



Inventory for Navajo Sedge, *Carex specuicola*, along Seeplines at Natural Bridges National Monument



ON THE COVER

A hanging garden surveyed for this project at Natural Bridges National Monument.

Inventory for Navajo Sedge, *Carex specuicola*, along Seeplines at Natural Bridges National Monument

Lyra Martin

National Park Service Southeast Utah Group
Moab
UT 84532

December 2023

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service publishes a range of reports that address natural and cultural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Park Resource Technical Report Series is used to disseminate results of scientific studies in the physical, biological, cultural, historical, and social sciences. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series provides contributors with a forum for presenting comprehensive information that may not be suitable for publication in external venues due page limitations. Two types of reports are included in the report series:

- Findings. Intended to present final results of scientific investigations, assessments, or analyses. Examples of appropriate material include condition assessments, monitoring status and trend reports, and results of resource inventories or other park projects.
- Open-File Report. Used to disseminate preliminary findings that will be superseded by final information published at a later time. Examples of appropriate material for release as an Open-File Report include preliminary maps or analytical results needed as supporting documentation that can be referenced, discussed, or interpreted in other NPS publications or used as the basis for park management decisions. Because of their preliminary nature, Open-File Reports should be infrequently used, are not the appropriate series to present significant new or novel findings that may be determinative of NPS policy decisions, nor should they be used as final reports for scientific investigations.

This Findings report presents final results of one or more scientific investigations conducted or supported by the National Park Service.

This report is available from the [National Park Service DataStore](#) as well as the [Natural Resource Publications Management](#) website. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

Please cite this publication as

Martin, L. 2023. Inventory for Navajo sedge, *Carex specuicola*, along seeplines at Natural Bridges National Monument. Park Resource Technical Report PRRR-2023/7. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2301739>

Contents

Figures	iv
Tables	iv
Appendices	iv
Introduction	1
Park resource management issues	1
Permits	1
Methods	3
Sample design	3
Survey methods	3
When suspected CASP was found	5
Leaf material collection for genetic analysis	5
Identifying CASP at Natural Bridges National Monument	5
Results	10
Field survey	10
Climate	12
Photos of CASP from their sites at NABR	16
Conclusion	18
Advice and suggestions for future research	18
Safety tips for seepline surveys	18
Literature Cited	19

Figures

Figure 1. Map of the major canyons at Natural Bridges National Monument.	2
Figure 2. Previously documented locations of hanging gardens at NABR.	4
Figure 3. <i>Carex rossii</i> at NABR, photo on right showing characteristic short inflorescence nestled at the base of the leaves.	6
Figure 4. <i>Carex aurea</i> at NABR with a male terminal spikelet.	7
Figure 5. <i>Carex aurea</i> at NABR with a gynecandrous terminal spikelet.	8
Figure 6. CASP at NABR found at hanging garden site WC2.	9
Figure 7. Presence of CASP at sites surveyed during the project.	10
Figure 8. Map showing all the seep lines documented during the project, including previously undocumented sites.	11
Figure 9. Monthly percentages of San Juan County, Utah in drought status from 2012 - 2022 according to the 9-month Standardized Precipitation Index.	13
Figure 10. Monthly departures from 30-year climate averages in Water Year 2022 based on weather data from the NABR visitor center weather station (COOP 426053).	13
Figure 11. CASP at site WC2.	14
Figure 12. CASP at site SIP1.	15
Figure 13. CASP at site DFirNorth.	16
Figure 14. CASP at site NDFir7.	17

Tables

Table 1. This table outlines the sites in which CASP was found or suspected and measurements along the transects: transect length, the percent of the transect that contained CASP, the total area of CASP along the transect, the frequency of the 1x4 meter squares with CASP, and the maximum CASP coverage in a 1x4 meter square from the transect.	12
Table 2. This table shows the duplicate Rink and NCPN sites that appeared on the GPS.	12
Table 3. This table shows the information collected in Survey123 during field work.	20

Appendices

Appendix A. Survey123 Data Attributes Collected	20
Appendix B. CASP inventory SOP	21
Appendix C. Collection Methods and Materials for CASP	23
Appendix D. NABR Hanging Garden Sedge Descriptions From Flora of North America	24

Introduction

Hanging gardens occur along seeps in canyon walls when water has percolated through a porous formation meeting a less permeable rock layer and then flowing laterally until a canyon intersects the plane (Malanson 1980). Because these hanging gardens have a constant supply of water, and because they are also protected from regular flash flooding, they support a diversity of unique plant life. Over 25% of the species within hanging gardens are ecological specialists of that habitat within the Colorado Plateau (Nebeker et al. 1977), and many of the species are endemic to hanging gardens. Hanging gardens often have a backwall habitat and a steep colluvial slope that can sustain obligate wetland species. The associated vegetation may stretch to hundreds of square meters and often contains a mix of graminoids. These hanging gardens also support a number of different *Carex* species including the federally-listed threatened Navajo sedge (*Carex specuicola*).

At NABR, hanging gardens can be found among many of the canyon walls. Known hanging garden locations are found primarily in the eastern walls of White and Armstrong Canyons at NABR (Figure 1). The Cedar Mesa sandstone dips to the west and south, causing water to emerge along seep lines and bedding planes in the canyon. Tributary canyons and drainages also affect the flow of water through the sandstone aquifer, resulting in more developed seeps and springs in some stretches of the seep line/hanging gardens. Seep lines may occur along several bands of the canyon wall. The monument is at the northernmost edge of CASP range, and CASP has been found in both linear, dryer stretches of seep line as well as in wetter, more developed hanging garden habitat.

Since the Navajo sedge is federally listed as threatened, it is required by law for the park track its populations and to make sure that any aspect of park management isn't leading to its decline. The purpose of this project was to gather information on CASP location and abundance within NABR and to collect leaf clippings that would contribute information to a genetic study of CASP within its known range. Questions asked in this study included:

- How many populations of CASP are present at NABR and what is their extent at each site?

- How are NABR CASP populations genetically related to other populations in the region?
- Has CASP dispersed to any sites where it was absent in the earlier survey?

Park resource management issues

Some of the threats to CASP populations that have been recognized regionally are water development projects and livestock grazing around CASP populations present on the Navajo Nation in Arizona. Livestock grazing is not permitted at NABR, and there has been very little evidence of wildlife browsing at the hanging garden sites. CASP populations are also under threat from global climate changes which can cause potential drying of the seeps where the CASP lives and drought stress on the plants (Roth 2004). Invasive plants in hanging gardens could also potentially endanger CASP populations through their competition for space and water resources.

This project was part of one of the steps to recovery outlined in the 7-part Navajo Sedge recovery plan involving the surveying of potential sedge habitat and the resurveying of known sites in order to check on their status (House 1987). Resurveying known CASP populations can also help to see how climate change and drought is affecting the populations. Knowing the population range and population numbers of CASP can help inform future management decisions about how to best protect the species. These management decisions may involve grazing discouragement through continued border fence maintenance or advocating for the protection of areas outside NABR that affect water recharge in the canyon seeps.

