THE IMPACTS OF AN EXPERIMENTAL FLOOD FROM GLEN CANYON DAM ON THE ENDANGERED KANAB AMBERSNAIL AT VASEYS PARADISE, GRAND CANYON, ARIZONA: FINAL REPORT

By

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Submitted to

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

An experimental high flow was conducted to determine the extent to which planned flooding can be used to maintain large, open sandbars in Glen and Grand canyons in Arizona. Potential ecological impacts of this planned flood on federally endangered species resulted in the U.S. Fish and Wildlife issuance of a Biological Opinion, including a program of research and monitoring. The endangered Kanab ambersnail (Succineidae: *Oxyloma haydeni kanabensis*) occurs only at two springs in the Southwest, one of which is Vaseys Paradise (VP) at Colorado River mile 31.5R. Recognizing that the test flow experiment would result in incidental take of this species and its habitat, we conducted a cooperative, interagency analysis of flood impacts on this snail population.

1) We topographically surveyed VP before and after the high flow event, and monthly through the 1996 growing season. We surveyed the rising hydrograph, including the 45,000 cfs (1275 m^3/s) stage elevation. We estimated that 163.7 m^2 of potential KAS habitat existed downslope of the estimated 45,000 cfs + 1.5' (1275 m^3/s + 0.5m) stage, including 97.8 m^2 of *Mimulus cardinalis* (cardinal monkeyflower) and 48.5 m^2 of *Nasturtium officinale* (watercress). We determined that 119.4 m^2 of KAS habitat existed downslope of the actual 45,000 cfs stage, including 66.2 m^2 of *Mimulus* and 38.0 m^2 of *Nasturtium*.

The flood scoured 54% of the flood zone vegetation, but virtually no suitable KAS habitat remained in April 1996. Following the flood, we surveyed 55.0 m^2 of KAS habitat in the inundated zone, including 14.4 m^2 of *Mimulus* and 14.2 m^2 of *Nasturtium*. Thus, 46% of primary KAS habitat remained in the flood zone, and it had been severely damaged by high velocity, debris-laden flows.

2) We surveyed KAS habitat area before, after, and monthly through the growing season for one year after the flood. Vegetation recolonization of the lower zone (downslope from the 45,000 cfs stage) was slow in the 1996 growing season. Low zone cover of *Mimulus* decreased from 66.2 m^2 on 22 March to 14.4 m^2 on 18 April, and to 13.2 m^2 on 15 June, and then increased to 24.5 m^2 on 16 September and to 26.4 m^2 on 24 October 1996. Low zone cover of *Nasturtium* decreased from 38.0 m^2 on 22 March to 14.2 m^2 on 18 April, and then increased from 14.0 m^2 on 15 June, to 18.5 m^2 on 16 September, to 24.8 m^2 on 24 October. Total KAS primary habitat cover was reduced by the test flow from 104.2 m^2 to 28.5 m^2 (a 72.6% reduction), and increased to 51.3 m^2 (49.2% of the pre-flood vegetated area) by the end of the 1996 growing season in late October. Normal cold conditions in the 1996-97 winter and a late winter, month-long constant discharge of 27,000 cfs resulted in die-back of overall KAS habitat below the 45,000 cfs stage to 53 m^2, with 16.6 m^2 of *Mimulus*, 1.2 m^2 of *Nasturtium*.

3) We sampled a total of 189 10 to 30-cm-diameter plots and total patches before the flood and estimated that 3,011 KAS existed below the predicted 45,000 cfs + 1.5' stage, and were at risk to loss during the flood. We subsequently estimated that 2,126 KAS existed below the actual 45,000 cfs stage.

All KAS existing below the 45,000 cfs flood stage were believed to have been lost. Loss of KAS was attributed to drowning as KAS were swept from the vegetation by water or floating debris. Based on 96 20-cm-diameter plots and total patch counts from the 18 April post-flood population survey, we estimated that 420 KAS existed downslope from the actual 45,000 cfs stage three weeks after the test flow. We observed that several KAS had recolonized a *Nasturtium* patch just below the 45,000 cfs stage by 18 April 1996.

