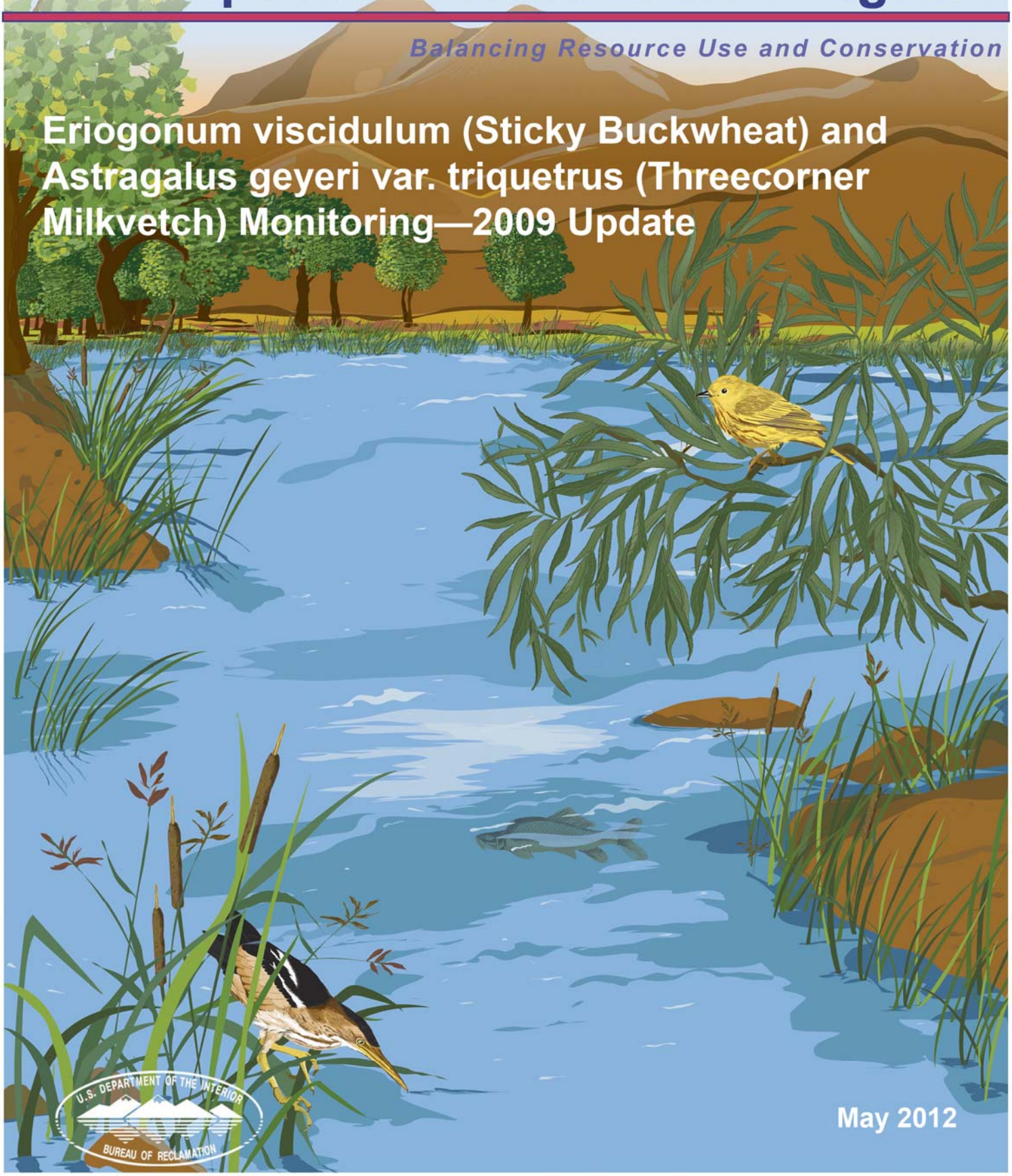
Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Eriogonum viscidulum (Sticky Buckwheat) and Astragalus geyeri var. triquetrus (Threecorner Milkvetch) Monitoring—2009 Update



May 2012

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Multi-Species Conservation Program

Eriogonum viscidulum (Sticky Buckwheat) and *Astragalus geyeri* var. *triquetrus* (Threecorner Milkvetch) Monitoring—2009 Update

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Lower Colorado River
Multi-Species Conservation Program
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Introduction

The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) is a coordinated, comprehensive, long-term multi-agency effort to conserve, monitor, and manage populations and habitat of covered species. The goals of the LCR MSCP are to avoid, minimize, and fully mitigate impacts on all covered species and their habitat, contribute to the recovery of listed covered species, and reduce the likelihood for future listings of non-listed covered species. Two rare plant species occur within the covered areas designated in the MSCP, *Eriogonum viscidulum* (sticky buckwheat) and *Astragalus geyeri* var. *triquetrus* (threecorner milkvetch). The LCR MSCP conservation measures for these species are to support existing sticky buckwheat and threecorner milkvetch conservation programs, and with implementation of these measures the LCR MSCP will help ensure that the existing abundance of the species in and adjacent to the LCR MSCP planning area is maintained or increased (LCR MSCP 2004).

Eriogonum viscidulum (Sticky Buckwheat)

Eriogonum viscidulum (Sticky buckwheat; Figure 1) is an annual plant endemic to Clark and Lincoln counties in southern Nevada and Mojave County in northwestern Arizona. Sticky buckwheat is listed as a critically endangered species in the state of Nevada, is on the Bureau of Land Management (BLM) sensitive species list, is listed on the Nevada Natural Heritage Programs Sensitive List (ranks G2 S2-defined as imperiled), and is a covered species under two local conservation plans: the LCR MSCP administered by the Bureau of Reclamation, and the Clark County Multiple Species Habitat Conservation Plan administered by Clark County, Nevada (Bangle 2005a).

Sticky buckwheat has a geographic distribution associated with a sedimentary deposit called the Muddy Creek Formation (Niles et al. 1995). This formation is widely exposed in the hills along the Overton Arm, Virgin Basin, and Boulder Basin sections of Lake mead National Recreation Area (LMNRA) and extends northward along the Virgin River valley and westward along the Muddy River and Meadow Valley Wash. Weathered sediments from this formation, redeposited as aeolian or fluvial sand, provide the substrate upon which threecorner milkvetch is found (Niles et al.1995).

In the mid-1990s, Niles et al. (1995) conducted an inventory of all known locations of sticky buckwheat, as well as searches for additional localities within LMNRA and adjacent regions of Nevada and Arizona. From this inventory effort, valuable knowledge was gained about the overall distribution and status of sticky buckwheat populations. Of the 22 locations where sticky buckwheat was located, 20,020 plants were recorded. Since the extensive surveys of Niles et al., surveys for sticky buckwheat have been geographically limited and only select sites have been monitored; thus, no systematic assessments of populations across the range of this species have occurred in recent years (Bangle 2005a).

Conceptual models were developed that illustrate the major stressors to sticky buckwheat populations (Figures 2-4). An assessment of threats by TNC (2007) resulted in seven threats being ranked as High. These threats included: rural development and sprawl, increased fire frequency and intensity, energy development (Figure 5), competition from invasive plant species, casual OHV use and trail development, surface water development, and agriculture practices. These threats and others have affected populations and habitats both by direct mortality of individuals and loss or fragmentation of habitats (TNC 2007). Specifically on the lands included in this monitoring project, primary threats are:

competition from invasive species, inundation and shoreline fluctuation, and trampling and grazing (cattle, burros, horses).

Astragalus geyeri var. *triquetrus* (Threecorner Milkvetch)

Astragalus geyeri var. *triquetrus* (threecorner milkvetch; Figure 6) is a rare, sand-loving, annual plant endemic to Clark and Lincoln counties in southern Nevada and Mojave County in northwestern Arizona. This species is listed as a critically endangered species in the state of Nevada, is on the Bureau of Land Management (BLM) sensitive species list, is listed on the Nevada Natural Heritage Programs Sensitive List (ranks G2 S2-defined as imperiled), and is a covered species on two local conservation plans: the LCR MSCP administered by the Bureau of Reclamation, and the Clark County Multiple Species Habitat Conservation Plan administered by Clark County, Nevada (Bangle 2005b).

The northern and eastern-most distributions of this species are at Sand Hollow Wash in Lincoln County and at Coon Creek in Mojave County. Threecorner milkvetch reaches a southern extension at Sandy Cove on the north shore of the Boulder Basin (LMNRA) and a western extension at Dry Lake Valley in Clark County. The highest concentration of populations is found in the Mormon Mesa area of Clark County on BLM land (Niles et al. 1995).

Threecorner milkvetch has a geographic distribution associated with a sedimentary deposit called the Muddy Creek Formation (Niles et al. 1995). This formation is widely exposed in the hills along the Overton Arm, Virgin Basin, and Boulder Basin sections of LMNRA and extends northward along the Virgin River valley and westward along the Muddy River and Meadow Valley Wash. Weathered sediments from this formation, redeposited as aeolian or fluvial sand, provide the substrate upon which threecorner milkvetch is found (Niles et al. 1995).