Permits

This project was conducted under U.S. Fish and Wildlife Service Native Threatened Species Recovery permit ESPER0036778, effective 6/2/2022 through 6/1/2027.

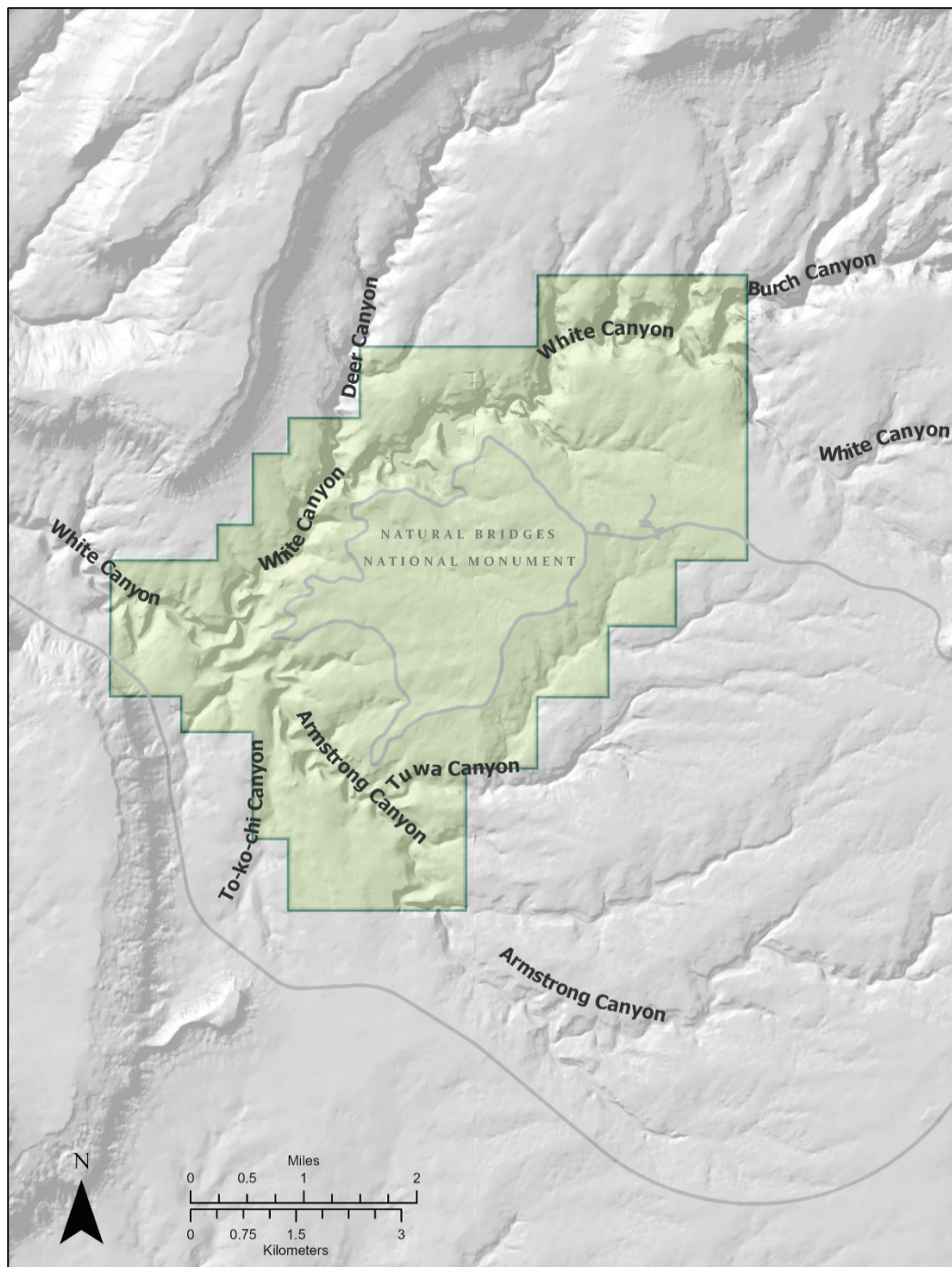


Figure 1. Map of the major canyons at Natural Bridges National Monument.

Methods

Sample design

A reconnaissance survey of 55 locations in NABR as part of the 5-year USFWS review found two suspected populations of CASP in 2013 (Rink and Hazelton 2014). A separate population of CASP was identified at NABR in fall 2021 (Weissinger, unpublished data). The Northern Colorado Plateau Network (NCPN), a regional National Park Service inventory and monitoring program, identified 25 hanging garden locations based on earlier surveys for hanging garden endemic plant species (Heil et al. 1993, Weissinger et al. 2011). This project combined and resurveyed all the Rink and NCPN target sites except for a few that proved difficult or unsafe to access. Furthermore, the project involved searching additional habitat in the area of known seeps for CASP and documented new seep lines. These new seeps were often found adjacent to previously documented seeps, because hanging gardens often occur in clusters due to the canyon topography when a dip occurs in the Cedar Mesa sandstone. In total, 64 previously documented sites were surveyed.

The surveyed seeps occurred in White Canyon and Armstrong Canyon and the Tuwa and Tokochi side-canyons of Armstrong/White Canyon (Figure 2). Many of the seeps were higher up in the canyon walls, so concerns about safety were always prioritized.

Most of the sites surveyed during this project were previously found by Rink and Hazelton (2014) and Weissinger et al. (2011; NCPN) and are located on the FieldMaps program for navigation. Due to poor satellite reception in canyon environments, some of the GPS points didn't identify precise locations of the hanging gardens, but they gave a good idea of general location. Usually, the actual location was just a ledge or two up or down in elevation from the point on FieldMaps.

Fieldwork for this project was conducted June 15th to September 3rd, 2022, at Natural Bridges National Monument. This time period was chosen because June through August was believed to be the time that CASP started flowering or fruiting and was therefore ideal for identification. At the start of the project (June 15th), all the *Carex* species had inflorescences, and the perigynia were not fully mature or dispersing.

This was an optimal time for identification. Starting around mid-July, the *Carex* began to dry up and got harder to identify. Though phenology can vary interannually with climate variability, mid-June seems an optimal time for *Carex* surveys at NABR.

Survey methods

Linear seeplines often extended well past developed hanging gardens in each direction. Seeplines also occurred along the same bedding plane or parallel bedding planes throughout the canyon. It was difficult to know the extent of this accessible habitat in advance. Linear features were accessed from known hanging garden locations and by safely contouring up canyon walls to the appropriate level.

Portions of hanging gardens proved to be inaccessible (i.e., unsafe to search). When accessing a seepline or searching within a hanging garden, personal safety and resource protection (i.e., trampling of plants, soil erosion) were the primary concerns. Steep areas where a fall would likely result in debilitating injury were not walked through. Areas that were steep or wet enough that plant roots would be displaced were also not walked through. If a site couldn't be safely accessed, the site was marked as inaccessible in Survey123 before proceeding to another site.