We monitored the recovery of the KAS population through the 1996 growing season in the flood zone (< 45,000 cfs stage). Monthly KAS population surveys for these same habitat patches revealed that the KAS population decreased from: 420 in April, to 391 on 19 May, to 104 on 15 June,

to 439 on 20 July during emergence of young from egg sacks, to 268 on 16 September. KAS were largely in dormant condition in October, and the population was not surveyed. The high initial population levels were attributed to the exceptionally warm, mild 1995-96 winter, which permitted KAS to be active early in the spring and which resulted in two peaks of reproduction. The normal, cold 1996-97 winter and 27,000 cfs constant flows reduced the estimated KAS population existing in the flood zone to 245 snails in March 1997.

4) We found that the STARS model (Randle and Pemberton 1988) estimate of the 45,000 cfs stage was extremely close to that actually surveyed during the flood. We surveyed the rising hydrograph and 45,000 cfs stage during the flood, and constructed a refined stage-to-discharge relationship at VP.

5) We assessed sampling methodologies for determining KAS population size by sampling circular 10-, 20-, 30-, and 50-cm-diameter plots, and by destructively sampling primary habitat plots lying downslope from the estimated 45,000 cfs + 1.5' stage after they had been initially surveyed for KAS. This analysis revealed that the proportion of KAS missed in initial surveys increased with plot diameter in *Mimulus*, but not in *Nasturtium*. In *Mimulus*, complete harvesting of 20-cm-diameter plots following the initial survey added, on average, 0.22 KAS/m², a 38.6% increase. In *Nasturtium*, follow-up harvesting added, on average, 0.35 KAS/m² (a 28.4% increase).

Time expenditure and stem breakage while searching 50-cm plots were prohibitive and the 10-cm plots were too small to allow for a well-defined sampling perimeter. Stem breakage increased 2.1-fold on *Mimulus* and 4.0-fold in *Nasturtium* on 30-cm-diameter plots as compared to 20-cm- diameter plots. From these analyses, we still favor the use of 20-cm-diameter study plots, but we recognize that we may underestimate KAS abundance by as much as one-third.

6) We conducted behavioral observations on 254 snails in 1996 and noted net and total distance moved, behavior, substrate use, interactions with other invertebrates, and measured snail shell length. Movement rates were strongly right-skewed; many snails were immobile during observations, and fewer than 5% moves more than 1 cm/min. Relationships between movement rates and month, time of day, and host plant were complex, and not clearly related to temperature or light conditions.

Forty-three snails were resighted after marking during the 1996 field season. Of these, 11 had changed patches (25%), and 4 of these (9%) had changed vegetation type. Growth rates estimated from these snails averaged 2.1 mm/month.

Eighty-nine KAS marked with bee-dots or fingernail polish and then released were found dead, as empty shells. We conducted caged predator experiments with *Catinella* species and various potential invertebrate predators and concluded that invertebrates were not a major source of KAS mortality in March 1996. We believe many of the KAS found dead after marked release were preyed upon by *Peromyscus maniculatus* and *P. crinitus*. High *Peromyscus*-related mortality may be attributed to naturally high densities and possibly local enhancement of snail densities because we initially released marked snails in small groups around patch margins. *Peromyscus crinitus* and *P. maniculatus* were the only rodents captured at VP in 1996 and 1997. A *Spermophilus spilosoma* was repeatedly seen near the site during the day, but was not observed engaged in KAS predation. Mammal trapping success of the two mice in KAS habitat patches was highest in April 1996 (18.8%), and decreased to 0% by 20 July, then increased in September to 9.7%, and slightly further in March 1997 (10.5%). This pattern generally follows seasonal abundance patterns of large KAS. However, no traces of KAS radulae were detected in approximately 30 *Peromysus* fecal pellets examined in the laboratory. Mouse diet was found to consist of vegetation and various arthropods, and appeared to be consistent between vegetation types and different sampling periods. These results do not support the contention that *Peromyscus* is a major predator on KAS.

In 1996 only a single KAS was found expressing sporocysts of *Leucochloridium cyanocittae*. This represents nearly an order of magnitude decrease in parasitism between 1995 and 1996.

7) The FWS Biological Opinion on the test flow originally requested that the Bureau of Reclamation move 90% of the KAS occurring downslope from the 45,000 cfs +1.5' stage to higher elevation primary habitat at VP. Subsequently, the FWS requested that technicians leave some flood zone KAS habitat by gleaning 50% of the primary flood zone habitat, and removing 75% of the KAS from that vegetation (FWS Memorandum, March 1996). We marked 1,275 KAS and moved them upslope from the estimated 45,000 cfs +1' stage during the week prior to the high flow event. Using the unadjusted 20-cm-diameter plot analysis, this number represented 40.8% of the total KAS population that existed downslope from the 45,000 cfs + 1.5' stage, 105 more KAS than the 1,170 KAS which the revised FWS Opinion requested be relocated. Given the seasonal variability of population size change for this species, and the low wintertime densities, no impacts of increased population were anticipated or detected from this mitigation activity.

