Mancos Milkvetch

(*Astragalus humillimus*)

Status Assessment and Monitoring Report

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INTRODUCTION

The genus *Astragalus* has more than 2,500 species worldwide (Lock and Simpson 1991), making it one of the largest flowering plant families. *Astragalus* are mainly distributed throughout the Northern hemisphere as well as within the Andes of South America and east Africa (Wojciechowski et al. 1993). Many species in this genus occur in small populations that are patchily distributed across the landscape, promoting genetic isolation between populations and a high degree of speciation in specific regions. In North America, the Great Basin/Colorado Plateau is one such region of taxonomic richness (Massati et al. 2018).

The Navajo Nation, located within the Colorado Plateau, has seven *Astragalus* species of conservation concern listed under the Navajo Endangered Species list (last updated in 2008, Table 1). Where G2, and G3 are equivalent to "Endangered" and "Threatened" designations under the U.S. Endangered Species Act and G4 designation indicates that there is not enough information about the species to warrant listing or delisting (NESL 2008). All of these species have small populations and/or occur in an extremely restricted range. Several of these species have very specific habitat requirements and exhibit a high degree of endemism. Of these, only one species, *Astragalus humillimus,* is also federally listed as endangered under the U.S. Endangered Species Act. *Astragalus humillimus* was originally listed by the U.S. Fish and Wildlife Service in June 1985 because the species had a very narrow distribution and low tolerance for disturbance (50 FR 26568-26572). The primary threats to plants identified at the time of listing were oil and gas development as well as disturbance activities related to electrical transmission line construction and maintenance.

Table 1. Seven species within the genus *Astragalus* are listed under the Navajo Endangered Species List (NESL), which was last updated in 2008.

Species	2008 NESL Status
A. beathii	G4
A. cremnophylax var. hevronii	G3
A. cronquistii	G3
A. culteri	G2
A. heilii	G4
A. humillimus	G2
A. naturitensis	G3

Astragalus humillimus (Mancos milkvetch) is a small, perennial mat-forming plant occurring on rimrock outcrops of Point Lookout and Cliffhouse sandstone in pinyon-juniper woodlands and desert scrub communities (Dick-Peddie 1993). This species is a narrow endemic, occurring in the four corners region of San Juan county, New Mexico, as well as Montezuma County, Colorado (USFWS 2011). The majority of *A. humillimus* populations known are found at least partially on the Navajo Nation, with several small populations also occurring on adjacent Bureau of Land Management (BLM) land, as well as New Mexico State Trust lands and Ute Mountain Ute tribal lands in Colorado. According to the 2011, 5-year review of the species by the U.S. Fish and Wildlife Service, there were four populations of *A. humillimus* found on Ute Mountain Ute Tribal lands during the last known survey by the Colorado Natural Heritage Program in 1987, with a total population size of 4,421 plants. Access to these populations has been restricted by the Ute Mountain Ute tribe since 1987 and it is currently unknown if *A. humillimus* continues to persist in Colorado. Five monitoring plots were established on BLM land in 1990 within the West Rim population (nicknamed Slickrock Flats), which shares a border with the Navajo Nation. Plots have been monitored on an annual basis, with some missing years,

since 1990 (Sivinski 2008). In 1998, a similar monitoring program was established at a population occurring within land managed by the State of New Mexico (nicknamed Sleeping Rocks). It is currently unknown whether monitoring continues at this population.

In 2008, Daniela Roth (previous NNHP botanist) conducted extensive surveys of 12 populations of *A. humillimus* occurring on Navajo Nation lands in order to assess the condition and numbers of plants occurring on Navajo and to track changes over time (Roth 2008). She also assigned Element Occurrence (EO) ranks to each population using NatureServe ranking specifications (Tomaino et al. 2008). EO ranks indicate an assessment of the probability that the population will continue to persist in the near future based on a variety of rank factors (including population size, condition, landscape context, and threats to the population). Roth reported that only two populations out of the 12 resurveyed in 2008 had more than 50 live plants and that only one population had more than 100 live plants. Only 18% of the sites monitored were ranked as "good estimated viability" (none were "excellent") and 82% were ranked as "fair", "possibly fair", or "poor". In contrast, during 1986 and 1989 surveys of the same populations, four out of the eleven populations known at the time contained more than 500 plants. Roth attributed this decline to the drought years occurring from 2001-2003 which caused similar declines to Mesa Verde cactus, another rare plant occurring in the Shiprock area. Other possible threats to *A. humillimus* reported by Roth were human-related activities associated with oil and gas development (access roads, pipelines, powerlines, oil wells), which are extensive through the Palmer Mesa and Hogback areas. Possible impacts to plants through exposure to emissions from the Desert Rock and two other coal-fired power plants in the area were also proposed as a possible threat, although the degree of sensitivity of *A. humillimus* to coal power emissions is currently unknown.

