Response of the Giant Garter Snake (*Thamnophis gigas*) to Water Primrose (*Ludwigia hexapetala*) Removal at the Cosumnes River Preserve

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Final Report Submitted to the Central Valley Project Conservation Program - Habitat Restoration Program

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Eric C. Hansen[1], Harry McQuillen[2], Sara Sweet[3], Satya Gala[4], and Jaymee Marty[5].

[1]Consulting Biologist, 2020 U Street, Suite 300, Sacramento, CA 95818; echansen@sbcglobal.net. [2]U.S. Bureau of Land Management, 13501 Franklin Blvd., Galt, CA 95632; hmcquill@blm.gov. [3] The Nature Conservancy, 13501 Franklin Blvd., Galt, CA 95632; ssweet@tnc.org. [4]Robertson-Bryan, Inc., 9888 Kent St., Elk Grove, CA 95624; satya@robertson-bryan.com. [5]The Nature Conservancy, 2015 J Street, Suite 103, Sacramento, CA 95811; jmarty@tnc.org.

Abstract

The giant garter snake (*Thamnophis gigas*) (GGS) is state and federally listed as a threatened species. The Badger Creek population, located in southern Sacramento County, California is one of 11 extant populations recognized range-wide by the U.S. Fish and Wildlife Service. Of those 11 populations, the Badger Creek population has been determined to be the most genetically distinct from all others. Giant garter snakes were formerly found throughout portions of Badger Creek. However, its local range has apparently shrunk in recent decades to include only the isolated marsh forming at the confluence of Badger and Willow Creeks at the Cosumnes River Preserve (Preserve). This reduction may be contemporaneous with changes in regional hydrology affecting the upper reaches of the watershed.

Recent changes in local GGS distribution have also occurred within the marsh at the Preserve. Data from the marsh suggest that one explanation for the distributional changes may be the recent expansion of invasive yellow water primrose (*Ludwigia hexapetala*) that has filled in GGS open-water foraging habitat with a dense monoculture of live primrose and its accumulated biomass. This drastic change in habitat conditions within the marsh has potentially caused premature drying of the open-water foraging habitat during the critical summer active season for GGS, thereby effectively reducing the availability of prey for the snakes. The level of impact of water primrose on GGS, however, remains debated by some experts.

In 2008 the Preserve began a pilot project (Project) to test whether restoration of open-water foraging habitat resulted in the return of GGS to previously occupied areas of the marsh. Pre-restoration surveys in summer 2008 found dense concentrations of GGS in the last remaining 7+/- acres of remnant open-water areas within the marsh, but essentially no usage by GGS in the proposed primrose-infested restoration site. In September 2008, an approximate one-acre area of the marsh was excavated to create new open-water habitat through the mechanical removal of live primrose and its accumulated biomass. Post-restoration surveys found a significant increase in the number of GGS within the newly restored open-water area, thereby demonstrating that GGS will immediately use newly created or restored habitats when they are made available to them. Giant garter snakes that had been captured and marked in previous years in remnant open-water habitat in other parts of the marsh had also colonized the newly restored habitat. This Project demonstrated that the creation or restoration of open-water foraging habitat for GGS by mechanically methods is an appropriate land management tool in GGS habitat without adversely affecting individual snakes or the population as a whole. While this project was successful in restoring open-water habitat in the short term, the long-term objective

remains to couple the creation or restoration with long-term management strategies to control the highly invasive yellow water primrose, as well as ensuring a reliable, long-term water source for the GGS inhabiting the Preserve's marsh.

Introduction

Habitat fragmentation and alteration caused by the intensification of human uses on the landscape have numerous negative impacts on habitat quality and biodiversity. For wetlands in California, draining and conversion to cropland and urban development has reduced the once vast expanses of marshland to less than 10% of its extent prior to European settlement (Dahl and Johnson 1991). Even relatively natural habitat that remains physically intact in these highly altered landscapes is often functionally impaired.

Wetlands are important natural features that provide critical ecosystem functions including regulation and maintenance of hydrologic processes through flood attenuation, groundwater recharge and water quality improvement (Wilen and Bates 1995). Wetlands also provide critical habitat for fish and wildlife species, with over one third of all threatened and endangered species occurring in wetlands (http://www.epa.gov/bioiweb1/aquatic/importance.html).

One such species, the giant garter snake (**Figure 1a**), is classified as a threatened species under both the State of California and Federal Endangered Species Acts. The species historically persisted from the northern portions of the Sacramento Valley southward to the southern portion of the San Joaquin Valley, generally in low-gradient streams, valley-floor wetlands, and marshes in California's Central Valley (Fitch 1940). They require freshwater wetlands for foraging on fish and amphibians (their primary prey species), upland areas for basking, upland burrows near aquatic habitat for summer shelter, and higher elevation uplands for winter habitat (Hansen and Brode 1980; USFWS 1993; USFWS 1999).

The Preserve's Badger Creek Unit is home to one of 11 distinct and separate populations of giant garter snakes recognized by the U.S. Fish and Wildlife Service (D. Kelly, pers. comm. 2009). Concentrated at the confluence of Badger and Willow creeks in a wetland known as "Snake Marsh" by Preserve staff, the Cosumnes population is unique in that a natural marsh and creeks make up most of the existing habitat. In other population areas rice crops and managed wetlands comprise most of the habitat (*e.g.,* Wylie et al. 1997). Recent genetic analysis demonstrates that the GGS in Snake Marsh are relatively unique compared to GGS in other population areas (Paquin *et al.,* 2006; Engstrom and Olson 2007).

Over the last several decades, new species of plants have dramatically changed the plant community composition of shallow, low-gradient water bodies in the Central Valley. The changes in vegetation have had strong influences on the hydrology and faunal communities that formerly characterized these habitats. These changes in turn affect wildlife and fish species that rely on these habitat types for their survival. For example, GGS are found in Central Valley wetlands with perennial water. While they may tolerate short-term loss of aquatic habitat, a prolonged drying of wetland habitat (*e.g.,* due to changes faunal communities that further exacerbate hydrological changes) would have significant adverse effects on a population mainly due to a loss of the snakes' prey base.

The problem at Snake Marsh is that the quality and quantity of the aquatic habitat has degraded rapidly over the past decade or more due to changes in hydrology and the faunal communities. A highly invasive yellow water primrose (*Ludwigia hexapetala*; (Hook. and Arn.) Zardini, Gu and Raven) (**Figure 1b**) has dramatically increased in cover while simultaneously reducing or completely eliminating GGS open-water foraging habitat in Snake Marsh, as well as other aquatic habitats on the Preserve and adjacent lands. The hydrologic integrity of Snake Marsh is already tenuous during the dry summer months due to both a lowered groundwater table and an unreliable water supply that is dependent on surface inputs from agricultural run-off. The additional stress of a highly invasive aquatic plant that can, in a very short period of time, completely eliminate open-water foraging habitat for GGS can have irreversible adverse effects on this already State and Federally listed "threatened" species.

In this Project, we documented the response of GGS and the invasive yellow water primrose to the mechanical removal of live primrose and its accumulated biomass from an approximate one-acre area within Snake Marsh and, we make recommendations for future actions that are necessary in Snake marsh to ensure the survival and recovery of the GGS at this location.

Photo: EC Hansen

Figure 1a. Giant garter snake (*Thamnophis gigas*)

Photo: The Nature Conservancy

Figure 1b. Yellow water primrose (*Ludwigia hexapetala*)

Background

Site Description & Location

The project site is located in the Badger Creek Unit of the Preserve in south Sacramento County, California (**Figure 2**). The Badger Creek Unit is located at the confluence of Badger Creek and the Cosumnes River, extending east to the Union Pacific Railroad near highway 99 between the Arno and Dillard Road interchanges (**Figure 3**). The Unit is entirely within the 100-year floodplain and supports several natural communities including valley oak riparian forest, annual grasslands, and freshwater wetlands. The 827-acre Badger Creek Unit is owned by the California Department of Fish and Game. The property formerly comprised a portion of the 4000-acre Valensin Ranch that was acquired, in part, using previously awarded CVPIA funding.

Hydrology

Badger and Willow creeks are both portions of the California Trough section of the Cosumnes River watershed (Phillip Williams and Associates 1997). Willow Creek is a tributary merging with Badger Creek at Snake Marsh on the west side of the Union Pacific Railroad, just west of Highway 99. Badger Creek is a tributary merging with the Cosumnes River approximately 2.25 miles west of Highway 99. It is characterized by a series of annual and perennial marshland habitats connected by open and wooded low-gradient channels. Approximately 0.5 miles east of Highway 99, Badger Creek divides into north and south tributaries that extend eastward approximately 7 to 8 miles. The North and South forks are characterized by annual and perennial marshland, artificial channels, and retention ponds supported mainly by agricultural runoff during the dry season. The downstream reach of Badger Creek below Snake Marsh traverses through a valley oak riparian forest and annual grassland area before draining into the Cosumnes River. Marshy habitat and the conditions that encourage use by GGS are not present below Snake Marsh.

The historical hydrology at Badger Creek was apparently much different than today's, with the pre-development water table in the Cosumnes River vicinity existing near ground levels, providing persistent surface water in channels and depressions year-round, despite varying seasonal precipitation in the basin (Phillip Williams and Associates. 1997). No historical flow data are available because there are no stream gauges on Badger Creek or its tributaries. Badger Creek's small and low-elevation watershed does not sustain any natural flow during the summer season. However, in the early to mid-1900s, water may have been present in deeper pools of the channel due to the presence of near-surface groundwater. **Figures 4 and 5** present the groundwater elevations in Sacramento County in fall 1982 and fall 2002, respectively. The groundwater table in this region had already reached depleted levels by 1982, presumably as a result of long-term overdraft earlier in that century. This decline has disconnected groundwater sources from the channel bottom, thereby eliminating the creek's historical source of dry season water. Current hydrology relies upon varying seasonal precipitation and agricultural runoff that provides no guarantee that suitable habitat can be sustained in perpetuity.