When getting to a previously surveyed or new hanging garden, after assessing personal safety and deciding how best to minimize damage to the site, the first step was to open FieldMaps and turn on route tracking on the GPS unit. The seepline was then followed while looking for *Carex* along the way. If a suspected CASP occurrence was found, the next step was to switch to Survey123 and take photo documentation and point information and then continue along the seepline until it was no longer accessible or until no wetland vegetation was noted for 200 m. The route on the GPS was ended once a turnaround point was reached.

If the seepline was previously undocumented and there was no CASP present, good representative photos of the seep were taken and attached to the recorded line on FieldMaps. No Survey123 was necessary if there was no CASP.

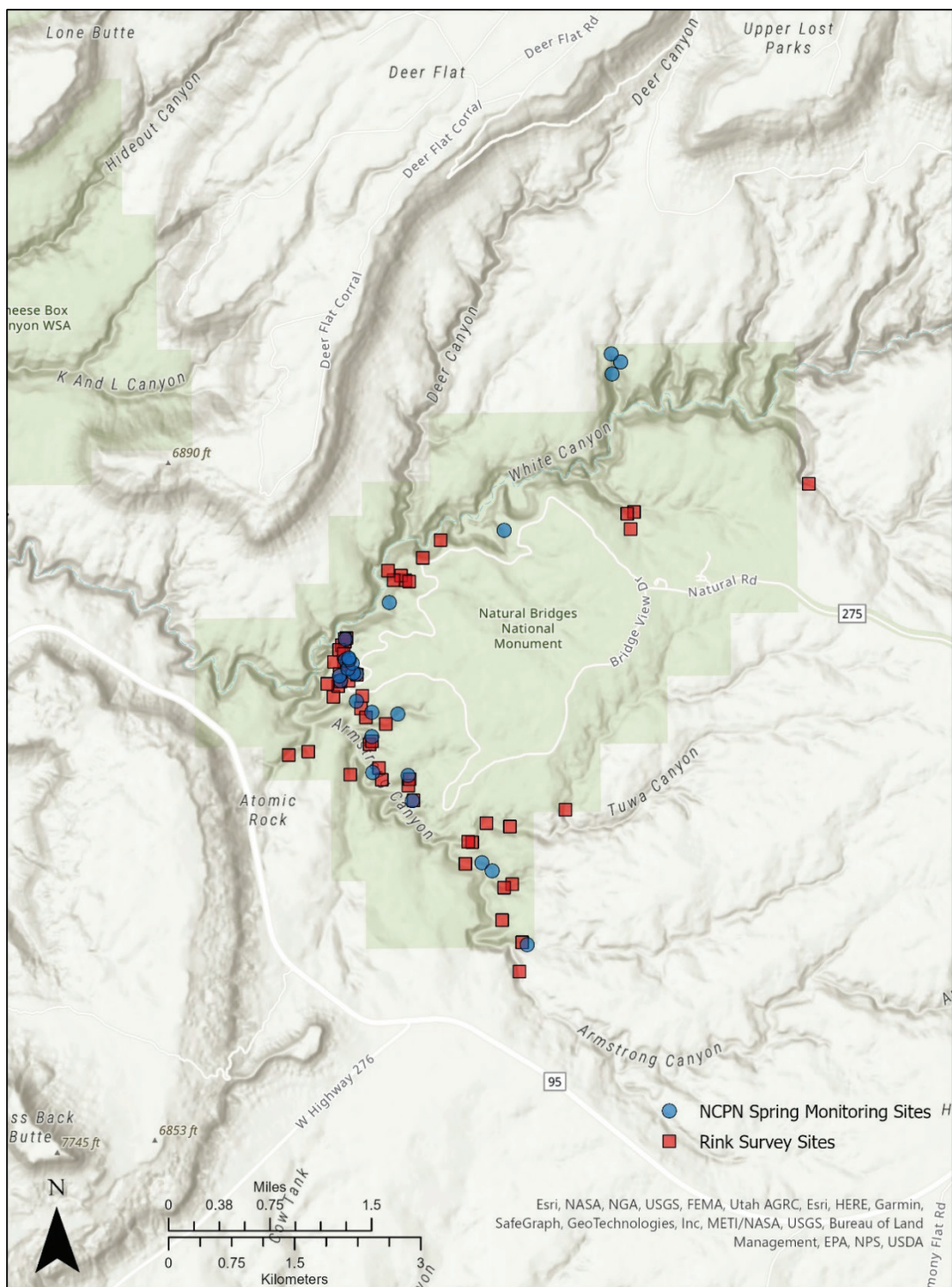


Figure 2. Previously documented locations of hanging gardens at NABR. Most known hanging garden habitat is found along seep lines emerging from the eastern walls of White and Armstrong Canyons in NABR. Locations surveyed by Rink are shown in red, and locations in the NCPN monitoring protocol are shown in blue.

New seeps with visible water leaking from the walls, but no hanging garden vegetation were not documented.

If the site was a previously documented hanging garden or if there was CASP in an undocumented one, no photo attachment on FieldMaps was taken, but it was necessary to start a survey123. Photos did not need to be taken on FieldMaps, because the photo attachments were taken on the survey123 form instead. On the Survey123, different data and features of the site were recorded ([Appendix A](#); [Table 3](#)).

When suspected CASP was found

Additional data were collected when a population of CASP was identified or suspected (i.e. if ID uncertain but looked like CASP). Quantitative transect data were collected on paper datasheets. Methods were adapted from methods established by Rink and Hazelton (2014) and can be found in the statement of purpose included in [Appendix B](#).

Their method included several different measurements taken at the site. It established a permanent 4m belt transect that intercepted the CASP population. CASP cover and substrate wetness were recorded within the belt at each meter mark. Photos of the ends of the transect were taken after marking them with pin flags. Physical features and bearing at the transect ends were also recorded to aid in relocation for future surveys.

Evidence of wildlife browsing to the site and to the CASP itself were recorded. Close-up and zoomed-out (habitat) photos of the CASP were taken on survey123, and photo numbers were recorded on the paper datasheet. All usual site measurements present on the survey123 form were also recorded.

Leaf material collection for genetic analysis

Three to ten green leaves were collected from 5-15 individual plants at each suspected CASP occurrence, preserved in silica, and shipped to the USGS Southwest Biological Science Center to be analyzed by Dr. Rob Massatti's lab in the Genetics for Western Restoration and Conservation working group. Field collection protocols were provided by the lab (Massatti 2019) and are found in [Appendix C](#). Leaf specimens were analyzed according to methods detailed in Chapin et al. (2022).

