

Death and *Taxus*: The contribution of mechanical damage to the multiple factors associated with *Taxus brevifolia* mortality

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S1.1 Annual mortality survey protocol

During each annual census, field crews checked all trees to record their current status as either live or dead. For trees that died in the current year, the crew documented basic mortality information, tree condition codes and factors associated with death (FAD). Each dead tree was assigned at least one FAD. Tree condition codes were recorded when applicable, depending on the physical form of the dead tree. In this study, pathogen corresponds to the “Biotic–Disease” category under FAD; insect corresponds to “Biotic–Insect” category under FAD; suppression corresponds to “Biotic–Suppression” category under FAD; and animal corresponds to “Biotic–Animal damage.” category under FAD; mechanical damage corresponds to “Physical” category under FAD.

For trees that were alive during the census but exhibited forms indicating potential mortality risk, condition codes were recorded from the tree list. These potential forms represent trees showing visible signs of physical injury, biotic infection, or bark beetle damage.

All field crew members were trained prior to the mortality survey by the Principal Investigator of the project (Lutz), every year.

Mortality Survey

Mortality Data

DBH (cm), one decimal place. If unmeasurable, estimate DBH in comments.

Root condition

- 1 = Root-soil interface intact
- 2 = Root-soil interface damaged but stem still freestanding
- 3 = uprooted, stem no longer free standing.

Stem condition

- 1 = Main stem intact
- 2 = Main stem pinned or ruptured (e.g., crushed)
- 3 = Main stem snapped (no longer connected)

Take snag height reading with laser

Snag top diameter (cm). If main stem is fully intact, record 0 cm.

% Crown: Estimate percent of crown still intact. Do not enter values <100% for sparse crowns or gradual dieback.

% Tree: Estimate percent of the entire main stem length that is standing unbroken.

Leaner Angle: If tree is still rooted and is leaning, estimate the angle of lean in degrees from vertical (see diagram). Use this category for trees that are standing with crown and for trees that are crushed but still rooted.

Down: Entering information here indicates that part or all of the dead tree is down. Use this category only if the % tree standing is less than 100% and only when the tree position code is 2 or 3. A tree that is crushed but still rooted is not considered to be down. Consider the down part of the stem only. The % on ground and % supported must equal 100%.

% on Ground: Estimate the percent of the down stem portion that is in direct contact with the ground.

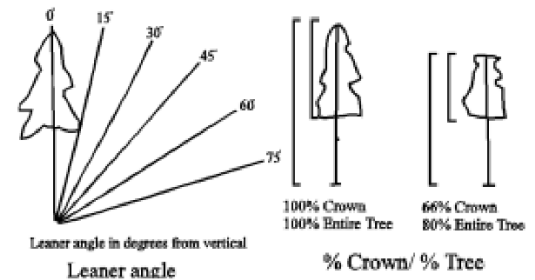
% Supported: Estimate the percent of the down stem portion that is supported above ground.

Special cases: If data can't be recorded, leave cell blank and note reason in comments. For example, if the top portion of the tree is broken off and can't be found, record data about the standing portion of the tree under STANDING and leave both columns of DOWN blank. Broken tops hung up in the canopy are considered down but supported. If tree cannot be found, look again, then comment "Not found" and list **CC=38**.

Fill out the Fallen/CWD data sheet for newly fallen tree parts ≥10 cm in diameter at base.

Knock nail completely into tree to ensure tag is secured.

Comments: Record details regarding the condition codes and F



Tree Condition Codes

Crown

- 01 Dead needles or leaves present
- 02 Earlier loss of crown portion
- 03 Foliage Damage
- 04 Spike top/ top dieback
- 05 Crown flat topped
- 06 Mistletoe plants observed (use binoculars)
- 07 Witches brooms

Bole/Branches/Roots

- 13 Rotten wood
- 14 Mycelia/ rhizomorphs/ fungal fruiting body (non-conk)
- 15 Rot at break
- 16 Pitch tube on bole
- 17 Beetle galleries
- 18 Exit/entrance holes
- 19 Conks (indicate type and position)
- 20 Swelling
- 21 Canker
- 22 Evidence of scale (black bark)
- 23 Tree is hollow
- 24 Pitching
- 25 Pitch sheets
- 26 Oozing wounds
- 27 Bark sloughing
- 28 Scar on bole (note cause, location, extent)
- 29 Girdling (note cause)
- 30 Woodpecker/ Sapsucker activity (note extent)
- 31 Snow/ ice damage