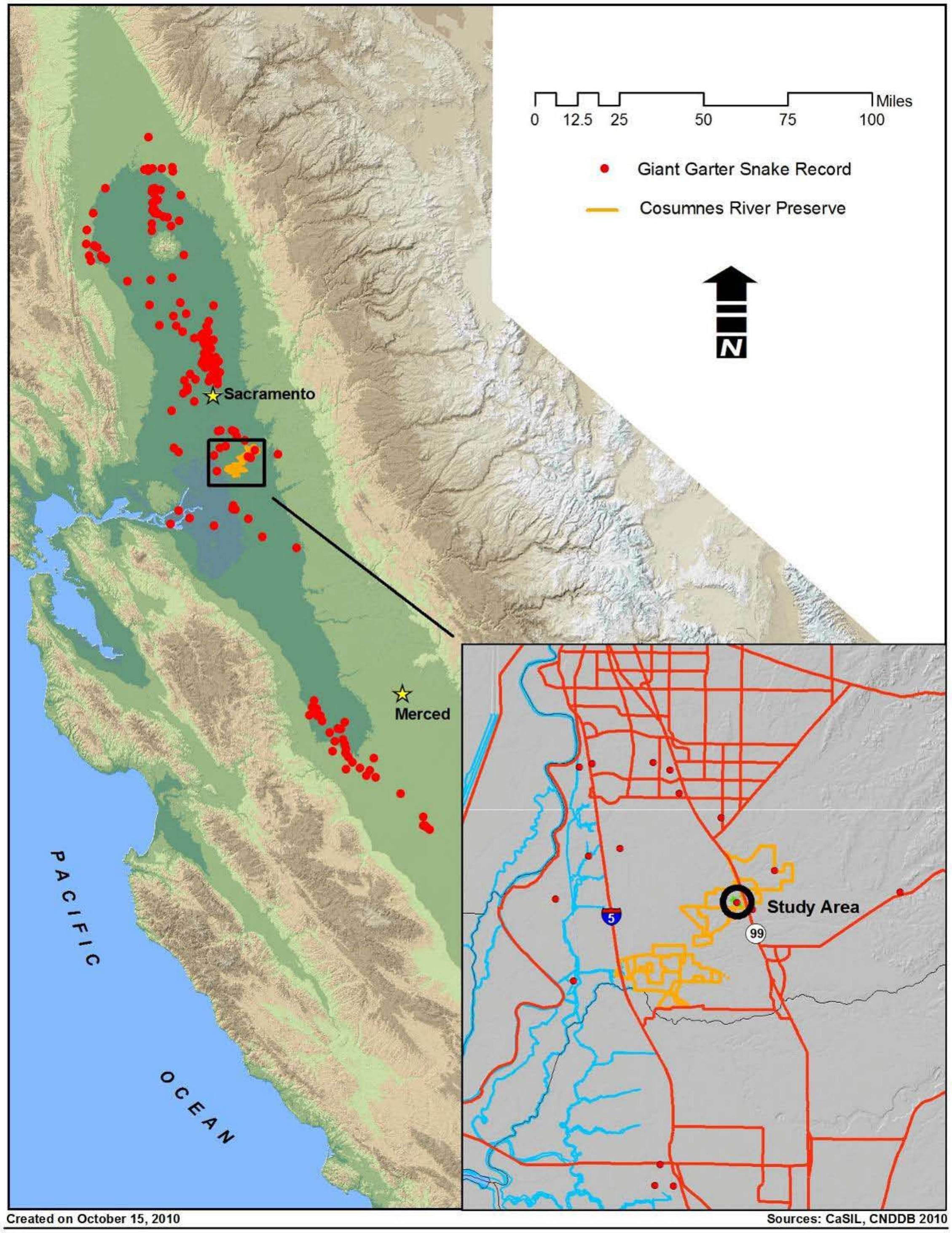


Figure 2. Project location

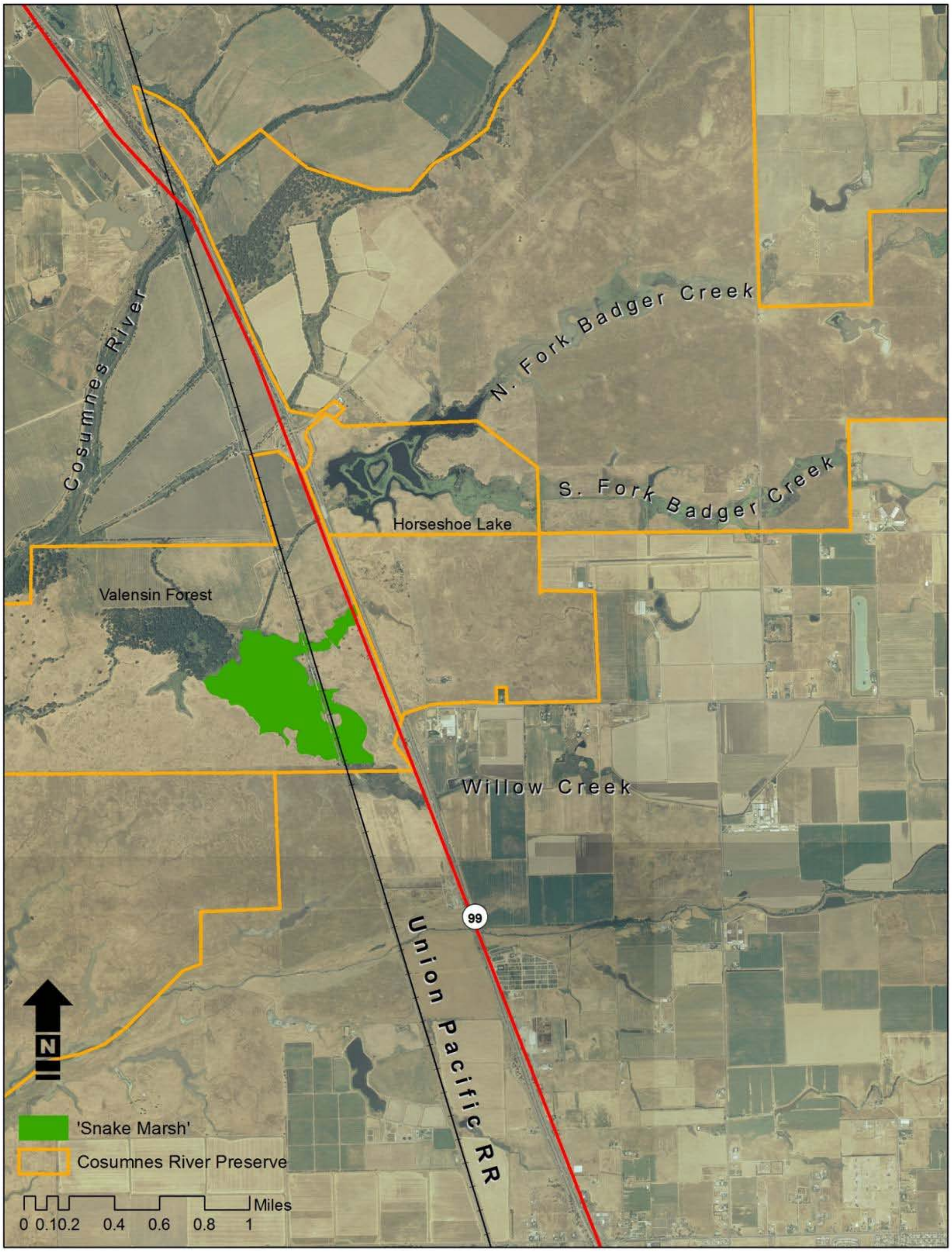


Figure 3. Project area detail

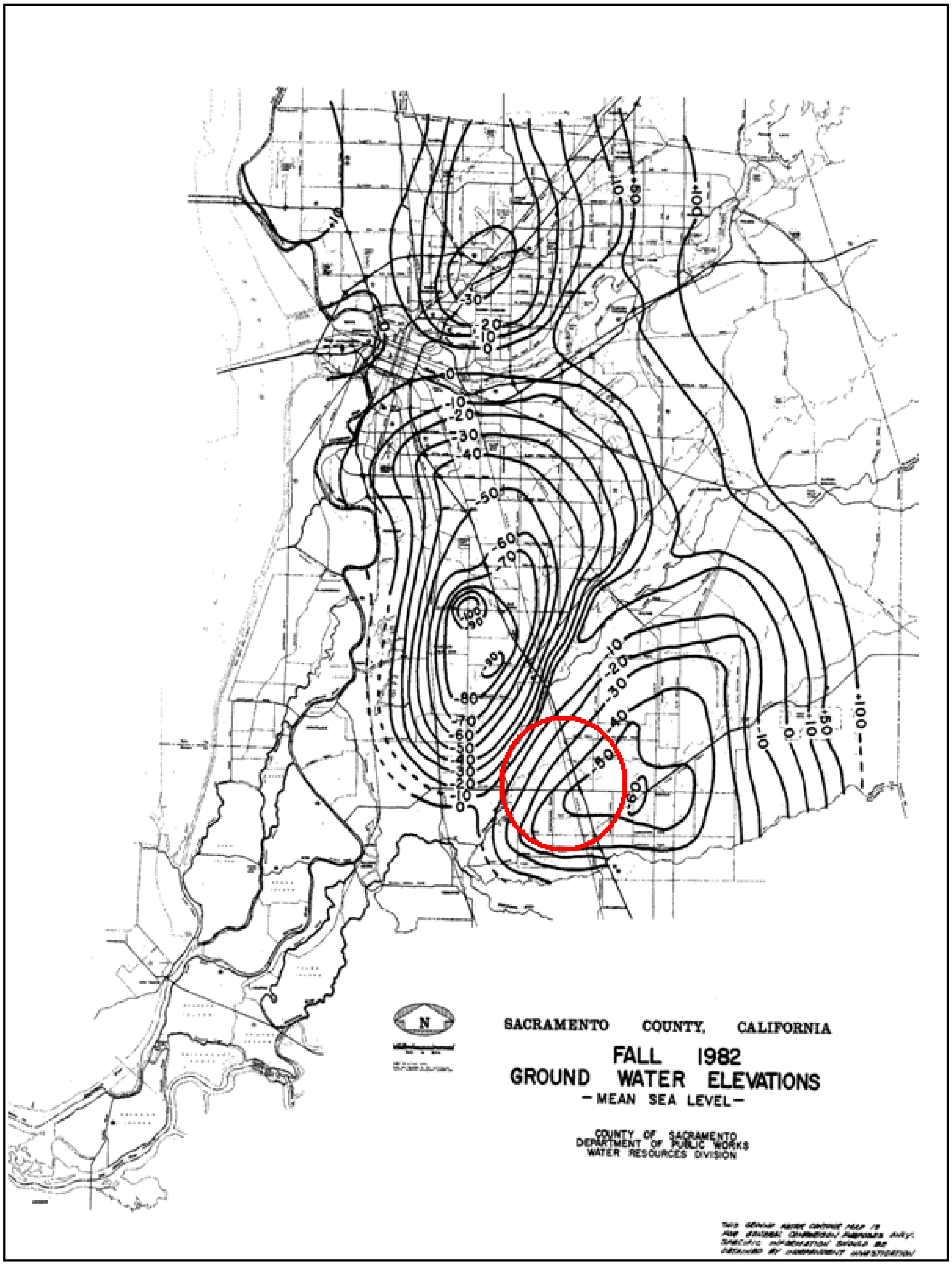


Figure 4. Fall 1982 Ground Water Elevations in Sacramento County (Project Site is shown in red).

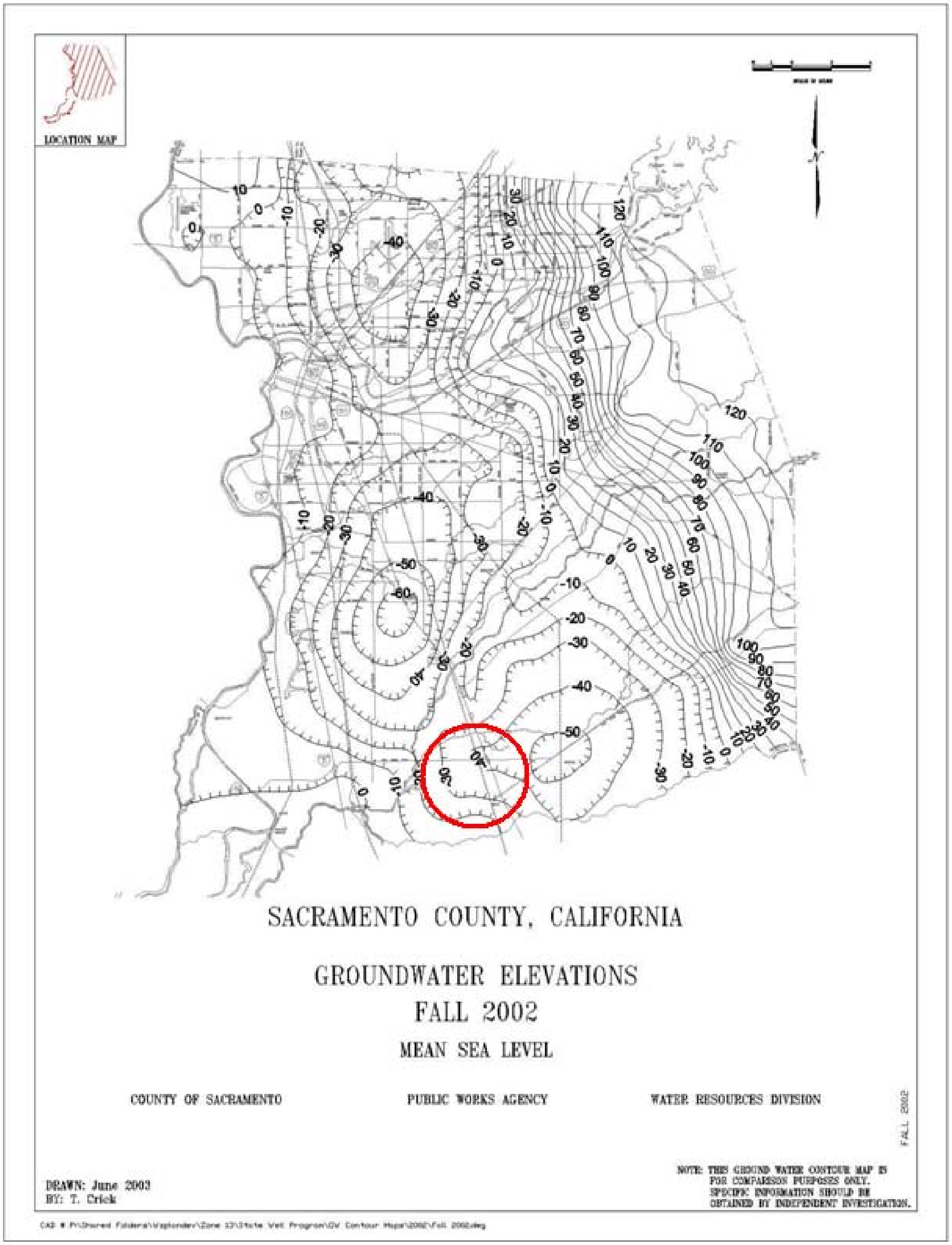


Figure 5. Fall 2002 Ground Water Elevations in Sacramento County (Project Site is shown in red).

Vegetation

Historically, Central Valley perennial marsh habitat was dominated by cattails (*Typha* spp.) and tules (*Schoenoplectus* spp.). Shallow margins and adjacent seasonally inundated areas harbored a variety of more amphibious species such as knotweeds (*Polygonum* spp.), water plantains (family Alismataceae), loosestrifes (family Lythraceae), docs (*Rumex* spp.), and native water primroses (*L. repens* and *L. palustris*). Deeper areas excluded most native emergent vegetation, although sparse populations of submerged plants like coontail (*Ceratophyllum demersum*) and waterweed (*Elodea* spp.) existed. Since the 1500s, many additional species have been introduced. Several of these non-natives are in the same genus or family as the natives, but they grow more aggressively and/or have wider environmental tolerances. Examples are curly doc (*R. crispus*), Brazilian waterweed (*Egeria densa*), and Uruguayan water primrose (*L. hexapetala*).

