United States Department of Agriculture Forest Service

Interactions among insects and weeds in western U.S. forests

Christopher J. Fettig, Justin B. Runyon, Jared A. Trilling, Leif A. Mortenson, and Jackson P. Audley

Fire, Weeds, and Forest Pests
2020 California Invasive Plant Council
October 28, 2020

Bark beetles

- 550 species in North America.
- Relatively few are economically important.
- Regulate certain aspects of primary production, nutrient cycling, ecological succession, and the size, distribution and abundance of forest trees.

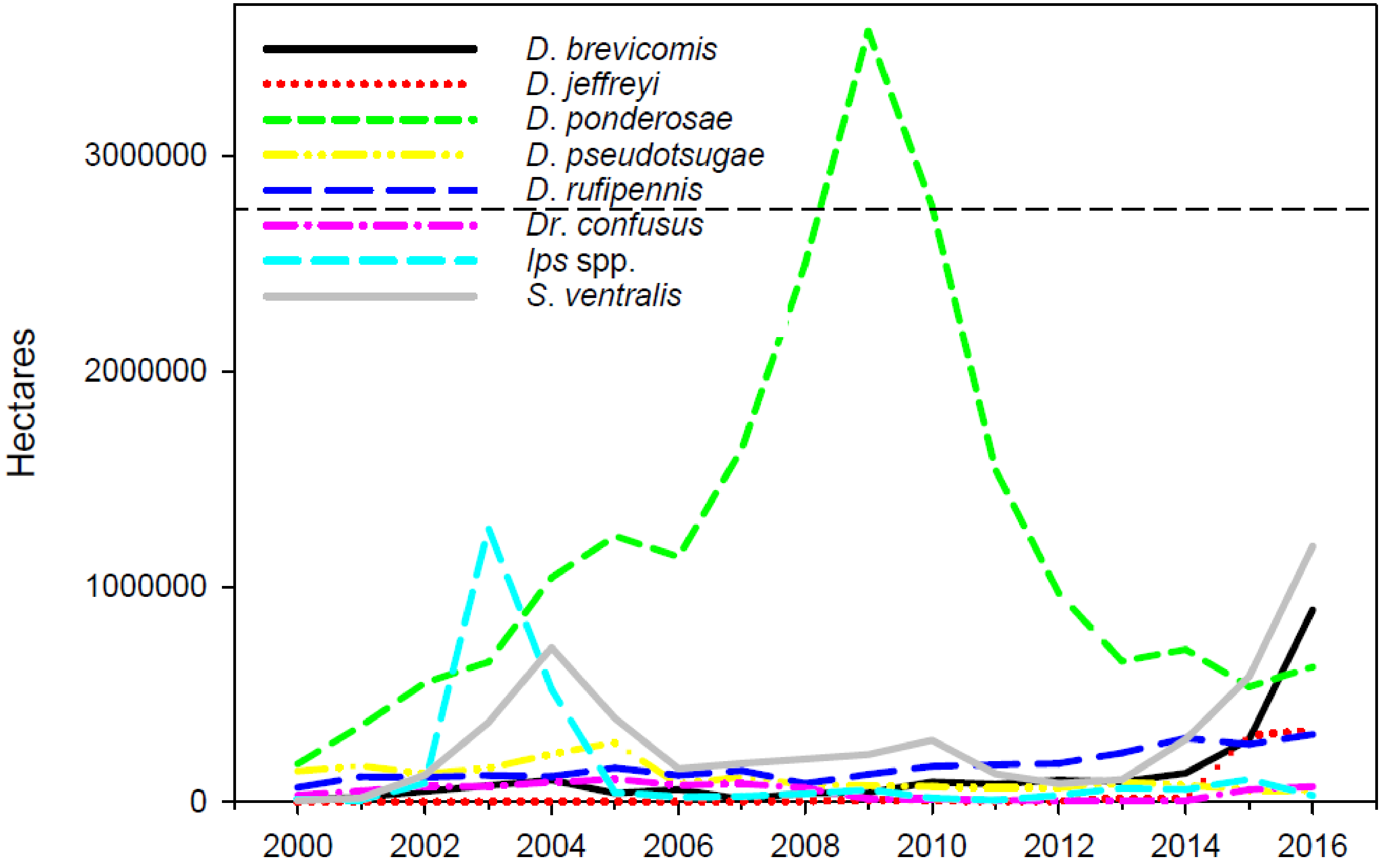
Robber fly (Asilidae) predating on red turpentine beetle (*Dendroctonus valens*) attracted to residual trees following harvesting, Eldorado National Forest, California.

Principle conifer-killing species

Common name	**Scientific name**	**Primary host(s)**
Arizona fivespined ips	*Ips lecontei*	*Pinus ponderosa*
California fivespined ips	*I. paraconfusus*	*P. contorta, P. jeffreyi, P. lambertiana, P. ponderosa*
Douglas-fir beetle	*Dendroctonus pseudotsugae*	*Pseudotsuga menziesii*
eastern larch beetle	*D. simplex*	*Larix laricina*
fir engraver	*Scolytus ventralis*	*Abies concolor, A. grandis, A. magnifica*
Jeffrey pine beetle	*D. jeffreyi*	*P. jeffreyi*
mountain pine beetle	*D. ponderosae*	*P. albicaulis, P. contorta, P. flexilis, P. lambertiana, P. monticola, P. ponderosa*
northern spruce engraver	*I. perturbatus*	*Picea glauca, Pi. x lutzii*
pine engraver	*I. pini*	*P. contorta, P. jeffreyi, P. lambertiana*
piñon ips	*I. confusus*	*P. edulis, P. monophylla*
roundheaded pine beetle	*D. adjunctus*	*P. arizonica, P. engelmannii, P. flexilis, P. leiophylla, P. ponderosa, P. strobiformis*
southern pine beetle	*D. frontalis*	*P. engelmannii, P. leiophylla, P. ponderosa*
spruce beetle	*D. rufipennis*	*Pi. engelmannii, Pi. glauca, Pi. pungens, Pi. sitchensis*
western balsam bark beetle	*Dryocoetes confusus*	*A. lasiocarpa*
western pine beetle	*D. brevicomis*	*P. coulteri, P. ponderosa*

Fettig and Hilszczański 2015 in *Bark Beetles: Biology and Ecology of Native and Invasive Species*

