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Toward Integrated Conservation of North America's Crop Wild Relatives

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Title:

Toward integrated conservation of North America's crop wild relatives

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ABSTRACT: North America harbors a rich native flora of crop wild relatives - the progenitors and closely related species of domesticated plants - as well as a range of culturally significant wild utilized plants. Despite their current and potential future value, they are rarely prioritized for conservation efforts, thus many species are threatened in their natural habitats, and most are under-represented in plant genebanks and botanical gardens. Further coordination of efforts among land management, botanical, and agricultural science organizations will improve conservation and general public awareness with regard to these species. We present examples of productive collaborations focused on wild cranberries (*Vaccinium macrocarpon* Aiton and *Vaccinium oxycoccos* L.) and chile peppers (*Capsicum annuum* L. var. *glabriusculum* [Dunal] Heiser & Pickersgill). We then discuss five shared priorities for further action: 1) understand and document North America's crop wild relatives and wild utilized plants, 2) protect threatened species in their natural habitats, 3) collect and conserve *ex situ* the diversity of prioritized species, 4) make this diversity accessible and attractive for plant breeding, research, and education, and 5) raise public awareness of their value and the threats to their persistence.

Index terms: Crop wild relatives, *ex situ* conservation, *in situ* conservation, wild utilized species

INTRODUCTION

North America harbors a rich flora of wild relatives of significant agricultural and horticultural crops, including wild apples (*Malus* Mill.), beans (*Phaseolus* L.), blueberries and cranberries (*Vaccinium* L.), chile peppers (*Capsicum* L.), corn (*Zea* L. and *Tripsacum* L.), cotton (*Gossypium* L.), grapes (*Vitis* L.), hops (*Humulus* L.), onions (*Allium* L.), pumpkins (*Cucurbita* L.), sunflowers (*Helianthus* L.), and many more (Supplementary Table 1) (Khoury et al. 2013; Contreras-Toledo et al. 2018; Greene et al. 2018b, 2019). The region is also home to a diversity of wild utilized plants still harvested and used by people, such as sugar maple (*Acer saccharum* Marshall) and wildrice (*Zizania palustris* L.).

Alongside direct uses for human nutrition and cultural importance (Cruz-Garcia and Price 2014; Gascon et al. 2015; Willis 2017), these plants offer valuable traits for crop breeding, including pest and disease resistance, and tolerance to climatic stresses (Hajjar and Hodgkin 2007; Dempewolf et al. 2017). For these reasons, it is worrisome that the natural habitats of many North American crop wild relative and wild utilized plant populations are degraded or disappearing, and most species lack sufficient representation in public genebanks, botanical gardens, and other *ex situ* repositories (Zhang et al. 2017; Frances et al. 2018; Greene et al. 2018b, 2019).

Collaborations among land management, agricultural research, and botanic research and education organizations interested in crop wild relatives and wild utilized plants are providing evidence of the efficacy of combined efforts. We describe two examples of ongoing initiatives in the section below. We then discuss the key elements of five shared priorities for further action,

which were recently developed with input from a wide range of botanical and agricultural researchers, land management professionals, and educators, both through online surveys and during in-person stakeholder consultations at the World Food Prize Foundation in Des Moines, Iowa, April 2-4, 2019 (Khoury et al. 2019b).

COLLABORATIVE CONSERVATION OF NATIVE CROP WILD RELATIVES

Wild cranberries (*Vaccinium* L.)

The US Forest Service (USFS) and the Agricultural Research Service (ARS), two sister agencies within the USDA, have joined forces to conserve crop wild relatives in the US (Williams et al., 2018). The *USFS-ARS Joint Strategic Framework on the Conservation and Use of Native Crop Wild Relatives in the United States* (USDA Forest Service and ARS, 2014) outlines the approaches used by the agencies. Conservation of populations of crop wild relatives occurring *in situ* on National Forests and Grasslands is linked with *ex situ* conservation of plants in the ARS genebanks. The agencies, often working with additional collaborators, identify key populations of crop wild relatives on National Forest lands. The USFS then monitors and manages the sites to maintain their long-term sustainability. The ARS collects seeds or plants from the sites and makes them available for use in research, education, and breeding.