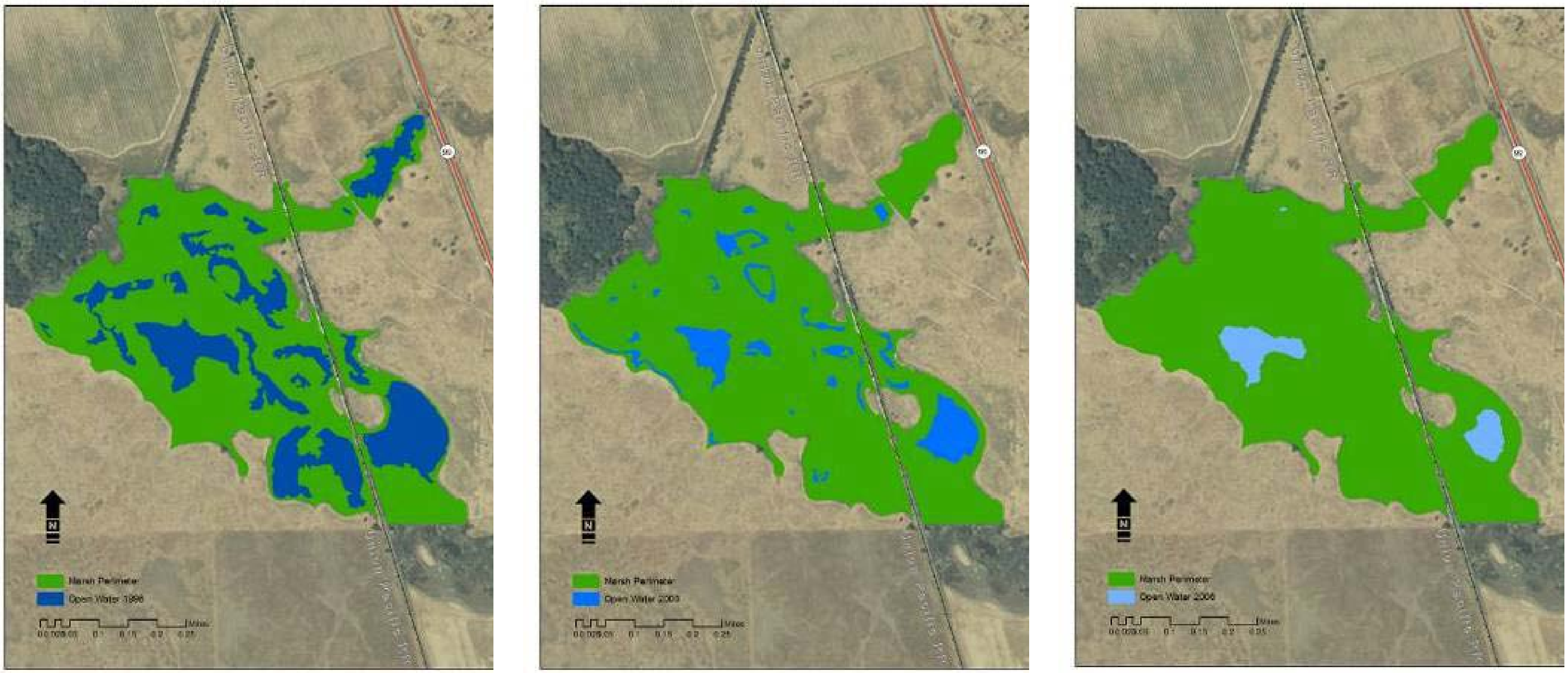
Many native species occur in perennial marsh habitats on the Preserve today including (*Typha* spp.) and tules (*Schoenoplectus* spp.), redstem (*Ammannia coccinea*), knotweed (*Polygonum* spp.), cocklebur (*Xanthium strumarium*), smooth goldfields (*Lasthenia glabrata*), northern water plantain (*Alisma triviale*), bigstem spikerush (*Eleocharis macrostachya*), and rushes (*Juncus* spp.). Non-natives, however, can affect composition dramatically. One genus that can become dominant in these wetland habitats is *Ludwigia.* Several species of *Ludwigia* have been collected in California, including *L. palustris, L. repens, L. peploides,* and *L. hexapetala*. Herbarium specimens document all but *L. hexapetala* as present in California from at least 1900. In the 1940s, *L. hexapetala* was collected in California from coastal sites from San Diego to Arcata. Only in the mid-1990s did it begin to be recognized as a troublesome invader among botanists, but its similarity to other *Ludwigia* species likely prevented widespread recognition.

Ludwigia hexapetala infestations quickly spread throughout shallow water bodies such as Snake Marsh (**Figure 6**). The growth form is fundamentally different from other *Ludwigia* spp. with dense mats of underwater stems, adventitious roots, and trapped sediment that clog the entire water column. The dense mats of underwater stems with their adventitious roots form the key factor differentiating *L.* hexapetala from historic marsh vegetation. Every summer, the plant produces large amounts of above-ground biomass. While alive, it traps great quantities of sediment. When it senesces in mid-winter, the stems fold down onto each other in a dense layer. The next summer's growth continues the cycle until eventually *L. hexapetala* transforms a marsh with formerly open-water areas into a saturated peat-like bog within a few years, leaving the new surface firm enough to support the full weight of an adult without getting wet. This is the prevailing condition in Snake Marsh today. Anecdotal observation by Preserve staff and other land managers of local wetlands fully support the above observations. Historical aerial photographs further corroborate claims that *L. hexapetala* will rapidly spread throughout open water and eventually render it unsuitable habitat for many obligate wetland species.

August 1998
Open Water = 53.2 ac

2003
Open Water =13.1 ac

August 2008
Open Water = 6.9 ac



Δ = -75%

Δ = -45%

Figure 6. Development of *L. hexapetala* resulting in an estimated 87% total reduction in open water over a 10-year period at the Cosumnes River Preserve in southern Sacramento County, California (1998 to 2008). *Green shading represents L. hexapetala and blue shading represents open water.*

Giant Garter Snakes

Conversion to agriculture and urban uses has led to an estimated 91% reduction in California's total wetlands since the 1780's (Dahl 1990). In the Central Valley alone, it is estimated that 43% of freshwater wetlands have been lost or converted since 1939 (Frayer et al. 1989). This loss of historical wetland habitat has resulted in extirpations or serious declines throughout much of the range of the giant garter snake (GGS), thereby resulting in the snake being listed on both the federal and state endangered species lists as "threatened" with extinction.

The GGS is endemic to the wetlands and marshes of California's Central Valley. It has been described as among California's most aquatic garter snakes (Fitch 1940). Throughout the Cosumnes River Watershed, GGS are known to have occupied reaches of Badger Creek, Willow Creek, and Snake Marsh at the confluence of these creeks (CNDDB 2010; G. Hansen 1988). East of Highway 99, GGS were reported in Willow Creek and North Fork Badger Creek as recently 1986 (CNDDB 2010). Residual populations may persist upstream (east) of Highway 99, however, extensive surveys conducted in 2001 and 2002 failed to detect GGS in the upper reaches, presumably due to changes occurring in local hydrology (Hansen 2003). Contemporaneous surveys conducted west of Highway 99 throughout Laguna Creek, Lost Slough, and associated wetlands also failed to detect GGS (Hansen 2003). Based on the last available survey data, the perennial waters of Snake Marsh now support the only verified population of GGS persisting in the watershed today (Hansen 2003).

Trapping and radio telemetry surveys at Snake Marsh over the past decade indicate a shift in the spatial distribution of giant garter snakes that appears to correlate with changing habitat conditions (Hansen 2003). Radio-marked snakes tracked between 2002 and 2003 altered their primary foraging areas in a pattern consistent with the concurrent expansion of invasive yellow water primrose, with all radio-marked snakes moving from formerly occupied habitat to areas where residual open-water foraging habitat still remained in advance of water surface occlusion by yellow water primrose.

Methods

Restoration Methods

In 2008 the Bureau of Land Management, in collaboration with Preserve Partners and others, secured funding from the Central Valley Project Habitat Restoration Program to conduct a pilot restoration and research project (Project) aimed at removing live yellow water primrose and its accumulated biomass to restore wetland function in a highly degraded portion of Snake Marsh. The main objective of the Project was to create immediate open-water foraging habitat for the GGS by removing the invasive primrose (*L. hexapetala*) and up to six feet of underlying sediment and plant biomass from an approximate one-acre portion of Snake Marsh. A secondary objective of the project was to use the dredged spoils from the newly created open-water area to enhance the adjacent upland habitat by creating additional winter hibernacula above the typical flood stages in and around Snake Marsh. A final objective of the restoration effort was to demonstrate that open-water foraging habitat could be successfully restored in the presence of a known population of giant garter snakes without adversely affecting individuals or the population as a whole.

A small remnant pond retaining roughly twenty square feet of open water within a continuous invasive primrose mat on the north side of Snake Marsh was selected as an “anchor” point for the restoration effort. The anchor pond was approximately two feet deep at the start of the restoration so we used that depth as the minimum depth for the shallow, upslope (east) end of the expanded pond. Restoration design was driven by hydrology and surface elevation with limits imposed by site characteristics and equipment. The general plan, however, was to restore one end of the open-water area to two feet deep, like the existing residual pond, and the other end to a maximum of six feet deep in order to observe the response of the invasive primrose to varying water depths throughout the newly restored area.

Prior to beginning the excavation of the live primrose and biomass, a bulldozer was used to build excavation pads that were approximately 12 feet wide and 4 feet deep to allow the equipment access into the primrose infested area (**Figure 7a**). A 60-foot long-reach excavator with a 35 to 50-foot effective reach, depending on material density and compaction, *etc.*, was then used from stationary locations inside the open-water area footprint to remove the live primrose, its accumulated biomass, and underlying sediment. A series of three earthen excavation pads were eventually constructed in order to provide access to the farthest corners and edges of the newly restored open-water area.

The live primrose and biomass was used to create hundreds of spoil piles in a proposed upland enhancement site that was immediately adjacent to the newly restored open-water area. The enhancement of the upland site was intended first and foremost to provide benefits for GGS by creating additional high ground winter hibernacula. High ground that is above typical flood stages is critically important at this site due to its location along the Cosumnes River. The high ground is also a critical step in getting snakes that are known to use the Union Pacific Railroad grade as a hibernacula site (Hansen 2003) away from railroad tracks and back into the upland areas that are protected in perpetuity by the Preserve. In October 2008 after the spoil piles had dried sufficiently, the piles were leveled and contoured into the existing landscape, effectively bringing the elevation of the site up about ten additional feet equivalent to approximately the elevation of a small naturally occurring high ground area on the site. Once completed, the stockpiled topsoil was spread evenly over the newly created high ground and the site was re-seeded with a native grass and forb mixture.

When completed, the newly restored open-water pond ranged in depth from two feet on the east side to approximately six feet on the west side as planned. The pond was subdivided east to west by a low dirt weir (**Figure 7b**) to ensure the natural drawdown of the pond was relatively even throughout the entire surface area, rather than unidirectional towards the deepest end (**Figure 8).**

Photo: The Nature Conservancy

Figure 7a. Excavation and construction of the earthern excavation pads, which were left in place after construction.

Photo: The Nature Conservancy

Figure 7b. Earthen weir ensuring pond drawdown remains even rather than unidirectional with regard to elevation.

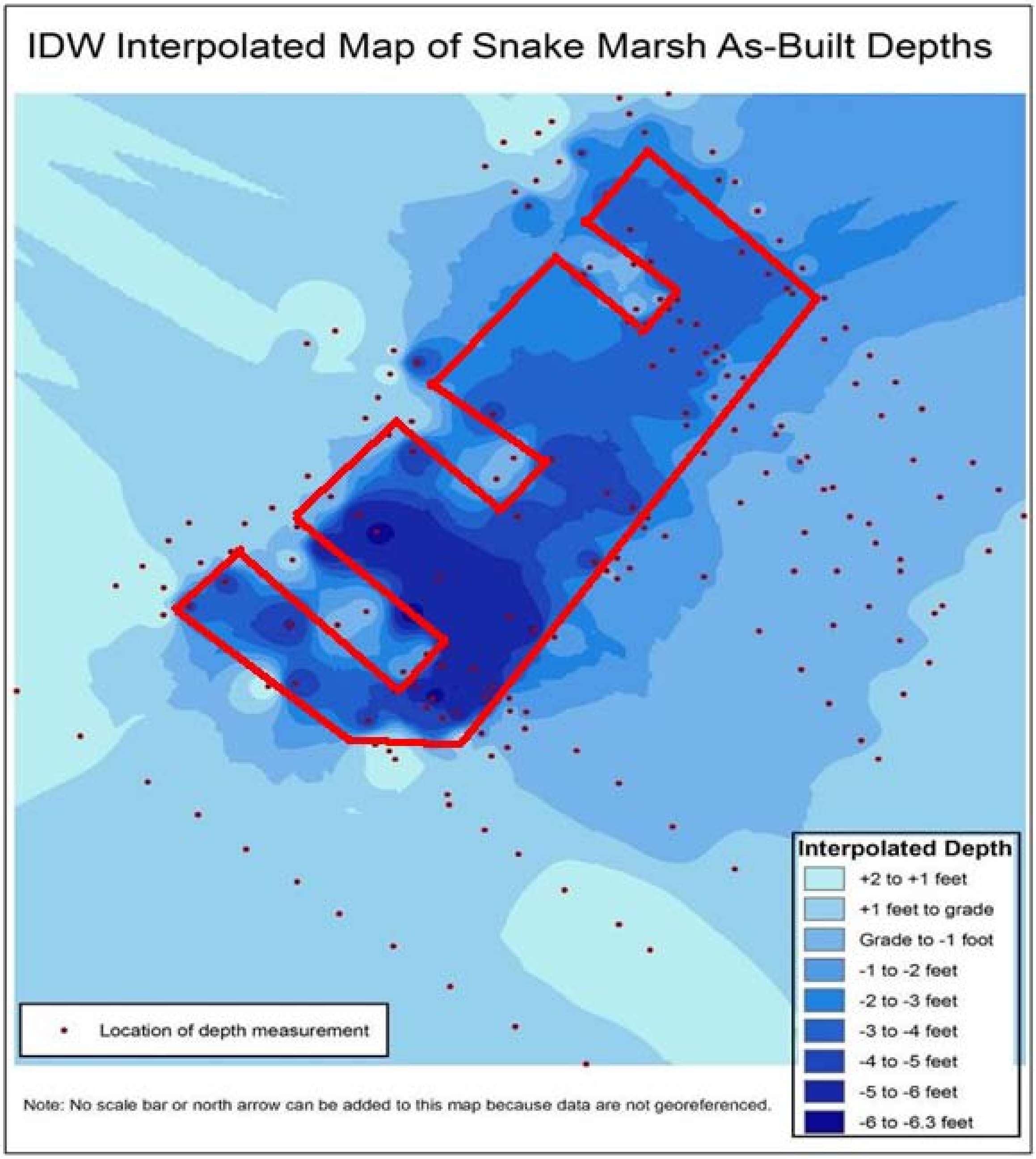


Figure 8. As-built depth contours of the restoration site following excavation. ***The red line is an approximation of the edge of the newly restored area.***

Biological Monitoring Methods

In order to assess species and habitat response to site restoration, we conducted sampling for GGS, vertebrate prey species, vegetation, and water quality in the restoration site and two control sites, which were chosen because they possessed sufficient open water needed to trap effectively and to provide effective comparisons with restored open water. Each of the three areas is referenced in relation to the Union Pacific Railroad (UPRR) tracks, which bisects Snake Marsh from north to south. Naming conventions for the three sites are as follows: (1) East Marsh (east of UPRR), (2) West Marsh (west of UPRR), and (3) Restoration Site (West of UPRR, North end of Snake Marsh (**Figure 9**).

