tant at the cell separation stage.

Because the inhibitor acts quickly, the new technique can also be used to assess the effects of blocking a protein's activity at specific points in the cell cycle. David Drubin's group at the University of California, Berkeley, has been doing just that. In work reported in the October issue of *Nature Cell Biology*, the researchers used the technique to study a protein called Cla4, a kinase involved in forming the bud that expands to form the daughter cell when a yeast cell divides. Analysis of this protein using temperature-sensitive mutants has been difficult because a shift to the higher temperature temporarily disrupts the cell's internal skeleton, interfering with bud formation even in normal cells.

In their experiments, Drubin and his colleagues replaced the normal *Cla4* gene with an inhibitor-sensitive version. They found, as others had using different techniques, that the protein is needed to build the collar that eventually squeezes off to separate the daughter cell from its parent. They were also able to pin down exactly when Cla4 acts. The researchers gathered cells that they had arrested at various points in the cell cycle, added the inhibitor, and then allowed the cells to resume growth. Cells that had started to bud before addition of the compound divided normally. But buds formed after inhibitor addition continued to elongate without pinching off. The observations suggest that Cla4 kinase activity is needed at or before an early stage of bud emergence, even though the defect isn't evident until much later when mother and daughter cells try to separate.

Now that the technique has worked in yeast and in isolated mammalian cells, scientists are trying it in whole animals, such as mice. The results have not yet been published, but they look promising. And although Shokat has so far applied the system only to enzymes that use ATP, he says it should work with proteins in other large families. The similarity of the members, he notes, has been a hindrance to researchers. But the new technique may turn that around, because a mutation and inhibitor that work with one family member may work with others as well. Says Shokat, "We've turned the disadvantage into an advantage." –EVELYN STRAUSS

MEETING ECOLOGICAL SOCIETY OF AMERICA

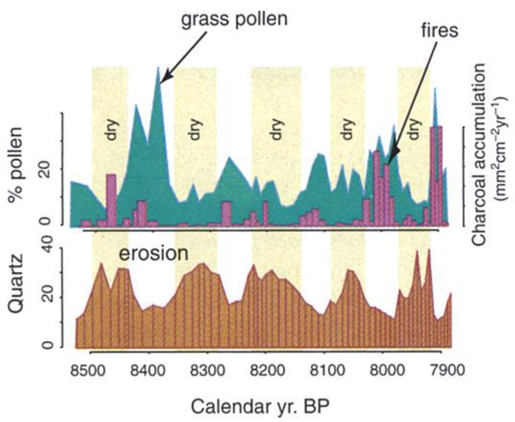
Global Warming, Insects Take the Stage at Snowbird

SNOWBIRD, UTAH—Some 2600 ecologists made their way to this sun-soaked canyon last month for the Ecological Society of America's (ESA's) 85th annual meeting. Topics ranged from ancient droughts to photosynthesis beneath snow and how trees resist insects.

Could Past Portend 50-Year Droughts?

The Dust Bowl that struck the southern plains of the United States in the 1930s devastated millions of hectares of rich farmland, leading 750,000 people to flee, burying houses with dirt, and darkening the skies for days. But that 7-year drought was a mere taste of what global warming may bring, warned ecologist Jim Clark of Duke University. Sediments from a North Dakota lake reveal that 8000 years ago, the plains were seesawing through droughts and wet periods that lasted a whopping 40 to 50 years. Similarly long drought cycles could happen again, asserts Clark, as accumulating greenhouse gases turn continental interiors warmer and drier.

By probing tree-ring records and other evidence, researchers have recently found hints that Dust Bowl–scale droughts were frequent over the past 2000 years. But to find out what might happen to ecosystems under much more arid conditions than today's, Clark's team looked even farther back in time, to the mid-Holocene, when the U.S. plains were arid. To do so, they went to Kettle Lake in North Dakota, which contains 20 meters of mud deposited over millennia. Clark, Eric Grimm of the Illinois State Museum in Springfield, Joe Donovan of West Virginia University in Morgantown, and others studied a 50-cm sediment core dating from the mid-Holocene. By examining minerals, charcoal, and pollen in the core, they have illuminated in unprecedented detail the wildly shifting ecology of the region during a 600-year period.



