Drought and Bark beetle-caused Tree Mortality: Implications to Forest Management with an Emphasis on Carbon

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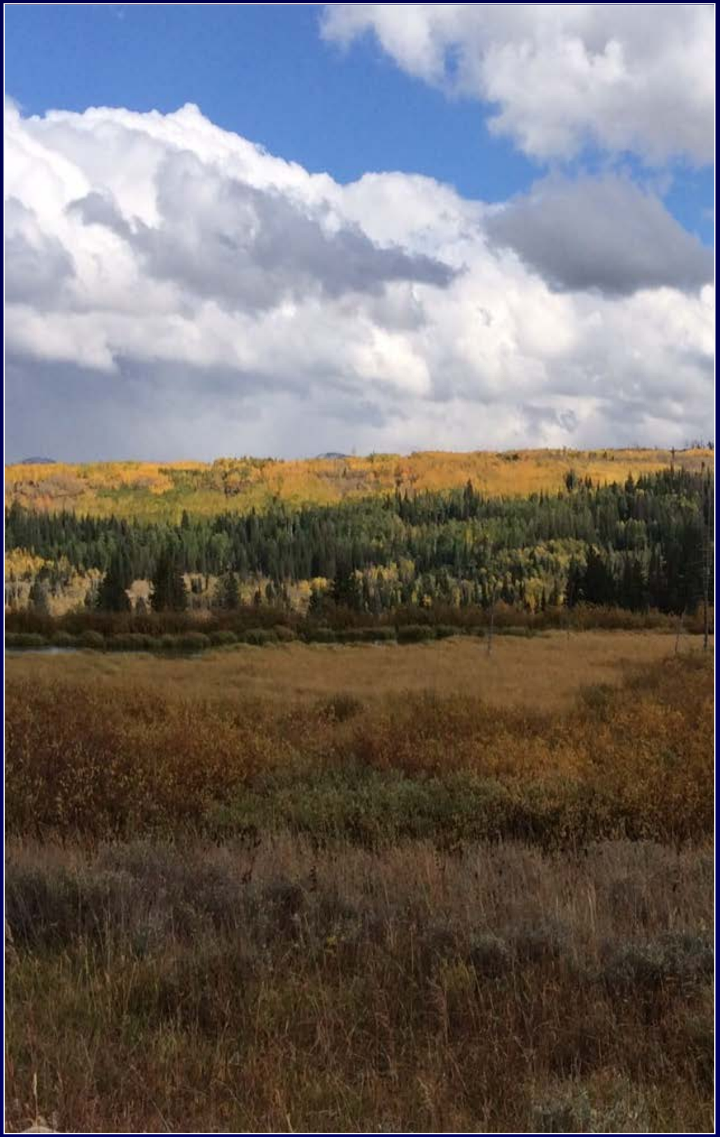
Outline

1. Bark beetles
2. Climate change
3. Causes and consequences of outbreaks, emphasis on carbon
4. Management options, emphasis on carbon
5. Questions



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Uinta-Wasatch-Cache National Forest, Wyoming, 2015.

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 (top) predating on red turpentine beetle (*D. valens*) attracted to residual trees following harvesting, Eldorado National Forest, California, 2005.

Principle native tree-killing species in western North America

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*

Chapter 18
Native Bark Beetles and Wood Borers in Mediterranean Forests of California

Christopher J. Fettig

Abstract Several species of bark beetles (Coleoptera: Curculionidae, Scolytinae), and to a much lesser extent wood borers (primarily Coleoptera: Buprestidae and Cerambycidae), are capable of causing conifer mortality in Mediterranean forests of California, U.S. This mortality is an important part of the ecology of these ecosystems, but the economic and social implications can be significant when outbreaks occur. I review the ecology, impact and management of the more notable species, including western pine beetle, *Dendroctonus brevicomis* LeConte, mountain pine beetle, *D. ponderosae* Hopkins, Jeffrey pine beetle, *D. jeffreyi* Hopkins, red turpentine beetle, *D. valens* LeConte, California fivespined ips, *Ips paraconfusus* Lanier, pine engraver, *I. pini* (Say), pinyon ips, *I. confusus* LeConte, fir engraver, *Scolytus ventralis* LeConte, cedar bark beetles, *Phloeosinus* spp., and several wood borers.

18.1 Introduction

Fettig 2016 in *Insects and Diseases of Mediterranean Forest Systems*

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Western pine beetle galleries, California, 2016.

- 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 western pine beetle (WPB), females release *exo*-brevicomin, which in combination with the host monoterpene myrcene is attractive to conspecifics. Frontalin, produced by males, enhances attraction).

Phoretic organisms

Table 3. Common fungal symbionts of *Dendroctonus ponderosae* in North America.

Fungal symbiont	Symbiotic relationship	*D. ponderosae* transport site (primary, secondary)
Ophiostomatales (blue-stain fungi)		
Ophiostoma montium (Rumbold) Arx	Mutualist	Mycangia, exoskeleton
Grosmannia clavigera (Rob.-Jeffr. and R.W. Davidson) Zipfel, Z.W. de Beer & M.J. Wing.	Obligate mutualist	Mycangia, exoskeleton
Leptographium longiclavatum S.W. Lee, J.J. Kim & C. Breuil	Mutualist	Mycangia, exoskeleton
Saccharomycetales (yeasts)		
Ogataea pini (Holst) Y. Yamada, M. Matsuda, K. Maeda & Mikata	Mutualist	Gut, exoskeleton
Kuraishia capsulata (Wick.) Y. Yamada, K. Maeda & Mikata	Mutualist	Gut, exoskeleton
Nakazawaea holstii (Wick.) Y. Yamada, K. Maeda & Mikata	Mutualist	Gut, exoskeleton
Yamadazyma scolyti (Phaff & Yoney.) Billon-Grand	Mutualist	Gut, exoskeleton
Russulales (filamentous yeast)		
Entomocorticium dendroctoni Whitney	Mutualist	Mycangia

Figure 2. Four *Trichouropoda* spp. (tortoise mites) transported around the front coxae of a MPB that rests on a pine needle. (Photograph by Javier E. Mercado.)