Area impacted by year, western U.S., 2000–2016



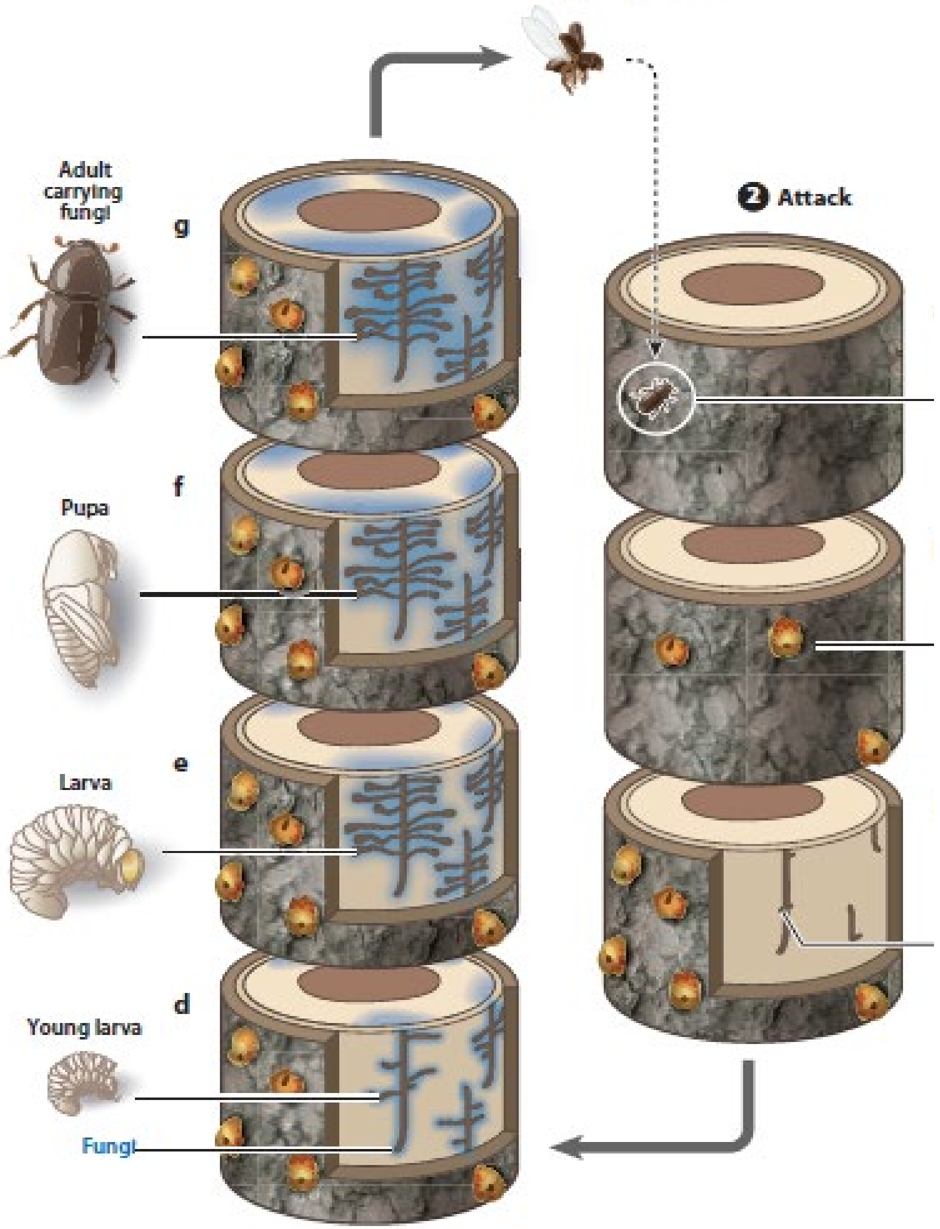
~2.8 million hectares burned annually nationwide

Fettig et al. (2020) in *Disturbance and Sustainability in the Forests of the Western United States*

Western pine beetle galleries in the inner bark of ponderosa pine (*Pinus ponderosa*), Sierra National Forest, California.

- Pioneers use a combination of random landings and visual orientations followed by olfactory and gustatory cues.

- Most tree-killing species have highly-evolved chemical communication systems (e.g., in the western pine beetle, females release *exo*-brevicomin, which in combination with the host monoterpene myrcene is attractive to conspecifics. Frontalin, produced by males, enhances attraction).



Six and Wingfield 2011. Ann. Rev. Entomol. 56:255–272.

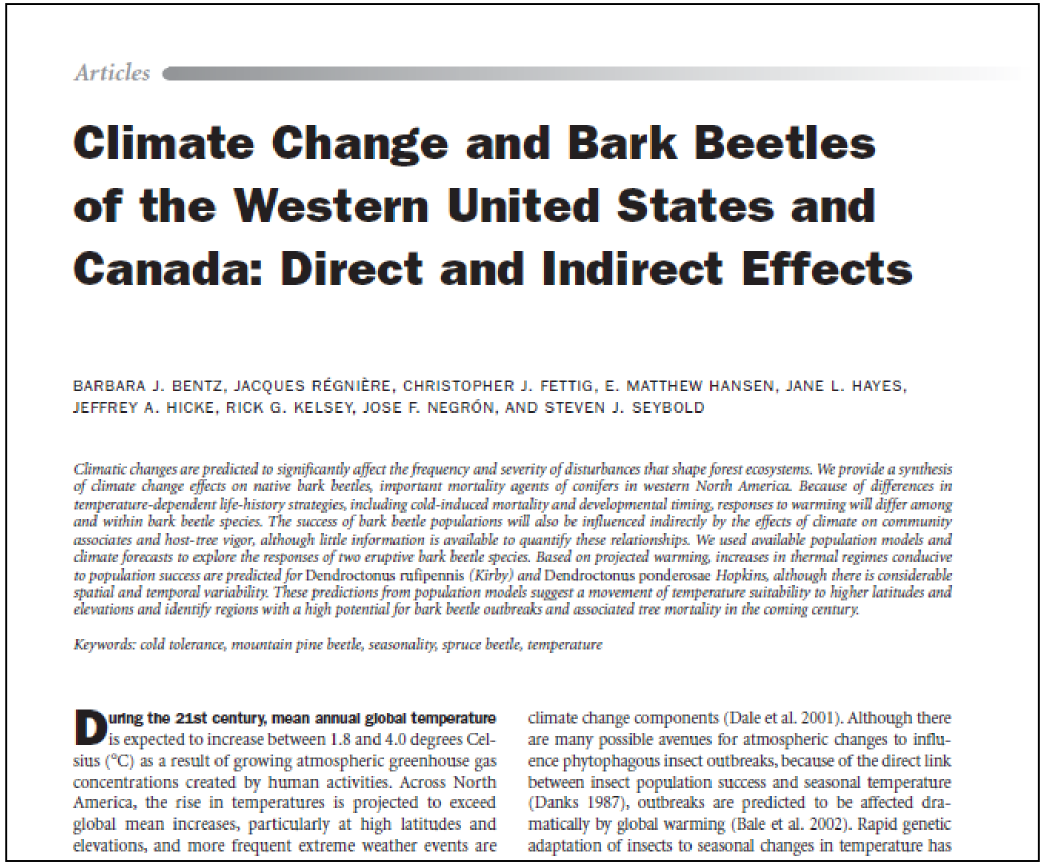
Bluestain fungi (*Ophiostoma* sp.) in the sapwood of ponderosa pine killed by western pine beetle, Sierra National Forest, California.