CREDIT: J. CLARK *ET AL.*

Shape of things to come? U.S. plains flipped between decades-long droughts and wet periods in the warm, arid mid-Holocene.

Clark and his colleagues found long wet periods, characterized by pollen, diatoms, and charcoal from naturally burned grasslands. They also charted a shift in plant type from cool-season grasses to warm-season grasses. Then the pattern flipped to drought: Quartz dust from erosion becomes abundant, while grass pollen and charcoal levels plummet. The repeating cycles lasted about 80 to 100 years. By contrast, a core from 2000 years ago showed no distinct patterns. "I was just blown away" by the work, says Brown University paleoclimatologist Tom Webb. "To get that high a frequency [of climate swings] and to get it so neatly told among the chemical data and the pollen is rather astounding."

Because the driver behind the warm, arid climate of the Holocene was a different tilt and orientation of Earth, not the rising carbon dioxide levels that seem to be contributing to warmer temperatures today, these results may not predict what's to come in a greenhouse world, concedes Clark. But even so, his group's data are worrisome, says ecologist Peter Leavitt of the University of Regina in Saskatchewan. "We've been adapting to some of the mildest possible droughts. These are beyond anything we've known in human society."

Snow Falling on Tundra

Few ecologists visit the Alaskan tundra before the winter snowmelts. They've long assumed that there's little biological activity to warrant the trip. But the notion of a snow-cloaked ecosystem too cold and dark for photosynthesis may no longer hold. At the meeting, ecologist Gregory Starr of the University of Florida, Gainesville, reported that he's peered under the snow on Alaska's North Slope and found plenty of photosynthesis by evergreen tundra plants—enough that estimates for how much carbon the tundra soaks up may need to be adjusted.

Along with other scientists doing separate arctic experiments, Starr may have stumbled upon a small but significant hidden "sink" for global carbon dioxide: early spring tundra growth. "It seems to be a pretty robust finding," says San Diego State University ecologist Walter Oechel, who's also recently detected photosynthesis by tundra ecosystems beneath the Alaskan snow.

Starr began his study in 1997 while a graduate student at Florida International University, working at the Toolik Lake Field Station, some 210 kilometers north of the Arctic Circle. His original plan was to explore how red pigments called anthocyanins help evergreen tundra plants get a jump start on photosynthesis during the spring snowmelt. But to his surprise—as well as that of his adviser, Steve Oberbauer—Starr found "a lot of light reaching the plants" through the snow. Starr then set up instruments to measure light, CO_2 levels, and temperatures weekly over a roughly 40-hectare snowfield during two springs. Looking at four species of evergreens, he gauged photosynthetic activity by dropping jars containing CO_2 detectors over individual plants, then correlating the results with levels of chlorophyll, anthocyanins, and other plant chemicals.

He found a naturally formed igloo greenhouse. Not only was it up to 5°C warmer under the snow, but the melting and refreezing snow forms "ice lenses" that let sunlight through and allow leaves to dry, aiding photosynthesis. The snowpack also traps CO_2 released by soil microbes and plant respiration, concentrating it for plants. The rates of photosynthesis in the four evergreen species, although quite variable, approached 20% of the peak rates Starr had measured in July. Adding up this activity for the 7 to 9 weeks in spring and early fall when there's both snow and sunlight, Starr estimates that tundra evergreens could be absorbing 15% more carbon than researchers had thought.

Starr's work adds to observations by Oechel and Japanese colleague Yoshi Harazono, who since the mid-1990s have both run experimental towers fitted with sensors to measure fluxes of CO_2 wafting into and out the arctic tundra. They've noticed that carbon uptake begins in spring while the tundra is still snow-covered—apparently from photosynthesis by mosses in the wet coastal tundra where they work.

