



~~63~~ ~~66~~ 67 Million Trees and Counting: Causes, Consequences and Carbon

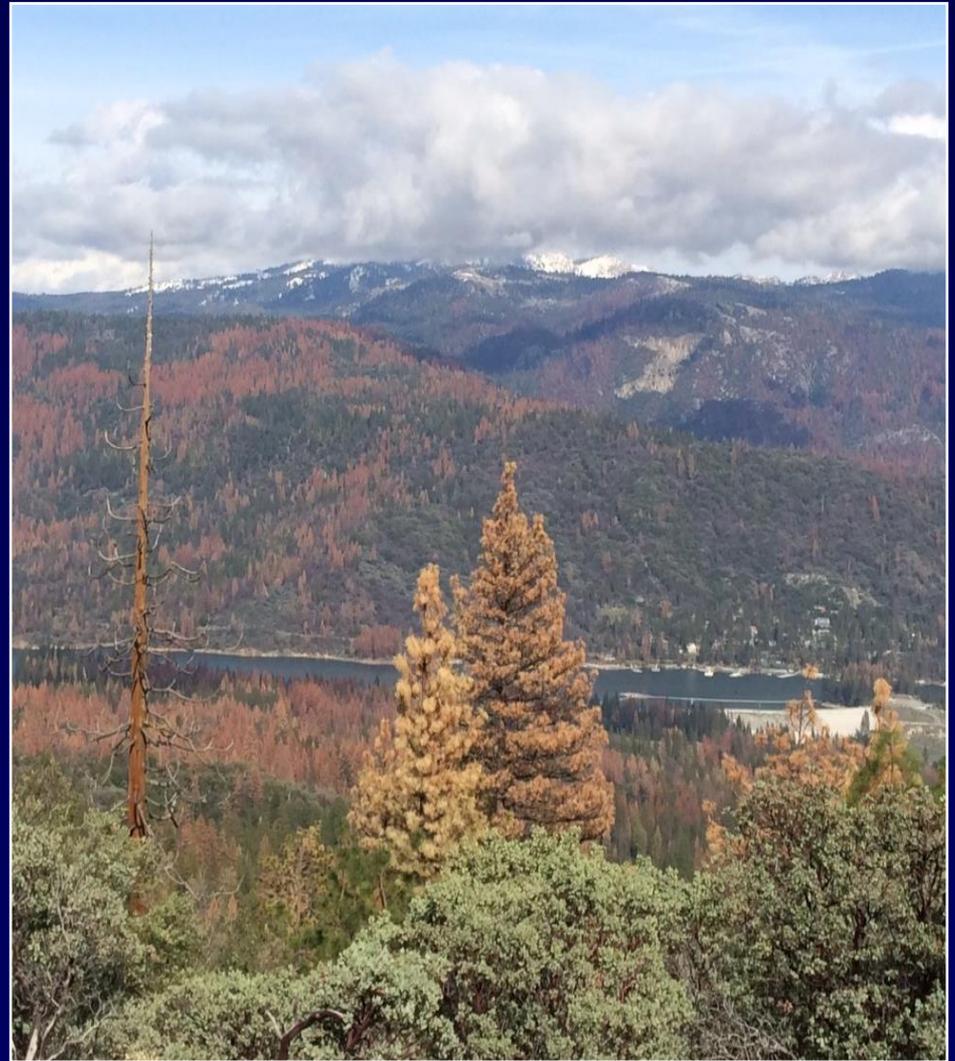
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California Board of Forestry Meeting
Sacramento, California, August 2016



Outline

1. Bark beetles
2. Causes of outbreaks
3. Management options, emphasis on carbon
4. Questions



Sierra National Forest, California, 2016.

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



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 *exobrevicomin*, which in combination with the host monoterpene *myrcene* is attractive to conspecifics. Frontalin, produced by males, enhances attraction).

Phoretic organisms



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.)

