

## **Review: Simulating Bark Beetle Outbreak Dynamics and their Influence on Carbon Balance Estimates with ORCHIDEE r7791**

In this manuscript, Marie et al. describe the implementation of a bark beetle outbreak model into the ORCHIDEE dynamic global vegetation model. Pests are an important driver of forest dynamics but are notoriously hard to simulate, so development in this area is always welcome. The authors do not attempt to reproduce specific real-world bark beetle outbreaks in this work, focusing instead on the model description and a more general evaluation of the model's behavior. They show that at least some patterns seen with regard to bark beetle dynamics, such as the duration of outbreaks and the effects of temperature, are reproduced well. I consider this effort a good first step and, in principle, worthy of publication.

However, there are a number of issues that prevent the current version of this manuscript from being accepted for publication. Some parts of the model description are confusing or too vague, and some analyses are insufficiently described (as I describe in my Substantive Comments below). The paper would also benefit greatly from some reorganization, and I have a large number of more minor comments and corrections. With all that in mind, I recommend this paper be **reconsidered after major revisions**.

### **Substantive Comments**

- 1) Many symbols are missing from Table 1 (which should be moved to an Appendix). I've listed some but not all of them in the "minor comments/corrections" section, but please do a thorough review and add any others you find.
- 2) The references to beetle "generations" are hard to understand. They don't seem to fit with how beetle dynamics are ultimately realized in the model, but even in context here it's confusing. The sentence at lines 240-241 says, "the index  $G$  reaches its maximum value of one when 2.5 or more generations occur in a single growing season." But isn't  $G$  "the number of beetle generations... that could occur in the current year"? Then the next sentence is confusing because of "of the first generation." So far we've only been learning about beetle pressure index, not what actually triggers a generation.
- 3) It's really important to include something like Sect. 2.2.4 (differences from beetles in LandClim; lines 365-374), but it's currently too vague. The "calculation of the susceptibility" differences are documented (although not explained, per se) in Table S1, but that's not referenced in the text here. As far as I can tell, the other mentioned differences are not explained at all. A model description paper in *GMD*, as outlined in the Manuscript Types webpage, "should be sufficiently detailed to in principle allow for the re-implementation of the model by others, so all technical details which could substantially affect the numerical output should be described." If such technical details need to go in an Appendix and/or a Supplement, that's fine, but they must be included somewhere. Note also that it doesn't need to be every line of code or even every equation—if you can describe what you did clearly enough using words, that's fine.

4) Although I have plenty of suggestions for Sect. 2.2.5 as you'll see below, I think it's great overall. For the most part, you do a good job of explaining how the model works in plain language. I would encourage you to consider, actually, moving Sects. 2.2.2-2.2.4 to an Appendix—they are highly technical and make more sense after reading Sect. 2.2.5. This may require a bit of reworking on Sect. 2.2.5, but with sufficient references to locations and equations in the Appendix I'm sure you can do it well.

5) Lines 399-403: What about the simulation results caused you to choose these thresholds? The second threshold's explanation seems circular. It is especially important to explain the reasoning here because the time spent in different stages is the crux of the comparison of your model against the literature.

6) Lines 531-534: This is not really apparent from Fig. 5. It might help to group the plots by "outbreak" vs. "no outbreak," then sort within groups by mean annual temperature (and add MAT labels to plot names). But it's unclear how the reader is supposed to tell which bars are "windthrow + beetle" vs "windthrow only that kills the same number [fraction?] of trees as beetle only."

7) Various metrics used in analyses need definition.

- Lines 506-508: How do you get recovery time from Fig. 3? Presumably looking at the areas of some of the wedges, but which? ... Or are you looking at Fig. 4? If so, mention that at the top of this paragraph, and still—define "recovery." Is it "time to return to Year 1 NPP"?
- Lines 592-593: "Persistence" quantified how?

8) Sect. 2.4: I think it sells this paper short to call it a "qualitative evaluation." There is a fair amount of quantitative evaluation happening here too, especially with regard to amount of time spent in different outbreak stages and time to recovery. I think what you're getting at here—and this is clarified at lines 567-571, which as you'll see I think should be moved here—is that you're not actually testing whether specific real-world beetle outbreaks can be reproduced. Right?

### Minor Comments/Corrections

- Throughout:
  - Please use equation mode whenever referring to model symbols. Also, use subscripts and commas. E.g.,  $B_{a,b}$  instead of Bdb or Bdb. This will help greatly with clarity and eventual typesetting.
  - Why is susceptibility index  $S_i$  or  $S_i$  (i.e., "i" lowercase) but beetle pressure index is  $BPI$  (all uppercase)? (Is the "i" even needed?)
- Table 1:
  - rDD and many other symbols are missing.
  - Bdb and Bdw descriptions should replace "dead" with "killed," as they refer to amounts killed in a single timestep rather than all existing + new dead wood from their respective causes.