KAS host plants readily grew in the Northern Arizona University greenhouse, an important consideration for establishment of secondary populations. The Arizona Game and Fish Department is developing suitability criteria for secondary population establishment. We recommend at least bi-monthly monitoring of this population during the growing season.

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INTRODUCTION

Project Overview

We conducted a cooperative, interagency analysis on the impacts of a high flow experiment from Glen Canyon Dam, as well as population changes for one year after the march/April 1996 Bureau of Reclamation test flood, on the Vaseys Paradise population of endangered Kanab ambersnail (KAS; SUCCINEIDAE: *Oxyloma haydeni kanabensis* Pilsbry). The experimental high release (45,000 cfs = 1,275 m^3/s from 26 March to 2 April 1996) was expected to inundate and potentially scour 11 to 16% of available KAS habitat, and to eliminate an equally high proportion of the KAS population there (Stevens et al. 1997). Information on immediate and longer-term responses of KAS and its habitat to the high flow event, as well as additional autecological and synecological KAS data, are needed to resolve KAS recovery and management issues related to future dam operations. This study provides the Bureau of Reclamation (BOR), the National Park Service (NPS), the Fish and Wildlife Service (FWS), Arizona Game and Fish Department (AGFD), and other interested parties with ecological information on short and long-term flood impacts on this endangered species.

KAS population monitoring and research is complicated by a number of physical and statistical constraints (Stevens et al. 1997). The cryptic morphology of KAS, steep topography of Vaseys Paradise, dense cover of poison ivy (*Toxicodendron rydbergii*), fragile host plants, and the snail's behavioral ecology all influence sampling design, and the associated precision and accuracy of population estimation. Vaseys Paradise is only accessible via a rugged trail from a remote North Rim location, or by a 1-2 day river trip from Lees Ferry, Arizona. At Vaseys Paradise, KAS avoid open areas, preferring decadent or dead *Mimulus cardinalis* stems and any portion of living *Nasturtium officinale* canopies. The stems of these primary host plant species are fragile and break easily during population surveys, making non-destructive sampling difficult. Many of the primary host plant patches lie on steep bedrock walls and are surrounded by dense stands of poison-ivy, thus access is limited and sampling is perilous. These issues make the study of KAS difficult, and require carefully trained field staff.

This report presents analyses of data collected during the 1996 growing season and March 1997. It constitutes an assessment of flood impacts, with one full year of post-flood monitoring of KAS habitat and population recovery.

Project Objectives

The following flood impacts study components were designed through discussions with the BOR, FWS, NPS and AGFD to aid in risk and impact assessment, population monitoring and recovery: (1) sampling protocol assessment and validation; (2) obligatory short-term studies based on Endangered Species Act (ESA) and the FWS Biological Opinion requirements; (3) studies to be used for longer-term (one-yr) assessment of test flow impacts, and KAS management and recovery (also required by the ESA); (4) ancillary studies that assist in (1) or (2); and (5) studies required by AGFD for the FWS Section 6 Cooperative Agreement and that help resolve issues in (1), (2) or (3).

The study objectives were organized into the following outline.

	Study Component
1. High flow impacts on KAS habitat	
a. Determine potential primary habitat loss due to the high flow experiment	1,4
b. Determine actual primary habitat loss due to the high flow experiment	1,4
c. Determine the mechanism(s) of habitat loss during the high flow experiment	2
d. Determine the mechanisms and recovery rate of primary KAS habitat after the test flow	2
e. Determine historic development of KAS habitat, particularly water-cress colonization	3

2. High flow impacts on the KAS population — Study Component
    a. Determine the proportion of the KAS population at risk to loss during the high flow experiment 1,4
    b. Determine the proportion of the KAS population lost during the high flow experiment . . 1,4
    c. Determine the mechanisms of KAS loss due to high flow experiment 2-4
    d. Determine KAS population recolonization for six months post-flood 2,3

3. Sampling and population surveying protocol assessment
    a. Refine stage-discharge relationship at VP 1,4
    b. Determine the accuracy of KAS density measurements 1
    c. Determine the effects of plot size on habitat impacts 1
    d. Determine species-area effects of plot size on KAS population estimation 1
    e. Compare KAS distribution and population estimation analytical techniques 1