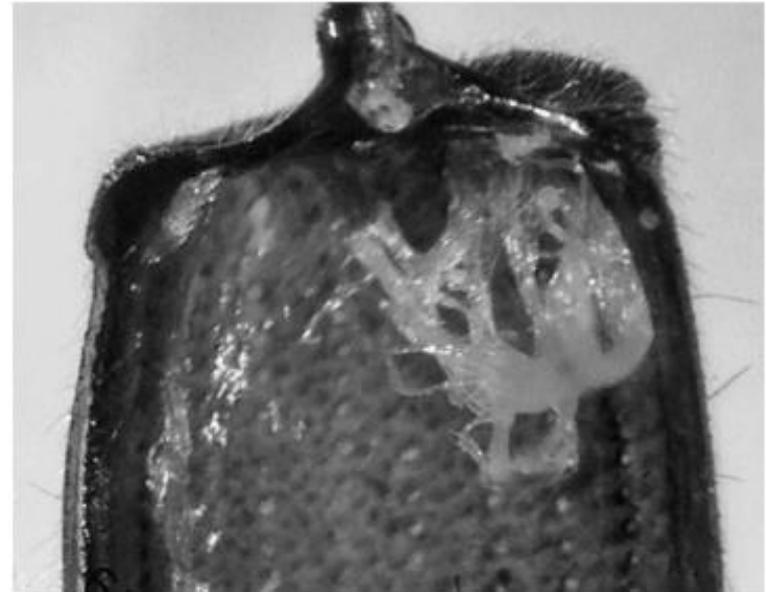
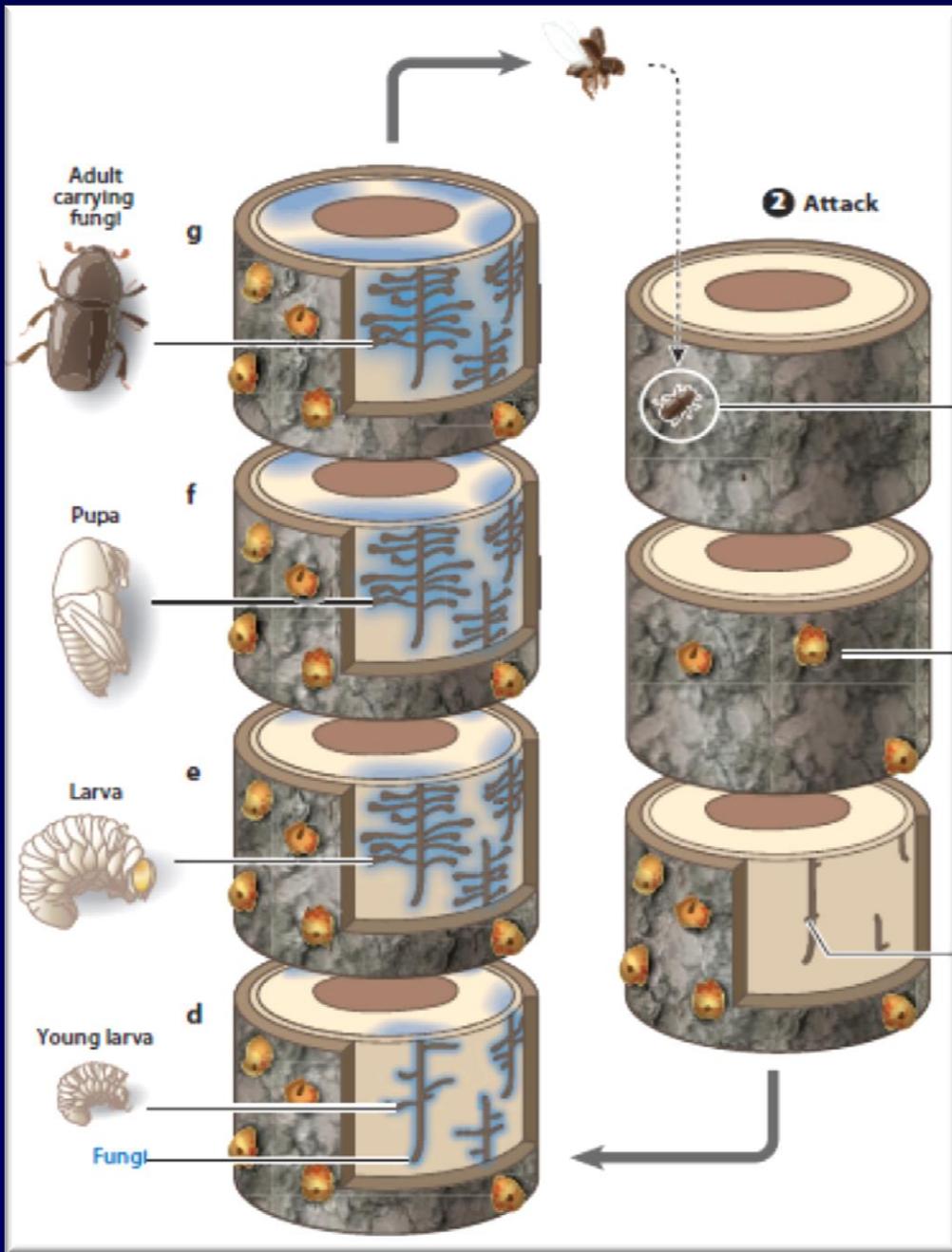