The USFS, ARS, and the University of Wisconsin are conducting a pilot project under the *Strategic Framework* to protect wild populations of the large cranberry (*Vaccinium macrocarpon* Aiton) and a close wild relative, the small cranberry (*Vaccinium oxycoccos* L.) on National Forests throughout the range of the species in the US. Twenty-one populations of *V. macrocarpon* and 26 populations of *V. oxycoccos* are included in the project. Botanists from ARS and the USFS have studied the populations of both species and collected leaf samples, herbarium specimens, and seeds, while geneticists at ARS and the University of Wisconsin have assessed their genetic diversity. Substantial variation was observed across the range of both species, and genetic analysis confirmed the discovery of a wild *V. macrocarpon* population outside the known range of the species (author Rodriguez-Bonilla, unpublished). The ARS plant genebank in Corvallis, Oregon is maintaining seed from the populations for long-term conservation. Collaborators are working together to select the highest priority sites for further conservation management, using factors including planned USFS land management activities, distance from other populations, sustainability, population size, genetic profile, ease of access, and significance to Native Americans.

Wild chile peppers (*Capsicum* L.)

Following a number of years of research and collaborations involving the USFS, academic partners, and local nonprofits including Native Seeds/SEARCH, the 2836 acre Wild Chile Botanical Area located in the Rock Corral Canyon subwatershed of the Coronado National Forest in southern Arizona was designated. Established in 1999 to protect and to provide opportunities to research the wild progenitor (*Capsicum annuum* L. var. *glabriusculum* (Dunal)

Heiser & Pickersgill) of the most important chile pepper crop species, the Wild Chile Botanical Area was the first special botanical area in the U.S. designated for crop wild relative protection.

Important scientific progress has been made through research performed in the Botanical Area over the past two decades. Spatial associations with nurse plants and associated microclimatic differences related to protection from frosts have been clarified (Tewksbury et al. 1999). Feeding studies of the wild chiles with birds and small mammals have contributed to a better understanding of the ecological determinants of pungency (hotness) and their association with host plants and migratory animals, as well as potential disruptions to these interactions due to climate change (Tewksbury et al. 2008; Tewksbury and Nabhan 2001; Carlo et al. 2009; Carlo and Tewksbury 2014). Genetic diversity and potential uniqueness of these northernmost populations of the taxon have also been investigated (Votava et al. 2002).

Involved organizations are currently examining the potential via the *Strategic Framework* to expand the scope of the Botanical Area to explicitly include other important native crop wild relatives, including wild quinoa (*Chenopodium berlandieri* Moq.), wild cassava (*Manihot angustiloba* [Torr.] Müll. Arg. and *Manihot davisiae* Croizat), and wild tepary bean (*Phaseolus acutifolius* A. Gray). Expansion of the Botanical Area scope is also expected to help ensure that the wild chile pepper populations persist while nearby commercially harvested wild populations of the taxon continue to suffer dramatic declines (Gonzalez-Jara et al. 2011).

SHARED PRIORITIES FOR NORTH AMERICAN CROP WILD RELATIVES AND WILD UTILIZED PLANTS

To accomplish the goals of enhanced conservation, facilitated use, and increased public awareness of North America's crop wild relatives and wild utilized plants, partnerships among plant conservation, land management, agricultural science, and botanical education and outreach organizations are essential. Five shared priorities for further action have been developed by these communities (published in full in Khoury et al. 2019b). Essential details are shared below.

1. Understand and document North America's crop wild relatives and wild utilized plants, assess threats to their natural habitats, and determine gaps in their conservation.

Species inventories and conservation assessments have been generated for various taxa and for some geographic regions in North America (e.g., Wiersema et al. 2012; Kantar et al. 2015; Khoury et al. 2013, 2015; Castañeda-Álvarez et al. 2015; Contreras-Toledo et al. 2018; Greene et al. 2019), but many land management areas have no comprehensive species lists, and for many species, assessments are either out of date or have not yet been performed (Frances et al. 2018).

Assessments are needed to further document and define the highest priority species across North America, understand spatial patterns with regard to their genetic diversity, analyze threats to populations, and identify the most important gaps in conservation. Results should be integrated into relevant information platforms used by the conservation, land management, genetic resource, and agricultural research communities (e.g. BGCI 2019; CONABIO 2019; NatureServe 2019; USDA ARS NPGS 2019; USDA USFS NRM 2019). Increased alignment of these platforms is recommended to support seamless sharing of information and priorities with professionals in these communities, as well as with the public.

