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INSIDE

Science FINDINGS

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"Science affects the way we think together."
Lewis Thomas

Fingerprints of a Forest Fungus: Swiss Needle Cast, Carbon Isotopes, Carbohydrates, and Growth in Douglas-fir

Barb Lachenbruch

Researchers examine new growth on a nursery-grown Douglas-fir as part of study to better understand how Swiss needle cast—a fungal disease—affects its host.

IN SUMMARY

Swiss needle cast is caused by a fungus native to the Pacific Northwest. Its host is Douglas-fir, an iconic evergreen tree in the region. The fungus does not kill its host, but it adversely affects the tree's growth. The fungal fruiting bodies block the stomata, small openings on the underside of the needle where carbon dioxide, water vapor, and other gases are exchanged. As more stomata become blocked, there is a corresponding reduction in photosynthesis this means the tree produces less carbohydrates necessary for growth.

Scientists with the Pacific Northwest Research Station and their collaborators conducted a study to learn how Douglas-fir survive even when exhibiting severe Swiss needle cast symptoms. They found that trees allocate available carbohydrates toward growing new needles and branches at the expense of sustaining trunk growth.

Aerial surveys of western Oregon show that Swiss needle cast has spread in the past two decades. Earlier studies suggest this increase to be a result of warmer winters and wetter springs. To better understand this relationship, the scientists analyzed tree rings of diseased trees and found that the previous year's relative humidity affects the severity of Swiss needle cast symptoms in following years.

"A tree is an incomprehensible mystery. Look deep into nature, and then you will understand everything better."
—Albert Einstein

Evergreen conifers, including those of the Pacific Northwest—Douglas-fir, western redcedar or western hemlock, for example—shed their needles. However, their needle loss is subtle, without the vibrant display of fall color and bare winter branches that define deciduous trees. A Douglas-fir needle may live up to 4 years before it's shed, and for a healthy Douglas-fir, gradual needle loss does not affect its overall growth. Yet when a tree has Swiss needle cast, it may retain its needles for less than 2 years, and those that remain in the sparse crown are often yellowish rather than dark green. The tree may live for many years with the disease, but it will never achieve its full growth potential or regrow a full crown. This can affect the long-term management of the forest, whether it is being managed for timber or as wildlife habitat.

Swiss needle cast is caused by the fungus *Phaeocryptopus gaeumannii* and was so

Swiss Needle Cast Cooperative

With its sparse crown and discolored needles, this Douglas-fir exhibits the telltale signs of Swiss needle cast.

KEY FINDINGS

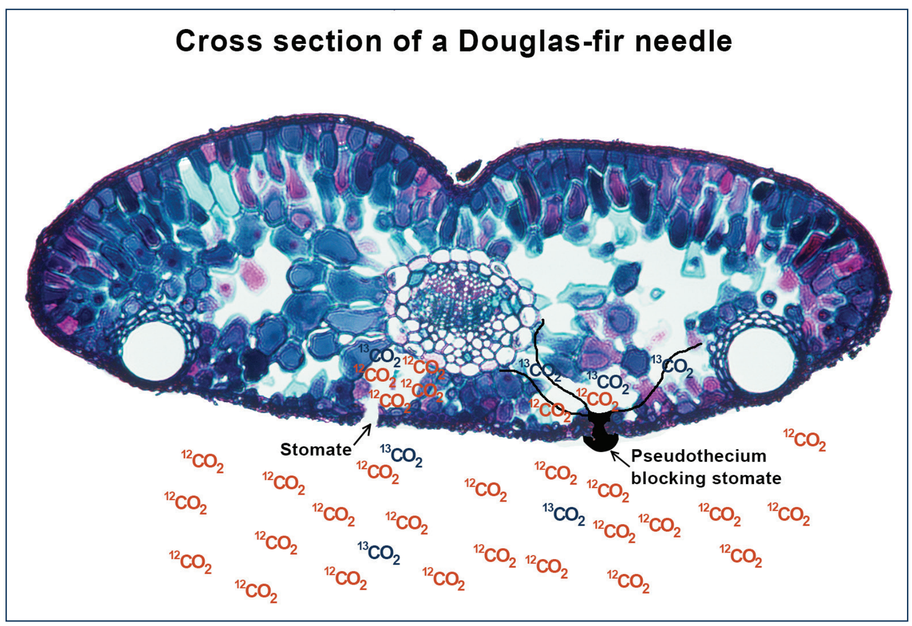
- Douglas-firs with Swiss needle cast are able to survive because carbohydrates are primarily allocated to fuel the growth of new foliage and supporting branches rather than increasing diameter growth of the trunk.
- Tree ring analyses showed that diseased Douglas-firs process an increased proportion of carbon isotope ^{13}C relative to ^{12}C, compared to healthy western hemlock trees and Douglas-fir treated with fungicide. This tree-ring evidence illuminated a link between Swiss needle cast and climate.
- The severity of Swiss needle cast appears climate related: higher summertime relative humidity in prior years leads to higher disease severity in following years.

