

Review Article

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Fifty years of collecting wild *Helianthus* species for cultivated sunflower improvement

<https://doi.org/10.1515/helia-2023-0003>

Received March 17, 2023; accepted March 18, 2023; published online June 20, 2023

Abstract: Wild *Helianthus* species have been undeniably beneficial in sustaining the sunflower crop by providing plant breeders with a diverse genetic pool of potentially useful traits. Exploration to collect populations of wild sunflowers is one of the more difficult and challenging activities in the conservation and utilization of these valuable genetic resources. The logistics of collecting requires careful planning, locating the target species, obtaining permission to access and collect, and timing the exploration to ensure the availability of mature seed. The US Department of Agriculture, Agricultural Research Service (USDA-ARS) established the wild *Helianthus* seed collection in 1976 at Bushland, Texas with the goal of collecting and conserving the broadest representative genetic diversity possible and serving as a central repository of germplasm and related information. In 1985 this collection was transferred to USDA-ARS, North Central Regional Plant Introduction Station, Ames, Iowa. Over the last half century, 37 explorations were undertaken covering 175,000 km to collect the 53 *Helianthus* species from their distributional ranges in the forty-eight conterminous states in the US, three Canadian Provinces (Manitoba, Saskatchewan, and Alberta), Argentina and Australia. The many explorations have created a global crop wild relatives (CWR) genebank collection. The current wild CWR sunflower genebank contains 2562 accessions of 53 species with 1065 wild *Helianthus annuus* accessions (42 %), 617

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accessions representing populations of the 13 other wild annual species (24 %), and 880 accessions representing 39 perennial species (34 %). This collection is the largest and most genetically diverse *ex situ* sunflower collection in the world and is vital to the conservation of wild sunflower species for the global sunflower community.

Keywords: crop wild relatives; exploration; genebank; genetic resources; germplasm.

1 Introduction

Sunflower (*Helianthus annuus* L.) is one of a few crops with its center of origin in North America where it was domesticated by Native American nations in the east-central United States (Blackman et al. 2011; Smith 2006, 2014). Plant genetic resources (or simply germplasm) management for sunflower crop wild relatives (CWR) comprises two phases. The first is germplasm acquisition through explorations for the CWR to secure the germplasm, followed by preserving seeds in *ex situ* genebanks (Bretting and Widrlechner 1995). Genetic resources of a crop ideally consist of the total pool of genetic variability that exists in the crop species or within species with which the crop plant is sexually compatible (Holden et al. 1993). The wild relatives of crop species have long been deemed important genetic resources for breeding and improvement programs because crop wild relatives (CWR) are typically adapted to different environmental conditions than their domesticated relatives, thus genetic material from these wild species has the potential to play an important role in breeding for greater abiotic and biotic stress tolerance (Warschefsky and Rieseberg 2021). The use of CWR genes to improve crop performance is well established with important examples dating back more than 80 years. Crop wild relatives have been undeniably beneficial to modern agriculture, providing plant breeders with a broad pool of potentially useful genes (Hajjar and Hodgkin 2007; Holden et al. 1993; Warburton et al. 2017). The CWR typically are genetically much more diverse than related cultivated lineages. Genetic diversity contributes to long-term preservation of species by allowing them to adapt quickly to changes in their environment. Although many secondary and tertiary gene pools may appear to have no immediate use in breeding and genetic programs (Burton 1979), they may contain genes that will protect crops with no or minimal host resistance against current pests or new pests in the future. Since we cannot predict the occurrence, severity, or even the nature of future stresses, germplasms with as wide a range of genetic diversity as possible should be available for breeding programs.

The genus *Helianthus*, besides constituting the basic genetic stock from which cultivated sunflower originated, continues to contribute specific characteristics for cultivated sunflower improvement. Therefore, there is a continued need to collect, maintain, and evaluate wild *Helianthus* germplasm to enhance the future improvement of cultivated sunflower. The diversity of the 53 species of *Helianthus* CWR (14 annual and 39 perennial species) native to North America have been extremely beneficial in sustaining global sunflower production, providing plant breeders with a diverse gene pool of potentially useful traits (Kane et al. 2013; Kantar et al. 2015, Marek 2016; Marek 2019a; Seiler et al. 2017; Terzić et al. 2020). The North American species of *Helianthus* are found in virtually all parts of the United States with several species extending into Canada and a few into Mexico (Heiser et al. 1969; Schilling 2006).

Aggressive collection of wild and domesticated sunflower germplasm for preservation in seed banks is critical so that germplasm may be readily available to the sunflower genetics and breeding community. Furthermore, given the tenuous situation of wild populations in nature, *ex situ* seed banks may provide the only way to preserve some wild populations or species for posterity. Since the sunflower CWR are native to North America, this has provided an easier opportunity to collect and preserve them in genebanks for current and future use, compared to CWR of crops found in other countries. Critical to successful collecting is careful preparation, planning, and timing to obtain enough mature seeds in relation to the prevailing environmental conditions. In more recent times, gaining access to collect germplasm has become much more restrictive, requiring permission or permits to collect almost anywhere in the US and Canada. Marek (2019b) recently extensively reviewed the practicality of collecting sunflower CWR in North America.

The need for germplasm is driven by the priority of new traits needed for the crop. Castañeda-Álvarez et al. (2016) assessed the collection priority of sunflower CWR as ‘medium’ because of the long history of the use of CWR in sunflower crop improvement, which has benefited from a relatively extensive germplasm collection. However, there are still taxa lacking comprehensive *ex situ* conservation, resulting in gaps in the sunflower collection. Kantar et al. (2015) used occurrence, bioclimatic, and biophysical data for 36 taxa of CWR to predict species hotspots and species gaps. This generated a gap analysis that sets the priority needs for further collection of each species and identification of possible sources of abiotic stress traits for plant breeding programs. Twenty-six CWR of sunflower were rated, with 10 high and 16 medium priorities for collection. Khoury et al. (2020) developed a national inventory of sunflower CWR of the United States, in which taxa are classified based on current knowledge of their relation to agricultural crops and their significance as wild food sources where he lists 10 very high priorities, 33 high priorities, and 10 low priorities.

Collection of germplasm not only preserves valuable germplasm, but also provides information about the diverse habitats occupied by wild sunflowers and associated species. The wild species are adapted to a wide range of habitats and possess considerable variability for most agronomic and achene quality characters, and reaction to insects and disease pathogens. This information is particularly important for the genus *Helianthus* because of the coevolution of its species and associated native insects and pathogens and abiotic stresses. Knowledge of the habitat of a species and its adaptation to the immediate environment facilitates more accurate and efficient selection of species with unique traits.

1.1 Collection methodology

Prior locations and generalized distribution maps were used to locate populations of sunflower CWR. Passport data including species, GPS location, population size (number and extent), habitat, vegetation type, soil type, seed-set per head, and the presence of diseases, insects, and other wild sunflower species, were recorded for each sampled population. Seed heads were collected from 20 to 200 plants within each population and bulked into a single sample. Herbarium specimens were deposited in the USDA-ARS wild *Helianthus* herbarium at Fargo, North Dakota, US. The seed samples were deposited at the USDA-ARS, National Plant Germplasm System (NPGS), North Central Regional Plant Introduction Station (NCRPIS) Ames, Iowa, where they are maintained and distributed. Subsamples were sent to the USDA-ARS, National Laboratory for Genetic Resource Preservation facility in Fort Collins, Colorado as a backup, and when inventory seed and quality allowed, to the Svalbard Seed Storage Vault in Norway. All populations were collected under permits and permission to collect and distribute.

A key component of a strong CWR collection is an active exploration program. The USDA, NPGS, Plant Exploration Office has generously provided funding for CWR explorations since 1984, funding 24 explorations. This has allowed for the aggressive collection of wild sunflower germplasm for preservation in seed banks and is critical so that germplasm may be readily available for the sunflower genetics and breeding community. Furthermore, given the tenuous situation of some wild populations in nature, seed banks may provide the only way to preserve some wild populations or species for posterity. Seiler and Gulya (2004a) reviewed the history of CWR explorations from 1970 to 2003. The objectives of the current paper were to briefly review past explorations (prior to 2003) and highlight explorations since then for specific species to fill geographic gaps in their distribution and to obtain a representative genetic diversity of the CWR for preservation in the NCRPIS genebank.

