Crop Wild Relatives and their Potential for Crop Improvement

by Madeline Fisher

In the late 1800s, a botanist named N.E. Hansen brought a Siberian alfalfa species to the United States, hoping its capacity to survive extreme cold and drought would benefit farmers in what he reportedly called “my American Siberia”—the northern Great Plains. And as he envisioned, farmers did sow the unusual, yellow-flowered alfalfa into their fields, while plant breeders used the new species to breed winter-hardiness into cultivated, blue-flowered alfalfa.

Left: Photo by Andreas Melikyan & Armen Danielyan. **Inset:** Copyright by Simone Cottrell, The Royal Botanic Garden, Sydney.

Then something happened that Hansen likely didn’t expect. Yellow-flowered alfalfa escaped cultivation and went wild, adapting itself to the Plains environment and piquing people’s interest once again. When a South Dakota rancher reported in 1997 that wild populations were boosting forage production and fattening his cattle, rangeland scientists started exploring the plant’s ability to restore degraded pasturelands. Breeders also gave yellow-flowered alfalfa a second look, using it to develop a new variety adapted to the region’s cold, dry rangelands.

Meanwhile, wild populations had settled in the Grand River National Grassland in northwestern South Dakota, and their tendency to displace other species had preserve staff wondering what to do. Should they leave yellow-flowered alfalfa as part of the landscape? Or should they control it to protect native communities? Either way, the plant hardly seems to need protection itself.

Or does it? That’s the question swirling around “crop wild relatives”: species that are genetically related to domesticated crops, forages, medicinal herbs, and other useful plants but are undomesticated themselves. Some, like yellow-flowered alfalfa, are common and weedy. Others, such as the walnut relative, *Juglans hindsii*, are globally imperiled. What they share is their importance to agriculture and their tendency to be overlooked in spite of this (exceptions like yellow-flowered alfalfa aside), both by agriculturalists, who attend mainly to cultivated plants, and conservationists, who typically focus on the rarest, most fragile wild species.

The lack of attention has put crop wild relatives, or CWR, in a precarious position, says ASA and CSSA member Stephanie Greene, a plant geneticist with the USDA-ARS in Prosser, WA and the U.S. National Plant Germplasm System, the country’s primary steward of seed and other crop genetic material. Twenty percent of all wild plants are now threatened with extinction, according to recent estimates, and that’s before the potential impacts of climate change are factored in. Yet, “as the world moves forward with all these initiatives to conserve biodiversity,” Greene says, “it’s recognized that crop wild relatives have been left behind.”

She now leads an effort to tally the CWR living in the United States, identify which are most important to global and American agriculture, and develop a nationwide strategy for protecting them both in gene banks and in the wild. But conserving CWR is only the first step. The real goal is to get their diverse stock of genetic ma-

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terial, or germplasm, into the hands of plant breeders, especially those seeking to adapt crops to the increased drought, greater disease pressure, and erratic weather that climate change is expected to bring.

That's the irony of CWR, Greene says: While they're threatened by climate change just like all wild species, they're also the same plants that could help us adapt our food systems to the new conditions. "That's why it always surprises me: Why aren't these plants the poster children [for plant conservation]?" she says. "We know they have value."

Developing Conservation Strategies

Indeed, plant breeders have recognized the value of CWR for decades, thanks to renowned Russian plant geneticist, Nikolai Vavilov. In the 1920s and 1930s, Vavilov advanced the idea that wild species could help improve wheat and other crops. He also identified what are called the Vavilov Centers: regions such as southern Mexico and the eastern Mediterranean, where the world's major crops were first domesticated and the greatest diversity of their wild relatives is still found. Plant breeders began working with CWR about a decade later and have used them since to achieve some significant breeding improvements. But in recent

Left: Photo by Brian Prechtel (USDA-ARS). **Inset:** Photo by RBG Kew and courtesy of the CWR & Climate Change Photostream on Flickr (www.flickr.com/photos/cropwildrelatives).

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years, few people have studied CWR more intensely or championed their protection more vigorously than Nigel Maxted, a scientist at the University of Birmingham in England.

Keen on travel, agriculture, and conserving nature from a young age, Maxted began studying CWR in 1981 and "basically my interest hasn't stopped since," he says. His first research job involved trying to breed legume crops, such as *Phaseolus* species, with their wild kin. From there, he devised methodologies for conducting "ecogeographic" surveys and analyses, which produce data that help in the planning of conservation efforts, he explains.