2. Protect North America's crop wild relatives and wild utilized plants in their natural habitats.

North America's public, private, military, Native American, and other open spaces conserve numerous crop wild relative and wild utilized plant populations collaterally, because of overall land protection practices. These plants are not explicitly prioritized except in a few exceptional cases, e.g., for the wild chile pepper and cranberry examples listed above, as well as for a few populations of wild maize in central Mexico (De La Torre et al. 2018). Most species are not currently sufficiently conserved in their natural habitats (Khoury et al. 2019a).

Conservation sites covering populations of the highest priority and/or most threatened crop wild relatives and wild utilized plants need to be designated in existing protected areas, and additional protected areas might need to be considered, to adequately protect the genetic diversity of these plants in their natural habitats to support continued evolution. Conservation of priority species which occurs collaterally within multiple land use areas should be upgraded to active management with the aim of ensuring the viability of populations for the long-term, including under the pressures of climate change. To do so, priorities for species conservation will need to be expanded beyond those few currently officially listed as threatened and endangered.

3. Collect and conserve North America's prioritized crop wild relatives and wild utilized plants in ex situ collections.

Ex situ collections of important crop wild relatives and wild utilized plants are maintained in public genebanks and botanic gardens across North America, but these collections are not currently complete with regard to coverage of taxa, nor of genetic diversity within species (Castañeda-Álvarez et al. 2016; Greene et al. 2018b, 2019; Khoury et al. 2019a). Prioritized crop wild relatives and wild utilized plants across North America need further collecting for *ex situ* conservation. Further research is needed to develop techniques for the maintenance of species that currently require expensive, non-standard approaches.

4. Make North America’s crop wild relatives and wild utilized plants accessible and attractive to plant breeders, researchers, and educators.

North America’s public genebanks, botanical gardens, and open spaces provide the foundation for making crop wild relatives and wild utilized plants accessible for research and education. These plants need to be carefully managed to ensure adequate, high quality, true to type propagules are available for distribution, and they need to be easily accessible via online databases. Indigenous, traditional, and local knowledge about these plants must be valued and protected through access provided by agreements based on mutually agreed terms. These plants should also be accessible to the public through botanic garden displays and through information initiatives on public lands.

5. Raise public awareness about North America’s crop wild relatives and wild utilized plants.

Creating coordinated educational and communications programs to help raise awareness and provide a backdrop for support of crop wild relative and wild utilized plant conservation is necessary to the long-term viability of conservation and plant breeding efforts. Skilled education and outreach professionals should lead collaborative efforts to raise awareness about the importance of, and threats to, North American crop wild relatives and wild utilized plants.

These five priorities are interdependent and require coordinated efforts. Current initiatives that combine the efforts of land managers, agricultural researchers, botanic gardens, and other organizations for the conservation and use of wild cranberries and wild chile peppers are demonstrating the value of collaborative approaches. Through partnerships, significant further progress can be made in conservation, use, and public engagement around North American crop wild relatives and wild utilized plants.

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Biographical sketches

Colin K. Khoury is a research associate at the USDA ARS National Laboratory for Genetic Resources Preservation in Fort Collins, Colorado, and a crop diversity specialist at the International Center for Tropical Agriculture (CIAT), Colombia. His broad research interests are in enhancing food security, human nutrition, and the sustainability of agricultural production systems through the conservation, exploration, and celebration of plant diversity. Current projects focus on conservation strategies for crop wild relatives and crop landraces; Aichi Biodiversity Target, Sustainable Development Goal, and International Plant Treaty indicators; and evidence based decision making in sustainable food systems.

Stephanie L. Greene is a Supervisory Plant Physiologist at the USDA ARS National Laboratory for Genetic Resources Preservation in Fort Collins, CO and a faculty affiliate with Colorado State University in the Department of Soil and Crop Sciences. She serves as seed curator, managing safety duplicate seed collections of the USDA National Plant Germplasm System, as well as over fifty other institutes, including international and national research centers, Native American, and botanical garden organizations. Her broad research interest is in ex situ conservation and the effective and efficient management of genebanks to support the use of agricultural biodiversity to develop climate resilient, sustainable food and agricultural production. She has a specific interest in conserving the rich diversity of crop wild relative species native to North America.