1.2 USDA sunflower crop wild relatives' genebank history

The USDA-ARS formally established a wild *Helianthus* repository at Bushland, TX, in 1976. The objectives of the program were to collect additional accessions, establish a formal structure for maintaining and distributing wild sunflower germplasm containing as many accessions of the known wild species as resources permitted. The decision to create a permanent wild species collection greatly increased the number of plant explorations for wild *Helianthus* species.

Prior to 1976, the wild species collection consisted of some 375 accessions forming the nucleus of the USDA's CWR collection housed at three locations: the USDA-ARS, Texas A&M, College Station, Texas collection curated by Murray Kinman; the USDA-ARS, University of California, Davis collection curated by Ben Beard; and the USDA-ARS, Fargo, ND collection curated by Bill Roath, but with no formal structure. These collections consisted of mainly annual species, particularly wild *H. annuus* and were incorporated into the genebank when the USDA-ARS NPGS formally established the CWR sunflower genebank in 1976 at Bushland, TX. The CWR collection was later transferred from Bushland, TX to the USDA-ARS NPGS, NCRPIS, Ames, Iowa in 1985.

1.3 Explorations 1960–2003

Explorations prior to 2003 were previously covered by Seiler (1988); Seiler and Gulya (2004a). Having the wild species of *Helianthus* within the boundaries of the US has facilitated the collection of sunflower CWR germplasm. The value of the wild progenitors as potential sources of genes for disease and insect resistance for cultivar improvement was recognized early by Sazperow (1916) in Russia for sunflower head moth, rust and broomrape and later by Murray Kinman, USDA, College Station, TX and Galena Pustovoit, VNIIMK, Krasnodar, the former USSR who were interested in rust, downy mildew, *Verticillium* and broomrape resistance (Pustovoit et al. 1976). This soon led to efforts to collect and use wild *Helianthus* germplasm. Charlie Heiser of Indiana University was one of the early collectors of *Helianthus* germplasm who began collecting in 1947 (Charles Heiser, pers. com., 2001). His focus was primarily on taxonomy, systematics, evolution and speciation of the genus. His early work formed the basis of the current knowledge and understanding of the *Helianthus* genus (Heiser et al. 1969).

Early explorations for rust-resistant germplasm were undertaken by Murray Kinman and Aurelia Luciano (Argentina) in Texas and Oklahoma in 1963 (Seiler 1988). The wild species most represented was wild *H. annuus* (Figures 1 and 2) which



Figure 1: Typical flower of wild annual *Helianthus annuus* (Common wild sunflower) with dark center disk flowers and many yellow ray flowers with attenuated bracts. Plants 1–3 m tall and very branched.



Figure 2: Typical habitat of a wild annual *Helianthus annuus* (Common wild sunflower) population growing along a distributed roadside west of Chugwater, Wyoming. Typical *H. annuus* plants about 1.5 m tall, but can be taller with multiple heads and multiple branches. This is the most widely distributed wild species found in all 48 contiguous states, and adjacent Mexico and Canada, plus naturalized in Europe, South America, Australia, Africa, Mid East, and Asia. Many annual species grow and survive in open disturbed areas.

was introgressed into cultivated sunflower and formed the basis for fertility restoration lines for many of the first hybrids in the US and around the world.

During the mid-1970s, Ben Beard collected wild sunflowers throughout the southwestern US. There were approximately 225 accessions in this collection (Seiler 1988). Most of the accessions were represented by 11 annual species, with mostly wild annual *H. annuus* accessions and 18 perennial species.

Another exploration for sources of rust resistance and a survey of rust races in the North Central Great Plains was undertaken in 1972 by Gerald Seiler (Zimmer and Rehder 1976). This exploration added 100 accessions of mostly wild annual species, predominantly *H. annuus*, to the wild species collection.

Prior to 1976, the wild species collection had no formal structure consisting of some 375 accessions forming the nucleus of the USDA's wild species sunflower collection. During 1976, Charlie Rogers and Tommy Thompson (USDA-ARS, Bushland, TX) undertook an exploration in Texas and New Mexico, adding 200 accessions to the collection. In 1978, they undertook explorations to the western, southwestern, and southeastern US adding 175 accessions.

Several explorations hosted by the USDA-ARS collecting wild sunflower species in the Mississippi River Valley, eastern and southeastern US were made in 1979 with participants Charles Gunn, USDA-ARS, Beltsville, MD, Walter Judd, and Kent Perkins, University of Florida, Gainesville, FL, Robert Mohlenbrock, Southern Illinois, University, Carbondale, IL, and Nickloy Bochkarev, and Anatoli Lukyanenko from the VNIINK Research Station, Krasnodar, the former USSR, adding 270 accessions.

In 1980, Gerald Seiler, USDA-ARS, Bushland, Texas and Luka Cuk, Institute of Field and Vegetable Crops (IFVC), Novi Sad, Serbia (Yugoslavia) collected 400 accessions of wild sunflower over a three month period represented by 11 annual and 24 perennial species from the southeastern, south central and southwestern US (Cuk and Seiler 1985; Seiler and Cuk 1981). *Helianthus paradoxus* (Pecos sunflower) (Figure 3) an annual salt tolerant species was thought to be nearly extinct. The only known population of this species in Texas had been destroyed by road construction in 1979. The 1980 exploration discovered new locations of the Pecos sunflower in Texas and New Mexico leading to the development of a species recovery plan by the US Fish and Wildlife Service (USFWS) and designation as a federally protected species (Seiler et al. 1981).

In 1981, Gerald Seiler and Charlie Rodgers, USDA-ARS, Bushland, Texas collected 34 accessions of two annual species, *H. annuus* (1) and *H. petiolaris* subsp. *petiolaris* (3) (Figure 4), and 9 perennial species: *Helianthus tuberosus* (6), *Helianthus maximiliani* (6), *Helianthus pauciflorus* (*rigidus*) subsp. *subrhomboideus* (7) (Figure 5), *Helianthus giganteus* (4), *Helianthus grosseserratus* (2), *Helianthus nuttallii* subsp. *rydbergii* (2) (Figure 6), and one each *Helianthus mollis* (Figure 7), *Helianthus hirsutus*, *Helianthus salicifolius* accessions from Texas to North Dakota.



Figure 3: *Helianthus paradoxus* (Pecos sunflower) is an annual species that grows in a shallow salt marsh habitat and is one of the sources of salt tolerance for cultivated sunflower. This population is growing near Diamond Y Springs, Pecos County, north of Fort Stockton, Texas and is the location of the type specimen from which the species was named in 1958. This species is federally protected as a threatened species by the US Fish and Wildlife Service (FWS) and has been found only in Texas and New Mexico.



Figure 4: Robust population of annual *Helianthus petiolaris* subsp. *petiolaris* (Prairie sunflower) with plants about 0.7 m tall, very branched with flowers with a distinctive white center of the disk flowers (see insert). Population characteristically growing in a very sandy roadside ditch near Clarendon, TX. This species is the source of the PET1 (French) cytoplasm used in cultivated hybrid sunflower. It is also the second most widely distributed species.



Figure 5: Perennial *H. pauciflorus* (*rigidus*) subsp. *subrhomboides* (Stiff sunflower) growing in sandy soil of oak-savanna near McLeod, North Dakota. Plants with single stems with generally three terminal heads and a basal rosette of leaves. Distribution west central US to the east Atlantic coast.



Figure 6: *Helianthus nuttallii* subsp. *rydbergii* (Rydberg's sunflower) is a perennial species here growing in a moist habitat near a wooded area, south of Fort Ransom, North Dakota. Stems are commonly purple and generally branched above. This species has been identified as a source of resistance to *Sclerotinia* stalk rot. Distribution in North and South Dakota and southcentral Canada.

This exploration added additional representative accessions of *H. giganteus* from the upper Midwest to the CWR collection.

A collection by Ted Van Bruggen, University of South Dakota, Vermillion, SD, US in 1982 added 61 accessions of annual *H. annuus* (21), *H. petiolaris* (3), and perennial *H. tuberosus* (13), *H. grosseserratus* (10), *H. maximiliani* (7), and *H. pauciflorus*



Figure 7: Dense population of perennial *Helianthus mollis* (Ashy sunflower) in a roadside ditch near Standberry, Missouri. This species is unique in that it has dense pubescence on the stems and leaves and near sessile leaves (see inset). Distribution is southeastern US.

(*rigidus*) subsp. *subrhomboideus* (5) from South Dakota and Iowa. This expedition added a good geographic representation of these species.