In the mid-1990s, Niles et al. (1995) conducted surveys of all known and potential locations of threecorner milkvetch within LMNRA and adjacent regions of Nevada and Arizona. Niles et al. identified 19 threecorner milkvetch sites. Since then, surveys have been geographically limited and have located new populations, but no modern range-wide surveys have been conducted.

Conceptual models were developed that illustrate the major stressors to threecorner milkvetch populations (Figures 7, 8). An assessment of threats by TNC (2007) resulted in nine threats being ranked as High or Very High. These included: urban development and sprawl, OHV use and trail development, increased fire frequency and intensity, energy development, surface water development, invasive plant species, utility corridor construction and maintenance, Lake Mead inundation and shoreline fluctuation, and inappropriate agricultural practices. Several of these threats are site-specific while others are more widespread. Specifically on the lands included in this monitoring project, the primary threats are urban development and sprawl, energy development (Figure 5), competition from invasive species, Lake Mead inundation and shoreline fluctuation, and utility corridor construction and maintenance.

Monitoring and Sampling Objectives

The objective of the monitoring is to assess the status of select populations of sticky buckwheat and threecorner milkvetch and to gain a greater understanding of the important abiotic and biotic factors that influence population condition. The specific objectives for the monitored populations occurring on NPS lands within Clark County are:

1. Maintain the current density (within 30% of the baseline measurement calculated from a year of average to above average rainfall) over the next 10 years. The sampling objective is to be 80% sure of detecting a 30% change in density of sticky buckwheat and threecorner milkvetch in average or above average rainfall years.

2. Correlate the abiotic factors of rainfall, temperature, relative humidity, and soil chemistry, with the density (measured in average to above average rainfall years) of sticky buckwheat and threecorner milkvetch.

3. Detect changes in species richness and cover of native and non-native plant species over the next 10 years, for species richness and for species cover within 30% of the first measurement taken in average to above average rainfall years. The sampling objective is to be 80% sure of detecting a 30% change in species richness and cover of native and non-native plant species in average or above average rainfall years.

Methods

Sampling Design (Sticky Buckwheat)

Two sticky buckwheat populations (Lime Cove and Glory Hole) were randomly selected for annual monitoring. Only three populations were included in the selection process because other historical and/or known locations did not meet the criteria for monitoring or were not re-surveyed for status assessments before the current monitoring began. All three sites are in close proximity to each other and are located along the eastern shoreline of the Overton Arm of LMNRA. We determined that two sites in this area would be sufficient to represent the area.

Due to the nature of the habitat, terrain, and location of sticky buckwheat plants at these sites (Figure 9), a systematic sampling approach for monitoring sticky buckwheat was used. One 50 m × 100 m macroplot was placed at each site. Each macroplot location was selected using a stratified random approach by placing a “virtual grid” (in ArcMap) over known habitat after which random numbers were generated and a point selected (within the virtual grid). This random point translated to the high water corner (left end when facing the lake) of the macroplot. Ten transects (1 m × 100 m) were laid perpendicular to the shoreline using a random start along the high water edge of the macroplot. Seven quadrats (1 m × 10 m) were placed along each transect, skipping 5 meters between each quadrat for a total of 70 quadrats per site.

Within each quadrat all plant species were recorded and data collection included foliar cover of all species, rock/gravel cover, and presence/absence of cattle/burro trails and dung. Any additional observations of threats or disturbances were noted. Sticky buckwheat spatial distribution within the

macroplot was estimated by recording number of sticky buckwheat plants within each subplot (1 m^2) on a field map. Dead plant material from saltcedar and Russian thistle was recorded in one "litter" category. GPS coordinates and compass bearings were recorded at each high water corner of the macroplot and at each transect start. Trampled and/or chewed plants of any plant species within the plots were noted.

Weather stations were established at both Lime Cove and Glory Hole. Because of difficulties acquiring the station equipment, the units were not installed until early 2009 after initial monitoring had begun. Soil samples were collected in late 2009 at each sticky buckwheat and threecorner milkvetch site and included: % CaCo3 (inorganic carbon), total carbon and nitrogen, pH, EC, and particle size.

Sampling Design (Threecorner Milkvetch)

One three-corner milkvetch population (Sandy Cove) was monitored in 2008 and two additional sites (Ebony Cove and Weiser Wash) were added in 2009 (Figure 10). A grid-cell sampling approach was used. Eight 36 m × 36 m temporary grids will be placed each year in the same locations and will include three separate dune areas (~one hectare total area). Each grid location was selected randomly (using stratified random approach) by placing a "virtual grid" (in ArcMap) over known habitat after which random numbers were generated to select a coordinate within the virtual grid. Each coordinate translated to the southwest corner of each grid and once on site a compass bearing for each direction was recorded and GPS coordinates for the three additional corners were recorded, including easting, northing, elevation, and level of accuracy. Eighteen quadrats (6 m ×12 m) were delineated within the grid and data collection and included threecorner milkvetch individual counts and locations for spatial patterning, plant species composition, and estimates of foliar cover for each species.

Individual GPS coordinates were not recorded for spatial analyses; instead, threecorner milkvetch locations were recorded by marking plants on a field map of each quadrat, thus showing spatial arrangement across each grid. The field maps were digitized using ArcMap after the field season was complete. Plant community data were collected in 2008 and 2009 and will be collected in subsequent years of average to above average rainfall. All live annuals, perennial herbs, shrubs and trees were recorded.

Weather stations were established at Ebony Cove, Sandy Cove, and Weiser Wash. Because of difficulties acquiring the station equipment, the units were installed in early to mid-2009 after initial monitoring had begun.

Soil samples were collected in late 2009 at each sticky buckwheat and threecorner milkvetch site and included: % CaCo3 (inorganic carbon), total carbon and nitrogen, pH, EC, and particle size.

Results and Observations (2008-2009)

The dominant annual and perennial species commonly associated with sand habitat known to support threecorner milkvetch and sticky buckwheat are listed in Table 1.

Sticky Buckwheat

Figure 11 shows sticky buckwheat spatial distribution at Lime Cove across years. Sticky buckwheat populations at the monitored sites appeared to be increasing across years (Table 2). Both sites were similar in total cover, perennial cover, and annual cover (Table 3). Shrub cover was significantly higher at Glory Hole compared to Lime Cove. Native and non-native cover was approximately equal at Lime Cove, while non-native cover was at least three-fold greater than native cover at Glory Hole. Glory Hole in 2008 had lower species richness than Glory Hole in 2009 or Lime Cove in either year, and diversity was lower in 2009 at Glory Hole, suggesting a few dominant species rather than a community with high evenness. On the whole-plot scale, sites in 2009 had greater species richness, but lower species diversity, than in 2008. This pattern suggests stronger dominance by a few species in 2009 compared to 2008 (Table 4). The relative representation of the most common species confirms this supposition. The most common species were all non-natives.

The presence of sticky buckwheat was positively correlated to native cover at Lime Cove and negatively correlated to non-native cover at Glory Hole (where non-native cover dwarfed native cover; Table 5). Native cover and species richness were moderately correlated ($\rho = 0.610$; Spearman rank correlation). Diversity and richness were correlated ($\rho = 0.677$). Annual cover and non-native cover were positively correlated ($\rho = 0.691$), and non-native cover was negatively correlated with diversity ($\rho = -0.696$). More data are necessary in order to determine the true trends across the range of the species.

Cattle tracks were recorded as present or absent in all plots. Cattle tracks were recorded in 71-90% of quadrats at Lime Cove and 80-86% at Glory Hole (Figure 12). There was a small presence of trespass burros at each site that may have contributed to the tracks, but based on observation and presence of cattle dung, the majority of the tracks appeared to be from trespass cattle.

A total of 40.8 and 42.8 mm of rainfall were recorded in 2009 (February-December) at Glory Hole and Lime Cove, respectively (Table 6).

Soil data were not yet analyzed at the time of preparing this report.

Threecorner Milkvetch

Threecorner milkvetch spatial distribution varied at Sandy Cove across years, as expected (Figures 13 and 14), and abundance declined across years at Sandy Cove (Table 7). All sites were similar in total cover in 2009, although Sandy Cove had significantly less total cover in 2009 than in 2008 (Table 8). Native cover was high in these sites compared to non-native cover. Between sites in 2009, non-native cover was substantially higher at Weiser Wash and slightly higher at Ebony Cove than at Sandy Cove. Sandy Cove in both years had lower quadrat-level richness and diversity than Ebony Cove and Weiser Wash in 2009. On the whole-plot scale, Sandy Cove had greater species richness, but lower species evenness than Ebony Cove and Weiser Wash, suggesting stronger dominance by the most common species, particularly the top two species (Table 9 and 10). More data are necessary in order to determine the true trends across the range of the species.

A total of 19.4, 2.2, and 16.6 mm of rainfall were recorded in 2009 at Ebony Cove, Sandy Cove, and Weiser Wash respectively (not complete year for all sites; Table 11). More data are necessary in order

to assess the hypothesis that micro-climate is correlated with rare plant recruitment/germination. Soil data were not yet analyzed at the time of preparing this report.