Figure 3. A mass of unidentified nematode dauerlarvae travels inside a MBP's elytral base. (Photograph by Javier E. Mercado.)



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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

C. Fettig, PSW



Mountain pine beetle (*D. ponderosae*)

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Spruce beetle (*D. rufipennis*)

T. Eager, FHP



Pinyon ips (*I. confusus*)

C. Fettig, PSW



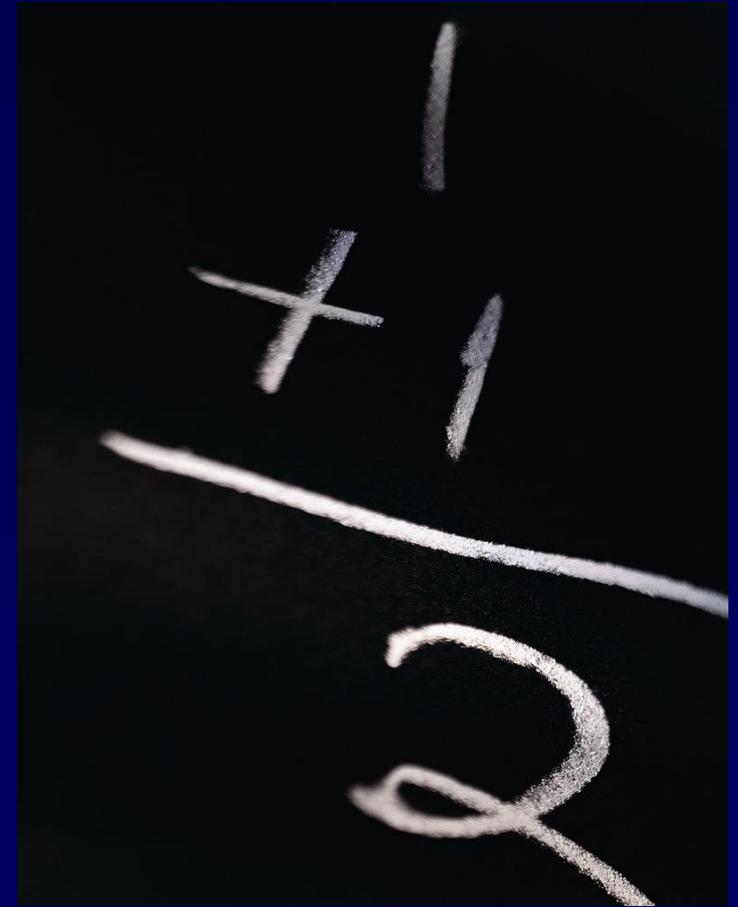
Western pine beetle (*D. brevicomis*)

- southern California, early 2000s
- southern and central Sierras, 2015s



Why? Outbreaks occur when...

- Favorable climatic conditions
- Favorable vegetative conditions



ClipArt

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 voltinism
- Hosts, predators, parasites and competitors
- Tree defenses
- Host finding and colonization success

Articles

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: Carculionidae, 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.

Its getting warmer and its getting warmer faster....