Identifying CASP at Natural Bridges National Monument

While surveying for CASP at NABR this summer, there were three different hanging garden sedges to distinguish between. Dichotomous keys are the ultimate authority, but brief descriptions from this summer's observations are presented here as they may be useful locally. *Carex rossii* was easy to tell apart from CASP, growing lower to the ground and bushier, with inflorescences appearing at the base of the leaves ([Figure 3](#)). *C. rossii* also usually grew in drier areas of the hanging gardens. *Carex aurea*, although often easy to tell apart from CASP, did get mixed up with it. Confusion occurred when the *C. aurea*, which most often had a male terminal spikelet ([Figure 4](#)), formed a gynecandrous terminal spikelet with the female above the male perigynia as is diagnostic of CASP ([Figure 5](#)). The main differences between these two *Carex* species were that the *C. aurea* perigynia had a more rounded "grapey" appearance and often appeared greener (or orange when they were matured). The CASP had flat, translucent, light brown perigynia (although they can be a green shade when young) and pistillate flowers above the staminate flowers ([Figure 6](#); Rink and Licher 2015). When the CASP and the *C. aurea* terminal spikelet were gynecandrous, they both had a funnel type shape, but the CASP perigynia lay flatter and therefore had a smoother transition into the end of the spikelet with the pistillate flowers. This contrasted with the *C. aurea* where the perigynia seemed to sit on top of the staminate flowers. The descriptions from Flora of North America (Flora of North America Editorial Committee 1993) for the three sedge species in NABR can be useful for identification ([Appendix D](#)).



Figure 3. *Carex rossii* at NABR, photo on right showing characteristic short



Figure 4. *Carex aurea* at NABR with a male terminal spikelet. The perigynia are mature here so they are more orange than they often appeared in the hanging gardens in June/early July, when they are greener.



Figure 5. *Carex aurea* at NABR with a gynecandrous terminal spikelet.



Figure 6. CASP at NABR found at hanging garden site WC2.

Results

Field survey

During this project, 64 previous Rink and NCPN hanging gardens were resurveyed and 26 new seep lines were found and searched for CASP (Figure 7). In total 90 seeps were surveyed (Figure 8). When taking into account the area surrounding the seeps, this project surveyed a total of 716 acres. The actual search area, if including all the ground covered

while looking for Navajo sedge and new seeps, was larger than this but is hard to quantify. This is because it's difficult to accurately estimate how many acres were covered while hiking and scanning cliff ledges or even hiking through an area that didn't seem like suitable habitat. There were four possible CASP populations surveyed in this project.

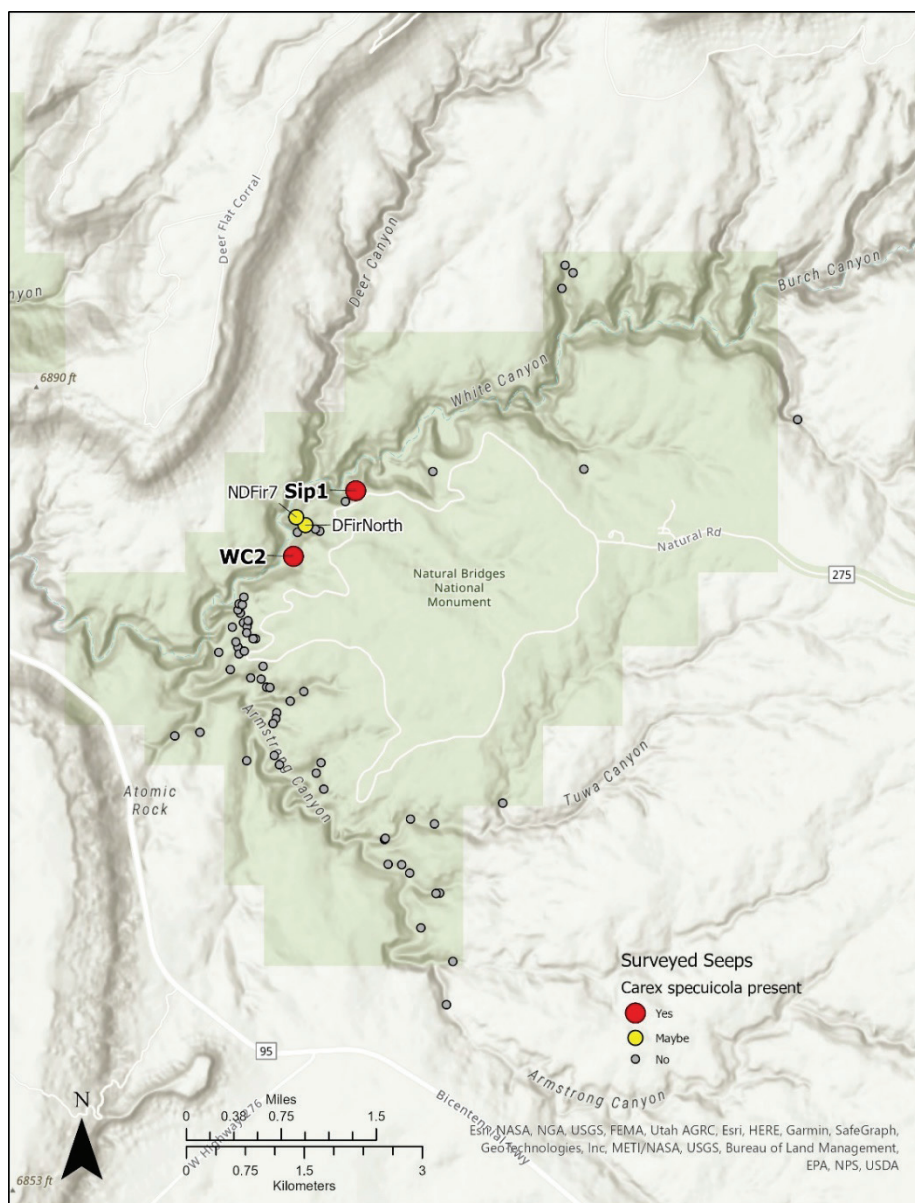


Figure 7. Presence of CASP. This map includes all the sites surveyed during the project. Sites where CASP was present (and previously documented) are in red, sites where CASP wasn't present are in grey, and sites where the ID of the CASP was uncertain but subsequently confirmed with genetic analysis are in yellow.