The Navajo Natural Heritage Program (NNHP) currently tracks the status of 14 populations of *A. humillimus* occurring at least partially on the Navajo Nation (Table 2). Population monitoring in the past has been largely opportunistic and a full census was not always completed for each population at each visit, making it difficult to assess trends over time. The Northernmost population (named West Palmer Mesa) crosses into the Ute Mountain Ute Indian Reservation in the state of Colorado. The southernmost population known on the Navajo Nation was found by NNHP botanist Andrea Hazelton in 2013 and is located approximately 40 miles south of the West Palmer Mesa population (named Little Water South). Given that there was significant evidence from D. Roth's 2008 report to indicate that *A. humillimus* populations have declined significantly since the 1980's, NNHP decided that establishing a monitoring program for this species was warranted. The following monitoring priorities were identified:

1) Repeat D. Roth's 2008 survey of all populations in order to get an up-to-date estimate of plant numbers and threats to *A. humillimus* occurring on the Navajo Nation and to determine if populations have recovered from 2001-2003 drought impacts.

2) Setup permanent monitoring plots for at least five Navajo Nation populations following established BLM methodology, with populations represented throughout the entire range of the species.

In addition, this monitoring project fulfills the following objectives listed under the quantitative recovery criteria for the species (USFWS 2011):

Objective 1: Census and map all known populations.

Objective 4: Establish permanent long-term monitoring plots at population sites.

METHODS

2017 NNHP Range-Wide Survey

A concerted effort was made by NNHP botanist Nora Talkington and others to resurvey a majority of the populations tracked by NNHP from May 31st -June 7th, 2017, roughly following D. Roth's 2008 survey methods (although her exact methodology was not documented). However, N. Talkington did not attempt to relocate the two populations originally reported to NNHP in the 1980's (No name 1 and 2, Table 2) because location data was too vague. In 1997, D. Roth and F. Eldridge attempted to relocate these two populations and failed to find either *A. humillimus* or suitable habitat for *A. humillimus* (Roth 2008). N. Talkington also did not revisit the Little Water South population discovered by A. Hazelton in 2013 because it had been surveyed in the last five years.

For each of the remaining populations (12 total), effort was made to count live and dead *A. humillimus* individuals found within the population polygon mapped by previous surveyors. The presence/absence of seedlings was also noted and seedlings were included in the total tally of live plants. Notes on the condition of the population, landscape context, possible or perceived threats, associated species, directions to the site, phenology, and other observations were also taken at each population following elemental occurrence data standards established by NatureServe (NatureServe 2002). In addition, GPS tracks were recorded for each of surveys so that future surveyors can follow the exact same survey boundaries. The habitat boundaries at some populations are fairly straightforward because plants are limited to discrete sections of Point Lookout and/or Cliffhouse sandstone outcrops, which are obvious landscape features (Figure 1a). However, at sites where there is a lot of available habitat and populations are scattered widely, it is much more difficult to ensure that each group of plants are counted (Figure 1b). At these larger sites, survey effort became much more important and at least one to two additional surveyors were recruited to help with counts. For example, Navajo Nation's largest population (West Palmer Mesa) has a lot of available habitat and a large area to cover. To census this site, four surveyors spaced approximately 50-100 meters apart walked in a parallel formation from the beginning of the habitat to the promontory of West Palmer Mesa, counting all live and dead *A. humillimus* plants in their immediate vicinity. All data collected at each of the

populations as well as polygon data from the survey tracks was entered into Biotics, NNHP's database for endangered species.

a) An example of discrete *Astragalus humillimus* Point Lookout sandstone habitat at the Long Point population where plants are limited to a relatively small area.

b) *Astragalus humillimus* habitat at the West Palmer Mesa population is more extensive and plants are widely scattered throughout.

Figure 1. Examples of discrete (a) and extensive (b) *A. humillimus* habitat.

Long-term monitoring plots:

Permanent monitoring plots were established at five populations on the Navajo Nation from June 3rd-June 5th, 2019 in collaboration with D. Roth (Program Coordinator for New Mexico Endangered Plant Program) and J. Kendall (Wildlife Biologist, BLM Farmington Field Office). Early June was selected as the most ideal monitoring time because, although plants have already flowered, all seedlings present have presumably survived into the dry summer season and will most likely survive the year (D. Roth, pers. comm. 06/03/2019). By early June it is also apparent which plants have produced seed and which have not. Locations were selected to encompass the northern, central, and southern ranges of the species on the Navajo Nation (Figure 2). Three plots were established within each of the five populations with the exception of the West Palmer Mesa population, which was broken into three sites with three plots established at each site (for a total of 21 plots and 7 monitoring sites). Plots were placed either in tinajas (potholes) or along cracks where *A. humillimus* individuals were found growing (Figure 3).

Effort was made to include a mix of tinaja and crack plots within each monitoring site. In June 2019, when plots were established, there were only a few individuals found at many of the populations. Therefore, it was not possible to randomly assign monitoring plots within the population boundaries and plots were established where there were a minimum of five individuals (including seedlings) within a defined area. This approach allowed for each plot to be a different size with plot boundaries delineated by natural landscape features. Essentially each plot is its own island, separated from other islands by unoccupied sandstone (Roth 2018). Permanent nails were placed at the beginning and ends of each plot and an aluminum tag number was attached to the nail. Plots were also marked with orange spray paint, GPS coordinates were recorded, and the azimuth from the plot nail was noted. Photos were taken of the plot and of the surrounding area for reference. Associated species for each plot as well as the plot length (in meters) from nail to nail were also noted.