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

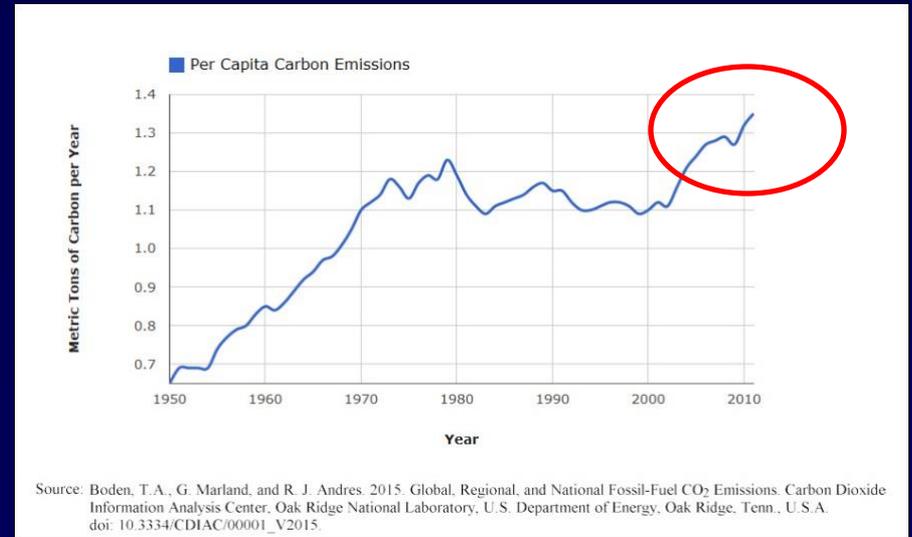
Table 3.1 The observed differences in annual global temperature anomaly for 2010 and its rank relative to the entire historical record since 1880 for the three primary datasets used to determine global average temperatures

	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

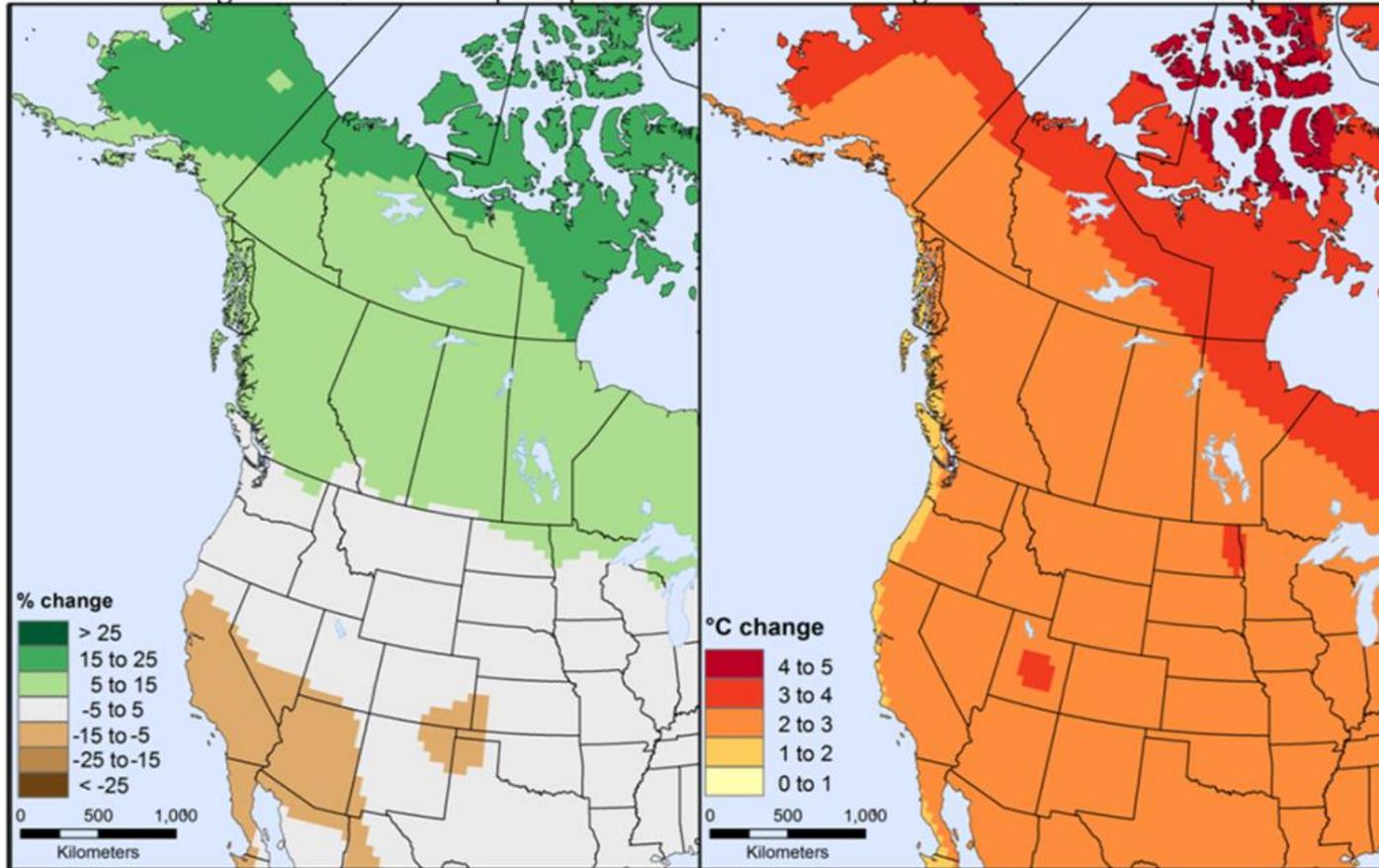
- Most of the warming has been attributed to the radiative effects of CO_2 , but other greenhouse gases such as methane, nitrous oxide and halocarbons are also important.