In 1984 an exploration to southern Texas by Gerald Seiler collected 49 accessions of annual *Helianthus argophyllus* (14) (Figure 8), *Helianthus debilis* subsp. *cucumerifolius* (1), *H. debilis* subsp. *silvestris* (7), *Helianthus praecox* subsp. *runyonii* (5) (Figure 9), *H. praecox* subsp. *praecox* (6), and perennial *Helianthus occidentalis* subsp. *plantagineus* (9), *H. pauciflorus* (*rigidus*) (4) and *H. annuus* (3). The addition of the 14 accessions of *H. argophyllus* and nine *H. occidentalis* subsp. *plantagineus* significantly increased the number of available accessions of these species.

An exploration to the eastern and northeastern US (VA, WV, MD, DE, NY, CT, MA, NH, VT and PA) was undertaken by Gerald Seiler, USDA-ARS Bushland, TX, Bill Roath (USDA-ARS, Ames, IA), and Dragan Škorić, IFVC, Novi Sad, Serbia (Yugoslavia) in 1985. Close to 100 accessions of wild perennial sunflower were added to the collection. The addition of 23 *H. tuberosus* (Figure 10), 14 *Helianthus strumosus* (Figure 11), 12 *Helianthus decapetalus*, and 10 *Helianthus divaricatus* accessions significantly increased the number of available perennial accessions from this geographic region (Seiler et al. 1987).

In 1987, an exploration was undertaken to the Pacific Northwest US (WA, ID, OR) by Gerald Seiler (USDA-ARS, Bushland, TX), Jeff Pomeroy (USDA-ARS, Ames, IA), and Radovan Marinkovic, IFVC, Novi Sad, Serbia (Yugoslavia) with the addition of 52 wild species accessions.



Figure 8: Luka Cuk, IFVC, Novi Sad, Serbia (Yugoslavia) standing next to very tall (3.5 m) annual *Helianthus argophyllus* (Silver-leaf sunflower) in moist roadside ditch near Rockport, Texas. Leaves are densely pubescent appearing silver in color (see insert). This species is the source of the downy mildew Pl_{arg} gene and genes for other races of downy mildew and rust.



Figure 9: Annual *Helianthus praecox* subsp. *runyonii* (Runyon's sunflower) growing in sandy soil in the coastal area near Falfurrias, Texas. This species is one of several species with downy mildew and rust resistance genes. There are three *H. praecox* subsp. (referred to as "Texas sunflower"), all restricted to southeastern coastal Texas.



Figure 10: Perennial *Helianthus tuberosus* (Jerusalem artichoke) growing along the edge of a wooded area near a stream, south of Westport, Indiana. This species is a common garden plant accounting for its wide distribution, especially eastern US. It has served as a source of several genes for disease resistance for over 70 years.



Figure 11: Dense population of perennial *Helianthus strumosus* (Rough sunflower) growing in a roadside ditch along edge of woodlands in thickets near Richmond, Indiana. Leaves gray on top and stems branched above. This species is common in the eastern USA and the most variable of the perennial species intermixing with many other perennials making it very difficult to definitively identify, therefore it has been described as the “garbage can” species.

Annual species included *H. annuus* (28) and *H. petiolaris* (4) accessions, while perennial species accessions included *H. nuttallii* (12), *H. maximiliani* (2), *H. pauciflorus* subsp. *subrhomboides* (1), *Helianthus pumilus* (1) and *H. cusickii* (4) (Figure 12) (Seiler et al. 1992a).

An exploration in 1989 to the Great Lakes region of the US (WI, MI, IN, IL, OH) by Gerald Seiler (UDSA-ARS, Fargo, ND), Jeff Pomeroy (USDA-ARS, Ames, IA), Branislav Dozet (IFVC), Novi Sad, Serbia (Yugoslavia), and Vera Gavrilova, Vavilov Institute (VIR), St. Petersburg, Russia resulted in the addition of 84 accessions of wild species. Twelve different species were collected from the mixed broadleaf and coniferous forest habitat represented by nine perennial and three annual species, typical of this geographic region. The exploration significantly increased the number of perennial *H. giganteus* (Figure 13) and *H. grosseserratus* (Figure 14) accessions in the collection. Additional accessions of *H. divaricatus* (Figure 15), *H. decapetalus*, *H. mollis*, and *H. hirsutus* were also collected (Dozet et al. 1990; Seiler et al. 1990).

In 1991, an exploration to seven Central Great Plains states of the US (ND, SD, NE, KS, CO, WY, MT) by Gerald Seiler (UDSA-ARS, Fargo, ND), Surendra Duhoon, (National Bureau of Plant Genetic Resources [NBPGR], New Delhi, India), Radovan Marinkovic (IFVC), Novi Sad, Serbia (Yugoslavia), and Cynthia Stauffer (USDA-ARS, Ames, IA), resulted in the addition of 144 accessions representing two annual and six perennial species (Duhoon et al. 1992; Seiler et al. 1992b; Seiler et al. 1993). Over half of the



Figure 12: Perennial *Helianthus cusickii* (Cusick's sunflower) being collected by Jeff Pomeroy (left), Sunflower Curator, USDA-ARS, Iowa State University, Ames, Iowa and Radovan Marinkovic, IFVC, Novi Sad, Serbia (Yugoslavia) (right). Steep rocky clay slope of roadside ditch, northeast of Warm Springs, Oregon. This species has a unique feature with a large parsnip-like root (see insert). Distribution is northwest US.



Figure 13: Perennial *Helianthus giganteus* (Giant sunflower) growing in moist open area near woodlands near Keshena, Wisconsin. Plants can be up to 4 m tall, with axillary flowers toward the top of the stem. Common in Great Lakes region, and east to the Atlantic coast.



Figure 14: Perennial *Helianthus grosseserratus* (Sawtooth sunflower) growing in moist roadside ditch north of Lorimor, Iowa. The stems are purple with leaves distinctively serrated giving it the common name of “sawtooth sunflower”. It is commonly distributed in open moderately wet places in central to northeastern US.

accessions were *H. annuus*, while *H. petiolaris* was represented by 25 accessions. The most frequently collected perennial was *H. maximiliani* (Figure 16), followed by *H. pauciflorus*, representative of the species distributions in that part of the US.



Figure 15: Perennial *Helianthus divaricatus* (Woodland sunflower) plants growing in a dry, open habitat near railroad tracks near Lewis, Indiana. Plants have sub-sessile opposite rather thick scabrous leaves. This species is the earliest blooming perennial in eastern North America with its range overlapping many other species, creating the opportunity for hybridization.



Figure 16: Robust population of perennial *Helianthus maximiliani* (Maximilian's sunflower) near Colfax, North Dakota in moist roadside ditch. Typical numerous light green narrow leaves conduplicately folded in the middle throughout the plant. This species has been identified to have resistance to *Sclerotinia* basal stalk and head rot. Commonly distributed in central to eastern US.

The first exploration undertaken outside of the US was in 1994 to the Prairie Provinces of Manitoba, Saskatchewan and Alberta, Canada. This collection was undertaken by Gerald Seiler and Mary Brothers, Curator of the NCRPIS sunflower collection (USDA-ARS, Ames, IA). Sixty-three accessions of wild sunflower were

collected. Thirty-one accessions were annual, while 32 were perennial. Almost 40 % of the accessions were *H. annuus*. *Helianthus maximiliani* and *H. nuttallii* subsp. *rydbergii* were the most common perennial species. The collected populations represent the first wild *Helianthus* germplasm from Canada to be incorporated into the USDA CWR sunflower collection. The northern limitation for collection was 53° north latitude. Beyond this latitude the vegetation is predominantly coniferous forests where wild sunflowers have not been reported (Seiler and Brothers 1996).

In 2000, an exploration to southwestern US (NV, UT, and AZ) for annual species *Helianthus anomalus* and *Helianthus deserticola* was undertaken by Gerald Seiler and Mary Brothers. The locations of all previously identified populations (over 25) of the two species were visited. Both species grow in very specific habitats which are very fragile, shifting sand dunes and sandy desert shrub habitat. Due to a drought, only two accessions of *H. anomalus* and one *H. deserticola* were located for collection. The addition of these accessions to the collection made seed of these species available for research for the first time in almost 20 years (Seiler 2004; Seiler and Brothers 2003).

Exploration for annual serpentine sunflower, *Helianthus exilis* (Figure 17), was undertaken in CA, US by Tom Gulya and Gerald Seiler (both USDA-ARS, Fargo, ND) in 2002 (Seiler and Gulya 2004b). Serpentine sunflower is endemic to serpentine soils and outcrops in California. The distribution of this soil type is the Coastal range and Klamath Mountains, and the western foothills of the Sierra Nevada Mountains. Twenty-six accessions were collected during the exploration and added to the wild sunflower collection. This almost tripled the nine accessions already in the USDA wild *Helianthus* collection, none of which had adequate seed for distribution. The geographic distribution of this species is much better understood now than 15 years ago when it was considered threatened because of habitat destruction in CA. *H. exilis* is currently considered an ecotype of *Helianthus bolanderi* (also called Serpentine sunflower).