Other

- 32 Uprooted or partially ruptured but foliage is still live and some cambium intact (use only if there is a chance of survival)
- 35 Sprouting at base (if sprout is from same stem, use 37)
- 36 Tree dead several years (note reasoning, estimate years)
- 37 Tree dead above breast height, live below (if sprouting at base, use 35)
- 38 Tree not found

Factors Associated with Death (list in order of importance) (cont.)

Biotic

Disease

- 61 White pine blister rust
- 62 Rot (specify accordingly, if possible)
 - 62.1 *Armillaria ostoyae*
 - 62.2 *Phellinus weirii*
 - 62.3 *Heterobasidion annosum*
 - 62.4 *Phaeolus schweinitzii*
 - 62.5 *Fomitopsis pinicola*
 - 62.6 *Echinodontium tinctorium*
 - 62.7 *Phellinus tremulae*
 - 62.8 *Phellinus hartigii*
 - 62.9 *Phellinus pini*
 - 62.11 *Omnia tomentosa*
 - 62.12 *Pentophora polygonia*
- 63 Canker
 - 63.1 Black spot canker
 - 63.2 *Cytospora* spp.
 - 63.3 Soot canker (*Encoelia pruinosa*)
- 64 Other (specify)
 - 64.1 Brown felt blight/Snow fungus
 - 64.2 Black/Brown stain (*Leptographium*)
 - 64.3 Blue stain (*Ceratocystis*, *Ophiostoma*)
- 65 Unknown

Insect

- 71 Bark (specify accordingly, if possible)
 - 71.1 *Dendroctonus brevicornis*
 - 71.2 *Dendroctonus ponderosae*
 - 71.3 *Dendroctonus pseudotsugae*
 - 71.4 *Dendroctonus rufipennis*
 - 71.5 *Dendroctonus valens*
 - 71.6 *Dryocoetes confusus*
 - 71.7 *Ips* spp.
 - 71.8 *Pityokteines* spp.
 - 71.9 *Phloeosinus* spp.
 - 71.11 *Scolytus subscaber*
 - 71.12 *Scolytus tsugae*
 - 71.13 *Scolytus ventralis*
 - 71.14 *Pseudopityophthorus pubipennis*
- 72 Defoliating (specify if possible)
- 73 Other (specify)

Physical – Note

- 80 Uprooted by falling tree or tree parts (note originating tree)
- 81 Uprooted (note cause)
- 82 Broken stem by falling tree or tree parts (entire or partial crown loss)
- 83 Broken stem (entire or partial crown loss) (note cause)
- 84 Crown damage (stripped, broken branches, etc.)
- 85 Crushed by falling tree or tree parts (note originating tree)
- 86 Crushed (note cause)
- 87 Lightning
- 88 Other (note cause)
- 89 Tree located, physically removed from plot, i.e. landslide.

Fire

- 91 Crown scorch (killed by fire scorch, not consumption)
- 92 Crown combustion (note extent of consumption)
- 93 Bole/stem scorch
- 94 Bole/stem combustion
- 95 Cambial heating
- 96 Burned through at base (for small trees, due to litter & duff consumption around base)
- 97 Other (describe)
- 98 Fire, mechanical (fire burned base, but tree died because of structural failure. The tree would have survived if it didn't fall over)
- 99 Complete consumption (<25% of stem remaining, or tag found on ground)

Factors Associated with Death (list in order of importance)

40 Unknown

Biotic

- 50 Suppression
- 51 Animal damage (specify animal if possible)
 - 51.1 Herbivory (specify)
 - 51.2 Elk scrape
 - 51.3 Cat scratch
- 52 Mistletoe