- Prior to the Industrial Revolution, atmospheric CO_2 was stable at ~ 270 ppm. Today, ~ 403 ppm (August 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.



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.

2050s – Change in mean annual precipitation 2050s – Change in mean annual temperature



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.

Three spatial scales



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Tree



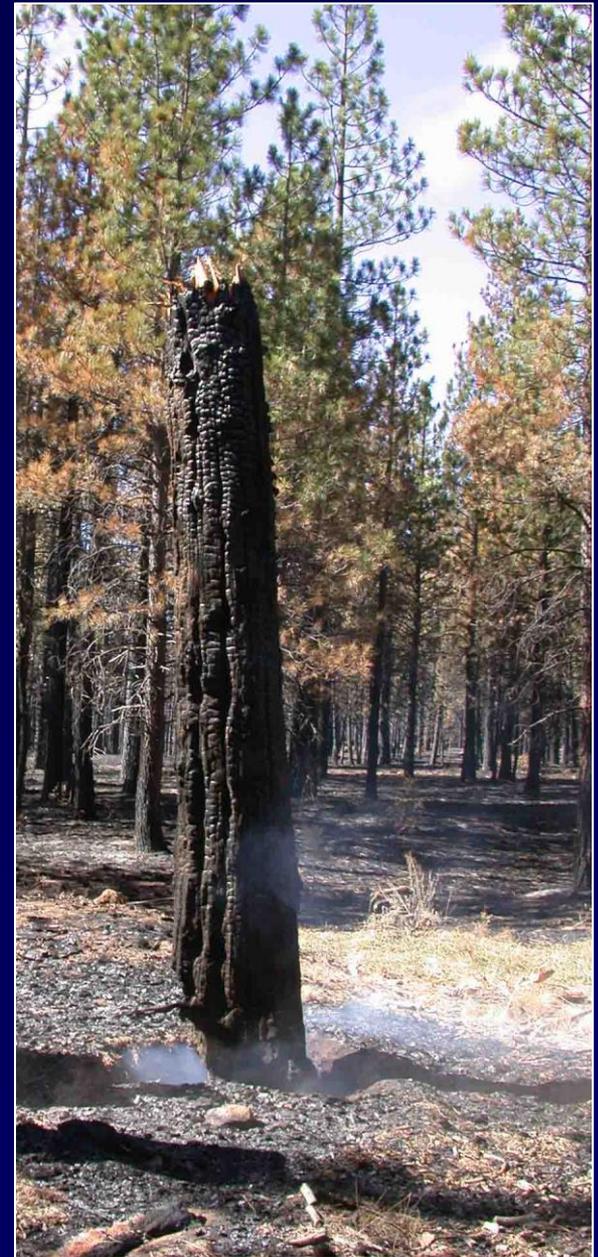
Stand

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.



