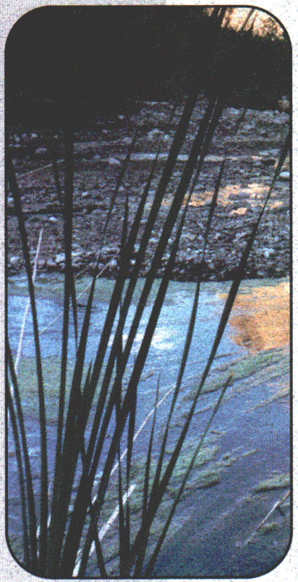

FINAL REPORT

Kanab Ambersnail at Vasey's Paradise, Grand Canyon National Park 1998-99 Monitoring and Research

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September 2000

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TABLE OF CONTENTS

TABLE OF CONTENTS continued

ABSTRACT

The 1998-99 research and monitoring field work for Kanab ambersnails (*Oxyloma haydeni kanabensis*) at Vasey's Paradise, Grand Canyon National Park, Arizona comprised four site visits each year in April, May, July, and late September/early October. In chronological order, population estimates were 18,062, 12,900, 9,073, and18,165 in 1998 and 6,373, 6,454, 18,352 and 33,953 in 1999; these numbers are within the range of previous estimates. With the exception of April, 1998, which had unusually variable data, 90% confidence intervals on population estimates ranged from 70-82% of the estimate (for the 5th percentile) to 119-136% of the estimate (for the 95th percentile). Breeding seemed to have been delayed in 1998 due to a late, cold spring. Breeding seemed to progress more normally during the erratic temperatures of spring, 1999. Habitat availability changed seasonally with no changes that were considered anomalous against the previous years' records. We trapped and tagged 40-50 *Peromyscus crinitus* (some juveniles and all mice newly trapped in October 1999 were not tagged) and detected 5 individuals who crossed the Vasey's pourout between Vasey's wet vegetation and the surrounding desert vegetation during the study period. Number of mice trapped per study period was relatively constant and small. Woodrats (*Neotoma lepida*) were trapped with greater frequency in 1999. Since they are relatively strict herbivores, there should be no direct impact on the ambersnail population. We recommend future monitoring work use fewer visits/year and cease monitoring mouse populations.

Note: The report of the expert panel chaired by Reed Noss in December 1999 is not addressed in this report.

INTRODUCTION

Kanab ambersnail is a terrestrial succineid snail associated with wetland and seep/spring vegetation on the Colorado Plateau. Its current taxonomic status is problematical as genetic investigations to determine relationships of several succineid populations in northern Arizona and southern Utah have been underway for more than a year, and results are not yet available (Paul Keim, Mark Miller, Northern Arizona University, pers. comm.). At present, for legal purposes, the species comprises at least two populations: one at Vasey's Paradise, in Grand Canyon National Park, Arizona and one on private land in southern Utah. The research we report was undertaken at Vasey's Paradise.

Vasey's Paradise is a small patch of spring-fed riparian vegetation 51 km downstream from Lees Ferry on the Colorado River in Grand Canyon National Park, Arizona. The site has been described repeatedly in previous reports (Stevens et al. 1997a, 1997b, 1998).

At Vasey's Paradise, ambersnails are found in the spring-fed vegetation, usually associated with cardinal monkeyflower (*Mimulus cardinalis*), watercress (*Nasturtium officinale*), and sedge (*Carex aquatilis*). Life history and general habitat associations are described in previous reports (Stevens et al. 1997a, 1997b, 1998).

The extent of vegetation at Vasey's Paradise is controlled, in part, by releases from Glen Canyon Dam. Dam operations are a federal action, and the effects of regulating the flow of the Colorado River in Grand Canyon are thus impacts of federal action, and are constrained by the Endangered Species Act. Research at Vasey's Paradise is designed, in part, to determine impacts of flow regulation and to permit managers to estimate impacts of planned dam activities (U.S. Fish and Wildlife Service 1994, U.S. Bureau of Reclamation 1995). The 1998-1999 tasks as approved by the Grand Canyon Monitoring and Research Center (GCMRC) included monitoring habitat, snail populations, and populations of mice (*Peromyscus* spp.; a snail predator) and research to determine the detectability of snail radulae (*Catinella*, another succineid snail) in mouse fecal pellets. This last topic was included to determine whether it might be possible to estimate numbers of *Oxyloma* in *Peromyscus* diets.

METHODS

General

We visited Vasey's Paradise during April, May, July, and September (1998) or October (1999). Snail monitoring was entirely performed by Vicky Meretsky, David Wegner, Hélène Johnstone, Lilian Jonas, Clay Nelson, Eric North, Larry Stevens, Jeff Sorensen, Peter Price, and Melinda Thompson; additional individuals served as recorders. Surveyors and boatmen were not the responsibility of this contract, but all assistance was cordial and competent.

Habitat monitoring

Habitat monitoring to assess quantities of vegetation and changes in vegetation composition followed protocols described in Stevens et al. (1997a). During each visit, vegetation patches below the 100,000 cubic feet per second (cfs) stage that were designated in 1994 and 1995 were surveyed and their composition described. In some instances, changes in vegetation required redesignating, adding, or eliminating patches; habitat maps document these changes. (Figures 1 through 8)

Ambersnail monitoring

Snail monitoring followed protocols described in Stevens et al. (1997a). During each visit, all major patches were surveyed for snails. Survey samples were circular patches of vegetation 20 cm in diameter. Vegetation and substrate in the circular plots were described, and ambersnails within the plots were counted and measured. Presence of other snails, egg masses and snail shells were noted.

In July, 1999, Jeff Sorensen volunteered to collect additional samples in patch 6RMDR, which is outside the normally designated patches. He collected a total of 21 samples. Of these, only 20 were used in population estimation. Soil moisture for all the 20 samples used was described as "moist." The sample that was not included had a soil moisture description of "flowing." This sample had been taken in one of the two or three very narrow waterways that cross the 6RMDR area. These waterways are in sharp contrast to the much drier area that constitutes more than 95% of 6RMDR, and they also tend to flash during rain events so that snails within the waterways are at higher risk of being washed out of the area.

Peromyscus monitoring

During each visit, we trapped small mammals on two nights. We set 20-45 Sherman live traps each night and checked them early the following morning. Trapped mice were weighed, sexed, and scanned for the presence of passive integrated transponders (PIT tags). PIT tags were injected into newly-trapped animals subcutaneously, following Animal Cave and Use protocols of Indiana University. Mice were released into the patch in which they were trapped. Traps were placed both upstream of the main pourout in the lower portions of ambersnail habitat, and downstream of the pourout, in desert vegetation. Precautions against Hantavirus were taken throughout the study.

Detection and digestion of *Catinella* radulae

Individuals of the genus *Catinella* were removed from Vasey's Paradise to the lab in order to remove radulae for experiments to determine their ability to persist in a chemical model of a *Peromyscus* stomach. Unfortunately, the individuals were too small for their radulae to be seen under field microscope, and the individuals died before we could determine a technique for dissecting out their radulae.

At Indiana University, Laura Hilden performed dissections of ramshorn snails (Ampullariidae, once Pilidae: *Marisa* sp.) and apple snails (Ampullariidae, once Pilidae:*Pomacea* sp.) purchased in a local pet store. She readily found the radulae and later isolated and cleaned these by immersing them for several hours in a 1 M solution of NaOH (Walker 1906). These snails are significantly larger than *Catinella* found at Vasey's Paradise (length of 2+ cm, as opposed to < 1 cm).

Ms. Hilden then isolated radulae in the dried *Catinella* specimens using NaOH on the remains. We mounted one of these on a slide for future comparison. A dried *Catinella* was rehydrated and subjected to the chemical stomach model: the snail was immersed in 0.1-0.2 ml of warmed HCl at pH 2-3 for 20 min and spun to mimic agitation. The radula and the snail survived almost entirely intact. An additional 20 min of "digestion" with a boiling bead to provide some further physical force did nothing further. The snail was then subjected to more of a direct analog of muscular contraction - it was gently kneaded with a thumb. This caused the radula to come loose from the snail body, and caused gaps in the "fabric" of the radula, however, the radula remained readily identifiable. Thus, it seems likely that *Catinella* radulae, at least, will survive digestion by *Peromyscus*. The manipulated radula was mounted in Permount fixative on a slide for future comparison with fecal pellet contents.

Due to complications involved in adhering Animal Care and Use protocols and obtaining U.S. Fish and Wildlife Service approval to feed snails to mice, we have not been able to feed snails to mice in order to look for radulae in fecal pellets.

Data Management

Ambersnail and vegetation data were initially collected on data sheets which were then entered into Excel spreadsheets. Summary spreadsheets and statistical data sets were prepared from the data spreadsheets. Because most data are processed in at least two different ways (by plot and by snail), internal data checks occur automatically when the final data presentations are prepared. All data were protected by nightly back-ups at Indiana University. In addition, copies of all field data sheets were mailed to Dr. Lawrence Stevens.

Reporting

Spreadsheets were submitted to Dr. Stevens in advance of these reports while he was employed at GCMRC, and final versions will be sent electronically when this report is submitted in final form. Metric units are reported, with the exception of dam discharge which is reported in cfs, the units used by Bureau of Reclamation.

RESULTS

General

All 1998 and 1999 monitoring work was successfully completed during the four visits each year to Vasey's Paradise with the exception of surveying during the April 1999 visit. Survey for April 1999 was accomplished by Dr. Lawrence Stevens and a GCMRC surveyor after our visit; as a result, survey polygons did not precisely match snail-census polygons, but differences were minor and remediable. All maps created during the study period were finalized during consultation with GCMRC surveyors (Figures 1-8).

Environmental occurrences of note during the 1998 season comprised a 31,500 cfs flow in early spring; a noncompliant, rapidly downramped, low flow below 10,000 cfs during the April visit; and a local flash flood approximately two weeks before the September visit. A long, wet spring contributed to high spring outflow at least until July. The region experienced a drought during the fall of 1998, however spring rains in 1999 were generous and extended nearly to the monsoons. Spring temperatures were erratic and our April visit had near-freezing temperatures although monkeyflower was in bloom, indicating warm weather had occurred for some time before our visit.

Spring temperature and outflow information for 1998 was as follows: April, 14.5°C, 0.64 cfs; May[1], 13° C, cfs not measured; July, 17°C, 2.47 cfs; September, 16.5°C, 0.61 cfs. Data for 1999 were: April, 14°C, 1.83 cfs; May, 15°C, 2.35 cfs; July, 17.0°C, 2.2 cfs, October, 11.5°C, 1.28 cfs.

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[1]May 10, 14.5°C, 6.5 cfs (Stevens, pers. comm.)

Habitat monitoring

The area of patches surveyed (all below the break in slope at approximately the 100,000 cfs stage) was relatively constant during 1998, ranging from 200 to 235 m^2 (Tables 1a-d). The April 1999 survey showed 293 m^2, whereas the remaining 1999 surveys indicated 265-269 m^2 (Tables 2a-2d). Total surveyed habitat area varied from 201-280 m^2. Excluding April 1998, the total area ranged from 258-280 m^2. During April 1998, patches 7U and 12 were particularly small (they contained no watercress or monkeyflower habitat and little sedge). These two patches were subject to more-than-usual proportional change: patch 12 is very subject to inundation, and patch 7U irregularly includes an area of several square meters of watercress when sufficient water flows through the patch.

1998

Patch 6NDS was under water during the April visit, and was essentially obliterated in the pourover during the flood event in September. The flood deepened and scoured the channel in which 6NDS was growing, which ended at patch 9. Red sediment was deposited along the upstream side of 6NDS, and a fine layer of sediment was deposited over much of the rest of patch 6, probably carried in spray. High outflows during the summer watered patch 6 heavily, and most of the platform was saturated in April and May, very moist in July, and moist in September. High flows (above 20,000 cfs) in the Colorado River scoured the lower ends of patches 11 and 12, and a 31,500 cfs flow in early spring inundated most of 11, 12, and 7L. Patch 7L escaped scouring because of its sheltered location on the downstream side of the debris fan.

Due to the high moisture levels in the matrix portions of patch 6 (outside the usually designated patches), and the concomitantly high densities of ambersnails outside the usually designated patches, patch 6RMDR was resurrected. The acronym denotes 6 Remainder, and the patch comprises the area not otherwise delineated on the platform downstream of the large rock outcrop between 8U and 6MU and the upstream edge of the main pourout. In the past, this patch has been a refuge for overwintering snails, but has been too dry to support many ambersnails during the summer.

Area of monkeyflower (MICA in the Tables) increased from 82 to 92 m^2 from April to May, a result, almost entirely, of expansion in 5M. The latter was probably a result of the new season's growth. Monkeyflower increased to 110 m^2 in July as a result, primarily, of increases in 6MU and 8U, and was stable from July to September.

Watercress (NAOF in the Tables) also increased from April to May, to 32 m^2, from expansion in several patches. Watercress area was relatively stable from May to July, and decreased to near-April levels in September.

Sedge (CAAQ in the Tables) occurred primarily on the platform supporting the 6 series of patches, with additional growth in 7L and 12. The spring and fall highs in sedge extent were due to the large portion of the 6 platform included in 6RMDR, and the large proportion of the vegetation in 6RMDR that was assigned as sedge in April and September. Variability in the proportion of 6RMDR assigned to sedge was primarily the result of methodology, and is explained further in the discussion.

1999

No major changes occurred over the winter with the exception of some minor scouring in patch 203 which eliminated much of the watercress cover. Vegetation on the downstream end of patch 6 was well recovered from the previous year's scouring. Despite heavy rains in the region during the monsoon period (July - September), no noticeable scouring occurred during the 1999 monitoring season. River flows were generally below 23,000 cfs and only patch 12 is much affected at such levels. Patch 6 became more homogeneous over time, with smartweed and poison ivy spreading more uniformly throughout the area. Whereas patches 6NU, 6MU, and 6NDS were still reasonably well-defined, patch 6NMid was only noticeable before the smartweed grew up; the other divisions surveyed in patch 6 were primarily for purposes of subdividing the snail samples - they did not correspond to breaks in vegetation type. Water availability in patch 6 changed seasonally, with the upstream ends of 6NU and 6NMid in 5-10 cm of water when the spring was very active, and decreasing at other times of the year. Area occupied by watercress shrank noticeably between May and July, largely as a result of reductions in 7U and 6NDS.

Ambersnail monitoring

The 1998 population estimates in the lower habitat area surveyed under this contract ranged from a low of 8,083 in July to a high of 16,090 in September (Tables 1a-d); these numbers are different from those presented in the 1998 report due to miscalculation of survey area in 1998. Population estimates in 1999 ranged from 7,101 in April to 34,951 in October (Tables 2a-d). One parasitized snail was observed in July 1999.

1998

In April, snail densities were highest in watercress patches which seems to be overwintering habitat (Stevens 1997b). Snail densities were also high in 6RMDR. Most snails (93%) found were out of dormancy (Table 1a). Snail lengths were unimodal (Figure 9) and averaged 7 mm.

Snail densities in May were highest in 203M, 203N, 5N, and 6MP, in a mix of habitat types (Table 1b). Snail length was bimodal, with peaks at 7 and 12 mm (Figure 9).