4. Behavior studies
    a. Determine the most appropriate marking technique for KAS survivorship and movement studies 5
    b. Develop a KAS ethogram 2-4
    c. Determine movement behavior in relation to the high flow 2-4
    d. Determine survivorship of marked and moved *versus* resident KAS 2-5
    e. Determine activity budgets and habitat use of resident and immigrant KAS throughout the growing season 2-4
    f. Determine KAS diet through the 1996 growing season 2-5
    g. Observe interactions between KAS, parasites, potential competitors and potential predators 2-5

5. Recovery and long-term studies
    a. Determine potential for growing KAS primary host plant species in controlled environments 2-5
    b. Determine use of alternate host plant food sources 2-5
    c. Move low-zone KAS to non-inundated habitat at VP 2-5
    d. Determine the fate of moved KAS 2
    e. Investigate comparable habitats in Grand Canyon for possible introduction sites 2,4

BACKGROUND

The KAS is a federally endangered succineid landsnail that occurs at two springs in the southwestern U.S. (Pilsbry and Ferriss 1911, Pilsbry 1948, Spamer and Bogan 1993): Three Lakes (near Kanab, UT), and Vaseys Paradise (VP, Colorado River mile 31.5 in Grand Canyon, Arizona). This taxon has also been reported from Alberta, Canada (Harris and Hubricht 1982). KAS was proposed for emergency listing as an endangered species by the U.S. Fish and Wildlife Service in 1991 (England 1991a, 1991b), and was subsequently listed (Anonymous 1992, England 1992). A recovery plan has been approved for this taxon (U.S. Fish and Wildlife Service 1995). Two KAS populations formerly occurred in the Kanab area, but one population was extirpated by desiccation of its habitat. The remaining Utah population at Three Lakes occurs at several, small spring-fed ponds on cattail (*Typha* spp.; Clarke 1991). The Three Lakes site is privately-owned and the land owner is developing the property.

KAS were first collected at VP in 1991 (Blinn et al. 1992; Spamer and Bogan 1993), and an interagency team lead by the Bureau of Reclamation examined KAS ecology there in 1994 and 1995 (Stevens et al. 1997). KAS occurs primarily on two host plant species at VP: native *Mimulus cardinalis* and non-native *Nasturtium officinale*. VP is a popular water source and attraction site for Colorado River runners. Anthropogenic impacts are limited by the dense cover of poison ivy and the nearly vertical terrain: Grand Canyon National Park recommends that river runners remain at least 5 ft from vegetation. Within Grand Canyon, KAS apparently is restricted to VP in Grand Canyon: no KAS were observed at 81 other Grand Canyon springs surveyed from 1991 to 1995 by Stevens et. al. (1997). Rematched historic photographs of VP (e.g. Turner and Karpiscak 1980:58-59) reveal that cover of the two host plant species has increased greatly at lower stage elevations since the completion of Glen Canyon Dam in 1963. The timing of KAS colonization of this post-dam vegetation is unknown, so we cannot determine the rate at which increased vegetation cover increased KAS habitat.

Topographic surveys in 1995 revealed rapid changes in vegetation cover over the growing season, with 5.9% to 9.3% of the primary habitat occurring below the 940 m^3/s (33,000 cfs) stage, and 11.1% to 16.1% occurring below the 45,000 cfs stage (Stevens et al. 1997). The total area of primary habitat was 0.09 ha, and the area of secondary habitat (patches of riparian vegetation that are not dominated by *Mimulus* or *Nasturtium*, and are little used by KAS) was also 0.09 ha, for a total vegetated area of the spring of 0.18 ha in June 1995.

The total estimated KAS population at VP in March 1995 rose from 18,476 snails to as many as 104,000 snails in September 1995. Reproduction took place in mid-summer (Stevens et al. 1997). The estimated proportion of the KAS population occurring below the 33,000 cfs (940 m^3/s) stage rose from 1.0% in March to 7.3% in September; proportions occurring below the 45,000 cfs stage were 3.3% in March, 11.4% in June and 16.4% in September 1995.