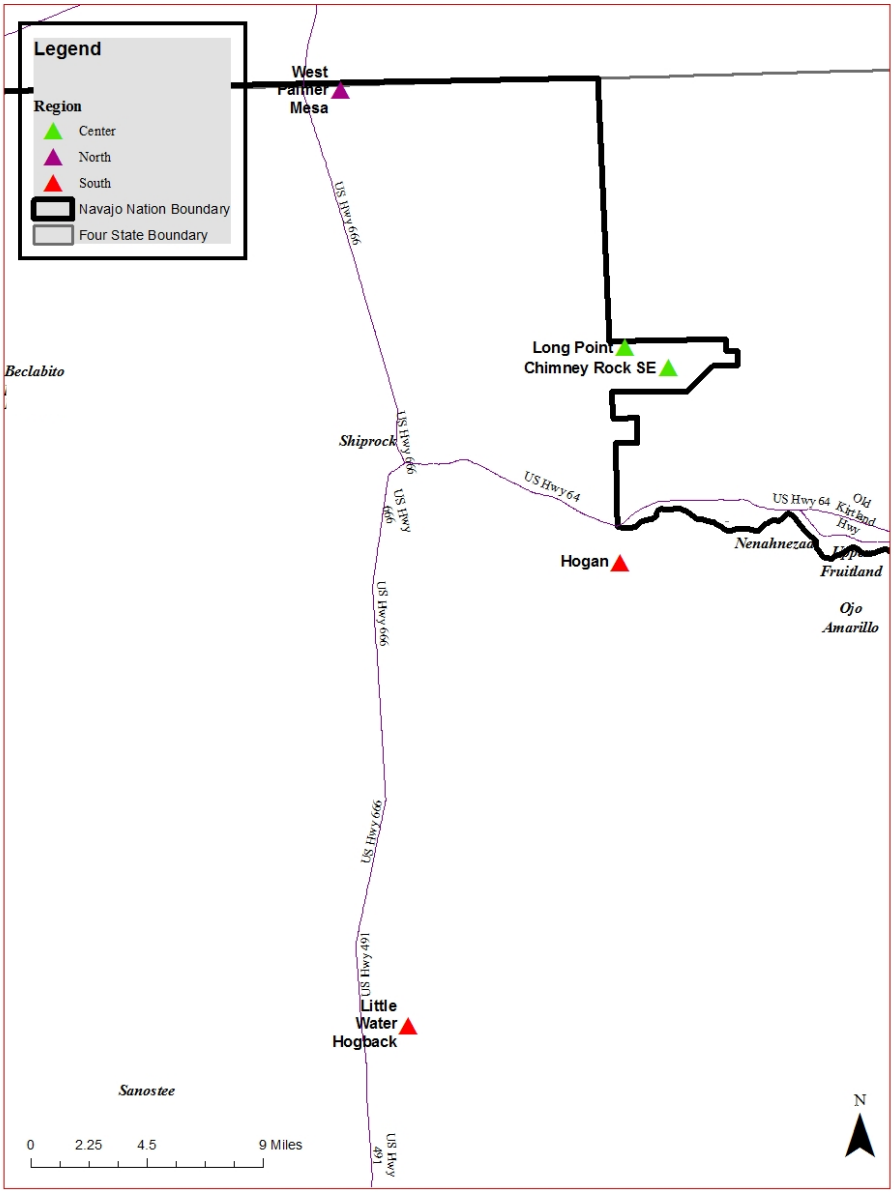

Figure 2. The five sites chosen for long-term monitoring are representative of the north, central and southern range of *A. humillimus* on the Navajo Nation.

Methodology followed protocols established for the existing monitoring sites at Sleeping Rocks and Slickrock Flats. These protocols been have refined over the years by the BLM and botanists from the NM Forestry Division (R. Sivinski and D. Roth) and allow for data comparisons across land management agencies. Historically, researchers drew each plot on graph paper and mapped the locations and sizes of each *A. humillimus* individual onto that plot drawing to get an estimation of change in live plant cover from year to year (Roth 2018). Simply tallying the number of live plants was problematic because plants growing adjacent to each other would sometimes grow together into one large mass and be impossible to distinguish. Since 2016, cover was estimated for adult plants by taking the measurement of the longest live axis and a measurement of the narrowest live axis.

a) *Astragalus humillimus* individuals growing in "crack" habitat at a plot established at the West Long Point population.

b) *Astragalus humillimus* growing in "tinaja" or "pothole" habitat at the West Long Point population.

Figure 3. Plots were established in both "crack" (a) and "tinaja" (b) habitat types at each site.

From these measurements, total live percent cover can be calculated for each individual using the formula for the area of an ellipse (area (cm^2)=pi*radius A* radius B). In 2019, NNHP also estimated the percent of the plant that was green/alive and multiplied this percentage by the formula above to get a more accurate calculation for live cover (live area=pi*radius A*radius B*percent live). Individuals were placed into size classes based on their live cover (Table 2). Seedlings were classified as anything less than 2.0 x 1.0 cm and were tallied for each plot (live area was not calculated). Whether or not each individual plant had fruits from this year was also noted.

Table 2. Size class definitions and example live dimensions for minimum and maximum inclusion in each of the size categories. Live area was calculated using the formula area=pi*radius A* radius B multiplied by percent live (green). Example dimensions refer to plants with 100% live cover.