Discussion

Annual species including sticky buckwheat and threecorner milkvetch show large variations in abundance from year to year. It is likely these fluctuations are due to annual temperature and precipitation conditions. Winter annuals typically respond to increased seasonal rainfall by germinating at higher densities. Our observations in recent years support this, but more data from this long-term monitoring project are necessary to effectively correlate environmental factors such as rainfall and temperature to increased germination of threecorner milkvetch.

Sticky buckwheat and threecorner milkvetch require open spaces and loose soils; thus, in areas heavily invaded by invasive species, it is unlikely that sticky buckwheat or threecorner milkvetch will be found.

Invasive species of annual grasses are a major factor in stabilizing sand sheets and dune habitats throughout the range of threecorner milkvetch (TNC 2007). Large areas of threecorner milkvetch habitat on the dunes at Sandy Cove supported Mediterranean grass, which appeared to be stabilizing portions of the dunes. If Mediterranean grass continues to spread, it may eventually alter the loose sand habitat enough that declines in threecorner milkvetch may occur.

The National Park Service has been controlling Sahara mustard on Sandy Cove since 2003. It appears that these efforts may be benefiting the three-corner milkvetch population in that fewer Sahara mustard plants occur on the dunes than on the surrounding areas, but no quantitative study has been conducted to support this.

One threat concerning sticky buckwheat that requires further evaluation is the seemingly increased presence and damage done by trespass cattle on the eastern side of the Overton Arm of LMNRA. Approximately 70-90% of quadrats had cattle tracks and every survey day researchers encountered or observed cattle in the area. On two occasions in 2008, researchers needed to scare the cattle off before accessing the site. Glory Hole was especially affected in that the beaches and sandy areas smelled intensely of cattle urine and had an abundance of cattle dung. We observed fewer cattle in 2009, and cattle tracks only decreased slightly at Glory Hole, yet increased by almost 20% at Lime Cove. The owners of the trespass cattle were asked to remove their cattle from NPS lands beginning in 2009, but it is unknown if the removal project was successful. The reduced cattle presence may also be partially attributed to the earlier data collecting time frame. In 2008, data was collected from April 7 to May19, with a maximum temperature of ~101ºC. In 2009, data were collected from April 6 to 9, with a maximum temperature of ~87ºC. In cooler temperatures the cattle would presumably require less water.

The absence of early weather data limited the extent to which the analyses of relationships between plant populations and site-specific temperature and precipitation conditions could be examined. The intention of the NPS was to establish weather gauges at all of the monitoring sites to record annual rainfall over time in order to correlate weather patterns with rare plant population densities. These weather gauges have been established and long-term maintenance is planned.

Nevada Conservation Corp (NCC) assisted with data collecting in 2009. The additional personnel enabled researchers to complete the data collecting within a 1-2 week time frame instead of 4-5 weeks.

Recommendations for 2010

Collecting microclimate data (rainfall/temp/Rh) at all monitoring sites should continue for the long term in order to correlate weather patterns with rare plant population densities.

Restricting the time frame for data collection minimizes variability in cover assessments as well as misidentifications of annual plants because of change in phenology. An ideal monitoring time frame needs to be established and maintained each year for both rare plant species in order to establish a true trend over time. Ideally, sticky buckwheat should be monitored within a 2-week time frame in early May and threecorner milkvetch within a 2-week time frame in early April.

The threecorner milkvetch experimental design could be modified to increase the power and reduce the variability of the data. We recommend keeping the grid method and the same random locations used for this project but change the shape to a more long and linear grid and allowing for space in between sampling units, thus establishing independence between sampling units.

It is also recommended that the experimental design for sticky buckwheat be modified. The design was tailored to the shoreline habitat along the Overton Arm of Lake Mead. In the future, additional sites should be monitored. Most of the remaining sites do not occur along the shoreline of Lake Mead. The specific design used for monitoring sticky buckwheat for this project would not work for other populations. A modified design is recommended.

We recommend initiating invasive species research to determine effective methods for Mediterranean grass control in rare plant habitats and how controlling this species will affect sticky buckwheat or threecorner milkvetch populations. Control protocols should also be developed for saltcedar and Sahara mustard in rare plant habitat.

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Tables and Figures

Table 1. Plant species commonly associated with sand habitat included in this study.

Species	Common Name	Annual/perennial
Abronia villosa S. Watson	Sand verbena	a
Ambrosia dumosa(A. Gray) Payne	White bursage	p
Astragalus geyeri A. Gray var. *triquetrus* M.E. Jones	Threecorner milkvetch	p
Astragalus sabulonum A. Gray	Gravel milkvetch	a
Camissonia brevipes(A. Gray) P.H. Raven	Suncups	a
Cryptantha angustifolia (Torr.) Greene	Narrowleaf cryptantha	a
Cryptantha pterocarya (Torr.) Greene	Wingnut cryptantha	a
Eriogonum viscidulum J.T. Howell	Sticky buckwheat	a
Larrea tridentata (DC.) Coville	Creosote bush	p
Lupinus shockleyi (S. Watson)	Desert lupine	a
Phacelia crenulata Torr. ex S. Watson	Notchleaf phacelia	a
Plantago ovata Forssk.	Woolly plantain	a
Psorothamnus fremontii (Torr. ex A. Gray) Barneby	Indigo bush	p
Schismus sp.	Mediterranean grass	a
Stephanomeria pauciflora (Torr.) A. Nelson	Wire lettuce	p
Streptanthella longirostris (S. Watson) Rydb.	Longbeak twistflower	a

Table 2. Total number of sticky buckwheat individuals recorded at each monitored site in 2008 and 2009.

	2008	**2009**
Lime Cove	4708	7043
Glory Hole	126	491

Table 3. Shown are summaries of mean and bootstrapped 95% confidence interval of quadrat-level and whole-plot measurements at sites containing sticky buckwheat. Diversity is back-transformed to Hill's number, richness is average number of species, and all other values are expressed as percent cover in the plot. Top panel includes summary values, the second life forms, the third information on nativity categories, and fourth whole-plot values (a-annual; p-perennial; s-shrub; n-native; w-non-native). Monitoring sites are denoted as Glory Hole (GLHO) and Lime Cove (LICO).

	Total cover	95% CI		Richness	95% CI		Hill diversity	95% CI	
2008 GLHO	22.11	18.88	25.93	8.53	7.63	9.46	4.62	3.99	5.34
2008 LICO	24.68	21.62	28.15	10.47	9.93	11.03	5.07	4.65	5.54
2009 GLHO	26.01	23.18	29.22	10.74	9.49	11.96	3.79	3.16	4.53
2009 LICO	24.26	20.56	28.59	11.54	10.91	12.19	4.56	4.02	5.14

	a	95% CI		p	95% CI		s	95% CI	
2008 GLHO	16.60	14.04	19.47	0.05	0.02	0.09	2.82	1.66	4.41
2008 LICO	22.81	20.02	25.98	0.03	0.01	0.07	0.35	0.09	0.83
2009 GLHO	19.57	17.15	22.20	0.05	0.02	0.11	2.19	1.03	3.83
2009 LICO	22.11	18.57	26.12	0.01	0.00	0.02	0.36	0.10	0.90

	n	95% CI		w	95% CI	
2008 GLHO	4.23	3.10	5.47	14.08	10.61	18.34
2008 LICO	11.32	9.69	13.19	11.42	8.92	14.18
2009 GLHO	4.75	3.45	6.27	17.91	14.57	21.63
2009 LICO	8.36	6.82	10.19	13.44	10.38	17.16

Table 4. The values provided are the sum of cover midpoints across all quadrats for each sticky buckwheat site and year. The 'Top1', 'Top2', and 'Top5' rows indicate the percent of total cover represented by the most common, two most common, and five most common species, respectively. Species abbreviations are as follows: Cryang-*Cryptantha angustifolia*, Salsola-d-dead litter from *Salsola* sp., Tamram-*Tamarix* sp., Cambre-*Camissonia brevipes*, and Erivis-*Eriogonum viscidulum*. Monitoring sites are denoted as Glory Hole (GLHO) and Lime Cove (LICO).

2008 GLHO		2008 LICO		2009 GLHO		2009 LICO	
Cryang	78	Cambre	177	Cryang	57	Cryang	65
Salsola	537	Erivis	329	Erivis	76	Erivis	348
Salsola-d	80	Salsola	123	Salsola	115	Salsola	126
Schismus	307	Schismus	716	Schismus	963	Schismus	895
Tamram	374	Tamram	114	Tamram	367	Tamram	119
Grand Total	1727		1872		1932		1877
Top1	31%		38%		50%		48%
Top2	53%		56%		69%		66%
Top5	80%		78%		82%		83%

Table 5. Estimated intercepts and slopes predicting presence of sticky buckwheat (log10-transformed +1) for species richness (ervi_richness), log10+1 transformed diversity (diversity), percent cover of annuals within plot (annual), percent cover of perennials within plot (perennial), percent cover of shrubs within plot (scovmid), percent cover of native plant species within plot (native), percent cover of non-native plant species within plot (w (non-native), and percent cover of litter (lcovmid) by year and site. The model included transect as a random effect and a two-dimensional exponential geometrically anisotropic spatial covariance structure (determined by AICC). The table provided is the minimum adequate model based on AICC. Monitoring sites are denoted as Glory Hole (GLHO) and Lime Cove (LICO).