Colonization of VP by non-native *Nasturtium* before 1938 (Clover and Jotter 1944), and construction of Glen Canyon Dam, increased the primary KAS habitat area by more than 40%, and probably resulted in an increase in the snail population (Stevens et al. 1997). The KAS population and habitat at Vaseys Paradise apparently survived and recovered from innumerable flows much larger than the planned during the pre-dam era, and this species survived a total of six flows $\geq$ 45,000 cfs during the post-dam era (in 1965, 1980, 1983-1986). Short-term reduction in primary habitat area by scouring flows was not predicted to jeopardize the existence of KAS; however, the FWS Biological Opinion required analysis of direct and long-term flood impacts on this isolated population.

METHODS, RESULTS, AND DISCUSSION

Study Area

Vaseys Paradise is a cool-water, dilute dolomitic spring that issues from the Mooney Falls member of the Mississippian Redwall Limestone 0.4 mi (0.9 km) downriver from the mouth of South Canyon in Grand Canyon National Park, 31.5 mi (51 km) downstream from Lees Ferry, Arizona (Huntoon 1974). The spring issues at 3200 ft (925 m) elevation from three primary mouths and divides into several large, and numerous small, rivulets as it flows ca. 100 yd (90 m) m to the Colorado River. The climate is arid and continental, with a mean annual precipitation of 5.5 (140 mm) inches at Lees Ferry, the nearest weather station (Sellers and Hill 1974). Precipitation is bimodally distributed between summer and winter. Temperatures at Lees Ferry range from <0°F in winter to >110°F in summer. Although the east-facing aspect of the spring allows it to thaw relatively quickly after freezing winter nights, Stevens (personal observation) noted that the spring was nearly completely frozen and covered with ice during freezes in early January 1975 and December 1990. Aspect also protects the spring site from hot, direct mid-afternoon sunlight during summer. Vaseys Paradise lies in the U.S. Bureau of Reclamation Glen Canyon Environmental Studies Program's (GCES) Geographic Information System (GIS) Reach 3 and is therefore well georeferenced for long-term monitoring.

OBJECTIVE 1: Measure High Flow Impacts on KAS Habitat.

1a. Determine potential primary habitat loss due to the high flow experiment.

Methods

We assessed potential KAS habitat loss using the methods of Stevens et al. (1997). The perimeters of all habitat patches lying downslope from the approximate 60,000 cfs (1700 m^3/s) stage elevation (the "low zone" of Stevens et al., 1997) were surveyed on 18-19 March 1996. Vegetation patches were resurveyed in April 1996 (post-flood), and approximately bimonthly during the remainder of the 1996 growing season (April-October; Table 1). Low level oblique photography of VP was collected in March (pre-flood and during flood), April (post-flood), and November 1996. Land surveys were conducted with a total station/prism combination, and mapping accuracy was consonant with the GCES survey protocol. The GCES GIS provided control network points (Arizona State Plane, Central Zone), which were used for instrument and backsight stations. This reference datum allowed accurate spatial referencing of map data, and provided suitable georeferencing for GIS analyses and future monitoring.

Surveyed elevation data were related to the stage-to-discharge model developed for the mainstream at Vaseys Paradise, which was based on the Bureau of Reclamation STARS hydraulic model (Randle and Pemberton 1988). A triangulated irregular network (TIN) topographic model of the low zone was produced by Stevens et al. (1997). The STARS-generated stage-to-discharge model was applied to the 1994 TIN model data, allowing us to conduct hypsometric analyses of the rectified area of vegetation above the estimated 45,000 + 1.5' stage prior to the high flow event. The stage-to-discharge relationship was validated using leveling surveying during the flood and in association with Objective 3a activities. We identified the area lying below the estimated 45,000 cfs stage, and allowed for an additional 1.5 ft. (0.5 m), the error margin suggested by Mr. Timothy Randle (U.S. Bureau of Reclamation, personal communication), and recommended as a safety measure by the FWS (FWS Memorandum 1996).

Table 1: List of trip dates, objectives and staff for KAS monitoring in 1996 and 1997.

