

Mike Small
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DRAFT

Abundance, Distribution, and Habitat Use of the Grand Wash
springsnail (*Pyrgulopsis bacchus*), Grand Canyon-Parashant
National Monument, Arizona

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By

Donald W. Sada
Division of Hydrologic Sciences
Desert Research Institute
2215 Raggio Parkway
Reno, Nevada 89512

For

U.S. National Park Service
Grand Canyon-Parashant National Monument



4 Nov 04

Darlas,

This was a very interesting report.

① How does this springsmail fit in with the n. leopard frog?

11/4

② I wonder if Pakeon Spw, Grapevine Spw, etc., should also be looked at for springsmails.

③ Speckled dace were found. How did he miss the gold fish?
—Mike S.

Det: _____
Lee "Post-it" _____
Who decides which _____
recommendations to _____
implement, and how _____
will the decisions be _____
documented? _____
J

Maintain upper Tassi spring in existing condition
(redirection may extirpate rare species)

Maintain existing conditions in existing spring brooks
to maximize diversity of aquatic & riparian habitats

Initiate minor restoration of upper spring brook

by decreasing erosion & density + increasing willows

Conduct taxonomic surveys to id. additional creobiotic spp

Install gauges to monitor discharge & quantify temporal changes

Monitoring: Qualitative method see p 27: Annually in the spring

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INTRODUCTION

The Grand Wash springsnail (*Pyrgulopsis bacchus*) was described in 1988 from several springs in Grand Wash, Mohave County, Arizona (Hershler and Landye 1988). It is endemic to springs in this area, which occur on private lands, and lands administered by the U.S. National Park Service (NPS) and U.S. Bureau of Land Management. The only known locality on Federal land is Tassi Springs, which is an important historical site for homesteading, ranching and agriculture. No studies have examined the demography, habitat use, distribution, or environmental factors affecting the abundance and distribution of the Grand Wash springsnail. Ecological information is needed to guide management through the challenges of protecting the historical and ecological values of Tassi Springs. This study assessed *P. bacchus* demography by examining its habitat use, distribution, and abundance at Tassi Springs. The specific questions addressed were: 1) What is the distribution and abundance of *P. bacchus*? 2) What habitat does *P. bacchus* prefer? and 4) What recommendations for the restoration of the spring brook will preserve *P. bacchus* populations while maintaining the historic landscape at Tassi Spring?

Not true.
Palmer found
it in 1991
at Whiskey
+ Grapevine.

GENERAL SPRINGSNAIL ECOLOGY

The family Hydrobiidae has a worldwide distribution that is represented in North America by approximately 285 taxa in 35 genera, and additional species are being described at regular intervals. There are seven hydrobiid genera in the western U.S. and approximately 100 species; *Pyrgulopsis* is the most common genus (approx. 85 spp. nationwide), followed by *Tryonia* (22 extant species in North America) (Hershler and Sada 1987, Hershler 1999, Hershler et al. 1999), and *Fluminicola* (5 spp. from North America) (Hershler and Frest 1994, Hershler 1999). *Eremopygrus* is a monotypic genus endemic to Nevada (Hershler 1999), and *Ipnobius* is a monotypic genus endemic to Death Valley National Park (Hershler 2001).

Current taxonomy is based largely on penial morphology that can be examined only by microscope after rather tedious methods of relaxation and preservation have prepared the material. There are no keys to assist with identification, but existing literature can be

used to identify species by those familiar with terminology. Recent genetic studies have shown that described species are valid taxa, but that morphologically-based taxonomy is conservative. Hamlin (1996) found fixed allelic differences among populations of *P. wongi* in eastern California and western Nevada and Hershler et al. (1999) found similar differences among populations of *T. variegata* in southern Nevada and southeastern California. These studies indicate that further genetic analysis is likely to show that some populations of some currently recognized species maybe described as new species in the future. A genetic study of 50 *Pyrgulopsis* spp. has been initiated, which should be completed during 2005.

The distribution of most springsnails is limited; a number are known only from single valleys, others from several valleys, and some species appear to be widespread. It is uncommon for a habitat to be occupied by more than one species, and less common for a spring to be occupied by more than a single species in a genus. Only *P. kolobensis* and *P. gibba* are comparatively widespread. *P. kolobensis* is known from habitats along the Virgin River, northward along the east side of the Great Basin to the Snake River, then westward across the Snake River Plain into central Nevada. This taxon includes a number of different morphological types and it will probably be separated into a number of different species when genetic studies have been conducted. *P. gibba* occurs along the western Great Basin boundary from the Walker River system north into southeastern Oregon and east to central Nevada (Hershler 1998).

It is difficult to determine the number of springs in the southwestern U.S., but it is reasonable to estimate that there are more than 100,000. Springsnails have been collected from approximately 800 habitats in this region. Most springsnail surveys have been limited to habitats lower than 2,000 m elevation (springsnails are rarely found above this elevation) and most surveys were made to collect material for taxonomic and biogeographic studies. Although these surveys provide some status information, it is unlikely that all populations of most species have been located, and new species continue to be found at previously unvisited sites. This sampling effort was limited because funding has been inadequate to visit all potential habitats, springsnail diversity known today was not anticipated when surveys were initiated, and taxonomic diversity is not high in most basins, indicating that it

is unnecessary to visit all populations to determine most of the taxonomic diversity. It would be surprising if new populations of most species could not be found with additional surveys. It is important to realize the infantile status of springsnail taxonomy and that new techniques and future studies will increase knowledge of diversity and distribution. It has taken fish taxonomy in western North America more than 70 years to reach the current level of understanding about genetic diversity; clearly it will be years before this level of knowledge can be achieved with springsnails.

Much of our knowledge about springsnail ecology comes from observations made during taxonomic and biogeographic surveys, but recent work by Mladenka (1992), Sada and Herbst (1999, 2001, 2004) and Sada (2001, 2000) quantitatively described habitat use and environmental factors affecting community structure of several species. Springsnails are small (usually $< 5\text{mm}$ high) and they are generally limited to spring sources and a short lengths of spring brook. Few species occupy large rivers (e.g., *Pyrgulopsis archimedis* and *P. idahoensis* from the Klamath and Snake Rivers, respectively) and lakes (e.g., the now extinct *Pyrgulopsis nevadensis* that occurred in Pyramid and Walker Lakes). They feed on algae gleaned from substrate and aquatic vegetation, and they occupy habitats with good water quality. Diatoms may be their preferred food, but food ingested by *P. bruneauensis* was proportional to the availability of algae in its habitat (Mladenka 1992). Hydrobiids occupy a number of different substrates and it appears that most species prefer either sand, gravel, or cobble. They also occupy aquatic vegetation, and they usually occur in slow to moderate ($> 0\text{ cm/sec}$ and $< 40\text{ cm/sec}$) current. Water temperature of their habitats ranges from 3°C to 36°C and discharge rates of springs they occupy ranges from $< 0.0001\text{ m}^3/\text{sec}$ to $0.28\text{ m}^3/\text{sec}$. *Pyrgulopsis* spp. and *Fluminicola* spp. generally occur in colder water (although several *Pyrgulopsis* spp. occur in thermal springs, e.g., Ash Meadows, Soldiers Meadows, and Fly Ranch Geyser, NV, and Bruneau Hot Springs, ID) and *Tryonia* spp. always occur in thermal habitats. Populations may be large ($> 10,000/\text{m}^2$, and habitats may be several hundred meters long) and small populations ($< 1,000$ individuals) are uncommon, even though habitat size may be limited. Longevity is probably about one year. Reproduction may occur throughout the year, but peak periods are in the late winter, spring, and late summer. Mladenka (1992) and Sada (2001)

observed several cohorts in monthly and seasonal samples of *P. bruneauensis* and Badwater snail (*Assiminea infima*, a close relative to springsnails) populations, respectively. In warm habitats preferred by *P. bruneauensis*, Mladenka (1992) found that sexual maturity was reached in approximately two months, and maximum size was reached in four months. Sex ratio in this species was 1:1. Nothing is known about reproductive habitat requirements.

Springsnails are not cosmopolitan inhabitants of their habitats, and it appears that many species occupy different microhabitats. In thermal springs of the Muddy River, Clark County, Nevada (inhabited by three species of springsnails), *P. carinifera* preferred shallow habitats with moderate current velocities between 30 cm/sec to 40 cm/sec, and avoided current velocities > 50 cm/sec. It showed no preference for substrate type. *P. aernalis* preferred deeper water with swift current (> 50 cm/sec) and gravel substrate. *T. clathrata* was less abundant than either *Pyrgulopsis* spp., and it preferred shallow habitats with low current velocity (< 10 cm/sec). It strongly avoided deeper habitats and current velocities > 10 cm/sec, while selecting habitats without gravel or cobble substrates. It slightly and strongly preferred fines and sand substrates, respectively. It also preferred habitats with algae and CPOM. In Soldiers Meadow, Humboldt County, *P. umbilicata* occurs only near the source of thermal springs in semi-aquatic habitat that is within 1 cm of water and in the splash zone at the base of riparian grasses and emergent rocks, and *P. limaria* occurs in downstream habitats where comparatively swift water flows over cobble substrate. In thermal springs along the east side of Death Valley, Sada and Herbst (2000) found that *T. robusta* was scarce near spring sources and most abundant from 50 m – 150 m downstream. It preferred warm water (approximately 34°C), and moderate current velocity and water depth. It avoided slow and fast currents (< 5 cm/sec and > 35 cm/sec), low and high water temperatures ($< 32^{\circ}\text{C}$ and $> 40^{\circ}\text{C}$), shallow and deep water (< 4 cm and > 14 cm), and open riparian cover ($< 20\%$ and $> 80\%$).

Temporal variation in Badwater snail abundance at springs on the Death Valley floor was not statistically significant, however, spatial variation was high between Badwater and Cottonball Marsh habitats (Sada 2001). In four Muddy River springs, Sada (2000a) found temporal variation was significant for populations of *P. carinifera* and *P. aernalis*,

and *T. clathrata*. Temporal variation in *P. owensensis* was not statistically significant in a single cold spring along the east side of the White Mountains, Mono County, California (Sada and Russi fieldnotes). Temporal variation was also minimal in *T. robusta* populations occupying thermal springs in the Funeral Mountains of Death Valley National Park (Sada and Herbst 2004).

Mladenka (1992) reported that *P. bruneauensis* abundance was influenced by food availability, predators on juvenile snails (by guppies, *Libistes reticulatus*, and aquatic insects, Zygoptera), and water temperature. Sada and Herbst (1999, 2004) found that macroinvertebrate communities dominated by hydrobiids were most strongly influenced by water temperature, water velocity, substrate, distance from the spring source, water depth, conductivity, and riparian cover. Their work in several Death Valley thermal springs also indicated that different environmental factors affect communities in each spring (Sada and Herbst 2004).