In September 2003, an exploration was undertaken to CA, US to collect the endemic perennial species *Helianthus californicus* by Tom Gulya and Gerald Seiler. The species habitat is specific to riparian areas occurring in both dry and wet sites ranging from small streams to large rivers and is indigenous to central and southern CA. The exploration resulted in the collection of 13 accessions of California sunflower. Prior to the exploration, only three accessions were present in the wild sunflower collection (Seiler and Gulya 2005).

An exploration to the southeastern US (TN, NC, SC, GA, AL) to collect perennial *H. eggertii* (Figure 18), *Helianthus schweinitzii* (Figure 19), *Helianthus verticillatus* (Figure 20), and annual *Helianthus porteri* (*Viguiera porteri*) (Figure 21) was undertaken in October 2003 by Tom Gulya and Gerald Seiler (both USDA-ARS, Fargo, ND) and Gary Kong (Queensland Department of Primary Industries, Toowoomba,



Figure 17: Typical dry ephemeral serpentine streambed with typical robust (about 1 m tall) annual *Helianthus exilis* (Serpentine sunflower) plants scattered along the edge, but decreasing in size with distance from the streambed, south of Knoxville, California. This species is endemic to California, and is currently considered by some as an ecotype of *H. bolanderi* (also called Serpentine sunflower).

Australia). Thirteen accessions of *H. eggertii*, 14 *H. schweinitzii* and eight accessions of annual *H. porteri* which were the first accessions of this species collected for the wild species genebank. One accession of perennial *Helianthus smithii* (Figure 22), a species with a limited distribution was also collected. Two accessions of perennial *Helianthus angustifolius* (Figure 23) and one of *Helianthus atrorubens* (Figure 24) were also collected during this exploration. Two accessions of *H. verticillatus*, a species first collected in western TN in 1892 and not seen again in the twentieth century when a population was discovered straddling the Alabama-Georgia state line in the Coosa River Valley in 1994, were added to the genebank (Seiler and Gulya 2005; Seiler and Gulya 2011; Seiler et al. 2008a).

1.4 Explorations post-2003 to present

Beginning with the post-2003 period, explorations became more selective to collect underrepresented species from more restricted distributional ranges to fill gaps in



Figure 18: Perennial *Helianthus eggertii* (Eggert's sunflower) plant with typical purple stem and top branching, and typical flower heads in an open wooded area west of Franklin, Tennessee. This species was recently removed from the federally protected Threatened and Endangered Species listing by the US Fish and Wildlife Service (FWS). Distribution is also in Kentucky and Alabama with over 300 populations now known.



Figure 19: Perennial *Helianthus schweinitzii* (Schweinitz's sunflower) in an open wooded area with typical single purplish stems, southwest of Mt. Pleasant, North Carolina. This species is federally protected by the US FWS as an Endangered Species endemic to the Piedmont region of North and South Carolina.

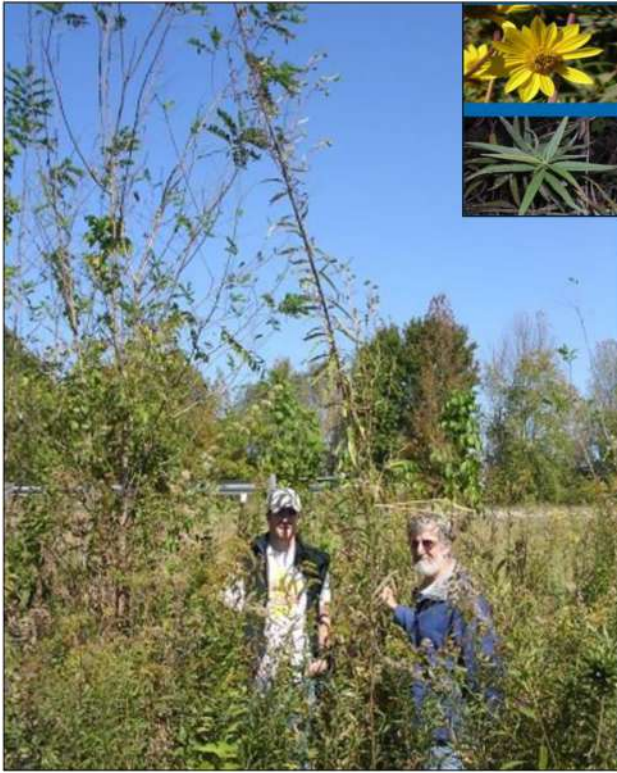


Figure 20: *Helianthus verticillatus* (Whorled sunflower) is very tall perennial, up to 3.5 m tall (center) dwarfing Claude Bailey (left), Tennessee Department of Conservation and Gerald Seiler (right), USDA-ARS, Fargo, North Dakota in a moist disturbed roadside ditch near a stream, northwest of Henderson, Tennessee. This species was recently rediscovered after first being named 100 years ago and is found in only three locations. It is considered endangered by the US FWS.

the collection. An exploration by Tom Gulya and Laura Marek to CA, US in 2004 to collect perennial species added eight accessions: three *Helianthus gracilentus*, three *H. californicus* (Figure 25), one *H. annuus*, and one *H. exilis*. The addition of three accessions of *H. gracilentus*, tripled the number accessions in the CWR collection (Seiler and Gulya 2005).

In 2005, a collection trip by Tom Gulya, Gerald Seiler, Laura Marek, and Chris Knauf (US Department of Interior, Bureau of Land Management) to collect *Helianthus niveus* subsp. *tephrodes*, endemic to active sand dune habitats of Algodones Dunes/Imperial Sand Dunes, Off-highway vehicle recreation area in southern CA, US, east of El Centro, CA. Five accessions of the endemic perennial or sometimes annual



Figure 21: Gerald Seiler (left) and Tom Gulya (right) behind a dense population of annual *Helianthus porteri* (Porter's sunflower, previously Confederate Daisy) on top of Rocky Face Mountain, northeast of Taylorsville, North Carolina. It is generally associated with granite outcrops. This species was recently transferred from the genus *Viguiera* to *Helianthus porteri* and distributed in Alabama, Georgia, and North and South Carolina.



Figure 22: Perennial *Helianthus smithii* (Smith's sunflower) plants in a cleared area of a roadside ditch near an oak-pine-hickory woodland south of Huntersville, North Carolina. Species has purple stems with a smooth waxy surface. It is rare with a limited distribution in Georgia, Alabama, North Carolina, and Tennessee.



Figure 23: Perennial *Helianthus angustifolius* (Swamp sunflower) growing along the sandy-loam moist roadside ditch near edge of woodlands northeast of Troy, Alabama. Plants are 1–2 m tall, much branched above with numerous smaller flowers and long narrowly lanceolate leaves up to 18 cm long. Common from east Texas to the Atlantic coast.



Figure 24: Perennial *Helianthus atrorubens* (Purple disk sunflower) population scattered along sandy loam roadside ditch near mixed woodlands west of Haydon, Alabama. Plants have a basal rosette of scabrous leaves with winged petiole and long densely pubescent single stem, 1–2 m tall, branching at the top. Distribution Virginia, south to Georgia and west to Kentucky and Louisiana.



Figure 25: Laura Marek, Sunflower Curator, USDA-ARS, Iowa State University, Ames, Iowa, standing next to a typical height (2.5–3.0 m) perennial *Helianthus californicus* (California sunflower) plant near a streambed in the San Antonio Valley, San Jose, California. This species is endemic to California.

H. niveus subsp. *tephrodes* (Figure 26) were added to the CWR collection, the only active accessions in the collection at that time. This collection trip also collected a closely related annual species, *H. niveus* subsp. *canescens* (Syn. *H. petiolaris* subsp. *canescens*) (Figure 27) from the Pinta Sands area of AZ, which is the northernmost extension of the Gran Desierto of Sonora, Mexico. Four accessions of *H. niveus* (*H. petiolaris* subsp. *canescens*) were added to the CWR collection (Seiler et al. 2006a,b).