Size Class (cm2)			**Example Live Dimensions (cm)**	
	Min	Max	Min	Max
Seedling				<2.0 x 1.0
Small	1.6	9.9	2.0 x 1.0	4.0 x 3.0
Medium	10	99.9	5.5 x 1.5	11 x 11.5
Large	1000		13.5 x 9.5	

RESULTS

2017 NNHP Range-Wide Survey

Population trends for *A. humillimus* were highly variable between sites and also between years, making assessments about the long-term viability of this species very difficult. For example, *A. humillimus* numbers fluctuated widely between monitoring years at the West Palmer Mesa and North Long Point populations (Figure 4). Some of this variation can likely be attributed to differing methods of quantifying population size employed by surveyors throughout the years (counts vs. estimations), as well as varying survey effort (cursory vs. extensive surveying of the population), which could lead to very different population estimates. However, the general trend for these two populations was a sharp decline in plant numbers between early monitoring points in the late 1980's/1990 and D. Roth's range-wide population census in 2007.

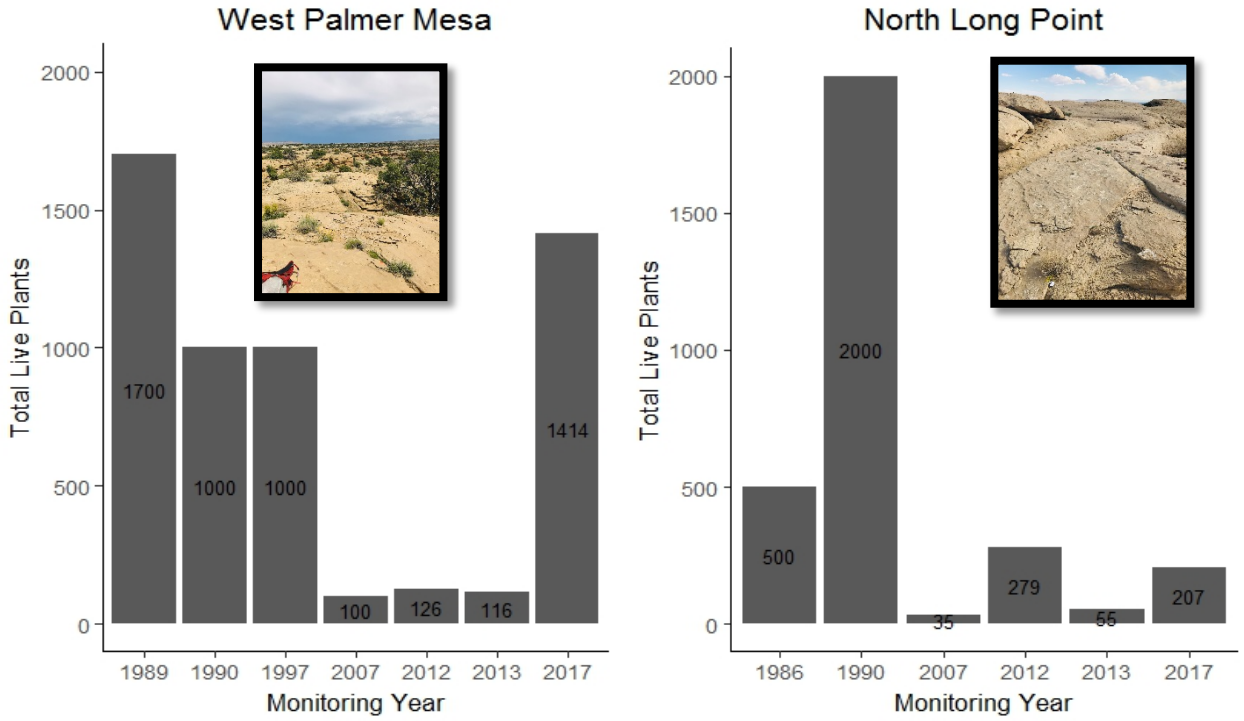

Figure 4. Population estimates recorded by NNHP staff during opportunistic monitoring of the West Palmer Mesa and North Long Point populations.

At the North Long Point site, numbers fluctuated slightly between 2007 and 2017 but the population was nowhere as large as it was in the late 1980's/1990 (500-2000 plants versus 35-279 plants). In contrast, the West Palmer Mesa site rebounded significantly in 2017 after several monitoring years of very low population sizes recorded (2007, 2012, and 2013). This data suggests that local dynamics play in important role in determining how many adults and seedlings are present at a site from year to year. Site-specific factors such as topography, geology, pollinator abundance, plant density, landscape context, and degree of disturbance may be just as important in governing *A. humillimus* population dynamics as region-wide factors such as precipitation and climate.

Given that plant numbers varied widely from year to year, and that monitoring methods have also varied, it is difficult to estimate short-term trends for this species. However, because most of the *A. humillimus* populations on the Navajo Nation were thoroughly censused upon their discovery in the late 1980's/early 1990's, NNHP has nearly 30 years of census data with

which to observe changes over time. Current *A. humillimus* population tallies on the Navajo Nation indicate that numbers have declined by approximately 67-71 percent range-wide since late 1980's/1990's tallies (7-8,000 total plants vs. 2, 278 total plants, Table 3). Of the 11 populations that had at least two monitoring visits, only three populations increased in size, while eight populations showed decreasing trends of varying magnitude. It's worth noting that the majority of the population tallies conducted in the late 1980's/1990's were estimations and not actual plant counts (indicated by an asterisk in Table 3). However, it is reasonable to assume that the margin of error for estimated vs. tallied counts are tens or hundreds of plants and not thousands of plants. Therefore, these population estimates are useful indications of ballpark numbers, even if they are not useful for capturing fine-scale population trends.