Cultural factors affecting spring condition also affect springsnail abundance and distribution. Mladenka (1992) reported decreased *P. bruneauensis* abundance from livestock trampling. Sada and Nachlinger (1998) reported extirpation of springsnail populations by diversions, and Sada et al. (2000) speculated that springsnail populations on Ruby Lake National Wildlife Refuge, Elko County, Nevada, had been extirpated by dredging. Hershler and Sada (1987) reported that springsnails were lost when Jackrabbit Spring was dried by ground water pumping, Landye (1981) found that ground water pumping caused extinction of several species in northern Mexico, and excessive ground water extraction is affecting *P. bruneauensis* (Mladenka 1992). Recent surveys indicate that extinction of *P. coloradensis* was caused by introduction of the red-rimmed thiara (*Thiara tuberculata*) into its only known habitat at Blue Point Spring, Lake Mead National Recreation Area (Sada field notes). Sada and Vinyard (2002) reported that extinction of *P. ruinosa* occurred after springs were impounded on the McNett Ranch in Fish Lake Valley, Esmeralda County, Nevada. Sada (field notes) reported extirpation of a *P. hubbsi* population from Hiko Spring, Lincoln County, Nevada, following development of the spring source to maximize diversion potential.

TASSI SPRING SITE DESCRIPTION

Tassi Springs occur on Tassi Ranch in Section 13, T 33N, R16W, Mojave County, Arizona. They lie approximately 15 km upstream from Lake Mead along a wash that is tributary to Grand Wash. Three springs, a homestead with a house, several out-buildings that cover approximately 0.5 hectare (Fig. 1), and several hectares of pasture and agriculture land comprise Tassi Ranch. Much of the area has been modified from natural condition since the early 1900's for agricultural uses that cleared land and diverted spring water through a series of ditches to support alfalfa and forage crops related to cattle production. The local rancher maintained these ditches through the 1980s and they are part of the historical Tassi Ranch.

All of the springs on Tassi Ranch have been modified from natural conditions when they flowed to the southeast, off of a hillside, and onto the wash floor. The highest, and largest, spring (and the only spring occupied by *P. bacchus*; No. 1 on Fig 1) has been excavated and diverted southward from its historic path in a naturalized ditch. The ditch extends for approximately 50 m where the channel bends sharply and cascades down a steep slope onto the wash. The existing ditch appears to differ from other historical ditches that delivered water to agriculture lands that lie above the wash and northeast and southwest of the upper spring (No. 9s, Fig. 1). All of these routes differ substantially from the historic, undiverted spring brook that followed the fall-line off of the hill and into the wash. The middle elevation spring is small and has been modified by a springbox (No. 2, Fig. 1). There is no discernable discharge or spring brook, but its water supports obligatory wetland plants over approximately 30 m². It is not possible to discern the historic, natural condition of this spring. The lowest spring (No. 3, Fig. 1) has no natural features, and its location is indicated only by a rubber pipe (approximately 3 inches in diameter) emerging from the ground. All of its discharge is captured in this pipe and delivered to a metal trough (No. 6, Fig. 1) that is located approximately 40 m from where the pipe emerges from the ground. Similar to the middle spring, it is not possible to determine the natural condition of the lower spring. After leaving the trough, its water flows onto the wash and

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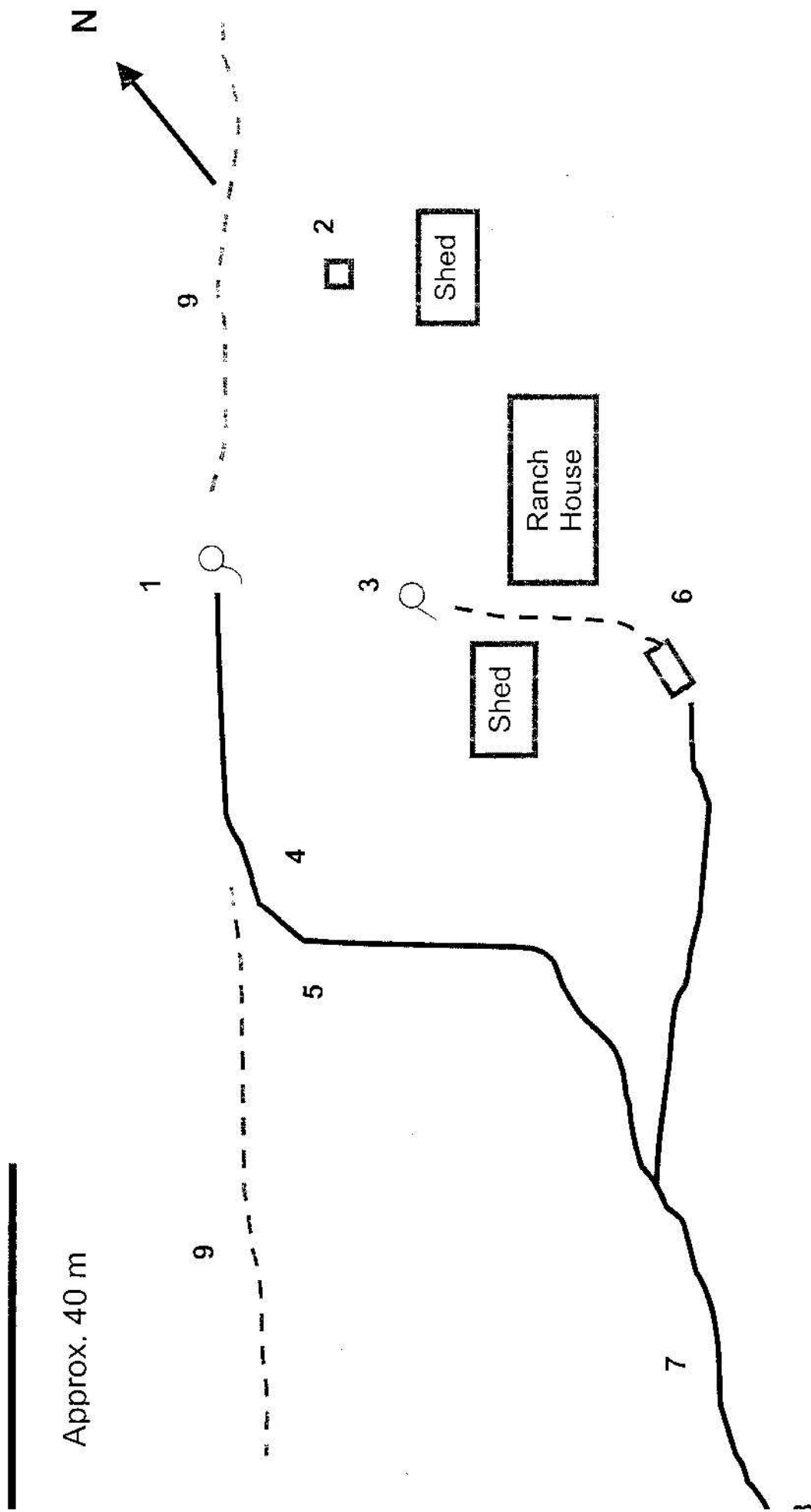


Figure 1. Schematic representation of the location of ranch buildings, spring sources, spring brooks, historic ditches, and the downstream distributional limits of important aquatic species at Tassi Springs, Mojave County, Arizona. Dashed blue line shows the pipeline route and the probable historic path of the lowest spring's spring brook; dash orange lines indicate historic diversion ditches. Numbers represent important locations on property. See Table 1 for description and UTM coordinates of important sites.

combines with upper spring water to flow approximately 150 m before percolating into the wash and drying (No. 8, Fig. 1). Springsnails presently occur only in approximately 65 m of the upper spring (No. 5, Fig. 1). They do not occupy the middle and lower springs, and there is no evidence that they were occupied by springsnails. Discharge from the lower spring suggests that it was historically occupied by springsnails, but the small size of the middle spring suggests that historic occupation is less likely. Aquatic communities in the two lower springs are depauperate and typical of springs that are highly disturbed by cultural activities (Sada et al. in press).

The upper and middle springs have naturalized from past disturbance and exhibit functioning riparian and aquatic communities. The lower spring also supports these community types, but only downstream from the trough. Upper reaches of the highest spring are densely covered by arrow weed (*Pluchea* sp.) and willow (*Salix* sp.). In the wash, these species are replaced by locally dense stands of mesquite (*Prosopis velutina* and *Prosopis glandulosa*) and salt cedar (*Tamarix* sp.). Several large cottonwood trees (*Populus fremonti*) are near the homestead and along the wash.

METHODS

Aquatic Communities

A 12" D-frame net was used to qualitatively sample (ergo 'grab sample') the aquatic community near the source of the upper spring and determine the potential presence of other rare species. The sample was a composite taken from all types of aquatic habitat (e.g., center of channel, backwater, open and densely covered by vegetation, etc.). All vertebrates were released and only macroinvertebrates were preserved. Samples were preserved in 90 percent ethyl alcohol and returned to the laboratory for sorting, enumeration, and identification.

Table 1. UTM coordinates (Zone 12) of important points shown on Figure 1 that represent the distribution of important aquatic species and important features of Tassi Springs, Mojave County, Arizona. PDOP = accuracy of GPS estimate; values < 6.0 indicate high accuracy.

Number	Feature	Northing	Easting	PDOP
1	Source, Upper Tassi Spg.	4016471	234237	4.16
2	Middle Spring Springbox	4016443	234276	3.75
3	Where Pipe Capturing Lower Tassi Spg. Enters Ground	4016442	234238	4.42
4	Point Where Upper Tassi Spg. Turns & Begins Down Cascade	4016451	234179	3.77
5	Lowest Point <i>P. bacchus</i> Observed	4016441	234181	3.89
6	Location of Trough	4016415	234232	3.56
7	Lowest Point <i>R. osculus</i> Observed	4016314	234085	3.76
8	Terminus of Water in Wash Spring Brook	4016149	233872	3.17
9	Location of Historic Ditches that Diverted Water to Agriculture lands			

Habitat and Demography

Distribution, habitat, and population studies were conducted in early May 2004 and followed similar methods described in Sada (2000). All aquatic habitats on the homestead were qualitative sampled to assess springsnail distribution. Quantitative sampling was limited the upper spring (which supported the only springsnail population) and the wash. This sampling occurred where vegetation density was sufficiently low and did not prevent access to the spring brook. Samples

were taken along transects spanning the spring brook and oriented perpendicular to the flow of water. Transects were placed every 2.5 m along the spring brook that supported springsnails and where riparian vegetation was sufficiently open to allow access to the aquatic environment. Transects were placed every 20 m along the spring brook in the wash, which did not support springsnails. A total of 23 transects were sampled ranging from the spring source to 162 m downstream. Habitat measurements and population estimates were made within 25 cm² (5 cm X 5 cm) quadrats that were placed at 5 evenly-spaced points along each transect, yielding a total of 114 habitat and population sample points along the spring brook (one sample at 50 m from the spring source was eliminated because the population estimate was inaccurate).