Also in 2005, an exploration to collect perennial *H. cusickii* from the WA and OR by Laura Marek, and Joe-Ann McCoy, resulted in the collection of nine accessions, significantly increasing the number of available accessions in the CWR collection. Tom and Katy Gulya collected *H. cusickii* and *H. deserticola* from CA and NV, adding 15 accessions, and Dean Tonenna, Bureau of Land Management, US Department of the Interior collected and donated seven accessions of *H. deserticola* through collaboration with Tom Gulya.

Perennial *H. pumilus* was extensively collected in 2005 from its endemic high elevational range (1500–2450 m) in CO and WY by Tom Gulya, Gerald Seiler, Laura Marek, and Mark Dahmer (BASF, Aurora, CO). The expedition resulted in the collection of 48 accessions: 46 *H. pumilus* (Figure 28) one *H. annuus*, and one *H. nuttallii* in CO and WY (Seiler and Marek 2012a).

In 2006, Tom Gulya, Gerald Seiler, and Laura Marek explored the southeastern states of MS, AL, FL, and GA, US collecting 23 accessions: 13 perennial *Helianthus resinosus* (Figure 29), three *H. smithii*, two *Helianthus floridanus* (Figure 30), two



Figure 26: Typical population of perennial or sometimes annual *Helianthus niveus* subsp. *tephrodes* (Algodones Dunes sunflower) growing in the Imperial Sands Recreation Area, east of El Centro, California. Mature plants have few flowers and long woody stem and roots to survive in the shifting sand. Notice the new seedlings in the upper right. This species has potential for drought tolerance and has a unique vanilla scent. The species is restricted to southeast California, southwest Arizona, and western Sonoran desert, Mexico.

Helianthus longifolius (Figure 31), one *H. strumosus*, and one annual *H. argophyllus*, and one *H. debilis* subsp. *cucumerifolius*. This exploration significantly increased the number of *H. resinusus* accessions in the collection. Of special interest was the recollection of *H. argophyllus* (ARG-1575) originally collected in FL in 1980, which yielded the Pl_{arg} gene conferring resistance to all known downy mildew races. This population is a unique disjunct population in FL outside of its endemic distributional range of the species along the east coast of Texas in the Gulf of Mexico (Seiler et al. 2007).

The first exploration outside of North America was undertaken in February of 2007 to Argentina. The exploration by Miguel Cantamutto, Department of Agronomy, Universidad Nacional del Sur, Bahia Blanca, Argentina, Monica Poverene, Center for Renewable Resources for Arid Areas (CERZOS-CONICET), Bahia Blanca, Argentina, and Gerald Seiler covered the provinces of Cordoba, La Pampa, Buenos Aires, Entre Rios, San Juan, San Luis, and Mendoza. Eighteen accessions of naturalized wild sunflower were collected including eight *H. annuus* (Figure 32), nine *H. petiolaris* subsp. *petiolaris* (Figure 33), and one *H. × laetiflorus*. The seed from this exploration is held at Universidad Nacional del Sur, Bahia Blanca, Argentina. The naturalized wild species populations appear to have been introgressed with cultivated sunflower which was quite evident in several of the populations resulting in mixed feral populations.



Figure 27: Annual or rarely perennial *Helianthus niveus* subsp. *canescens* (Syn. *Helianthus petiolaris* subsp. *canescens*) (Showy sunflower) growing in the Pinta Sands of the Cabeza Prieta National Wildlife Refuge, east of Yuma, Arizona. Plants with grayish stems and leaves distributed in southern Arizona and New Mexico. This species has potential for drought tolerance traits. The remaining *H. niveus* subsp. *H. niveus* subsp. *niveus* is only found in coastal dunes of Baja California, Mexico.

The second exploration outside of North America was undertaken in March of 2007 to collect in Australia. Tom Gulya, Gerald Seiler, Gary Kong, Sue Thompson and Jeff Mitchell (Queensland Department of Primary Industries, Toowoomba, Australia) collected 56 naturalized accessions of *H. annuus* (Figures 34–36) and two *H. debilis* ssp. *cucumerifolius* (Figure 37) in Queensland, New South Wales, Victoria, South Australia, and West Australia. In 2009, Sue Thompson collected and donated eight *H. argophyllus* accessions from Queensland. These accessions represent the first and only naturalized accessions of CWR from Australia (Seiler et al. 2008b; Seiler et al. 2018).

An exploration to TX, OK, NM, and AZ in 2007 by Laura Marek and Gerald Seiler collected 35 accessions: 19 perennial *Helianthus ciliaris* (Figure 38), eight *Helianthus laciniatus* (Figure 39), three *Helianthus arizonensis* (Figure 40), and three annual *H. argophyllus*, and two *H. annuus*. This expedition significantly added accessions from the Ciliare series to the collection, especially *H. arizonensis* that is restricted to a few sites in AZ and NM.



Figure 28: Perennial *Helianthus pumilus* (Little sunflower) along a roadside ditch near the Colorado and New Mexico border with Chimney Rock, Colorado in the background. This species is restricted to rocky soils from central and southeastern Wyoming to central Colorado.



Figure 29: *Helianthus resinosus* (Resin dot sunflower) is a perennial species growing near the Tugaloo River near Mountain Rest, South Carolina. Flowers have characteristic large reflexed bracts and the lower surface of the leaves tomentose with effervescent resin dots. Distribution southeastern US. This species has been identified as a source of resistance to several pathogens, particularly Sclerotinia.



Figure 30: Perennial *Helianthus floriculus* (Florida sunflower) growing in sandy soil along the edge of a pine plantation north of Moultrie, Georgia. Plants 1.5 m tall, generally branching above, leaves with distinctive wavy undulating margins, sessile or sub-sessile. Distribution in Florida, Georgia, and South Carolina.



Figure 31: Perennial *Helianthus longifolius* (Longleaf sunflower) population growing along the edge and into woodland in sandstone outcrop southeast of Flat Rock, Alabama. Plants have a basal rosette of narrow leaves with flowering stem branched at the top. This species has a very limited distribution found only in Georgia, Alabama, and Tennessee.



Figure 32: Monica Poverene, Center for Renewable Resources for Arid Areas (CERZOS-CONICET), Bahia Blanca, Argentina (Left) and Miguel Cantamutto, Department of Agronomy, Universidad Nacional del Sur, Bahia Blanca, Argentina (Right) collecting a robust annual population of naturalized wild *Helianthus annuus* (Common wild sunflower) growing along the edge of an irrigation ditch, north of Las Malvinas, Mendoza Province, Argentina.



Figure 33: Robust population of naturalized annual *Helianthus petiolaris* subsp. *petiolaris* (Prairie sunflower) with plants about 1.0 m tall, very branched with flowers with a distinctive white center of the disk flowers (see insert). Population growing in sandy roadside ditch near a cultivated sunflower field near La Gloria, La Pampa Province, Argentina.



Figure 34: Gerald Seiler collecting seeds of a typical wild naturalized annual *Helianthus annuus* (Common wild sunflower) on top of the town's landfill (rubbish tip) near the town of Dalby, Queensland, Australia.



Figure 35: Gary Kong, (QDPI, Toowoomba, Australia) collecting naturalized wild *Helianthus annuus* (Common wild sunflower) from a roadside population north of Port Augusta, South Australia.



Figure 36: Sue Thompson collecting naturalized wild *Helianthus annuus* (Common wild sunflower) in an isolated population along a roadside in the vicinity of Mildura, Victoria, Australia.

In 2008 Laura Marek and Gerald Seiler explored GA, SC, NC and TN and collected 50 accessions: 10 *H. resinosus*, 12 *Helianthus glaucophyllus* (Figure 41), eight *Helianthus radula* (Figure 42), four *Helianthus heterophyllus* (Figure 43), two *Helianthus microcephalus* (Figure 44), three *Helianthus laevigatus* (Figure 45), two *H. argophyllus*, two *H. atrorubens*, three *H. smithii*, one *H. giganteus*, one *H. angustifolius*, one *H. divaricatus*, and one *H. floridanus*. One of the more interesting discoveries during this exploration was the collection of two *H. argophyllus* (Figure 46) populations on Bald Head Island (Cape Fear) off the east Atlantic Coast of NC. This is another disjunct population from its endemic distributional range along east Gulf Coast of Texas.

An exploration in 2009 to the south-central US, KS, MO, OK, and AR, US by Laura Marek and Gerald Seiler collected 51 accessions: 20 *H. salicifolius* (Figure 47), 13 *H. pauciflorus* (*rigidus*), nine *Helianthus silphoides* (Figure 48), four *H. × laetiflorus*, three *H. occidentalis* subsp. *plantagineus*, and two *H. annuus*. The large number of *H. salicifolius* accessions substantially increased the number of in the CWR collection, as well as the number of *H. silphoides* from AR and MO.