In July, snail densities were highest in 8U, 9, 5N, and 6NU (Table 1c). Patches 9, 5N, and 6NU are watercress patches; 8U is not a watercress-dominated patch, but does have a section of rich soil which has often supported high snail densities. Snail length was strongly bimodal, with peaks at 3 and 13 mm (Figure 9). Proportions of small snails did not always increase as total snail densities within a patch increased. For example, patch 9 contained no small snails but had high snail densities, whereas patches 6NU and 8U had moderately high proportions of small snails and high total snail densities. Small snails were a greater proportion of the population in patches 5M and 5N

(Table 3), whereas total snail densities in these patches were not so high. We observed 139 snails larger than 10 mm in July 1998, but no snails in this size class were observed to be parasitized by *Leucochloridium cyanocittae*.

The September visit occurred during warm weather, and all snails we encountered were still active. The length histogram was unimodal, with most snails between 3 and 10 mm, with a slight peak at 4 mm (Figure 9); there were more small snails than in any earlier visit in 1998. The highest densities occurred in patch 6NU, at 310 snails/m^2 (Table 1d). Densities were also higher than in any other patch in previous visits in 6NMX (a mixed monkeyflower/smartweed patch), 6P (monkeyflower and smartweed), 5N (watercress), and 7U (watercress). These high densities were unremarkable in comparison with high densities of previous years (Stevens et al. 1998). Again, patches with high densities of snails were not necessarily patches with high proportions of small snails. Small snails were the greatest proportion of snails in patches 8U and 6NMid (Table 3).

1999

Rates of dormancy were higher in April 1999 (19%; Table 2a) than the previous April (7%; Table 1a) but this likely represented short-term dormancy in response to unseasonable cold during our visit. In early October, we had 6% dormancy (9% among snails$\geq$ 4 mm in length), primarily in the more shaded patches; this likely represented the onset of long term dormancy.

Snail densities in April were high in the patches with dry ground (6RMDR, 7L, 8U and 8L) and in some of the watercress patches (9, 6NDS). In May, monkeyflower patches (203M, 5MU) as well as watercress patches (9, 203NU, 6NU) had higher densities. Young snails were 40% of the sampled snails in July (Table 3), and high snail densities in major patches were largely restricted to watercress (6NM, 6NU, 7U, 9, 5N). A small monkeyflower patch (13) also had very high snail density. This patch sat in a watercourse and had generally higher soil moisture than other monkeyflower patches. We observed 85 snails larger than 10 mm in July 1999, with one being parasitized by *Leucochloridium cyanocittae*. Small snails made up 32% of the population in October (Table 3), with high snail densities occurring in a wider variety of patches than in July (5N, 7U, 8U, 203M, 203NL) including watercress, monkeyflower, and mixed sedge-forbs. Snail lengths suggest reproduction was well underway by July (Figure 10).

Uncertainty in Population Estimation

In order to demonstrate which patches contribute most to uncertainty, we analyzed the visit statistics for 1999 to highlight patches with the largest 90th percentile range (the distance from the 5th to the 95th percentile) in the patch estimate of snail numbers, patches with the largest 90th percentile range relative to the mean patch estimate of snail numbers, patches with the largest 90th percentile range relative to number of samples collected, and patches with the largest area relative to number of samples collected (Table 4a-d). Unsurprisingly, 6RMDR is often one of the patches contributing heavily to uncertainty on several of the calculated scales.

Patch 6RMDR is more than twice as large as the next largest patch in every month except April, and if 6RD and 6RU are combined in April, (the patch was split only for "bookkeeping" purposes), then the composite is nearly three times larger than the next largest patch. Even in July, 1999, when Jeff Sorensen spent considerable time collecting 20 samples in the patch, the area/sample ratio remained the highest in the survey, although the 90% range dropped from first (in all other 1999 surveys) to fourth, and the range relative to the number of samples dropped even farther. Other patches contributing significantly to uncertainty (as measured by 90th percentile range/number of samples) in at least one of the four surveys include 203M, 5M, 6NU, and 8U. Of these, only 203M and 5M contribute more than once.

Peromyscus monitoring

1998

We caught 25 canyon mice (*Peromyscus crinitus*) during the 1998 monitoring season (Table 5). Overall trap success was 15% and we had 46% recaptures. Reproduction apparently did not begin until mid-late April; we caught no immature mice in April. Similarly, we caught only subadults and adults in September; reproduction may have ended slightly earlier. Two animals crossed the pourout channel: an adult male moved downstream between May and July, and an immature male moved upstream during the July trapping. We inadvertently killed one mouse during the 1998 season. Despite careful bookkeeping, a trap was left in the field after the July visit, and was later found with a mouse in it. As a result, we were more careful in our accounting for traps during subsequent efforts. One woodrat was trapped during the season.

1999

We caught a minimum of 20 canyon mice during the 1999 monitoring season. We did not tag mice in the October trapping because it was the end of the monitoring study. In addition, we trapped four or five immature mice too small to tag during our July visit. One individual crossed the pourout between the September 1998 visit and the April 1999 visit, and two individuals crossed during the 1999 monitoring season. Three mice died during the 1999 field season, two apparently of hypothermia and the other by inadvertent drowning when the trap it was in was washed before the occupant was returned to the site. Woodrats were trapped on five occasions.

Detection and digestion of *Catinella* radulae

Catinella radulae seem well able to withstand chemical and physical processes in *Peromyscus* gut tracts, assuming the information we were given concerning that chemical environment was accurate. Radulae are readily visible at 200x after simulated digestion. Tests with a live, rather than laboratory model are needed to confirm this experiment.

DISCUSSION

Vegetation

Vasey's Paradise had still not recovered the monkeyflower habitat it lost during the 1996 experimental flood by the end of the 1999 season (see Stevens et al. 1997b). Monkeyflower seems to reproduce primarily by vegetative means at Vasey's Paradise, probably because soil does not accumulate readily on the sloping surfaces. At least on the upstream end, on steep, bare limestone, vegetative reproduction has been quite slow, and the plants that were above the flood line in 1996 have not extended their rootmat to retake the originally occupied area.

Other habitats (e.g. 7L and 11) have grown back, and at times the total amount of vegetation exceeds pre-flood levels. However, most of the regrowth is in watercress, a species that snails rarely use for overwintering. Watercress rapidly re-colonized wet, open areas, with watercress area being one of the most changeable habitat statistics at Vasey's Paradise. Thus, although watercress regrowth has erased many traces of the scouring caused by the experimental flood, the functional role that was played by monkeyflower in the lower ends of patches 5, 4.5 and 203 has yet to be refilled.

Vegetation continued to shift at Vasey's Paradise. Some regions were relatively static with respect to vegetation composition; others, especially in patches 6, 7L and 8U, changed fairly rapidly. Discounting the rapid swings in watercress cover, plants favored by ambersnails continued to cover a large proportion of the site. Poison ivy, although still constituting a relatively small proportion of the platform containing the #6 patches, increased in density, reducing accessibility.

The major swings in extent of sedge habitat were a result of a protocol established in 1995 and continued through this investigation. Despite the frequent occurrence of multi-layered vegetation at Vasey's Paradise, vegetation cover proportions were estimated in such a way that maximum total vegetation cover in a sampling circle or in a vegetation patch was 100 percent. Because of this, when sedge was the major vegetation in non-watercress patches on the 6 platform in April, it receives a large value for proportion of cover. However, later in the season, when the amount of sedge was nearly exactly what it was in April, but monkeyflower and smartweed had matured, the proportional cover of sedge dropped precipitously.

Snails

The April 1998 population estimate (18,062) was probably elevated, relative to other early spring surveys, due to unusually warm weather which resulted in a larger proportion of active snails. Previous population estimates from early spring surveys (February-April) ranged from 5,200 - 10,900 individuals, or, eliminating the post-experimental flood estimate from April 1996, 7,300 - 10,900 (Stevens et al. 1997a, b, 1998). The proportion of dormant snails in the April 1999 survey was three times larger than the proportion in April 1998 (19% vs 6.7%), and population estimate was 6,373.

Previous population estimates from surveys later in the growing season ranged from 2,600 - 108,000 (Stevens 1997a, b, 1998). The low estimate is from 1996, following the experimental flood, in May. But adjusting the low bound to the next lowest estimate (9,700) still gave a very wide range of values. Once reproduction began, population estimates increased dramatically with the increase in immature snails. However, immature snails were comparatively difficult to detect, and they were likely subject to heavy mortality. Samples taken after reproduction occurs may be useful to track reproductive output in a given year, but are less useful for population estimates.

Length histograms from our samples suggested most reproduction occurred late in the growing season in 1998, probably in response to a long, cold spring. The 1999 data showed a more prolonged reproductive season. Data from 1997 showed a strong reproductive pulse in August, and data from 1996 showed reproduction occurring from July through September, probably a result of an early summer (Stevens et al. 1997a, b, 1998). Ambersnails at Vasey's Paradise have evolved in a region of climatic variability and clearly time their reproduction fairly flexibly.

Comparison of early spring histograms to late fall histograms suggested that overwinter mortality struck hardest at younger snails. Fall histograms were essentially unimodal with the proportion of snails in each length class dropping as snail length increased - the largest class is the smallest length snails. In spring, the proportion of smaller size classes was relatively less than in fall, and the smallest size class was not the largest, suggesting disproportionate loss of the smallest individuals during the winter. A similar pattern can be seen in data from 1996 (Figure 11). Small snails have less thermal and moisture inertia than larger snails, having a larger surface area-to-volume ratio, and may suffer more quickly from freezing or drying.

Parasitization rates of ambersnails at Vasey's Paradise by the trematode parasite *Leucochloridium cyanocittae* were reported in 9.5% of snails larger than 13 mm (Stevens et al. 1995), <1% of snails larger than 13 mm (apparently) in 1996 (Stevens et al. 1997b), and 6.2% of snails larger than 10 mm in 1997 (Stevens et al. 1998). Larger numbers of parasites were generally encountered in late summer, when large snails were still abundant. Our rates of 0% and >1% were as low and lower than earlier observations. Jeff Sorensen of Arizona Department of Game and Fish observed four parasitized individuals during his July 1999 visit (Sorensen, pers. comm.); if his ratio of small to large snails was similar to ours, he observed approximately a 2.5% parasitization rate among snails >10 mm in length. His observations were concentrated in a subset of our study area, but suggest, as our observations do, that parasitization rates were low during the study period.

Uncertainty in population estimation

Current methods of surveying patch 6RMDR clearly were responsible for a substantial portion of uncertainty in the reported estimations of population size. Patch 6RMDR was also the only patch strongly infiltrated by poison ivy, and possessed of a thick litter composed primarily of dead sedge, interspersed with poison ivy stems and roots. Work in 6RMDR was slow and careful as snails in the litter became detached and rolled out of the sampling circle if sufficient care was not taken. In all seasons except early spring, snail densities were quite low in 6RMDR - the size of the patch, not the densities of snails therein, caused the estimated snail numbers to be so large. Even with an effort almost double any other effort during 1999, Mr. Sorensen was only able to bring the 90th percentile range down from 1st to 4th rank for that survey. Had an extreme outlier sample that Mr. Sorensen collected been included in the calculations (see Methods), it is likely the range would have ranked even higher.

Patches 5M and 203M also contributed substantially to estimation uncertainty. These patches were nearly pure stands of monkeyflower. The report on the effects of the planned flood of 1996 explained the difficulties involved in surveying snails in this fragile vegetation (Stevens et al. 1997b). Samples can rarely be made safely in the interior of these patches; due caution restricts sampling activity to the outer margins, thereby limiting the number of samples that can reasonably be collected.

Difficulty in detecting small snails (those <4 mm in size) also contributed to uncertainty in population estimates. Ability to detect these snails varied among observers, among habitat types, and even among weather conditions during surveys. In addition, minor changes in timing of summer visits relative to snail reproduction had the clear potential to effect major changes in population estimates. Proportions of snails <4 mm were as high as 40% during our study. For so much of the estimation base to come from a group of snails with known difficulties in detection adds additional, unquantifiable error to population estimates.

Peromyscus

The downstream area in which we set traps was roughly the same size as the area trapped in the upstream spring vegetation (the snail habitat), but generally upstream trap density was roughly two to three times greater than downstream trap density. During 1998, the proportion of upstream and downstream captures was roughly what would be expected given a 2-3:1 ratio of upstream:downstream traps (contrary to the 1998 interim report). However, during 1999, the proportion of downstream captures was somewhat lower than expected; given the small samples, we cannot indicate the importance of the apparent difference.

The high proportion of recaptures suggests we were seeing a relatively high proportion of the population of mice in the area. Although snails may supply food to some animals below the pourout, the water channel seems to function as a barrier that is not frequently crossed; 90% of recaptures did not involve a cross of the pourout. Thus, animals are not moving from Vasey's to the nearby desert area on a daily basis, but there is reason to believe that some dispersal occurs into and out of the wet habitats at Vasey's.

We had very small capture populations in any given visit, and complex mark-recapture statistics could not be attempted - we had too few individuals to estimate the number of parameters required. The differences in capture among the sexes suggested capturability may have varied by sex, possibly also by age. In addition, the data suggested a tendency to reenter traps after initial trapping ("trap-happiness"). For all these reasons, Lincoln-Peterson estimates (Sutherland 1996) were inappropriate, but they remained the most readily calculated. Depending on what one used as the "marked" population (and using all animals for the entire season is unwise, given the relatively short lifespan of the species), very crude population estimates ranged from 12 to 36 for the upstream area in 1998, and somewhat lower in 1999. *Peromyscus* populations are known to vary markedly in size from year to year.

This is the first study to collect mark-recapture data, so there are no grounds for comparison. Trap success rates were higher than those reported in 1997 (Stevens et al. 1998) but that may be a result of newer traps and more rigorous field protocols. There is no reason to think that either the mice or the snails are a recent addition to the vicinity, and hence no obvious reason for concern about the presence of the predatory rodents at the spring. PIT tags have worked quite well; animals are apparently quite unharmed by the injection, and tags are readily detected on recapture.

Snail radulae

If radulae do survive digestion, and are as readily visible as our results seem to indicate, then earlier attempts conducted by Clay Nelson to detect radulae in fecal pellets suggest that mice do not invariably eat snails. Earlier reports indicating that mice eat snails also pointed out that the single confirming observation was made under conditions which may have made snails easier to detect, either by concentrating them, or by conferring a unique scent from the identifying markers or the adhesive used to apply them. In any event, we have no strong reason at present to suppose that mouse population is increasing or that snail populations are in decline as a result of mouse predation.

Due to complications involved in passing Animal Care and Use protocols and obtaining U.S. Fish and Wildlife Service approval to feed snails to mice, we have not been able to feed snails to mice in order to look for radulae in fecal pellets.

Other topics

In fulfillment of contract requirements, Dr. Meretsky attended three Kanab Ambersnail Working Group (KAWG) meetings during the contract period, was available for conference calls during the others, and received and commented on minutes of most meetings. She also attended the expert panel meetings convened by Western Area Power Administration and the Arizona Game and Fish Department and presented information from this project. Note that the panel's recommendations are not considered here as they are beyond the scope of the current project and, in any case, stand on their own merits.