The extent of tree mortality resulting from bark beetles may be limited to small spatial scales (e.g., individual trees or small groups of trees at endemic or transient population levels) or may affect entire landscapes during outbreaks (i.e., tens of millions of hectares in western North America).

Bark beetles and climate change

Bark beetles are sensitive to thermal conditions conducive to population survival and growth. Shifts in temperature and precipitation affect:

- Fecundity and fitness
- Phenology and voltanism
- Predators, parasites, competitors and symbionts
- Host finding and colonization success
- Host physiology



Articles

Climate Change and Bark Beetles of the Western United States and Canada: Direct and Indirect Effects

BARBARA J. BENTZ, JACQUES RÉGNIÈRE, CHRISTOPHER J. FETTIG, E. MATTHEW HANSEN, JANE L. HAYES, JEFFREY A. HICKE, RICK G. KELSEY, JOSE F. NEGRÓN, AND STEVEN J. SEYBOLD

Climatic changes are predicted to significantly affect the frequency and severity of disturbances that shape forest ecosystems. We provide a synthesis of climate change effects on native bark beetles, important mortality agents of conifers in western North America. Because of differences in temperature-dependent life-history strategies, including cold-induced mortality and developmental timing, responses to warming will differ among and within bark beetle species. The success of bark beetle populations will also be influenced indirectly by the effects of climate on community associates and host-tree vigor, although little information is available to quantify these relationships. We used available population models and climate forecasts to explore the responses of two eruptive bark beetle species. Based on projected warming, increases in thermal regimes conducive to population success are predicted for Dendroctonus rufipennis *(Kirby) and* Dendroctonus ponderosae *Hopkins, although there is considerable spatial and temporal variability. These predictions from population models suggest a movement of temperature suitability to higher latitudes and elevations and identify regions with a high potential for bark beetle outbreaks and associated tree mortality in the coming century.*

Keywords: cold tolerance, mountain pine beetle, seasonality, spruce beetle, temperature

During the 21st century, mean annual global temperature is expected to increase between 1.8 and 4.0 degrees Celsius (°C) as a result of growing atmospheric greenhouse gas concentrations created by human activities. Across North America, the rise in temperatures is projected to exceed global mean increases, particularly at high latitudes and elevations, and more frequent extreme weather events are climate change components (Dale et al. 2001). Although there are many possible avenues for atmospheric changes to influence phytophagous insect outbreaks, because of the direct link between insect population success and seasonal temperature (Danks 1987), outbreaks are predicted to be affected dramatically by global warming (Bale et al. 2002). Rapid genetic adaptation of insects to seasonal changes in temperature has

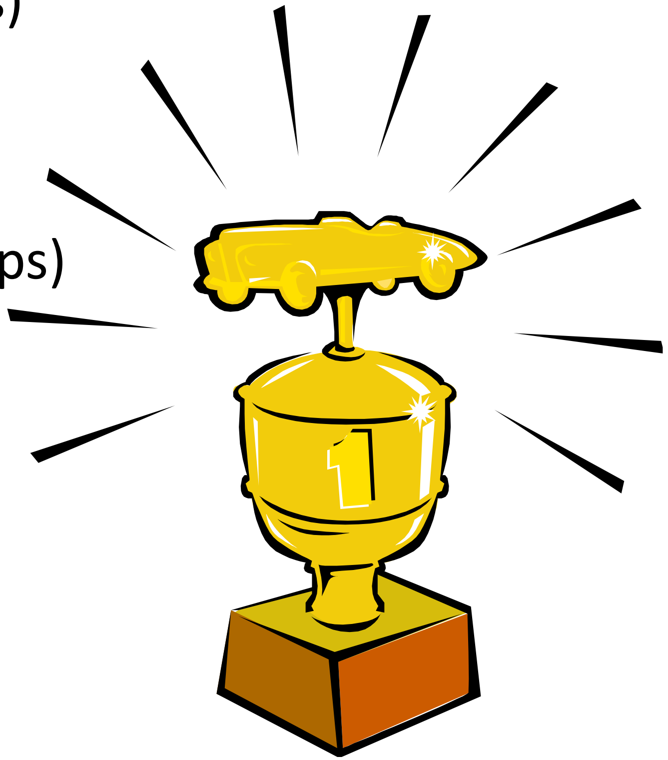
Intensification of outbreaks and impacts

Mountain pine beetle (*D. ponderosae*)
(inciting factor – increase in winter temps)

Spruce beetle (*D. rufipennis*)
(inciting factor – increase in summer temps)

Western pine beetle (*D. brevicomis*)
(inciting factor – temps X drought)

Pinyon ips (*I. confusus*)
(inciting factor – temps X drought)



United States Department of Agriculture
Forest Service

1,122 m elevation, Sierra National Forest

<u>2014</u>

495 trees/ha
42 m^2/ha basal area
65% ponderosa pine
30% incense cedar
5% canyon live oak

<u>2016</u>

148 trees/ha
3.0 m^2/ha basal area
83% incense cedar
17% canyon live oak

In a period of <u>two</u> years, 70% of trees and 93% of basal area were killed. All ponderosa pine were colonized by western pine beetle (Fettig et al. 2019).