In 2010, an exploration by Laura Marek and Gerald Seiler to the southeastern US, LA, MS, AL, and FL resulted in the collection of 56 accessions: 22 *H. radula*, 12



Figure 37: Gerald Seiler (left), Sue Thompson (center) and Gary Kong (right) (QDPI, Toowoomba, Australia) collecting wild naturalized annual *Helianthus debilis* subsp. *cucumerifolius* (Cucumber leaf sunflower) from a robust population at the Boonarga Memorial, southeast of Chinchilla, Queensland, Australia.



Figure 38: *Helianthus ciliaris* (Texas Blueweed), a perennial, growing in a sunflower field in the Rio Grande Valley, near Hidalgo, Texas. This species has a distinctive leaves that are smooth, have a wavy margin, and blueish waxy surface on the leaves. Distribution southwest US into Mexico. This is considered a noxious weed in several states.



Figure 39: Population of perennial *Helianthus laciniatus* (Alkali Sunflower) growing in moderately dry alkali soil along edge of vacant lot in Alpine, TX. This species has distinctive ray petals, narrow at the base and wider at the tip (see insert). Distribution primarily in the Chihuahuan desert of Mexico, with outliers into southwest New Mexico and Texas.



Figure 40: Dense roadside population of perennial *Helianthus arizonensis* (Arizona sunflower) near the entrance of Sitgreaves National Forest, south of Snowflake, Arizona. This species has bluish-green leaves with a waxy surface, whose habitat is open pine woodlands. This species is endemic to few sites in Arizona and New Mexico.

H. heterophyllus, seven *H. angustifolius*, six *Helianthus agrestis*, four *H. silphoides*, two *Helianthus resinous*, one *H. smithii*, one *Helianthus simulans* (Figure 49), and one *H. floridanus*. *H. agrestis* (Figure 50) is a unique species in that it does not appear to be



Figure 41: Perennial *Helianthus glaucophyllus* (White leaf sunflower) growing in a moist forest south of Tryon, South Carolina. Plants with long peduncles, leaves scabrous above and glaucous (covered with a fine whitish waxy surface below). This species is restricted in distribution to the Blue Ridge and Smokey Mountains of North and South Carolina and Tennessee.



Figure 42: *Helianthus radula* (Rayless or Pineland sunflower) is a perennial species growing in a sandy open pine-barren east of Slidell, Louisiana. This species generally lacks or has much reduced ray petals. The stalk is generally singular with a basal rosette of leaves and one head per 0.5–1 m tall stalk with purple disk flowers. Distribution southern Gulf Coast to Florida, Georgia, and South Carolina.



Figure 43: Large population of perennial *Helianthus heterophyllus* (Variable leaf sunflower) growing in wet sandy saline roadside ditch near pine woods northwest of Newport, North Carolina. Plants with compact basal rosette of narrow leaves with single stem 1 m tall usually with one central flower and two lateral ones. Distribution coastal plains from North Carolina to Louisiana.



Figure 44: Profusely branched perennial *Helianthus microcephalus* (Small-headed or woodland sunflower) population growing in roadside back slope in a semi-wooded area, west of Waynesboro, Tennessee. This species is common in the southeast US and can be up to 2.5 m tall with compound branching with multiple smaller heads.

closely related to the other *Helianthus* species and has never been crossed with cultivated sunflower. It has very large chromosomes ($n = 17$) with $2\times$ DNA content compared to other species in the genus. It grows in wet habitats.



Figure 45: Perennial population of *Helianthus laevigatus* (Smooth sunflower) northwest of Troy, North Carolina in roadside slope shale-barren. Plants slender, usually branched above with glabrous narrow lanceolate leaves often with whitish waxy surface. Relatively common in shale-barrens of the Allegheny Mountains of Virginia, West Virginia, and North and South Carolina.



Figure 46: Annual *Helianthus argophyllus* (silver-leaf sunflower) in moist roadside ditch on Bald Head Island, off the coast of North Carolina. Typical plants with leaves densely pubescent appearing silver in color. This is a disjunct isolated population outside of the native distribution of the Gulf coast of Texas, and an isolated population in Florida.



Figure 47: Perennial *Helianthus salicifolius* (Willow-leaved sunflower) growing in a roadside ditch on a limestone ridge west of Stark, Kansas. Plants 3–4 m tall with fine thin leaves and upper branching with small heads, similar in appearance to *H. angustifolius*, but leaves are longer and narrower, and distribution is in western Kansas, eastern Missouri, to northern Texas,



Figure 48: Perennial *Helianthus silphioides* (Rosinweed sunflower) growing in an open disturbed roadside ditch near mixed woodland near Paragould, Arkansas. Typical plants 1.5 m tall, branched above with larger lower scabrous leaves reducing in size as they go up the stem and rounded leafy bracts on the heads (see insert). This species can be confused with *Silphium* species. Distribution Tennessee to southern Illinois and Missouri, south to Louisiana.



Figure 49: Robust population of tall (3.0 M) perennial *Helianthus similans* (Muck sunflower) in a moist roadside ditch along edge of a power line right-of way near Denham Springs, Louisiana. This species can be distinguished from *H. floridanus* and *H. angustifolius* with its very tall plants with much thicker stems. Distribution is along Louisiana and Florida Gulf Coast.

An exploration by Laura Marek and Gerald Seiler to TX and NM in 2012 collected 32 accessions including nine *H. paradoxus*, three *H. petiolaris*, three *H. nuttallii*, six *Helianthus neglectus*, five *H. ciliaris*, three *H. pauciflorus* (*rigidus*), two *H. annuus*, and one *H. niveus* subsp. *canescens* (*H. petiolaris* subsp. *canescens*). This exploration collected additional accessions under permit of *H. paradoxus*, a threatened endemic species in TX and NM. Several accessions of *H. neglectus* (Figure 51), a narrow endemic in the Trans Pecos area of TX were added to the CWR genebank.

In 2013, Laura Marek and Gerald Seiler collected in western US in CA and OR adding 21 accessions: eight *H. bolanderi*, five *H. annuus*, four *H. gracilentus*, three *Helianthus winteri*, and one *H. californicus*. *H. winteri* (Figure 52) was described as a new perennial species from Fresno and Tulare Counties in the southern Sierra Nevada foothills of CA (Stebbins et al. 2013). It is distinguished from *H. annuus* by its woody trunk, year-round blooming, and other morphological characteristics. It occurs in open, ungrazed foothill woodlands and annual grasslands on well-drained, granitic soils, generally on lower-elevation, south-facing foothill slopes east of the San Joaquin Valley. This exploration was unique in the collection of the first accessions of *H. winteri*, from California for the USDA genebank (Marek et al. 2014). Laura Marek returned to that area of California a month later and made two additional *H. winteri* collections with the assistance of the botanists who described the species.

An exploration in the summer of 2015 to the southwest US to AZ and UT by Laura Marek and Gerald Seiler collected 22 accessions: nine *H. anomalus* (Figure 53), five



Figure 50: Annual *Helianthus agrestis* (Southeastern or rural sunflower) growing in a moist sandy roadside ditch near Bradenton, Florida. Dense population of 2 m tall plants with leaves with a milky latex. This species is reported to be self-compatible, but has never been successfully crossed with cultivated sunflower with chromosomes $2\times$ larger than any other *Helianthus* species. Main distribution is in central Florida, with one population in South Georgia.

H. deserticola, (Figure 54), five *H. petiolaris* subsp. *fallax*, and three *H. annuus*. In late July, Laura Marek returned to UT and collected seeds from two additional accessions of *H. anomalus* which had no seed in June. *H. anomalus* grows in shifting sand dunes with deep roots and is very sensitive to seasonal moisture to germinate (Seiler and Marek 2016a; Seiler and Marek 2016b).

In the fall of 2015, Laura Marek and Gerald Seiler collected in FL, US adding 29 accessions: eight *H. debilis* subsp. *vestitus*, five *H. debilis* subsp. *tardiflorus* (Figure 55) three *H. debilis* subsp. *cucumerifolius*, and one *H. debilis* subsp. *debilis* (Figure 56) annual species, and four *H. angustifolius*, two *H. heterophyllus*, four *H. radula*, one *H. floridanus*, and one *H. smithii* perennial species. The collections of *H. debilis* subsp. *vestitus* (Figure 57) from the barrier islands off the Gulf Coast of FL was critical since recent hurricanes had battered the islands and put the populations in danger of being destroyed (Seiler and Marek 2018).