LITERATURE REVIEW

Succineids

Published information on Succineidae is relatively scarce, and occasionally misleading. Tellingly, there is no ecological work available for the single other endangered U.S. succineid, the Chittenango ovate ambersnail. Recent genetic work performed in Paul Keim's lab (Miller et al., in revision) suggests that current taxonomy may be, in part, in error. Other work is somewhat limited in its applicability due to the unique nature of habitat at Vasey's. Whereas most other reports of *Oxyloma* place it in freshwater wetland habitat, Vasey's is a steeply sloped, rocky spring. Lannoo and Bovbjerg (1985) report on *Oxyloma retusa* response to changes in water availability, but their observations are of snails moving in response to a relatively smooth gradient of water availability in depression wetlands. They concluded that the species selected a precise microhabitat, resulting in a relatively predictable distribution of snails relative to the water's edge, apparently in response to humidity. In contrast, the tidal marsh species, *Succinea wilsoni*, apparently responded to a salinity gradient (Burnham and Fell 1989).

Shrader (1972) studied *Succinea ovalis*, *Oxyloma retusa*, and *Catinella vermeta* and reported that "all species seemed to ingest what is available - parts of living and dead vascular plants that occur on land and near water, as well as the fungi associated with their habitats (p. 13)."

Dispersal in non-succineid rock-dwelling land snails has been reported to vary from 68 cm/yr in stone piles to 264 cm/year on limestone pavement (median distances; Baur and Baur 1995); the authors suggest intervening grassland inhibits dispersal, and that isolated stones may serve as "stepping stones" to aid dispersal.

Conservation

Published information on conservation biology of snails is also somewhat limited. Land snails in the genus *Partula* have been extensively studied in Polynesia where populations are principally threatened by a deliberately introduced New World snail, *Euglandina rosea* (Murray et al. 1988, Coote et al. 1999). One species, Partula turgida, recently became the first "concrete example of an infection disease leading to the extinction of a species" (Ferber 1998, p 215; see also, Cunningham and Daszak 1998); the species was in "protective custody" at the time, in a captive breeding program. Conservation programs for *Partula* species include both in situ and ex situ components, and releases from captive breeding of some species have commenced (Mace et al. 1998). Translocations are also urged as a general technique by other practitioners (Webb 1980).

E. rosea is also a threat to aquatic snails in Hawaii (Kinzie 1992), while tree snails are subject to predation, shell collecting and other factors (Hadway and Hadfield 1999). Other introduced gastropods, introduced predatory flatworms, and introduced rodents are threatening a variety of other land snails (Bauman 1996, Sherley et al. 1998). Warming by thermal radiation from an urban area has been suggested as another possible cause of local extinction in a land snail (Baur and Baur 1993).

Attempts to conserve *Myxas glutinosa*, an extremely rare freshwater snail in Britain, apparently threatened by deteriorating water quality (Whitfield et al. 1998), have been postponed until it can be determined that the snail still exists (Drake 1998). A population of another snail, *Vertigo moulinsiana*, was apparently successfully saved from road construction by translocation of its wetland habitat (Stebbings and Killeen 1998).

The Iowa Pleistocene snail, *Discus macclintocki*, is a snail inhabiting Pleistocene relictual habitats in the midwestern US (Ross 1999). Population genetics suggest that watersheds contain monophyletic groups, a situation possibly analogous to the isolated springs occupied by the succineids of the Colorado Plateau. Relevant genetic work has been more thoroughly reviewed in Miller et al. (in revision). Studies of other hermaphroditic snails may offer some insights into conservation issues associated with hermaphroditic reproduction (Baur 1994, Jarne et al. 1996, Tomiyama 1996, Baur and Baur 1998).

Research Techniques

Results of comparisons of population estimation techniques are available for aquatic snails (McRae and Lepitzki 1994, Darby et al. 1999) and for snails in dry grasslands (Oggier et al. 1998). Neither setting is similar to the setting or habitats at Vasey's Paradise.

Snails of the Southwestern US

Studies of snails in the Southwest have traditionally focused on taxonomy. Limited ecological information is available, but generally too little is known to provide the kind of detailed picture that would permit useful comparison to Vasey's Paradise. Habitat of *Pecosorbis kansasensis* has been described - it uses ephemeral pools associated with trans-Pecos shrub savannah in New Mexico (Smartt and Sullivan 1990). The ability of spring snails at Montezuma's Well to withstand high-CO_2 environments has been described (O'Brien and Blinn 1999). The anatomy and cladistics of the springsnail genus *Pyrgulopsis* have been reviewed (Hershler 1994). The ability of a physid snail to withstand extreme variations in stream flow characteristics has been discussed (Stanley et al. 1994).

Summary

The ecological and conservation literature on invertebrates is still relatively immature. Existing studies are generally only tangentially related to work at Vasey's Paradise. As is often the case with endangered species, the importance of context-specific details may limit the usefulness of information on other species even as the literature matures (Snyder et al. 1996).

RECOMMENDATIONS

Habitat monitoring

Current methods of monitoring habitat are adequate for the present purpose. We recommend that future monitoring acknowledge the layered nature of habitat at Vasey's and present the proportion of total area covered by each species, rather than the proportion of total vegetation.

Snail monitoring

The ambersnail population at Vasey's Paradise has been monitored at least four times/year for four years. At this point, sufficient information on yearly patterns seems to exist to permit less intensive monitoring. Spring and fall monitoring could be continued to determine the size of the population surviving winter and the size of the population at the end of the season. If the purpose of monitoring is to determine that the population is continuing at some size with which managers feel comfortable, the midsummer estimates are not necessary as they are redundant with the fall estimates which more clearly show the size and composition of the population that will overwinter. The proportion of young snails on some haphazardly chosen day in midsummer (the primary datum uniquely available in midsummer) is not useful information.

An additional monitoring visit in midsummer could be used to confirm reproduction if there is reason to suspect that the snails are likely to fail to breed in some year. However, given the lifespan of the snail, there are few courses of action available in such an event, and we have no reason to suspect such an event. However, given the number of research trips, perhaps a trip with another main purpose might put in to Vasey's in July or August long enough to confirm that egg masses and small snails can be found.

Accuracy of population estimates is affected by many factors that cannot easily be offset. However, differential observability of small snails (those < 4 mm in length) is one factor that could be eliminated. Given the likely high mortality rate of these smallest snails suggested by the reproductive output of adults (Nelson, pers. comm), and our severely impaired ability to count them in a timely and repeatable fashion, we recommend that population estimates be based on snails ≥ 4 mm in length.

If at some later time, narrower confidence intervals are desired, increased sampling from Patch 6 is (at this time) the best use of additional effort. We do not encourage increased sampling in the monkeyflower patches due to their fragility.

We do not wish to suggest that everything is known that can be known about the Vasey's Paradise ambersnail population. Rather, our comments address what may be needed in order to responsibly monitor this population.

Peromyscus

It is not clear that deer mice are a threat to the ambersnail population at Vasey's Paradise. Had the snail been added to the endangered species list because of dangerously small populations, concern would clearly be warranted. However, no party has suggested that the ambersnail population at Vasey's Paradise is at risk in any way that can be reduced by on-site management. Nevertheless, major resources are not committed to this line of investigation, and pursuing the current question of level of predation may be a useful safety precaution in the long term; however, perpetual monitoring of the *Peromyscus* population does not seem warranted at this time.

PUBLICATIONS AND PRESENTATIONS RELATED TO THIS CONTRACT

Related publications

Meretsky, V.J., D.L. Wegner, and L.E. Stevens. 2000. Balancing endangered species and ecosystems: a case study of adaptive management in Grand Canyon. Environmental Management 25:579-586.

Meretsky, V.J., and L.E. Stevens. 1998. Kanab ambersnail, an endangered succineid snail in southwestern USA. Tentacle 8:8-9.

Presentations

Meretsky, V.J. 1999. Presentations on ambersnail populations in northern Arizona and southern Utah. Invited presentations to expert panel convened by Arizona Game and Fish Department and Western Area Power Administration to evaluate conservation and management activities associated with endangered Kanab ambersnail.

Meretsky, V.J., M. P. Miller, C.B. Nelson, J.A. Sorenson, and L.E. Stevens. 1999 Conservation of an endangered succineid land snail. Freshwater Mollusk Conservation Symposium.

Meretsky, V.J., L.E. Stevens and C. Nelson. 1999. Monitoring at a snail's space: the endangered Kanab ambersnail at Vasey's Paradise. Ecological Society of America Annual Meeting.

Meretsky, V.J., L.E. Stevens, M.P. Miller and D.L. Wegner. 1999. Which differences make a difference? Comparisons among 5 ambersnail taxa. Society for Conservation Biology Annual Meeting.

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FIGURES AND TABLES

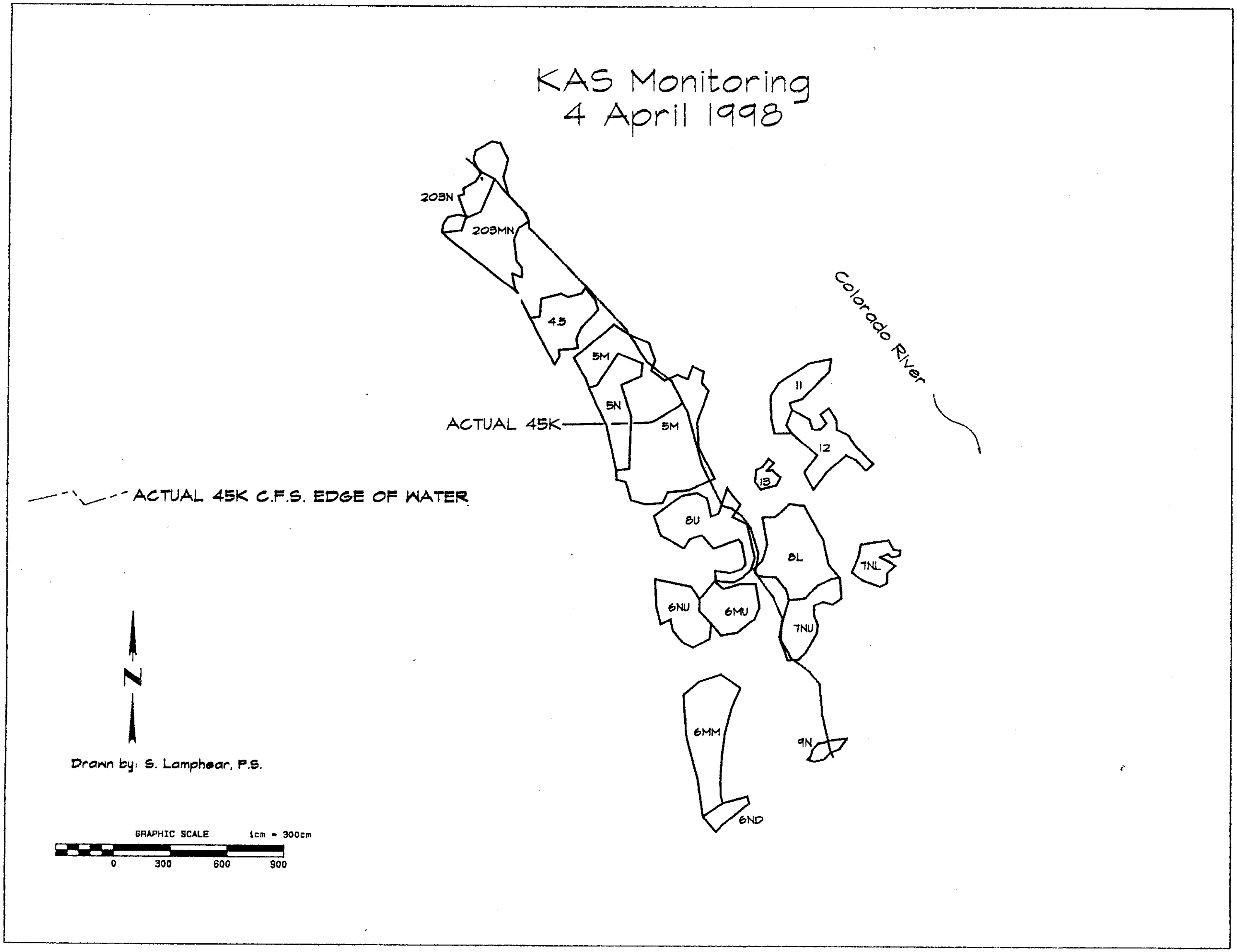

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Figure 1: April 1998 KAS habitat survey at Vaseys Paradise

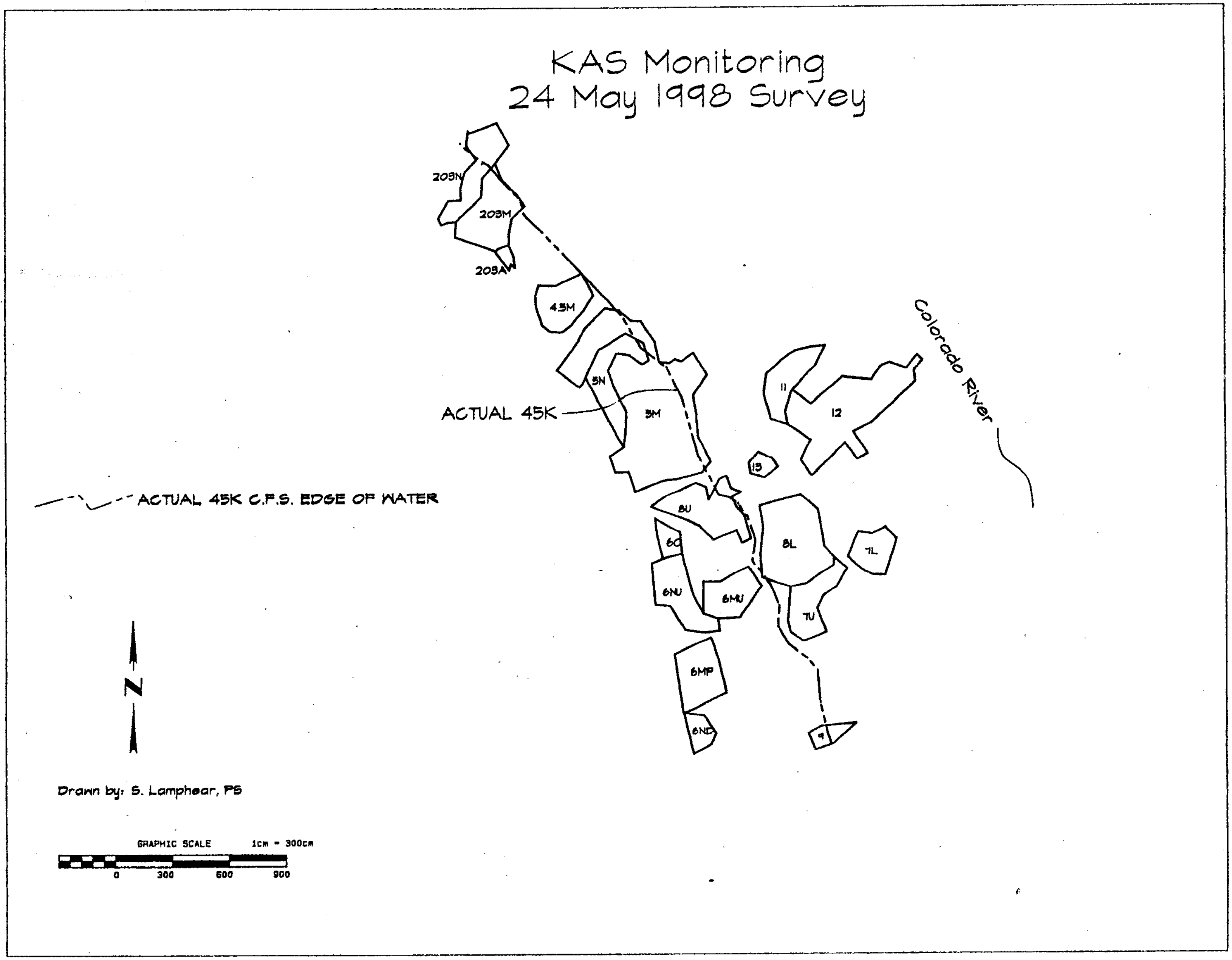

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Figure 2: May 1998 KAS habitat survey at Vaseys Paradise