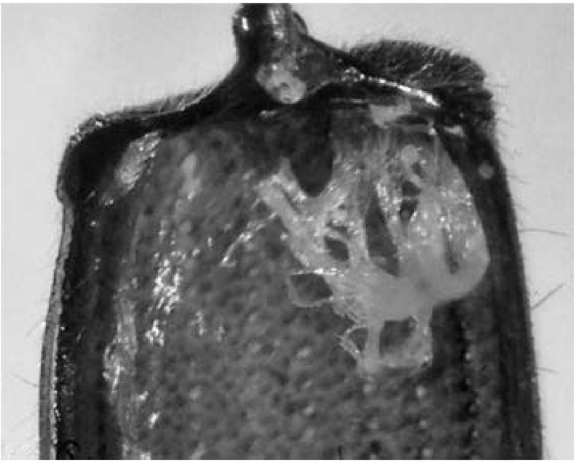
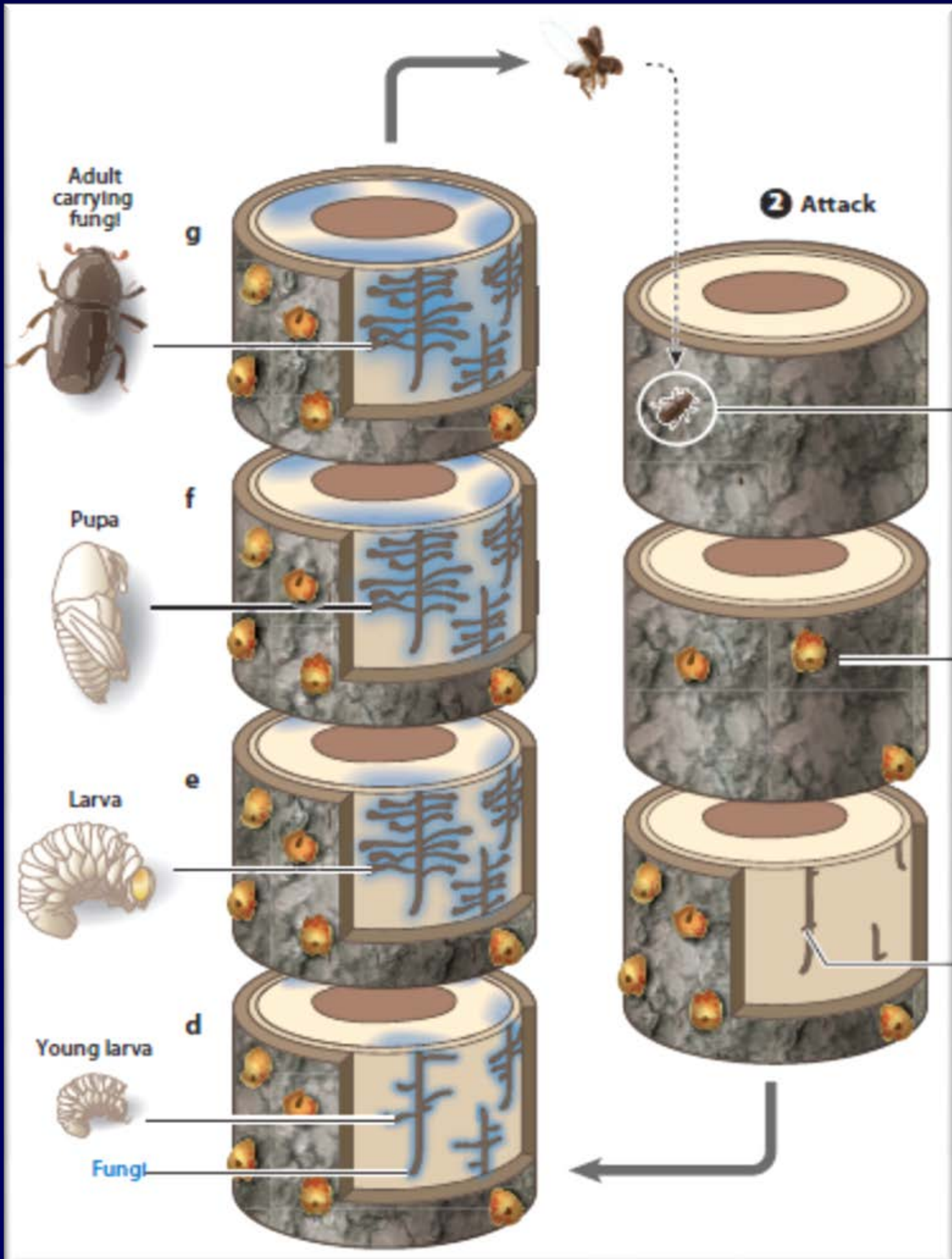


Figure 3. A mass of unidentified nematode dauerlarvae travels inside a MBP's elytral base. (Photograph by Javier E. Mercado.)

Mercado et al. 2014. Forest Science 60:512–526.

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



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Tree death occurs by girdling of the phloem (i.e., layers of cells just inside the bark that transport photosynthate) by both colonizing adults and developing larvae.

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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.


IN GENERAL
Elevated levels of bark beetle-caused tree mortality on the forested landscape

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

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

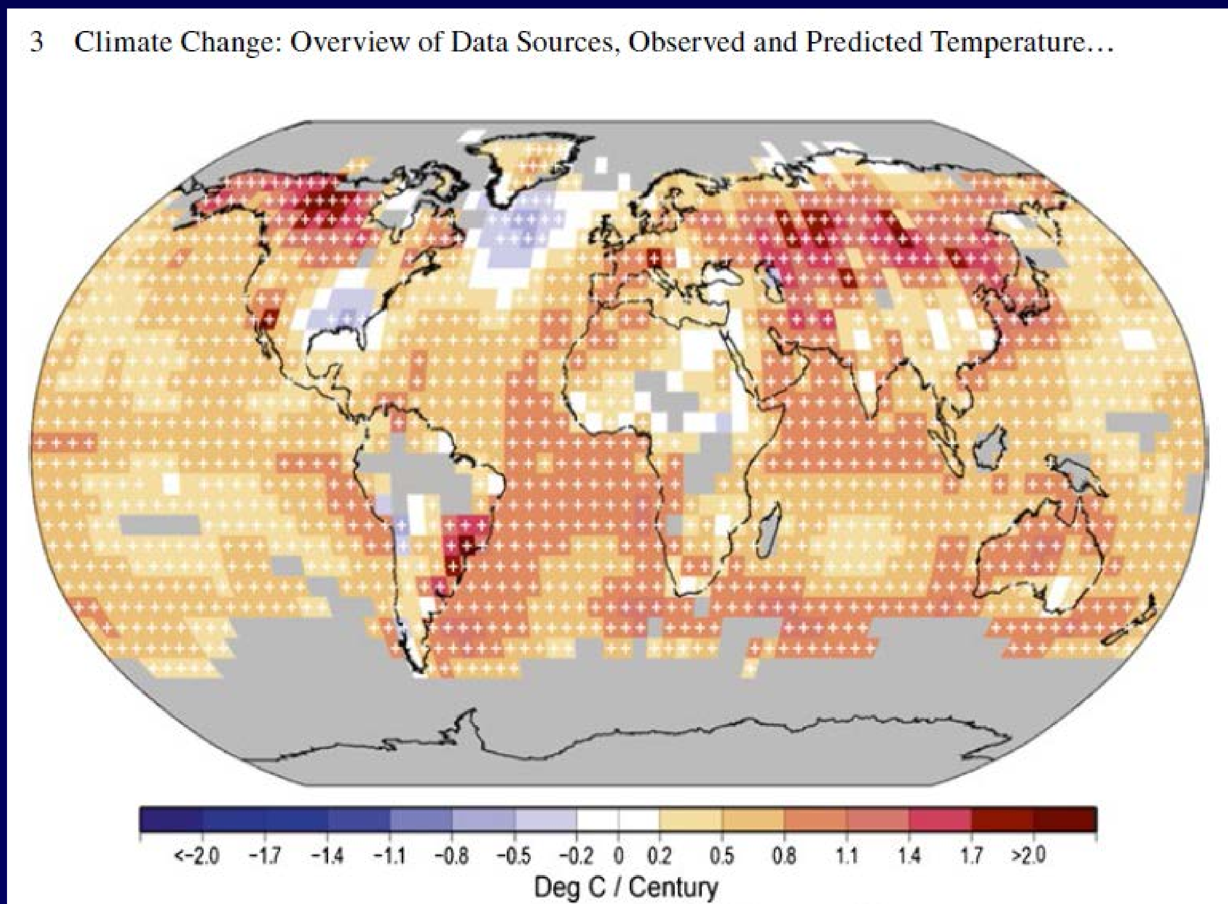
T. Eager, FHP

Pinyon ips (*I. confusus*)
(increase in summer temps X drought)

C. Fettig, PSW

Western pine beetle (*D. brevicomis*)
(drought, lowest precip. in recorded history 2001-02).

The vast majority of the earth's surface has warmed during the 20th century, with the largest increases observed at mid- to high-latitudes in the Northern Hemisphere…



Levinson and Fettig 2014 in *Climate Change and Global Public Health*

Its getting warmer and its getting warmer faster….

Since 2000, 15 of the 16 warmest years on record have occurred.