named because Swiss researchers are credited with identifying the disease in the 1920s. They found the fungus in Douglas-fir plantations grown from U.S.-imported seedlings. "When it was first described in Europe as a disease, the pathologists in the United States immediately went out looking for it and found it," says David Shaw, a forest health specialist with Oregon State University and director of the Swiss Needle Cast Cooperative. "But they concluded that it was a reasonably innocuous fungus in its native range."

In subsequent decades, Christmas tree plantations in the western portions of Oregon and Washington became infected with Swiss needle cast. According to Shaw, during the late 1980s and into the mid-1990s, Swiss needle cast appeared more consistently in the Douglas-fir forests along the Oregon coast and throughout the southwestern portion of Washington State. With both industry and government recognizing the threat of this disease to the future of Pacific Northwest forests, the Swiss Needle Cast Cooperative was established in 1997. Part of the cooperative's mission is to generate information so that landowners have the tools to manage for productive Douglas-fir forests and plantations despite the threat of Swiss needle cast.

HOW A MICROSCOPIC FUNGUS TAKES ON A DOUGLAS-FIR TREE

Trees are most vulnerable to colonization by the fungus following their bud break in early May. The fungal spores, dispersed by wind or water, primarily infect the tree's new needles. A spore's survival depends on the amount of moisture in the air:



©Image from Biodisc/Visuals Unlimited/Corbis

The carbon isotopes ^{12}C and ^{13}C are naturally present in CO_2 in the atmosphere. A tree takes in both through stomata on the underside of the needle during photosynthesis. Douglas-fir preferentially uses ^{12}C, but when infected with Swiss needle cast, the stomata become blocked, forcing the tree to use more ^{13}C.

if it's too dry, the spore dries out. If the spore survives, it grows thread-like structures called hyphae, which colonize the host needle's surface and penetrate its stomata. Stomata are small openings on the underside of the needle through which carbon dioxide (CO_2) is taken in and oxygen and water vapor are released during photosynthesis.

The following year, the mass of hyphae produces fruiting bodies called pseudothecia. These are visible as black or brown dots within the white rows of stomata on the needle's underside. With their stomata blocked by the pseudothecia, trees absorb less CO_2 during photosynthesis than they normally would. The decrease in CO_2 absorption results in

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decreased carbohydrate production, which in turn affects a tree's growth and metabolism.

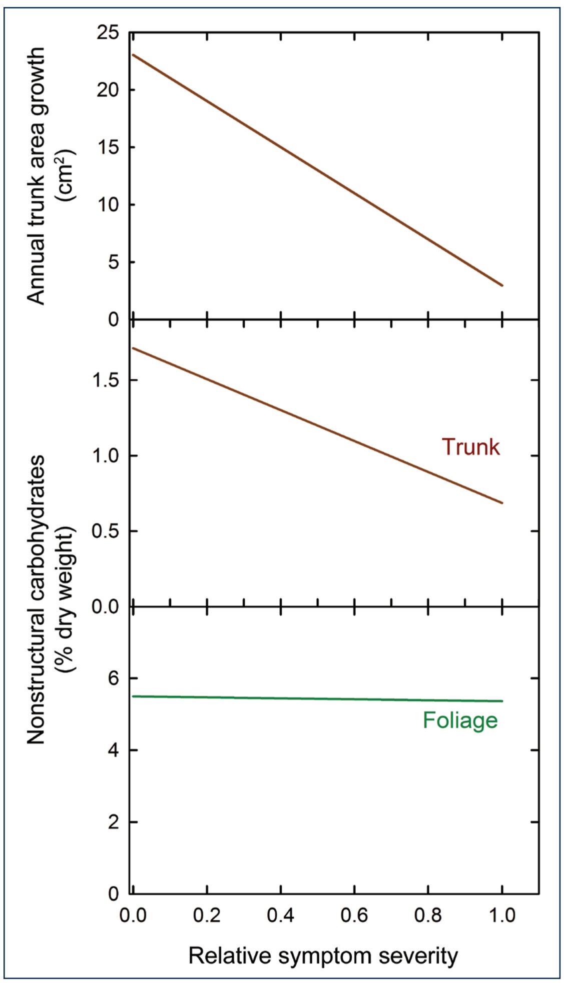
Spores can be killed by fungicide, and field trial studies have shown that diseased trees do respond with increased growth following treatment. However, "In terms of a fungicide treatment, I doubt whether it would be economically or even ecologically feasible, because there are good forest fungi" that would be killed too, says Frederick Meinzer, a research ecologist with the PNW Research Station.