Maxted then applied these new methods in studies of many groups of CWR, publishing proposals for protecting the plants as he went. "But unfortunately few people would pay any attention," he says. "It then became clearer that not only as a scientist do you have to publish conservation recommendations, you then have to lobby for their implementation."

In the years since, Maxted has pressed for CWR conservation in many ways, most significantly by developing a step-by-step, standardized protocol that countries can use to identify and protect the CWR within their borders. The first countries he worked with to actually execute such a plan were Syria, Lebanon, and Jordan. More recently, he helped Portugal, Switzerland, the U.K., and several other European nations complete conservation strategies, and he's now collaborating with several more. Two of his graduate students currently work in China and North Africa. And a former student is assisting Greene with the U.S. strategy.

As alfalfa curator for the National Plant Germplasm System, Greene says that CWR have interested her for a long time. But she only started investigating them in depth a few years ago, after realizing the United States had yet to identify its CWR—the first step in Maxted's protocol. "So, I leapt right in," she says, "and started to put an inventory together."

Which U.S. CWR are Most Valuable?

Combing through the scientific literature and other resources, Greene made lists of CWR growing in the United States and then gathered information on them, including their status in the wild and the crops they had been used to improve. She also determined how closely related each wild relative was to its respective crop, getting help here from USDA-ARS plant taxonomist John Wiersema, who manages taxonomic information for the National Plant Germplasm System's database of crop genetic material, known as GRIN. Along similar lines, Wiersema and his colleagues started in 2008 methodically identifying CWR from all over the world and classifying them taxonomically, the idea being that the closest relatives should be easiest for breeders to use.

"That's true in traditional breeding and perhaps even true with advanced genetic techniques," he says. "The most related plants will offer the best chance to transfer favorable genes into crops."

When Greene was finished, her inventory contained more than 3,000 species, subspecies, and varieties of U.S. CWR, making clear the need for the next step in Maxted's strategy: setting priorities for conservation. Fortunately, this is when Colin Khoury, a former Maxted student and current doctoral candidate at Wageningen University in the Netherlands, came along. A native Californian, Khoury not only wanted to study CWR, but also the CWR of the United States, where he hopes eventually to return after many years of living overseas. So, from Colombia, South America, where he works currently for the International Center for Tropical Agriculture (CIAT) as part of his graduate studies, Khoury got started on a prioritization scheme.

His method takes several factors into account. Because ensuring food security is the primary goal, U.S. wild relatives of the world's 70 most important food crops form the bulk of the prioritized list. But Khoury also added wild relatives of what he calls "iconic U.S. crops"—plants of value mainly to American agriculture, including sugar maple, pecan, wild rice, and *Echinacea*. To whittle the list down further, he then identified the very closest kin of crop plants, or "primary

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genetic relatives," and those CWR that are rare or endangered. After a round of review by curators, plant breeders, and other experts, the list now contains roughly 300 taxa that seemingly have the most potential to contribute to future crop improvement.

So, which crops have valuable wild relatives in the United States? The one that tops everybody's list is sunflower, Greene says—likely the country's only major agronomic crop plant to have originated in North America. But the fruit and nut crops also stand out, she adds, including cranberry, blueberry, and currant; pecans, hazelnut, and walnut; and the stone fruits: almond, peach, and cherry. Lettuce, onion, bean, squash, sugar cane, and grape also have rich native gene pools in the United States—all of which was pleasantly surprising to Greene.

"The general consensus is that CWR taxa are usually found in the Mediterranean Basin or in the Fertile Crescent in the Middle East and that North America is kind of depauperate," she says. "So it was nice to see that in fact we do have some important crop wild relatives."

This is precisely why Maxted argues not only for setting global priorities for CWR protection (see his paper in the March–April 2012 issue of *Crop Science*), but establishing national conservation strategies, as well. "If you look at the most important crop wild relatives, they are found, as you might expect, in the Vavilov Centers, and in terms of global food security, those are the ones we should be focusing on internationally," he says. "But every country has some crop wild relatives. And, if you like, it's a way for the biodiversity community [in

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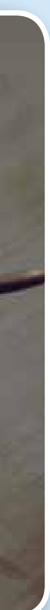
each country] to show the ecosystem service value in their native floras."