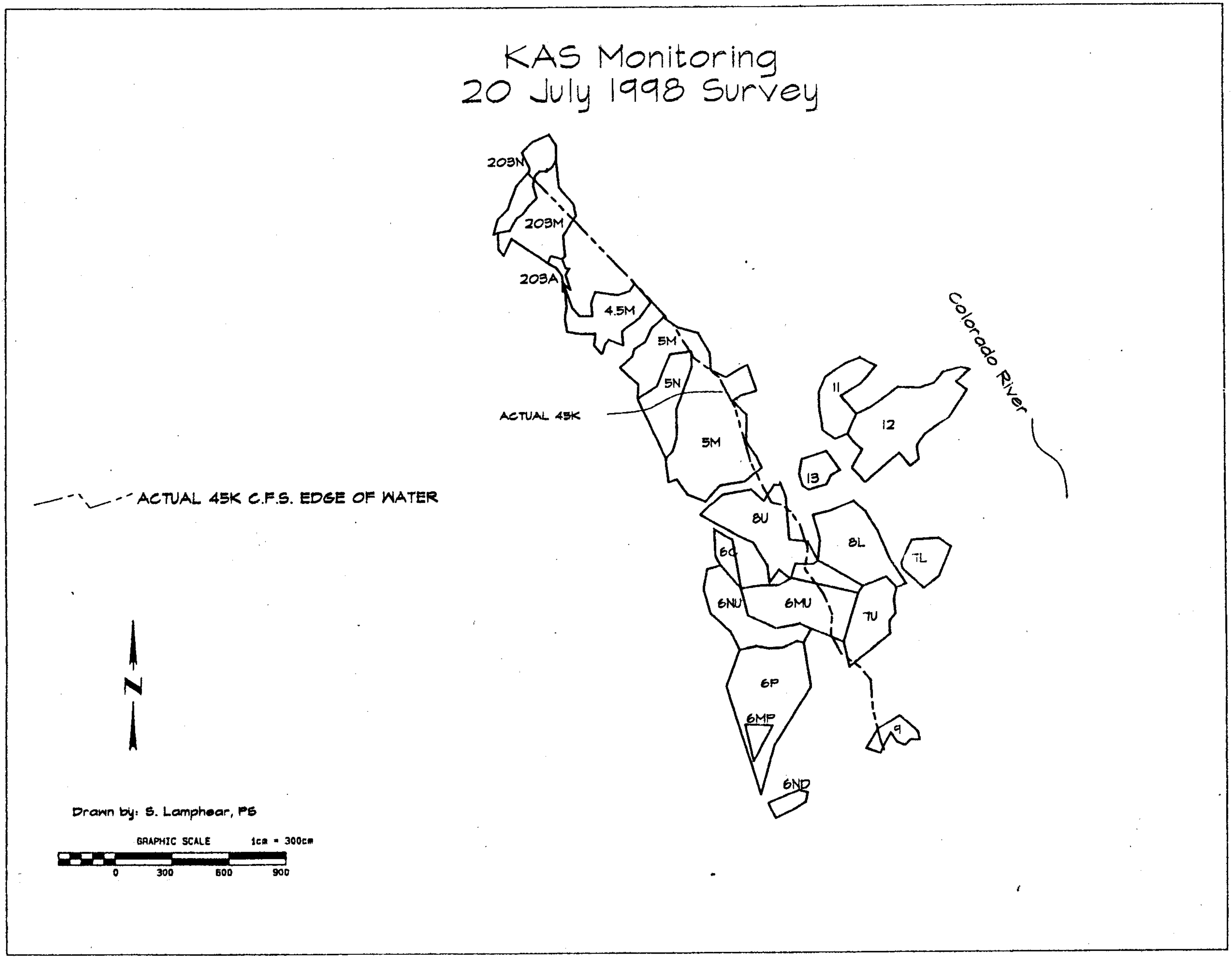

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Figure 3: July 1998 KAS habitat survey at Vaseys Paradise

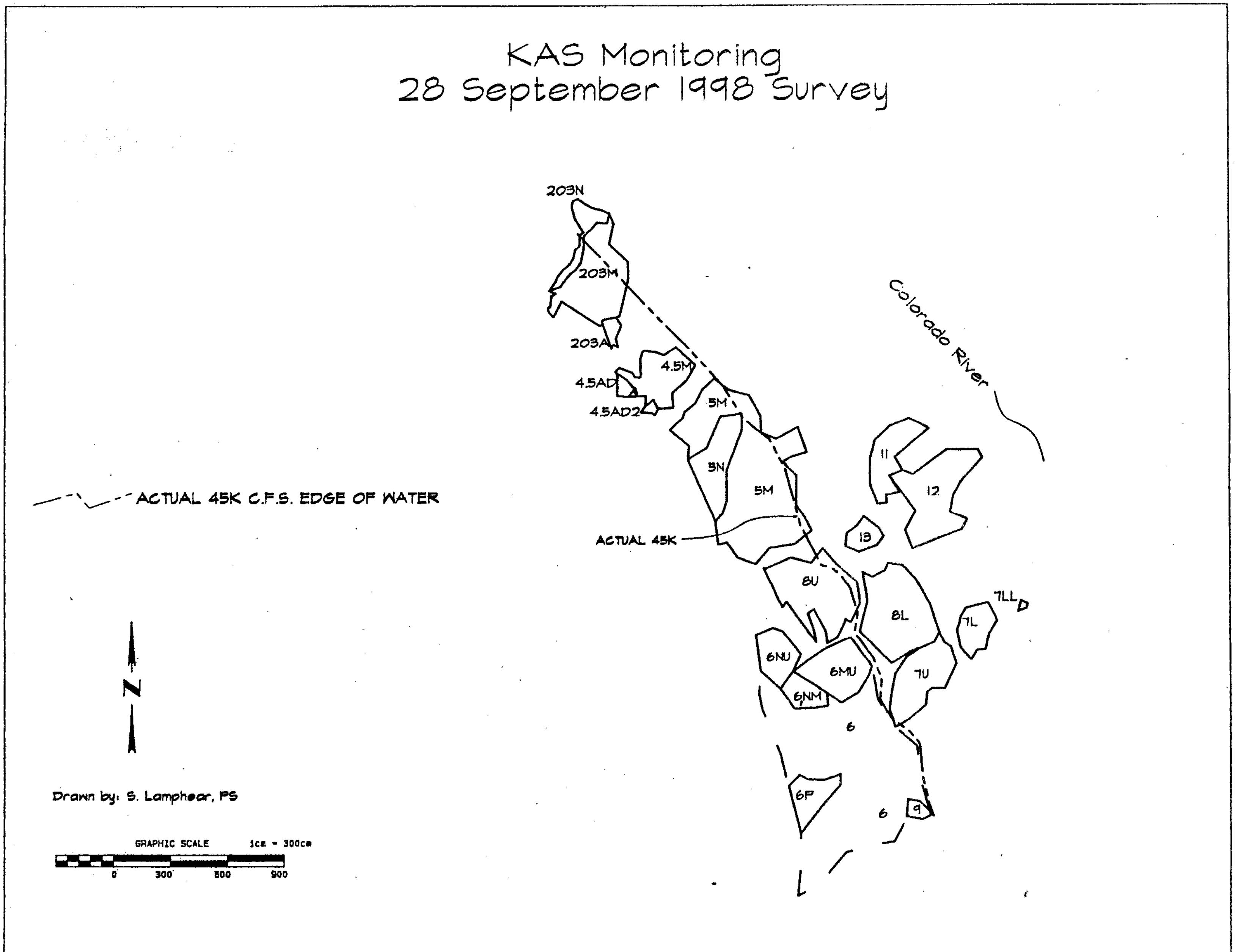

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Figure 4: September 1998 KAS habitat survey at Vaseys Paradise

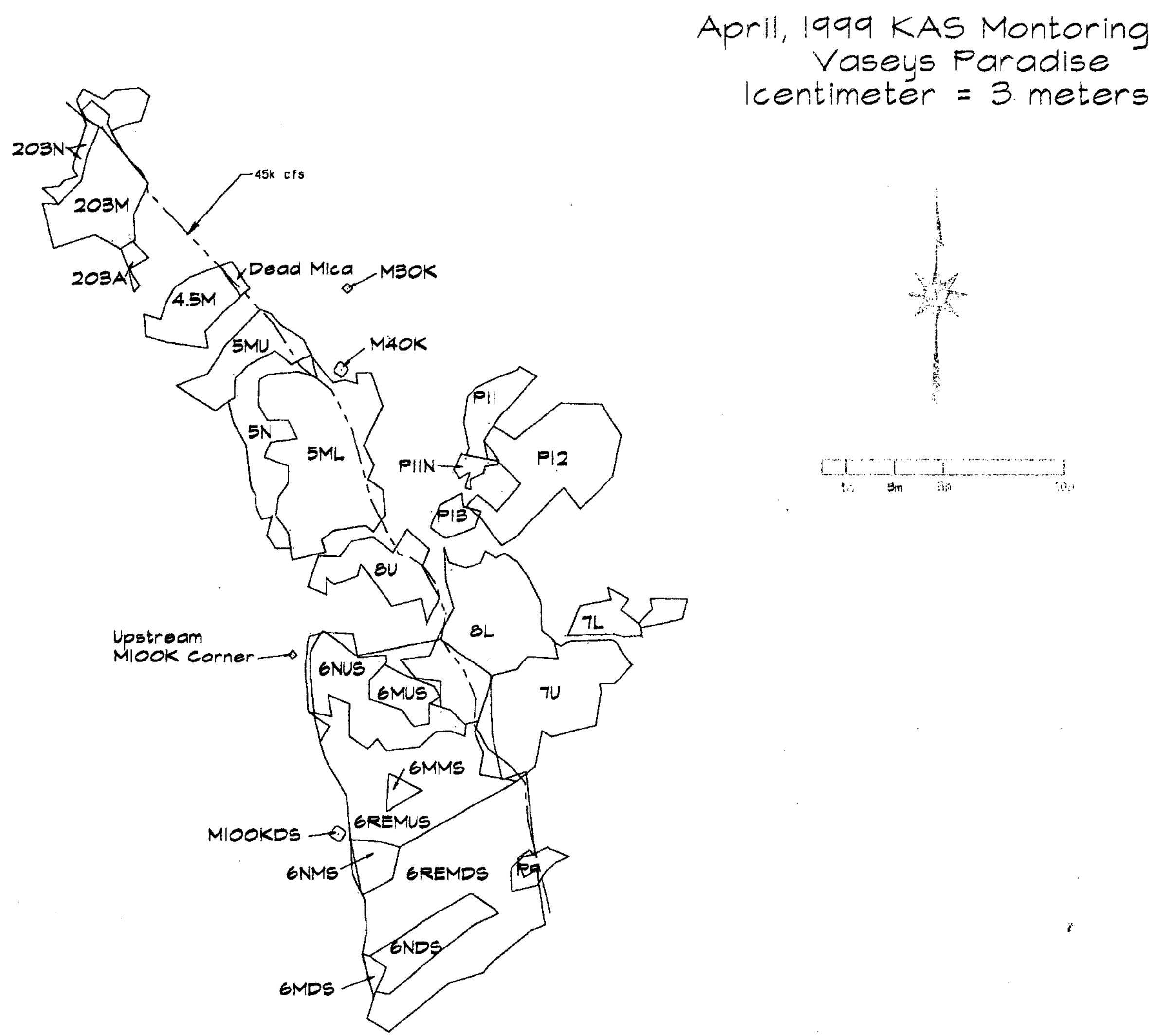
April, 1999 KAS Montoring
Vaseys Paradise
1centimeter = 3 meters
203N
203M
203A
45k cfs
Dead Mica
M30K
4.5M
5MU
M40K
5N
5ML
P11
P11N
P12
P13
8U
8L
7L
7U
Upstream
M100K Corner
6NUS
6MUS
6MMS
6REMUS
M100KDS
6NMS
6REMDS
6NDS
6MDS

Figure 5

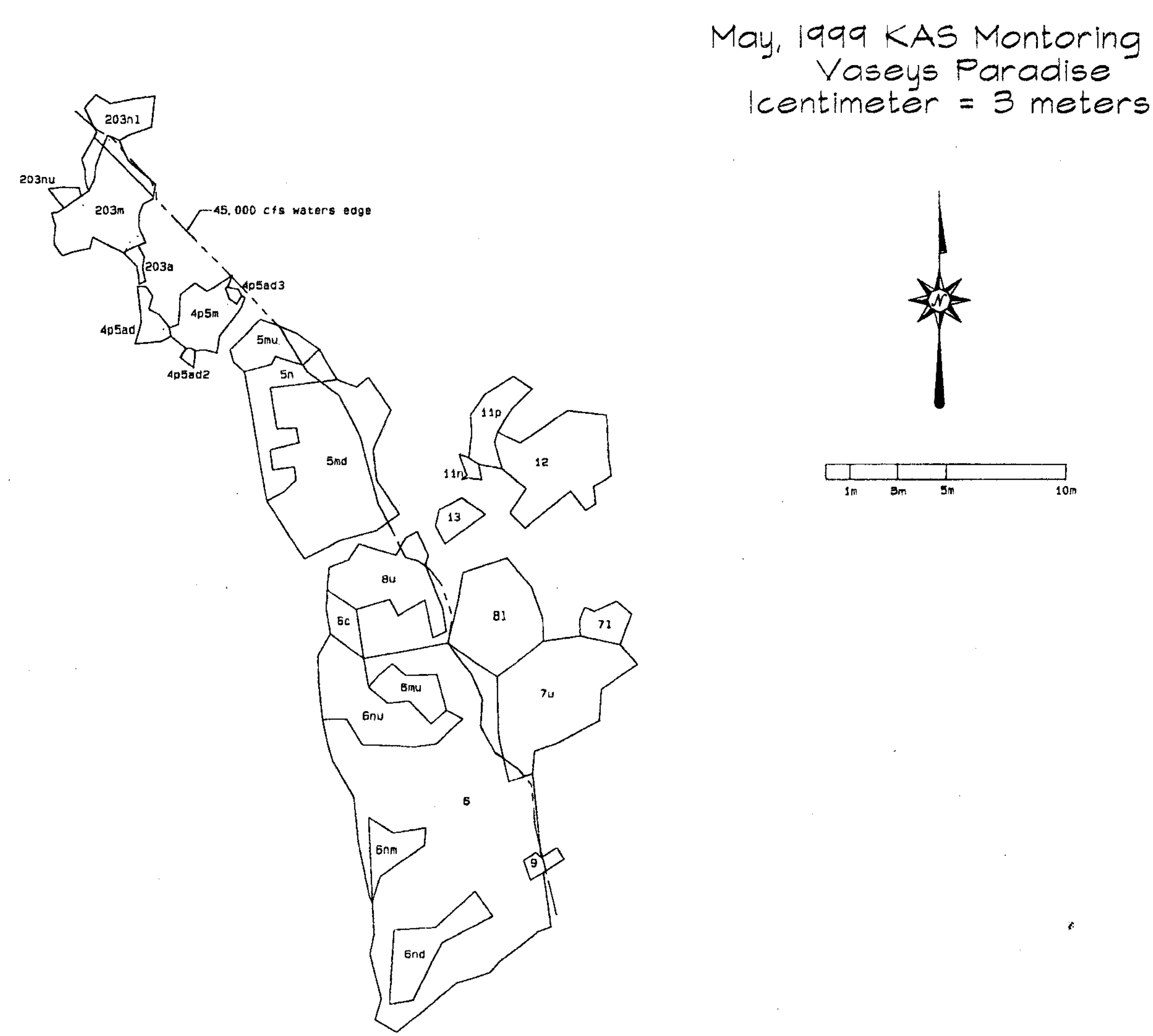
May, 1999 KAS Montoring
Vaseys Paradise
1centimeter = 3 meters
N
1m
3m
5m
10m
203n1
203nu
203m
45,000 cfs waters edge
203a
4p5ad3
4p5m
4p5ad
4p5ad2
5mu
5n
5md
11p
12
11n
13
8u
81
6c
71
8mu
6nu
7u
6
6nm
9
6nd