Mollusk density in each 25 cm² quadrat was estimated using a modified surber sampler to collect snails and temporarily remove them from the spring brook. Estimates were made using depletion techniques (White et al. 1972); most estimates were made from three depletions. Two species of mollusks occurred along the spring brook: *Physa* sp. and *Pyrgulopsis bacchus*. Mollusks were identified to species, counted, and returned immediately to the spring brook. Abundance estimates were calculated using a maximum-likelihood analysis in Microfish (Van Deventer and Platts 1985).

Habitat data quantified characteristics of channel morphology and characteristics of habitats within the wetted width. Table 2a shows parameters measured to describe channel morphology, and Table 2b shows parameters measured to describe habitat characteristics within the wetted width. Presence/absence of substrate types, algae, and submerged vegetation were recorded. Substrate types included course particulate organic matter (CPOM), fines, sands, gravel, or cobble (using a Wentworth particle scale analysis, which classifies materials as: Fines (< 1 mm), Sand (1 mm - 5 mm), Gravel (> 5 mm - 80 mm), Cobble (> 80 mm - 300 mm), Boulder (> 300 mm), or bedrock. Size was defined as the minimum particle size of substrate as measured on a two-dimensional axis, as would pass through a substrate sieve). Submerged vegetation and algal types were

recorded as *Potamogeton* sp., watercress (*Rorippa nasturtium-aquaticum*), *Chara* sp., riparian vegetation roots, blue-green algae (cyanobacteria), and filamentous green algae. Percent the substrate was covered by shade (either by riparian or instream vegetation) was also recorded. Mean water column velocity and water depth were measured at the center of each quadrat. Water temperature (measured using a YSI Model 30 hand-held salinity, conductivity, temperature meter) and wetted width were measured at each transect. Current velocity was measured using a Marsh-McBirney Model 2000 current meter.

Data Analysis

Habitat preference and niche breadth were calculated for 16 measured and categorical habitat parameters. Preference was calculated using the formula of Jacobs (1974): $D = r - p / r + p - 2rp$; where p is the proportion of the resource available in the habitat and r is the proportion of the resource utilized by the species

Table 2. Habitat parameters measured (units shown in parentheses) in the wash and upper spring at Tassi Springs: **a**—variables measured at transects placed along the spring brook continuum, and **b**—at five, evenly-spaced points across the wetted width of each transect.

a. Parameters Measured At Transects

Wetted Width (cm)
Water Temperature (°C)

b. Parameters Measured At 5 Equally-Spaced Points Across Transects

Water Depth (cm)
Mean Water Column Velocity (cm/sec)
Riparian Cover (%)
Substrate Category (Presence/Absence)
Vegetation Presence/Absence
Vegetation Type (roots, algae, etc., Presence Absence)
CPOM Presence/Absence

(Manly et al. 1993). Habitat availability was determined using data collected within quadrats ($N = 114$ for each variable, see Table 3), and habitat preference calculations were made by weighting resource use in accordance with springsnail abundance within quadrats. Preference was categorized as moderate (between 0.25 and 0.5) or strong (> 0.5), or strongly (< -0.5) or weakly avoided (between -0.25 and -0.5).

RESULTS

Habitat

Tassi Springs support approximately 200 m of aquatic habitat. The length of habitat varies seasonally and daily in response to air temperature and evapotranspiration rates. During our studies, the daily variation exceeded 30 m, with greatest lengths observed during early morning. Environmental characteristics of aquatic habitat along the spring brook supported by these springs are summarized in Tables 3 and 4. Discharge from upper Tassi Spring (as calculated from

Table 3. Mean and range of wetted width, current velocity, water depth, cover, and water temperature recorded during quantitative springsnail and habitat surveys at Tassi Springs, May 2004.

Parameter	Mean	Range
Wetted Width (cm)	108.5	50 – 270
Mean Water Column Velocity (cm/sec)	12.7	0 – 75
Water Depth (cm)	3.4	1 – 10
Cover (%)	49.2	0 – 100
Temperature (°C)	24.3	23.4 – 25.2

Table 4. Proportion of quadrats where environmental parameters were recorded as present during quantitative springsnail and habitat surveys at Tassi Springs, May 2004.

Parameter	Percent Occurrence
Substrate	
Fines	0.0
Sand	0.42
Gravel	0.63
Cobble	0.0
CPOM	0.27
Submerged Vegetation	
Green Algae	0.18
Blue-Green Algae	0.0
<i>Chara</i> sp.	0.0
<i>Potamogeton</i> sp.	0.13
Roots	0.10
Watercress	0.43

measurements taken within each quadrat, $N = 74$) was $0.00399 \text{ m}^2/\text{sec}$, and in the wash (with combined discharge from upper and lower springs) it was $0.00495 \text{ m}^2/\text{sec}$ ($N = 40$).

Aquatic Communities

A total of 14 taxa were collected by grab sample near the source of upper Tassi Spring (Table 5). *P. bacchus* was the most abundant organism in the community, which included several rare species in addition to other potential crenobiontic macroinvertebrates. The presence of *Microcylloepus* sp. and *Ambrysus* sp. is particularly interesting because genera include crenobiontic species in arid land springs of the western U.S. (e.g., La Rivers 1953, Shepherd 1992, Schmude 1999, Polehmus and Polhemus 2002). Identification of these specimens

Table 5. Taxonomic list of macroinvertebrates collected during grab sample near the source of upper Tassi Spring during May 2004.

Taxon	Number
Insects	
Order Trichoptera	
<i>Helicopsyche borealis</i>	1
Order Ephemeroptera	
<i>Tricorythodes</i> sp.	1
Order Coleoptera	
<i>Heterelmis</i> , larva	1
<i>Heterelmis</i> , adult	1
<i>Microcylloepus</i> , larva	8
<i>Microcylloepus</i> , adult	3
Order Odonata	
<i>Argia pulla</i>	4
Order Hemiptera	
<i>Ambrysus</i> sp.	1
<i>Nerthra</i> sp.	1
Order Megaloptera	
<i>Corydalus</i> sp.	1
Order Diptera	
<i>Polypedilum-flavum</i>	2
<i>Rheotanytarsus</i>	9
<i>Tanytarsus</i>	4
<i>Limonia</i> sp.	1
Gastropods	
<i>Pyrgulopsis bacchus</i>	269
<i>Physa/Physella</i> sp.	1
Mites	
<i>Oribatei</i> sp. (genus key unavailable in English)	1
Fish	
Speckled dace (<i>Rhinichthys osculus</i>)	
Amphibians	
Red-spotted toad (<i>Bufo punctatus</i>)	
Southwestern toad (<i>Bufo microscaphus</i>)	

No bull frogs ?!

will be verified by scientists that are experts with these groups. *Nerthra* sp. is another uncommon group of semi-aquatic heteropterans with limited distribution. The occurrence of speckled dace is also notable because of its virtual absence from historical habitat in the lower Colorado River.

Goldfish?

Springsnail Distribution and Abundance

Pyrgulopsis bacchus occurred only in upper Tassi Spring where it inhabited approximately 65 m of the spring brook (see Fig. 2). Its occupied habitat covered approximately 70 m², and its habitat extended from the spring source to approximately 10 m down the cascade toward the wash (see Fig. 1, No 5 and Table 1). *Physa* sp. was the only other mollusk observed in the system. It occupied only habitats in the wash and it was never syntopic with *P. bacchus*.

Mean springsnail density in the occupied portion of the spring brook was 29.0 individuals/ 25 cm² (range 0 – 106). Greatest density occurred in reaches between and 10 m and 40 m from the source (or upstream from the cascade) (see Fig. 2). Qualitative surveys indicated that springsnails were scarce in portions of this area where dense arrow weed shaded the spring brook (e.g., in reaches between 20 m and 30 m from the source).

Springsnail Habitat Preference

Springsnails preferred deeper habitats (Fig. 3) with slow current (Fig. 4). Habitats less than 4 cm deep and swifter than 30 cm/sec were avoided. It preferred shaded habitats where sunlight penetrated onto the spring brook (e.g., shaded by willow trees or sparse arrow weed) and avoided areas shaded by grass and without shading (Fig. 5). It preferred moderate water temperatures and avoided both cold and warm conditions (Fig. 6). It occupied all of the substrate types occurring in upper Tassi Spring, but showed no preference for any particular type (Fig. 7). It preferred habitats with watercress and roots, avoided *Potamogeton* sp., and occasionally occupied sites with green algae but exhibited neither preference or avoidance of it (Fig. 8).