Sarada Krishnan is director of horticulture and global initiatives at Denver Botanic Gardens. She is also a faculty affiliate with Colorado State University in the Department of Horticulture and Landscape Architecture. She is a coffee genetic resources specialist and was involved in the development of the Global Conservation Strategy for Coffee Genetic Resources. Her broad interests include biodiversity conservation - both ex situ and in situ, agrobiodiversity, sustainable coffee cultivation, agroforestry, food security, botanic gardens and economic empowerment of women and girls in developing countries. She currently serves on USDA's National Genetic Resources Advisory Council.

Allison J. Miller is in a joint faculty partnership between Saint Louis University and the Donald Danforth Plant Science Center in St. Louis, MO. She is a Research Associate at the Missouri Botanical Garden. Her research group studies perennial plant diversity and evolution. The goal of this work is to advance the basic understanding of phenotypic plasticity and the genetic underpinnings of phenotypic variation in long-lived plants, and to apply this work to the conservation of perennial plant genetic resources, perennial crop improvement, and development of perennial crops for sustainable agricultural systems.

Tara Moreau is Associate Director of Sustainability and Community Programs at University of British Columbia Botanical Garden. With the goals of advancing sustainability and biodiversity conservation, Tara designs and contributes to programs and partnerships such as the Sustainable Communities Field School and the Grow Green Guide. Tara has over 15 years experience working to advance sustainable food systems. Her publications, presentations and educational programs integrate climate change, food systems policy and planning, sustainability education, agriculture, biodiversity, behavioural science and citizen science.

Karen A. Williams is a Botanist with the USDA Agricultural Research Service National Germplasm Resources Laboratory in Beltsville, Maryland. She manages the Plant Exploration Program for the US National Plant Germplasm System. She has been involved in the collection, documentation, and conservation of crop wild relatives in several countries. One of her current interests is the development of partnerships among different institutions to link in situ and ex situ conservation of crop wild relatives in the United States.

Lorraine Rodriguez-Bonilla is a postdoc in the Cranberry Genetics and Genomics laboratory at the University of Wisconsin-Madison. Her research and interests include assessing the genetic diversity of wild populations of cranberry in their native ranges, conservation of agricultural resources, food security and the nexus of agriculture, and food production and society. Her current projects involve understanding the diversity of wild populations, development of linkage maps, and evolution of species in the genus *Vaccinium*.

Carol S. Spurrier is an Ecologist in the USDA Forest Service Washington Office. She has a wide variety of botanical interests and work experiences in land management agencies including plant community classification, standardized monitoring for plant community conditions and trends, rare plant management, native pollinator management and protection, and native seed collection.

Juan Zalapa is a USDA-ARS Research Geneticist in the Vegetable Crop Research Unit at the Horticulture department of the University of Wisconsin-Madison. His current research focuses on cranberry breeding, genetics, and genomics. His lab uses the molecular tools in conjunction with traditional plant breeding to meet current and future challenges in the cranberry industry, including increasing yield in sustainable production systems, improving berry quality and nutrition, and responding to increasingly variable and extreme climates, insects, and disease pressures.

Gary Paul Nabhan is the the W.K. Kellogg Endowed Chair in Sustainable Food Systems at the University of Arizona Southwest Center, and a research scientist at the Desert Laboratory on Tumamoc Hill. He works with students, faculty, and nonprofits to build a more just, nutritious, sustainable and climate-resilient foodshed spanning the U.S./Mexico border.

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Supplementary Table 1: Prioritized list of crop wild relatives and wild utilized plant taxa native to the U.S. Priorities adapted and updated from Houry et al. 2013, with Priority (1)A= native, close relative of important crop, or iconic, important wild utilized plant; Priority (1)B = native, distant relative of important crop; Priority (1)C = native, very distant or unknown status relative of important crop. In Type field, CWR = crop wild relative, and WUP = wild utilized plant, although we note that many species serve both roles. Genepool status (level of relation to crop) is also noted, as per USDA ARS NPGS, 2019.