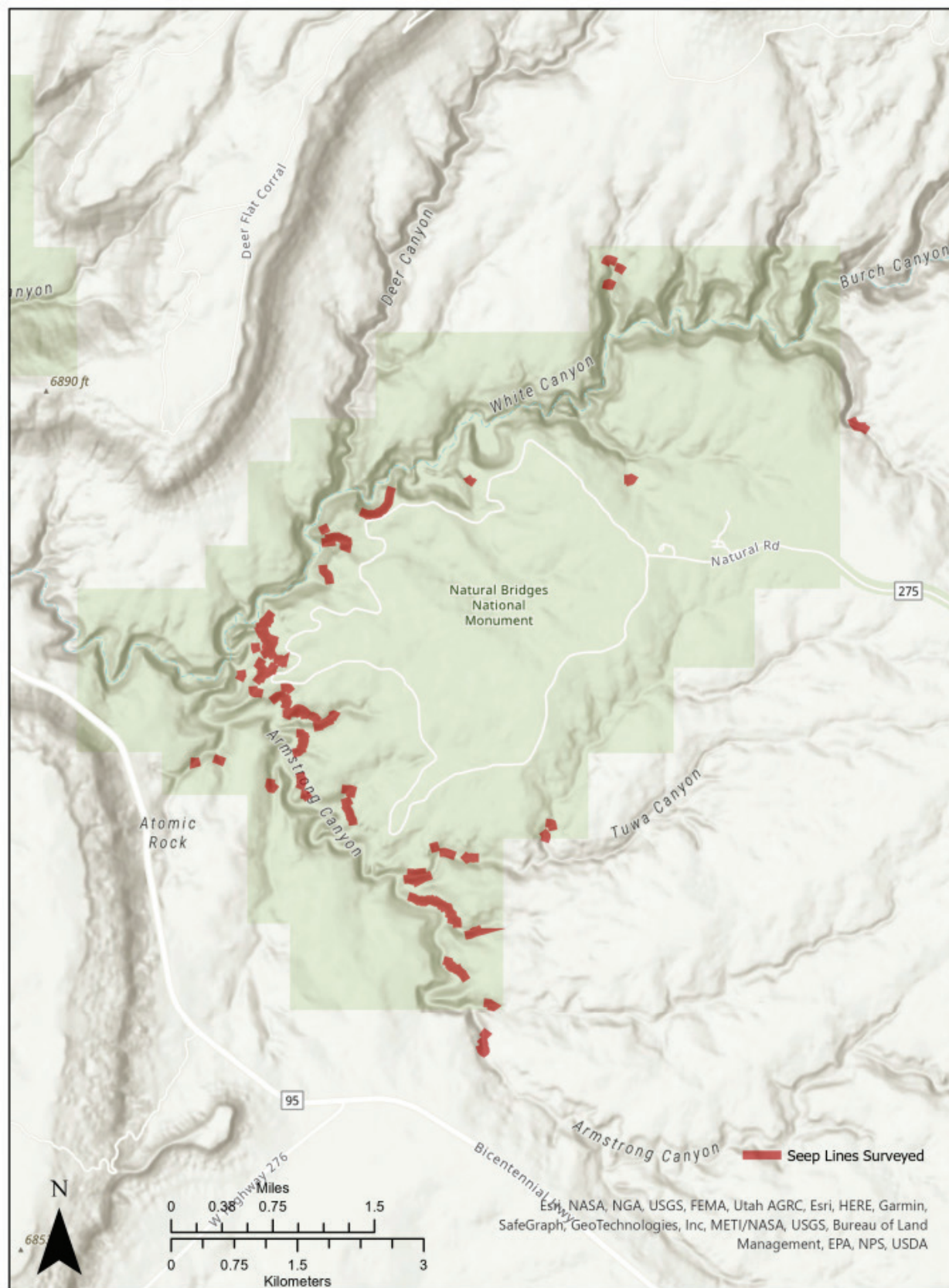


Figure 8. Map showing all the seep lines documented during the project, including previously undocumented sites.

Of the sampled sites, only one new population of CASP was found at hanging garden site Sip1, and all populations documented in the Rink and NCPN surveys were relocated. The CASP population from 2021 at site WC2 (Weissinger, unpublished data) was resurveyed and more clippings of the leaves taken for genetic analysis. There was a smaller bunch of CASP found along this same seep at WC2 that hadn't been recorded in the previous year. Data was collected from this as well. The two suspected occurrences within the park (Rink and Hazelton 2014) at sites DFirNorth and NDFir7 were also resurveyed, and clippings of the sedge were taken for genetic analysis. These occurrences were subsequently confirmed by genetic analysis. A description of these populations are in [Table 1](#). Several of the Rink and NCPN sites were the same seep in the canyon but had separate GPS points and names. The final names are included in [Table 2](#).

Climate

Southeastern Utah, similar to much of the southwestern United States, is in a multi-decadal period of long-term drought. From 2000-2018 conditions in the southwest were the second driest in the last 2500 years (Williams et al. 2020), with periods of extreme drought causing widespread vegetation mortality. In San Juan County where NABR is located, drought status has fluctuated over the previous ten years, with the majority of the county experiencing periods of extreme wet followed by periods of extreme drought ([Figure 9](#)). Leading up to this year's sampling, 2018 and 2020-2021 were extremely dry; however, from winter 2021 - spring 2022 drought conditions lessened ([Figure 9](#)). Conditions at the NABR weather station in Water Year 2022 leading up to July 2022 also fluctuated ([Figure 10](#)). A relatively cooler, wetter winter and spring compared to recent history likely resulted in fairly good conditions for identifying Navajo sedge during early summer 2022, despite long-term drought in the region.

Table 1. This table outlines the sites in which CASP was found or suspected and measurements along the transects: transect length, the percent of the transect that contained CASP, the total area of CASP along the transect, the frequency of the 1x4 meter squares with CASP, and the maximum CASP coverage in a 1x4 meter square from the transect.

Site Name	CASP Found?	Transect Length (m)	% Transect Area with CASP	Total Area of CASP (m ²)	Frequency of 4m ² Blocks with CASP	Max cover (%) within a 4m ² Block
WC2	Yes, confirmed	10	0.22	0.09	0.3	2
DFirNorth	Yes, confirmed	6	1.5	0.36	1	4.5
NDFir7	Yes, confirmed	9	5.4	1.94	1	7
SIP1	Yes, unconfirmed	4	2	0.32	0.75	5

Table 2. This table shows the duplicate Rink and NCPN sites that appeared on the GPS. Site names that have an asterisks next to them are the names that were used on the Survey123 form.

NCPN Site Name	Rink Site Name
UASpring*	Armstrong5
Shoe*	Armstrong7
NABR14*	Armstrong 11
NABR11*	Armstrong9
NABR1*	NEofArnolds
NABR4*	NofArnoldsNo
KB1*	Micro
KBAIcove*	NofAm
KB2*	Cutoff
KB3*	Either Slickrock or Daisy (couldn't find one of them)