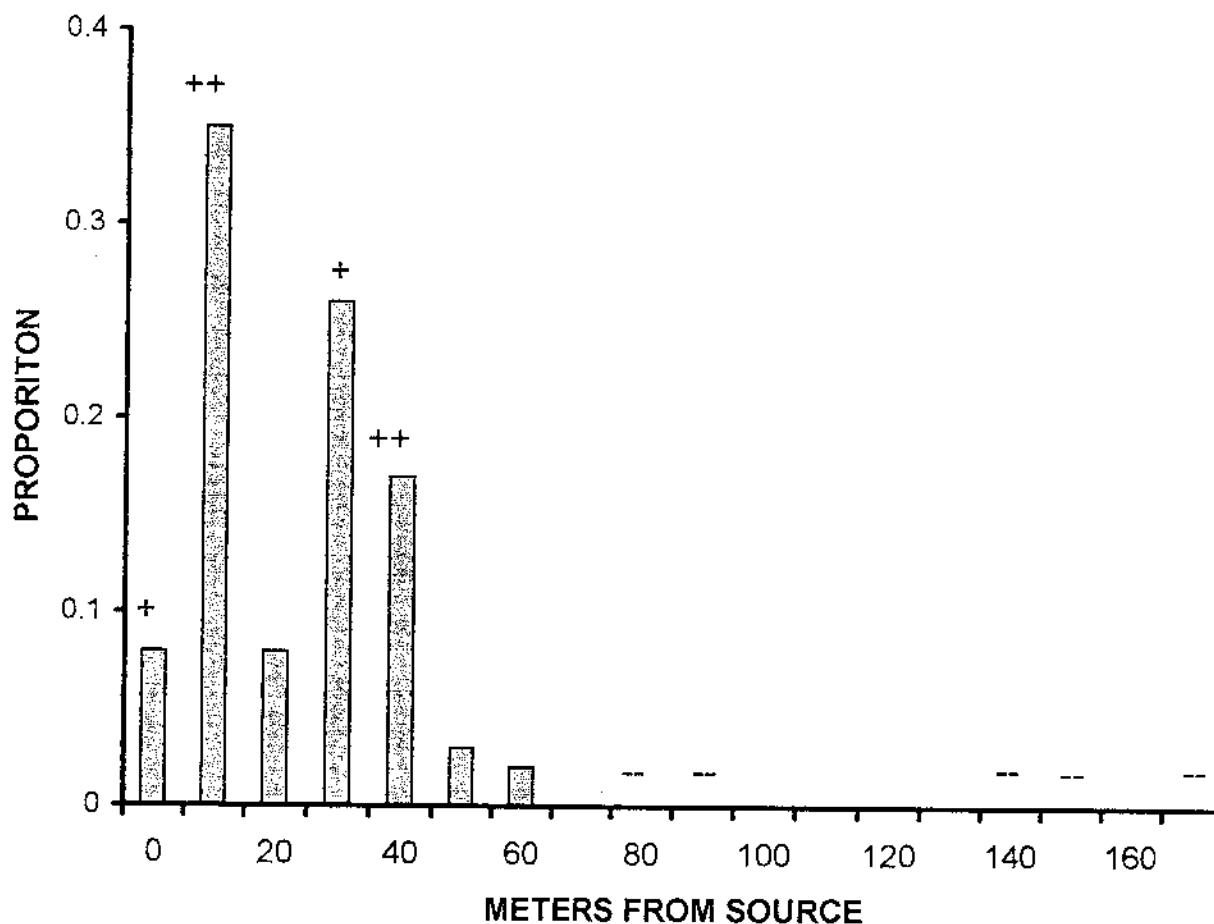


Figure 2. The distribution of *P. bacchus* along the upper Tassi Spring spring brook shown as the proportion of the total population estimate ($N = 1647$). Preference for each resource category is identified as '+' or moderate (values between 0.25 and 0.5), or '++' strong (values > 0.5), or '-' moderately avoided (values < -0.5) or '--' strongly avoided (values between -0.25 and -0.5). Absence of these identifiers indicates resources for which there was no preference or avoidance.

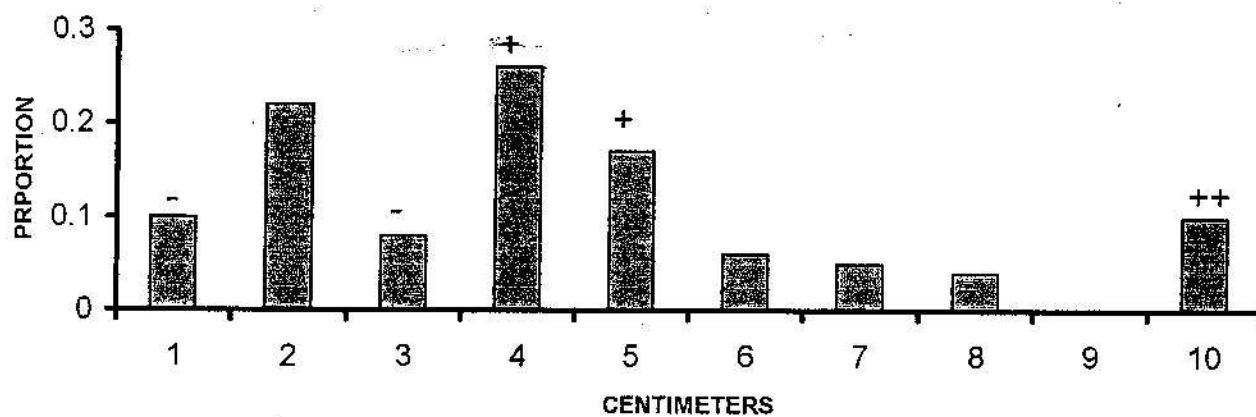


Figure 3. Water depth of habitat occupied by *P. bacchus* in upper Tassi Spring during May 2004. Identification of preference and avoidance of resource categories as described in Fig. 2.

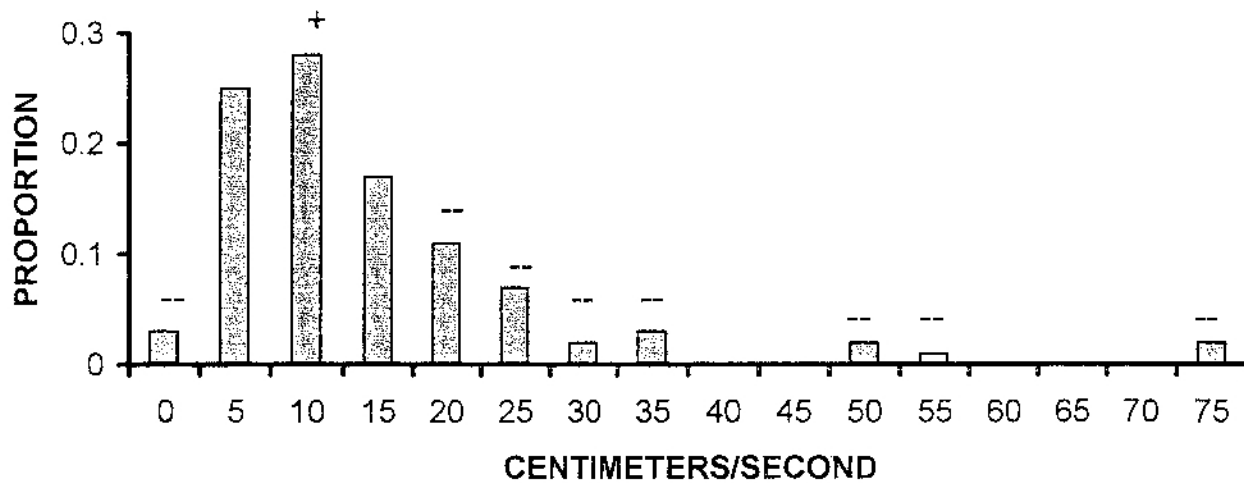


Figure 4. Mean water column velocities occupied, preferred and avoided by *P. bacchus* in upper Tassi Spring during May 2004. Identification of preference and avoidance of resource categories as described in Fig. 2.

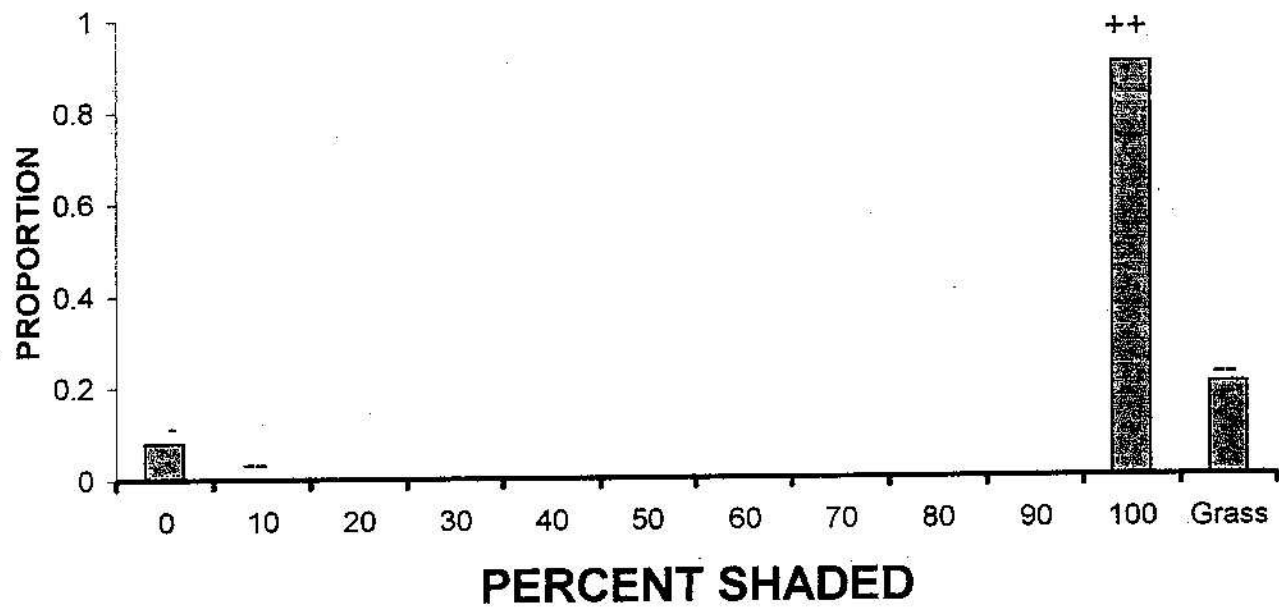


Figure 5. Percent shading of habitats occupied by *P. bacchus* in upper Tassi Spring during May 2004. Identification of preference and avoidance of resource categories as described in Fig. 2.

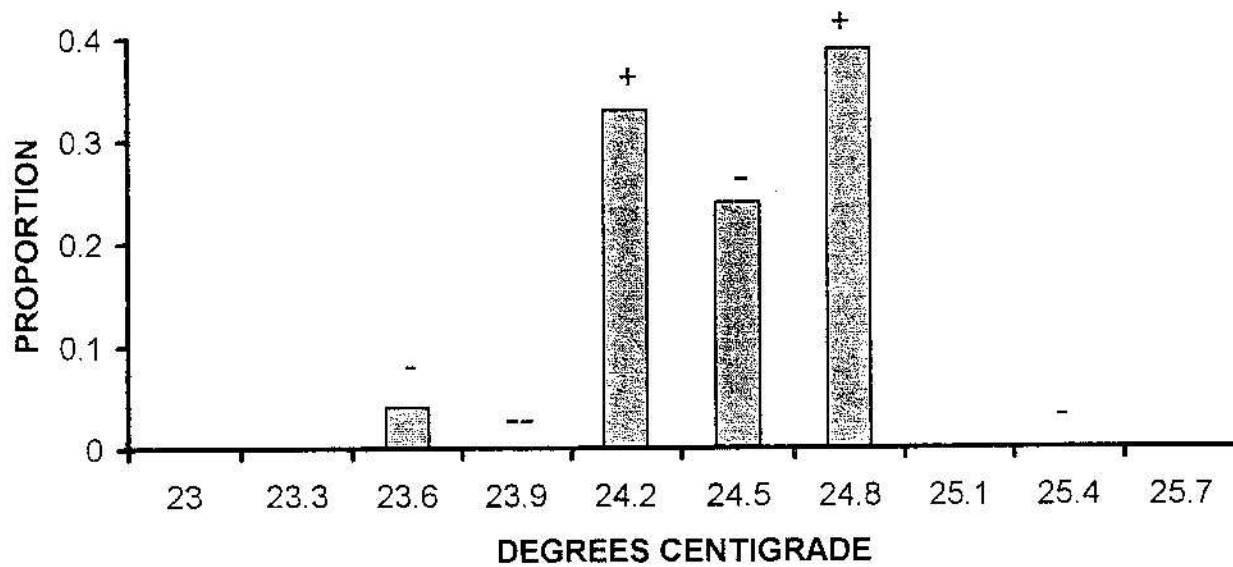


Figure 6. Water temperatures occupied, preferred and avoided by *P. bacchus* at Tassi Springs during May 2004. Identification of preference and avoidance of resource categories as described in Fig. 2.