Year Site	Effect	Estimate	StdErr	DF	tValue	Probt
2008GLHO	Intercept	-0.45	0.67	9	-0.66	0.5241
2008GLHO	diversity	0.54	0.22	55	2.49	**0.0160**
2008GLHO	perennial	0.02	0.41	55	0.04	0.9673
2008GLHO	annual	0.33	0.15	55	2.28	**0.0263**
2008GLHO	w (non-native)	-0.49	0.12	55	-4.13	**0.0001**
2008GLHO	scovmid	0.22	0.35	55	0.64	0.5254
2009LICO	Intercept	-0.07	0.34	9	-0.20	0.8480
2009LICO	diversity	0.71	0.22	50	3.18	**0.0025**
2009LICO	perennial	-0.61	0.58	50	-1.07	0.2916
2009LICO	native	1.67	0.14	50	12.03	**0.0000**
2009LICO	scovmid	-0.16	0.14	50	-1.16	0.2521
2008LICO	Intercept	-0.94	0.97	9	-0.98	0.3548
2008LICO	ervi_richness	0.10	0.04	55	2.52	**0.0147**
2008LICO	diversity	1.09	0.64	55	1.71	0.0928
2008LICO	perennial	-1.45	0.80	55	-1.80	0.0772
2008LICO	native	1.18	0.32	55	3.69	**0.0005**
2008LICO	scovmid	-0.51	0.35	55	-1.43	0.1571
2009GLHO	Intercept	0.64	0.45	9	1.42	0.1903
2009GLHO	diversity	0.48	0.24	54	1.97	0.0540
2009GLHO	perennial	1.90	0.44	54	4.35	**0.0001**
2009GLHO	w (non-native)	-0.41	0.18	54	-2.32	**0.0242**
2009GLHO	shrub	0.36	0.12	54	2.93	**0.0050**
2009GLHO	scovmid	-0.08	0.19	54	-0.44	0.6646
2009GLHO	lcovmid	-0.49	0.18	54	-2.80	**0.0070**

Table 6. Summaries of monthly precipitation (in mm) at sticky buckwheat monitoring sites in 2009. Both weather stations were installed in February 2009. Months that do not include completed data are denoted by '*'.

2009	Glory Hole (mm)	Lime Cove (mm)
January	-	-
February	8.6*	7.8*
March	0	0.6
April	2.8	2.6
May	1.6	3.4
June	0	0.2
July	1.2	2.4
August	2	0.2
September	0.6	0.4
October	0	1.4
November	0.6	0.6
December	23.4	23.2
Total	40.8	42.8

Table 7. Total number of threecorner milkvetch individuals recorded at Sandy Cove in 2008-2009 and Ebony Cove and Weiser Wash in 2009.

	2008	**2009**
Sandy Cove	3968	2027
Ebony Cove		424
Weiser Wash		78

Table 8. Shown are summaries of mean and bootstrapped 95% confidence interval of quadrat-level measurements at sites containing threecorner milkvetch. Diversity is back-transformed to Hill's number, richness is average number of species, and all other values are expressed as percent cover in the plot. Top panel includes summary values, then second life forms, and the third information on nativity categories (a-annual; p-perennial; s-shrub; n-native; w-non-native). Sites are denoted as Sandy Cove (SACO), Ebony Cove (EBCO) and Weiser Wash (WEWA).

	Total cover	95% CI		Richness	95% CI		Diversity	95% CI	
2008 SACO	23.51	20.68	26.45	12.97	11.89	14.06	5.48	4.99	6.01
2009 EBCO	21.76	19.85	23.86	20.41	18.80	21.98	10.03	8.96	11.18
2009 SACO	16.81	14.63	19.07	12.42	11.06	13.81	6.28	5.63	6.95
2009 WEWA	24.80	23.20	26.55	19.65	18.92	20.40	10.06	9.03	11.19

	a	95% CI		p	95% CI		s	95% CI	
2008 SACO	5.72	5.06	6.42	0.32	0.23	0.42	15.92	13.75	18.26
2009 EBCO	9.77	8.86	10.67	0.02	0.00	0.06	11.67	10.32	13.21
2009 SACO	5.88	5.22	6.59	0.23	0.17	0.31	9.74	8.22	11.45
2009 WEWA	9.31	8.63	10.12	2.59	2.35	2.84	11.89	10.20	13.78

	n	95% CI		w	95% CI	
2008 SACO	21.68	19.09	24.48	0.96	0.81	1.13
2009 EBCO	19.90	18.11	21.79	1.37	1.16	1.59
2009 SACO	15.28	13.35	17.40	1.08	0.93	1.25
2009 WEWA	18.76	17.06	20.62	4.90	4.27	5.67

Table 9. Shown are the top five species by cover for each threecorner milkvetch site. Values are the sum of mid-points (of cover) for each quadrat by site and year. The grand total is the total sum of mid-points for each site and year. The percentage of relative cover represented by the most common, the two most common, and the five most common species is provided in the 'Top1', 'Top2', and 'Top5' rows. Species abbreviations are as follows, Ambdum-*Ambrosia dumosa,* Kraere-*Krameria erecta*, Lartri-*Larrea tridentata*, Psofre-*Psorothamnus fremontii*, Pecpla-*Pectocarya platycarpa*, Plaova-*Plantago ovata*, and Strlon-*Streptanthella longirostris.* Sites are denoted as Sandy Cove (SACO), Ebony Cove (EBCO) and Weiser Wash (WEWA).

2008 SACO		2009 EBCO		2009 SACO		2009 WEWA	
Ambdum	1541	Ambdum	324	Ambdum	1072	Ambdum	322
Kraere	112	Lartri	79	Kraere	83	Ephedra	67
Lartri	1072	Pecpla	23	Lartri	747	Kraere	39
Psofre	279	Psofre	29	Plaova	101	Lartri	42
Schismus	102	Schismus	43	Strlon	86	Schismus	142
Grand Total	4117		815		3027		914
Top1	37%		40%		35%		35%
Top2	63%		49%		60%		51%
Top5	75%		61%		69%		67%

Table 10. Shown are whole-site richness and diversity at each threecorner milkvetch site by year. Sites are denoted as Sandy Cove (SACO), Ebony Cove (EBCO) and Weiser Wash (WEWA).

	Richness	Diversity
2008 SACO	60	9.54
2009 EBCO	42	13.63
2009 SACO	55	11.61
2009 WEWA	49	12.90

Table 11. Summaries of monthly precipitation at threecorner milkvetch monitoring sites in 2009. Weather stations were installed at Ebony Cove in July, Sandy Cove in February and Weiser Wash in August 2009. Months that do not include completed data are denoted by '*'.

2009	Ebony Cove (mm)	Sandy Cove (mm)	Weiser Wash (mm)
January	-	-	-
February	-	0.8*	-
March	-	0.2	-
April	-	0.4	-
May	-	0	-
June	-	0	-
July	0*	0	-
August	1.2	0.8	0.6*
September	4.4	0	3.4
October	0	0	0
November	0	0	0.6
December	13.8	0	12
Total	19.4	2.2	16.6

Figure 1. Photos of sticky buckwheat: a) sticky buckwheat plant; b) sticky buckwheat sticky stems; c) sticky buckwheat flower.