The NPGS genebank received a significant donation of 140 accessions of three wild annual species, *H. annuus*, *H. argophyllus*, and *H. petiolaris* subsp. *petiolaris* and



Figure 51: Annual *Helianthus neglectus* (Neglected sunflower) population in a sandy roadside in the Trans-Pecos area near Kermit, Texas. The plants can be up to 2 m tall, much branched with light green leaves and very long peduncles up to 40 cm long and leaf petioles up to 10 cm long. This species is endemic to this area and the Southeast corner of New Mexico and adjacent Texas and is of conservation concern because of its limited distribution.

fallax in 2016 from a collecting exploration targeted for habitat type and species funded by Loren Rieseberg's laboratory at the University of British Columbia. Dylan Burge made the collections during a three-month exploration in the western and southwestern US (Marek 2016).

Multiple researchers have traveled 175,000 km (the equivalent of several times around the world) in search of wild *Helianthus* species. Several explorations were joint efforts between the USDA-ARS and the Food and Agriculture Organization of the United Nations (FAO), European Cooperative Research Network (SCORENA), Wild Species Working Group, the International Plant Genetic Resources Institute, European Cooperative Program for Genetic Resources (IPGRI/ECP/GR), US Agency for International Development (USAID), USDA Office of International Cooperation and Development (OICD), Institute of Field and Vegetable Crops, Novi Sad, Serbia (Yugoslavia), National Bureau of Plant Genetic Resources (NBPGR) New Delhi, India, VIR, Saint Petersburg, Russia, Queensland Department of Primary Industries, Toowoomba, Australia, and the Universidad Nacional del Sur, Bahía Blanca, Argentina,



Figure 52: Gerald Seiler collecting perennial *Helianthus winteri* (Winter's sunflower) a newly discovered tall perennial species from Fresno and Tulare Counties in the southern Sierra Nevada foothills of California on well-drained, granitic soils, generally at lower-elevations, south-facing foothill slopes east of the San Joaquin Valley in the vicinity Fresno, California. It can be distinguished from *H. annuus* by its woody trunk, year-round blooming, and morphological characteristics.



Figure 53: *Helianthus anomalus* (Anomalus sunflower) is an annual species growing in shifting sand in the desert near Hanksville, Utah. Notice the wave patterns in the sand from the wind shifting the sand in the dunes. Typical plant with whitish stem and multiple heads with large bracts. This population had a very high oil concentration of 460 g/kg and the largest seed of any wild species and potential drought tolerance. Distribution in Utah and Arizona.



Figure 54: Annual *Helianthus deserticola* (Desert sunflower) near Big Water, Utah in a typical desert shrub habitat interspersed among the shrubs in open sandy areas. Distribution in Utah, Nevada, and northern Arizona. Potential drought tolerance traits.



Figure 55: *Helianthus debilis* subsp. *tardiflorus* (Slow flowering sunflower) is an annual species growing along a sandy beach near thickets in Cedar Key, Florida. This is one of five subspecies of the Beach sunflower. Plants are branched near base, erect stems with showy flowers, blooming spring to fall found in western Florida, southwest Georgia, and south Alabama. This species is the source of resistance for broomrape race G and higher.



Figure 56: *Helianthus debilis* subsp. *debilis* (Beach sunflower) is an annual species growing along the east Atlantic coast on a sandy beaches near Flagler Beach, Florida. This species blooms throughout most of the year along the east coast of Florida. This is one of five subspecies of the Beach sunflower.



Figure 57: Annual *Helianthus debilis* subsp. *vestitus* (one of five subspecies of the Beach sunflower) in Gasparilla Island State Park, south of Boca Grande, Florida on a sandy secondary beach dune southwest of the boardwalk and lighthouse. This species is restricted to the barrier islands off the west coast of Florida and Florida Keys.

and the Center for Renewable Resources for Arid Areas (CERZOS-CONICET), Bahia Blanca, Argentina.

1.5 Excluded and new species

The CWR collection contains seeds of populations of most all species, but lacks one for *H. niveus* subsp. *niveus* (Figure 58) which occurs only in the sand dunes of the western Pacific coast in Baja California (Mexico). Additionally, *H. paradoxus* subsp. *cuatrociénegensis* (Pecos sunflower) described from wetlands of the Cuatro Ciénegas basin in Coahuila, Mexico (Sivinski 2016) is not represented in the NPGS collection. It differs from more northern populations of subsp. *paradoxus* by its bushy branching pattern of dense, well-developed flowering branches from the base of the plant to near the middle of the central stem, its longer outer whorl of phyllaries that are subulate and usually reach half or more the length of the ray flowers, and its central paleae that have shorter, acute terminal lobes with a short slender point. Interestingly, *Helianthus nuttallii* subsp. *parishii*, nicknamed the ‘Los Angeles sunflower’, was last collected in 1937 in what is now the city of Los Angeles and is now presumed to be extinct. Heiser et al. (1969) lists a species, *Helianthus ludens*, collected from a single population in 1964 from the Trans-Pecos region, east of Van Horn, TX. No additional populations have been found, with recent discussions to transfer it to



Figure 58: Perennial *Helianthus niveus* subsp. *niveus* (Snowy sunflower) plants growing in the sand dunes of the western Pacific Coast in southern Baja California (Mexico) illustrating the perennial habit and gray pubescent leaves and plants with few flowering heads and prostrate plant type. Not found in the US.

Viguiera ludens. Heiser et al. (1969) also listed *Helianthus similis* from southern CA, and northern Baja Mexico with only three populations collected several years ago indicating that this species may be better treated as *Viguiera*.

A population of plants recently discovered along the Santa Clara River in northern Los Angeles County was thought to be the long lost Parishii sunflower. The plants in the populations were tetraploid ($2n = 68$), morphologically similar to and intermediate in some characteristics between diploid *H. nuttallii* and hexaploid *H. californicus* (Keil and Elvin 2010). This resulted in the naming of a new species *Helianthus inexpectatus* described from the Newhall Ranch of northern Los Angeles County, California. More recently, a new species *Helianthus devernii* was described as an endemic species from two small desert spring populations found within Red Rock Canyon National Conservation Area, Clark County, NV (Draper and Esque 2021). Morphological data and nuclear ribosomal ITS marker data place it in section Ciliares series Pumili. Furthermore, the molecular data allies it most closely to *H. pumilus*. *H. devernii* differs from *H. pumilus* by its sessile one nerved opposite and alternate leaves, glabrous glaucous stems, and overall smaller heads. The two known populations of *H. devernii* of approximately 400 individuals occur near the Las Vegas Valley are threatened by heavy recreational use and invasive plants and animals. No accessions of either *H. devernii*, *H. inexpectatus*, *H. niveus* subsp. *niveus*, or *H. paradoxus* subsp. *cuatrocienezensis* are currently in the NCRPIS CWR collection.

1.6 Rare and endangered species

The US FWS protects endangered and threaten plant species from becoming extinct through the Endangered Species Act (ESA) enacted in 1973. The ESA protection includes discovery of additional populations, protection of critical habitats, and recovery plans. It is illegal to import, export, take possess, sell, or transport any endangered or threatened species, and destruction of their critical habitat. Special permits to collect seeds of the species can be issued for scientific studies to facilitate recovery and preservation of seeds in genebanks. Three sunflower species are currently listed as threatened or endangered by the US FWS: *H. schweinitzii* (listed in 1991) and *H. verticillatus* (listed in 2014) are both considered endangered; *H. paradoxus* (listed in 1999) is considered threatened. The recovery plan for each species defines the conditions required to be met for that species to be considered recovered. One *Helianthus* species represents a success story within the US FWS's endangered species program. *Helianthus eggertii* was listed as threatened in 1997 with a recovery plan and delisted in 2005 after reviews of all available data indicated that *H. eggertii* was more widespread and abundant than was documented at

the time of listing eventually documenting 300 populations. No *Helianthus* species are currently listed at the federal level in Canada or Mexico (Marek 2019a).

The states in the US and provinces and territories in Canada maintain lists of species considered at risk in their jurisdictions. Twenty-three states and 11 provinces and territories do not have any *Helianthus* species on their endangered/species of concern plants lists (Marek 2019a, b). Two states list only species which are federally listed, and 25 states and 2 provinces list non-US federally listed *Helianthus* species as vulnerable or imperiled, all of which are secure in another state or states except *Helianthus carnosus* (Figure 59), endemic to and listed by Florida, and *H. niveus* subsp. *tephrodes*, listed by CA with US populations only in CA; the majority of populations are in Mexico (Marek 2019a).