Table 3.1 The observed differences in annual global temperature anomaly for 2010 and its rank relative to the entire historical record since 1880 for the three primary datasets used to determine global average temperatures

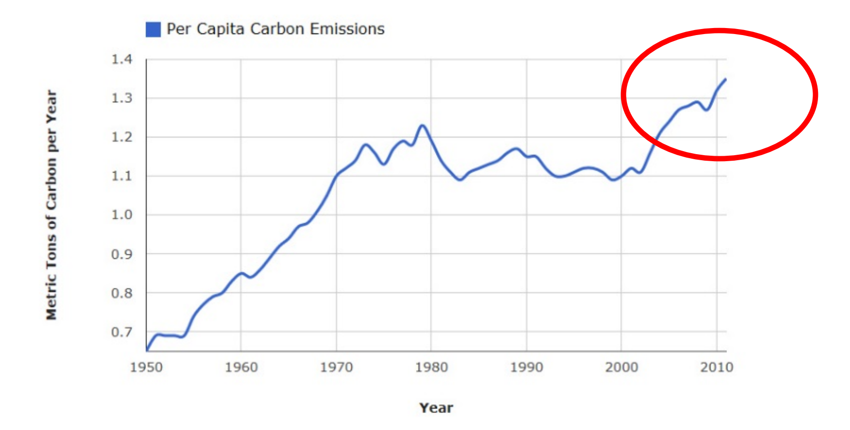
	2010 Global anomaly relative to the 1961–1990 annual mean	Rank of 2010 to all years since 1880
HadCRUT3	0.50 °C	Second warmest after 1998
NASA-GISS	0.56 °C	Tied warmest with 2005
NOAA-NCDC	0.52 °C	Tied warmest with 2005

From Sanchez-Lugo A, Kennedy JJ, Berrisford P (2011) Surface temperatures. In "State of the Climate 2010," *Bull Amer Meteor Soc* 92:6:S36-S37, with permission

Levinson and Fettig 2014 in *Climate Change and Global Public Health*

- Most of the warming has been attributed to the radiative effects of CO_2, but other greenhouse gases such as methane, nitrous oxide and halocarbons are also important.

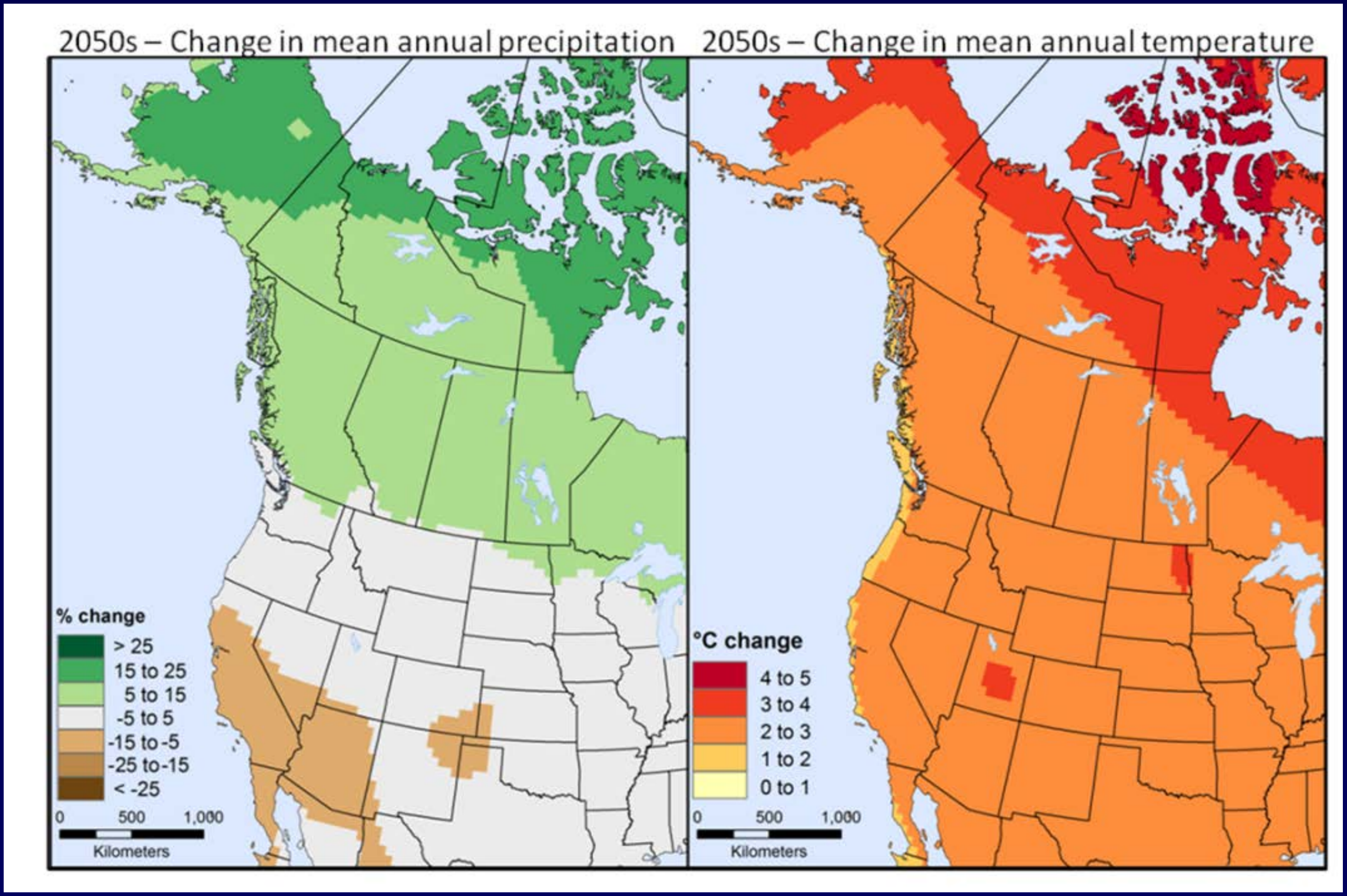
- Prior to the Industrial Revolution, atmospheric CO_2 was stable at ~270 ppm. Today, ~408 ppm (May 2016), and by the middle of this century is expected to reach 550 ppm and to surpass 700 ppm by the end of the century.



Source: Boden, T.A., G. Marland, and R. J. Andres. 2015. Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi: 10.3334/CDIAC/00001_V2015.

ww.esrl.noaa.gov

Since 1751, 374 billion metric tons of carbon have been released from the consumption of fossil fuels and cement (second most consumed substance on earth) production. Half since 1980s.



Fettig et al. 2013. *Journal of Forestry* 111:214-228.

Median change in mean annual precipitation (left) and air temperature (right) compared to the climatic normal period (1961-90) based on projection by 13 global climate models.

Impacts

- For long-lived tree species, climate change will likely result in a mismatch between the climate to which trees are currently adapted and the climate that trees will experience in the future.
- Individuals or populations exposed to climate conditions outside their climatic niches may be maladapted (*P. radiata*), resulting in compromised productivity.
- Efforts to model the climatic niche of forest tree species and associate forest ecosystems, and to project their shifts under future climates, have proliferated.

There will be winners and losers…

The fate of any tree, species or population will depend on genetic variation, phenotypic variation, fecundity and dispersal mechanisms, and their resilience and resistance to a multitude of disturbances.

Shifts in bioclimatic envelopes

- E.g., increases in grassland and montane forest at the expense of Great Basin woodland and subalpine forest.
- Rehfeldt et al. (2006) suggested that ~48% of the western U.S. landscape is likely to experience climate profiles with no contemporary analog for the current coniferous vegetation by the end of this century.