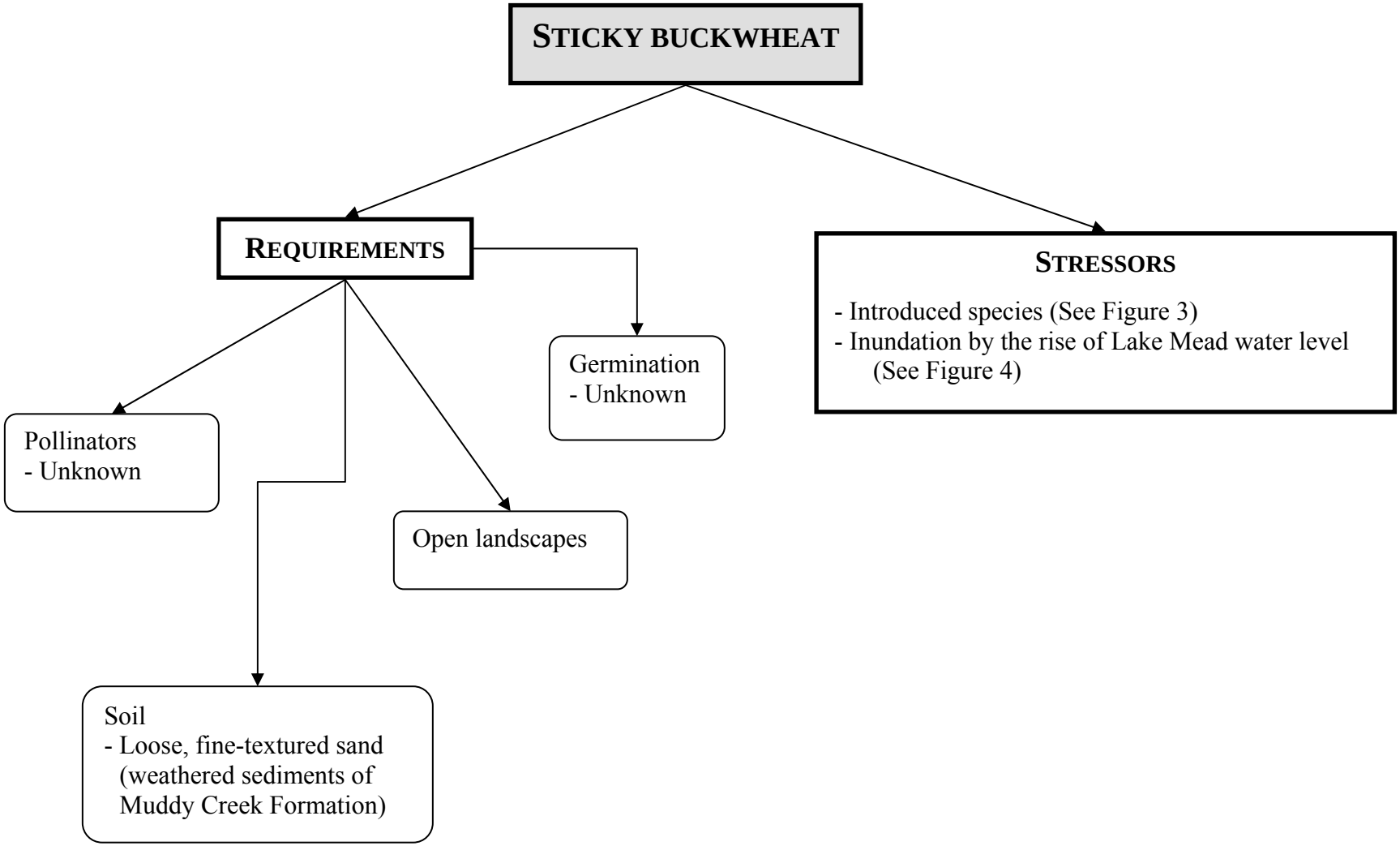


Figure 2. A conceptual model illustrating the requirements and stressors of sticky buckwheat.

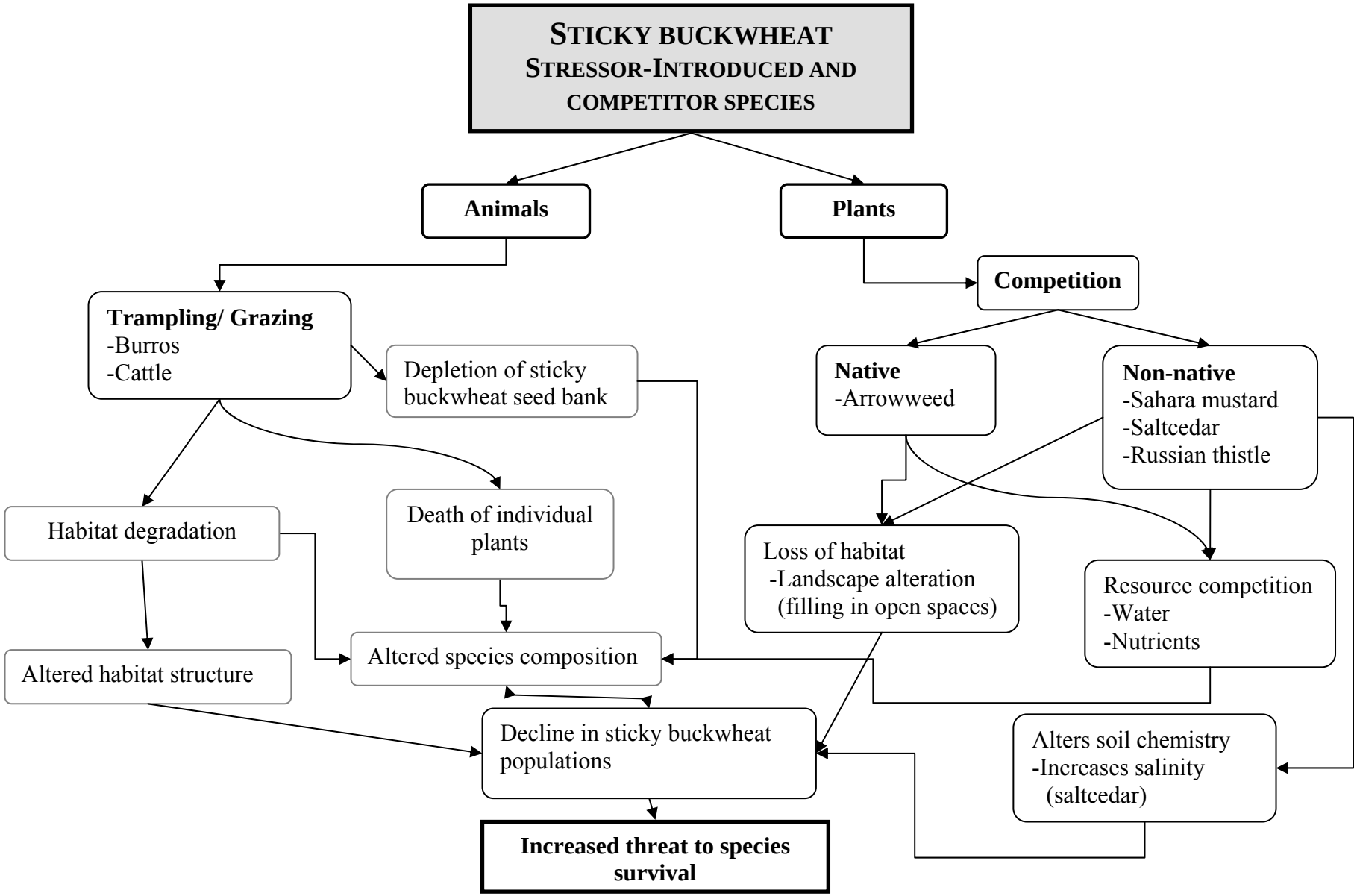


Figure 3. Conceptual model illustrating the effects of introduced species on sticky buckwheat.

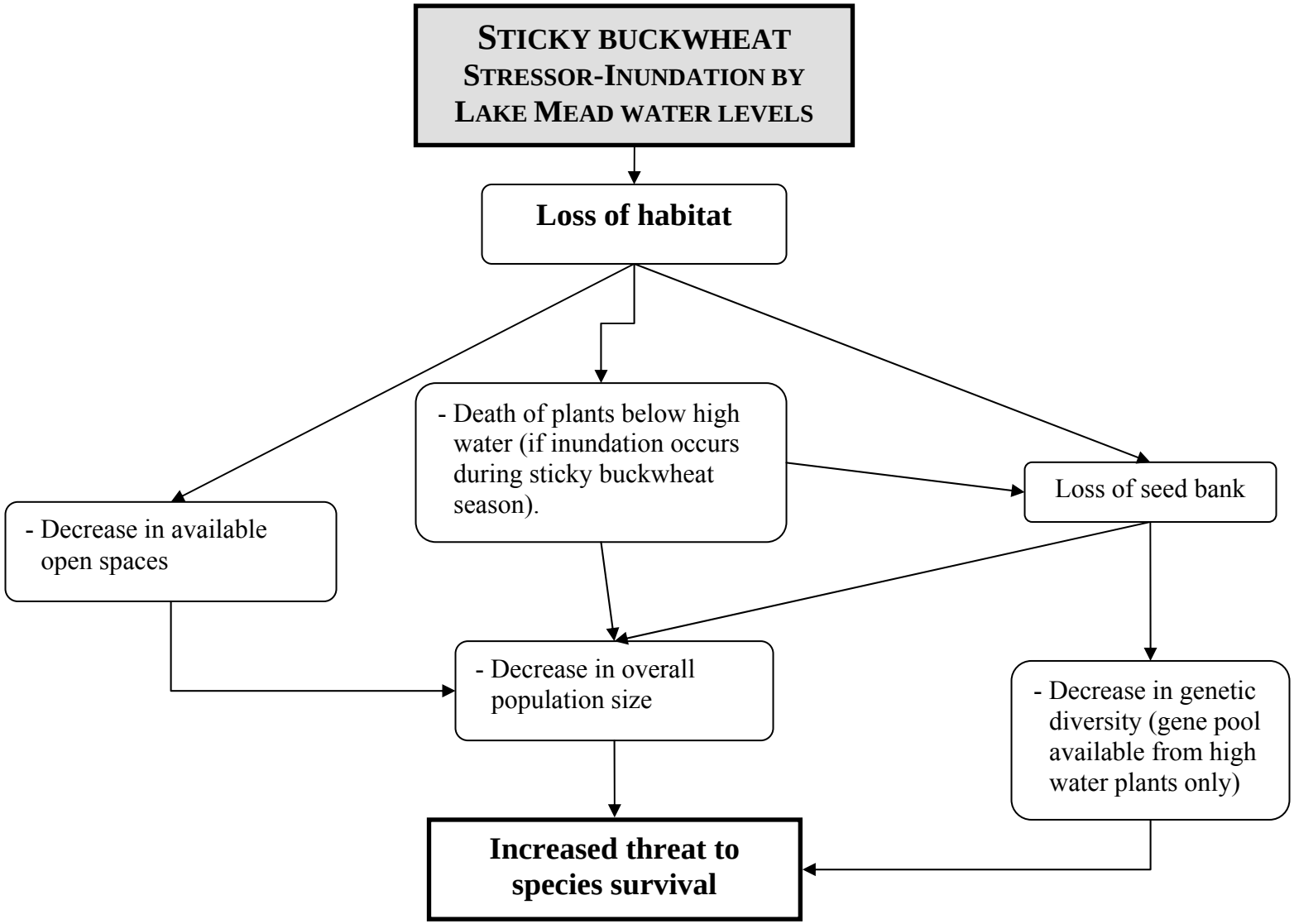


Figure 4. Conceptual model illustrating the effects of inundation by Lake Mead water levels on sticky buckwheat.