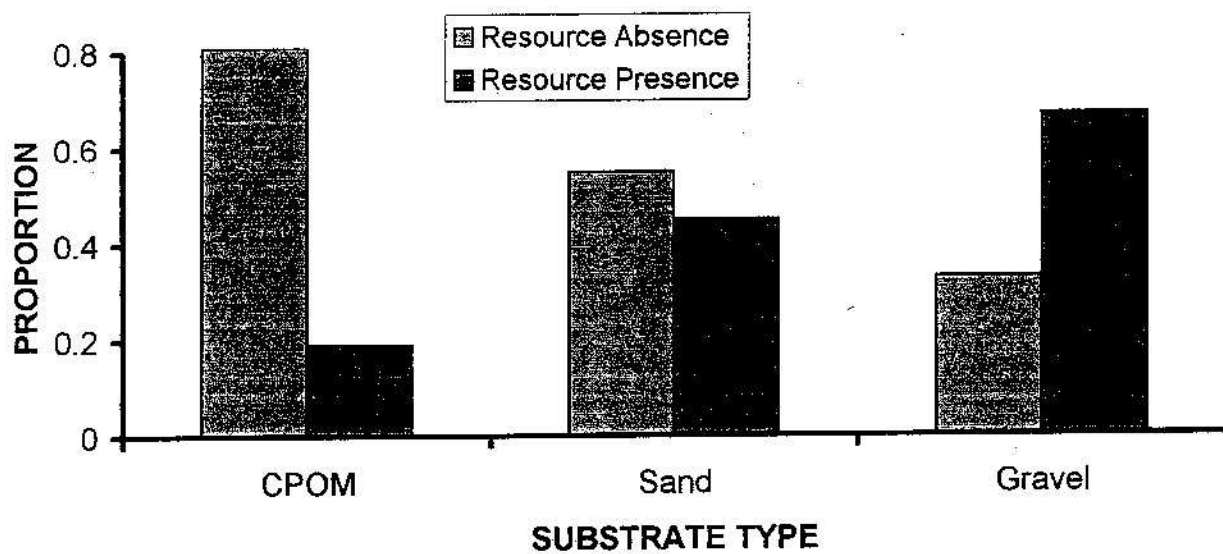


Figure 7. Proportion of *P. bacchus* occurring where CPOM, Sand, and Gravel occur and do not occur at Tassi Springs during May 2004. *P. bacchus* did not exhibit preference for any particular type of substrate.

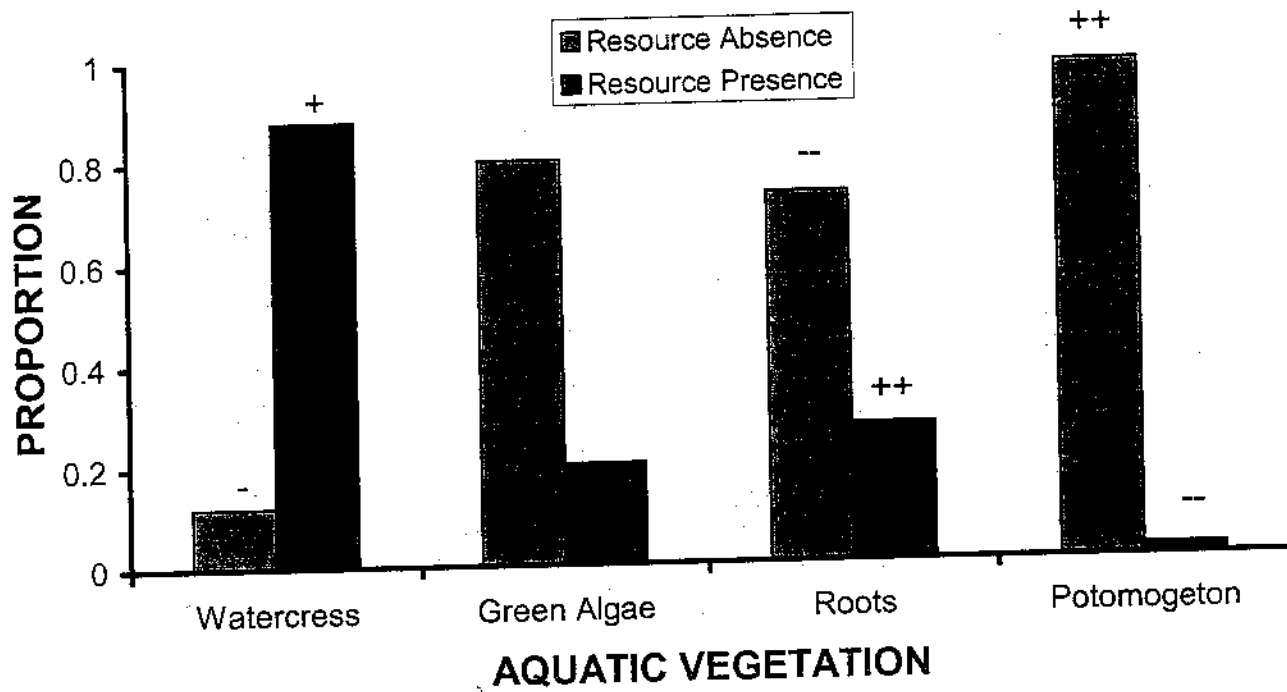


Figure 8. Proportion of *P. bacchus* occurring with submerged aquatic vegetation at Tassi Springs during May 2004. Identification of preference and avoidance of resource categories as described in Fig. 2.

DISCUSSION

Springs are small-scale aquatic systems that occur where ground water reaches the surface (Meinzer 1923). They range widely in size and morphology. Some dry each year, some dry only during extended droughts, while some persist for millennia. Thousands are scattered over all climates, elevations, and geological settings in the western U.S., where they are frequently the most common source of water. They support diverse aquatic communities and their riparian zones are habitat for numerous terrestrial species. Myers and Resh (1999) believed that these aquatic communities contribute substantially to the biodiversity of semi-arid landscapes. Springs also support riparian systems, which Thomas et al. (1979) estimated to be habitat for approximately 80 percent of all Great Basin terrestrial species. Saab et al. (1995) estimated that between 2/3 and 3/4 of non-game bird species are associated with riparian habitats during breeding season. Springs in the western U.S. are also important for many crenobiontic invertebrates and vertebrates with limited distribution (e.g., Hubbs and Miller 1948, Hershler 1998, Baldinger et al. 2000, Shepard 1992, Schmude 1999, Wiggins and Erman 1987).

Springs support distinctive aquatic systems, and many studies have shown that they are influenced by geology, climate, and ground water hydrology (e.g., Freeze and Cherry 1979, McCabe 1998). Each spring is a unique assemblage of interacting biotic and abiotic factors, where water chemistry, temperature, and spring morphology most commonly influence aquatic biota (Resh 1983, Cushing 1996), and soil moisture, chemistry, and soil structure and particle size most strongly influence riparian systems (Knopf et al. 1988, Castelli et al. 2000). Springs are distinctive aquatic systems because their chemistry, temperature, and flow regime are comparatively stable and minimally influenced by drought and runoff attributed to snow melt or rain (Mattson et al. 1995). Environmental variation in springs is lowest near the source and greatest downstream (McCabe 1998), which is contrary to lotic systems where environmental variation is greatest near the source and lowest downstream (e.g., Hynes 1970, Vannote et al. 1980). Aquatic

communities in springs include many species that also occupy lotic and lentic systems, but they may also be inhabited by crenobiontics that are often weakly vagile and limited in their distribution (Taylor 1985, Hershler 1998, Schmude 1999). Their energy pathways also are distinct because organic material is usually limited near spring sources (except in some karst systems), but it rapidly increases downstream, where energy pathways are similar to low order streams (Thorup 1974). This is contrary to lotic systems, where organic material is not limited near the stream sources (Vannote et al. 1980). The diversity of aquatic species is usually lowest near spring sources, and increases downstream because of changes in thermal regime, suspended solids, water chemistry, and nutrient availability (Minckley 1963, Meffe and Marsh 1983). As with lotic systems, faunal diversity in springs may also be attributed to other factors such as physical habitat characteristics and microhabitat diversity (Williams 1991, Ferrington 1998). Although much is known about springs, few studies have examined spring-fed riparian systems and most ecological studies have examined springs that are minimally affected by disturbance.

Humans have used Great Basin wetlands since the early Holocene (e.g., Janetski and Madsen 1990). Intermittent settlement near wetlands and daily activities of hunting and gathering naturally tended to focus upon the biotic resources concentrated at these habitats. For a short period before the region was settled by European immigrants, a few tribes also diverted water to irrigate land and increase production of commonly eaten native plants. The Fremont Tribe diverted from large rivers near the Wasatch Range (Madsen 1989) and Owens River Basin Paiutes diverted streams from the east flank of the Sierra Nevada (Steward 1933). Great Basin wetlands also produced food such as Owens pupfish (*Cyprinodon radiosus*), Tahoe sucker (*Catostomus tahoensis*), cui-ui (*Chasmistes cujus*), Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*), tui chub (*Gila bicolor*) and brine flies (*Ephydra hians*) that were eaten by Paiutes along the eastern Sierra Nevada (Steward 1933, Knack and Stewart 1984). Excavation of Fremont Tribe sites found that their diet included Utah sucker (*Catostomus ardens*), Utah chub (*Gila atraria*),

and cutthroat trout (*Oncorhynchus clarki utah*) (Janetski 1990). Greenspan (1990) also documented fish remains from archaeological sites in the Great Basin of Oregon and Drews (1990) reviewed the dietary role of shellfish.

While Native Americans used and altered Great Basin wetlands, the major anthropogenically-induced changes to aquatic biogeography accompanied habitat alterations and non-native taxa introductions during the past 120 years. Since the beginning of the twentieth century, most rivers in the region have been dammed and diverted for irrigation, flood control, or power generation (La Rivers 1962, Sigler and Sigler 1987). Many springs and streams have been modified by livestock grazing, diversion, and ground water use (see Miller 1961, Dudley and Larson 1976, Fleischner 1994). Native aquatic biota also have been impacted by addition of 43 non-native fish species for sport, pest management (Sigler and Sigler 1987), and unspecified recreational or commercial interests (Moyle 1984). Fisheries management agencies have enhanced non-native sport fish populations by poisoning thousands of miles of streams, causing the consequent reduction or elimination of native fish populations and macroinvertebrates (Moyle et al. 1986, Rinne and Turner 1991, Andersen and Deacon 1996). These habitat modifications and introductions have caused many populations to decline and driven some species to extinction (Minckley and Deacon 1968, Williams et al. 1985, Miller et al. 1989, Minckley and Douglas 1991).