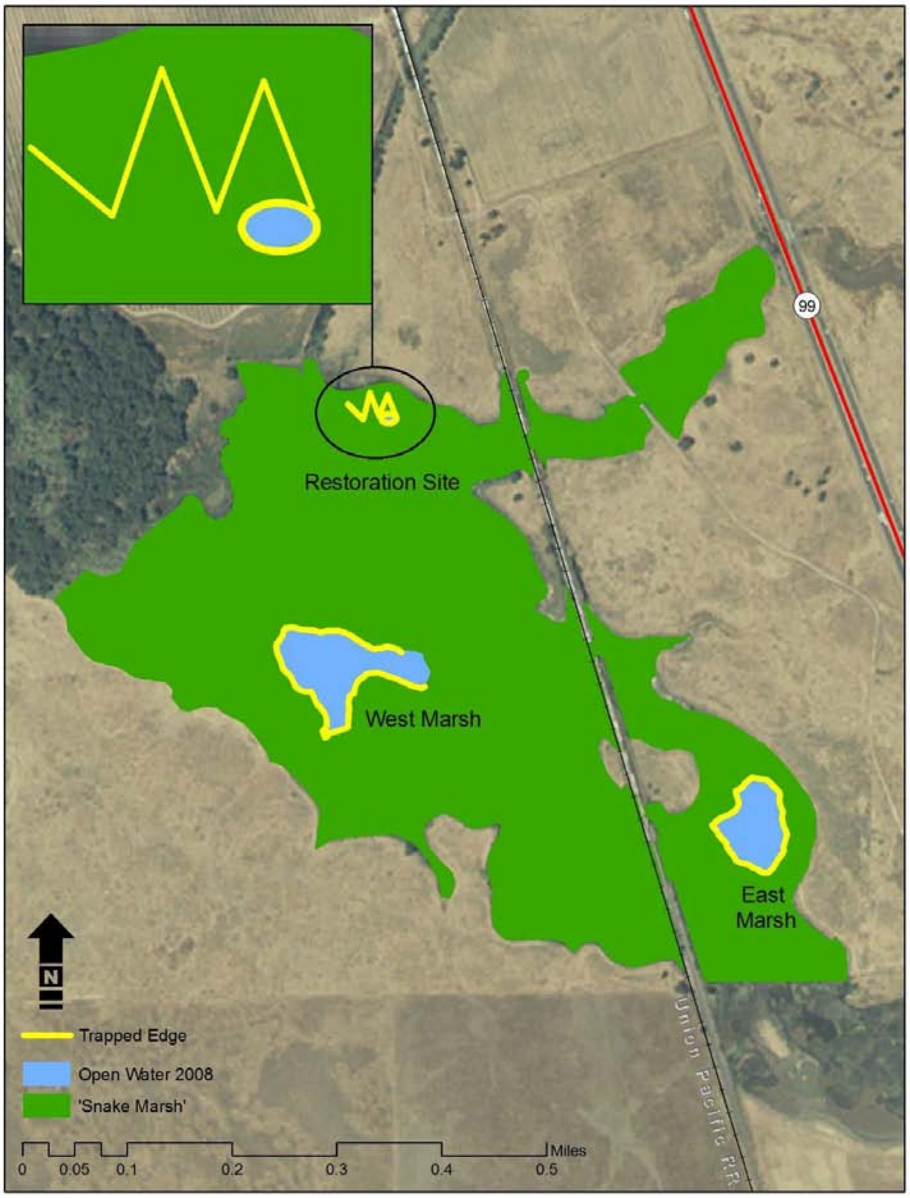


Figure 9. 2008 Trapping Locations (drift fence panels are indicated by the yellow zigzag line)

Giant Garter Snake

Standard sampling techniques were used to survey GGS (Casazza et al. 2001), with 50 modified floating minnow traps placed along the open water/vegetative interface in each of the three sampling units. Because the open water required for aquatic trapping was limited at the restoration site prior to excavation, trenches were cut into the vegetation and soil to accommodate panels of vertical silt barrier installed to create drift fence array intended to intercept snakes moving through the excavation area.

In 2008, four traps were placed along the perimeter of a small pool of open water at the Restoration Site and 46 traps were set in conjunction with the drift fence array (Figure 9). As summer water gradually receded, traps going dry along the drift fence were disabled to avoid potential mortality associated with thermal stress. Eight traps were ultimately moved from the drift fence to the open water pool. Precise trap replication was not possible in 2009 due to habitat changes resulting from the restoration. Instead, 30 traps were set along the perimeter of the restoration pool and the remaining 20 traps were divided between four drift fence panels (five traps each) at four corners of the restoration pool (**Figure 10**). As in 2008, drift fence traps were eventually disabled in response to gradually receding water levels.

All traps were checked daily. Global positioning system (GPS) units were used to determine the geocoordinates of capture locations. The vegetation type, approximate water depth, and substrate type were recorded at each trap, and time of day and ambient temperature were recorded each time traps were checked.

Data were collected from all snakes upon capture. Weight, total length, snout to vent length (SVL), sex, scale counts on head and mid-body, and other physical features such as scars and tumors were noted. Captured snakes were implanted with passive integrated transponder (PIT) tags for permanent identification. For snakes that were too small to implant with PIT tags (≤ 30 grams), medical cautery units were used to heat brand caudal scutes in a pattern consistent with established scale-clip marking techniques (Winne *et. al.* 2006). Prey species were periodically catalogued, counted, and removed from traps, and catch per unit effort (CPUE) was calculated for each prey species at each trapline.

Pair-wise analyses (2-sample t-tests) were conducted using the statistical software package JMP 4.04 (SAS Institute Inc., Cary, North Carolina) to assess potential differences in individual covariates such as electrical conductivity (EC), pH, and snake size and abundance between years at each site. Analysis of variance (ANOVA) techniques were not required since we did not test for significant variance amongst more than two groups in any of our comparisons. Multiple comparisons tests were not required because all pair-wise comparisons were made independently, between only two groups, and the results were not statistically analyzed as a whole.

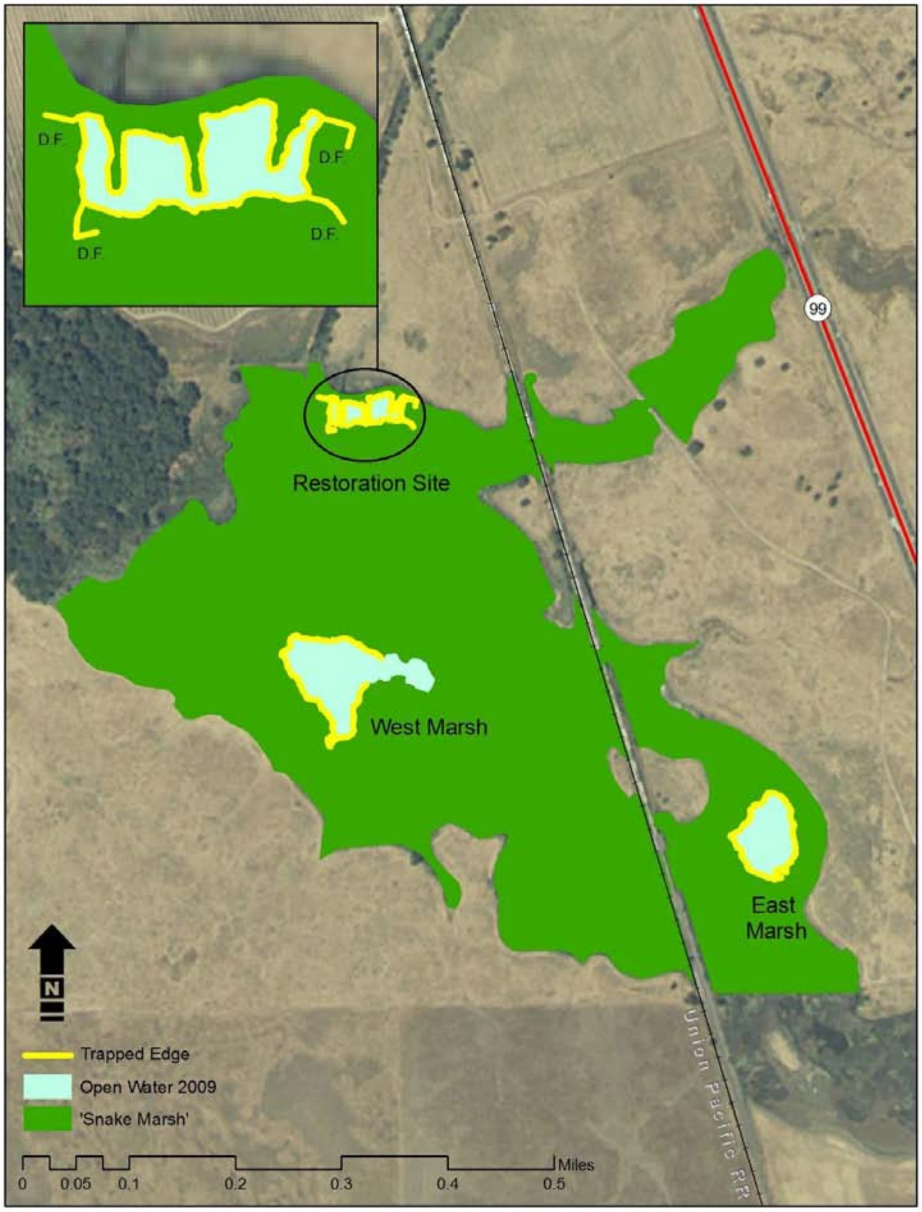


Figure 10. 2009 Trapping Locations (D.F. indicates drift fence panels)

Vegetation

Primrose re-growth was documented qualitatively through photo-monitoring and anecdotal observation. GPS units were used to document the primrose edge in each unit before and after construction and at the end of the sampling season in September 2009. The Geographic Information Systems (GIS) program ArcGIS 9.2 was then used in conjunction with aerial photographs obtained from the National Agricultural Imagery Program (NAIP) to estimate change in the open water surface during the first two years of the pilot project by digitizing and comparing the water edge.

Water Quality

Water quality metrics including pH, conductivity (EC), and temperature, were measured in 14 unique events using a portable YSI 556 Multi-Probe unit at each of the three sites before and after restoration.

Watershed & Hydrology Characterization Methods

Robertson-Bryan (2009) (**Appendix 1**) provide a detailed explanation of the methods used to characterize the Badger Creek watershed. A brief summary is provided below.

Development of a Seasonal Flow Regime

An estimated flow regime for Badger Creek was developed based on a rainfall-runoff relationship, because there are no stream gauges on Badger Creek or its tributaries. The National Resource Conservation District (NRCS) curve number method was chosen to estimate flow from precipitation. The NRCS method classifies land use and soil type by a single parameter called the Curve Number (CN). Soil data and information specific to the Badger Creek study area was obtained through the Web Soil Survey (WSS) tool provided by NRCS. Land use data were extracted from the Department of Water Resources land use data for Sacramento County collected in the year 2000.

Historical rainfall data collected from three rainfall stations near the Badger Creek watershed (Wilton Road, Herald, and Rio Cosumnes Correctional Facility), along with soil classifications and land use distributions specific to Badger Creek, were used to calculate stream flow runoff. The historic data were taken from 1995-2007 water years. This period included every year type as defined by the San Joaquin River Index: wet (6 yr), above normal (2 yr), below normal (1 yr), dry (3 yr) and critical (1 yr). Therefore, a flow value could be estimated for each month of each year type using actual historic data. Because none of the precipitation gauges lie within the Badger Creek watershed, the estimated runoff for the Badger Creek watershed was calculated as the average estimated runoff resulting from the three precipitation stations that surround the Badger Creek watershed.

Dry-season flow sources were evaluated by investigating field conditions in the summer of 2008.

Identification of Water Needs

The residual water demand for Snake Marsh was defined as the difference between water supply (as determined through the calculations of the seasonal flow regime) and water loss. This was calculated for each month of the year. Water loss during the summer at Snake Marsh occurs through evapotranspiration (ET) of plants (primarily primrose), evaporation directly to the air, and subsurface seepage through the ground. Due to lack of information on ET of primrose, we used the ET values of alfalfa for the San Joaquin Valley to predict theoretical losses at Snake Marsh.

Results

The most immediate result of this Project was the successful restoration of approximately one-acre of open-water foraging habitat for GGS without any adverse effects to individual snakes or the population overall. The second immediate result of the Project was the creation of an approximate one-acre area of additional high ground that can serve as a summer aestivation or winter hibernacula area for GGS, especially during winter flooding events such as the December 2010, 11,000 cubic feet per second (cfs) event (as measured at Michigan Bar) shown in **Figure 11**.

Response of Giant Garter Snakes to Restoration

Appendix 3 provides additional, detailed statistical information about the GGS response results.