C. Fettig, USDA Forest Service

P_s Allocations

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

Tree defenses

- 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

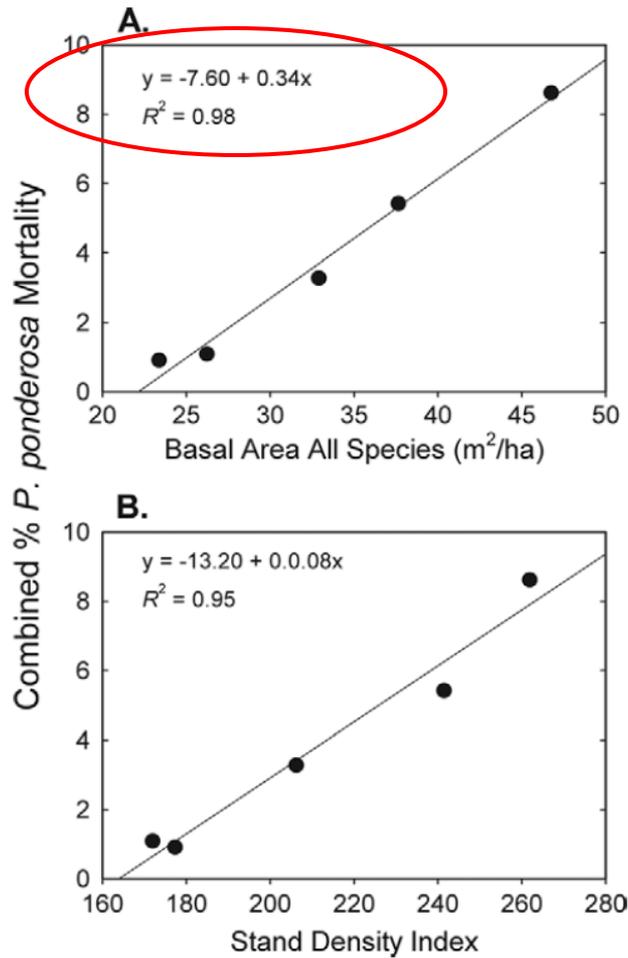
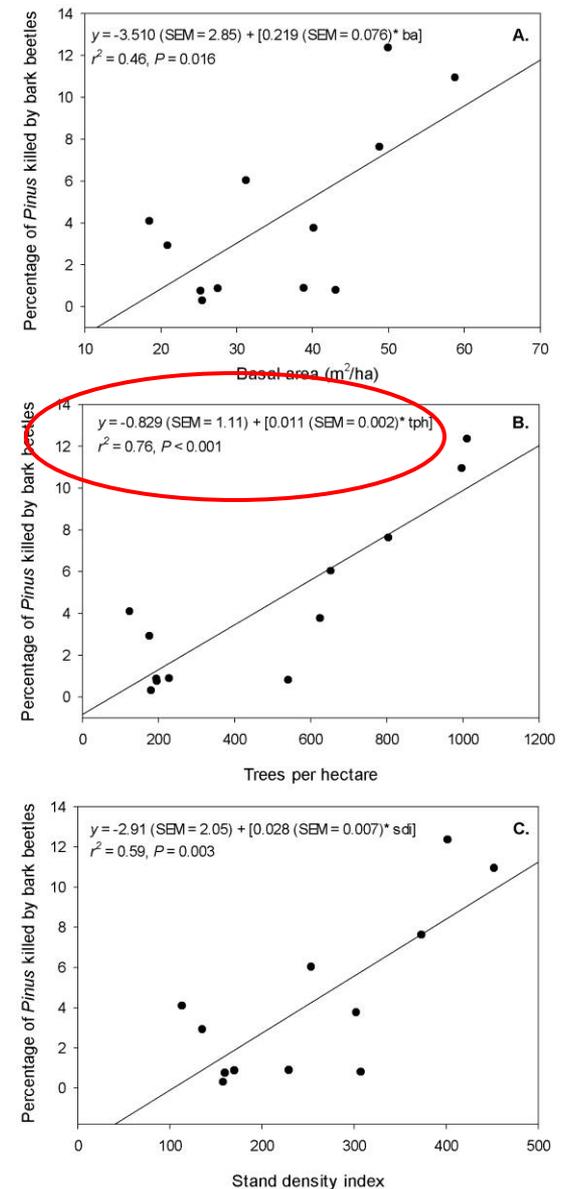


Fig. 5. Linear regressions overlaid on observed data points for (A) basal area of all tree species and mean percentage of ponderosa pine killed by western pine beetle in yr-1 and yr-2 combined (see Table 5, model D for additional statistics), and (B) stand density index and mean percentage of ponderosa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