- This should probably be moved to an Appendix (note: not the Supplement).
  - Add references to this table throughout the manuscript.
- Line 105: How is a one-minute temporal resolution possible if photosynthesis and energy budget happen at 30-minute timesteps?
- Fig. 1:
  - “Windtrow” typo in (1)
  - “Developped” typo in legend at top right
  - Refer to Sect. 2.2.5 and Table 2.
  - Use of “phase” here (e.g. “Green phase”) contrasts with use of “stage” in Sect. 2.2.5.
- Lines 225-227: This was confusing to parse and should be broken up into separate sentences. First list the variables, then explain that they’re indices [0-1]. Then add a sentence indicating you’ll start by walking through G.
- Lines 261-262: It’s confusing to think about negative weights, because presumably all weights always sum to 1.
- Lines 264-265: So  $S_i$  shows up as  $S_i^2$  in the calculation of  $RI$ ?
- Line 268 (eq. 6):
  - Should it be  $(1 - W_s - W_d)$ ?
  - What are  $r_1$  and  $r_2$ ?
- Line 285 (eq. 9): Logic is circular here. Should be changed to  $SIW = \min\left(\frac{Litw}{Bw \times Litt}, 1\right)$ .
- Line 286:
  - What is “breeding substrate,” exactly? All dead wood? All litter wood (i.e., not also standing dead wood)?
  - Is “total woody biomass” just wood in living plants, or does it also include (some? all?) dead wood?
- Lines 294-301: This explanation should come before “ORCHIDEE formalizes this dependency” at line 282?
- Lines 312-215 (eqs. 10 and 11): What are  $MO$ ,  $n$ ,  $a$ ,  $c$ ,  $d_1$ , and  $d_2$ ? They’re not in Table 1.
- Line 319: How is  $RDI$  calculated?
- Line 324 (eq. 12): What are  $a_1$ ,  $a_2$ ,  $a_3$ ,  $s$ , and  $p$ ? They’re not in Table 1.
- Line 334 (eq. 13): What are  $s_1$ ,  $s_2$ ,  $s$ , and  $p$ ? They’re not in Table 1. Is  $Sh_{sp}$  the same as  $sh$ ?
- Line 353: What does “actual” mean here? Should it be replaced with “current”?
- Line 356 (eq. 16): What is the summation range here? “ $nac$  to  $ac=1$ ” means what?
- Lines 376-377: Referring to these as “bark beetle **outbreak** development stages” would avoid confusion with “development” in the sense of physiological growth from larva to adult, as well as improve consistency with Table 2.
- Lines 378-379: Does this refer to the hysteresis described at lines 264-278? If so, refer to Sect. 2.2.2 here. If not, please clarify.
- Line 388: Table 2 seems to be the wrong reference.
- Line 389: Replace “can be” with “are” (?).

- Line 407:  $Act_{year-1}$  is confusing here, because it's referring to activity both in the current year (previously in the text) and the next year (second part of this sentence). I suggest just removing it, or at least deleting the subscript.
- Line 408: Add reference to  $G$ . Also, "generations" conflicts with "generation" in Table 1.
- Line 410: Clarify here that "accessible breeding substrate" refers to dead wood only, not also live wood (?).
- Lines 417-420: Use plain language to explain this instead of symbols. E.g., instead of "In the epidemic stage  $Ww=0$ ," try "In the epidemic stage the weight for susceptibility induced by windthrow damage ( $Ww$ ) is zero".
- Line 437: "*Abies*" should be lowercase.
- Table 4 should be Table 3.
- Fig. 2:
  - Y-axis should be added with data for BPI, with the transition thresholds labeled. This will avoid requiring the reader to find them in the text.
  - "Exiting" should be removed from the "BPI threshold" labels, since the thresholds apply for both entering and exiting.
- Lines 457-473 (continuous vs. abrupt experiment methods):
  - This should be its own subsection.
  - Was fire (another "abrupt" source of mortality) disabled for this experiment?
- Line 474: Shouldn't this be "Qualitative"?
- Line 482: Table 6 should be Table 5.
- Line 487: "heterotrophic respiration, **and disturbance.**"
- Lines 488-489: What about emissions from combusted biomass?
- Line 492: "windthrown" should be "windthrow"
- Fig. 3
  - Caption:
    - Table 5 describes results, not the criteria for delineating stages.
    - What "left panel" is being referred to?
    - "i.e." should be "e.g."
    - "In the left panel... outbreak stages." These sentences can be simplified for clarity by saying that the rows are sites and the columns are windthrow intensities.
  - Figure:
    - Is there any significance to "small," "medium," and "large"? How are they defined?
    - Y-axis label: Delete "gradient".
    - What is the significance of the one plot that is circled with an arrow and labeled with "1" and "12 years cycle"? I think it means "Areas represent fraction of 12-year simulation spent in each outbreak stage." This would be much clearer written out in the caption rather than hinted at on the figure.
    - What is the significance of the dashed lines on each plot?
    - Rightmost column label should be ">60%"