United States Department of Agriculture | Forest Service

Impacts of mountain pine beetle outbreaks

Forest Ecology and Management 475 (2020) 118403

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

ELSEVIER

Impacts of mountain pine beetle outbreaks on lodgepole pine forests in the Intermountain West, U.S., 2004–2019

Jackson P. Audley[a], Christopher J. Fettig[a,*], A. Steven Munson[b], Justin B. Runyon[c], Leif A. Mortenson[d], Brytten E. Steed[e], Kenneth E. Gibson[e], Carl L. Jørgensen[f], Stephen R. McKelvey[a], Joel D. McMillin[g], Jose F. Negrón[h]

[a] Pacific Southwest Research Station, USDA Forest Service, 1731 Research Park Drive, Davis, CA 95618, USA
[b] Forest Health Protection, USDA Forest Service, 4746 South 1900 East, Ogden, UT 84403, USA
[c] Rocky Mountain Research Station, USDA Forest Service, 1648 South 7th Avenue, Bozeman, MT 59717, USA
[d] Pacific Southwest Research Station, USDA Forest Service, 2480 Carson Road, Placerville, CA 95667, USA
[e] Forest Health Protection, USDA Forest Service, 26 Fort Missoula, Missoula, MT 59804, USA
[f] Forest Health Protection, USDA Forest Service, 1249 South Vinnell Way, Suite 200, Boise, ID 83709, USA
[g] Forest Health Protection, USDA Forest Service, 2500 South Pine Knoll Drive, Flagstaff, AZ 86001, USA
[h] Rocky Mountain Research Station, USDA Forest Service, 240 West Prospect Road, Fort Collins, CO 80526, USA

ARTICLE INFO

Keywords:
Bark beetles
Climate change
Dendroctonus ponderosae
Disturbance
Forest change
Forest composition
Forest structure
Pinus contorta
Tree mortality

ABSTRACT

Mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Curculionidae), is the most important forest insect in western North America. We determined causes and rates of tree mortality and changes in forest structure and composition associated with *D. ponderosae* outbreaks in the Intermountain West, U.S. during 2004–2019 based on a network of 125 0.081-ha circular plots installed in Colorado, Idaho, Montana, Utah and Wyoming. Incipient populations of *D. ponderosae* began in 2004; peaked in 2007; and returned to endemic levels in 2011 in Idaho, Montana, Utah and Wyoming. In Colorado, incipient populations began in 2004; peaked in 2009; and returned to endemic levels in 2012. A total of 5107 trees died, 98.6% were lodgepole pine, *Pinus contorta* Dougl. ex Loud. Fifteen contributing factors were identified, including (in order of importance, highest to lowest) *D. ponderosae*, unknown causes, pine engraver, *Ips pini* (Say), wind, breakage and/or adjacent tree fall,

- A network of 125 0.081-ha circular plots in Colorado, Idaho, Montana, Utah and Wyoming.

- Overall, significant reductions in mean dbh (by 5.3%), mean QMD (by 8.6%), mean tree height (by 15.9%), mean number of trees (by 40.8%), mean basal area (by 52.9%), and mean stand density index (SDI) (by 51.8%) were observed.

