Forest mortality and climate change: The big picture

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Over the past two decades, extensive forest death triggered by hot and dry climatic conditions has been documented on every continent except Antarctica. Forest mortality due to drought and heat stress is expected to increase due to climate change. Although research has focused on isolated incidents of forest mortality, little is known about the potential effects of widespread forest die-offs. A new analysis of the current literature on this topic by Carnegie's William and Leander Anderegg is published September 9 in *Nature Climate Change*.

Along with co-author Jeffrey Kane of Northern Arizona University, the Andereggs examined papers dealing with different aspects of forest die-off events from studies all over the world. They divided their findings into the effects on a forest community of trees and other species; on ecosystem processes as a whole; on services forests provide to humans; and on the climate.

"This study provides a state-of-the-art overview of the many benefits forests provide to humans, from water purification to climate regulation," said William Anderegg, "Many of these roles can be disrupted by the widespread tree mortality expected with climate change."

They found that heat and drought, including drought-related insect infestation, can disproportionately affect some species of trees, or can hit certain ages or sizes of trees particularly hard. This can result in long-term shifts in an area's dominant species, with the potential to trigger a

transition into a different ecosystem, such as grassland. It can also impact the understory—the layer of vegetation under the treetops—as well as organisms living in the soil. More research on forest community impacts is needed, particularly on the trajectories of regrowth after forest die-off.

From an ecosystem perspective, forest die-off will also likely affect hydrological processes and nutrient cycles. Depending on the type of forest, soil moisture could be increased by the lack of tree-top interception of rainfall or decreased by evaporation due to more sun and wind exposure. Debris from fallen trees could also increase a forest's fire risk.

Forests also have an effect on the climate as a whole. Forests play an important role in determining the amount of heat and light that is reflected from the Earth and into space and in taking up carbon dioxide from the atmosphere. On one hand, forest mortality increases the reflection of the sun's energy back into space, thus providing a cooling effect. But on the other hand, the decomposition of fallen trees releases carbon into the atmosphere, thus producing a warming effect. Overall, whether forest die-offs result in local cooling or warming is expected to depend on the type of forest, the latitude, the amount of snow cover, and other complex ecosystem factors.

Mass tree mortality would likely cause substantial losses to the timber industry, even if saplings and seedlings were unaffected. Little research has been conducted on other types of forest products that humans use, such as fruit or nuts, but there would presumably be changes in those sectors as well. Recent research has examined other services provided by forests which would likely be affected by die-off, such as declines in real-estate property values following widespread tree mortality.

Overall, the analysis found that although there are many recent advances

in understanding the effects of severe forest die-off, many critical research gaps remain. These gaps are especially critical in light of increasing forest die-off with climate change.

One urgent gap is how this summer's US-wide severe drought might affect forests. William Anderegg is helping to tackle this question by spearheading a project involving dozens of research groups from around the country (see the Drought Open-Source Ecology project for details).

"The varied nature of the consequences of forest mortality means that we need a multidisciplinary approach going forward, including ecologists, biogeochemists, hydrologists, economists, social scientists, and climate scientists," William Anderegg said. "A better understanding of forest die-off in response to climate change can inform forest management, business decisions, and policy."

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