Historically, there were at least seven populations that each contained more than several hundred plants, with two populations (Coal Mine Creek and West Palmer Mesa) each containing over 1,000 plants. Recent tallies indicate that the majority of the populations on the Navajo Nation have under 200 individuals, with just one population (West Palmer Mesa) still containing over 1,000 plants. In addition, two populations on the Navajo Nation have worryingly small population sizes (just 5 individuals counted at Oil Tanks and SE Palmer Mesa) and two populations were never relocated by a NNHP botanist because location data was too vague.

Possible and observed threats to populations were also recorded by current and historic observers during monitoring visits (Table 4). Impacts from human activities related to oil and gas development (proximity to well access roads, pipelines, active or plugged wells) were historically listed as possible threats at eight out of the 12 sites for which there were data (66%), and at one out of 12 sites currently (8%). Human disturbance caused by non-oil and gas related activities (powerlines, roads, residences, trash dumping, wood collecting, borrow pits) were listed as a possible concern at four out of 12 sites by both current and historic monitors (33%). Livestock grazing impacts were mentioned at zero of the sites historically and at three of the sites currently (25%). Invasive species were listed as a possible threat to *A. humillimus* at zero of the 12 sites historically and at two of the 12 sites currently (16%). Possible emission impacts to the Little Water Hogback population from the Desert Rock Powerplant (located just several miles away) was noted as a possible past and current threat, although more information is needed (Roth 2008).

Currently, most of the oil wells that are located near known *A. humillimus* populations are plugged and inactive but infrastructure (pipelines, access roads, equipment, etc.) remain on-site. Since no NEPA documentation exists, it is unknown how past impacts from oil and gas activities have impacted plants when the wells were active (Roth 2008). At the West Palmer Mesa site, which is currently the largest known population on the Navajo Nation, P&E oil and gas drilling activities were observed to be causing damage to *A. humillimus* individuals in 2007 and 2008 (Roth 2008). Today, wells near the West Palmer Mesa site have been plugged and the access road is unmaintained so that there is little to no vehicle traffic to the site. Populations should be monitored closely, however, because opening new wells or unplugging old wells could cause impacts to plants and regulatory compliance with Navajo Nation and federal environmental compliance laws has been nonexistent in the past (Roth 2008).

Table 3. Historic and current population estimates for 14 *A. humillimus* populations occurring at least partially on the Navajo Nation which are monitored by NNHP staff. Census numbers with asterisks are estimated, those without are counts.

Site Name	Approx. Pop Extent (acres)	Year/Surveyor First Survey	Number Plants	Year/Surveyor Last Survey	Number Plants	Landowner	Trend
Burnt Squash Draw	16.8	1997/D. Roth, F. Eldridge	*Few plants	2017/N. Talkington, G. Kluwin	78	Navajo Nation	Increasing
Coal Mine Creek	16.6	1986/ P. Knight	*4200	2017/N. Talkington	100	Navajo Nation	Decreasing
Hogan	11.2	1985/P. Knight & House	*200	2017/N. Talkington	188	Navajo Nation	Decreasing
Hogback	16.8	1997/D. Roth, F. Eldrige	30	2017/N. Talkington, G. Kluwin	66	Navajo Nation	Increasing
Little Water Hogback	41.4	1997/F. Eldridge	*Hundreds	2017/N. Talkington	40	Navajo Nation	Decreasing
Long Point	35	1986/P. Knight	*200	2017/N. Talkington, G. Kluwin	57	Navajo Nation	Decreasing
North Long Point	19.8	1986/P. Knight	*500	2017/N. Talkington, G. Kluwin, N. Brown	205	Navajo Nation	Decreasing
Oil Tanks	14	1997/D. Roth, F. Eldrige	17	2017/N. Talkington, G. Kluwin, N. Brown	5	Navajo Nation	Decreasing
SE Palmer Mesa	0.5	2008/D. Roth	1	2017/N. Talkington, G. Kluwin	5	Navajo Nation	Increasing
West Palmer Mesa	286.7	1989/B. Hevron, B. Jones	*1700	2017/N. Talkington, G. Kluwin, L. Begay, J. Deel	1414	Navajo Nation, Ute Mountain Ute Reservation	Decreasing
West Rim	42.5	1986/P. Knight	*500	2017/N. Talkington, G. Kluwin	120	Navajo Nation, Bureau of Land Management	Decreasing
Little Water South	15.12	2013/A. Hazelton	130	NA	NA	Navajo Nation	No trend
No Name 1	Unknown	1986/ W. Dunmire	NA	1997/F. Eldridge, D. Roth	Failed to find	Navajo Nation, New Mexico State, Bureau of Land Management	No trend
No Name 2	Unknown	1984/J. Mark Porter	NA	1997/F. Eldridge, D. Roth	Failed to find	Navajo Nation	No trend
Totals	516.42	**Historic**	7,000-8,000	**Present**	2,278		

Table 4. Possible and perceived threats to the 14 *A. humillimus* populations occurring on the Navajo Nation recorded by NNHP staff at the time of the last visit as compared to previous monitoring visits.