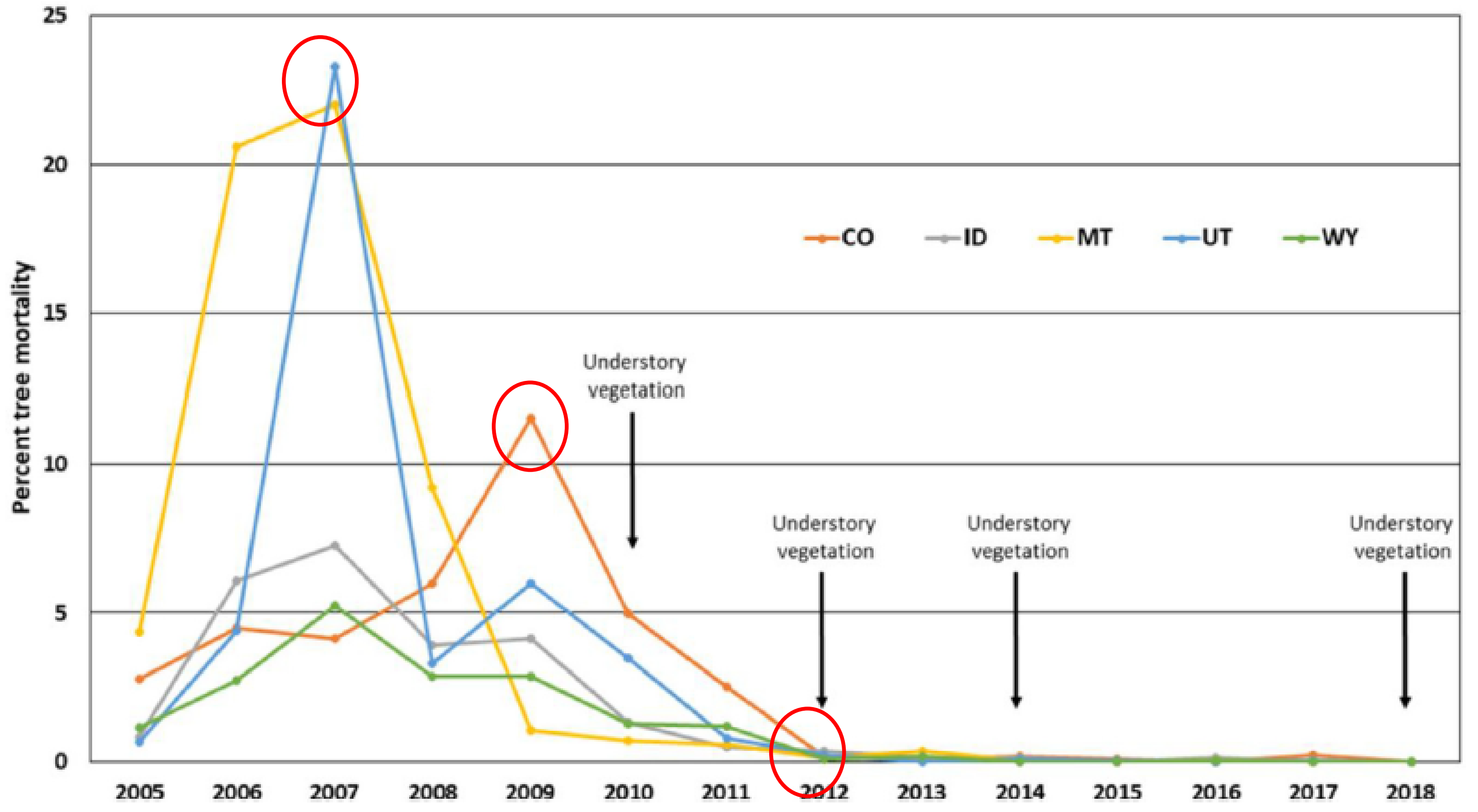
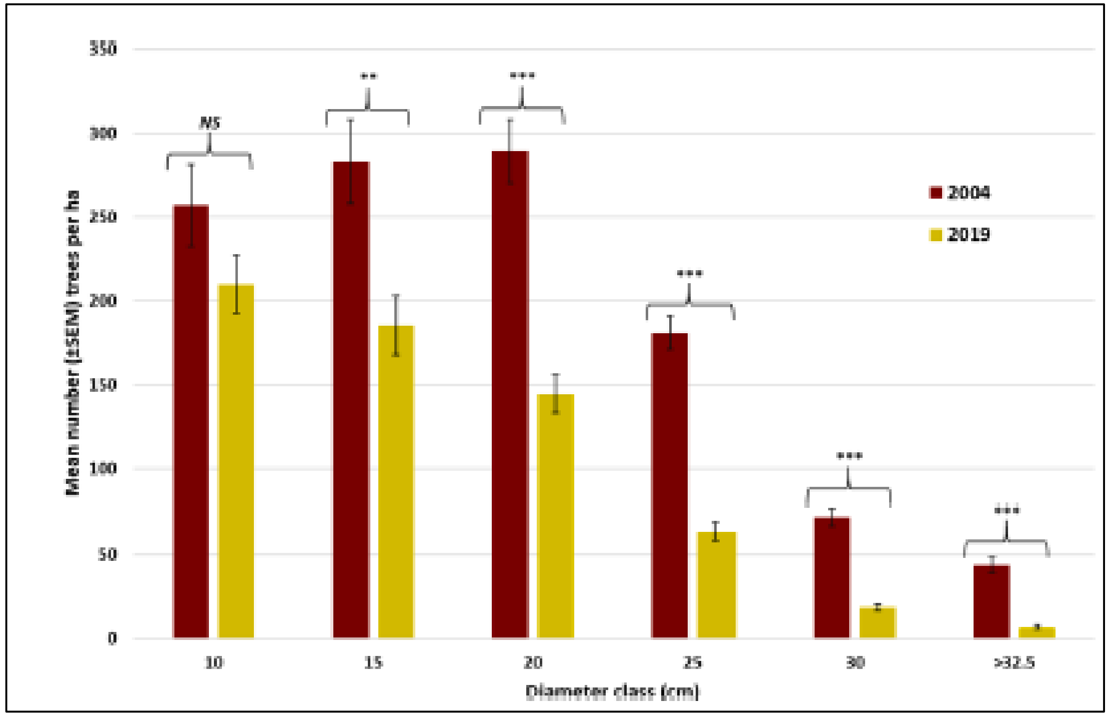
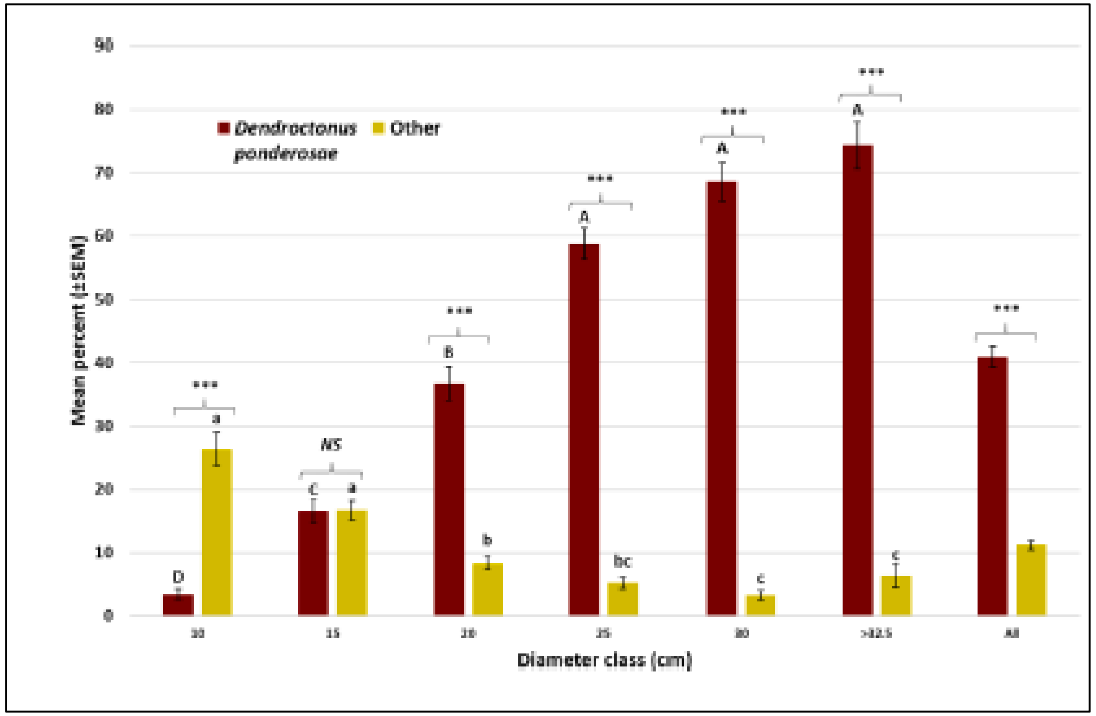


Fig. 1. Mean percentage of number of *Pinus* killed per year by year following *Dendroctonus ponderosae* outbreaks in Colorado, Idaho, Montana, Utah and Wyoming, 2005–2018. Arrows denote years when understory vegetation was sampled. Modified from Audley et al. (2020).

Runyon et al. 2020. *Trees, Forests and People, doi.org/10.1016/j.tfp.2020.10038.*



Audley et al. 2020. *Forest Ecology and Management, doi.org/10.1016/j.foreco.2020.118403.*



Audley et al. 2020. *Forest Ecology and Management, doi.org/10.1016/j.foreco.2020.118403.*

Significant reductions in tree density were observed in all diameter classes, except the smallest (midpoint = 10 cm, 5-cm classes). Most mortality attributed to mountain pine beetle, especially in the larger-diameter classes.