Figure 6

July, 1999 KAS Montoring
Vaseys Paradise
1centimeter = 3 meters

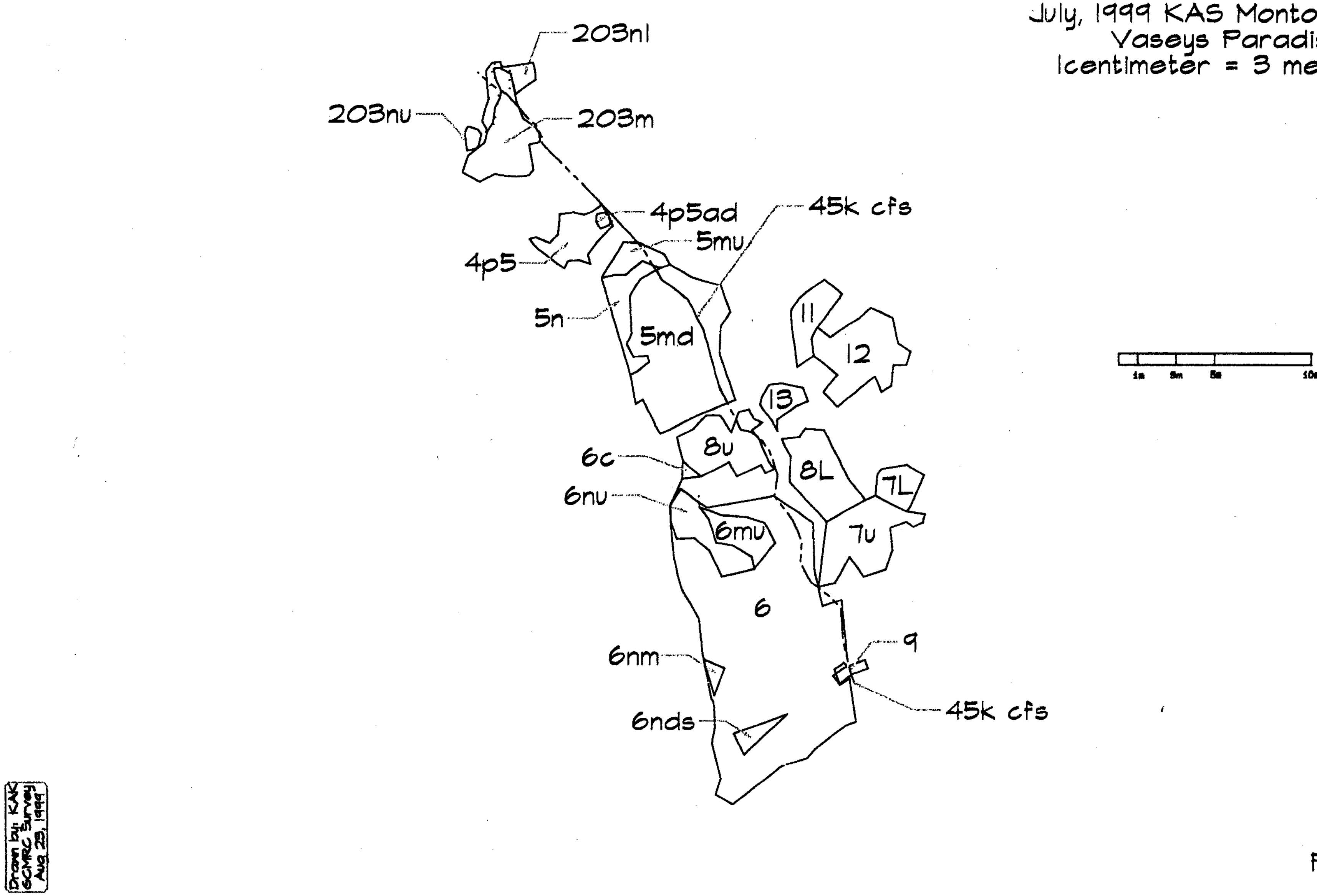

Figure 7

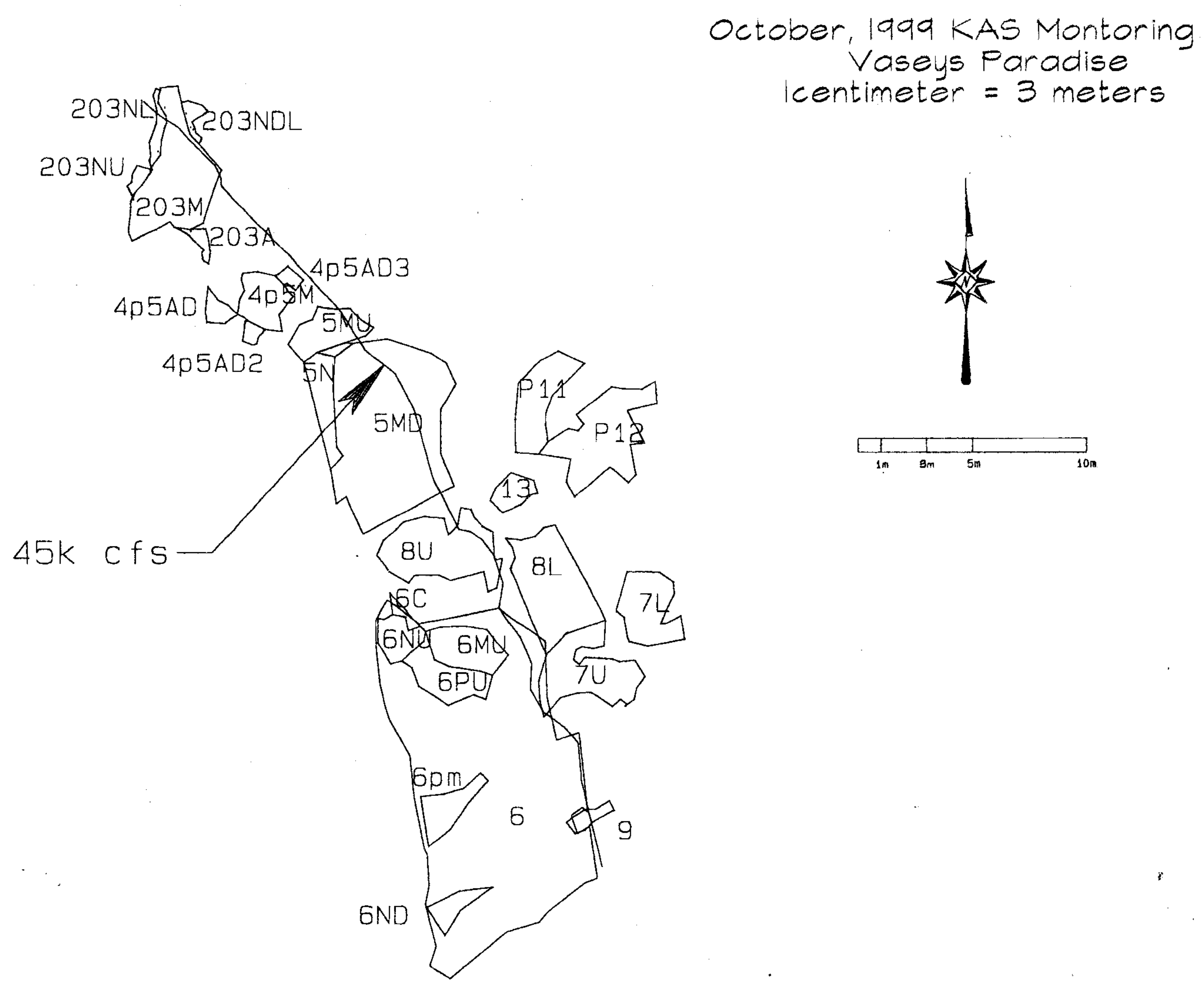
October, 1999 KAS Montoring
Vaseys Paradise
1centimeter = 3 meters
203NL
203NDL
203NU
203M
203A
4p5AD3
4p5AD
4p5M
5MU
4p5AD2
5N
5MD
P11
P12
13
45k cfs
8U
8L
6C
7L
6NU
6MU
6PU
7U
6pm
6
9
6ND
1m
5m
10m

Figure 8

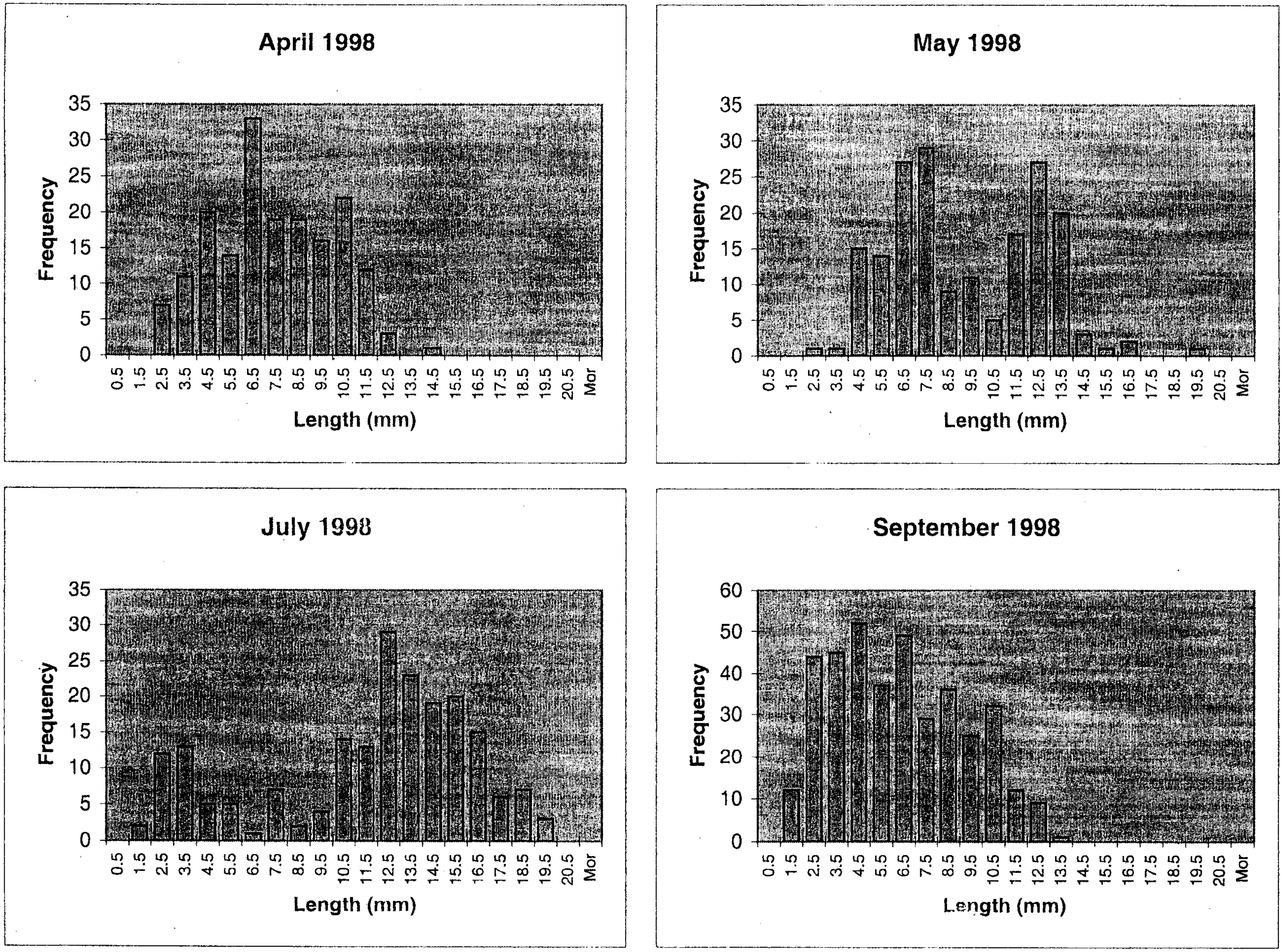

Figure 9. Length-frequency histograms for Kanab ambersnails at Vasey's Paradise, Grand Canyon National Park, Arizona during 1998 sampling.

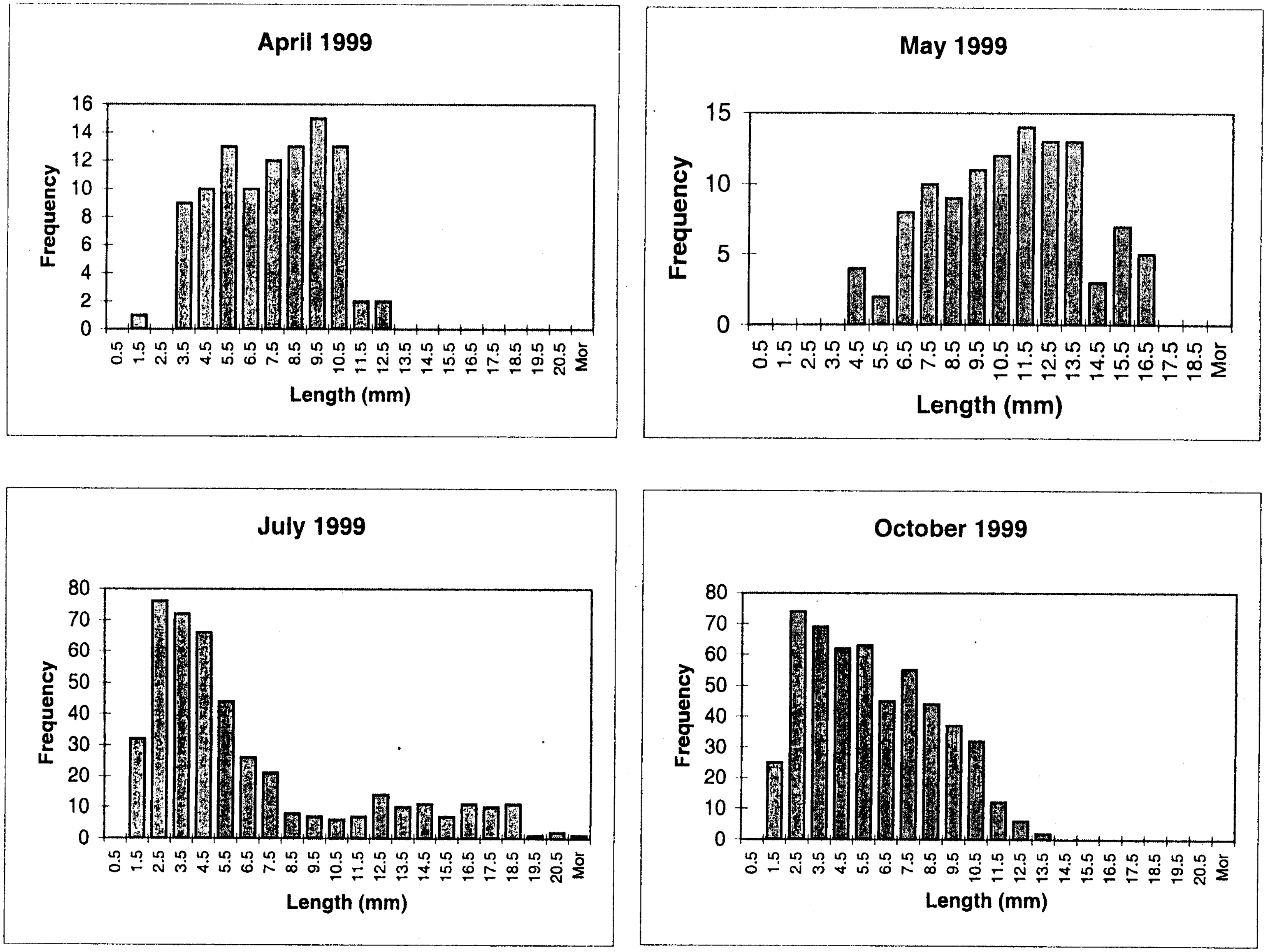

Figure 10. Length-frequency histograms for Kanab ambersnails at Vasey's Paradise, Grand Canyon National Park, Arizona during 1999 sampling.