Tree List Condition Codes	
Code	Description
<i>Physical</i>	
DT	Dead Top: Top of main stem dead
BT	Broken Top: Top of main stem broken – broken portion at least 2 cm diameter
RT	Reiterated Top: Secondary top grown to replace dead or broken original top
FT	Flat Top: Tree displays crown morphology consistent with long-term suppression
NL	Nurse Log: The original rooting location of stem was on or within a nurse log
SCAR	Scar present on bole (note location and extent in comments)
SWELL	Swelling of bole or branches present
FROST	Major frost crack present
L=##	Lean angle of main stem [## = degrees from vertical (0=vertical, 90=horizontal)]
<i>Biotic</i>	
SPRT	Tree is sprouting from the base (separate ground emergences)
FLAG	Tree displays flagged branch morphology (long-term growth next to obstruction)
MT	Mistletoe: Evidence of current or past mistletoe infection in tree crown
WB	Witch's brooms not caused by mistletoe (broom rust fungus infection)
ES/DS/CS	Physical damage to stem or branches due to animals: Elk Scrape
DS	Physical damage to stem or branches due to animals: Deer Scrape
CS	Physical damage to stem or branches due to animals: Cat Scratch
SS	Sapsucker/woodpecker holes (many) present on bole
HERB	Herbivory damage to twigs or leaves (must be extensive). ID species if possible.
NEC	Necrosis or necrotic tissue observed
BFB	Brown felt blight on twigs/branches (must be extensive)
BSC	Black spot canker observed on living stem (ACCI only)
CONK##	Conk growing from tree [indicate species if known by replacing "CONK" with 4-letter species code, ## = year]
DEF##	Defoliated (by cold or insects) [## = year]
GALL	Galls present (must be large or extensive)
APHID	Aphids present (seedlings only)
<i>Bark Beetles</i>	
PITCH	Tree pitching (for pitching due to bark beetles). Note other pitching in comments
FRASS	Bark beetle frass visible on bole or in bark
EE	Bark beetle entry/exit holes visible on bole
BEET##	Actual beetles observed attacking tree (must see insect) [indicate species if known by replacing "BEET" with 4-letter beetle species code, ## = year]

S1.2. Deadwood distance and sensitivity diameter selection test

For each piece of deadwood, we calculated the distance to the nearest dead *Taxus* and selected the shortest distance for analysis. Each deadwood piece was characterized by three measurements: large-end diameter (D_{LE}), small-end diameter (D_{SE}), length of dead wood (L , from large end to small end). The mapped location of each piece was determined relative to mapped trees (Lutz et al. 2021). Using these measurements, we identified the nearest *Taxus* to each deadwood piece and computed the diameter of deadwood at the nearest point ($D_{nearest\ point}$).