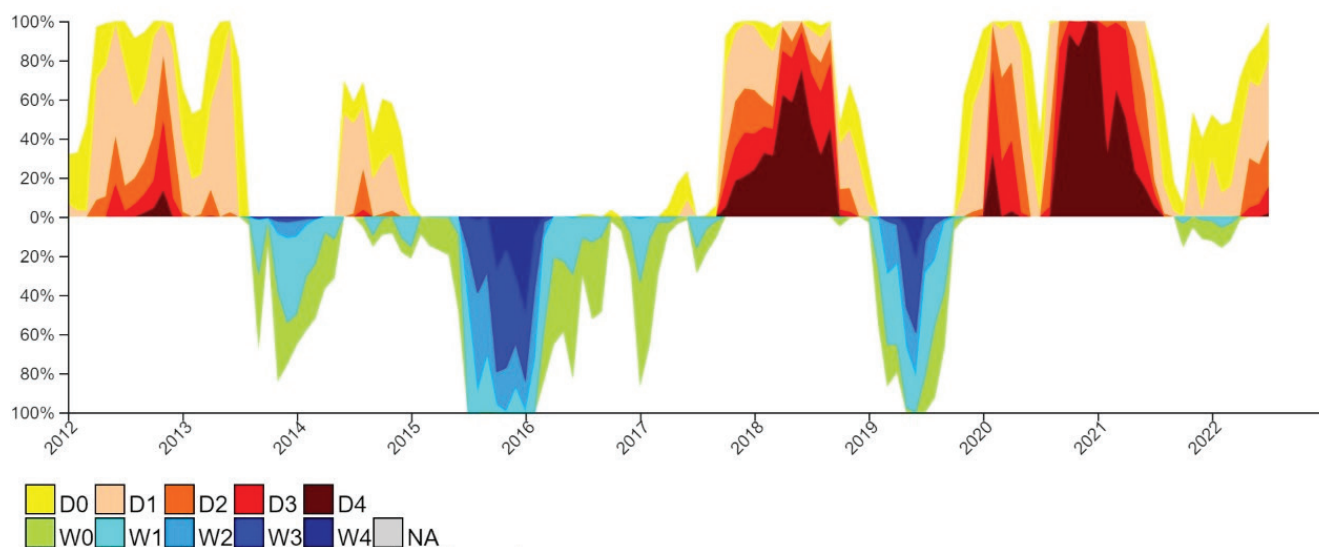


Figure 9. Monthly percentages of San Juan County, Utah in drought status from 2012 - 2022 according to the 9-month Standardized Precipitation Index. D0: Abnormally dry, D1: Moderate drought, D2: Severe drought, D3: Extreme drought, D4: Exceptional drought, W0: Abnormally wet, W1: Moderate wet, W2: Severe wet, W3: Extreme wet, W4: Exceptional wet. Figure accessed 8/18/22 at <https://www.drought.gov>.

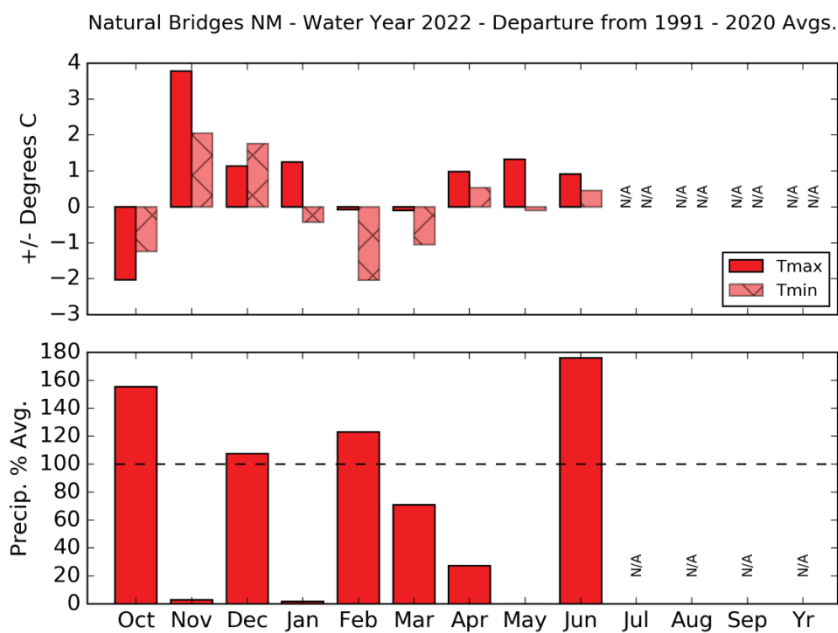


Figure 10. Monthly departures from 30-year climate averages in Water Year 2022 based on weather data from the NABR visitor center weather station (COOP 426053). Figure accessed 8/18/22 at www.climateanalyzer.us.



Figure 11. CASP at WC2.



Figure 12. CASP at SIP1.

Photos of CASP from their sites at NABR

The following figure shows CASP at various sites throughout the National Monument ([Figure 11](#); [Figure 12](#); [Figure 13](#); [Figure 14](#)).



Figure 13. CASP at DFirNorth.



Figure 14. CASP at NDFir7.

Conclusion

Good management and protection are important for the few known populations of CASP at NABR. Because CASP populations are inside a national monument, they are being protected from livestock grazing. This is significant, because the greatest regional threat to CASP appears to be grazing, and there has been no evidence of that in the hanging gardens at NABR. However, there are some other steps the park can take to ensure overall hanging garden health:

1. Encourage visitors to clean their boots before hiking the trails. Invasive spread in hanging gardens can endanger native plant health.
2. Make sure that grazing livestock from surrounding public lands don't get into the park, through measures such as maintaining border fences.
3. Involve park management in helping protect areas outside NABR that contribute to water recharge for NABR hanging gardens, if development or extractive industry threatens those areas.

Advice and suggestions for future research

During this project, it was found that the best time for identifying the CASP was from June 15th (when the project started) to early July. However, it should be noted that starting even earlier could be important to maximize the time where it is possible to get a good sedge ID, especially in the coming years considering the increasingly warming climate.

Finding more hanging gardens is important to getting an accurate assessment of CASP population numbers in the park. The upper reaches of White Canyon have some new ground to cover from about hanging garden site FF1 to the park boundary and beyond. Deer Canyon is unexplored from about the park boundary and upstream. However, this is only accessible when the canyon is dry and when there

hasn't been any recent flash flooding. Furthermore, Armstrong Canyon upstream of the entrance to Tuwa Canyon seems to have a lot of seeps, and exploring around existing sites could be wise as there are many accessible ledges.

There are some places in the canyon that have already been searched well for CASP or don't have accessible hanging garden territory. One of the areas that has been well searched for potential seeps is Tuwa Canyon up to the boundary line and even a ways past it. From Sipapu bridge up to FF1/FF2/FF3 sites, the canyon walls are high and don't seem conducive to finding new seeps. However, upstream of the First Finger sites, there is another side canyon to the north that could possibly be accessible from Deer Flat Road. Lastly, it doesn't seem likely to find new seeps from about Deer Canyon to Sipapu bridge

It could be helpful to revisit sites to see if the known populations of CASP are growing or if the old sites are being populated. However, when a new population of CASP is found, it's hard to tell if it is actually new to that site or if it was missed in a previous survey, likely due to late phenology or absent inflorescences.

Safety tips for seepline surveys

1. Don't climb up what you can't get back down.
2. Always go down the same way that you came up unless you can see a clear/safe route down. In canyon country, it is easy to hop off a ledge and then get stuck because there is no way to keep going down or to go back up.
3. The seeps can get slippery with water, so be sure to test out footing and make sure it is secure. The same goes for slickrock where loose debris can cause you to slip, or a seemingly secure rock can be loose.
4. Carry an inreach or SPOT with you at all times and file a backcountry permit for each day of field work.