If this under-snow photosynthesis does indeed occur throughout the tundra, then it could add a new wrinkle to the Arctic's role in global warming. The tundra has flipped from an overall carbon sink to a source during the last 2 decades as the permafrost has begun to thaw and microbial activity has speeded up. The tundra may become an even bigger carbon source, speculates Starr, if the arctic climate keeps getting warmer and deciduous plants replace mosses and evergreens. At this stage, however, notes ecologist Terry Chapin of the University of Alaska, Fairbanks, "it's hard to know what the net effect" would be on the global carbon budget.

Even so, Oechel thinks that the tundra findings hold a lesson for ecologists searching for the so-called missing sink—a large chunk of carbon that's likely absorbed by plants yet is not accounted for by existing inventories of forests and land-use changes. "People are looking for one smoking gun, but it may be the global sum of much smaller pieces," Oechel says. "I think we're going to have to step through each major biome and understand the pattern of controls."

How an Old Tree Outwits Its Foes

Trees and caterpillars are locked in mortal combat. Each spring a new generation of voracious caterpillars emerges and quickly begins munching on tree leaves. The trees, in turn, spew out chemical weapons to deter the hungry critters. But ecologists have long wondered why the caterpillars haven't been able to develop resistance to these agents, as they have to pesticides. New studies of a very long-lived tree, mountain birch, and its number one enemy may have uncovered the secret: The tree churns out a shifting array of chemicals throughout the season—confounding the caterpillar's genetic ability to adapt to them all. Ecologists think that other tree species may also adopt a similar strategy.

Moving target. Mountain birch fend off autumnal moth larvae by blasting them with multiple chemical defenses.

Plant-herbivore ecologist Erkki Haukioja of the University of Turku in Finland, who described the work at an ESA symposium, compares the tree's multipronged defense to the drug cocktails used to combat ever-mutating viruses such as HIV. Although ecologists had suspected that this strategy might help explain how centuries-old trees resist insects year after year, "the story has never been put together in this way," says ecologist Anurag Agrawal of the University of Toronto. "It's actually very logical. [A caterpillar] can't be a jack of all trades."

These new findings had their genesis a few years ago, when Haukioja's team began probing seasonal changes in the birch's chemical defense against the ravenous larvae of the autumnal moth *Epirrita autumnata*. When chemists working with Haukioja analyzed birch leaves, they found that the leaves crank out some 150 chemicals, from sugars to amino acids to phenolics, that fluctuate from June to September. Haukioja's group has since found that three types of chemical and physical traits keep the larvae in check.

First, budding leaves produce gallotannins, phenolic compounds that gum up proteins in the gut of the autumnal moth larvae and make leaf proteins hard to digest. Growing leaves later abound in another stomach-knotting group of tannins, proanthocyanidins. And finally, the trees produce chemicals that deter larvae by toughening leaf structures.

The caterpillars seemed able to evolve counterdefenses to one of these defenses but not all. For instance, caterpillars that grew fast as young larvae on gallotannin-rich leaves weren't always particularly good later in life at digesting proanthocyanidins or chewing tough leaves. The Finnish team suspected that these traits might involve a genetic trade-off—that is, inheriting the ability to deal with one chemical might make an individual vulnerable to the other. To check this hypothesis, they tested batches of genetically related larvae for tolerance to the chemicals. Verifying their hunch, they found an inverse relationship between resistance to gallotannins and to proanthocyanidins. Although they're still analyzing results from more experiments, Haukioja says: "We may be on the right track. … Natural selection has not been able to provide the ability to be good on both" plant defenses.

This "moving target" idea may also explain why other deciduous trees, such as oaks, put so much metabolic energy into producing a whole chemist's shelf of chemicals, says ecologist Jack Schultz of Pennsylvania State University, University Park. "This is the best data to support the view" that it's no accident but a clever defense system, he says.

–JOCELYN KAISER

CREDITS: E. HAUKIOJA