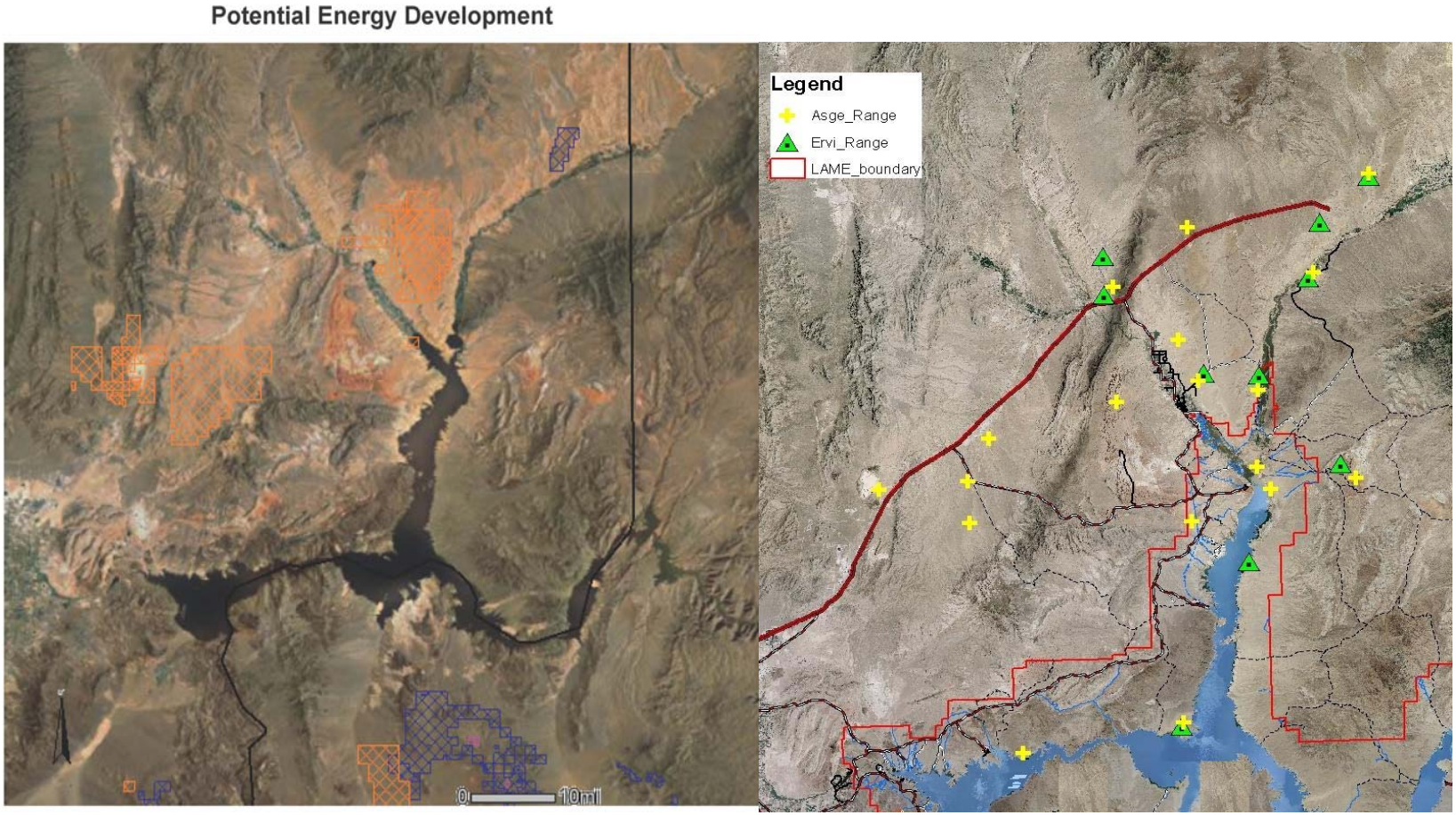


Figure 5. Threats of energy development on rare sand species: a) map showing proposed areas for energy development in Clark County(orange and blue); b) map showing threecorner milkvetch and sticky buckwheat distributions.

Figure 6. Photos of three corner milkvetch: a) threecorner milkvetch plant; b) threecorner milkvetch flower; c) threecorner milkvetch fruit.

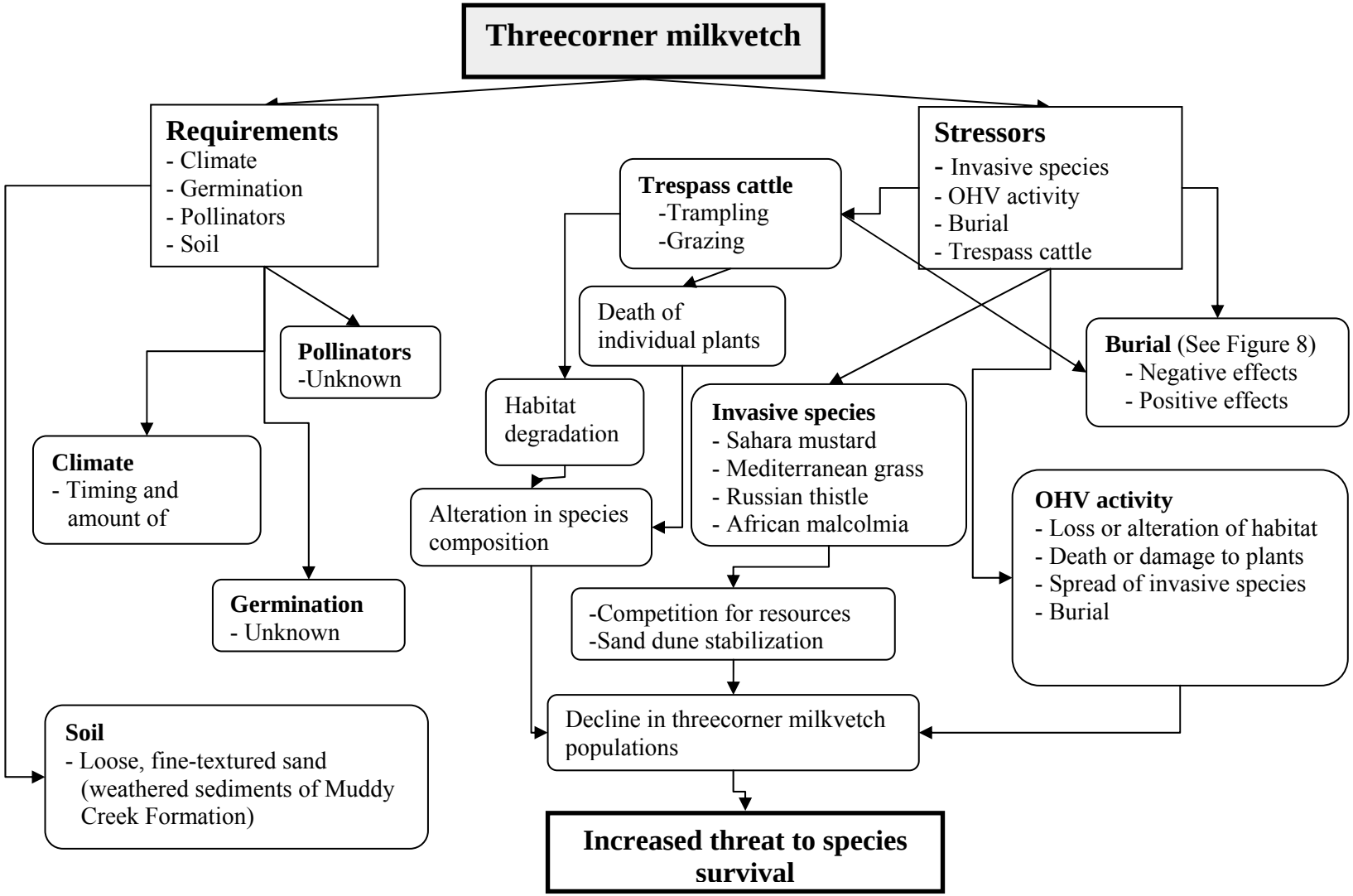


Figure 7. Conceptual model illustrating requirements and the effects of stressors on threecorner milkvetch.