- Line 495: “Back beetle” typo
- Line 499: Fig. 3 shows that these sites never left the endemic stage, but it’s my understanding that trees can still be killed by bark beetles during that stage. If my understanding is correct, please change “remained unaffected by bark beetles” to “never left the endemic stage” (unless you have other data, not shown, indicating that biomass loss to beetles was actually zero). If my understanding is incorrect, Sect. 2.2.5 should be improved.
- Fig. 4:
  - Consider labeling sites where outbreaks occurred with an icon of some kind in the subplot title.
  - SOR: Put a vertical line where the second windthrow event occurred. Also, what intensity was that event?
  - Lines 569-571: This text should be included in Sect. 2.4.
  - Plots should be ordered according to mean annual temperature, not alphabetically.
- Line 519: “Back beetle” typo
- Line 521: Refer to Fig. 3 at the end of this first sentence to tell the reader where they should be looking.
- Fig. 5:
  - Figure:
    - X-axis label: “Cumulative” typo
    - For consistency with other figures, please replace wind speed values in legend with wood loss values.
  - Caption:
    - Note that SOR had an extra windthrow event.
    - “undisturbed” should be “less disturbed”.
- Table 5:
  - This should probably be body text instead of a table. I suggest sub-headings corresponding to each row in the table, with paragraphs for each idea. (This will also make it possible to refer to line numbers in future review.) E.g., for Stage A, you’d have a paragraph for “post-windthrow temperature affects beetle dynamics” that covers the expected pattern and the results, then another paragraph for “intermediate windthrow sees the largest outbreaks.”
  - There is a fair amount of text here that doesn’t fit in Results because it’s purely model description (Methods), although some would fit well in Discussion. Specifically:
    - Stage C rows 1 and 3
    - Stage D
    - Stage 4-6 row 2
  - Alternatively, you could add some data from the results illustrating each of those. But without data, they don’t fit in Results.
  - Stage A:

- Literature: Add text about what sort of pattern is expected in terms of beetle dynamics after windthrow events of various intensities. Is it the “outbreaks most likely after intermediate events” that you see in the simulations?
    - ORCHIDEE:
      - Please provide a figure in the Supplement with time series of mean monthly temperature (or some other indicator of temperature) to support assertions about post-windthrow temperatures affecting beetle dynamics.
      - Add a note that the assertions are supported by comparing COL to SOR (COL is colder but has outbreaks at various windthrow intensities where SOR doesn’t) and THA to WET (THA is warmer but has no outbreak at 12% where WET does).
  - Stage B, Literature: “*I. typographus*” should be italicized.
  - Stage C:
    - First and last rows don’t belong in the Results, as they’re purely model description.
    - Row 2, ORCHIDEE:
      - What data support the second sentence?
      - Missing period at end.
  - Stages 4-6, row 1, ORCHIDEE:
    - “extended” compared to what? It’s *shorter* than the 25-year number from the literature.
    - Why mention the entire range of modeled recovery when you’re comparing to a specific beetle kill observation (52%)?
    - How did Pfeiffer et al. (2011) define “recovery”?
    - “back beetle” typo
- Line 548: Refer to Fig. 6 at the end of this sentence.
- Fig. 6:
  - How can the “background mortality only” treatment (i.e., no windthrow) be “after the windthrow event”?
  - Note in caption that positive values represent sinks and negative values represent sources.
- Sect. 4.2: Lines 567-571 should be moved to Sect. 2.4, because it provides great justification for what initially seemed a questionable choice. Then the remaining text doesn’t really warrant a Discussion section; it’s more Conclusion.
- Line 572: Table 6 should be Table 5.
- Line 586: Reference to Fig. 4 (Results) should be changed to Table 3 (Methods).
- Line 587: “**bark beetle** resistance”
- Line 590: Define “elasticity”
- Line 592: First comma should be a period.
- Lines 592-593: How does modeled “persistence” compare to the literature?

- Lines 598-599: “remains consistent” contradicts the differences seen at 20 and 50 years. Instead, I think you mean to say something like, “cumulative net biome production is similar after about 100 years.”
- Line 600: “convergence” should be “converge”.
- Lines 613-614: How does the study show anything about the importance of initial conditions? Where was that tested?
- Line 622: “degrees” should be “degree-days”.
- Line 623: This citation should be converted to GMD style.
- Line 633: “Outlook” should be combined into Sect. 4.4.
- Conclusion: Also mention plans for more quantitative comparison against observed bark beetle events.
- Table S1:
  - Please compose this page in landscape orientation to make room for more equations to be on one line. Also note that cell at row 2 column 3 has text cut off.
  - Various subscripts are unexplained and various symbols are missing from Table 1.