In 2008, five to six weeks prior to restoration, 170 individual giant garter snakes were captured in 265 capture events (47 individuals were captured more than once). Of these 170 individuals, 59 were male and 111 were female. Five of the individuals captured (1 male and 4 females) had been marked during surveys in previous years. Four of these snakes were marked by E. Hansen, two in 2002 and two in

2003; the other is assumed to have been marked by USGS researchers in the late 1990's (Wylie et al. 1997). The breakdown of results at each trapline was as follows: 82 individuals (25 males and 57 females), including the five previously marked individuals, were captured in 105 capture events in the East Marsh; 9 individuals (5 males and 4 females) were captured in 10 capture events at the Restoration Site, including two individuals captured by hand during biological monitoring of the excavation work; and 79 individuals (29 males and 50 females) were captured in 150 capture events in the West Marsh. No snakes were captured in more than one trapline or area during 2008.

In 2009, one year after the restoration, 195 individuals were captured in 284 capture events (55 individuals were captured more than once). Of these 195 individuals, 69 were male and 126 were female. Two females had been marked prior to 2008. One of these snakes was marked by E. Hansen in 2003; the other is assumed to have been marked by USGS researchers in the late 1990's (Wylie et al. 1997). The breakdown of results at each trapline was as follows: 39 individuals (23 males and 16 females) were captured in 44 capture events in the East Marsh; 43 individuals (12 males and 31 females), including the individual marked by E. Hansen in 2003, were captured in 60 capture events at the Restoration Site; and 113 individuals (34 males and 79 females), including the individual assumed to have been marked by USGS, were captured in 180 capture events in the West Marsh. No snakes were captured in more than one trapline or area during 2009.

Of the 195 individuals captured in 2009, 23 were recaptures from the 2008 field season. Eighteen of these were captured at the same location in 2008 and 2009 (two at the East Marsh and 16 at the West Marsh). Five individuals were captured at different locations in 2008 and 2009, including three individuals moving from the West Marsh to the Restoration Site, one individual moving from the Restoration Site to the West Marsh, and one individual moving from the East Marsh to the West Marsh. Additionally, one of the individuals captured at the Restoration Site in 2009 had previously been captured in the East Marsh by E. Hansen during 2003. As noted above, no snakes were captured in more than one trapping location within a single season. The numbers of individual GGS observed per year and by site are reported in **Table 1**. Sampling effort, and capture results, including individuals captured per unit effort (ICPUE), for each trapline in 2008 and 2009 are reported in **Table 2**.

Table 1. Numbers of individual GGS observed per year and by site

	East Marsh	West Marsh	Restoration Site	Total
2008				
Male	25	29	5	59
Female	57	50	4	111
Total	82	79	9	170
2009				
2008	23	34	12	69
2009	16	79	31	126
Total	39	113	43	195

Table 2: Trapping effort and capture results, 2008-2009. Statistically significant changes are shaded (observed decrease) or highlighted (observed increase).

Year	Location	Trap Days	Captures	Individuals	ICPUE	Trend
2008	East Marsh	2,150	105	82	0.0381	-
	West Marsh	1,500	150	79	0.0527	-
	Restoration Site	1,068	10*	9*	0.0066	-
	Overall	4,718	265*	170*	0.0356	-
2009	East Marsh	2,246	44	39	0.0174	↓
	West Marsh	2,248	180	113	0.0503	-
	Restoration Site	1,718	60	43	0.0250	↑
	Overall	6,212	284	195	0.0314	-
Total	East Marsh	4,396	149	118	0.0268	-
	West Marsh	3,748	330	177	0.0472	-
	Restoration Site	2,786	70*	52*	0.0179	-
	Overall	10,930	549*	342*	0.0311	-

*Includes two individuals hand-captured by biological monitors during restoration work

In 2008, male GGS snout-vent length (SVL) ranged from 202 mm (Restoration Site) to 737 mm (East Marsh); mean SVL at the East Marsh, West Marsh, and Restoration Site was 518 mm, 436 mm, and 439 mm, respectively. In 2009, male GGS SVL ranged from 344 mm (East Marsh) to 768 mm (West Marsh); mean SVL at the East Marsh, West Marsh, and Restoration Site was 461 mm, 466 mm, and 528 mm, respectively. Among comparisons of mean male GGS SVL at each trapping location between years, a statistically significant (α=0.05) decrease in size was observed at the East Marsh from 2008 (518 mm) to 2009 (461 mm) (p=0.05). Additionally, in 2008, males captured at the East Marsh were significantly smaller than males captured at the West Marsh (436 mm) (p<0.01), and in 2009, males captured at the East Marsh (461 mm) were significantly larger than males captured at the Restoration Site (528 mm) (p=0.04). **Appendix 3** depicts additional statistical information about the distributions of male GGS size classes at each trapping location during 2008 and 2009.

In 2008, female GGS SVL ranged from 243 mm (Restoration Site) to 954 mm (East Marsh); mean SVL at the East Marsh, West Marsh, and Restoration Site was 650 mm, 590 mm, and 393 mm, respectively. In 2009, female GGS SVL ranged from 212 mm (Restoration Site) to 889 mm (West Marsh); mean SVL at the East Marsh, West Marsh, and Restoration Site was 553 mm, 603 mm, and 615 mm, respectively. Among comparisons of mean female GGS SVL at each trapping location between years, a statistically significant (α=0.05) decrease in size was observed at the East Marsh from 2008 (649 mm) to 2009 (553 mm) (p=0.02). In contrast, a statistically significant (α=0.05) increase in size was observed at the Restoration Site from 2008 (393 mm) to 2009 (615 mm) (p=0.02). Additionally, in 2008, females captured at the Restoration Site (393 mm) were significantly smaller than females captured at the East Marsh (649 mm) (p<0.01) and the West Marsh (590 mm) (p=0.04). **Appendix 3** depicts additional statistical information about the distributions of female GGS size classes at each trapping location during 2008 and 2009.

Changes in Prey Abundance and Distribution and Water Quality

Detected prey species consisted of adult and larval bullfrogs (*Rana catesbeiana*), mosquitofish (*Gambusia affinis*), Centrarchids including black bass (*Micropterus* spp.), sunfish (*Lepomis* spp.), and common carp (*Cyprinus carpio*). Bullfrog larvae were sparse overall, but decreased in the East Mash from 2008 to 2009, while observed Centrarchid fishes increased slightly. Prey species, including carp and bullfrogs, were most numerous at the restoration site in both years. Prey detected at the west marsh was sparse, with little change in composition across both years of the project. Sampling effort, and capture results, including capture per unit effort (CPUE), for each trapline in 2008 and 2009 are reported in **Table 3**.

Table 3: Prey catch per unit effort (CPUE)

Year	Location	Trap Days	Ranid Larva	CPUE	Ranid Adult	CPUE	Bass, sunfish, crappie	CPUE	Carp or Minnow	CPUE
2008	East Marsh	2,150	6	0.0028	0	0	0	0	0	0
	West Marsh	1,500	1	0.0007	3	0.0020	0	0	0	0
	Restoration Site	1,068	1	0.0009	1	0.0009	10	0.0074	40	0.0375
2009	East Marsh	2,250	1	0.0004	2	0.0009	12	0.0053	0	0
	West Marsh	2,250	0	0	5	0.0022	0	0	5	0.0022
	Restoration Site (Pool)	1,350	2	0.0015	25	0.0185	0	0	65	0.0481
	Restoration Site (DF)	368	0	0	65	0.1770	10	0.0074	40	0.1087

A total of 85 measurements of pH and EC were recorded in 2008 and 2009 comprising nine separate sampling locations. Repeated samples were collected at the following five locations: (1) Restoration Site, (2) East Marsh, (3) West Marsh, (4) Badger Creek South Fork, and (5) Willow Creek. As a result, 15 to 17 repeated measurements were obtained at each of these locations.

In 2008, individual pH measurements ranged from 7.0 (East Marsh) to 8.3 (East Marsh); mean pH at the East Marsh, West Marsh, and Restoration Site was 7.7, 8.0, and 8.0, respectively. In 2009, individual pH measurements ranged from 6.8 (East Marsh) to 8.2 (Restoration Site); mean pH at the East Marsh, West Marsh, and Restoration Site was 7.5, 7.7, and 7.9, respectively (**Table 4**). Among comparisons of mean pH values at each sampling location between years and between locations within each year, the only statistically significant difference (α=0.05) was between the East Marsh (pH=7.46) and the Restoration Site (pH=7.89) (p=0.01) during 2009.

In 2008, individual EC measurements ranged from 0.279 (Restoration Site) to 0.458 (East Marsh); mean EC at the East Marsh, West Marsh, and Restoration Site was 0.448, 0.432, and 0.364, respectively. In

2009, individual EC measurements ranged from 0.345 (Restoration Site) to 0.470 (West Marsh); mean EC at the East Marsh, West Marsh, and Restoration Site was 0.443, 0.440, and 0.359, respectively. Among comparisons of mean EC values at each sampling location between years and between locations within each year, statistically significant differences ($\alpha=0.05$) were observed during 2009 between the East Marsh (EC=0.443) and the Restoration Site (EC=0.359) ($p<<0.001$) and between the West Marsh (EC=0.440) and the Restoration Site (EC=0.359) ($p<<0.001$).

Table 4. pH measurements among sites in each year.

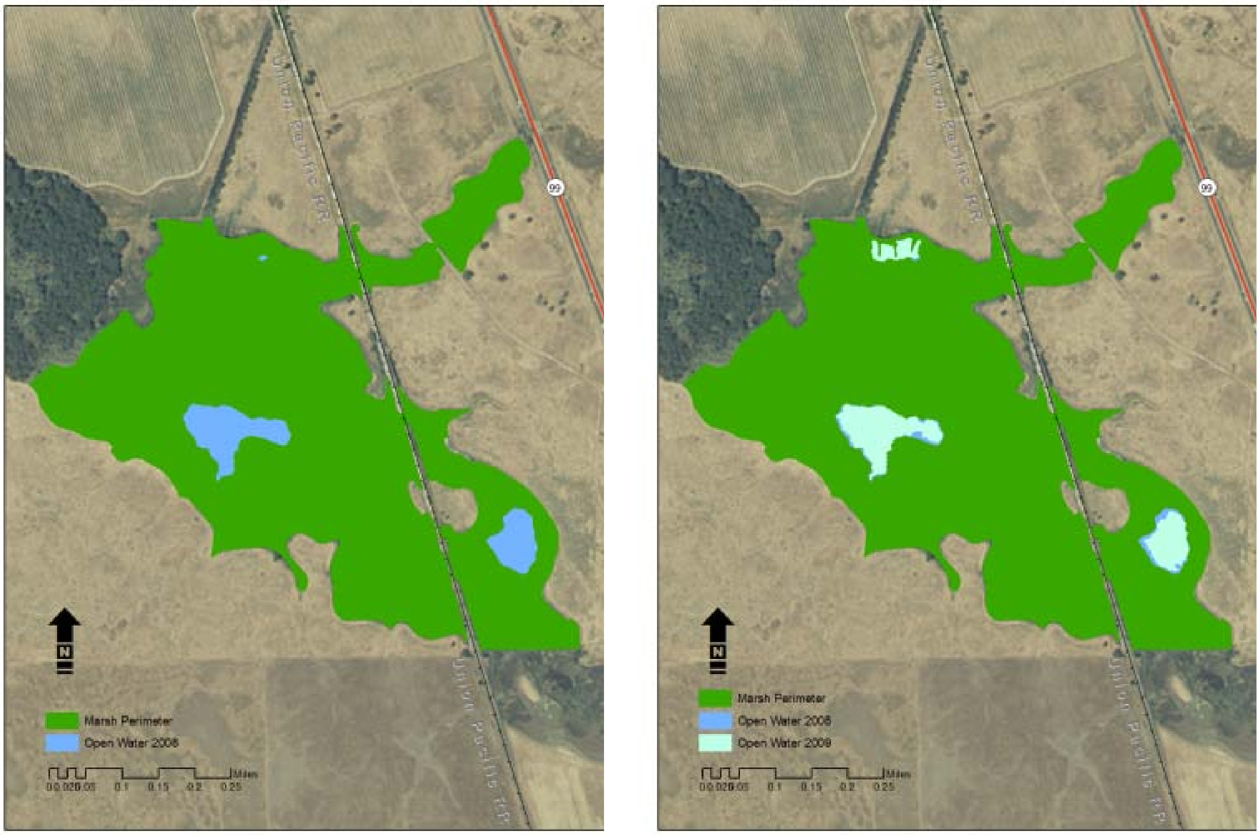
		Sampling Event									
Year	**Location**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2008	East Marsh	7.8	8.3	7.0	7.9	-	-	-	-	-	-
	West Marsh	-	8.0	7.9	8.1	-	-	-	-	-	-
	Restoration Site	7.9	-	7.9	8.1	-	-	-	-	-	-
2009	East Marsh	8.0	8.1	7.5	7.7	6.8	7.2	7.5	7.2	7.4	7.4
	West Marsh	8.0	8.0	7.7	7.8	7.4	7.7	7.3	7.3	8.0	7.8
	Restoration Site	8.1	7.9	8.2	8.2	8.0	7.5	7.5	7.6	7.9	8.2

Vegetation Response

GIS was used to calculate the area of open water at Snake Marsh in 2008 and immediately after restoration of the pilot pond in 2009. Excavation of the one-acre open-water area resulted in a 95% increase in local surface water at the restoration site. However, this was not enough to keep pace with the primrose that was growing and expanding elsewhere in the Marsh. Marsh-wide calculations indicated a 4% net decrease in overall surface water by September 2009, mostly due to rapid occlusion measured within the East Marsh. Open water within the West Marsh remained relatively stable over the course of the project (**Figure 12**).