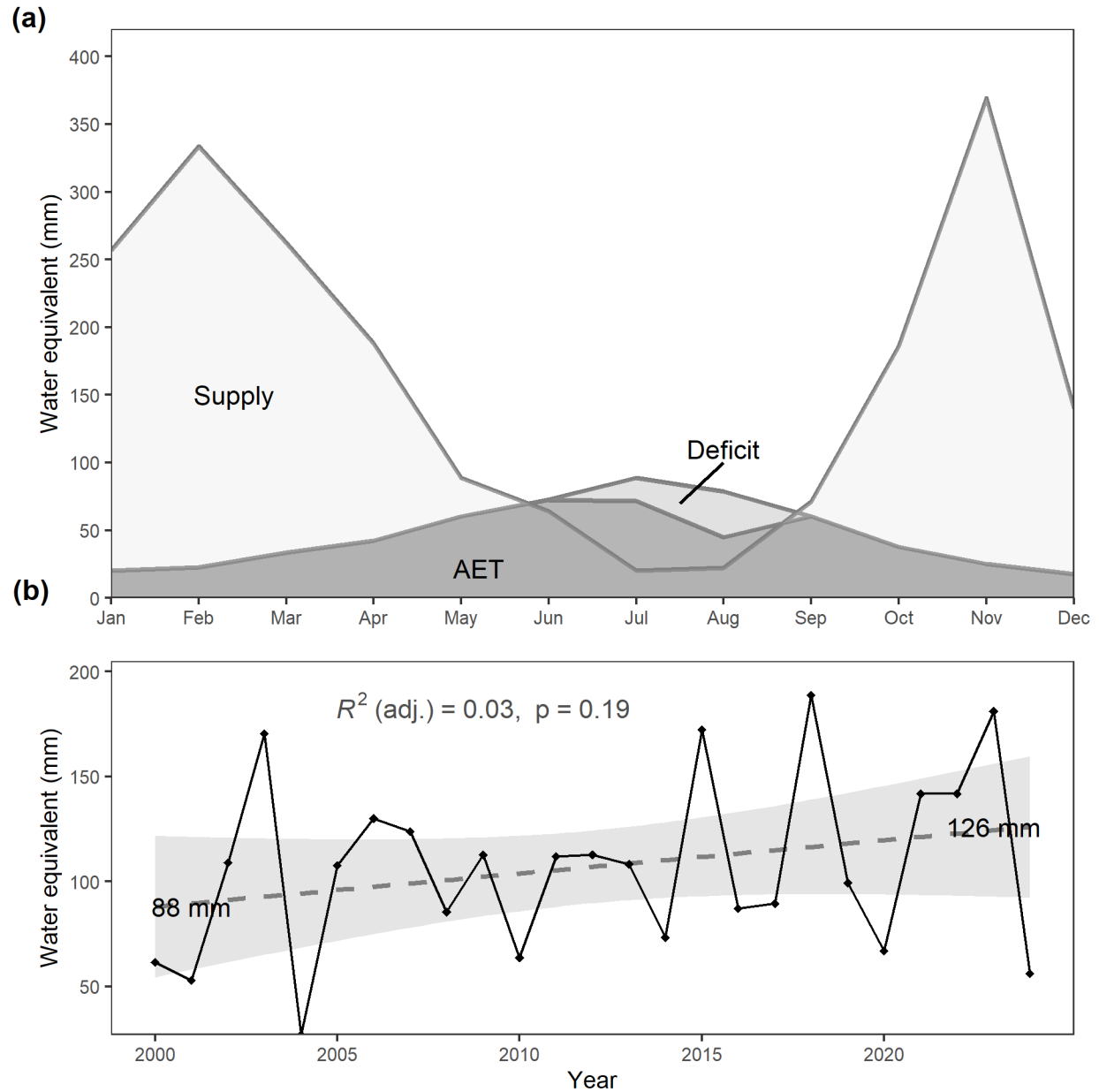
A conceptual diagram of the nearest distance measurement is provided in Figure S 5, and the diameter at the nearest point was calculated using the following equation:

$$D_{nearest\ point} = D_{LE} - \frac{(D_{LE} - D_{SE}) \times d}{L}$$

Where D_{LE} is the diameter of large end side of deadwood, D_{SE} is the diameter of small end side of deadwood, d is the nearest distance between *Taxus* and deadwood, and L is the distance from the large end to small end, following the methods of Birch and Lutz (2023).

We conducted a sensitivity analysis to determine the critical size threshold eventually associated with *Taxus* mortality. We classified deadwood diameter ($D_{nearest\ point}$) from 1 cm to 60 cm in 5 cm intervals. We then applied the bivariate inhomogeneous pair correlation function to examine the relationship between the deadwood and dead *Taxus*. The value of $g_{inhom}(r) > 0$ indicates positive relationship, suggesting aggregation of deadwood around dead *Taxus* whereas $g_{inhom}(r) < 0$ indicates a negative relationship, suggesting a lower chance of deadwood being around dead *Taxus*. There was a significant positive relationship for $r < 1.2$ m and the strength of the aggregation dropped at diameters larger than 10 cm (Figure. S3).