Foresters and silviculturists are looking for other ways to reduce the spread of the disease and for treatments to minimize it effects upon tree growth. Recognizing this challenge, Meinzer and Brandy Saffell, a graduate student at Oregon State University, approached Shaw and the Swiss Needle Cast Cooperative with a proposal for two studies that could shed new light on the fungus.

A GROWING TREE NEEDS ITS CARBOHYDRATES

"One thing known about Swiss needle cast is that unlike a lot of pathogens, as far as we know, it does not kill the tree," Meinzer explains. "The tree can go on for decades and decades without dying." What is not known is how and why exactly this happens, but the explanation had to reside in understanding the Douglas-fir's energy reserves.

The process by which trees store and allocate sugars and starches is "a hot topic in the plant physiology world because it is such a complicated and debated aspect of how trees work," Saffell notes.



As the severity of Swiss needle cast symptoms increase, growth and nonstructural carbohydrate content in the trunk decrease. The tree survives by directing carbohydrates to replace damaged foliage at the expense of trunk growth.

Photosynthesis produces sugars and starches, also known as carbohydrates, which are used to fuel the tree's growth. A tree can use these carbohydrates in different ways: allocate them to fuel its growth, consume the carbohydrates to maintain metabolism, or temporarily store them as nonstructural carbohydrates for future growth needs, such as producing new foliage in the spring or increasing its diameter growth.

Under normal growing conditions, a tree produces enough carbohydrates to support all these options during the growing season. The result is increased diameter growth and new foliage and branches. But what happens when the trees are stressed?

Early carbohydrate research focused on how trees allocate nonstructural carbohydrates under drought or other stressful conditions that potentially can kill the tree. Meinzer saw an opportunity to study nonstructural carbohydrate allocation under conditions in which the trees are experiencing stress that reduces CO_2 uptake, but is not life-threatening. If this reduction in CO_2 absorption could be recorded as a signal in a tree's annual growth rings, Meinzer and Saffell hypothesized that year-to-year variation in the severity of the disease could be linked to variation in climate factors, such as rainfall, relative humidity, and temperature.

"The neat thing about working with the Swiss Needle Cast Cooperative is they were very interested in better understanding the deeper intricacies of the disease and host," Saffell says. "Although these studies are primarily proof-of-concept-type projects and will not necessarily answer big management questions right now, the results improve our basic knowledge of Swiss needle cast and will be useful in future studies."

Saffell and Meinzer designed their study by constructing a chronology of tree rings to learn (1) how trees manage to survive even with severe disease symptoms and (2) how tree-rings can document past variations in Swiss needle cast symptom severity and its relationship to climate factors.

Their first study site was a stand near Tillamook, Oregon. They collected growth measurements, trunk sapwood tissue, and foliage and twig wood from 15 trees that were expressing a range of Swiss needle cast disease symptoms. Back in the lab, they analyzed the tissue samples to determine the concentrations of carbohydrates in the form of starch, sucrose, glucose, and fructose. They wanted to see if the severity of Swiss needle cast symptoms affected the concentrations of these various carbohydrates, and if so, how?