Landscape susceptibility

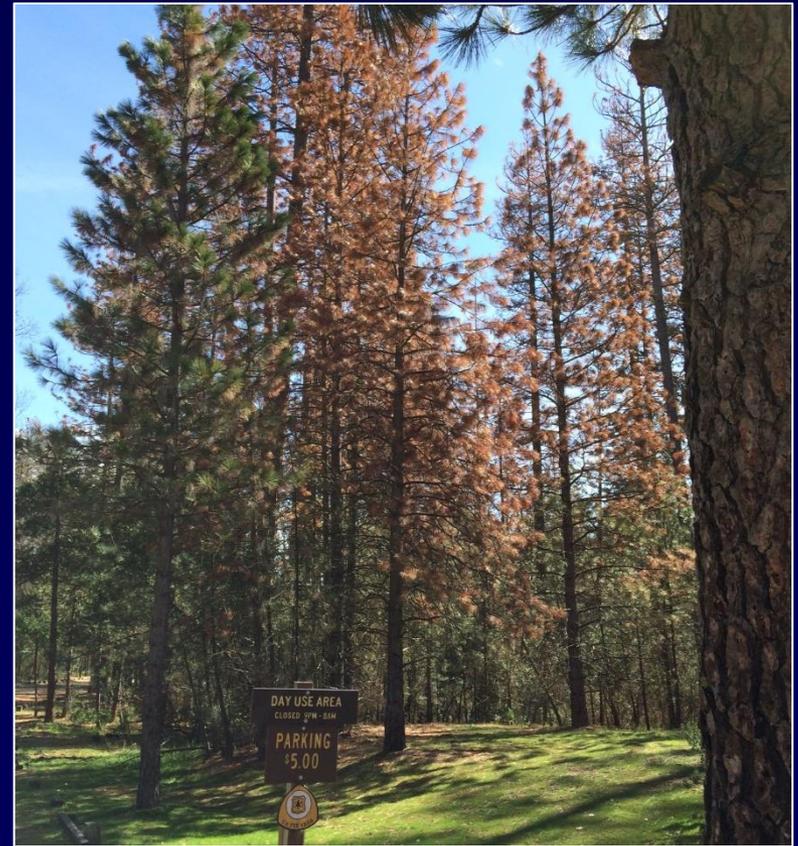
- Spatial arrangement is important.
- Forested landscapes that contain little heterogeneity promote the creation of large contiguous areas susceptible to similar disturbances.



C. Fettig, USDA Forest Service

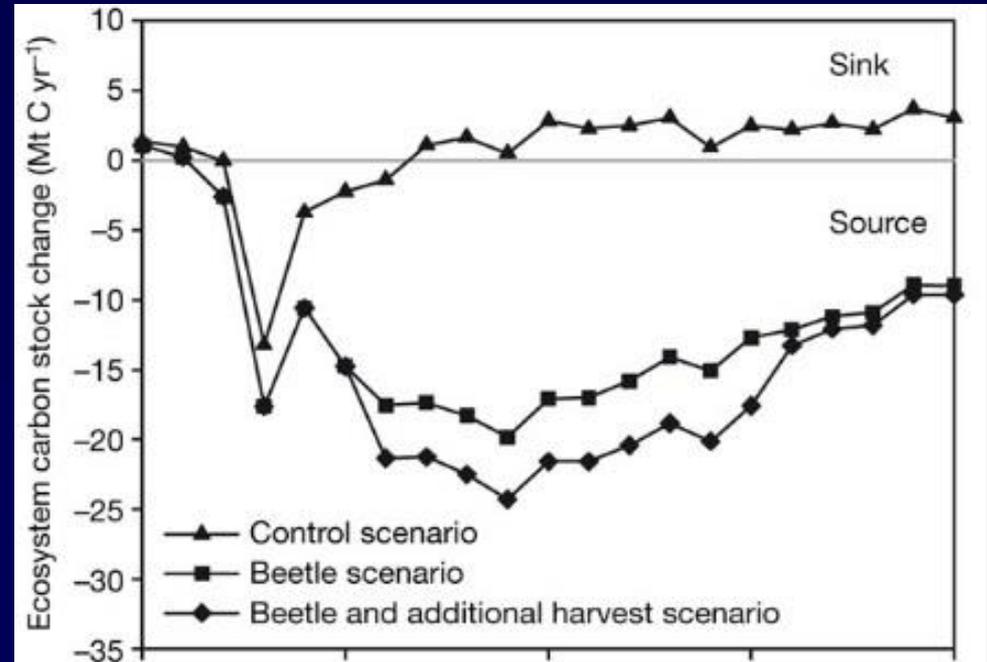
Consequences?

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**, endangered species and cultural resources.



Carbon

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



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).