Section 2: Supplemental figures and table



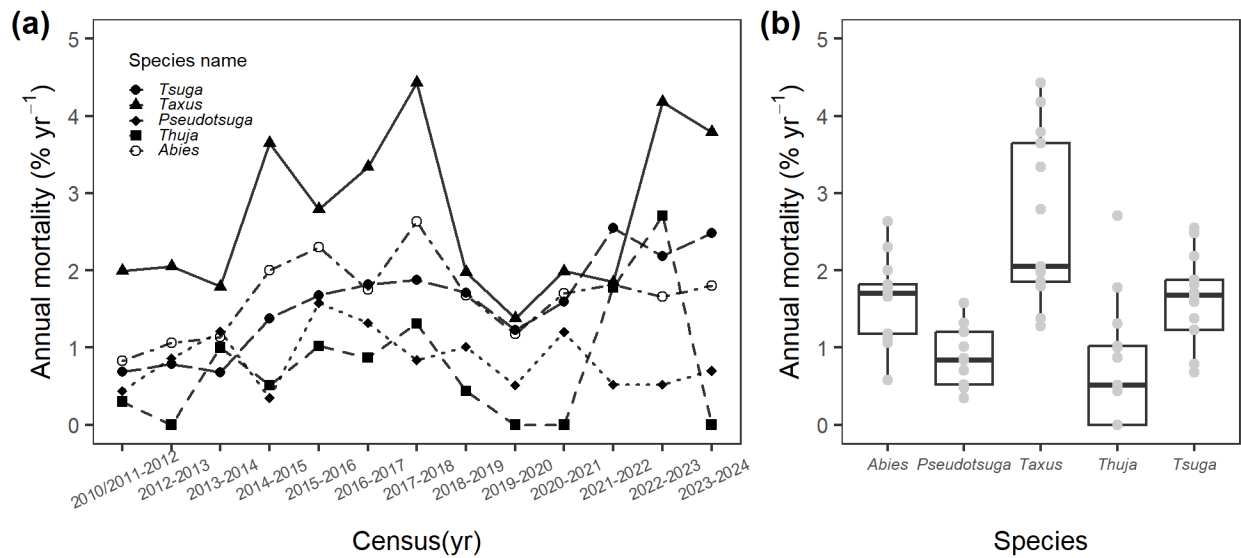


Figure S 2. Annual mortality rate (%) between 2010/2011 and 2024 of tree species with the highest basal area in the Wind River Forest Dynamic (a) and variability in mortality (b). Annual mortality variance for each species, grey dot represent the annual mortality in each census period.

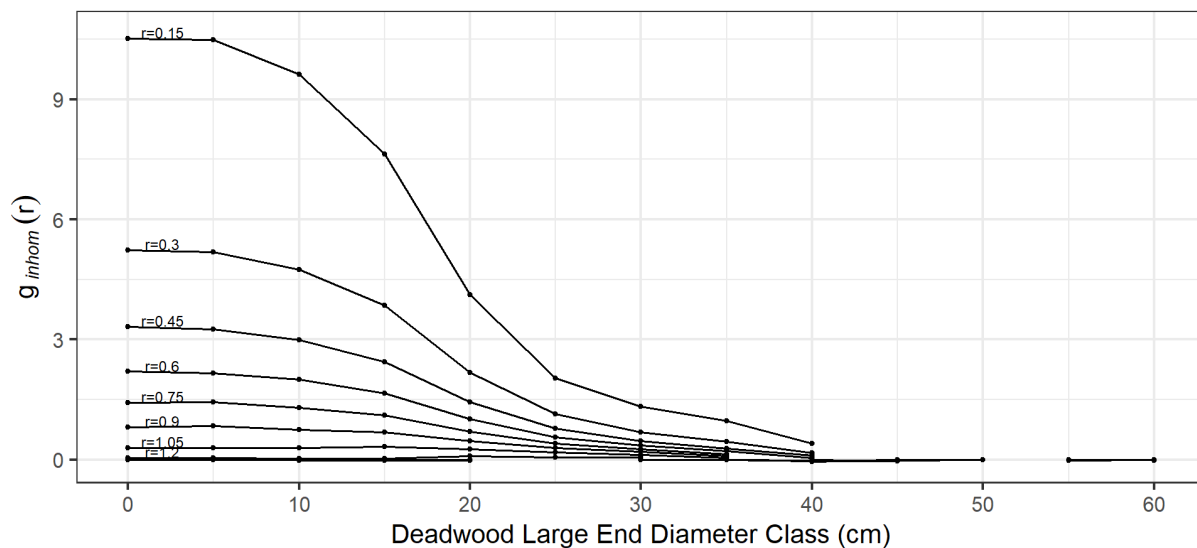


Figure S 3. Sensitivity analysis for the aggregation of deadwood and dead *Taxus* by different diameter classes and distances (r). Each line represents different distance under $g_{inhom}(r)$. A value of $g_{inhom}(r) > 0$ indicates positive relationship, suggesting aggregation of deadwood around dead *Taxus*; whereas $g_{inhom}(r) < 0$ indicates a negative relationship, suggesting a lower chance of deadwood being around dead *Taxus*.