The researchers found a strong negative relationship between annual growth and disease severity: greater symptom severity corresponded to less trunk growth. "It has been well documented that Swiss needle cast can cause very substantial reductions in tree growth and timber yield, up to a 55 percent decrease compared to a healthy stand in a similar environment," Meinzer says. "So the carbohydrate study provides some insight into the specific constraints that the trees are dealing with."

Interestingly, they found that concentrations of nonstructural carbohydrates in the trunk decreased with increasing disease severity, but concentrations of nonstructural carbohydrates in foliage and twig samples were nearly constant throughout the range of disease severity among the trees.

"A tree must retain enough carbohydrates in its crown to be able to generate new foliage the following season; foliage from prior years drops off because it is so diseased and cannot hold its own in terms of taking up carbon dioxide," Meinzer explains. "A tree can't generate new tissue for photosynthesis without enough carbohydrates accessible in the crown to fuel a burst of growth in the spring." At the expense of producing new wood in the trunk, the tree opts to produce new foliage so it can survive.

A TREE RING DOCUMENTS EVERYTHING

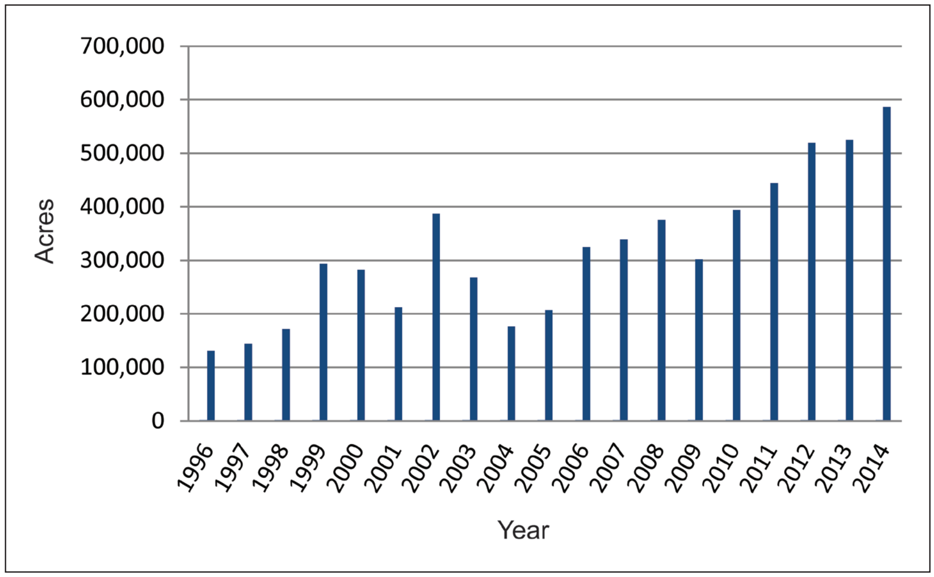
In a joint effort each spring, the Swiss Needle Cast Cooperative, the Oregon Department of Forestry, and the U. S. Forest Service conduct aerial surveys just before bud break to record the distribution of Swiss needle cast. Over the past 18 years, the area of Douglas-fir affected by Swiss needle cast has quadrupled in the Oregon Coast Range. In 2014, the survey found 580,000 acres affected, up from 520,000 acres in 2013. "It's on a trajectory of intensification," says Shaw. "The disease is not abating, and we're having to really deal with it within the 18 to 25 miles from the coast, which is probably the real impact area."

The intensification is assumed to be related to warming winters and increased wetness throughout the year. To determine if this assumption was correct, Saffell and Meinzer turned to stable isotopes. There are two stable (nonradioactive) carbon isotopes, ^{12}C and ^{13}C, in the atmospheric CO_2 that enters the needle through the stomata. Of the two isotopes, ^{13}C is heavier and is less preferred by healthier trees. When the stomata are blocked, limiting the intake of CO_2, trees infected by Swiss needle cast are forced to use more ^{13}C once the preferred ^{12}C has been depleted.

Saffell and Meinzer were curious to know whether this difference in ^{12}C and ^{13}C absorption in healthy versus Swiss needle cast-infected trees could be recorded in carbon isotope ratios in the tree rings. If so, it may be possible to find a link between Swiss needle cast and climate, because climate-related variation in Swiss needle cast symptoms should be reflected in variations in ratios of ^{12}C and ^{13}C absorbed by the trees.