Literature Cited

- Chapin, K. J., M. R. Jones, D. E. Winkler, G. Rink and R. Massatti. 2022. Evolutionary dynamics inform management interventions of a hanging garden obligate, *Carex specuicola*. *Front. Conserv. Sci.* 3:941002. doi: [10.3389/fcsc.2022.941002](https://doi.org/10.3389/fcsc.2022.941002)
- Flora of North America Editorial Committee, eds. 1993. *Flora of North America North of Mexico*. 22+ vols. New York and Oxford.
- Heil, K. D., L. Floyd-Hanna, L. Reeves, D. Hyder and R. Fleming. 1993. Composition, distribution, abundance and habitat requirements of endangered, threatened and rare plant species in the Southeast Utah Group of national parks. San Juan College, Farmington, NM.
- House, D. E. 1987. Navajo sedge (*Carex specuicola*) recovery plan. U.S. Fish and Wildlife Service. Albuquerque, NM.
- Malanson, G. P. 1980. Habitat and Plant Distribution in Hanging Gardens of the Narrows, Zion National Park, Utah. *The Great Basin Naturalist* 40:178–182.
- Massatti, R. 2019. Leaf tissue collection protocol. U.S. Geological Survey, Southwest Biological Science Center, Flagstaff, AZ.
- Nebeker, G. T., K. T. Harper, J. D. Brotherson, and S. L. Welsh. 1977. Characteristics of plants of common occurrence in hanging gardens of the Colorado Plateau, Utah. Unpublished manuscript, Brigham Young University, Provo, UT.
- Rink, G. and A. Hazelton. 2014. Demography Studies for *Carex specuicola* (Navajo sedge, Cyperaceae). 2014 section 6 final report for the U.S. Fish and Wildlife Service. Reference No. 2013-2014-07.
- Rink, G. and M. Licher. 2015. Cyperaceae Sedge Family. School of Life Science. Arizona State University, Phoenix, AZ.
- Roth, D. 2004. *Carex specuicola* Navajo Sedge Status Report. Navajo Fish and Wildlife. Navajo Natural Heritage Program, Window Rock, AZ.
- Weissinger, R., E. Jensen and A. Wight. 2011. Status of rare endemic plant species in selected habitats in Arches National Park and Natural Bridges National Monument. Natural Resource Technical Report NPS/NCPN/NRTR-2011/443. National Park Service, Ft. Collins, CO.
- Williams, A. P., E. R. Cook, J. E. Smerdon, B. I. Cook, J. T. Abatzoglou, K. Bolles, S. H. Baek, A. M. Badger, and B. Livneh. 2020. Large contribution from anthropogenic warming to an emerging North American megadrought. *Science*, 368:6488 314-318.

Appendix A. Survey123 Data Attributes Collected

Table 3. This table shows the information collected in Survey123 during field work.

Attribute	Site information collected	Notes
1	The date	In format MM-DD-YYYY.
2	Who the site was previously surveyed by	If the site was new, it was marked as “new” and given a new name. Otherwise, it was a NCPN or Rink site.
3	Site ID	Code of the site.
4	Detailed location description	Enough defining features and information were included for another person to be able to relocate the seep.
5	If the site was accessible	Hanging gardens that seemed unsafe were marked as inaccessible and none of the following information was filled out. It was also marked as inaccessible if walking along the seep would have torn up roots and caused significant damage to the hanging garden vegetation.
6	Geomorphic setting	It was either an alcove or an exposed seep line. Alcoves were far back in the canyon wall under a deep ledge, while exposed seep lines were more open to the elements.
7	Moisture class	Classes for moisture were: 1) f = discernable flow, 2) w = wet wall, saturated soil, 3) m = moist wall, moist soil, 4) d = dry, no discernable moisture.
8	Level of wildlife browsing	Ranking options were 1) none (no evidence of wildlife browsing directly impacting plants), 2) light (evidence of browsing, but plants not eaten down to the base in any part of the site), 3) medium (some, but not all plants eaten to the base), or 4) heavy (all, or nearly all, plants at a site browsed to the base).
9	Orientation of the site	Taken around the center of the seep.
10	Length of the seep	If the accuracy of the location on FieldMaps seemed pretty good the whole way, the seep length it displayed was used for survey123. Otherwise, the distance was measured using a range meter.
11	Overview photos	Taken to give a good overall feel of the site so that the photos could be used in the future to positively identify the site.
12	If CASP was present	Unsure identification was marked as “maybe”.
13	If search transects were conducted or not	If CASP was present or if the survey was marked as maybe, it was indicated that search transects were conducted. However, all the transect information went on a paper datasheet rather than the fields that followed.

Appendix B. CASP inventory SOP

Searching for CASP

Points

Use FieldMaps to navigate to previously visited points, taking all necessary safety precautions. If sites are not safely accessible, do not access them.

Open Survey123 and pull up the target site. Take an **overview photo(s)** of the site, and mark whether the site is inaccessible. When possible, the photo should include distinguishing landscape characteristics, such as the cliffline, so that relocating the site is easier in the future. If accessible, record the **aspect** near the center of the site. Record a **wildlife browsing category** for the site: 1) none (no evidence of wildlife browsing directly impacting plants), 2) light (evidence of browsing, but plants not eaten down to the base in any part of the site), 3) medium (some, but not all plants eaten to the base), or 4) heavy (all, or nearly all, plants at a site browsed to the base). Record the **maximum moisture level** for the site: 1) f = discernable flow, 2) w = wet wall, saturated soil, 3) m = moist wall, moist soil, 4) d = dry, no discernable moisture.

Search for *Carex specuicola*. Large portions of hanging gardens may be unsafe or unwise to search. When accessing a seepline or searching within a hanging garden, personal safety and resource protection should be the primary concerns. Do not walk through steep areas where a fall would likely result in debilitating injury. Do not walk through areas that are steep or wet enough that plant roots would be displaced.

If a suspected CASP occurrence is found at a site, use **photo documentation** to voucher the site. Take a close-up photo of the sedge perigynia, if possible. Then take one or more overview photo(s) showing where the plants are located within the site. This/these photo(s) should be annotated by drawing circles around the suspected CASP plants.

Other Habitat

Linear seeplines often extend well past developed hanging gardens in each direction. Seeplines may also occur along the same bedding plane or parallel bedding planes throughout the canyon. It is difficult to know the extent of this accessible habitat in advance. Map search areas by drawing search routes in FieldMaps using aerial imagery and topographic maps to estimate the search area. Linear features should be accessed from known hanging garden locations and by safely contouring up canyon walls to the appropriate level. If a suspected CASP occurrence is found, open up the Point feature in Survey123 and create a point for the occurrence as above. Once the point is recorded, searching can continue by annotating FieldMaps.

CASP occurrences

Quantitative Survey Transects

At CASP occurrences, 4-m belt transects are established for recording CASP cover on paper datasheets.

1. Take photographs of the site from afar, so that there can be no confusion regarding the exact location of the site.
2. Record any evidence of wildlife browsing within the hanging garden, including scat, tracks, and damage to plants including *Carex specuicola*. Assign two browsing impact ranks; one ranking the impact of browsing on the hanging garden overall, and the other ranking the impact of browsing on the *C. specuicola* population. Ranking options are 1) none (no evidence of wildlife browsing directly impacting plants), 2) light (evidence of browsing, but plants not eaten down to the base in any part of the site), 3) medium (some, but not all plants eaten to the base), or 4) heavy (all, or nearly all, plants at a site browsed to the base).