The paucity of water in the desert has focused human use on springs in areas with sparse streams, rivers, and lakes. As a consequence, most springs have been modified by diversion, livestock trampling, and introduction of non-native species (Hendrickson and Minckley 1984, Sada and Vinyard 2002). Complete loss of aquatic communities occurs when springs are dried by diversion or excessive ground water pumping (Minckley and Deacon 1968, Brune 1975, Williams et al. 1985, Johnson and Hubbs 1989) or degraded by other cultural activities (Miller et al. 1989, Sada and Vinyard 2002).

Tassi Springs support comparatively diverse riparian and aquatic systems that change along the spring brook continuum from source to terminus. Similar to other

arid land springs in the western U.S., upper reaches of spring brook are occupied by crenobiontic species that require stable environments and are relatively intolerant of disturbance or harsh conditions. Lower reaches (in the wash) are occupied by more tolerant species that persist through stressful environmental change (e.g., flooding, high water temperatures, etc.).

Historical cultural activities at Tassi Springs altered its springs in a manner that is similar to human impacts observed at other springs over the past 120 years. Each of its springs bears little resemblance to natural condition because of diversion activities, such as spring box construction, ditching, and capture in pipes. As a result, it is doubtful that the biological and environmental condition of these springs is similar to historical, pre-cultural disturbance. Absence of information that describes pre-disturbance conditions prevents a quantitative assessment of change, but changes similar to those at Tassi Springs have caused resulted in loss of populations of rare species and extinction (see Miller 1961, Brune 1975, Shepard 1993, Hershler 1998, Sada and Vinyard 2002). Extensive alteration of these springs suggests that the historical community included species that no longer persist, and that further alteration may result in extirpation of some aquatic species.

?
← have caused
resulted

The presence of several extant crenobiontic species indicates that these springs also provide a distinctive and important resource that is occupied by a suite of crenobiontic species, some of which may not occur elsewhere (see Sada and Vinyard 2002). Work in other springs also suggests that each of these taxa occupy specific microhabitats (e.g., Sada and Herbst 1999, 2004), and that resource management should consider the affect of activities on a wide array of aquatic habitat types. Failure to consider these factors increases the potential of extirpating aquatic species from the community.

Management Recommendations

- Maintain upper Tassi Spring in existing condition. Although this spring is altered from its historic condition, attempts to redirect it toward its historic spring brook would constitute a disturbance that may extirpate rare species.
- Maintain existing conditions in existing spring brooks to maximize the diversity of aquatic and riparian habitats on the ranch.
- Initiate minor restoration of the upper spring brook by decreasing arrow weed density. Arrow weed is rapidly established in riparian systems following vegetation removal, and its density frequently prohibits establishment of other riparian species. Over several years, selectively remove arrow weed from the riparian system to allow additional sunlight to reach the spring brook and establish later seral stages of vegetation in the riparian community (e.g., willow dominated).
- Conduct taxonomic surveys to identify additional crenobiontic species.
- Install guage(s) to monitor discharge and quantify temporal changes.

Springsnail Monitoring

Resource monitoring programs should be designed to assess environmental and biotic change and place them in context of ecosystem health. They should be tailored to assess circumstances at particular localities and to assist with designing future management (Hunsaker and Carpenter 1990). Monitoring programs vary in the amount of information they accumulate, and range from cursory, ocular surveys to highly quantitative data collection over long periods of time.

Work with other springsnail species shows that seasonal variation in their abundance may exceed one order of magnitude (e.g., Sada 2000), and that they usually occupy specific microhabitats. Two basic monitoring programs are outlined below to assess the status of *P. bacchus* at Tassi Springs. The first program can be conducted with little training or specific equipment, the second program is highly

quantitative and involves intensive accumulation of ecological information. Survey and preservation method are also summarized in Appendix B.

It is the responsibility of the surveyors to acquire any permits needed and to secure permission for access across non-federal lands. State Departments of Wildlife and the National Park Service require a Scientific Collection Permit to collect, study, or display mollusks. Several people can collect under the same Collection Permit, but all names and birth dates must be listed as sub-permittees. The Permit is granted following submission of a proposal describing reasons for collection, methods of take, disposition of specimens, and completion of annual report.

Monitoring Method I is a qualitative assessment of status and distribution. Required equipment are: A 6" diameter kitchen sieve (mesh size ~ 1mm), a 6" plastic tray, field notebook, and digital camera. This program focuses on known *P. bacchus* distribution in Tassi Springs and field assessments should be conducted annually, preferably during the spring (which is the time that surveys were conducted for this report), so that future abundance and distribution can be compared to observations during May 2004. The survey should take no longer than a day and include the following activities:

- 1) Establish at least 4 photo points showing the source and various portions of spring brook occupied by *P. bacchus*. Record the date photos were taken.
- 2) Conduct a general springsnail distribution survey by working the sieve over substrate and through aquatic vegetation at various sites along the spring brook continuum. At each point surveyed, move the sieve through the spring brook for approximately 10 second then empty the contents into the plastic container with approximately 1 cm of water. Record only presence or absence, and do not sample intensively, this will occur under item 3. Return all macroinvertebrates alive to the spring brook. Continue sampling down the spring brook until springsnails no longer occur in the sample. Record the distance from the source of the downstream-most springsnail, and using GPS.

Springsnails are easy to identify; see Appendix A for schematic drawings of a typical *Pyrgulopsis* shell.

- 3) Working the sieve over substrate and through aquatic vegetation at points located approximately every 2.5 m down the spring brook until springsnails are no longer found. At each location work the sieve in the water for approximately 20 seconds then empty its contents into the plastic tray. Count the number of springsnails in each sample, record the number and the distance downstream from the source of the sample, and return snails alive to the spring brook. Do not let the sample dry and cause springsnail mortality. This sampling will yield an estimate of number of individuals captured per unit effort (both number of samples and number per unit time). Record the downstream limit of springsnails.
- 4) Identifying any other non-native aquatic species observed in the spring brook. Non-native species that are most likely to be introduced in the system are mosquito fish, crayfish, red-rimmed melanoides (a gastropod), and bullfrogs. These, and other likely species, are shown in Appendix A.
- 5) A gauge(s) should be installed to record spring discharge.

Monitoring Method II is a highly quantitative program to assess spatial and temporal variation in the spring environment and springsnail abundance. These surveys should be conducted if changes in the spring environment are anticipated (e.g., decreased discharge attributed to diversions, ground water pumping, or other habitat alterations). These surveys should:

- 1) Be conducted for a minimum of three years, during periods of minimum (winter) and maximum (summer) springsnail abundance. Methods and variables measured/estimated for this program are as described for work conducted during May 2004.
- 2) Springsnails should be collected, relaxed, and preserved at least once every five years and sent to a specialist to verify their identity.

- 3) Grab samples of the macroinvertebrate community should be collected, and returned to a qualified laboratory for sorting, identification, and enumeration.

REFERENCES

- Andersen, M.E. and J.E. Deacon. 2001. Population size of Devils Hole pupfish (*Cyprinodon diabolis*) correlates with water level. *Copeia* 2001:224-228.
- Baldinger, A.J., W.D. Shepard, and D.L. Threlhoff. 2000. Two new species of *Hyalella* (Crustacea: Amphipoda: Hyalellidae) from Death Valley National Park, California, U.S.A. *Proceedings of the Biological Society of Washington* 113: 443-457.
- Brune, G. 1975. Major and historical springs of Texas. Texas Water Development Board Report 189:1-94.
- Castelli, R.M., J.C. Chambers, and R.J. Tausch. 2000. Soil-plant relations along a soil-water gradient in Great Basin riparian meadows. *Wetlands* 20:251-266.
- Cushing, C.E. 1996. The ecology of cold desert spring-streams. *Archiv für Hydrobiologie* 135:499-522.
- Drews, M.P. 1990. The dietary role of freshwater shellfish from Stillwater Marsh. Pages 63-74, *In* J.C. Janetski and D.B. Madsen, editors, *Wetland adaptations in the Great Basin*. Brigham Young University, Museum of Peoples and Cultures Occasional Papers No. 1.
- Dudley, W.W., Jr. and J.D. Larson. 1976. Effect of irrigation pumping on desert pupfish habitats in Ash Meadows, Nye County, Nevada. United States Geological Survey Professional Paper, 927:1-52.
- Erman, N.A. and D.C. Erman. 1995. Spring permanence, Trichoptera species richness, and the role of drought. *Journal of the Kansas Entomological Society* 68:50-64.
- Fleischner, T.L. 1994. Ecological cost of livestock grazing in western North America. *Conservation Biology* 8:629-644.
- Ferrington, L.C. 1998. Generic composition of the chironomid fauna in springs of North America. Pages 141-155, *In* L. Botosaneanu (ed.), *Studies in crenobiology. The biology of springs and spring brooks*. Backhuys Publishers, Leiden, The Netherlands.

- Freeze, R.A. and J.A. Cherry. 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
- Greenspan, R.L. 1990. Prehistoric fishing in the northern Great Basin. Pages 207-232, *In* J.C. Janetski and D.B. Madsen (eds.), Wetland adaptations in the Great Basin. Brigham Young University, Museum of Peoples and Cultures Occasional Papers, No. 1.
- Hamlin, R.A. 1996. Conservation genetics of remnant springsnail, *Pyrgulopsis wongi*, populations in desert valleys of California and Nevada. Unpublished M.S. thesis, University of Nevada, Reno.
- Hendrickson, D.A. and W.L. Minckley. 1984. Cienegas—Vanishing climax communities of the American southwest. *Desert Plants* 6:130-175.
- Hershler, R. 2001. Systematics of the North and Central American aquatic snail genus *Tryonia* (Rissooidea: Hydrobiidae). *Smithsonian Contributions to Zoology*, Number 612.
- Hershler, R. 1999. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part II. Genera *Colligyrus*, *Eremopygrus*, *Fluminicola*, *Prinstinicola*, and *Tryonia*. *The Veliger* 42:306-337.
- Hershler, R. 1998. A systematic review of the Hydrobiid Snails (Gastropoda: Rissooidea) of the Great Basin, Western United States. Part 1. Genus *Pyrgulopsis*. *The Veliger* 41:1-132.
- Hershler, R. and T.J. Frest. 1996. A review of the North American freshwater snail genus *Fluminicola* (Hydrobiidae). *Smithsonian Contributions to Zoology* 583.
- Hershler, R. and J.J. Landye. 1988. Arizona Hydrobiidae (Prosobranchia: Rissoacea). *Smithsonian Contributions to Zoology* Number 459.
- Hershler, R. and D.W. Sada. 1987. Springsnails (Gastropoda: Hydrobiidae) of Ash Meadows, Amargosa basin, California-Nevada. *Proceedings of the Biological Society of Washington* 100:776-843.
- Hershler, R., Liu, H., and M. Mulvey. 1999. Phylogenetic relationships with the aquatic snail genus *Tryonia*: Implications for biogeography of the North American southwest. *Molecular Phylogenetics and Evolution* 13:377-391.