Figure 12. Net change in open water surface from 2008 to September 2009.

2008 – 6.95a Open Water **2009 – 6.67a Open Water**



Net Δ = -4%

The pattern of primrose growth one year before the start of the Project is shown in **Figure 13a** (September 2007). **Figure 13b** depicts the pattern of primrose growth approximately 2 months prior to the start of the Project (July 2008). Following restoration, the patterns of primrose growth in the newly restored open water varied significantly according to water depth and between years 2009 and 2010. Very little primrose growth was observed in the restored area in 2009 (**Figure 13c**). The only area of the pond with more than roughly two feet of lateral primrose growth was the eastern edge (the shallowest side of the pond at two feet deep), which showed about 8-10 ft of re-growth. Water levels remained bank-full throughout the GGS active period. The minimal primrose growth and high water levels allowed the amount of open water to remain very similar to the intended design.

Figure 13a. Pattern of primrose growth at restoration site one year prior to the restoration effort (September 2007)

Figure 13b. Pattern of primrose growth at the restoration site approximately two months prior to restoration effort (July 2008)

Photo: The Nature Conservancy

Figure 13c. Pattern of primrose growth at the restoration site in 2009

During the summer of 2010 water levels dropped considerably and primrose re-growth was substantial in some portions of the pond, whereas other portions of the pond continued to provide substantial open-water foraging habitat for giant garter snakes (**Figure 13d**). As expected, the shallowest end of the pond (at two feet deep) had the earliest lateral expansion of the invasive primrose. Most reaches of the pond's shoreline showed 4.5-6 m (15-20 ft) of lateral primrose growth, and emergent stems sprouted from most of this length. By September 2010, primrose from the bank and the parallel construction pad closest to the east end of the pond had grown together on the surface, each side extending 7-8 m (22-26 ft) (**Figure 13e**). As of late October 2010, the eastern part of the restored pond had drawn down naturally and was completely dry while the remainder of the deeper end continued to hold water and provide foraging habitat for the GGS. In the eastern third of the pond, Lateral primrose stems had been stranded on mud as the water receded and these stems had firmly rooted in the soil (**Figure 13f**). The western, six-foot deep portion of the pond showed primrose re-growth as well but it still provided ideal foraging and basking habitat for giant garter snakes. By September 2010, emergent primrose extended about 4.5 m (15 ft) from the westernmost bank and about 1.5 m (5 ft) from the western-most parallel construction pad. The solitary floating stems from these two shorelines occasionally met across the 15 m (50 ft) of basin (**Figure 13g**). As of late December 2010, there was still approximately ½ meter of water remaining in the western half of the newly restored pond, thereby still supporting GGS prey species until the winter rains. However, primrose in the remaining inundated areas was also likely rooted, judging by the difficulty of pushing through submerged matted stems in October 2010 order to measure water depth.

Figure 13d. Substantial open water with plenty of edge habitat for foraging and basking giant garter snakes remains in the restored area in spite of re-growth of primrose (3-4 foot deep area, June 2010)

Figure 13e. Pattern of primrose growth at the shallow, 2-foot deep end of the restoration site in late summer 2010. Little to no foraging habitat value to giant garter snakes in late summer.

Figure 13f. Stranded primrose in pond after drawdown and drying

Figure 13g. Pattern of primrose growth at the deeper, 6-foot end of the restoration site in 2010. Still holding water into late summer and providing foraging habitat for giant garter snakes.

Watershed & Hydrology Characterization Study

Robertson-Bryan (2009) (**Appendix 1**) reports the full results of the watershed characterization and hydrologic study.

Development of a Seasonal Flow Regime

Table 5 shows the estimated flow through Badger Creek as average monthly flows for each year type (wet, above normal, below normal, dry, and critical). The natural runoff in this watershed is driven entirely by rainfall and, as expected, the Snake Marsh area of Badger Creek receives virtually no natural runoff during the summer and fall months.

Table 5. Estimated runoff (cubic feet per second(cfs)) in Badger Creek by month within water year type*.

Month	Wet[1]	Above Normal[2]	Below Normal[3]	Dry[4]	Critical[5]
Oct	59	111	7	63	0
Nov	73	44	157	69	0
Dec	720	0	682	167	64
Jan	389	768	0	227	0
Feb	437	531	5	37	532
Mar	85	7	86	34	0
Apr	103	123	151	64	26
May	102	23	0	17	0
Jun	0	0	13	0	0
Jul	0	0	0	0	0
Aug	0	0	13	0	0
Sep	0	0	0	0	0
Total (ac-ft)	**3,901**	**3,187**	**2,206**	**1,345**	**1,236**

* Based on San Joaquin River Index classification from 1995 to 2007.
[1] Average of estimated runoff based on rainfall data from 7 water years (1995-1998 and 2005-2006).
[2] Average of estimated runoff based on rainfall data from 2 water years (1999-2000).
[3] Estimated runoff based on rainfall data from 1 water year (2003).
[4] Average of estimated runoff based on rainfall data from 3 water years (2001-2002 and 2004).
[5] Estimated runoff based on rainfall data from 1 water year (2007).

Evaluation of Dry-Season Flow Sources

The investigation of dry-season flow sources showed that nearly all of the water entering Snake Marsh was agricultural discharge into Willow Creek, a southern tributary to Badger Creek. Willow Creek receives discharge from a fish farm operation on Valensin Road as well as several irrigated agriculture operations in the same vicinity. Snake Marsh also receives agricultural runoff from the two fields immediately north of the marsh. These two sources of water are the only ones that provide water to Snake Marsh during the rainless summer months.

Identification of Water Needs

Table 6 shows the estimated residual demand for Snake Marsh for each of the year type distributions based on San Joaquin River Index. Based on the estimated run-off and water demand, the marsh has a residual need for about 200 acre-feet between May and October in most years. Critically dry years would need about 300 acre-feet. The agricultural inputs described above provide some water to fill this residual need, but the amount of water provided is currently unknown. The timing of input from agriculture is also unknown, and not based on the needs of GGS.

Table 6. Snake Marsh Estimated Residual Demand (ac-ft) Based on San Joaquin River Index Water Year Classification.

Month	Estimated Demand	Wet		Above Normal		Below Normal		Dry		Critical	
		Runoff	Residual Demand	Runoff	Residual Demand	Runoff	Residual Demand	Runoff	Residual Demand	Runoff	Residual Demand
Oct	26	116	0	220	0	14	12	124	0	0	26
Nov	13	144	0	87	0	311	0	138	0	1	12
Dec	7	1,427	0	0	7	1,351	0	331	0	127	0
Jan	8	771	0	1,524	0	0	8	451	0	0	8
Feb	13	866	0	1,053	0	10	3	73	0	1,056	0
Mar	22	168	0	13	9	171	0	68	0	0	22
Apr	34	205	0	244	0	300	0	126	0	52	0
May	48	203	0	45	3	0	48	34	14	0	48
Jun	54	0	54	1	53	25	29	0	54	0	54
Jul	56	0	56	0	56	0	56	0	56	0	56
Aug	50	0	50	0	50	25	24	0	50	0	50
Sep	38	0	38	0	38	0	38	0	38	0	38
Total	**368**	**3,901**	**197**	**3,187**	**215**	**2,206**	**218**	**1,345**	**211**	**1,236**	**312**

Literature Review: Water Primrose Information Summary

More detailed information and analysis is available in the full document at **Appendix 4**: *Existing Information on Uruguayan Water Primrose (Ludwigia hexapetala) Biology, Ecology, and Control*.

Summary of Existing Available Information in the Literature

The taxonomy of the genus *Ludwigia* has been debated and revised several times since first described by Linnaeus. Recent debate has centered on whether to give two taxa full species status, or to lump them under one. Currently, American scholars usually follow Zardini, Gu, and Raven (1991), who split the taxa into *L. hexapetala* and *L. grandiflora*. European scholars tend to follow Nesom and Kartesz (2000), who lumped the taxa under *L. grandiflora*. Therefore, European publications about *L. grandiflora* ssp. *hexapetala* refer to the same species as American publications about *L. hexapetala*.

Regarding biology and ecology, sources report that water primrose:

- quickly develops thick, dense mats of rooting stems
- spreads primarily by clonal fragments, but can recruit from seed on bare mud
- impedes water flow, thereby increasing sedimentation rates and decreasing flood capacity
- can cause decrease in dissolved oxygen to near zero at dawn
- can cause increase in sulfide concentrations due to harboring sulfur-reducing bacteria
- tolerates a wide range of hydrologic regimes once established (from no standing water to several feet of submersion)

Decisions about *L. hexapetala* management are currently based on known species biology, case studies, and personal experience, because no quantitative, controlled studies comparing efficacy of different management tools have yet been published for this weed. Management goal, plant growth habit, and season are the three determining factors thus far in choosing control methods for *L. hexapetala*.

In many situations the goal is maximum control of the weed. Where *L. hexapetala* grows as an extensive, dense mat of stems several feet thick, control is often incomplete and short-lived, stressing the importance of securing funding for multi-year initial efforts and ongoing long-term maintenance. In these situations, harvesting biomass in spring or summer and then spraying re-sprouts with triclopyr in September or October appears to be most promising, but ongoing maintenance must continue. Where *L. hexapetala* has not yet grown thick mats, an application of triclopyr in September or October has provided good control. Excavation is an appropriate method for areas where additional habitat or infrastructure goals require removal of sediment to pre-infestation grade or below. Although excavation does completely remove plant material, follow-up control with herbicides is necessary to kill seedlings and the re-sprouts from fragments dropped by the heavy machinery.

Other management goals may tolerate *L. hexapetala* presence to a greater degree, such as goals for waterfowl pond management and irrigation conveyance. The infrastructure built into such systems also expands control options. Many wetland managers have met ecological goals through dewatering the affected habitat, disking areas where the plant is not desired, and allowing plant fragments to dry over the summer.

Non-herbicidal methods such as harvesting, water level control, and aqueous nutrient reduction may be essential aspects of an integrated management plan, but if applied alone cannot provide control of an established infestation. Manual control is extremely slow and risk of injury is high, making it unsuitable for all but very special instances. Insect or fungal bio-control is not yet available.

Discussion

The results of this project indicate that mechanical removal of invasive yellow water primrose immediately increased open-water foraging habitat use by the giant garter snake in Snake Marsh. We saw, however, that in the absence of adequate water depth in a pond, adequate water supplies throughout the summer, or long-term maintenance strategies, *L. hexapetala* can rapidly reclaim areas of open water that would otherwise support the primary prey species of giant garter snakes and other wildlife. We also observed that deeper areas of the restored pond will generally hold water throughout the entire dry season (absent a prolonged drought). However, re-growth in deeper restored areas may occur much more rapidly if water fluctuates substantially throughout the dry season, or if the restored area is too narrow, thereby allowing growth from both sides of the pond to come together and form a closed canopy over the open water. Even when this occurs, however, it does not necessarily adversely affect GGS's ability to forage for their primary prey within the open-water area. It is not until the invasive primrose canopy and biomass completely occlude the water column and/or create temperatures, oxygen, soil or water chemistry, *etc.* conditions that no longer support the snakes' primary prey species that it becomes a significant problem. This observation is corroborated through observations of several other aquatic plant species. For example, cattails readily colonize and completely displace all other aquatic plant and animal species when water in managed wetland pond is too shallow or is allowed to fluctuate too drastically during the prime cattail growing season. While we had documentable successes in reducing yellow water primrose cover and increasing available open-water foraging habitat for giant garter snakes in the first year, on-going, long-term, rotational management of open-water areas within Snake Marsh will be required. This is more fully discussed below in the next section.

The importance of using the excavated spoils to build additional high ground immediately adjacent to the newly restored open-water foraging area cannot be understated for this location, as was shown in **Figure 11** above. Based on radio telemetry data collected nearly a decade ago, many of the GGS are known or thought to spend the winter in the Union Pacific Railroad grade and the adjacent available upland areas. However, winter rains frequently cause torpid snakes residing in the adjacent uplands to flee their winter hibernacula in advance of approaching flood waters. This can result in higher rates or mortality due to predation of slow-moving snakes and/or the simple lack of high ground above the flood water. This conclusion is easily corroborated by the hundreds of people that are displaced from their homes each year by floods. Based on our observations of the December 2010 flooding event at Snake Marsh, future restoration project should plan to use the spoils from excavation activities to build additional high ground that is even higher than the area that was created in 2008. Future upland enhancement sites should be able to stay above flood levels from at least 30,000 cfs events (as measured at Michigan Bar). Doing so will contribute significantly to the survival and recovery of GGS at this site.

Though data are inadequate for robust statistical comparisons, GGS capture results appear at least superficially associated with observed trends in open-water foraging habitat availability. For instance, while the ICPUE remained nearly same at the West Marsh from 2008 to 2009 (%Δ=+0.6), differences at the East Marsh and the Restoration Site were noteworthy. ICPUE decreased at the East Marsh by more than half (%Δ=-67) where primrose development continued, while ICPUE at the Restoration Site increased dramatically (%Δ=+278). A statistically significant increase in use by larger female giant garter snakes in areas of open water was also observed at the Restoration Site, perhaps due to the substantial increase in the number of adult frogs observed following restoration. While reasons for the decrease at the East Marsh remain unclear, these data strongly suggest a positive response to the increased open water resulting from habitat expansion at the Restoration Site.