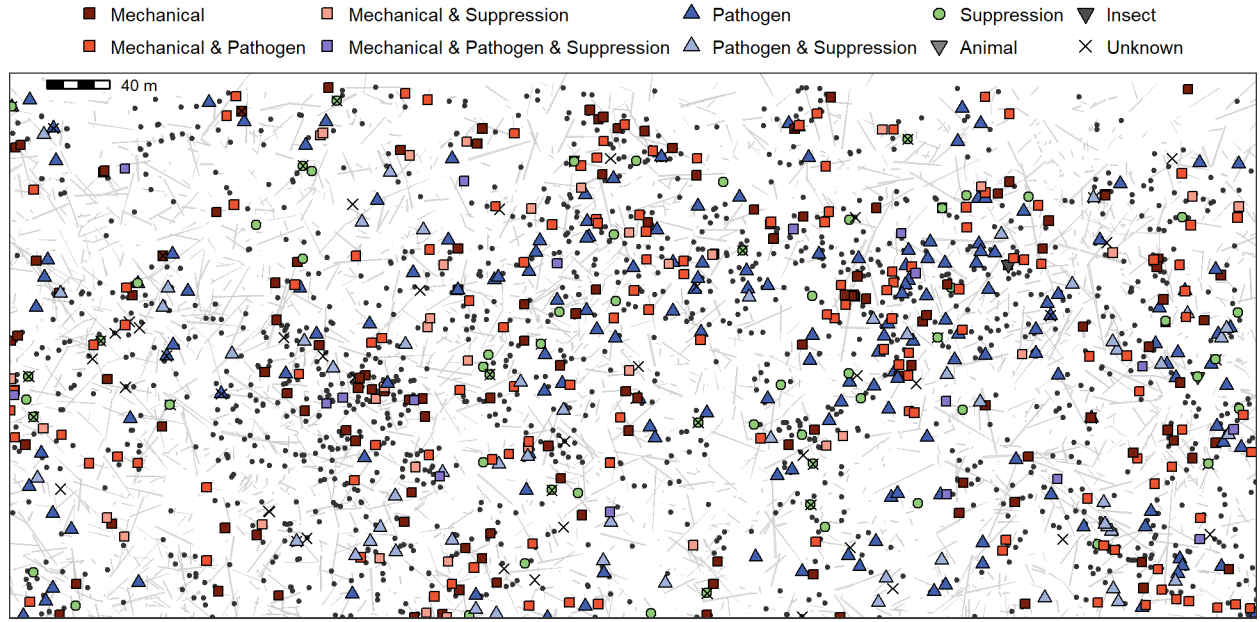


Figure S 4. Spatial distribution of deadwood with the nearest point to dead *Taxus*, having a diameter ≥ 25 cm ($n=2447$, grey polygons), live *Taxus* ($n=1523$, grey dots), and dead *Taxus* ($n=671$, from 2012 to 2024) in the Wind River Forest Dynamics Plot.