Changes in understory vegetation

Trees, Forests and People 2 (2020) 100038

Contents lists available at ScienceDirect

Trees, Forests and People

journal homepage: www.elsevier.com/locate/tfp

ELSEVIER

Review Article

Changes in understory vegetation including invasive weeds following mountain pine beetle outbreaks

Justin B. Runyon[a,*], Christopher J. Fettig[b], Jared A. Trilling[a], A. Steven Munson[c], Leif A. Mortenson[d], Brytten E. Steed[e], Kenneth E. Gibson[e], Carl L. Jørgensen[f], Stephen R. McKelvey[b], Joel D. McMillin[g], Jackson P. Audley[b], Jose F. Negrón[h]

[a] *Rocky Mountain Research Station, USDA Forest Service, 1648 South 7th Avenue, Bozeman, MT 59717, USA*
[b] *Pacific Southwest Research Station, USDA Forest Service, 1731 Research Park Drive, Davis, CA 95618, USA*
[c] *Forest Health Protection, USDA Forest Service, 4746 South 1900 East, Ogden, UT 84403, USA*
[d] *Pacific Southwest Research Station, USDA Forest Service, 2480 Carson Road, Placerville, CA 95667, USA*
[e] *Forest Health Protection, USDA Forest Service, 26 Fort Missoula, Missoula, MT 59804, USA*
[f] *Forest Health Protection, USDA Forest Service, 1249 South Vinnell Way, Suite 200, Boise, ID 83709, USA*
[g] *Forest Health Protection, USDA Forest Service, 2500 South Pine Knoll Drive, Flagstaff, AZ 86001, USA*
[h] *Rocky Mountain Research Station, USDA Forest Service, 240 West Prospect Road, Fort Collins, CO 80526, USA*

ARTICLE INFO

Keywords:
Bark beetles
Dendroctonus ponderosae
Disturbance
Invasive plants
Literature review
Pinus contorta
Scolytinae

ABSTRACT

Bark beetle outbreaks alter forests in many ways including stand structure, fuels and fire behavior, wildlife habitat, and aesthetic value. Less understood are the effects outbreaks have on understory vegetation, despite the importance for overstory succession, nutrient cycling, water quality, soil erosion, and wildlife. Beetle outbreaks also change forests in ways that could promote invasion by nonnative weeds, but this is rarely studied. We assessed changes in cover of understory vegetation and presence/abundance of weeds in lodgepole pine forests in Colorado, Idaho, Montana, Utah and Wyoming, USA following recent mountain pine beetle outbreaks. Incipient beetle populations began in 2004, peaked around 2008, and returned to endemic levels by 2012. Understory vegetation was sampled in 2010, 2012, 2014 and 2018. Total understory cover and cover of shrubs and graminoids remained

- Total understory cover and cover of shrubs and graminoids remained unchanged, while cover of forbs and invasive weeds increased.
- By 2018, 20% of plots contained invasive weeds. Invasive weed abundance increased by ~31% (from 7,482 to 9,825 individual plants).

- Six invasive weeds were documented:
    - Canada thistle [*Cirsium arvense* (L.) Scop.]
    - bull thistle [*C. vulgare* (Savi) Ten.]
    - musk thistle (*Carduus nutans* L.)
    - lamb's quarters (*Chenopodium album* L.)
    - prickly lettuce (*Lactuca serriola* L.)
    - sulphur cinquefoil (*Potentilla recta* L.).
- Canada thisle was dominant representing ~95% of total weed abundance, and most widely distributed occurring on 20% of plots.
- Bull thistle was the next most common invasive weed, and was present on 4% of plots. The remaining four weed species each occurred on 1–2% of plots.