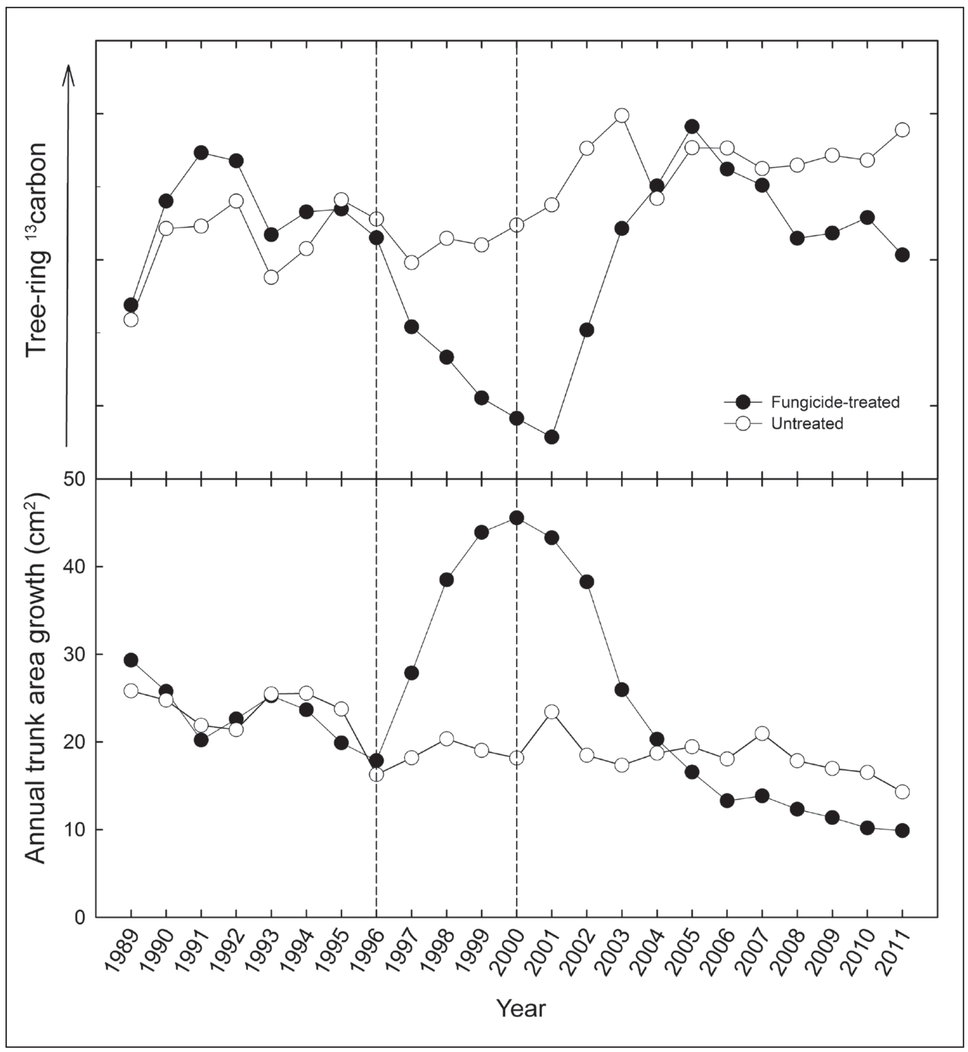
Stable isotope analysis in tree rings has primarily been used for reconstruction of past climate. "This is one of the first projects I've ever read about or heard about where you're actually measuring a pathogen with stable isotopes in tree-rings," Saffell says. "That's a very novel idea."

Building on a previous study that had involved 5 years of applying fungicide treatments to infected Douglas-fir, the researchers returned to that study site and took core samples so they could analyze the tree rings for the abundance of the ^{13}C isotope. A tree's entire growing season is recorded within each tree ring. By comparing the tree rings of 30-year-old Douglas-fir infected with Swiss needle cast, but treated with fungicide, and western hemlock (which is naturally immune to Swiss needle cast) against untreated Douglas-fir trees in the same stand, they could determine if there was a noticeable difference in ^{13}C.