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These changes <u>are</u> mediated by disturbances…

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Mountain pine beetle (*D. ponderosae*) outbreak, British Columbia, Canada. 2005

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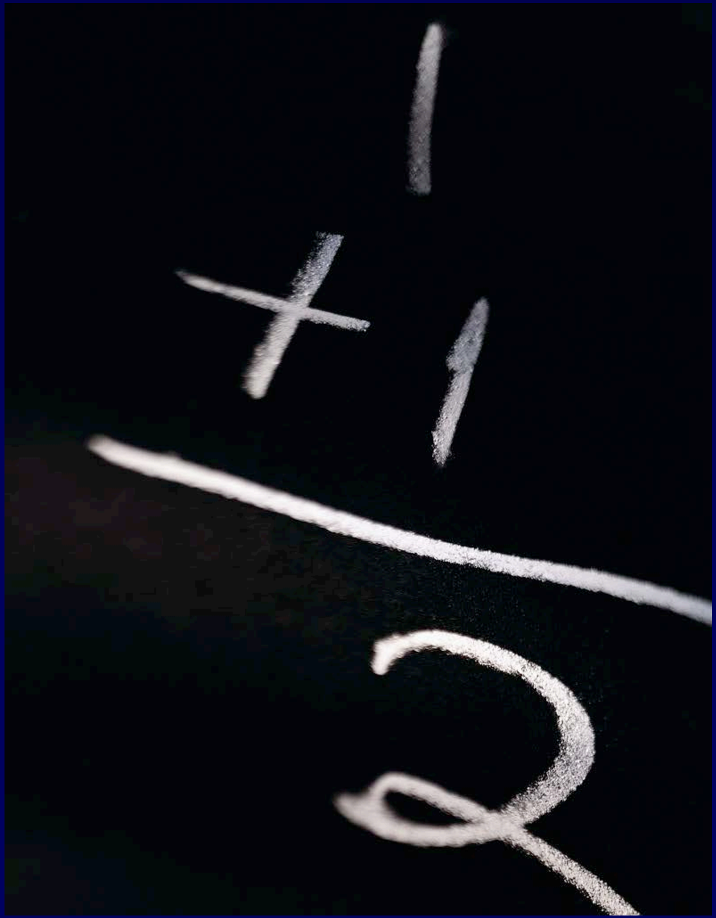
Cone Fire, Blacks Mountain Experimental Forest, California, U.S., 2003

Outbreaks occur when....

- Favorable vegetative conditions
- Favorable climatic conditions



ClipArt

Three spatial scales

Tree

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Stand

Landscape

Growing space

- Individual trees utilize growth factors (i.e., sunlight, water, nutrients, temperature, oxygen, carbon dioxide, etc.) until one or more factors become limiting.
- A forest contains a certain amount of intangible *growing space*, which varies spatially and temporally.
- As growing space diminishes, a tree's photosynthates are allocated to different uses in an order of priorities.

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Ps Allocations

- maintenance respiration
- production of fine roots
- reproduction
- primary (height) growth
- xylem (diameter) growth
- insect and disease resistance mechanisms

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adapted from Oliver and Larson (1996), Fettig et al. (2007)

Tree defenses


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- Most coniferous species have a well-defined resin duct system, which is capable of mobilizing large amounts of oleoresin following wounding.

Mass attack

- A critical minimum number of beetles is required to overcome defenses (Wood 1972, Hodges et al. 1979, 1985; Raffa et al. 1993), which varies with changes in host vigor.
- Several bark beetle species (e.g., *Ips* spp.) preferentially attack logs, slash, or dead and dying trees. In these cases, little or no host resistance is encountered.
- All other things equal:

  - Less competition among trees = higher individual tree vigor (e.g., OEP) = more beetles required to kill the tree

Stand susceptibility

Stocking (measured as tree density, basal area, or stand density index), host abundance and tree age are consistently linked with the occurrence of bark beetle infestations.

C. Fettig, USDA Forest Service

Fettig et al. 2007. *Forest Ecology and Management* 238:24–53.

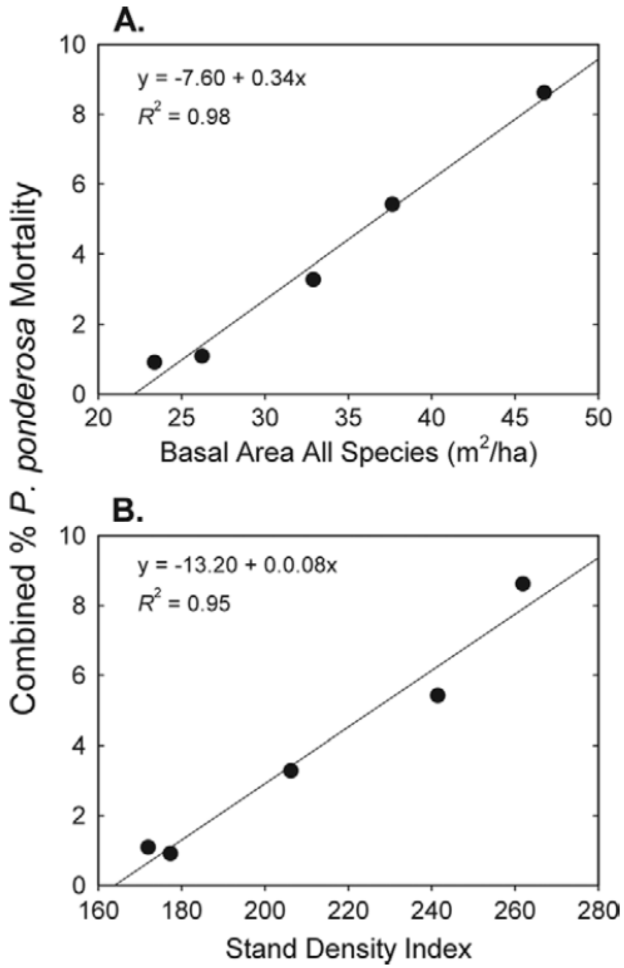
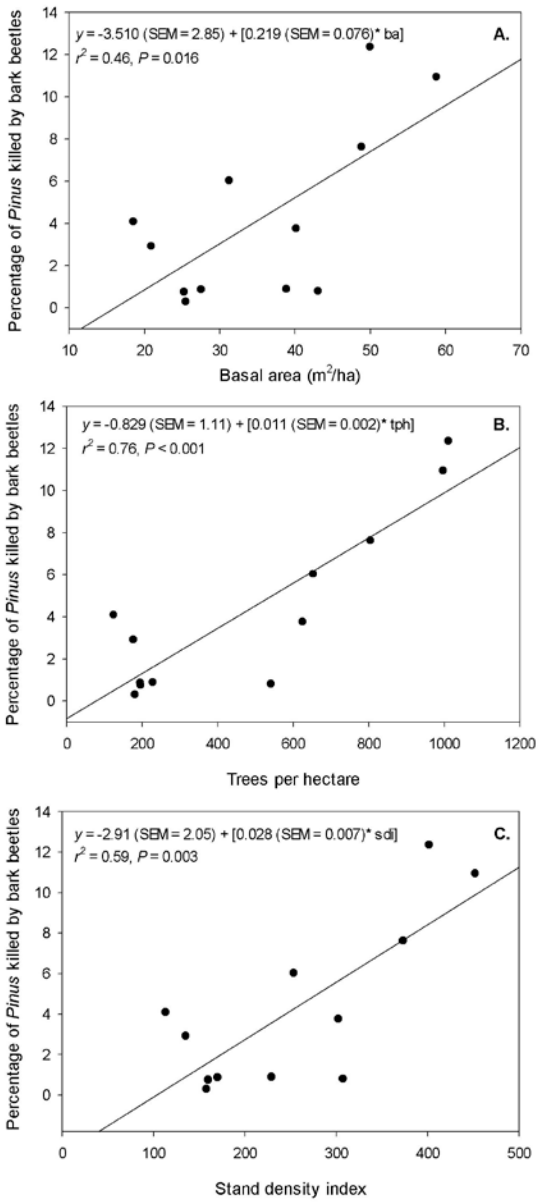


Fig. 5. Linear regressions overlaid on observed data points for (A) basal area of all tree species and mean percentage of ponderosa pine killed by western pine beetle in yr-1 and yr-2 combined (see Table 5, model D for additional statistics), and (B) stand density index and mean percentage of ponderosa pine killed by western pine beetle in yr-1 and yr-2 combined (see Table 5, model E for additional statistics).