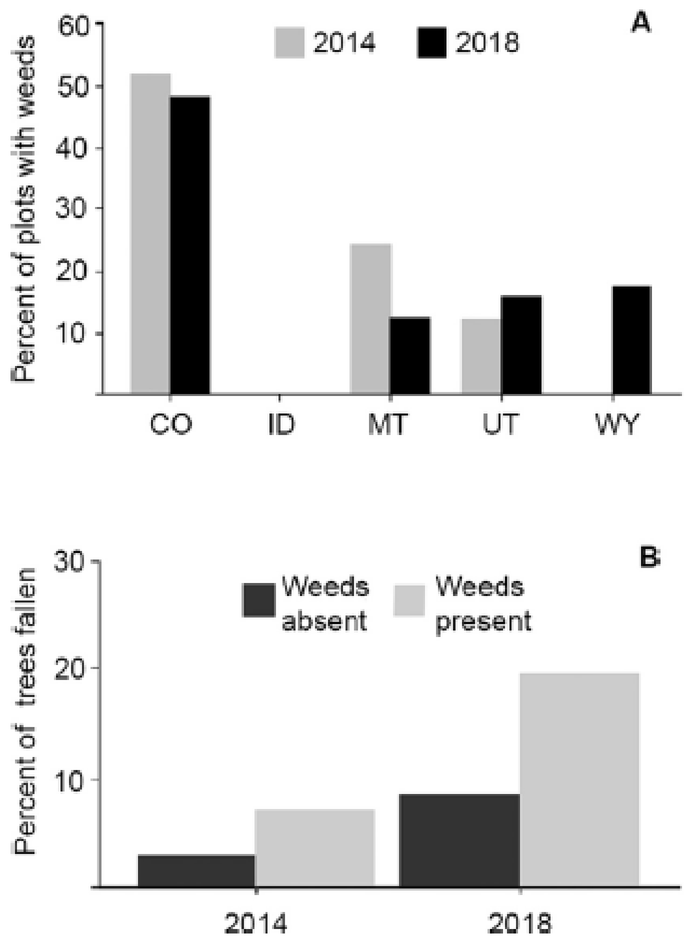


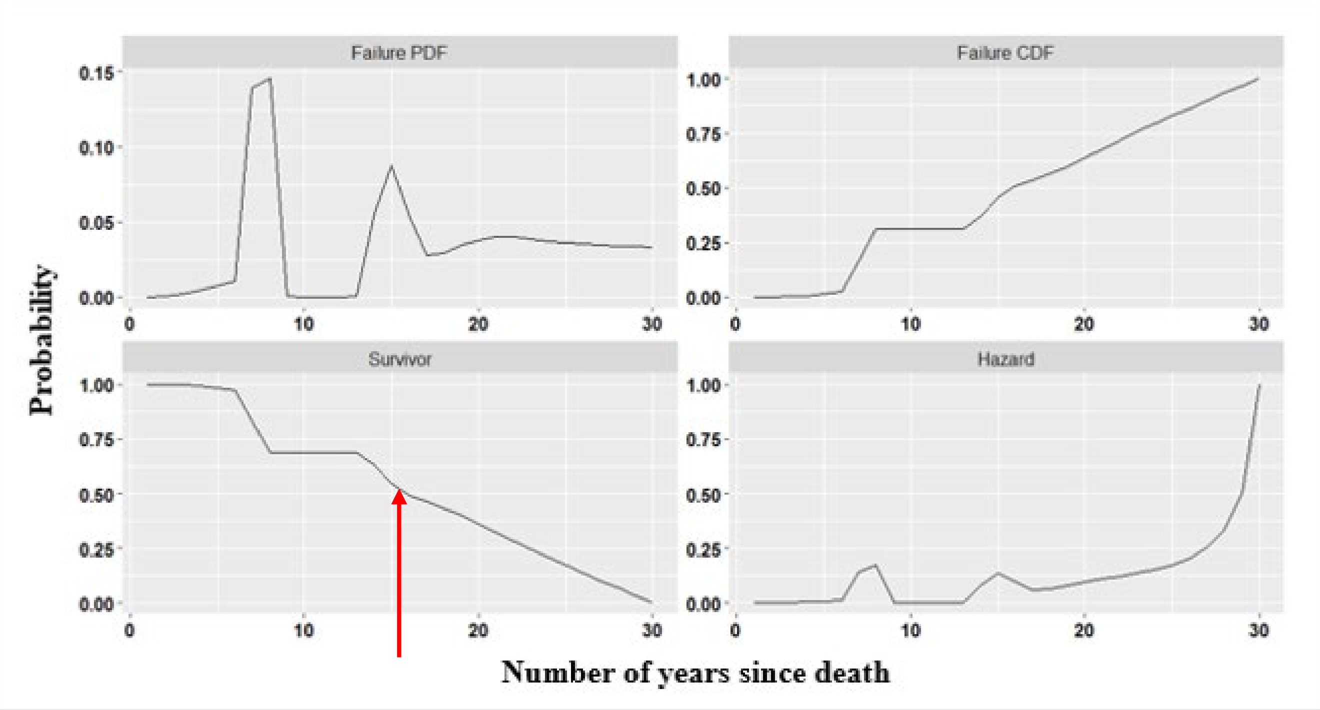
Fig. 4. (A) Percent of all plots with invasive weeds in each state in 2014 and 2018 (B) mean percent of snags fallen on plots with and without invasive weeds in 2014 and 2018.

- Weed abundance was most positively correlated with canopy cover, cover of shrubs, litter, bare ground, and percent dead trees in 2014.
- By 2018, abundance of weeds was only positively correlated with snag fall. The mean percentage of fallen trees in plots with weeds was greater than twice that in plots without weeds.
- A key factor promoting weed invasion is propagule pressure. Many plots within our network that contained invasive weeds had nearby (within ~250 m) weed populations, usually along roadways.

The soil disturbance created when snags tip up and fall appears prone to establishment and spread of invasive weeds. Canada thistle (here in a plot in Colorado) frequently invaded these sites and spread to nearby less-disturbed areas.

United States Department of Agriculture Forest Service

Snag fall rates



Only <u>24.7%</u> of snags have fallen. The predicted half-life is ~<u>16 YSD</u> after which the function predicts a fairly linear, ~0.04/year decline in snag survival probability 15–30 YSD.

United States Department of Agriculture

Forest Service

Global literature review

Table 4
Summary of literature examining effects of bark beetle outbreaks on understory vegetation. +, increase; –, decrease; 0, no change. If empty, variable not examined. Number of + or – symbols indicates estimated magnitude of change: one symbol for <10% change, two symbols for 10–25% change, and three symbols for >25% change.