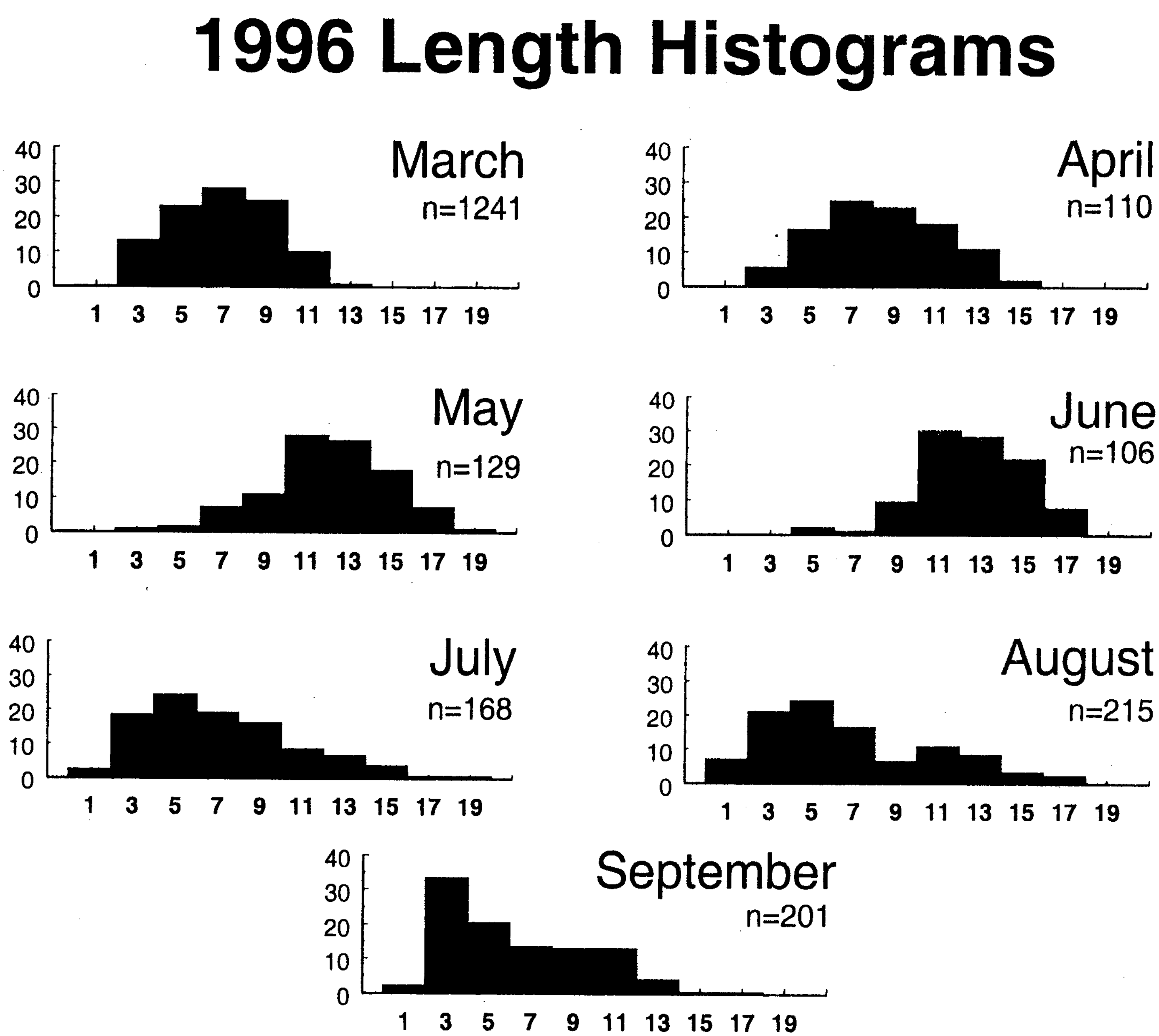

Figure 11. Length-frequency histograms for Kanab ambersnails at Vasey's Paradise, Grand Canyon National Park, Arizona during 1996 sampling. (From Stevens et al. 1997a)

Table 1a. April 4-5 ambersnail and habitat survey data, 1998.
Snail estimates are corrected for areas of bare rock and open water.

Patch	Patch area	N of samples	N of snails	Snail density (#/sq m)	Boot-strap 5-ile	Cal-culated Mean	Boot-strap 95-ile	N dor-mant	% of Vegetation			% Veg That is Live	% Cov Total Veg	Live Veg'd Area	Total Veg'd Area	Area Mica	Area Naof	Area Caaq
									Mica	Naof	Caaq							
4.5	11.19	8	3	11.9	45	134	223		77			81	100	9.06	11.19	8.6		
5M	38.04	12	7	18.6	198	692	1,286		88	2		90	98	33.55	37.28	32.8	0.7	
5N	9.51	6	19	100.8	505	959	1,413		5	95		100	100	9.51	9.51	0.5	9.0	
6NU	7.04	10	3	9.6	23	67	135		1	96	1	98	100	6.90	7.04	0.1	6.8	0.1
6MU	7.55	5	2	12.7	0	96	289		63		1	76	100	5.74	7.55	4.8		0.1
6MM	12.56	12	16	42.5	164	522	915	6	16	5	7	31	98	3.82	12.31	2.0	0.6	0.9
6NM	1.3	3	0	0.0		0												
6NDS	2	6	2	10.6	0	21	43	1	5	95		100	100	2.00	2.00	0.1	1.9	
6RMDR*	78.05	3	17	180.5	3,247	13,796	24,348	1			90	10	98	7.65	76.49			68.8
7L	3.93	8	0	0.0		0			8		80	87	95	3.25	3.73	0.3		3.0
7U	7.04	7	3	13.6	23	67	113		18	75	5	98	70	4.83	4.93	0.9	3.7	0.2
8L	14.27	10	5	15.9	39	193	387		56	2	10	60	85	7.28	12.13	6.8	0.2	1.2
8U	12.35	11	17	49.2	251	608	1,001	4	38.5			71	100	8.77	12.35	4.8		
9L	0.61	all	1	1.6		1				100		100	100	0.61	0.61		0.6	
9U	0.91	5	16	101.9	24	93	168			98	1	100	100	0.91	0.91		0.9	0.0
11	5.78	6	0	0.0		0						31	60	1.08	3.47			
12	8.18	8	0	0.0		0					12.5	65	90	4.79	7.36			0.9
13	1.44	4	2	15.9	0	23	46		76.5	5		82	100	1.18	1.44	1.1	0.1	
203M	24.23	6	2	10.6	0	257	515		76.7			89	100	21.56	24.23	18.6		
203N	3.59	6	26	138.0	153	495	896		10	90		100	100	3.59	3.59	0.4	3.2	
others +			38			38												
Total	201.1 sq m	131 samples	179 snails counted		6,727 snails	18,062 snails	29,309 snails	12 dorm. 6.7%						136.1 sq m	238.1 sq m	81.6 sq m	27.8 sq m	75.2 sq m

6MM comprises old 6POAM, 6MM, 6NM.
*Vegetation in 6RMDR estimated from photographs.
+ C3437 snails were found on small *Juncus articulatus* patches in 5M. These snails are excluded from density calculations, and but are added to totals of snails counted. and mean ambersnail estimate)

Table 1b. May 24-25 ambersnail and habitat survey data, 1998.
Snail estimates are corrected for areas of bare rock and open water.

Patch	Patch area	N of samples	N of snails	Snail density (#/sq m)	Boot-strap 5-ile	Cal-culated Mean	Boot-strap 95-ile	% of Vegetation			% Veg That Is Live	% Cov Total Veg	Live Veg'd Area	Total Veg'd Area	Area Mica	Area Naof	Area Caaq
								Mica	Naof	Caaq							
4.5	8.82	10	16	51.0	281	449	618	97	0	0	98	100	8.6	8.8	8.6	0.0	
5M	42.18	14	15	34.1	864	1,438	2,014	98	2	0	98	100	41.3	42.2	41.3	0.8	
5N	7.94	7	16	72.8	253	578	939	5	95	0	95	100	7.5	7.9	0.4	7.5	
6NU	7.81	12	9	23.9	41	183	346	TR	100	0	100	98	7.7	7.7	0.0	7.7	
6MU	6.56	8	0	0.0		0		80	0	16	95	100	6.2	6.6	5.2	0.0	1.0
6MP	7.87	8	18	71.7	181	541	962	25	0	50	98	96	7.4	7.6	1.9	0.0	3.8
6NDS	2.35	0	0			0			ER WA								
6C	2.16	3	4	42.5	68	90	112	4		95	100	98	2.1	2.1	0.1		2.0
6RMDR*	86.06	0	0		1,979	5,917	10,520	25	5	50	91	96	75.3	82.6	20.7	4.8	41.3
7L	4.66	6	4	21.2	43	85	171	5	TR	85	100	86	4.0	4.0	0.2		3.4
7U	7.16	8	4	15.9	18	68	120	2	95	1	100	60	4.3	4.3	0.1	4.1	
8L	15.28	12	10	26.5	138	345	586	85	0	10	91	85	11.8	13.0	11.0		1.3
8U	10.02	13	18	44.1	169	433	722	70	TR	8	97	98	9.5	9.8	6.9		0.8
9	2.37	6	8	42.5	63	101	139		98	2	100	100	2.4	2.4		2.3	
11	6.27	7	1	4.5	0	27	82		4	25	100	95	6.0	6.0		0.2	1.5
12	20.51	6	0	0.0		0				30	100	60	12.3	12.3			3.7
13	1.49	3	1	10.6	0	16	32	97	TR	3	100	100	1.5	1.5	1.4		
203M	14.28	8	27	107.5	796	1,534	2,387	98	1		100	100	14.3	14.3	14.0	0.1	
203N	9.18	8	30	119.4	220	1,096	2,484	2	98		100	100	9.2	9.2	0.2	9.0	
203A	1.72	3	0	0.0		0		5			91	100	1.6	1.7	0.1		
others			3			3											
Total w/o 6RMDR	178.63 sq m	142 samples	184 snails counted		5,431 snails	6,986 snails	8,740 snails							161.2 sq m	91.4 sq m	31.8 sq m	17.5 sq m
Total w/ 6RMDR	264.69					12,900							233.0	243.9	112.1	36.6	58.8

*6RMDR vegetation composition extrapolated, in part from 6MP.

Table 1c. July 20, 21 ambersnail and habitat survey data, 1998.
Snail estimates are corrected for areas of bare rock and open water.

Patch	Patch area	N of samples	N of snails	Snail density (#/sq m)	Boot-strap 5-ile	Cal-culated Mean	Boot-strap 95-ile	% of Vegetation			% Veg That Is Live	% Cov Total Veg	Live Veg'd Area	Total Veg'd Area	Area Mica	Area Naof	Area Caaq
								Mica	Naof	Caaq							
4.5	11.71	6	12	63.7	0	745	1,491	92			100	100	11.7	11.7	10.8		
5M	38.81	20	18	28.7	666	1,090	1,574	99	TR	TR	100	98	38.0	38.0	37.7		
5N	9.57	10	33	105.1	687	985	1,284	10	90		96	98	9.0	9.4	0.9	8.4	
6NU	10.41	11	33	95.5	679	974	1,299	10	80	5	100	98	10.2	10.2	1.0	8.2	0.5
6MU	15.29	8	1	4.0	0	61	183	80		10	100	100	15.3	15.3	12.2		1.5
6NP	1.44	3	4	42.5	46	61	77		100		100	100	1.4	1.4		1.4	
6P	20.3	9	4	14.2	72	287	575		2	55	100	100	20.3	20.3		0.4	11.2
6ND	1.64	5	11	70.1	74	115	157		99	1	100	100	1.6	1.6		1.6	0.0
6C	2.33	4	0	0.0	0	0	0	5		95	100	100	2.3	2.3	0.1		2.2
6RMDR	62.8	not counted		(14.2)	223	889	1,779	10		50	100	100	62.8	62.8	6.3		31.4
7L	4.89	6	0	0.0	0	0	0	10		85	100	95	4.6	4.6	0.5		3.9
7U	8.87	8	4	15.9	35	138	243	2	98	TR	100	98	8.7	8.7	0.2	8.5	
8L	13.75	8	7	27.9	94	326	559	90		5	100	85	11.7	11.7	10.5		0.6
8U	15.17	6	23	122.1	805	1,851	2,978	73		15	100	100	15.2	15.2	11.1		2.3
9	3.27	8	34	135.4	287	442	599		98	1	100	100	3.3	3.3		3.2	0.0
11	7.35	6	2	10.6	0	76	230			12	100	98	7.2	7.2			0.9
12	21.33	8	0	0.0	0	0	0			38	100	60	12.8	12.8			4.9
13	3.43	not counted				102		88	2	10	100	100	3.4	3.4	3.0	0.1	0.3
203M	15.67	5	7	44.6	391	684	978	100			100	98	15.4	15.4	15.4		
203N	7.13	7	8	36.4	62	246	493	95	5		95	95	6.5	6.8	6.4	0.3	
203A	1.66	3	0	0.0	0	0	0	10			92	100	1.5	1.7	0.2		
Total w/o 6RMNDR or 13	276.82 sq m	141 samples	201 snails counted		6,541 snails	8,083 snails	9,702 snails							201.0 sq m	109.9 sq m	32.2 sq m	28.3 sq m
w/6RMNDR and 13						9,073											

Vegetation in 6RMDR extrapolated, in part, from 6MP.

Table 1d. Sep 27, 28 Ambersnail and habitat survey data, 1998.
Snail estimates are corrected for areas of bare rock and open water.