On a related note, people also assume that only native plants, such as sunflower in the United States, are the critical CWR, Wiersema says. And yet, the U.S. inventory uncovered dozens of non-native CWR taxa that developed useful traits as they became adapted, or naturalized, to North American environments. "What I was surprised to find is that some genetic resources in the United States are weedy, non-native plants that breeders have told us are very interesting," Khoury notes; for example, yellow-flowered alfalfa, relatives of lettuce, and the wild beets of California's Imperial Valley desert. This suggests "there's still an opportunity for evolution of naturalized species even though they haven't been here that long," Wiersema adds—and that scientists who look for crop diversity only in places like the Vavilov Centers may overlook some important genetic resources.



Identifying the Gaps—and Filling Them

With the key U.S. CWR now identified, Khoury will next use a tool developed by Maxted, called "gap analysis," to determine the precise conservation action required for each plant on the list. In the first step, Khoury will use database information and Geographic Information Systems (GIS) mapping models to predict the full geographic extent of each CWR taxon across the United States. Within those predicted ranges, he'll then pinpoint the locations where each wild relative has been previously collected (if any) and the places where they're already protected: in a national park, for example, or on U.S. Forest Service land.

The idea is to find the "interesting gaps" in collection and conservation efforts, Khoury says, whether they be taxonomic, geographic, or environmental. Of these, large taxonomic gaps in gene bank collections are already known to exist; out of the 540,000 plant varieties, or accessions, currently stored by the National Plant Germplasm System, for example, fewer than 3% are wild plants collected in the United States. But obtaining one of each missing CWR taxon also won't be enough, Wiersema says.

"We want not just to conserve these wild relatives, but also to conserve the *diversity* of crop wild relatives, which is something that's probably not paid so much attention to in conservation generally," he says. It's obviously vital, in other words, to preserve CWR with very limited distributions, such as *Cucurbita okeechobeensis*, a threatened squash relative that grows only along the shore of Florida's Lake Okeechobee. But just as critical is conserving weedier, more widely distributed CWR across the full range of environments they inhabit—especially in places where they may have developed important traits, such as drought tolerance.

"Our goal is to preserve all that genetic variability," Wiersema says, "because for crop breeding purposes we're likely going to need it."

So, once Khoury finds the critical gaps, the National Plant Germplasm System will begin trying to fill them by collecting U.S. CWR seed and other genetic material for its gene bank, or *ex situ*, collections. Meanwhile, Khoury and Maxted are involved in a similar effort at the international level, spearheaded by the food security foundation known as the Global Crop Diversity Trust.

While gene bank collections are indispensable, however, they also represent mere "snapshots in time" of continuously adapting and evolving plants, Wiersema says. This is why he, Khoury, and the others encourage a second, complementary approach of protecting plants in the wild, or *in situ*.

Maintaining CWR *in situ* is advantageous because it allows species to continue evolving and helps protect their native habitat and associated species, as well. But in country after country, *in situ* protection has also proven more difficult than one might expect, Maxted says. People who want to preserve CWR can't simply set up their own conservation areas; instead they must work with the managers of state or provincial parks, national parks and forests, and other protected lands to ensure that existing conservation plans are expanded to include CWR. But this requires cooperation and understanding between agricultural scientists and plant conservationists "and getting those two

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Check out the March–April 2012 *Crop Science* article, "Toward the Systematic Conservation of Global Crop Wild Relative Diversity," by Maxted et al. at www.crops.org/publications/cs/tocs/52/2. And visit the Crop Wild Relatives of the United States blog at http://cwroftheus.wordpress.com.

communities to talk with one another is extremely difficult," Maxted says, because of their different goals.

Still, a CWR management plan he's currently developing with a U.K. conservation authority has a real chance of creating the first reserve for CWR genetic diversity in Europe, he adds. And the National Plant Germplasm System and U.S. Forest Service recently signed a memorandum of understanding, outlining how the two can cooperate to protect CWR on national forest lands, Greene says.

There's still much more to do, though, and time is short. The human population is booming. Habitat for wild plants continues to be lost through urbanization and agricultural expansion. Plant distributions are already shifting in response to warmer global temperatures. Meanwhile, it takes 10 years or more for a novel source of germplasm to get into farmers' hands as an improved plant variety—leaving breeders precious little time now to adapt crops to climate change.

"The window for securing these genetic resources so that they can be safe but also be used, it's narrowing for sure," Khoury says. "So it's really time to move forward and get these resources conserved."

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Left: Photo by A. Lane/Biodiversity International. **Inset:** Photo by Danny Hunter/Biodiversity International.