1.7 Current status of the USDA crop wild relatives' collection

Over the last half century, the USDA, NPGS, in cooperation with several national and international institutions has undertaken 37 explorations covering over 175,000 km. Explorations since 2003 have added 500 accessions of new species and additional accessions of several endemic species to the USDA, NPGS, NCRPIS, Ames, Iowa, CWR genebank collection. This has resulted in a genebank collection at the USDA, NPGS, NCRPIS, Ames, IA that contains 2562 accessions with 1682 annual



Figure 59: *Helianthus carnosus* (Lakeside sunflower) is a rare perennial species restricted in distribution, here growing in a moist sandy roadside ditch in Flagler Estates, Flagler, Florida. This species is rare and listed as endangered by the State of Florida. It is endemic to several counties along the northeast coast of Florida where it is considered vulnerable or imperiled and protected.

species, 1065 of which are *H. annuus*, the closest relative of cultivated sunflower, and 880 perennial species accessions of the 53 species (Table 1). Currently, 97 % of the annual accessions are available, and 83 % of the perennial accessions are available, with a collection average of 94 %. As impressive as these numbers are, however, the need for continued, future explorations is apparent in the number of species with low accession numbers. Currently there are five taxa with less than five available accessions (*H. arizonensis*, *H. carnosus*, *H. longifolius*, *H. occidentalis* ssp. *occidentalis*, and *H. verticillatus*). Additionally there are seven species with less than ten available accessions and another four that currently have no accessions in

Table 1: Current accessions of the sunflower crop wild relatives’ *ex-situ* collection at the USDA, National Plant Germplasm System genebank at Ames, Iowa.

<i>Helianthus</i> species	Active number	Available number	<i>Helianthus</i> species	Active number	Available number
<i>agrestis</i> ^a	10	10	<i>mollis</i>	30	28
<i>angustifolius</i>	29	29	<i>neglectus</i>	40	40
<i>annuus</i>	1065	1045	<i>niveus</i> subsp. <i>canescens</i>	19	19
<i>anomalus</i>	17	15	<i>niveus</i> subsp. <i>tephrodes</i>	11	11
<i>argophyllus</i>	81	76	<i>niveus</i> subsp. <i>niveus</i> ^b	0	0
<i>arizonensis</i>	2	2	<i>nuttallii</i> (subsp. unknown)	10	10
<i>atrorubens</i>	12	12	<i>nuttallii</i> subsp. <i>nuttallii</i>	25	24
<i>bolanderi</i>	17	16	<i>nuttallii</i> subsp. <i>parishii</i> ^c	0	0
<i>californicus</i>	21	20	<i>nuttallii</i> subsp. <i>rydbergii</i>	12	12
<i>carnosus</i>	4	4	<i>occidentalis</i> (subsp. unknown)	6	6
<i>ciliaris</i>	31	12	<i>occidentalis</i> subsp. <i>occidentalis</i>	2	1
<i>cusickii</i>	26	26	<i>occidentalis</i> subsp. <i>plantagineus</i>	12	12
<i>debilis</i> subsp. <i>cucumerifolius</i>	15	13	<i>paradoxus</i>	13	13
<i>debilis</i> subsp. <i>debilis</i>	13	13	<i>paradoxus</i> subsp. <i>cuatrociengensis</i> ^b	0	0
<i>debilis</i> subsp. <i>silvestris</i>	22	22	<i>pauciflorus</i> (subsp. unknown)	11	11
<i>debilis</i> subsp. <i>tardiflorus</i>	13	11	<i>pauciflorus</i> subsp. <i>pauciflorus</i>	19	19

Table 1: (continued)

<i>Helianthus</i> species	Active number	Available number	<i>Helianthus</i> species	Active number	Available number
<i>debilis</i> subsp.	12	12	<i>pauciflorus</i> subsp.	16	15
<i>vestitus</i>			<i>subrhomboideus</i>		
<i>decapetalus</i>	29	27	<i>petiolaris</i> (subsp. unknown)	30	30
<i>deserticola</i>	23	21	<i>petiolaris</i> subsp. <i>fallax</i>	62	60
<i>devernii</i>	0	0	<i>petiolaris</i> subsp. <i>petiolaris</i>	133	122
			<i>porteri</i>	12	12
<i>divaricatus</i>	21	18	<i>praecox</i> subsp. <i>hirtus</i>	7	7
<i>eggertii</i>	12	12	<i>praecox</i> subsp. <i>praecox</i>	8	6
<i>exilis</i>	35	35	<i>praecox</i> subsp. <i>runyonii</i>	26	26
<i>floridanus</i>	10	10	<i>pumilus</i>	61	59
			<i>radula</i>	44	44
<i>giganteus</i>	26	26	<i>resinosus</i>	28	23
<i>glaucophyllus</i>	11	10	<i>salicifolius</i>	19	19
<i>gracilentus</i>	19	16	<i>schweinitzii</i>	1	0
<i>grosseserratus</i>	46	45	<i>silphioides</i>	15	15
<i>heterophyllus</i>	19	18	<i>simulans</i>	8	8
<i>hirsutus</i>	14	12	<i>smithii</i>	7	7
<i>inexpectatus</i>	0	0	<i>strumosus</i>	27	18
<i>laciniatus</i>	7	7	<i>tuberosus</i>	89	54
<i>X laetiflorus</i>	10	9	<i>verticillatus</i>	2	2
<i>laevigatus</i>	7	7	<i>winteri</i>	5	5
<i>longifolius</i>	3	3	Total	2562	2415 ^d (94 %)
<i>maximiliani</i>	65	60			
<i>microcephalus</i>	14	12			

^aAnnual species in bold; all others are perennial. ^bSpecies only found in Mexico, which has not been collected. ^cPresumed to be extinct. ^dPercent available accessions.

the collection (Table 1). Some accessions do not have adequate seed for distribution at this time but will be increased and become available in the future.

The distribution of the sunflower CWR accessions for the 2001–2011 period was for 520 requests from 430 recipients totaling 10,683 accessions items (Seiler and Marek 2012b). For the period from 2010 to 2019, 36,000 accessions items from 1214 orders, 923 domestic and 291, international were distributed (Seiler and Marek 2021). This indicates that there is considerable interest in utilizing the sunflower CRW for potential sunflower improvement.

The NPGS genebank accessions have become the basis of wild species research programs in Argentina, Bulgaria, China, France, Germany, Hungary, India, Italy, Romania, Russia, Serbia (Yugoslavia), Spain, and Mexico. Notable collections are at

the Institute of Field and Vegetable Crops, Novi Sad, Serbia (Yugoslavia), INRA, Toulouse, France, Vavilov Institute, St. Petersburg, Russia, ICAR-IOR, New Delhi, India, Dobroudja Agricultural Institute (DAI) at General Toshevo, Bulgaria, IPK, Gatersleben, Germany, INTA, Cordoba, Argentina genebanks (Terzić et al. 2020), the Universidad Nacional del Sur, Bahia Blanca, Argentina, and the Center for Renewable Resources for Arid Areas (CERZOS-CONICET), Bahia Blanca, Argentina.

2 Summary

Wild *Helianthus* species have been undeniably beneficial in sustaining the sunflower crop by providing plant breeders with a diverse genetic pool for improving cultivated sunflower. This was made possible by the many explorations traveling some 175,000 km capturing the vast genetic diversity of the sunflower gene pool assembling the USDA NCRPIS wild species collection with 2562 accessions. It is the largest and most genetically diverse *ex situ* wild sunflower collection in the world and is vital to the conservation of wild sunflower species for the global sunflower community, preserving them for future generations. Recent genomic developments have made the use of wild species more feasible in shorter timelines emphasizing their potential value for sunflower improvement, and also emphasizing the continuing need to collect and preserve crop wild relatives.

Acknowledgment: This paper is dedicated to all the people who have participated and supported the many explorations for wild *Helianthus* species preserving them for future generations and to the national and international institutions for providing exploration funding. Also, iNaturalist for permission to use inset photos in Figures 7 and 8.

Author contributions: All the authors have accepted responsibility for the entire content of this submitted manuscript and approved submission.

Research funding: This work was supported by the U.S. Department of Agriculture, Agricultural Research Service, Current Research Information System Project No. 3060-21220-043-00D. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. The USDA is an equal opportunity provider and employer.

Conflict of interest statement: The authors declare no conflicts of interest regarding this article.

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