Site Name	Threats Last Visit	Threats Previous Visits
Burnt Squash Draw	None	All old oil wells in this area are plugged, hogan nearby abandoned. No grazing, few invasives.
Coal Mine Creek	None	Site is remote near abandoned hogan, access limited.
Hogan	Population close to main Highway. Used by pedestrians and trash in area. Livestock grazing present.	A gravel borrow pit is active approx. 50 m North of the population.
Hogback	Powerlines run through part of the population, trash observed.	Site remote, difficult to access. Capped oil well nearby.
Little Water Hogback	Impacts of Desert Rock Powerplant unclear.	Several miles away from the Desert Rock Powerplant.
Long Point	Minimal threats. There are few weeds in the area, no evidence of livestock.	Capped oil well at site.
North Long Point	Invasive species present, road approx. 300m to the South.	Historic oil and gas development.
Oil tanks	Very small population.	Oil well in vicinity.
SE Palmer Mesa	Very small population, heavy wood cutting activities in vicinity.	Two old & plugged oil wells in the vicinity and old access roads.
West Palmer Mesa	Cheatgrass abundant, likely as a result of site disturbance.	Site disturbed by P&A activities, plants were driven over and destroyed in 2007, wells plugged without clearance.
West Rim	Oil and gas development in this general area is ongoing, cattle in vicinity.	Site relatively remote but crisscrossed with dirt roads, recent survey stakes, abandoned oil wells, trash dumping evident off the rim.
Little Water South	Sheep grazing in the area.	None
No Name 1	No information.	No information.
No Name 2	No information.	No information.

Long-term monitoring plots:

Aggregate live cover of *A. humillimus* for all three monitoring plots installed at each of the seven monitoring sites ranged from 774 cm^2 at the Chimney Rock Southeast site to 2308 cm^2 at the West Palmer Mesa Southwest site (Table 5). Total numbers of plants within the seedling, small, medium, and large size classes also varied by monitoring site (Figure 5); with seedling numbers ranging from 0 at the Long Point site to 52 at the Hogan site. Palmer Mesa Southwest had the most plants within the three monitoring plots (90 total) while Long Point Mesa had the least (13 total), and was the only site with zero seedlings. Of the 327 total *A. humillimus* (seedlings and adults) found within 21 monitoring plots installed at seven monitoring sites, 57% were seedlings, 13% were classified as “small”, 22% were classified as “medium”, and 8% were classified as “large”. There were a total of 10 plots installed in “crack” type habitat and 11 plots installed in “tinaja” type habitat across the seven monitoring sites. Crack habitat supported more seedlings than tinaja habitat (106 vs. 80 seedlings). On average, 37% of the plants monitored had seed pods (63% were vegetative), but there was great variation in seed production by population,

with the percentage of plants with pods as low as 9.5% at the West Palmer Mesa Northwest population and as high as 61.5% at the Long Point population (Table 5).

Table 5. Aggregate live cover and *A. humillimus* numbers by size class for three monitoring plots established at the seven monitoring sites in June, 2019. For each of the plants monitored, phenology was recorded (with pods or vegetative) and aggregate percentages for the site were calculated. The West Palmer Mesa monitoring site is a large site with several distinct populations and was therefore broken into three monitoring sites with three plots established at each subpopulation.

Site Name	Total Adults	Total Seedlings	Small	Medium	Large	Percentage With Pods	Percent Vegetative	Aggregate Live Cover (cm^2)
Chimney Rock SE	14	10	5	5	4	35.7%	64.3%	774
Hogan	25	52	6	14	5	40.0%	60.0%	1569
Little Water Hogback	9	18	2	3	4	44.4%	55.6%	848
Long Point	13	0	0	10	3	61.5%	38.5%	1326
West Palmer Mesa Northwest	21	23	5	16	0	9.5%	90.5%	853
West Palmer Mesa Southeast	18	34	6	8	4	33.3%	66.7%	1060
West Palmer Mesa Southwest	41	49	17	17	7	34.1%	65.9%	2308
Totals	**141**	**186**	**41**	**73**	**27**	**37.0% (Avg.)**	**63.0% (Avg.)**	**8737**