Carbon - WPB, SoCal

- We estimated that the total amount of C in all trees killed (all causes, except wildfire) was 1,698,558 mt equivalent to annual emission from ~1.3 million cars. The well-publicized Angora Fire burned 1,255 ha in LTBMU in 2007 estimated CO₂ 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-



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SPLAT®

Verb

Bark Beetle Repellent

SPLAT is a matrix for the sustained passive release of insect pheromones. SPLAT Verb provides control of bark beetles by use of the anti-aggregation pheromone, repelling beetles from pine trees.

For Organic Production (optional marketing logo and claim)



ACTIVE INGREDIENT:
 Bark Beetle Anti-Aggregation Pheromone
 Verbenone, 4,6,6-Trimethylbicyclo(3.1.1) hept-3-en-2-one: 10.00%
OTHER INGREDIENTS: 90.00%
TOTAL: 100.00%
 Net Contents: _____ Lbs _____ Kg
 Batch Number: _____
 EPA Reg. No. 80286-20
 EPA Est. No. 80286-CA-004

**KEEP OUT OF REACH OF CHILDREN
 CAUTION**

FIRST AID STATEMENT	
IF IN EYES:	<ul style="list-style-type: none"> Hold eye open and rinse slowly and gently with water for 15-20 minutes. Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. Call poison control center or doctor for treatment advice.
IF ON SKIN OR CLOTHING:	<ul style="list-style-type: none"> Wash skin immediately with soap and water, then rinse with plenty of water for 15-20 minutes. Take off contaminated clothing.
IF SWALLOWED:	<ul style="list-style-type: none"> Call poison control center or doctor immediately for treatment advice. Do not induce vomiting unless told to do so by poison control center or doctor. Do not give anything by mouth to an unconscious person.
HOTLINE NUMBER	
<ul style="list-style-type: none"> Have the product container or label with you when calling a poison control center or doctor or going for treatment. For emergency information on (product, use, etc.), call the National Pesticide Information center at 1-800-858-7378, 6:30AM to 4:30PM Pacific Time (PT), seven days a week. During other times, call the poison control center 1-800-222-1222. 	

General Classification: It is a violation of Federal Law to use this product in a manner inconsistent with its labeling. Do not apply this product in a way that will directly contact workers or other persons. Only protected handlers may be in the area during application. For any requirement specific to your State and Tribe, consult the State/Tribal agency responsible for pesticide regulation.



Thinning

- Affects vigor of residual trees.
- Changes the physical environment within stands.
 - microclimate
 - pheromone plumes
 - inter-tree spacing



Sampling levels of tree mortality attributed to mountain pine beetle in thinned lodgepole pine stands, Montana.

Untreated lodgepole pine

Treated lodgepole pine



"Carbon storage forestry"



C. Fetting, USDA Forest Service

Keeping forests as forests through active management to increase resistance and resilience to a multitude of disturbances exacerbated by climate change.

Fuel-reduction and forest-restoration treatments, California, 2014.

We are part of the solution...

- 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.

Wooden skyscrapers

Barking up the right tree

Apr 2nd 2014, 9:45 by M.H. | BOSTON



MORE than 15 years have elapsed since America, the birthplace of the skyscraper, was last home to the world's tallest building. But though it lacks the highest high-rise made from traditional concrete



- The greatest gains in both CO₂ and FF savings is through avoiding FF needed to manufacture, transport and construct concrete and steel (avoidance pathway) by substitution of wood products.

Journal of Sustainable Forestry, 33:248–275, 2014
ISSN: 1054-9811 print/1540-756X online
DOI: 10.1080/10549811.2013.839386



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 (CO₂) and fossil fuel (FF) saved by various solid wood products, wood energy, and unharvested forests. Some products proved very efficient in CO₂ and FF savings, while others did not. Not considering forest regrowth after harvest or burning if not harvested, efficient products save much more CO₂ 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 CO₂ 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 CO₂ and FF savings. Using wood substitutes could save 14 to 31% of global CO₂ emis-

(IPCC 2007, p. 543)



C. Fettig, USDA Forest Service

“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”.

The future, managing in the face of uncertainty - assisted migration?

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 (CO₂). 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 CO₂ 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.



We are in a new realm...

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- www.fs.usda.gov/CA_TreeMortality
- www.fire.ca.gov/treetaskforce/
- www.readyforwildfire.org/Bark-Beetles-Dead-Trees/
- <http://scholar.google.com/citations?user=SnRHtAMAAAJ&hl=en>