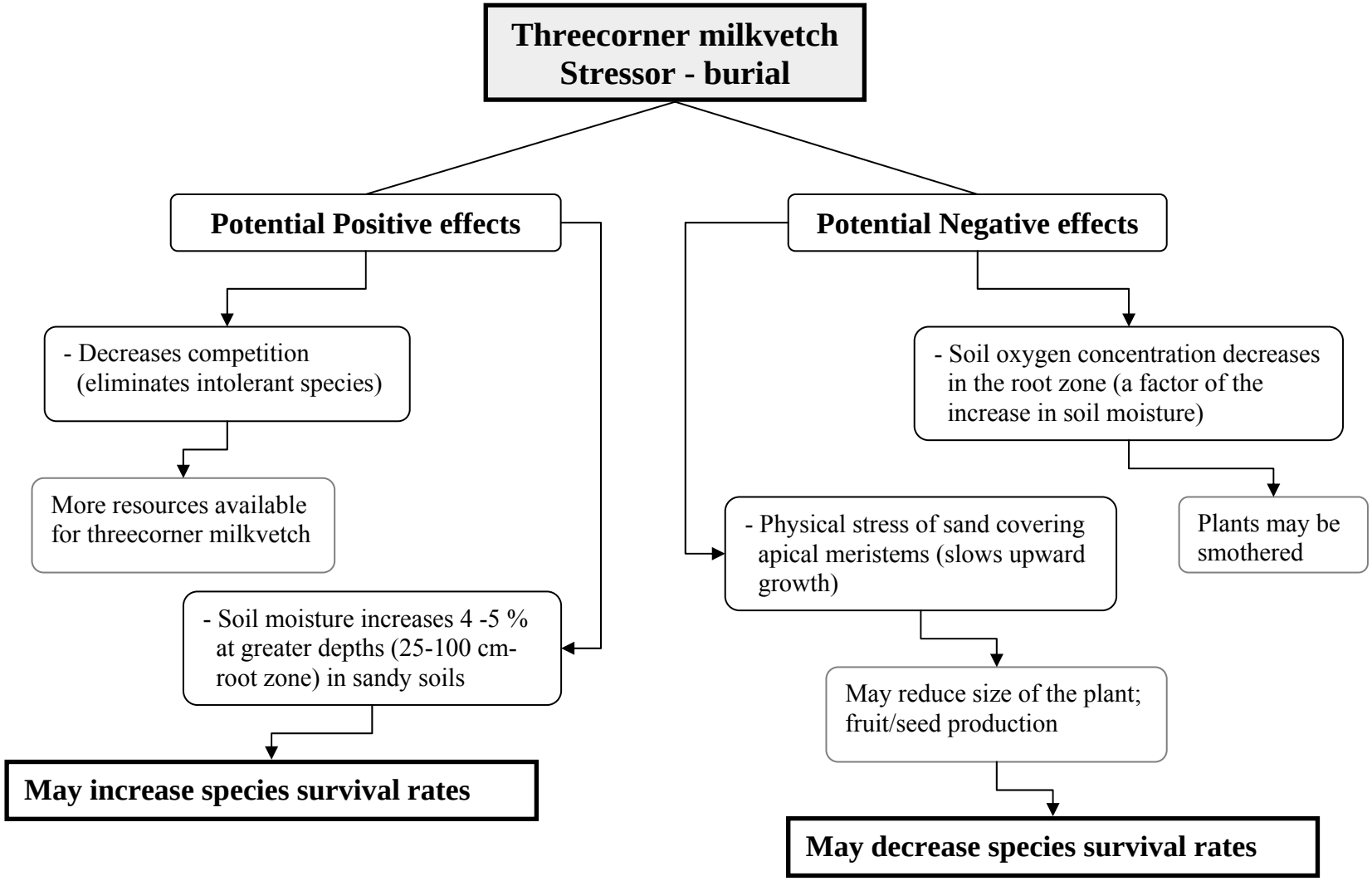


Figure 8. Conceptual model illustrating potential effects of burial by sand on threecorner milkvetch on Sandy Cove. Concepts based on research presented in the Canadian Journal of Botany 76:713-738.

a)

b)

c)

d)

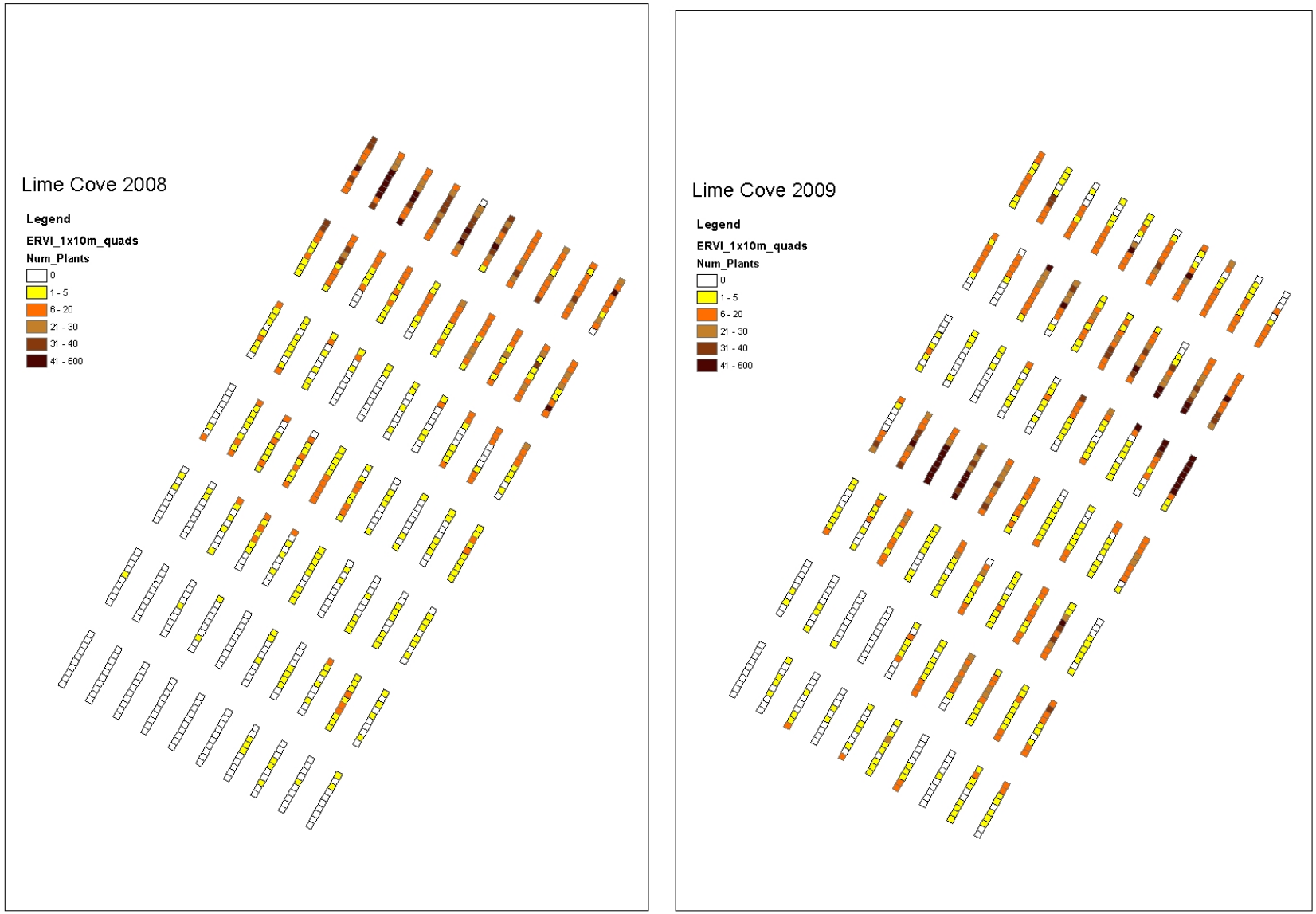
Figure 9. Sticky buckwheat monitoring sites: a) Lime Cove quadrat; b) Lime Cove site; c) Glory Hole top corner of Macroplot; d) Glory Hole site.

a)

b)

c)

Figure 10. Threecorner milkvetch monitoring sites: a) Sandy Cove; b) Ebony Cove; c) Weiser Wash.



a) **b)**

Figure 11. Spatial distribution of *Eriogonum viscidulum* at Lime Cove: a) 2008; b) 2009. The entire macroplot is shown; high water is along the top row of quadrats.