Patch	Patch area	N of samples	N of snails	Snail density (#/sq m)	Boot-strap 5-ile	Cal-culated Mean	Boot-strap 95-ile	% of Vegetation Mica	Naof	Caaq	% Veg That Is Live	% Cov Total Veg	Live Veg'd Area	Total Veg'd Area	Area Mica	Area Naof	Area Caaq
4.5	11.86	7	15	68	428	809	1175	85			99	100	11.7	11.9	10.1	0.0	0.0
5M	38.81	15	22	47	1,223	1,794	2691	100			98	99	37.7	38.4	38.4		
5N	9.57	7	34	155	1,132	1,480	1872	10	90		100	100	9.6	9.6	1.0	8.6	
6NU	5.05	11	107	309.8	1,006	1,517	2113	5	70	25	100	97	4.9	4.9	0.2	3.4	1.2
6MU	9	9	14	49.5	191	446	733	92		4	100	100	9.0	9.0	8.3		0.4
6NMX	3.35	6	43	228.2	427	764	1156	10	60		100	100	3.4	3.4	0.3	2.0	
6P	4.5	5	24	152.9	316	688	1118	TR	10	TR	100	100	4.5	4.5		0.5	
6RMDR	89.16	13	27	66.1	3,057	5,894	8951			80	100	100	89.2	89.2		0.0	71.3
7U	9.94	6	30	159.2	633	1,582	2532.0	1	99	TR	100	100	9.9	9.9	0.1	9.8	
7L	4.29	6	9	47.8	43	190	339	7	7	75	100	93	4.0	4.0	0.3	0.3	3.0
7LL	0.28	2	3	47.8	0	11	23				100	85	0.2	0.2			
8U	15.28	8	27	107.5	894	1,609	2324	90			100	98	15.0	15.0	13.5		
8L	15.45	7	4	18.2	66	261	458	95		3	100	93	14.4	14.4	13.7		0.4
9	1.06	6	4	21.2	5	19	34		50	40	100	85	0.9	0.9	0.0	0.5	0.4
11	6.96	6	1	5.3	0	37	111		TR	5	55	100	3.8	7.0			0.3
12	15.48	8	5	19.9	93	231	370			48	100	75	11.6	11.6			5.6
13	2.73	5	3	19.1	0	51	103	98	TR	2	100	98	2.7	2.7	2.6		0.1
203M	18.25	7	8	36.4	332	664	996	100			100	100	18.3	18.3	18.3		
203N	3.94	2	2	31.8	0	119	239	20	80		100	95	3.7	3.7	0.7	3.0	
203A	2.11	3	0	0.0		0		5			100	99	2.1	2.1	0.1		
Total	267.07 sq m	139 samples	382 snails counted		14,867 snails	18,165 snails	21,599 snails							260.5 sq m	107.6 sq m	28.1 sq m	82.7 sq m

Table 2a. April 3-4 ambersnail and habitat survey data, 1999.
Snail estimates are corrected for areas of bare rock and open water.

Patch	Patch area	N of samples	N of snails	Snail density (#/sq m)	Boot-strap 5-ile	Cal-culated Mean	Boot-strap 95-ile	N dor-mant	% of Vegetation			% Veg That is Live	% Cov Total Veg	Total Veg'd Area	Area Mica	Area Naof	Area Caaq
									Mica	Naof	Caaq						
4.5AD	0.53	3	4	42.4	0	22	45		5			93	100	0.5	0.0	0.0	0.0
4.5	10.56	9	2	7.1	0	73	147		94			93	98	10.3	9.9	0.0	0.0
5MUU	1.5	3	4	42.4	48	64	80		100			80	100	1.5	1.5	0.0	0.0
5MU	10.26	7	3	13.6	47	140	234		90	10		80	100	10.3	9.2	1.0	0.0
5MD	31.89	9	2	7.1	0	226	452		99	1		95	100	31.9	31.6	0.3	0.0
5N	11.63	7	5	22.7	53	264	476		20	80		100	100	11.6	2.3	9.3	0.0
6NU	15.39	6	0	0.0		0			2	93	5	98	100	15.4	0.3	14.3	0.8
6MU	4.6	6	1	5.3	0	24	74		63		20	70	100	4.6	2.9	0.0	0.9
6NM	1.19	3	0	0.0		0			4	95		100	100	1.2	0.0	1.1	0.0
6NDS	7.5	6	8	42.4	80	318	637		3	96		100	100	7.5	0.2	7.2	0.0
6RD	39.39	7	14	63.7	896	2,508	4,299	2	2		90	50	100	39.4	0.8	0.0	35.5
6RU	24.09	4	3	23.9	0	575	1,151	2	5		90	40	100	24.1	1.2	0.0	21.7
7LL	0.28	3	0	0.0		0					tr	45	98	0.3	0.0	0.0	0.0
7L	3.75	7	15	68.2	56	207	387	3	15	0	75	100	81	3.0	0.6	0.0	2.8
7U	22.37	6	0	0.0		0			tr	99		100	100	22.4	0.0	22.1	0.0
8L	24.91	6	8	42.4	476	761	1,047	6	85		8	100	72	17.9	21.2	0.0	2.0
8U	9.99	6	8	42.4	0	394	888	4	68		5	60	93	9.3	6.8	0.0	0.5
9	2.75	6	11	58.4	30	160	365		tr	99	tr	100	100	2.8	0.0	2.7	0.0
11	6.38	6	1	5.3	0	32	97			6	10	50	95	6.1	0.0	0.4	0.6
12	20.55	6	5	26.5	142	354	638	2			49	50	65	13.4	0.0	0.0	10.1
13	2.53	4	0	0.0		0			95		5	100	100	2.5	2.4	0.0	0.1
203M	20.3	10	4	12.7	119	238	417		70	15		90	92	18.7	14.2	3.0	0.0
203N	6	7	0	0.0		0			12	88		100	100	6.0	0.7	5.3	0.0
203AD	1.8	5	1	6.4	0	11	33		tr			90	95	1.7	0.0	0.0	0.0
Total	280.1 sq m	142 samples	99 snails		4,487 snails	6,373 snails	8,451 snails	19 snails						262.3 sq m	105.9 sq m	66.9 sq m	75.0 sq m

0.192

Table 2b. May 25-26 ambersnail and habitat survey data, 1999.
Snail estimates are corrected for areas of bare rock and open water.

Patch	Patch area	N of samples	N of snails	Snail density (#/sq m)	Boot-strap 5-ile	Cal-culated Mean	Boot-strap 95-ile	% of Vegetation			% Veg That Is Live	% Cov Total Veg	Total Veg'd Area	Area Mica	Area Naof	Area Caaq
								Mica	Naof	Caaq						
4.5	7.88	9	6	21.2	56	166	276	90			95	99	7.8	7.1	0.0	0.0
5MD	32.15	12	8	21.2	251	669	1,171	99	1		100	98	31.5	31.8	0.3	0.0
5MU	5.39	5	15	95.5	261	489	718	85	15		98	95	5.1	4.6	0.8	0.0
5N	9.21	11	5	14.5	27	133	267	2	98		100	100	9.2	0.2	9.0	0.0
6NU	12.85	10	12	38.2	246	491	737	10	85	5	98	100	12.9	1.3	10.9	0.6
6MU	4.64	5	1	6.4	0	27	80	90		5	98	90	4.2	4.2	0.0	0.2
6NM	4.74	6	7	37.1	28	176	278	1	95		100	100	4.7	0.0	4.5	0.0
6NDS	7.21	6	3	15.9	39	115	192	1	97		100	100	7.2	0.1	7.0	0.0
6C	2.6	5	0	0.0		0		5		80	100	97	2.5	0.1	0.0	2.1
6RMDR	81.26	6	5	26.5	863	2,155	3,880	10	5	50	100	100	81.3	8.1	4.1	40.6
7L	2.68	3	1	10.6	0	20	40	7		45	95	70	1.9	0.2	0.0	1.2
7U	21.44	8	3	11.9	0	218	508		100		80	85	18.2	0.0	21.4	0.0
8L	13.97	6	7	37.1	189	441	693	88		10	98	85	11.9	12.3	0.0	1.4
8U	11.59	5	1	6.4	0	68	204	63		15	98	92	10.7	7.3	0.0	1.7
9	1.41	5	16	101.9	54	144	252	1	96		100	100	1.4	0.0	1.4	0.0
11P	4.9	6	2	10.6	0	51	102			15	100	98	4.8	0.0	0.0	0.7
11N	0.57	3	2	21.2	0	12	24		95		100	98	0.6	0.0	0.5	0.0
12	17.01	8		0.0		0				26	90	60	10.2	0.0	0.0	4.4
13	2.39	4	2	15.9	0	38	77	99			98	100	2.4	2.4	0.0	0.0
203M	17.09	4	7	55.7	130	904	1,551	100			95	95	16.2	17.1	0.0	0.0
203NL	5.93	3	1	10.6	0	63	126	30	70		100	100	5.9	1.8	4.2	0.0
203NU	1.19	2	4	63.7	38	76	114		100		100	100	1.2	0.0	1.2	0.0
203A	1.42	2	0	0.0		0		2			100	100	1.4	0.0	0.0	0.0
Total	270 sq m	134 samples	108 snails		4,622 snails	6,454 snails	8,349 snails						253.2 sq m	98.6 sq m	65.3 sq m	53.1 sq m

Table 2c. July 19,20 ambersnail and habitat survey data, 1999.
Snail estimates are corrected for areas of bare rock and open water.

Patch	Patch area	N of samples	N of snails	Snail density (#/sq m)	Boot-strap 5-ile	Cal-culated Mean	Boot-strap 95-ile	% of Vegetation Mica	Naof	Caaq	% Veg That Is Live	% Cov Total Veg	Total Veg'd Area	Area Mica	Area Naof	Area Caaq
4.5	9.25	7	8	36.4	167	333	500	92			100	99	9.2	6.4	0.0	0.0
5MU	3.88	6	3	15.9	20	61	101	98	2		100	98	3.8	3.8	0.1	0.0
5MD	39.94	14	38	86.4	1798	3416	5214	99		TR	100	99	39.5	39.5	0.0	0.0
5N	6.53	7	34	154.6	742	1010	1247	10	100		100	100	6.5	0.7	6.5	0.0
6NU	8.58	6	74	392.6	2364	3301	4326	1	95	4	100	98	8.4	0.1	8.2	0.3
6NM	0.8	4	69	549.1	191	439	655					100	0.8	0.0	0.0	0.0
6MU	6.2	6	11	58.4	66	362	724	95		5	99	100	6.2	5.9	0.0	0.3
6C	0.53	3	7	74.3	6	39	73	10		90	100	100	0.5	0.1	0.0	0.5
6NDS	1.89	4	4	31.8	0	54	108	10	90		95	90	1.7	0.2	1.7	0.0
6RMDR	93.23	20	11	17.5	594	1632	2820	20		80	100	100	93.2	18.6	0.0	74.6
7U	14.5	8	95	378.0	2740	5207	8057		99	1	98	95	13.8	0.0	14.4	0.1
7L	4.42	5	3	19.1	27	80	134	5		90	100	95	4.2	0.2	0.0	4.0
8U	12.23	5	1	6.4	0	76	229	70		20	98	98	12.0	8.6	0.0	2.4
8L	12.16	12	0	0.0		0		92		8	95	88	10.7	11.2	0.0	1.0
9	1.16	4	23	183.0	72	208	317	1	98		85	98	1.1	0.0	1.1	0.0
11	6.11	6	14	74.3	130	454	843		3	30	80	100	6.1	0.0	0.2	1.8
12	15.48	6	2	10.6	0	125	374			35	100	76	11.8	0.0	0.0	5.4
13	3.7	3	19	201.6	459	671	883	100		10	100	90	3.3	3.7	0.0	0.4
203M	17.73	7	9	40.9	395	711	1027	100			100	98	17.4	17.7	0.0	0.0
203NL	4.05	6	5	26.5	42	105	168	2	98		70	98	4.0	0.1	4.0	0.0
203NU	1.28	3	5	53.1	27	68	109	2	98		100	100	1.3	0.0	1.3	0.0
Totals	264 sq m	142 samples	435 snails		14,872 snails	18,352 snails	22,052 snails						255.5 sq m	116.8 sq m	37.4 sq m	90.9 sq m
Total w/extra plot from 6R		143	448		15,894	20,134	25,023									

Table 2d. Ambersnail and habitat survey data, Oct 1-2, 1999.
Snail estimates are corrected for areas of bare rock and open water.

Patch	Patch area	N of samples	N of snails	Snail density (#/sq m)	Boot-strap 5-ile	Cal-culated Mean	Boot-strap 95-ile	% of Vegetation Mica	Naof	Caaq	% Veg That Is Live	% Cov Total Veg	Total Veg'd Area	Area Mica	Area Naof	Area Caaq
4.5	6.19	4	16	127.3	435	772	1,062	93			100	98	6.1	5.8	0.0	0.0
5MD	39.36	10	21	66.8	983	2,578	4,666	98	TR	TR	80	98	38.6	38.6	0.0	0.0
5MU	5.74	5	17	108.2	144	609	1,326	98	TR	TR	80	98	5.6	5.6	0.0	0.0
5N	4.31	5	52	331.0	961	1,427	1,894	10	90		100	100	4.3	0.4	3.9	0.0
6C	2.08	4	22	175.1	158	346	645	TR	TR	90	100	95	2.0	0.0	0.0	1.9
6MU	6.12	5	22	140.1	78	857	1,754	70		13	100	100	6.1	4.3	0.0	0.8
6NDS	2.13	3	7	74.3	68	158	249	45	40	2	100	95	2.0	1.0	0.9	0.0
6NUS	3.03	5	27	171.9	281	510	730	TR	82	13	100	95	2.9	0.0	2.5	0.4
6PM	3.73	4	4	31.8	119	119	119	TR		15	100	100	3.7	0.0	0.0	0.6
6PU	5.73	5	18	114.6	256	657	1,058	10	40	15	100	100	5.7	0.6	2.3	0.9
6RMDR	88.9	9	40	141.5	7,861	12,576	17,294	10		50	60	100	88.9	8.9	0.0	44.5
7L	7	7	31	141.0	191	987	2,133	5	45	40	98	97	6.8	0.4	3.2	2.8
7U	10.59	11	112	324.1	1,562	3,363	5,616	TR	90	8	100	98	10.4	0.0	9.5	0.8
8L	13.43	6	17	90.2	722	1,114	1,574	69		23	80	92	12.4	9.3	0.0	3.1
8U	13.26	5	38	241.9	1,588	3,176	5,349	50		20	80	99	13.1	6.6	0.0	2.7
9	1.46	4	1	8.0	0	9	27		25	10	100	50	0.7	0.0	0.4	0.1
11	7.09	6	9	47.7	113	339	602		1	80	50	100	7.1	0.0	0.1	5.7
12	14.48	6	1	5.3	0	58	173			25	75	75	10.9	0.0	0.0	3.6
13	2.5	3	10	106.1	160	265	372	85		15	80	100	2.5	2.1	0.0	0.4
203M	18.01	5	32	203.7	2,293	3,669	5,045	98			100	100	18.0	17.6	0.0	0.0
203NL	1.43	3	19	201.6	137	288	440		100		100	100	1.4	0.0	1.4	0.0
203NU	1.02	3	7	74.3	65	76	87		100		100	100	1.0	0.0	1.0	0.0
Total	257.59 sq m	118 samples	523 snails		27,897 snails	33,953 snails	40,301 snails						250.2 sq m	101.1 sq m	25.1 sq m	68.2 sq m

Table 3. Proportion of snails less than 4 mm in length (%) among all *Oxyloma* (n) found in sample circles in vegetation patches at Vasey's Paradise, Grand Canyon National Park in Apr 1998 - Oct 1999.