- Hubbs, C. 1995. Springs and spring runs as unique aquatic habitats. *Copeia* 1995:989-991.
- Hubbs, C.L. and R.R. Miller. 1948. The zoological evidence: correlation between fish distribution and hydrographic history in the desert basins of western United States. *Bulletin of the University of Utah* 38:17-166.
- Hunsaker, C.T. and D.E. Carpenter (eds.). 1990. Ecological indicators for the environmental monitoring and assessment program. EPA 600/3-90/060. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC.
- Hynes, H.B.N. 1970. The ecology of running waters. University of Toronto Press: 555 pp.
- Jacobs, J. 1974. Quantitative measurement of food selection: a modification of the forage ratio and Ivlev's electivity index. *Oecologia (Berlin)* 14:413-417.
- Janetski, J.C. 1990. Wetlands in Utah Valley prehistory. Pages 233-258, *In* J.C. Janetski and D.B. Madsen (eds.). Wetland adaptations in the Great Basin. Brigham Young University, Museum of Peoples and Cultures Occasional Papers, No. 1.
- Janetski, J.C. and D.B. Madsen (eds.). 1990. Wetland adaptations in the Great Basin. Brigham Young University, Museum of Peoples and Cultures Occasional Papers, No. 1.
- Johnson, J.E. and C.L. Hubbs. 1989. Status and conservation of poeciliid fishes. Pp. 310-318, *In* G.K. Meffe and F.F. Snelson, Jr. (eds.). Ecology and evolution of livebearing fishes (Poeciliidae). Prentice Hall, New Jersey. 453 pp.
- Knack, M.C. and O.C. Stewart. 1984. As long as the river shall run. An ethnohistory of Pyramid Lake Indian Reservation. University of California Press, Berkeley:433 pages.
- Knopf, F.L., R.R. Robinson, T. Rich, F.B. Samson, and R.C. Sazo. 1988. Conservation of riparian ecosystems in the United States. *Wilson Bulletin* 100:272-284.
- Landye, J.J. 1981. Current status of endangered, threatened, and/or rare mollusks of New Mexico and Arizona. Unpublished report to U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

- La Rivers, I. 1962. Fishes and fisheries of Nevada. Nevada State Fish and Game Commission, Carson City:782 pages.
- La Rivers, I. 1953. New Gelastocorid and Naucorid records and miscellaneous notes, with a description of an new species, *Ambrysus amargosus* (Hemiptera: Naucoridae). *Wasmann Journal of Biology*, 11:83-96.
- Madsen, D.B. 1989. Exploring the Fremont. University of Utah Occasional Publication, 8.
- Manly, B. L., L. McDonald, and D. Thomas. 1993. Resource selection by animals. Chapman and Hall, London.
- McCabe, D.J. 1998. Biological communities in springbrooks. Pages 221-228, *In* Botosaneau, L. (ed.). Studies in crenobiology. The biology of springs and spring brooks. Backhuys Publishers, Leiden, The Netherlands.
- Meffe, G.K. and P.C. Marsh. 1983. Distribution of aquatic macroinvertebrates in the Sonoran Desert springbrooks. *Journal of Arid Environments* 6:363-371.
- Meinzer, O.E. 1923. Outline of ground water hydrology, with definitions. U.S. Geological Survey Water Supply Paper 494.
- Miller, R.R. 1961. Man and the changing fish fauna of the American southwest. *Papers of the Michigan Academy of Science, Arts, and Letters* 46:365-404.
- Miller, R.R., J.D. Williams, and J.E. Williams. 1989. Extinctions of Northern American fishes during the past century. *Fisheries*, 14:22-38
- Minckely, W.L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix, AZ:293 pp.
- Minckley, W.L. 1963. The ecology of a spring stream, Doe Run, Meade County, Kentucky. *Wildlife Monographs* 11:1-124.
- Minckley, W.L. and M. E. Douglas. 1991. Discovery and extinction of western fishes: A blink of the eye in geologic time. Pages 7 – 18, *In* W.L. Minckley and J.E. Deacon (eds.). Battle against extinction. Native fish management in the American west. University of Arizona Press, Tucson.
- Minckley, W.L. and J.E. Deacon. 1968. Southwestern fishes and the enigma of 'endangered species'. *Science* 159:1424-1432.

- Mladenka, G.C. 1992. The ecological life history of the Bruneau hot springs snail (*Pyrgulopsis bruneauensis*). Unpublished M.S. Thesis, Idaho State University, Pocatello, Idaho.
- Moyle P.B. 1984. Fish introductions into North America: Patterns and ecological impact. In H.A. Mooney and J.A. Drake (eds.). Ecology of biological invasions of North America and Hawaii. Ecological Series, 58. Springer-Verlag, New York.
- Moyle, P.B., H.W. Li, and B.A. Barton. 1986. The Frankenstein effect: Impact of introduced fishes on native fishes in North America. Pages 415-426, In R.H. Stroud (ed.). Fish culture in fisheries management. American Fisheries Society, Bethesda, Maryland.
- Myers, M.J. and V.H. Resh. 1999. Spring-formed wetlands of the arid west. Islands of aquatic invertebrate biodiversity. Pages 811- 828, In D.P. Batzer, R.B. Radar, and S.A. Wissner (eds.). Invertebrates in freshwater wetlands of North America: Ecology and management. John Wiley and Sons, New York.
- Polhemus, D.A. and J.T. Polhemus 2002. Basins and ranges: The biogeography of aquatic true bugs (Insecta:Heteroptera) in the Great Basin. Pages 235-244, In R. Hersher, D.B. Madsen, and D.R. Currey (eds.). Great Basin aquatic systems history. Smithsonian Contributions to the Earth Sciences No. 33.
- Resh, V.H. 1983. Spatial differences in the distribution of benthic macroinvertebrates along a springbrook. Aquatic Insects 5:193-200.
- Rinne, J.N. and P. R. Turner. 1991. Reclamation and alteration of management techniques, and a review of methodology in stream renovation. Pages 219 – 244, In W.L. Minckley and J.E. Deacon (eds). Battle against extinction. Native fish management in the American west. University of Arizona Press, Tucson.
- Saab, V.A., C.E. Brock, T.D. Rich, and D.S. Dobkin. 1995. Livestock grazing effects in western North America. Pages 311-353, In T.E. Martin and D.M. Finch (eds.). Ecology and management of Neotropical migratory birds. Oxford University Press, New York.
- Sada, D.W. 2001. Demography and habitat use of the Badwater snail (*Assimineia infima*), with observations on its conservation status, Death Valley National Park, California, U.S.A. Hydrobiologia 466:255-265.

- Sada, D.W. 2000. Spatial and temporal variation in aquatic mollusk abundance and habitat as indicators of environmental change, Muddy River springs, Clark County, Nevada. Unpublished report to Southern Nevada Water Authority, Las Vegas, Nevada.
- Sada, D.W. and G.L. Vinyard. 2002. Anthropogenic changes in historical biogeography of Great Basin aquatic biota. Pages 277-293, *In* R. Hershler, D.B. Madsen, and D.R. Currey (eds.). Great Basin aquatic systems history. Smithsonian Contributions to the Earth Sciences No. 33.
- Sada, D.W. and D.B. Herbst. 2004. Ecology of aquatic macroinvertebrates in Travertine and Nevares Springs, Death Valley National Park, California, with an examination of diversion effects on abundance and community structure. Unpublished report to U.S. National Park Service, Death Valley National Park.
- Sada, D.W. and D.B. Herbst. 2001. Macroinvertebrates and environmental characteristics of Owens Valley springs, Inyo County, California. Unpublished report to City of Los Angeles Department of Water and Power, Bishop, CA.
- Sada, D.W. and D.B. Herbst. 1999. Habitat use by rare aquatic macroinvertebrates in springbrooks of the upper Muddy River, Clark County, Nevada. Unpublished report to The Nature Conservancy, Southern Nevada Projects Office, Las Vegas, Nevada.
- Sada, D.W. and J. Nachlinger. 1998. Spring Mountains ecosystem. Vulnerability of spring-fed aquatic and riparian systems to biodiversity loss. Part II. Springs sampled during 1997. Unpublished report to U.S. Bureau of Land Management, Las Vegas, Nevada.
- Sada, D.W., D.B. Herbst, and F.J. Smith. 2000. A survey of springs on Ruby Lake National Wildlife Refuge (Elko and White Pine Counties, Nevada) and the influence of habitat alteration on the structure of aquatic animal communities. Unpublished report to the U.S. Fish and Wildlife Service, Ruby Lake National Wildlife Refuge, Ruby Valley, Nevada.
- Sada, D.W., E. Fleischman, and D.D. Murphy. Accepted. Associations among spring-dependent aquatic assemblages and environmental land use gradients in a Mojave Desert mountain range. *Diversity and Distributions*.
- Sada, D.W., R. Hershler, and G.L. Vinyard. 1992. Environmental characteristics of small springs in northern Nevada. Page 76, *In* E.P. Pister (ed.). Proceedings of the Desert Fishes Council XXII.

