendix I**
Look up table developed from Fig. 4, used to determine degree-hour (DH) boxwood blight infection risk units as a function of temperature during periods of leaf wetness.

| Temp ºF | DH |
|---|---|
| 47 | 0 |
| 48 | 0.7 |
| 49 | 1.2 |
| 50 | 1.8 |
| 51 | 2.4 |
| 52 | 3 |
| 53 | 3.6 |
| 54 | 4.3 |
| 55 | 5 |
| 56 | 5.35 |
| 57 | 5.7 |
| 58 | 6.2 |
| 59 | 6.7 |
| 60 | 7.275 |
| 61 | 7.85 |
| 62 | 8.45 |
| 63 | 9.05 |
| 64 | 9.625 |
| 65 | 10.2 |
| 66 | 11.35 |
| 67 | 12.5 |
| 68 | 14.7 |
| 69 | 16.9 |
| 70 | 18.95 |
| 71 | 21 |
| 72 | 23.75 |
| 73 | 26.5 |
| 74 | 28.85 |
| 75 | 31.2 |
| 76 | 32.5 |
| 77 | 32.3 |
| 78 | 29.3 |
| 79 | 26.3 |
| 80 | 19.95 |
| 81 | 13.6 |
| 82 | 8 |
| 83 | 2.4 |
| 84 | 1.2 |
| 85 | 0.3 |
| 86 | 0.25 |
| 87 | 0.2 |
| 88 | 0.1 |
| 89 | 0 |