Swiss Needle Cast Cooperative

Since 1996, aerial surveys have found that Swiss needle cast is spreading along the Oregon Coast Range. The trend is expected to continue as winters warm and springs are wetter, as projected by future climate scenarios for the area.



Building on a previous study that applied fungicide (from 1996 to 2000) to infected Douglas-firs, researchers returned to the study site and took core samples to analyze the tree rings for the abundance of the ^{13}C isotope. This confirmed that when Swiss needle cast symptoms were minimized, ^{13}C was less abundant in the tree rings and annual trunk growth increased.

The researchers found a noticeable difference in ^{13}C between the diseased and treated Douglas-fir. The treated Douglas-fir increased their annual growth and had lower levels of ^{13}C similar to those in western hemlock tree rings. Next, the researchers tested correlations between the previous year's climate factors, such as precipitation and temperature, and increased ^{13}C absorption found in the following year's tree ring. Relative humidity, which is an indicator of the amount of moisture in the air, proved to be the significant factor, Saffell explains. When there is high relative humidity, water condenses on the leaf, creating the damp conditions the fungal spores need to germinate.

LAND MANAGEMENT IMPLICATIONS

- By applying a tree-ring analysis across a larger geographic area, it may be possible to reconstruct the epidemiology of Swiss needle cast and identify the climatic factors, in addition to relative humidity, that increase the likelihood of outbreaks and increased infection.
- Knowledge of climatic factors associated with variations in the severity of Swiss needle cast can help project yield loss so Douglas-fir can be planted where it is economically feasible under current and potential climate regimes.
- Aerial surveys over two decades show an increase in the spread and intensification of Swiss needle cast, particularly along the Oregon coast. Because Swiss needle cast negatively affects Douglas-fir growth, it may be difficult to create old-growth conditions, and thus, vital wildlife habitat.

MANAGING DOUGLAS-FIR FORESTS WITH SWISS NEEDLE CAST

With this new understanding about how Swiss needle cast actually affects a tree's metabolic processes, and a way to track this via the abundance of ^{13}C in tree rings, further questions can begin to be addressed. For example, "How long has the disease been a problem in this area? Has it been a problem in the past? Is this just part of a larger cycle? Is it possible that maybe 100 years ago this same thing happened and then it went away? These can all be investigated through the tree ring analyses," says Saffell.

Designing a study covering a longer period of time that looks more closely at the environmental variables most correlated with variation and severity of the infection might provide clues for management as to where Douglas-fir may be expected to grow reasonably well in spite of Swiss needle cast, Meinzer explains. With Swiss needle cast on a trajectory to increase, such a study could be valuable.

Management prescriptions for stands infected with Swiss needle cast vary based on landowner objectives, forest stand age, and disease severity for a given geographic area. Shaw notes that research indicates disease severity is not influenced by techniques such as thinning, vegetation management, or fertilization.

Keeping the trees well spaced is one management technique for minimizing the spread of Swiss needle cast spores.

Shaw explains that investments in the stand require a nuanced approach because forest plantations will respond to thinning, albeit at a reduced rate of growth. For example, early precommercial thinning is recommended because trees with the most symptoms can be culled early and alternative tree species can be planted where appropriate. Trees infected with Swiss needle cast retain more foliage on their lower branches than in the upper crown where new growth is concentrated. Therefore, keeping the trees well spaced with room for lower branches allows for more foliage retention. Shifting away from Douglas-fir in heavily affected areas is also recommended.

Although models already exist regarding the expected growth and yield of diseased trees, Shaw says that these studies "tell us more about the mechanism that keeps these trees alive and… it helps the modelers understand the basic carbon dynamics of the tree."

Within the Swiss Needle Cast Cooperative, Shaw continues, "We knew about some of the basic physiological mechanisms behind Swiss needle cast and the effect on photosynthesis. The nonstructural carbohydrate component was new, however. This really contributes to a better understanding of what's going on mechanistically within the tree."

"All truths are easy to understand once they are discovered; the point is to discover them."
—Galileo Galilei

FOR FURTHER READING

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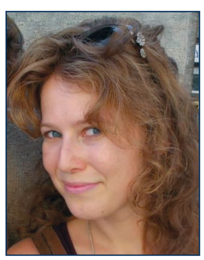

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