	April 1998		May 1998		July 1998		Sep 1998		April 1999		May 1999		July 1999		October 1999	
Patch	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n
4.5		3		16		12	**13**	15		2		6	**25**	8	**63**	16
5M		7		18	**22**	18	**18**	22	**11**	9		20	**53**	40	**18**	39
5N	**11**	19		16	**36**	33	**29**	34		5		5	**24**	34	**15**	52
6MU		2		0		1	**7**	14		1		1	**55**	11		22
6NU		1		9	**13**	32	**20**	107		0		12	**41**	71	**57**	21
6NMid						4	**42**	43		0		7				
6MMid	**19**	16		18									**33**	69		
6NDS		2							**13**	8		3		4	**86**	7
6P (approx 6RU)					**50**	4									**25**	4
6R(D)	**24**	17					**15**	27	**29**	14		5		11	**18**	40
6RU										3					**6**	18
7L		0		4		0	**22**	9	**19**	16		1	**67**	3	**65**	31
7U		3		4		4	**7**	30		0		3	**48**	95	**49**	113
8L	**20**	5		10	**14**	7	**25**	4		8		7		0	**11**	19
8U		17	**11**	18	**13**	23	**59**	27		8		1		1	**47**	38
9		17		8		34		2		11		22	**26**	23		1
11(P)		0		1		2		1		1		2	**50**	14		9
11N												2				
12		0		0		0		5	**20**	5		0	**100**	2		2
13		2		1			**20**	5		0		2	**79**	19	**30**	10
203M		2		27		6	**11**	9		4		7		9	**16**	32
203N	**4**	26		30	**13**	8	**50**	2		0		5		10		22
203A				0		0		0		1					**33**	3
Overall	**8**		**1**		**14**		**26**		**10**		**0**		**40**		**32**	

Table 4a. Data variability information for April 1999 survey. The range of the 90th percentile boostrapped confidence interval of the population size in the patch, the range of the 90th percentile divided by the mean estimate of population size for the patch, the range of the 90th percentile divided by the number of samples taken in the patch, and the area of the patch divided by the number of samples taken are shown.

Patch	Patch area	N of samples	N of snails	Snail density (#/sq m)	Boot-strap 5-ile	Cal-culated Mean	Boot-strap 95-ile	90%rng	90%/mn	90%/# samples	area/# samples
6RD	39.4	7	14	63.7	1,137	**2,508**	5,230	**4093**	1.6	**584.7**	**5.6**
8L	24.9	6	8	42.4	476	761	1,047	571	0.8	95.2	**4.2**
6RU	24.1	4	3	23.9	0	575	1,883	**1883**	**3.3**	**470.8**	**6.0**
8U	10.0	6	8	42.4	0	394	888	888	**2.3**	148.0	1.7
12	20.6	6	5	26.5	142	354	638	496	1.4	82.7	**3.4**
6NDS	7.5	6	8	42.4	80	318	637	557	1.7	92.8	1.3
5N	11.6	7	5	22.7	53	264	476	423	1.6	60.4	1.7
203M	20.3	10	4	12.7	119	238	417	298	1.3	29.8	2.0
5MD	31.9	9	2	7.1	0	226	452	452	2.0	50.2	**3.5**
7L	3.8	7	15	68.2	56	207	387	331	1.6	47.3	0.5
9	2.8	6	11	58.4	30	160	365	335	**2.1**	55.8	0.5
5MU	10.3	7	3	13.6	47	140	234	187	1.3	26.7	1.5
4.5	10.6	9	2	7.1	0	73	147	147	**2.0**	16.3	1.2
5MUU	1.5	3	4	42.4	48	64	80	32	0.5	10.7	0.5
11	6.4	6	1	5.3	0	32	97	97	**3.0**	16.2	1.1
6MU	4.6	6	1	5.3	0	24	74	74	**3.0**	12.3	0.8
4.5AD	0.5	3	4	42.4	0	22	45	45	**2.0**	15.0	0.2
203AD	1.8	5	1	6.4	0	11	33	33	**3.0**	6.6	0.4
6NU	15.4	6	0	0.0		0					2.6
6NM	1.2	3	0	0.0		0					0.4
7LL	0.3	3	0	0.0		0					0.1
7U	22.4	6	0	0.0		0					**3.7**
13	2.5	4	0	0.0		0					0.6
203N	6.0	7	0	0.0		0					0.9
Total	292.9	142	99		4,834	7,101	9,603				

Table 4b. Data variability information for May 1999 survey. The range of the 90th percentile boostrapped confidence interval of the population size in the patch, the range of the 90th percentile divided by the mean estimate of population size for the patch, the range of the 90th percentile divided by the number of samples taken in the patch, and the area of the patch divided by the number of samples taken are shown.

Patch	**Patch area**	**N of samples**	**N of snails**	**Snail density (#/sq m)**	**Boot-strap 5-ile**	**Cal-culated Mean**	**Boot-strap 95-ile**	**90%rng**	**90%/mn**	**90%/# samples**	**area/# samples**
6RMDR	81.26	6	5	26.5	856	**2,155**	3,848	**2992**	1.4	**498.7**	**13.5**
203M	17.09	4	7	55.7	130	904	1,551	**1421**	1.6	**355.3**	**4.3**
5MD	32.15	12	8	21.2	251	669	1,171	920	1.4	76.7	2.7
6NU	12.85	10	12	38.2	246	491	737	491	1.0	49.1	1.3
5MU	5.39	5	15	95.5	261	489	718	457	0.9	91.4	1.1
8L	13.97	6	7	37.1	189	441	693	504	1.1	84.0	2.3
7U	21.44	8	3	11.9	0	218	508	508	**2.3**	63.5	2.7
4.5	7.88	9	6	21.2	56	166	276	220	1.3	24.4	0.9
9	1.41	5	16	101.9	54	144	252	198	1.4	39.6	0.3
5N	9.21	11	5	14.5	27	133	267	240	1.8	21.8	0.8
6NDS	7.21	6	3	15.9	39	115	192	153	1.3	25.5	1.2
6NM	4.74	6	4	21.2	28	176	278	250	1.4	41.7	0.8
203NU	1.19	2	4	63.7	38	76	114	76	1.0	38.0	0.6
8U	11.59	5	1	6.4	0	68	204	204	**3.0**	40.8	2.3
203NL	5.93	3	1	10.6	0	63	126	126	**2.0**	42.0	2.0
11P	4.9	6	2	10.6	0	51	102	102	**2.0**	17.0	0.8
13	2.39	4	2	15.9	0	38	77	77	**2.0**	19.3	0.6
6MU	4.64	5	1	6.4	0	27	80	80	**3.0**	16.0	0.9
7L	2.68	3	1	10.6	0	20	40	40	**2.0**	13.3	0.9
11N	0.57	3	2	21.2	0	12	24	24	**2.0**	8.0	0.2
6C	2.6	5	0	0.0		0					0.5
203A	1.42	2	0	0.0		0					0.7
12	17.01	8		0.0		0					2.1
Total	268.9	134	105		4,635	6,453	8,312				

Table 4c. Data variability information for July 1999 survey. The range of the 90th percentile boostrapped confidence interval of the population size in the patch, the range of the 90th percentile divided by the mean estimate of population size for the patch, the range of the 90th percentile divided by the number of samples taken in the patch, and the area of the patch divided by the number of samples taken are shown.

Patch	Patch area	N of samples	N of snails	Snail density (#/sq m)	Boot-strap 5-ile	Cal-culated Mean	Boot-strap 95-ile	90%rng	90%/mn	90%/# samples	area/# samples
7U	14.50	8	95	378.0	2,740	**5,207**	8,057	**5317**	1.0	**664.6**	1.8
5MD	39.94	14	38	86.4	1,798	**3,416**	5,214	**3416**	1.0	**244.0**	2.9
6NU	8.58	6	74	392.6	2,364	**3,301**	4,326	**1962**	0.6	**327.0**	1.4
6RMDR	93.23	20	11	17.5	601	**1,632**	2,855	**2254**	1.4	112.7	**4.7**
5N	6.53	7	34	154.6	742	**1,010**	1,247	505	0.5	72.1	0.9
203M	17.73	7	9	40.9	395	711	1,027	632	0.9	90.3	2.5
13	3.70	3	19	201.6	459	671	883	424	0.6	141.3	1.2
11	6.11	6	14	74.3	130	454	843	713	1.6	118.8	1.0
6NM	0.80	4	69	549.1	191	439	655	464	1.1	116.0	0.2
6MU	6.20	6	11	58.4	66	362	724	658	1.8	109.7	1.0
4.5	9.25	7	8	36.4	167	333	500	333	1.0	47.6	1.3
9	1.16	4	23	183.0	72	208	317	245	1.2	61.3	0.3
12	15.48	6	2	10.6	0	125	374	374	**3.0**	62.3	2.6
203NL	4.05	6	5	26.5	42	105	168	126	1.2	21.0	0.7
7L	4.42	5	3	19.1	27	80	134	107	1.3	21.4	0.9
8U	12.23	5	1	6.4	0	76	229	229	**3.0**	45.8	2.4
203NU	1.28	3	5	53.1	27	68	109	82	1.2	27.3	0.4
5MU	3.88	6	3	15.9	20	61	101	81	1.3	13.5	0.6
6NDS	1.89	4	4	31.8	0	54	108	108	2.0	27.0	0.5
6C	0.53	3	7	74.3	6	39	73	67	1.7	22.3	0.2
8L	12.16	12	0	0.0		0					
Totals	264.83	142	435		14,977	18,373	22,245				
Total w/extra plot from 6R		143	448		15,894	20,155	25,023				

Table 4d. Data variability information for October 1999 survey. The range of the 90th percentile boostrapped confidence interval of the population size in the patch, the range of the 90th percentile divided by the mean estimate of population size for the patch, the range of the 90th percentile divided by the number of samples taken in the patch, and the area of the patch divided by the number of samples taken are shown.

Patch	Patch area	N of samples	N of snails	Snail density (#/sq m)	Boot-strap 5-ile	Cal-culated Mean	Boot-strap 95-ile	90%rng	90%/mn	90%/# samples	area/# samples
6RMDR	96.03	9	40	141.5	8,831	**12,576**	18,680	**9849**	0.8	**1094.3**	**10.7**
203M	18.01	5	32	203.7	2,293	**3,669**	5,045	**2752**	0.8	**550.4**	**3.6**
7U	10.59	11	112	324.1	1,562	**3,363**	5,616	4054	1.2	368.5	1.0
8U	13.26	5	38	241.9	1,588	**3,176**	5,349	3761	1.2	**752.2**	2.7
5MD	39.36	10	21	66.8	983	**2,578**	4,666	**3683**	1.4	368.3	**3.9**
5N	4.31	5	52	331.0	961	**1,427**	1,894	933	0.7	186.6	0.9
8L	13.43	6	17	90.2	722	**1,114**	1,574	852	0.8	142.0	2.2
7L	7	7	31	141.0	191	987	2,133	**1942**	**2.0**	277.4	1.0
6MU	6.12	5	22	140.1	78	857	1,754	**1676**	**2.0**	335.2	1.2
4.5	6.19	4	16	127.3	435	772	1,062	627	0.8	156.8	1.5
6PU	5.73	5	18	114.6	256	657	1,058	802	1.2	160.4	1.1
5MU	5.74	5	17	108.2	144	609	1,326	**1182**	**1.9**	236.4	1.1
6NUS	3.03	5	27	171.9	281	510	730	449	0.9	89.8	0.6
6C	2.08	4	22	175.1	158	346	645	487	1.4	121.8	0.5
11	7.09	6	9	47.7	113	339	602	489	1.4	81.5	1.2
203NL	1.43	3	19	201.6	137	288	440	303	1.1	101.0	0.5
13	2.5	3	10	106.1	160	265	372	212	0.8	70.7	0.8
6NDS	2.13	3	7	74.3	68	158	249	181	1.1	60.3	0.7
6PM	3.73	4	4	31.8	119	119	119	0	0.0	0.0	0.9
203NU	1.02	3	7	74.3	65	76	87	22	0.3	7.3	0.3
12	14.48	6	1	5.3	0	58	173	173	**3.0**	28.8	2.4
9	1.46	4	1	8.0	0	9	27	27	**3.1**	6.8	0.4
Total	264.72	118	523		28,610	34,961	41,642				

Reviewer beginning Review Comment A with "No hypotheses ..."

Comment A: material added re trematode parasite in Results and in Discussion.

Comment B: no changes indicated.

Comment C: additional material added to Recommendations section to address specific concerns.

Comment D: literature review section added.

Comment E: no changes indicated.

Comment F: literature review section added. Other studies of snails in desert spring systems tend to relate to aquatic snails, or offer relatively shallow ecological information.

Ms. comments: addressed as appropriate.

Reviewer beginning Review Comment A with "Researchers obviously ..."

Comment A: minor change in Recommendations.

Comment B: no changes indicated.

Comment C: passage clarified.

Comment D: additions to Discussion and Recommendations.

Comment E: decline change in wording. "Constrained" is accurate.

Ms. comments: some of these indicated misunderstanding of the material. Clarifications have been made in those instances, and otherwise, appropriate changes were made.

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September 29, 2000

Dr. Barbara Ralston
Biological Resources Manager
Grand Canyon Monitoring and Research Center
2255 N. Gemini Dr., Room 341
Flagstaff, Arizona 86001

Dear Dr. Ralston,

Attached is our final report on the 1998-1999 contract for monitoring and research of Kanab ambersnail at Vasey's Paradise. An attachment summarizes changes made in response to reviewer comments. We appreciate the opportunity to respond to thoughtful review and believe you will find the report improved thereby.

Two comments by one reviewer address possibly contract concerns. One of these we have addressed in text by indicating that our decision not to PIT tag on our final visit was supported by GCMRC. As there was no certainty that future researchers would be monitoring PIT tags, there was no point in injecting animals with tags that would never be read.

The other issue was the inconclusive results of snail radula work to date. We were in contact with Dr. Stevens about this issue, due to logistical difficulties, and did not include a discussion of these in the report. Our original proposal suggested spending extra time at Vasey's in order to hold mice captive on site to conduct feeding experiments to see if mice would accept *Catinella* and if *Catinella* radulae could be detected in fecal pellets thereafter. We confirmed that radulae would likely survive digestion during our first field season. Changes in Park Service protocol and funding shortages at GCMRC in the second season made it clear that lengthening an oar-supported trip at Vasey's in order to experiment with mice was not feasible. We discussed trapping a related *Peromyscus* species near Flagstaff, and feeding them extra ambersnails from Clay Nelson's work, but Debra Bills indicated this was unlikely to be permitted by USFWS, and similarly, carrying *Catinella* out of the canyon to feed to field mice in Flagstaff was likely to prove difficult due to NPS permitting procedures. Dr. Stevens was aware of these problems and did not indicate that they would constitute a "stopper" with regard to our work.

In all other particulars we have conducted and presented our work as proposed, and we hope you will find our report useful. Electronic copies of all data will be submitted under separate cover. If you have further questions please contact Dr. Meretsky or myself.

Sincerely,

William Leibfried
Senior Scientist/Project Manager
SWCA, Inc.