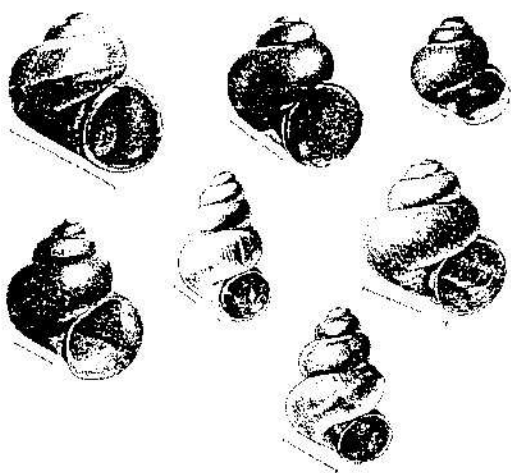
- Schmude, K.L. 1999. Riffle beetles in the genus *Stenelmis* (Coleoptera:Elmidae) from warm springs in southern Nevada: new species, new status, and a key. *Entomological News* 110:1-12.
- Shepard, W.D. 1993. Desert springs—both rare and endangered. *Aquatic Conservation: Marine and Freshwater Ecosystems* 3:351-359.
- Shepard, W.D. 1992. Riffle beetles (Coleoptera:Elmidae) of Death Valley National Monument, California. *Great Basin Naturalist* 52:378-381.
- Steward, J.H. 1933. Ethnography of the Owens Valley Paiute. *University of California Publications in American Archaeology and Ethnology* 33:233-350.
- Taylor, D.W. 1985. Evolution of freshwater drainages and molluscs in Western North America. Pages 265-321, *In* C.J. Hocutt and A.B. Leviton (eds.). *Late Cenozoic history of the Pacific Northwest*. American Association for the Advancement of Science and California Academy of Science, San Francisco.
- Thomas, J.W., C. Maser, and J.E. Rodiek. 1979. Wildlife habitats in managed rangelands—The Great Basin of southeastern Oregon. *Riparian Zone*. U.S. Bureau of Land Management General Technical Report PNW-80. 18 pp.
- Thorup, J. 1974. Occurrence and side-distribution of Simuliidae (Diptera) in a Danish spring. *Archiv für Hydrobiologia* 74:316-335.
- Vannote, R.C., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37:130-137.
- White, G.C., D.R. Anderson, K.P. Burnham, and D.L. Otis. 1972. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory Report No. LA-8787-NERP, UC-11.
- Wiggins, G.B. and N. Erman. 1987. Additions to the systematics and biology of the caddisfly family Uenoidae (Trichoptera). *The Canadian Entomologist* 119:867-872.
- Williams, N.E. 1991. Geographical and environmental patterns in caddisfly (Trichoptera) assemblages from coldwater springs in Canada. Pages 107 – 124, *In* Williams, D.D. and H.V. Danks (eds.). *Arthropods in springs, with general reference to Canada*. *Memoirs of the Entomological Society of Canada*, No. 155.

Williams, J.E., D.B. Bowman, J.E. Brooks, A.A. Echelle, R.J. Edwards, D.A. Hendrickson, and J.J. Landye. 1985. Endangered aquatic ecosystems of North American deserts with a list of vanishing fishes of the region. Arizona-Nevada Academy of Science 20:1-62.

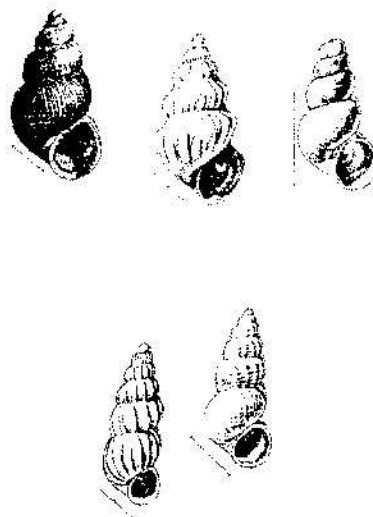
Appendix A –Springsnails and Potential Non-Native Aquatic Species at Tassi Springs.

Springsnails

Springsnails are small (1mm – 3mm) crenobiontic species that occur in two general body forms. Most species in southern U.S. deserts are in the genus *Pyrgulopsis* or genus *Tryonia*. Most *Pyrgulopsis* species (including *P. bacchus*) are round and slightly inflated and most *Tryonia* spp. are elongate (see figure below). All springsnails are usually black or brown. *Pyrgulopsis* spp. generally occur on gravel and cobble substrates, and on watercress (*Rorippa nasturtium-aquaticum*) in areas with higher water velocity. *Tryonia* spp. are usually found in slow currents where there are fine substrates.



Body forms of several *Pyrgulopsis* spp.



Body forms of several *Tryonia* spp.

Measurement lines = 1 mm

Potential Non-Native Species

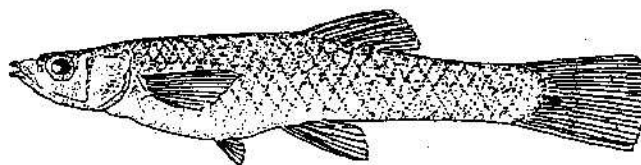
Spring surveys throughout the western U.S. have found a number of non-native aquatic species are established in these systems. Species that are most likely are listed below and some are illustrated.

Fish

Mosquito fish and goldfish are the most common non-native fish in springs, and they are comparatively easy to identify. Most people are familiar with goldfish from aquaria, but the mosquito fish is less well known. The mosquito fish is illustrated below.

Mosquito fish (*Gambusia affinis*)

Mosquito fish are native to the southeastern U.S. and they have been introduced throughout the world as a biological control agent for mosquitoes. They are hardy, highly predatory, and feed on macroinvertebrates as well as fish eggs and larvae. While they occur throughout the water column, they are usually near the water surface. They are small (< 3 cm), gray, and easily identified because of their flattened head.



The Mosquito fish body form

Amphibians

A number of amphibians are known from springs, but they are often difficult to identify without training, and adults are typically seen only during nocturnal sampling. It is very difficult to identify amphibians by examining tadpoles. If an unknown amphibian is seen, take its picture. If tadpoles are seen, record 'unknown amphibian' and 'tadpoles present' in your notes. Bullfrogs occupy only larger springs, and adults are large and comparatively easy to see and identify. No amphibians are illustrated in this field guide.

Mollusks

Red-rimmed thiara (*Melanoides tuberculata*)

This mollusk was introduced into North America by the aquarium trade, and it has become widespread throughout the western U.S. It is native to Asia, parthenogenic (reproduces asexually), and it can survive long periods out of water. It can be easily transplanted, it is tolerant of harsh conditions, and it prefers warm water. It prefers fine substrates and slow water. It is easy to identify because its shape and color are distinctive and very different from all other mollusks in the western U.S. It is long (up to 2.5 cm) and conical, with body whorls terminating at a sharp point. Its shell is slightly sculptured and its coloration is an attractive and distinct modeled, reticulated mixture of tan and brown. Since these mollusks are easily transplanted, care should be taken to completely clean and inspect field gear to insure they are not carried and introduced into other springs.

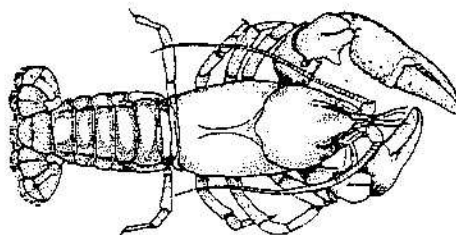


The generalized body form of the red-rimmed thiara (measurement line = 1mm)

Arthropods

Crayfish

Crayfish are not native to the southwestern U.S., but they have been introduced into many springs. They occur only in large springs that do not dry.



Schematic drawing of a Crayfish

Appendix B. Springsnail Preservation Methods

Surveying and collecting springsnails is challenging because it requires specific techniques to properly collect, relax, and preserve animals for identification and archival. These techniques must be followed to identify most species of springsnails; identification of many other gastropod groups is possible without using these stringent protocols. If these techniques cannot be used for springsnails, specimens may be collected and either dried or preserved in 75% ethyl alcohol to record the mollusk presence at a spring. Another site visit to properly collection and preserve material will be required for a species' identification. Mollusk collection and preservation methods are described below.

EQUIPMENT

Equipment that is necessary for mollusk collection includes:

- 1-quart glass Mason jars with clean lids. Clean, without residue from soap or other chemicals. Each jar can be used for only one collection, so, carry a number of jars if several collections are to be made in a single day.
- Specimen labels prepared from write-in-the-rain paper. Label should record, at least, date, location information (State, County, spring or site name, Township, Range, Quarter Section), field note number, and collector.
- ≤ 1 mm mesh kitchen sieve (finer mesh may be necessary to collect some hydrobiid species). The size of a sieve is relatively unimportant, but the most convenient sizes range from 2 inches to 6 inches in diameter. They can be purchased at most grocery stores.
- Fine-tipped forceps.
- "Tupperware" container for sandwiches (measuring approx. 6 in.X 6 in.X 1 in.). Clean, without soap or chemical residue.
- Ice chest and ice if living specimens are to collected for identification or species confirmation.

- Reagent grade menthol crystals.

SURVEYOR SKILLS

Personnel who will be doing these surveys will need to display an ability to recognize target mollusk species. Training should be provided for individuals not already familiar with mollusk systematics. Each surveyor should have sufficient knowledge and experience to demonstrate skills in executing these survey methods and in finding and recognizing the target species. They should be trained for these abilities by person(s) knowledgeable of mollusk taxonomy and survey methods.

TRAINING

Objectives of the training will be for the surveyors to be able to: (1) recognize examples of adults of most genera of snails that occur in their area; (2) recognize rare species that might occur within their area; and (3) to accurately implement the survey protocol.

Training should include one day in a classroom for instruction to recognize the most common mollusk taxonomic groups, and to learn survey and handling and preserving methods. This should be followed by a day of field training in survey methods and identifying mollusks.

COLLECTION AND PRESERVATION FOR IDENTIFICATION

Aquatic mollusks occupy a wide diversity of habitats in a spring, and they may be dense or very scarce. Widespread, common species may occur at any habitat from the source to the terminus of aquatic habitat. Endemic species are most abundant near spring sources, and decrease in abundance in downstream habitats. Consequently, springsnail surveys can focus on habitats near spring sources.

Aquatic mollusks are collected by roiling substrates and vegetation to dislodge macroinvertebrates and capture them as they drift downstream into the

kitchen sieve. Minimize the amount of debris, substrate, etc. that is collected. Empty the sieve into a Tupperware container and inspect for mollusks. When springsnails are common, a collection can be made in several minutes. When they are scarce, it will take much longer (maybe up to 1 hr.). An adequate collection includes approximately 100 individuals because species can be determined only by examining male genitalia of sexually mature individuals (hence not every animal can be used for identification) and all specimens will not be adequately relaxed (which is necessary for identification). If larger mollusks are present in the sample, they should be removed and relaxed separately.

Following collection, the sample must be kept cool and alive. This is best accomplished by keeping the collection in a Mason jar that is filled (to within 1 in. of the top) with high quality water from the spring inhabited by the collected animals. Do not use water from any other source!!! Place the collection in a cooler that with sufficient ice to keep the sample cool until the end of the field day. Menthol crystals should also be kept in the cooler because menthol has a very low boiling point and must be kept cold for crystals to remain intact.

At the end of the day, prepare material for relaxation and preservation. Do not keep samples in the cooler for more than 12 hrs. Samples must first be thoroughly cleaned to remove extraneous matter such as other macroinvertebrates (e.g., aquatic insects, amphipods, flatworms, oligochaete worms, etc.) and organic material. This is necessary because springsnails must be relaxed in a clean environment that is unaffected by other macroinvertebrates (that may die or remain active and disturb springsnails during relaxation) or decaying organic material (which will decrease dissolved oxygen concentrations and water quality). Any movement or irritation will prevent effective relaxation of snail specimens.

After cleaning, decant water from the Mason jar until approximately 1 inch of clear, well-oxygenated water remains in the bottom. Attempt not to crowd individuals and avoid allowing them to frequently touch one another in as many flat-based containers as necessary. Place the samples in a dark area where they will not be disturbed and where the temperature for the next 12-14 hrs. ranges between