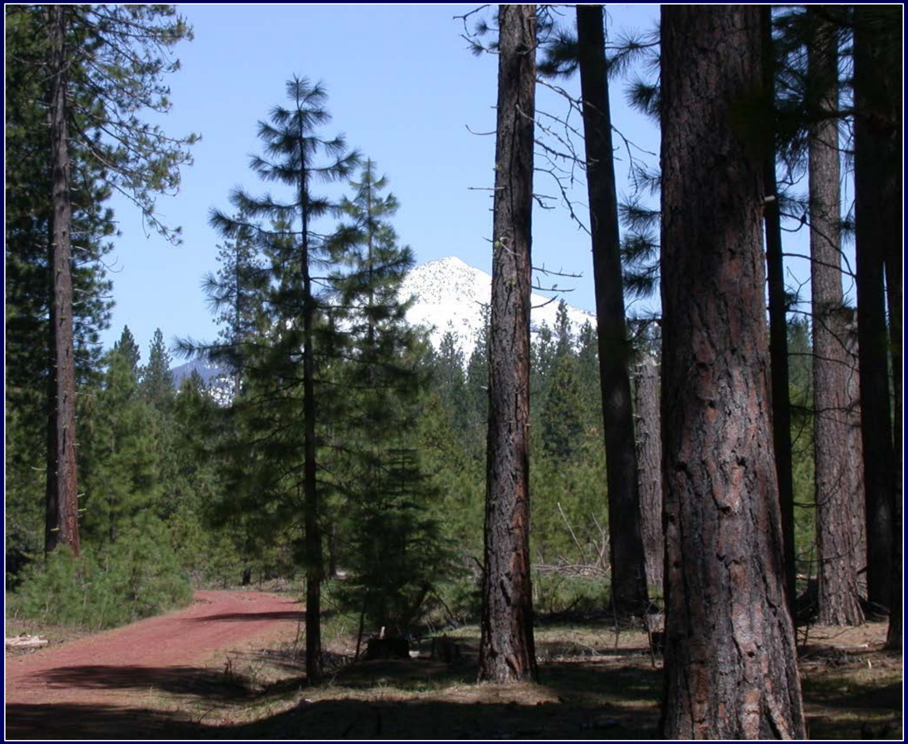
Fettig et al. 2009. *Journal of Economic Entomology* 102:2170 – 2182.



Fettig et al. 2010. *Forest Science* 56:60–73.

Landscape susceptibility

- Spatial arrangement is important.
- Forested landscapes that contain little heterogeneity promote the creation of large contiguous areas susceptible to similar disturbances.



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Climatic…direct and indirect

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
- Hosts, predators, parasites and competitors
- Competitive ratios
- Host finding and colonization success

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

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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 expected (IPCC 2007). Associated changes in precipitation patterns may result in earlier and longer dry seasons across the western United States, with a greater frequency and duration of droughts (Seager et al. 2007). These changes in climatic conditions over the next century will significantly affect the condition, composition, distribution, and productivity of multiple ecosystems (Easterling et al. 2000).

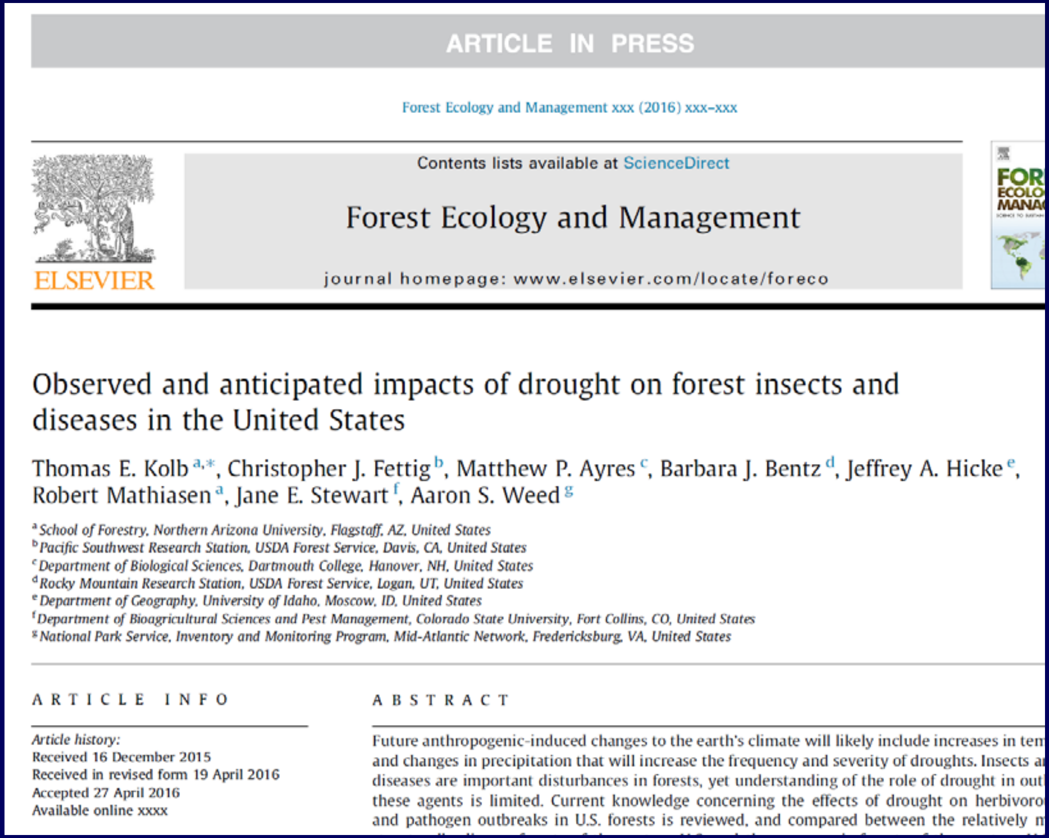
Coniferous forests, which provide essential ecosystem services and host a vast array of plant and animal species, are

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 already been documented (Balanyá et al. 2006, Bradshaw and Holzapfel 2006), and range expansion has occurred in many cases as species move into new niches created by increasing temperature (Battistia et al. 2006, Nealis and Peter 2009).

Native bark beetles (Coleoptera: Curculionidae, Scolytinae), which evolved within the coniferous forest ecosystems of western North America, are key agents of change in these systems. Beetle outbreaks raise tree mortality rates and can result in subsequent replacement by other tree species and

Bentz et al. 2010. *Bioscience* 60:602-613.