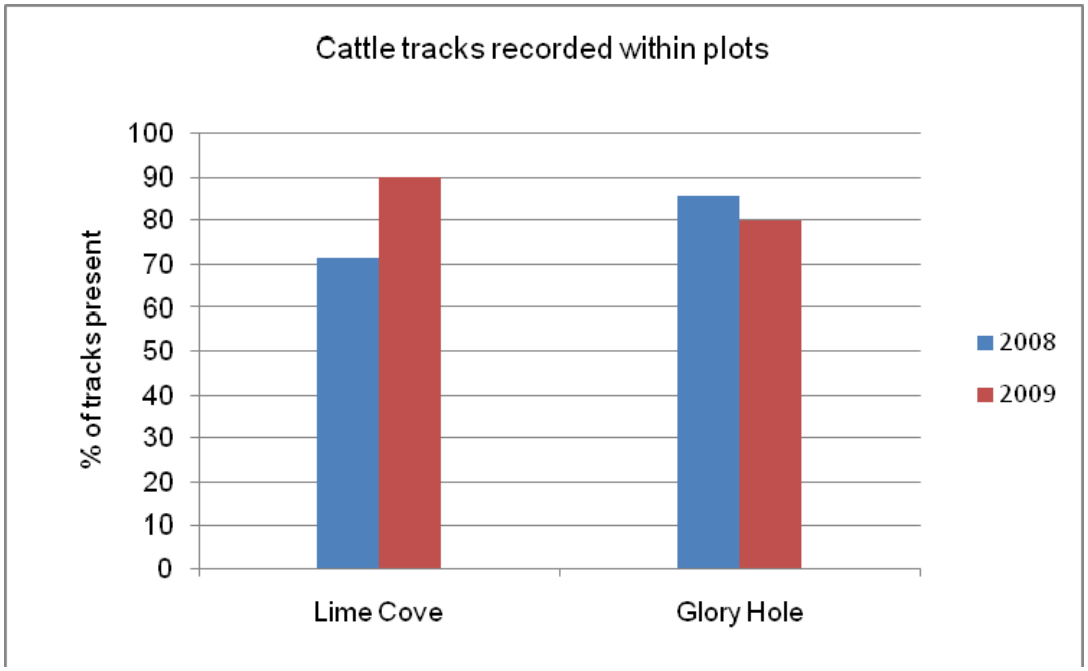
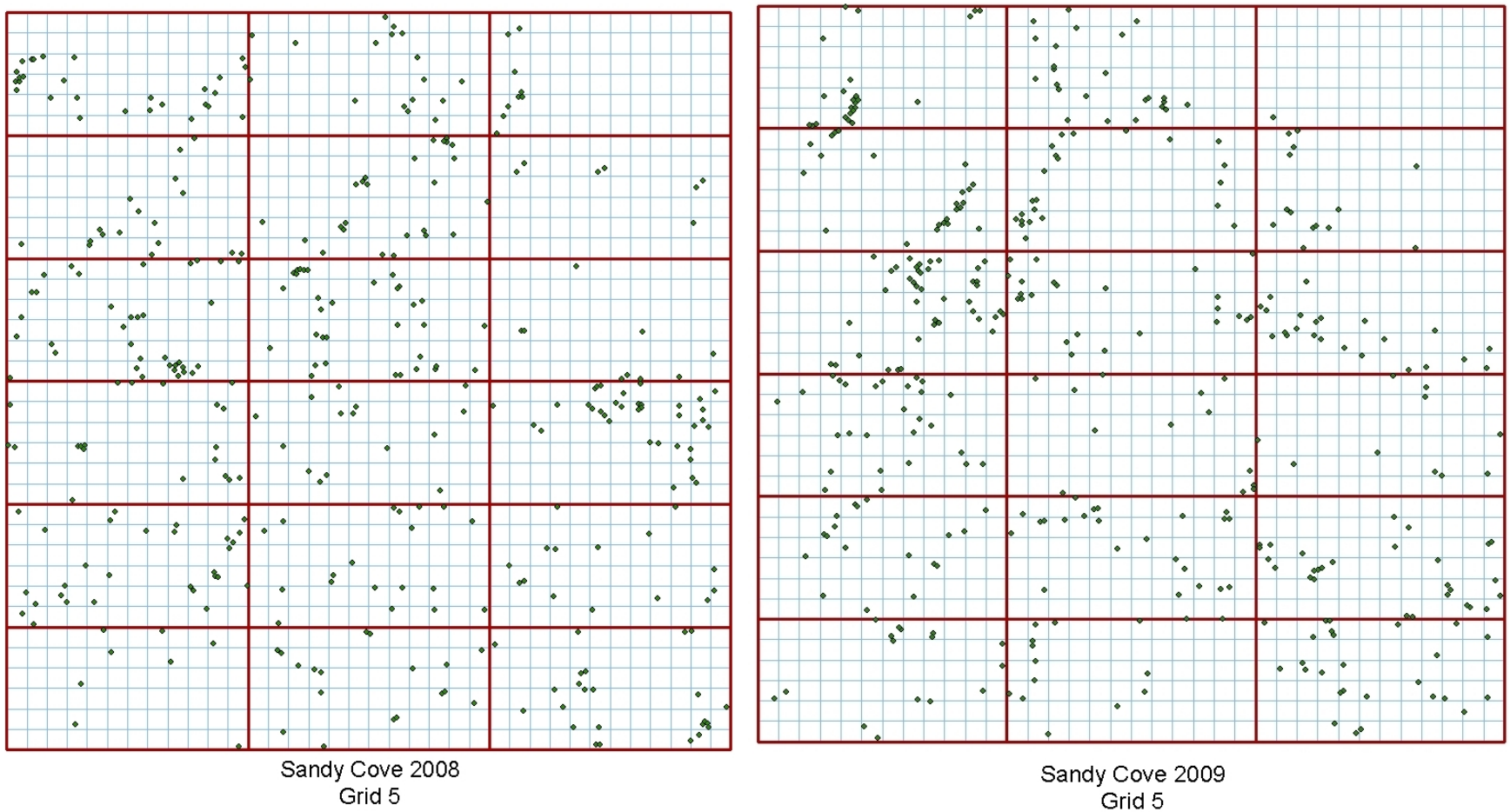


Figure 12. Shown are the percentages of quadrats (total 70 quadrats per site) within which cattle tracks were recorded each year (only 56 quadrats were evaluated at Lime Cove in 2008).



a) **b)**

Figure 13. An example of spatial distribution of *Astragalus geyeri* var*. triquetrus* on Sandy Cove: a) 2008; b) 2009. Grid 5 is shown.

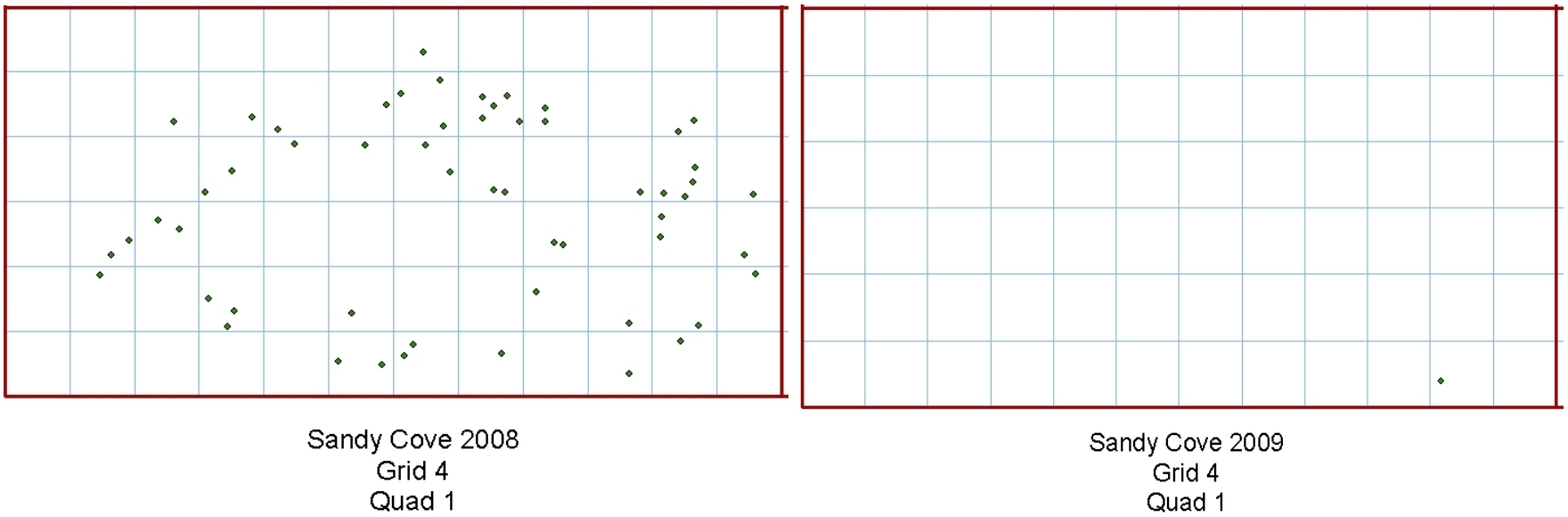


Figure 14. An example of spatial distribution of *Astragalus geyeri* var. *triquetrus* on Sandy Cove: a) 2008; b) 2009. Grid 4 Quadrat 1 is shown.