Surface and ground water are highly unreliable in this marsh and the lack of water in the future could be a major limiting factor. A stable water supply throughout the active season of the snake must be ensured in order for a core GGS population to persist in this area in perpetuity. While GGS may tolerate the short-term loss of aquatic habitat noted at Badger Creek west of Highway 99 during 2001 (Hansen 2003), it is likely that a prolonged loss of supporting habitat would have significant negative impacts to the population. Receding water separates aquatic foraging habitat from upland retreats, subjecting snakes to elevated risk of predation, and limits available prey during critical periods during the active season. Also, the timing of this dry-down corresponded with parturition in August, subjecting newborn giant garter snakes to predation at unsheltered pools of concentrated prey during the critical period of post-parturition dispersal and foraging.

Future Restoration and Long-Term Management

The restoration of the 2008 open-water pond, and all future open-water areas at Snake Marsh, is the primary step in controlling invasive yellow water primrose. Once removed, long-term management of primrose will seek to maintain a vegetated interface between the shoreline and the open-water areas. This approach will provide maximum edge effect to foraging and basking GGS while maintaining a healthy open-water pond interior that supports abundant prey species. Open-water areas within the Marsh should be restored to at least six feet deep with steep sides (1:1 slopes) that help prevent the re-growth of primrose. Ideally, water levels should not fluctuate, especially during the summer growing season. However, in Snake Marsh, this is currently beyond the control of Preserve staff and it will be difficult to achieve given the current surface hydrology of Badger Creek and the lack of water control infrastructure at Snake Marsh.

No short-term management of the restored open-water foraging habitat has yet occurred due to the on-going research on the response of the primrose to the Project. However, beginning in 2011, short-term management will be implemented in the new pond, as well as in remnant ponds as needed. Due to the shallow, two-foot depth of the water in the east end of the new pond, the primrose has rapidly re-colonized the open-water foraging habitat. While not yet a threat to completely occluding the open-water foraging habitat, the primrose will be kept in check using a variety of techniques such as manual hand removal, spot-spraying with triclopyr or other herbicides, mechanical removal via land-based equipment, and/or using standard managed wetland techniques like water draw-downs followed by discing, if possible. These techniques will be used on a rotational basis depending on the pace of primrose re-growth to limit the plant's growth to a pre-determined length, similar to pruning a tree or shrub to maintain its shape or rate of growth. Currently, we are anticipating some form of management in each pond every 3-5 years, depending on the number of ponds, conditions of each pond, and the response of the primrose to our management strategies. In doing short-term management such as this, the open-water areas of Snake Marsh should have a continual ring of primrose growing around the outside edge of each pond while still maintaining an open-water component in the center. This short-term management strategy will create ideal foraging, resting and basking habitat for the GGS as well as other species using Snake Marsh. In the case of the two-foot deep end of the 2008 pond, the long-term plan is to deepen that end of the pond to six feet like the western section of the pond. This follow on restoration will occur when additional funding has been secured to continue the Preserve's long-term restoration and management work at the Marsh.

Each of the aforementioned management techniques has advantages and disadvantages based on site-specific circumstances. Choosing the specific method will require evaluation of the logistical necessities and the field conditions at the time management actions are planned to occur. It is most likely that more than one method will be used at Snake Marsh due to varying conditions within the site.

Short-term management on the upland enhancement site has been limited to using hand tools to reduce the dominance of invasive plant species colonizing the upland site. The primary species of concern so far have been competitive ruderal species such as mustard and the highly invasive yellow star thistle. While invasive and unattractive to visitors during site visits to the Snake Marsh area, the mustard and yellow star thistle do not appear to have adversely affected the usage of the upland enhancement site by snakes. Two individual GGS were hand captured on the upland enhancement site in 2010 along with four other individual snakes including a mountain garter snake and three valley garter snakes.

Long-term management strategies for the newly created open-water foraging habitat, as well as the remnant, historic open-water foraging habitat and future restoration sites within the Marsh, will involve maintenance of open-water foraging habitat within each pond area through the use of mechanical (*e.g.,* by hand or excavators), biological (possibly concentrated grazing of cattle, sheep, or goats around the perimeter of each pond), or herbicidal treatments. Mechanical treatment of invasive plants and biomass, whether it is for primrose or other species, can be effectively implemented on a rotational basis across all open-water areas where equipment access can be obtained. For example, if there are eventually a series of six open-water ponds within the Marsh, each pond can receive mechanical treatment of excessive vegetation once every 6 to 12 years depending on the necessary treatment frequency. This management regime is what is currently used throughout the Central Valley in managed wetland ponds and units to maintain the desired successional stages of desirable and undesirable plant species. Doing long-term maintenance in this way allows the land manager to adjust the desired level of primrose, for example, to maximize its benefit to the GGS without letting it get out of control to the point where it completely occludes the open-water foraging habitat.

While not tested yet, the possibility exists that concentrated, short-term grazing by cattle, sheep or goats around the perimeter of a pond could be used similarly to mechanical treatments to prevent excessive growth of invasive plants such as primrose. While grazing livestock may not eat substantial amounts of the plants, their presence, especially cattle, within a confined area adjacent to the edge of a pond, could create enough physical disturbances in a plant’s root zone to prevent all areas of the shoreline from being overtaken by an invasive plant like primrose. Once again, this could create a mosaic of habitat that is beneficial to the GGS without allowing a complete take-over of the open-water foraging habitat by the invasive plant.

Herbicide treatment of primrose, and other highly invasive aquatic plant species like water hyacinth, has been proven to be effective if it is applied at the right time and the right concentrations using the appropriate active ingredients and surfactants. However, in endangered species habitat the use of herbicides, or any chemicals for that matter, can be highly controversial. The fact remains, herbicides have an appropriate role in endangered species habitat management and they should not be readily discarded from the land manager’s tool box. In the case of primrose infestations around open-water foraging habitat for GGS, herbicidal treatments can be used to supplement mechanical and biological control methods. For example, mechanical removal of primrose could reduce the amount of living biomass that herbicide would have to kill. Other potential effects include shortening the distance herbicide would have to travel within a stem to reach the roots, increasing the ratio of surface area (on which herbicide comes in contact) to biomass, and depleting starch reserves in storage structures. Two to three months following mechanical removal of primrose, a light herbicidal treatment approved for aquatic use could be applied to the re-sprouts to kill underground plant organs and lengthen the time between control treatments. Pre-treating vegetation prior to mechanical methods could also be highly effective by killing the vegetation first, thereby making it drier and easier to remove by hand or machine. Additionally, if the primrose is killed using herbicides prior to mechanical means, it could prevent small pieces of the plant's roots from re-establishing and causing more of an infestation after treatment. If applied at the right time of year when the snakes are not actively using the ponds, herbicidal treatments could be effective at spot treating areas along a shoreline to open up resting and basking areas prior to the emergence of snakes from the winter hibernacula. This selective, controlled use of herbicides once again benefits the GGS by maintaining the primrose at a pre-determined successional stage of growth and infestation within the open-water foraging habitat. This is a practice that is commonly used by land managers in managed wetland ponds and units throughout the U.S. to achieve the desired vegetational outcome of those ponds or units.

Long-term management of the upland enhancement site, as well as other adjacent upland areas, includes the use of cattle, sheep or goats to graze the uplands off to appropriate residual dry matter management levels. The use of mechanical treatments such as tractors and mowers, and hand-held power tools such as weed whackers can also be used for long-term management of the upland areas. Grazers and mechanical means would be used to minimize and control undesirable plant species, such as mustard and star thistle, while promoting the growth of native species, or at a minimum more desirable naturalized plant species such as annual and perennial rye grasses. Herbicidal treatments of undesirable plant species is also highly effective in upland areas and is a common long-term management strategy used by the Preserve, usually as a secondary treatment method to mechanical and biological control methods. In most cases, herbicides are used as secondary control methods in areas that cannot be accessed by equipment, in areas that are too large to treat by hand, and on plant species that cannot be controlled through mechanical means alone, *e.g.,* perennial pepperweed. Herbicide use at the Preserve is most prevalent during the winter/spring growing season. Thistles are generally the first invasive plant species to be treated with herbicides, beginning as early as December some years when they are still in the rosette stage. Treating thistles and other undesirable plant species at this stage uses the least amount of product, thereby introducing the least amount of contaminant into the environment. Throughout the rest of the winter and spring thistles, mustard, hemlock and other invasive plant species are targeted. As spring moves into early summer, perennial pepperweed becomes the most targeted species for control.

Future challenges

Logistics & Funding

Resources including staff and funding continue to be challenges for all land managers and the Preserve is no different in that regard. At present, the Preserve has an aggressive weed treatment program that outlines certain species for treatment in specific areas. Obviously due to the size of the Preserve, all weeds cannot be treated and controlled. The goal is to attack the most invasive species in the highest priority areas first. Once control has been achieved and can be maintained over the long term, control operations are shifted to newly identified priority areas. Monitoring efforts follow up treatments to ensure success and re-treatment at sites. In order to achieve success at Snake Marsh for the GGS, additional open-water foraging habitat must first be created through the removal of additional live primrose and its accumulated biomass. Once open-water foraging habitat is created, long-term management strategies, as described above and commonly used on the Preserve and by other land management agencies, can then be implemented as part of the Preserve's standard operations.

The Snake Marsh upland habitat enhancement site and the newly created 2008 pond are part of the current weed treatment schedule and they will continue to be part of the schedule in the future until the desired vegetation and successional stages in the uplands and in the ponds, respectively, are achieved. There are currently efforts to re-introduce limited grazing back onto the Badger Creek Unit where Snake Marsh is located. If these efforts are eventually successful, the grazing livestock will do much of the land management work in the uplands while at the same time providing a valuable income that can be used to further the Preserve's restoration and management efforts in Snake Marsh and the surrounding uplands.

Summary and Conclusions

The results of this project indicate that mechanical removal of the invasive yellow water primrose and its accumulated biomass definitely increased open-water foraging habitat use by the GGS in Snake Marsh. Not only did snakes marked with PIT tags elsewhere in Snake Marsh move to the newly created habitat, but observed snakes within the restoration area increased nearly five-fold. We also observed a statistically-significant increase in the number of large females using the newly restored habitat; females that are crucial for successful colonization and population persistence because they contribute the greatest number of offspring. We also demonstrated that using excavated spoils to enhance upland sites immediately adjacent to open-water foraging areas definitively helps GGS survive winter flooding events at Snake Marsh.

However, in the absence of adequate water depth in restored areas, adequate incoming water from upstream sources to maintain pond depths throughout prolonged dry periods (especially droughts), and/or continuing long-term maintenance of *L. hexapetala,* to maintained desired seral stages of development, gains in open-water foraging habitat for giant garter snakes can be lost in a few short years. Additionally, not properly enhancing upland sites to appropriate elevations could mean the difference between success and failure for GGS during flooding events.

The success of GGS in Snake Marsh depends on the availability of both aquatic and upland habitat to support all of its life needs: breeding, feeding and sheltering. In the absence of either of these critical components, the snakes at Snake Marsh are at continued risk of extinction. Highly invasive yellow water primrose will rapidly claim areas of open water if it is not properly managed. Because completely eliminating primrose is impractical, the on-going, long-term management of *L. hexapetala,* and securing of an adequate water source, will be critical for maintaining balance at Snake Marsh and ensuring the survival and recovery of the GGS at the Preserve in perpetuity.

Acknowledgements

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Appendix 1. Badger Creek Hydrologic Study, September 2009

Appendix 2. Summary of expenditures

Costs Incurred Thru June 30, 2010

Task 1: Watershed characterization- hydrologic study

The total contract with RBI was for $63,119 (TNC $25,000 and BLM via CVPIA $ 38,119). As of June 30, 2010, RBI spent $24,856.82 from TNC's contribution ($143.18 remaining) and $36,936.88 from BLM ($1,182.12 remaining). All remaining funding will be invoiced towards the preparation of the draft and final reports.

Task 2, 3, 5: Water quality, prey base, and giant garter snake monitoring

The total contract with Hansen Consulting was for $50,000. As of June 30, 2010, Hansen consulting spent $46,813.38 for trapping and monitoring giant garter snakes prior to, during, and after the restoration effort as well as for preliminary data analysis and report preparation. Any remaining funding will be invoiced towards the preparation of the draft and final reports.

Task 4: Primrose control method research, pilot restoration project plan and implementation, contract management

The total contract with The Nature Conservancy was for $20,796.12. As of mid-June 2010, TNC has submitted another invoice for $2,151. 32. Any remaining funding will be invoiced towards the preparation of the draft and final reports.

The BLM has spent approximately $61,786.26 throughout the total project, of which $25,771 was billed to other funding sources. Any remaining funding will be invoiced towards the preparation of the draft and final reports, contract close-outs and other project management related labor expenses.

Appendix 3. Statistical Tables

Table 1. Statistical attributes of giant garter snake size demographics across site and year.