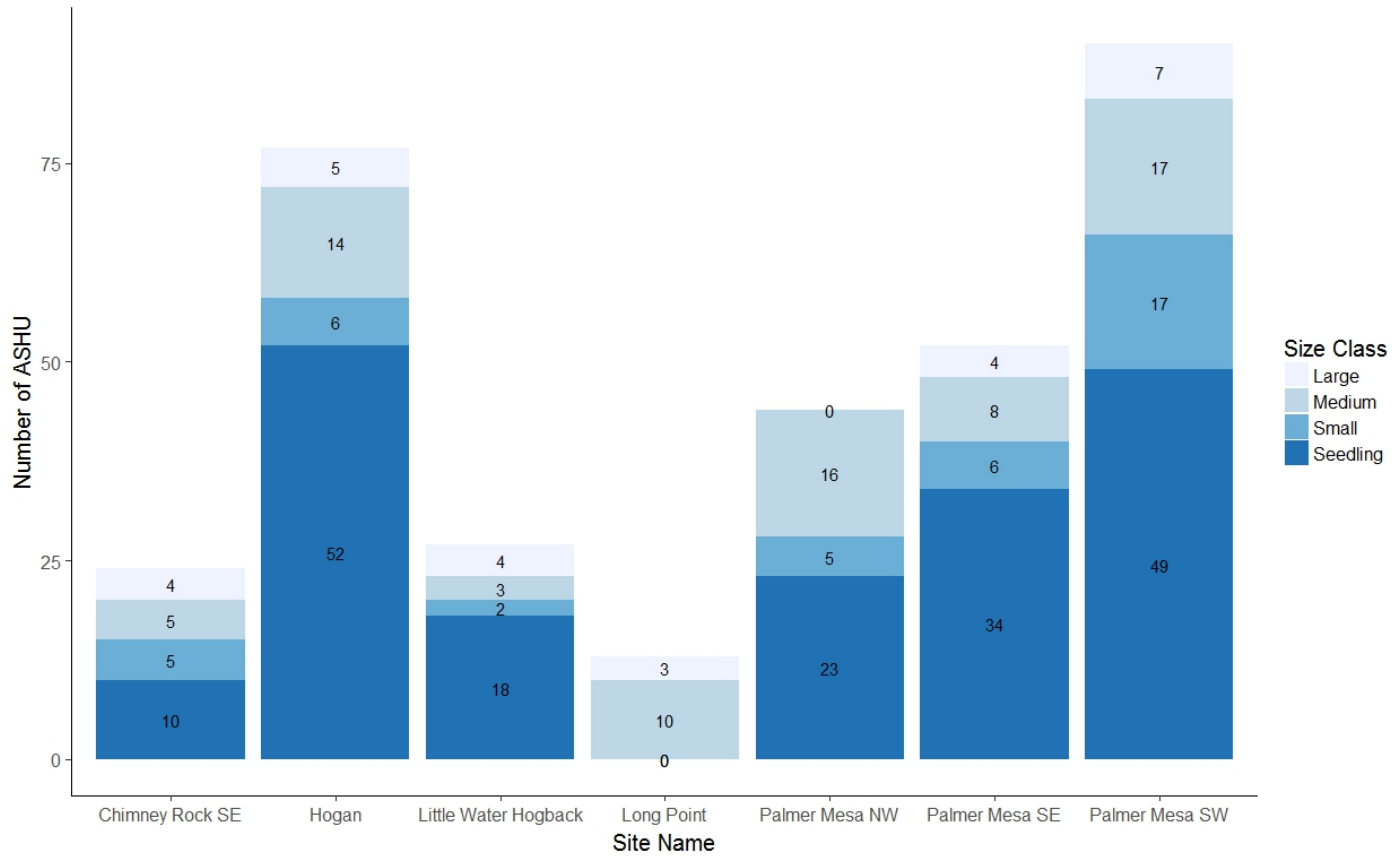

Figure 5. Aggregate *A. humillimus* totals by size class for three permanent plots established at seven monitoring sites across the species range on the Navajo Nation in June, 2019. See Table 2 for size class definitions.

DISCUSSION

Although NNHP has only a single monitoring season from which to draw conclusions, it is useful to compare our data to 28 years of data collected at the Slickrock Flats and Sleeping Rocks monitoring sites on adjacent BLM and State Trust land, where ten plots (five at each) were established in 1990 (Roth 2018, Sivinski 2008). Demographic data collected over this time period showed that seedlings generally comprised the majority of plants in the population. However, the number of seedlings varied greatly year to year, depending on the amount of precipitation received and the number of live adults present in the plots (Sivinski 2008). According to R. Sivinski, adult *A. humillimus* compete with seedlings for limited moisture and root space within the tinaja and pothole habitats. During years when live adult plant abundance is low, new seedlings are able to establish and survive in the space-limited habitat. Every five to seven years, as adult plants mature and die, Sivinski hypothesized that there will be a related increase in seedling germination and establishment the following year, if rainfall conditions are also favorable. Seedlings also made up the majority (57%) of the plants found in the NNHP plots. While seedlings may be present and even abundant during favorable years, seedlings must survive for at least two growing seasons before flowering and contributing to the seed bank during their third or fourth year of life (Sivinski 2008). It will be interesting to see in future years how many of the seedlings counted in NNHP plots will survive an additional two to three seasons to become reproductive adults.