Drought



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Observed and anticipated impacts of drought on forest insects and diseases in the United States

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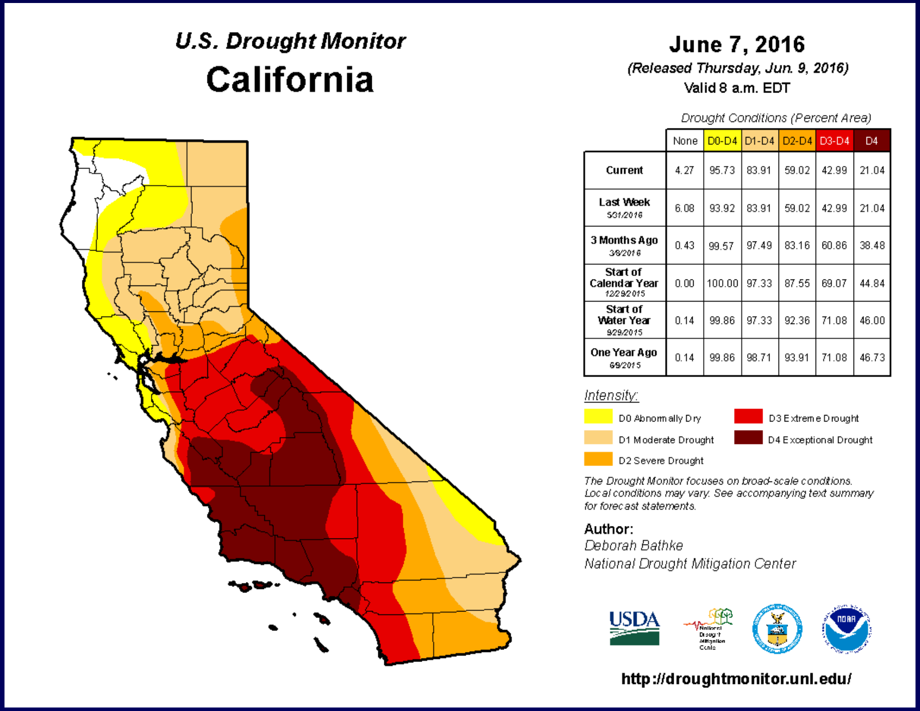
ABSTRACT

Future anthropogenic-induced changes to the earth's climate will likely include increases in tem and changes in precipitation that will increase the frequency and severity of droughts. Insects a diseases are important disturbances in forests, yet understanding of the role of drought in out these agents is limited. Current knowledge concerning the effects of drought on herbivoro and pathogen outbreaks in U.S. forests is reviewed, and compared between the relatively m

- One of the most important and best recognized inciting factors.
- Short-term deficiencies may result in recurrent infestations of limited scale.
- Long-term deficiencies may result in large amounts of tree mortality over extensive areas.

California's WPB outbreak



	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	4.27	95.73	83.91	59.02	42.99	21.04
Last Week 5/31/2016	6.08	93.92	83.91	59.02	42.99	21.04
3 Months Ago 3/8/2016	0.43	99.57	97.49	83.16	60.86	38.48
Start of Calendar Year 12/29/2015	0.00	100.00	97.33	87.55	69.07	44.84
Start of Water Year 9/29/2015	0.14	99.86	97.33	92.36	71.08	46.00
One Year Ago 6/9/2015	0.14	99.86	98.71	93.91	71.08	46.73

- California is currently in its fourth year of severe drought. Water Year 2015 (ended 30 September 2015) was the hottest and driest on record.
- 2014 was the third driest and second hottest.

Site 1 - 3679' elevation, southern Sierra Nevada

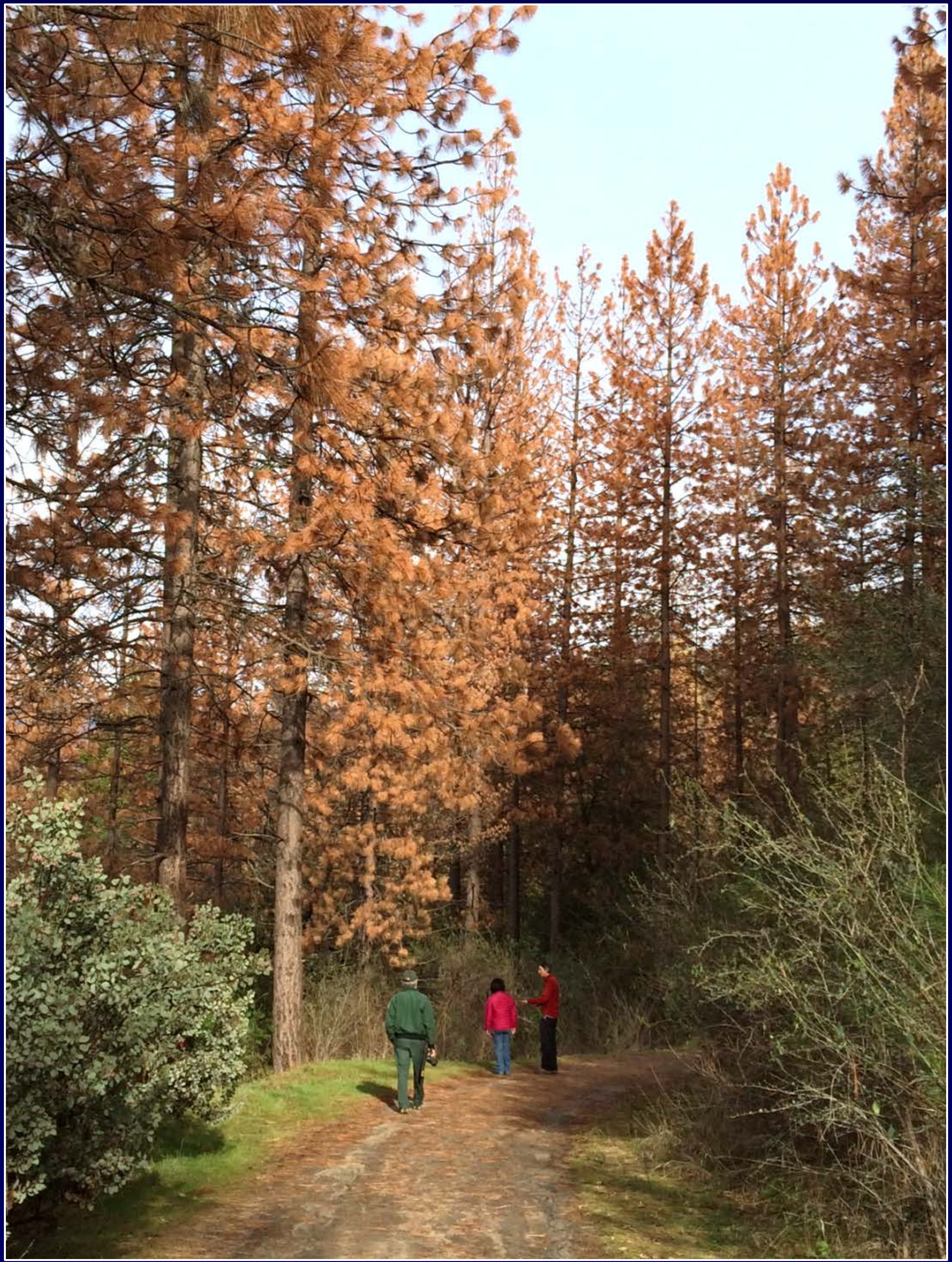
<u>March 2014</u>

200 TPA
180.7 ft^2 BAA
65% PIPO
30% CADE
5% QUCH

<u>March 2016</u>

60 TPA
13.0 ft^2 BAA
83% CADE
17% QUCH

In a period of <u>two</u> years, 70% of trees and 93% of basal area were killed.
All PIPO were colonized by western pine beetle, most in 2015.