3. Lay out a meter tape along the length (or a subset) of the population. Choose the transect length and location based on which parts of the hanging garden are safely accessible and which portions have CASP. Try to locate the beginning and end of the transect at geomorphic breaks that will allow for easier relocation in the future (e.g., cracks in the cliff wall, significant staining on the wall, etc.). Mark the corners of the transect with brightly colored pin flags by inserting a pin flag into the ground or using plumber's putty to attach it to bedrock. Flagging tape can be used to mark the end of the transect on taller vegetation if the pin flag is not visible. Photograph the ends of the tape and record the transect length and bearing. Indicate whether the transect is the top, middle, or bottom of a 4m belt for CASP cover estimates (this may vary due to the topography of the site).
4. At each meter mark, estimate the foliar cover of CASP within the preceding 4m x 1m belt.
5. At each meter mark, describe the maximum moisture level within the preceding 4m x 1m belt. Categories for moisture are: 1) f = discernable flow, 2) w = wet wall, saturated soil, 3) m = moist wall, moist soil, 4) d = dry, no discernable moisture.
6. Remove all equipment, including pin flags, plumber's putty, and flagging tape, before leaving the site.

Leaf Material Collection for Genetic Analysis

At CASP occurrences, collect 3-10 leaves from 10-15 individual plants (or whatever is available).

1. Identify individual plants and collect 3-10 leaves from the same stem. Collect leaves that are young, green, and healthy looking. Do not collect from a plant if its vegetation is dying. Clip leaves to the length of a snack baggie and to the width of about your index finger.
2. Maximize the distance between sampled plants, when possible. Optimally, plants would be spaced at least 5-10 meters apart (even more would be better). If the population occupies a small area, for example about 100 square meters, space out 10-15 collections to maximize the distance between individuals. If the population occupies a smaller area, collect fewer leaves.
3. Mark baggies with a population information (name, latitude, longitude, photo #s, date, etc.). One or two spoonfuls of silica should be put into the baggies immediately (i.e., after work is done at the population) so that the leaves yield high quality DNA. Silica should be abundant compared to leaf material. Store tissues in a dark, cool location (room temp fine, don't refrigerate or freeze) until they are picked up or shipped.

Appendix C. Collection Methods and Materials for CASP

Materials for collection

- Silica: Buy from a craft store or amazon: Activa Flower Drying Art Silica Gel – 5lb (see <https://www.michaels.com/product/activa-flower-drying-art-silica-gel-10300251>). Note; that silica dust should not be inhaled!
- Sharpies: fine or ultra fine point
- Spoon to put silica into baggies
- Snack baggies (size 6.5” x 3.25”. Baggies must close with a seal zipper (e.g., Ziploc baggies). Target brand baggies are cheap and work great.

Collection protocol for CASP in the field

- One or two spoonfuls of silica should be put into the baggies before collecting leaves so that the leaves yield high quality DNA. Silica should be abundant compared to leaf material.
- The goal is to collect leaves from 10-15 individuals for a target species at a locality. However, less collections can be taken for a smaller population, if 10-15 would harm the population.
- Optimally, plants would be spaced at least 5-10 meters apart (even more would be better). If the population occupies a small area, for example about 100 square meters, space out 10-15 (or less) collections to maximize the distance between individuals. If the population occupies a smaller area, collect fewer leaves.
- The leaves for 1 individual must be collected from 1 stem, unless the collector is absolutely certain that stems are connected either aboveground or belowground. Leaves should be as young as possible, green, and healthy looking. Do not collect from a plant if its vegetation is dying. Collectors can get leaves from plants that aren’t flowering or fruiting only if they are 100% certain of the plant’s identity.
- The goal is to get ~3-10 leaves per plant (we only need about as many leaves as it takes to cover your index finger – don’t go overboard, or they won’t dry appropriately, but also don’t skimp). Leaves only need to be clipped to the extent that they will fit into the baggies.
- Mark baggies with a site name and collection number. Record this data on the paper datasheet as well. Store tissues in a dark, cool location (room temp fine, don’t refrigerate or freeze) until they are picked up or shipped.

Appendix D. NABR Hanging Garden Sedge Descriptions From Flora of North America

C. rossii

Culms 5–40 cm. Leaves: blades 3–20(–30) cm × 1.4–3 mm. Inflorescences: proximal bracts with well-developed blades exceeding inflorescence sheaths 2–4(–10) mm; lateral spikes with 4–20 perigynia, approximate or proximal distant, lax, 4–20(–30) × 3–5 mm, middle internodes (0.5–)0.7–1.5 mm; terminal spike usually staminate, occasionally gynecandrous, sessile or short-pedunculate, 3–10(–15) × 0.9–2 mm. Pistillate scales brown with paler or green midvein, divergent in mature fruit, ovate to ovate-circular, 1.2–2.5 × 1.1–1.8 mm, apex subacute to obtuse or cuspidate. Proximal staminate scales brown with paler or green midvein and hyaline margins, oblong-ovate, 2–3.5(–4) mm, apex obtuse to subacute. Perigynia divergent, bright orange, somewhat inflated and fleshy when mature, circular-obovate, 2.3–3.2 × 1.2–1.8 mm, smooth or minutely papillose. Achenes subcircular, 1.4–1.8 × 1–1.5 mm. $2n = 52$.

C. aurea

Culms 5–40 cm. Leaves: blades 3–20(–30) cm × 1.4–3 mm. Inflorescences: proximal bracts with well-developed blades exceeding inflorescence sheaths 2–4(–10) mm; lateral spikes with 4–20 perigynia, approximate or proximal distant, lax, 4–20(–30) × 3–5 mm, middle internodes (0.5–)0.7–1.5 mm; terminal spike usually staminate, occasionally gynecandrous, sessile or short-pedunculate, 3–10(–15) × 0.9–2 mm. Pistillate scales brown with paler or green midvein, divergent in mature fruit, ovate to ovate-circular, 1.2–2.5 × 1.1–1.8 mm, apex subacute to obtuse or cuspidate. Proximal staminate scales brown with paler or green midvein and hyaline margins, oblong-ovate, 2–3.5(–4) mm, apex obtuse to subacute. Perigynia divergent, bright orange, somewhat inflated and fleshy when mature, circular-obovate, 2.3–3.2 × 1.2–1.8 mm, smooth or minutely papillose. Achenes subcircular, 1.4–1.8 × 1–1.5 mm. $2n = 52$.

C. specuicola

Plants loosely cespitose. Culms 25–45 cm, distally finely scabrous. Leaves 1–3 mm wide. Inflorescences: proximal bracts shorter than inflorescences; spikes erect or, sometimes, lateral spikes pendent or divergent, separate, short-pedunculate, short-oblong or elongate, 5–20 × 3.5–4 mm; lateral 1–3 spikes pistillate, of similar lengths; terminal spike gynecandrous, consisting of few pistillate flowers at summit of an otherwise staminate spikes (when perigynia fall at maturity, spikes appear to be wholly staminate). Pistillate scales light brown, somewhat hyaline, margins hyaline, often broadly so, narrowly lanceolate or ovate, shorter than and narrower than perigynia, midvein broad and lighter colored than body, conspicuous, sometimes raised, prominent, apex acute or short-mucronate. Perigynia ascending, pale yellow to light brown, faintly veined, obovate or circular, 2.5–3.5 × 1.5–2 mm, apex abruptly beaked, distal margins papillose, serrulate; beak 0.25–0.5 mm, bidentate, finely papillose and serrulate. Achenes nearly filling body of perigynia.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

National Park Service
U.S. Department of the Interior



Natural Resource Stewardship and Science

1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525