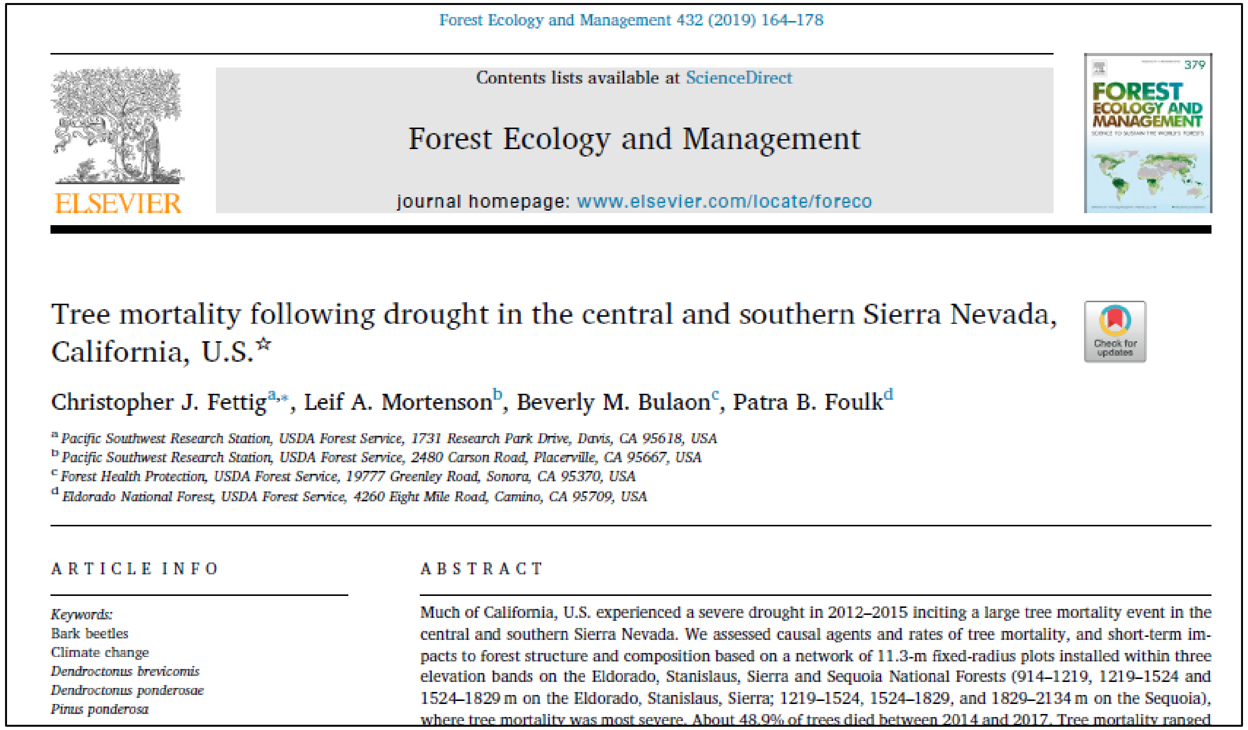
Bark beetle species	Forest type	Country	Time since outbreak (years)	Cover				Vegetation height	Above-ground biomass	Plant species diversity[1]	References
				Forbs	Shrubs	Graminoids	Total				
Dendroctonus ponderosae	*Pinus contorta*	USA	4–7						+++	+	Stone and Wolfe (1996)
		USA	20	0	0	0		+++ (shubs)	+++ (shrubs)		Page and Jenkins (2007)
		USA	0–3, 4–7	0	0	0	0	0 (0–3 yrs) +++ (4–7 yrs, grasses and forbs)			Klutsch et al. (2009)
		USA	2, 4, 30	+++ (2, 4 yrs) 0 (30 yrs)	0	0	+++ (2, 4 yrs) 0 (30 yrs)				Griffin et al. (2011)
		USA	5				+++				Norton et al. (2014)
		USA	10	+++	0	0	0				this study
		Canada	1–2						+ (yr 1) 0 (yr 2)	+ (forbs) 0 (shrubs)	Pec et al. (2015)
		Canada	7–8				– – –[2]			0	Edwards et al. (2015)
Dendroctonus ponderosae	*Pinus ponderosa*	USA	1–5						+ ++ (forbs, grasses) – (shrubs)		McCambridge et al. (1982)
		USA	0–10						+++[3]		Kovacic et al. (1985)
		USA	4–11	+	++	++	+++			–	Crotteau et al. (2019)
Dendroctonus pseudotsugae	*Pseudotsuga menziesii*	USA	5–10	+++	++	++	+++	+++			McMillin and Allen (2003)
		USA	4–5	++	0	++	++				Griffin and Turner (2012)
Dendroctonus rufipennis	*Picea glauca*	USA	17	0	0	+	+			–	Holsten et al. (1995)
		USA	8–9	0[4]	+[4]	0[4]	+[4]				Matsuoka et al. (2001)
Dendroctonus rufipennis	*Picea engelmannii*	USA	5	+++	0			+++ (forbs)	+++ (forbs)		Jorgensen and Jenkins (2011)
Dryocoetes confusus	*Abies lasiocarpa*	USA	1–4	+	+	+	+	+++			McMillin et al. (2003)
Ips typographus	*Picea abies*	Czech Republic	2–10	+			0			+ (vascular) – (moss)	Jonášová and Matějková (2007); Jonášová and Prach (2008)
		Germany	15							+	Lehnert et al. (2013)
		Germany	<20							+	Beudert et al. (2014)
		Germany	3–15	+	+	+	+			0	Fischer et al. (2015)
		Germany	3, 17–25	+++	0 (3 yrs) +++ (17–25 yrs)		+++	+		0 (3 yrs) + (17–25 yrs)	Winter et al. (2015a; 2015b)

[1] Only increase (+) or decrease (–) reported, not magnitude of change since different measures of diversity were used and species lists usually not provided.
[2] Decrease in total plant cover driven almost completely by reduction in the moss, *Pleurozium schreberi* (Brid.) Mitt.
[3] Biomass peaked at 5 years.
[4] Counted stems and leaves rather than cover.

Our global search only yielded 23 papers. All studies were from North America (16) and Europe.

- Only two studies addressed the influence of bark beetle outbreaks on invasive weeds.
- McCambridge et al. (1982) noted a large increase in musk thistle about 5 years after a mountain pine beetle outbreak in ponderosa pine in Colorado.
- Crotteau et al. (2020) reported no changes in invasive weeds for ~11 years following a mountain pine beetle outbreak in Montana.

Some related ongoing research in California


Forest Ecology and Management 432 (2019) 164–178

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

ELSEVIER

Tree mortality following drought in the central and southern Sierra Nevada, California, U.S.☆

Christopher J. Fettig[a,*], Leif A. Mortenson[b], Beverly M. Bulaon[c], Patra B. Foulk[d]

[a] Pacific Southwest Research Station, USDA Forest Service, 1731 Research Park Drive, Davis, CA 95618, USA
[b] Pacific Southwest Research Station, USDA Forest Service, 2480 Carson Road, Placerville, CA 95667, USA
[c] Forest Health Protection, USDA Forest Service, 19777 Greenley Road, Sonora, CA 95370, USA
[d] Eldorado National Forest, USDA Forest Service, 4260 Eight Mile Road, Camino, CA 95709, USA

ARTICLE INFO

Keywords:
Bark beetles
Climate change
Dendroctonus brevicomis
Dendroctonus ponderosae
Pinus ponderosa

ABSTRACT

Much of California, U.S. experienced a severe drought in 2012–2015 inciting a large tree mortality event in the central and southern Sierra Nevada. We assessed causal agents and rates of tree mortality, and short-term impacts to forest structure and composition based on a network of 11.3-m fixed-radius plots installed within three elevation bands on the Eldorado, Stanislaus, Sierra and Sequoia National Forests (914–1219, 1219–1524 and 1524–1829 m on the Eldorado, Stanislaus, Sierra; 1219–1524, 1524–1829, and 1829–2134 m on the Sequoia), where tree mortality was most severe. About 48.9% of trees died between 2014 and 2017. Tree mortality ranged

- Overall, 49% of trees died. Ponderosa pine exhibited the highest levels of mortality (90%).
- About 22% of plots had invasive weeds:
  - Cheatgrass (*Bromus tectorum* L.)
  - ripgut brome (*Bromus diandrus* Roth)
  - bull thistle
  - yellow star-thistle (*Centaura solstitalis* L.)
  - mullein (*Verbascum thapsus* L.)
  - Himalayan blackberry (*Rubus armeniacus* Focke)

United States Department of Agriculture Forest Service

Thank You!

Christopher J. Fettig
chris.fettig@usda.gov
530-604-9152