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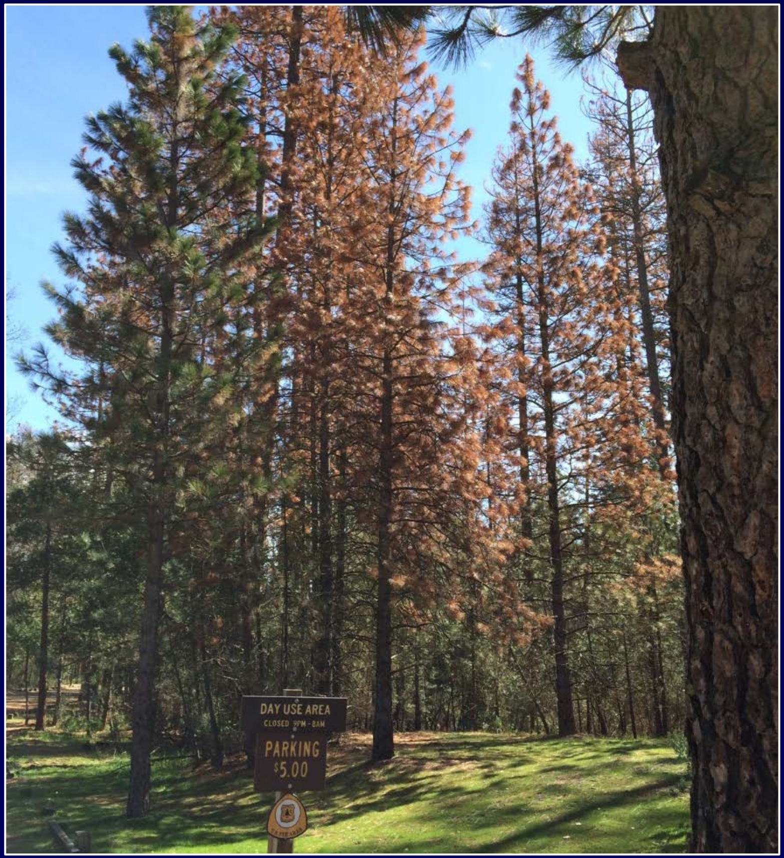
In the most heavily impacted areas, >80% (81.4 ± 3.9%) of the pine basal area has been killed in unthinned stands.

Consequences?

Significant modification of stand structure and composition, which may impact…timber and fiber production, fuel conditions, water quality and quantity, fish and wildlife populations, recreation, grazing capacity, real estate values, biodiversity, carbon storage, endangered species and cultural resources.



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Strong effects on fuels

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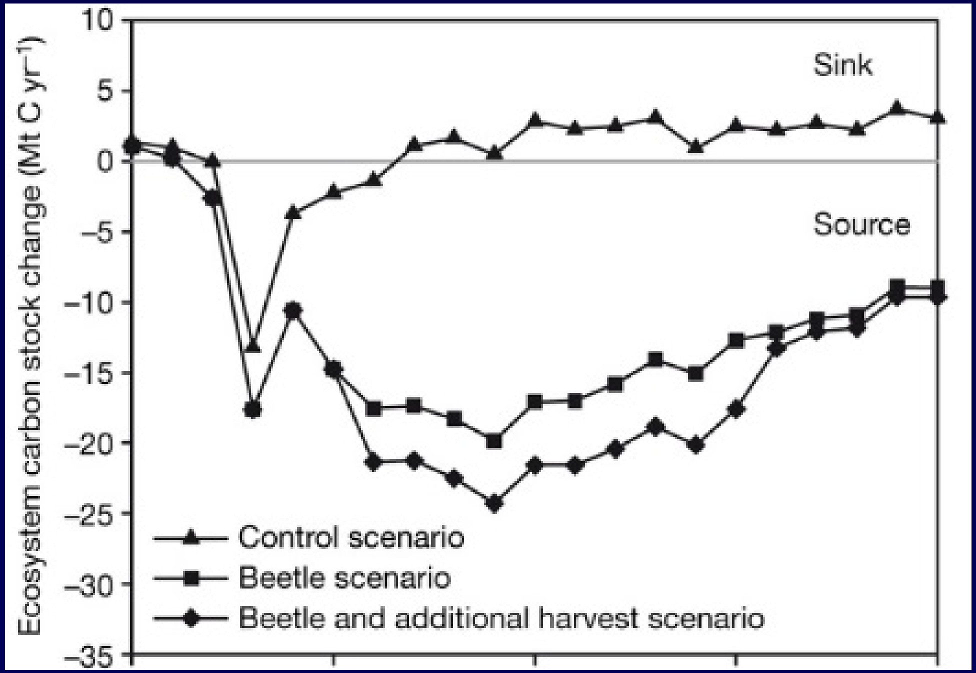
Carbon

- Tree death leads to the eventual release of stored carbon (~50% DW), although some carbon may stay locked in soil.

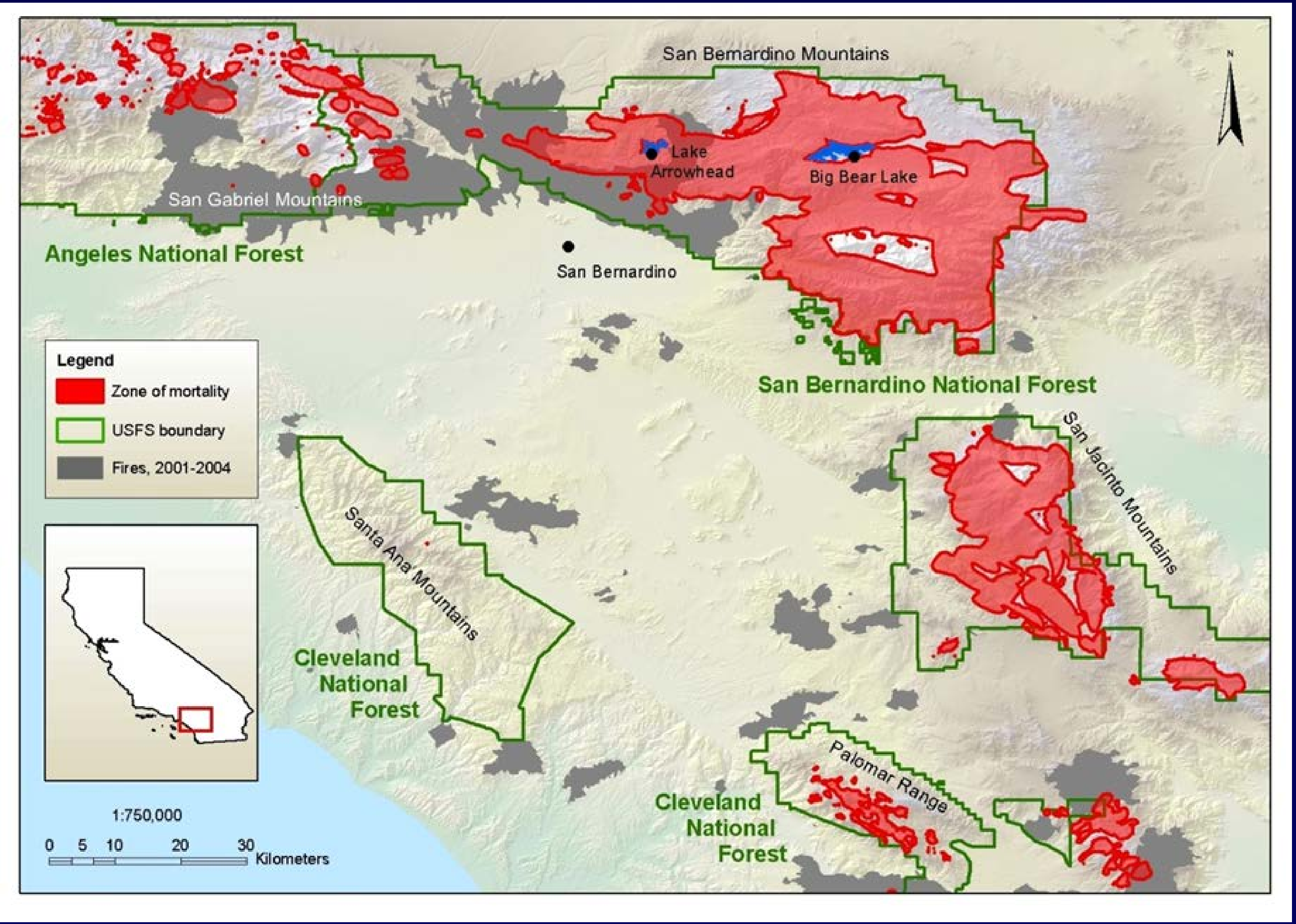


Kurz et al. 2008. Nature 452:987-990

Mountain pine beetle outbreak in BC converted the forest from a small net carbon sink to a large net carbon source both during and immediately after the outbreak. In the worst year, the impacts resulting from the beetle outbreak in British Columbia were equivalent to 75% of the average annual direct forest fire emissions from all of Canada during 1959-1999.