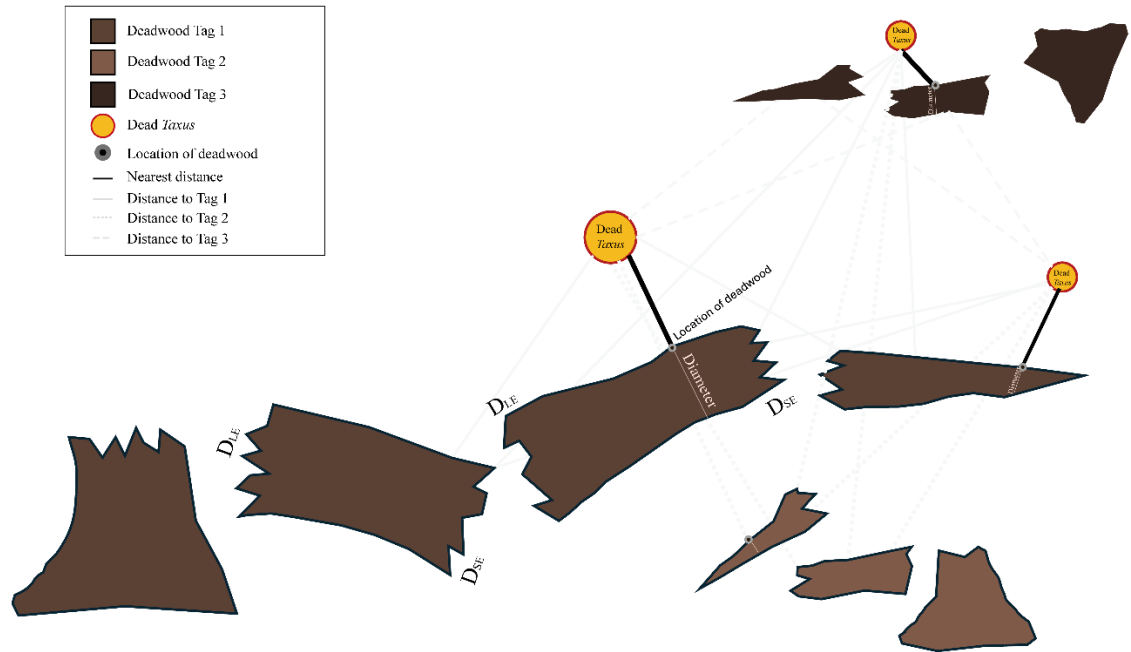


Figure S 5. Conceptual diagram illustrating the nearest distance between deadwood and dead *Taxus brevifolia* (D_{LE} and D_{SE} indicate represent the large- and small-end diameter of the deadwood, respectively; “Diameter” indicates the diameter calculated at the nearest distance point between dead *Taxus* and deadwood).

Table S1. Interactions among mortality factors and population dynamics across diameter classes of dead *Taxus*. Values for each mortality factor represent percentage[†].

Diameter class (cm)	Dynamic		Mortality factors (%)										
	Initial live <i>Taxus</i>	Annual mortality rate (%)	n	Mechanical	Pathogen	Suppression	Mechanical with Pathogen	Mechanical with Suppression	Suppression with Pathogen	Mechanical Pathogen	Insect	Animal	Unknown
1-5	125	5.86	76	13.2 (10)	23.7 (18)	25.0 (19)	9.2 (7)	5.3 (4)	9.2 (7)	5.3 (4)	-	1.3 (1)	11.8 (9)
5-15	1246	2.88	403	21.6 (87)	26.3 (106)	9.2 (37)	17.6 (71)	6.5 (26)	10.2 (41)	3 (12)	0.2 (1)	-	5.7 (23)
15-25	558	2.34	147	24.5 (36)	29.9 (44)	3.4 (5)	29.3 (43)	3.4 (5)	5.4 (8)	1.4 (2)	-	-	2.7 (4)
≥ 25	190	1.90	45	28.9 (13)	26.7 (12)	2.2 (1)	35.6 (16)	2.2 (1)	-	-	-	-	4.4 (2)
Total	2119	2.79	671	21.8 (146)	26.8 (180)	9.2 (62)	20.4 (137)	5.4 (36)	8.3 (56)	2.7 (18)	0.1 (1)	0.1 (1)	5.7 (38)

[†]Trees within each diameter class had multiple factors associated with death, resulting in percentages >100%

Section S3: Supplemental references

Birch JD, Lutz JA (2023) Spatial patterns of seedlings dominated by proximity to deadwood and adult trees for *Pinus flexilis* and *Pinus longaeva*. For Ecol Manag 540:121049.

<https://doi.org/10.1016/j.foreco.2023.121049>

Daly C, Halbleib M, Smith II, et al (2008) Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. Int J Climatol J R Meteorol Soc 28:2031–2064

Lutz JA, Struckman S, Germain SJ, Furniss TJ (2021) The importance of large-diameter trees to the creation of snag and deadwood biomass. Ecol Process 10:28.

<https://doi.org/10.1186/s13717-021-00299-0>