Male GGS SVL Statistics

Year	n	$\bar{x}$	SE	SD	Min	Q1	Med	Q3	Max	Kurt	Skew
East Marsh											
2008	22	518	21.5	100.8	380	465.3	491.5	553.5	737	0.4	1.0
2009	23	461	19.2	92.3	344	392.5	457	493	717	1.9	1.2
West Marsh											
2008	28	435.8	12.4	65.8	244	397.3	437	473	552	1.4	-0.5
2009	33	466.2	18.3	105.1	364	383.3	435	466.5	768	1.2	1.3
Restoration Site											
2008	5	439	100.3	224.4	202	211	504	572	706	-2.4	-0.1
2009	12	527.8	22.6	78.2	414	484.8	534	550	679	0.1	0.4

Key: n=sample size; $\bar{x}$=sample mean; **SE**=standard error; **SD**=standard deviation; **Min**=minimum; **Q1**=1st quartile; **Med**=median; **Q3**=3rd quartile; **Max**=maximum; **Kurt**=kurtosis; **Skew**=skewness

Female GGS SVL Statistics

Year	n	$\bar{x}$	SE	SD	Min	Q1	Med	Q3	Max	Kurt	Skew
East Marsh											
2008	57	649.5	19.8	149.3	364	531	642	767	954	-0.8	0.1
2009	16	552.5	37.7	150.6	382	393	573.5	596	835	-0.8	0.5
West Marsh											
2008	50	589.6	25.4	179.3	330	425.8	565.5	737	898	-1.5	0.2
2009	79	602.9	17.3	155.1	232	456	599.5	676	889	-0.8	-0.2
Restoration Site											
2008	4	392.5	54.1	108.3	243	348.8	422	465.8	483	0.7	-1.2
2009	30	614.8	30.6	167.5	212	527	621.5	732.5	880	-0.2	-0.6

Key: n=sample size; $\bar{x}$=sample mean; **SE**=standard error; **SD**=standard deviation; **Min**=minimum; **Q1**=1st quartile; **Med**=median; **Q3**=3rd quartile; **Max**=maximum; **Kurt**=kurtosis; **Skew**=skewness

Table 2. Statistical comparisons of snout-vent length (SVL) of giant garter snakes for several pairings of variables. Statistically significant *p*-values are highlighted.

t-Tests: Two-Sample Assuming Equal Variances

Male GGS SVL:	**East Marsh**		**West Marsh**		**Restoration Site**	
2008 vs. 2009 by location	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**
Mean	518	461	436	466	439	528
Variance	10,160	8,520	4,335	11,043	50,339	6,112
Observations	22	23	28	33	5	12
Pooled Variance	9,320	-	7.793	-	17,906	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	43	-	59	-	15	-
t Stat	1.98	-	-1.33	-	-1.25	-
P(T<=t) two-tail	0.05	-	0.19	-	0.23	-
t Critical two-tail	2.02	-	2.00	-	2.13	-

Male GGS SVL: 2008 location vs. location	**East Marsh**	**West Marsh**	**East Marsh**	**Rest. Site**	**West Marsh**	**Rest. Site**
Mean	518	436	518	439	436	439
Variance	10,160	4,335	10,160	50,339	4,335	50,339
Observations	22	28	22	5	28	5
Pooled Variance	6,833	-	16,589	-	10,271	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	48	-	25	-	31	-
t Stat	3.50	-	1.24	-	-0.07	-
P(T<=t) two-tail	<0.01	-	0.22	-	0.95	-
t Critical two-tail	2.01	-	2.06	-	2.04	-

Male GGS SVL: 2009 location vs. location	**East Marsh**	**West Marsh**	**East Marsh**	**Rest. Site**	**West Marsh**	**Rest. Site**
Mean	461	466	461	528	466	528
Variance	8,520	11,043	8,520	6,112	11,043	6,112
Observations	23	33	23	12	33	12
Pooled Variance	10,015	-	7,717	-	9,782	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	54	-	33	-	43	-
t Stat	-0.18	-	-2.12	-	-1.85	-
P(T<=t) two-tail	0.86	-	0.04	-	0.07	-
t Critical two-tail	2.00	-	2.03	-	2.02	-

Table 2. Statistical comparisons of snout-vent length (SVL) of giant garter snakes for several pairings of variables (continued).

t-Tests: Two-Sample Assuming Equal Variances

Female GGS SVL:	**East Marsh**		**West Marsh**		**Restoration Site**	
2008 vs. 2009 by location	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**
Mean	649	553	590	603	393	615
Variance	22,302	22,689	32,154	24,307	11,723	28,063
Observations	57	16	50	79	4	30
Pooled Variance	22,384	-	27,335	-	26,531	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	71	-	127	-	32	-
t Stat	2.29	-	-0.44	-	-2.56	-
P(T<=t) two-tail	0.02	-	0.66	-	0.02	-
t Critical two-tail	1.99	-	1.98	-	2.04	-

Female GGS SVL: 2008 location vs. location	**East Marsh**	**West Marsh**	**East Marsh**	**Rest. Site**	**West Marsh**	**Rest. Site**
Mean	649	590	649	393	590	393
Variance	22,302	32,154	22,302	11,723	32,154	11,723
Observations	57	50	57	4	50	4
Pooled Variance	26,900	-	21,764	-	30,975	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	105	-	59	-	52	-
t Stat	1.88	-	3.37	-	2.16	-
P(T<=t) two-tail	0.06	-	<0.01	-	0.04	-
t Critical two-tail	1.98	-	2.00	-	2.01	-

Female GGS SVL: 2009 location vs. location	**East Marsh**	**West Marsh**	**East Marsh**	**Rest. Site**	**West Marsh**	**Rest. Site**
Mean	553	603	553	615	603	615
Variance	22,689	24,308	22,689	28,063	24,308	28,063
Observations	16	79	16	30	79	30
Pooled Variance	24,047	-	26,231	-	25,325	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	93	-	44	-	107	-
t Stat	-1.19	-	-1.24	-	-0.35	-
P(T<=t) two-tail	0.24	-	0.22	-	0.73	-
t Critical two-tail	1.99	-	2.02	-	1.98	-

t-Tests: Two-Sample Assuming Equal Variances

pH: 2008 vs. 2009 by location	East Marsh		West Marsh		Restoration Site	
	2008	**2009**	**2008**	**2009**	**2008**	**2009**
Mean	7.72	7.46	8.01	7.71	7.96	7.89
Variance	0.28	0.14	0.01	0.07	0.01	0.08
Observations	4	10	3	10	3	10
Pooled Variance	0.18	-	0.06	-	0.07	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	12	-	11	-	11	-
t Stat	1.04	-	1.80	-	0.39	-
P(T<=t) two-tail	0.32	-	0.10	-	0.70	-
t Critical two-tail	2.18	-	2.20	-	2.20	-

pH: 2009 location vs. location	East Marsh	West Marsh	East Marsh	Rest. Site	West Marsh	Rest. Site
Mean	7.46	7.71	7.46	7.89	7.71	7.89
Variance	0.14	0.07	0.14	0.08	0.07	0.08
Observations	10	10	10	10	10	10
Pooled Variance	0.11	-	0.11	-	0.08	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	18	-	18	-	18	-
t Stat	-1.72	-	-2.89	-	-1.43	-
P(T<=t) two-tail	0.10	-	0.01	-	0.17	-
t Critical two-tail	2.10	-	2.10	-	2.10	-

pH: 2008 location vs. location	East Marsh	West Marsh	East Marsh	Rest. Site	West Marsh	Rest. Site
Mean	7.72	8.01	7.72	7.96	8.01	7.96
Variance	0.28	0.01	0.28	0.01	0.01	0.01
Observations	4	3	4	3	3	3
Pooled Variance	0.18	-	0.18	-	0.01	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	5	-	5	-	4	-
t Stat	-0.91	-	-0.75	-	0.55	-
P(T<=t) two-tail	0.41	-	0.49	-	0.61	-
t Critical two-tail	2.57	-	2.57	-	2.78	-

Table 3. EC measurements and tests of statistical significance between year and site. Statistically significant changes are shown in highlight.

Year	Location	Sampling Event 1	2	3	4	5	6	7	8	9	10
2008	East Marsh	0.458	0.435	0.449	0.449	-	-	-	-	-	-
	West Marsh	-	0.419	0.438	0.439	-	-	-	-	-	-
	Restoration Site	0.279	-	0.384	0.429	-	-	-	-	-	-
2009	East Marsh	0.441	0.440	0.431	0.442	0.462	0.445	0.450	0.449	0.435	0.439
	West Marsh	0.404	0.423	0.433	0.427	0.428	0.447	0.452	0.470	0.457	0.461
	Restoration Site	0.345	0.347	0.352	0.351	0.360	0.362	0.365	0.367	0.367	0.376

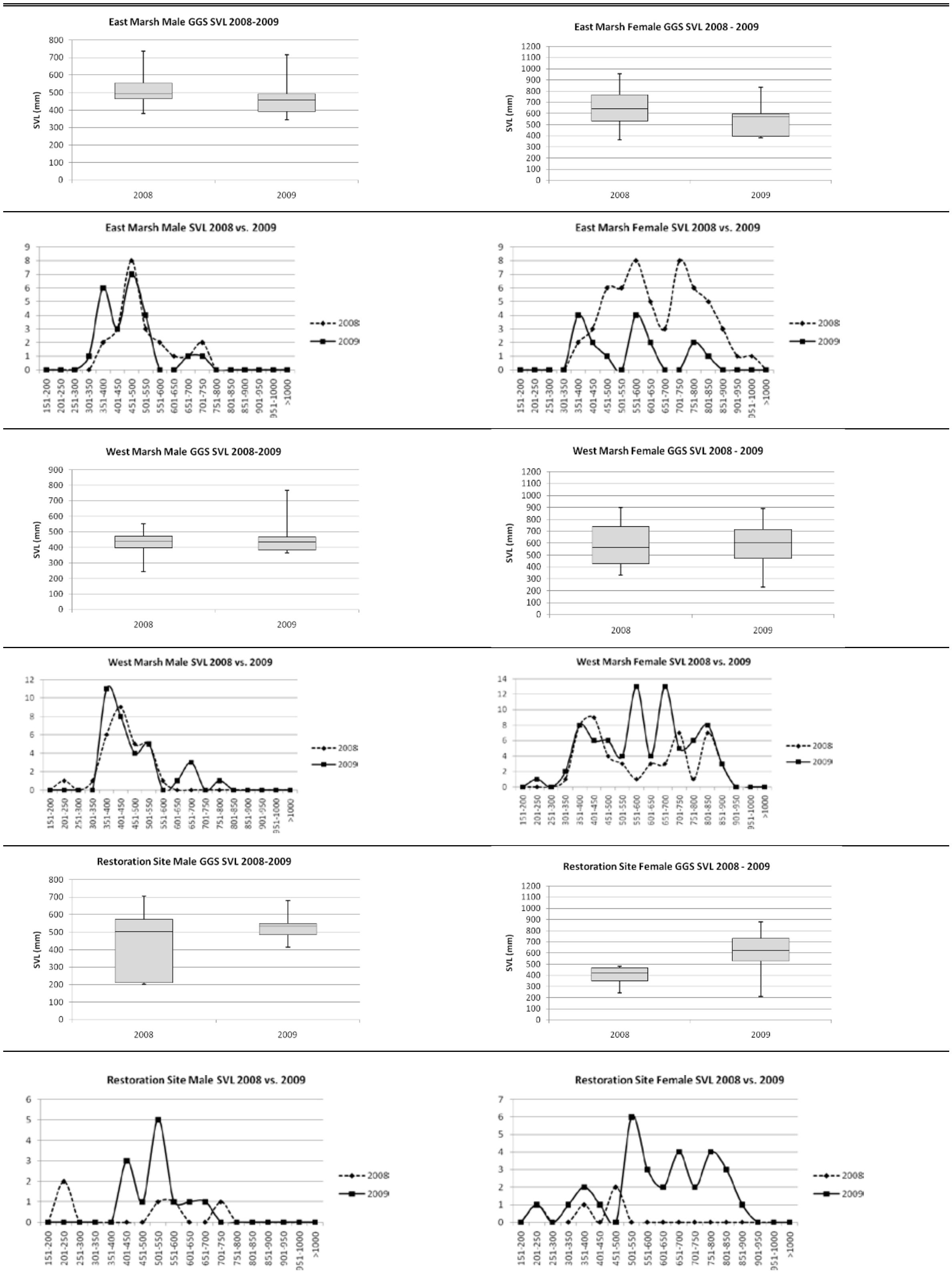
t-Tests: Two-Sample Assuming Equal Variances

EC: 2008 vs. 2009 by location	East Marsh 2008	East Marsh 2009	West Marsh 2008	West Marsh 2009	Restoration Site 2008	Restoration Site 2009
Mean	0.448	0.443	0.432	0.440	0.364	0.359
Variance	9.02E-05	7.63E-05	0.000	0.000	0.006	0.000
Observations	4	10	3	10	3	10
Pooled Variance	7.98E-05	-	0.000	-	0.001	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	12	-	11	-	11	-
t Stat	0.823	-	-0.651	-	0.214	-
P(T<=t) two-tail	0.426	-	0.528	-	0.834	-
t Critical two-tail	2.179	-	2.201	-	2.201	-

EC: 2008 location vs. location	East Marsh	West Marsh	East Marsh	Rest. Site	West Marsh	Rest. Site
Mean	0.448	0.432	0.448	0.364	0.432	0.364
Variance	9.02E-05	0.000	9.02E-05	0.006	0.000	0.006
Observations	4	3	4	3	3	3
Pooled Variance	0.000	-	0.002	-	0.003	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	5	-	5	-	4	-
t Stat	2.013	-	2.227	-	1.514	-
P(T<=t) two-tail	0.100	-	0.076	-	0.205	-
t Critical two-tail	2.571	-	2.571	-	2.776	-

EC: 2009 location vs. location	East Marsh	West Marsh	East Marsh	Rest. Site	West Marsh	Rest. Site
Mean	0.443	0.440	0.443	0.359	0.440	0.359
Variance	7.63E-05	0.000	7.63E-05	0.000	0.000	0.000
Observations	10	10	10	10	10	10
Pooled Variance	0.000	-	8.90E-05	-	0.000	-
Hypothesized Mean Difference	0	-	0	-	0	-
df	18	-	18	-	18	-
t Stat	0.455	-	19.957	-	11.226	-
P(T<=t) two-tail	0.655	-	9.99E-14	-	1.46E-09	-
t Critical two-tail	2.101	-	2.101	-	2.101	-

Figure 1. Size distribution of giant garter snakes at Snake Marsh before and after restoration.



APPENDIX 4. LITERATURE REVIEW: Existing Information on Uruguayan Water Primrose (Ludwigia hexapetala) Biology, Ecology, and Control