Despite the presence and even abundance of *A. humillimus* seedlings during favorable years, there is some indication that this species is reproductively-limited. Monitoring methods for the Sleeping Rocks and Slickrock Flats sites did not include collecting phenology data so it is unknown how NNHP's results compare. However, *A. humillimus* is known to be a poor reproducer (only 30% viable mature seed/ovule) relative to sister rare taxa *A. cremnophylax vars. myriorrhaphis* and *hevronii* (79% viable mature seed/ovule, Allphin et al. 2005). We found on average that just 37% of plants had seed pods and that this percentage was highly variable by monitoring site (ranging from 9.5% to 61.5%). Although the species is known to be self-compatible, *A. humillimus* exhibits a high degree of outcrossing and is therefore reliant on insects (mainly bees) to move pollen from one plant to another (Tepedino 2000). Even for self-compatible plants, pollinators are still needed at the site to move pollen from one flower to another on the same plant. A 2000 pollinator study by V. Tepedino found no evidence that *A. humillimus* was pollinator-limited. However, this study only looked at a single population of *A. humillimus*, the West Palmer Mesa population, which is the largest population known on the Navajo Nation. The high degree of variation in seed-set by monitoring site suggests that local dynamics could play a role in determining whether or not plants are pollinated. For example, a pothole with just one to three flowering adults surrounded in all directions by slickrock may have less of a chance of attracting bees than a pothole with ten flowering adults located in edge habitat near other flowering plants. Further studies are needed to determine whether certain populations of *A. humillimus*, or indeed the species as a whole, is pollinator-limited, or if there are other

factors limiting seed-set in this species.

Inbreeding depression could also be a concern for this species, especially because plants occur in small, fragmented populations that are relatively isolated from each other within their sandstone habitats. A study of genetic divergence and reproductive success in the *Astragalus* section *Humillimi* investigated seed set and genetic variability in *A. humillimus* and related taxa, including three varieties of *A. cremnophylax (*Allphin et al. 2005). *Astragalus humillimus* had lower observed heterozygosity than expected heterozygosity, indicating that within-population genetic variation is low for the species. However, *A. humillimus* had higher genetic variation (as measured by polymorphic index) than any of the rare taxa studied, with the exception of *A. cremnophylax var. hevronii*. A recent genetic analysis of three populations of *A. humillimus* occurring on the Navajo Nation found that there was low genetic differentiation between populations (Massatti et al. 2018). This may not be abnormal given that the genus *Astragalus*, in general, is known to have relatively low population-level genetic diversity, which indicates recent genetic divergence of this group (Sanderson and Wojciechowski 1996). However, reduced genetic variation caused by crossing with closely related individuals could result in lower seed viability for this species if adequate outcrossing is not occurring. Further studies investigating multiple populations are needed to verify that inbreeding depression is indeed impacting seed viability in *A. humillimus* and is a factor contributing to declining population numbers.

The overall trend at the Sleeping Rock and Slickrock Flats monitoring sites has been a decline in *A. humillimus* total live cover from 1990-2018 despite yearly boom and bust cycles of high and low cover in response to favorable climactic conditions (Roth 2018). Declining plant cover observed at the BLM and NM State Trust Land sites is consistent with the overall population declines observed by NNHP personnel on the Navajo Nation over the same time period. Reasons for these drastic declines were largely attributed to poor recovery post-drought. For example, the Coal Mine Creek population was historically the largest population known on the Navajo Nation (4200 estimated plants in 1986). Ten years later F. Eldridge returned to the population and counted just 130 plants, which is much closer to the 2017 estimate of 100 plants. R. Sivinski ascribed much of this mortality to the 1988-1989 drought years that resulted in severe mortality of *A. humillimus* throughout its range (Sivinski 2008). It's clear from subsequent monitoring visits to the Coal Mine Creek site that this population was never able to recover from the 1988/89 drought event despite having a presumably large seedbank as a result of there being so many plants at the site prior to 1986. A similar drought event occurring from 2001-2003 was attributed to causing the very low population numbers recorded by D. Roth in 2007 and 2008 surveys of Navajo Nation populations, even though these surveys took place five to six years after the drought event occurred (Roth 2008). These observations suggest that *A. humillimus* recovery after severe and/or prolonged drought is limited, which is worrying given the predication that drought frequency and severity is predicted to increase in this region due to climate change (Cayan et al 2010). Indeed, the Southwest region of the United States is already feeling the effects of a warmer, drier climate. Annual temperature means for the late 20th and early 21st centuries were much warmer relative to the 20th century, and regional precipitation has declined overall in the same period (MacDonald 2010). Certain *A. humillimus* individuals may be better able survive periods of drought if they are growing within certain habitats. For example, plants growing in deep cracks in bedrock had better survivability during drought years than plants growing in tinajas or shallow cracks with less soil water holding capacity (Sivinski

2008).

Population monitoring and demography data from the past 30 years suggests that *A. humillimus* has experienced population-wide declines since the late 1980's-1990's and that these declines are largely in response to severe and/or prolonged drought events. Reduced seed viability due to inbreeding depression and possible pollination limitation are also factors that may be contributing to population declines and should be explored in future studies. *Astragalus humillimus*'s extreme natural rarity and endemism coupled with predicted threats from climate change as well as continued threats from oil and gas development mean that this species is particularly vulnerable to extinction. *Ex situ* seed banking and even artificial augmentation of populations is warranted, especially if inbreeding depression is reducing seed viability of populations and/or genetic diversity is lacking. Further genetic analyses are needed across the species range in order to best guide translocation and population augmentation efforts in order to pinpoint populations with high genetic diversity (if they indeed exist) to prioritize for these efforts (Massatti et al. 2018). Strengthening regulatory mechanisms for oil and gas activities occurring on Navajo Nation in *A. humillimus* habitat is also crucial to ensuring damage to this species is minimized to the greatest extent possible.

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