SoCal outbreak

- In 2000, WPB were first noticed colonizing Coulter pines at elevated levels in several ranges. Activity peaked in 2002-03 when WPB were reported to be the most common mortality agent associated with dead and dying pines throughout the region (USDA Forest Service 2002).
- In some areas, mortality was >80%. Ponderosa and Coulter pines >43.2 cm dbh experienced 73.5% and 78% mortality, respectively.
- Despite continuing drought and an availability of suitable hosts, WPB populations rapidly declined in 2004 (Hayes et al. 2009).



Areas impacted by WPB during 2001-04 based on aerial survey data (ADS). Red excludes mortality attributed to wildfire (gray) and areas occupied by nonhosts except for Jeffrey pine, which is indistinguishable from ponderosa and Coulter pines during ADS.

Carbon – WPB, SoCal

- We estimated that the total amount of C in all trees killed (all causes, except wildfire) was 1,698,558 mt. The well-publicized Angora Fire burned 1,255 ha in LTBMU in 2007 estimated CO_2 emission from combustion (immediate) and decay (over 100 yrs) at 518,495 mt (Bonnicksen 2008).

- Only a small portion of this material was salvaged and made into solid wood products.

Chapter 14

Management Strategies for Bark Beetles in Conifer Forests

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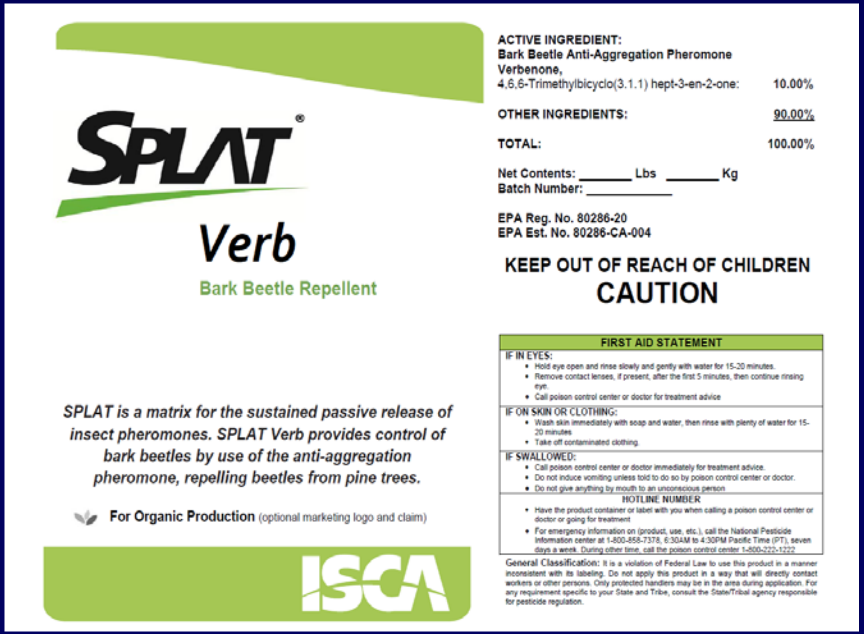
1. INTRODUCTION

Bark beetles (Coleoptera: Curculionidae, Scolytinae) are important disturbance agents in conifer forests. The genera *Dendroctonus*, *Ips*, and *Scolytus* are well recognized in this regard (Table 14.1). For example, in western North America, the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) colonizes several tree species, most notably lodgepole pine (*Pinus contorta* Dougl. ex Loud.), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), and whitebark pine (*Pinus albicaulis* Engelm.). Recent outbreaks have been severe, long lasting, and well documented, with over 27 million hectares impacted (BC Ministry of Forests, Lands

designed to address current infestations by manipulating beetle populations, and often includes the use of fire, insecticides, semiochemicals (i.e., chemicals released by one organism that elicit a response, usually behavior, in another organism), sanitation harvests, or a combination of these treatments. *Indirect control* is preventive, and designed to reduce the probability and severity of future bark beetle infestations within treated areas by manipulating stand, forest, and/or landscape conditions by reducing the number of susceptible hosts through thinning, prescribed burning, and altering age classes and species composition. Unlike direct control, the focus of indirect control is on the suscep-

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

C. Fettig, USDA Forest Service



Why does thinning work?

- Affects vigor of residual trees, but unlike most people think this may not be the most important effect in some systems.
- Thinning changes the physical environment within stands.
  - microclimate
  - pheromone plumes
  - inter-tree spacing

Thinning ponderosa pine stands, California, 2006.


Untreated lodgepole pine
Treated lodgepole pine

Healthy forests have the potential to assimilate, accumulate and sequester large amounts of C…

Management and Policy Implications

The earth's climate is changing and will continue to do so at a faster rate than in recent history due to anthropogenic-induced increases in concentrations of greenhouse gases, primarily carbon dioxide (CO_2). Climate change poses a significant challenge for society because it is unlikely that efforts to control greenhouse gas emissions will eliminate the risk of anthropogenic-induced climate change. A sound forest carbon policy informed by the best available science represents an important part of the solution because forests have the potential to assimilate, accumulate, and sequester large amounts of carbon from the atmosphere, thus reducing one of the primary drivers of climate change. Alternatively, large amounts of CO_2 are released when forests are killed, burned, defoliated, or deforested, and carbon may be lost when forests are converted to other systems (e.g., shrublands) that have smaller carbon pools. Individual trees or populations exposed to climate conditions outside their climatic niches may be maladapted, resulting in compromised productivity and increased vulnerability to disturbance. Tree distributions and plant associations, as we know them today, will change. Although forest managers, policymakers, and scientists have been working to develop and implement strategies that increase the resistance and resilience of forests to climate change in western North America, much of this work has not been well-coordinated. By collaborating with scientists, managers can implement adaptive strategies based on the best available science, which in turn informs forest policy. We encouraged flexible management approaches that promote learning and sharing and recognize the need for a more collaborative approach, in which managers, policymakers, and scientists of broad expertise from various disciplines and across political borders work to address climate change.

Fettig et al. 2013. *Journal of Forestry* 111:214-228.

(IPCC 2007, p. 543)

C. Fettig, USDA Forest Service

Mill, California, 2004.

"In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre, or energy from the forest, would generate the largest sustained mitigation benefit".

- Recognizing that substantial quantities of carbon can be stored in wood products.
- Promoting wood products as a substitute to other building materials (e.g., aluminum, concrete and steel) that do not provide the associated carbon benefits of wood.

C. Fettig, USDA Forest Service

- The greatest gains in both CO_2 and FF savings is through avoiding FF needed to manufacture, transport and construct concrete and steel (avoidance pathway) by substitution of wood products.

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Carbon, Fossil Fuel, and Biodiversity Mitigation With Wood and Forests

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Life-cycle analyses, energy analyses, and a range of utilization efficiencies were developed to determine the carbon dioxide (CO_2) and fossil fuel (FF) saved by various solid wood products, wood energy, and unharvested forests. Some products proved very efficient in CO_2 and FF savings, while others did not. Not considering forest regrowth after harvest or burning if not harvested, efficient products save much more CO_2 than the standing forest; but wood used only for energy generally saves slightly less. Avoided emissions (using wood in place of steel and concrete) contributes the most to CO_2 and FF savings compared to the product and wood energy contributions. Burning parts of the harvested logs that are not used for products creates an additional CO_2 and FF savings. Using wood substitutes could save 14 to 31% of global CO_2 emis-

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- www.fire.ca.gov/treetaskforce/
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