DATE	STAFF	OBJECTIVES
960229	LES,VJM,FRP	Equipment drop-off and VP reconnaissance.
960319-0401	LES,VJM,FRP,JAS,CN, (R. Noonan)	Pre-flood habitat and population surveys; VP Q and WQ, KAS preflood photogrammetry, marking/moving expts; genetics collections; during flood inundation experiments; pre-flood topographic surveys and during flood stage discharge measurement; pre-flood population estimation.
960416-18	LES,VJM,CN,FRP,DK,JAS Debra Bills	Post-flood habitat and population surveys; KAS marking and behavior; rodent trapping; postflood topography; VP discharge and WQ measurements; post-flood photogrammetry.
960518-20	LES,VJM,JAS,CN, E. Baldwin	May 1996 population survey; behavioral observations; rodent trapping; patch descriptions.
960615-17	LES,VJM,JAS,JN, P. Lewis, E. Baldwin, J. Rys	June 1996 population survey; behavioral observations; rodent trapping; patch descriptions.
960719-20	LES,CN,JAS, H. Johnstone	July 1996 population survey; behavioral observations; rodent trapping; patch descriptions.
960826-27	JAS,CN	August 1996 population survey; behavioral observations; patch descriptions.
960915-16	LES,VJM,CN,JAS, K.Buck, G.Nabhan, D. Martin	Sept. population survey; behavioral observations; rodent trapping; patch descriptions
961023-24	LES,VJM,JAS,CN, J.Hazel	Oct. 1996 population survey; behavioral observations; rodent trapping; patch descriptions.
961115	LES	Nov. 1996 photogrammetry.
970316-17	LES,VJM,JAS,CN	March 1997 population survey; behavioral observations; rodent trapping; patch descriptions.

Results

We topographically surveyed VP before and after the high flow event, and approximately bimonthly, thereafter (Figs. 1-6) and surveyed the rising hydrograph, including the 45,000 cfs stage. The STARS model predicted the 45,000 cfs stage quite accurately, only differing by a few centimeters from the stage measured during the flood.

Using preliminary pre-flood habitat area data, we estimated in the field that 130.3 m^2 of vegetation cover existed downslope of the 45,000 cfs + 1.5' stage, including 97.8 m^2 of *Mimulus* and 48.5 m^2 of *Nasturtium* (Figure 1, Table 2-3). These latter two species have been defined as primary host plant species for KAS at VP, however KAS occur sparingly on other wetland species (e.g., *Carex aquatilis*, *Polygonum amphibium*, *Dicanthelium languinosum*, *Phragmites australis* and *Equisetum* spp.) which we have grouped under "Other" for these analyses.

Our mitigation efforts were based on the preliminary pre-flood habitat analysis. We subsequently refined those estimates using the full range of data collected prior to the flood (Table 3). This more refined analysis revealed that 163.7 m^2 of vegetation cover existed downslope from the estimated 45,000 cfs +1.5' stage, including 97.8 m^2 of *Mimulus* and 46.6 m^2 of *Nasturtium*. Lastly, we used the observed 45,000 cfs stage elevation (measured during the flood) and determined that 119.4 m^2 of vegetation cover existed downslope of the observed 45,000 cfs stage, including 66.2 m^2 of *Mimulus* and 38.0 m^2 of *Nasturtium* (Table 4).

1b. Determine actual KAS habitat loss due to the high flow experiment.

We measured KAS habitat loss by comparing surveyed habitat in the <45,000 cfs stage before and after the high flow event (Tables 4 and 5, respectively), in comparison with changes during the 1996 growing season (Tables 6-11). We found 55.0 m^2 of vegetation in the flood zone in April 1996, including 14.4 m^2 of *Mimulus* and 14.2 m^2 of *Nasturtium*. Thus, the flood scoured 75.6 m^2 of primary KAS habitat, leaving only 27.4% of the pre-flood cover. The remaining vegetation had been severely damaged by high velocity, debris-laden flows, and <10 m^2 of the remaining habitat appeared suitable for KAS in mid-April. The pre-flood topographic survey showed 119.4m^2 of potential KAS habitat lying below the 45,000 cfs stage, and 199.9 m^2 lying between the 45,000 and ca. 70,000 cfs stages. Using the November 1994 measurement of 759.6 m^2 of *Mimulus* and *Nasturtium* habitat above the 1275 m^3 stage, this final analysis suggests that 13.6 % of potential KAS habitat was inundated, with only 1.1% persisting in suitable condition after the flood.

Patch 203M&N and a portion of Patch 5M had been left intact as controls (no destructive sampling), and we observed that those patches were completely scoured by the high flow up to the 45,000 cfs stage elevation. Small portions of root mass remained in patches P5M, P7L, P8M, P11PE, and P10M below the 45,000 cfs stage, where the vegetation was protected by bedrock or large boulders (Table 5); however, the viability of remaining root masses was unknown. Close-range oblique site photographs also document these changes.

Figure 1.

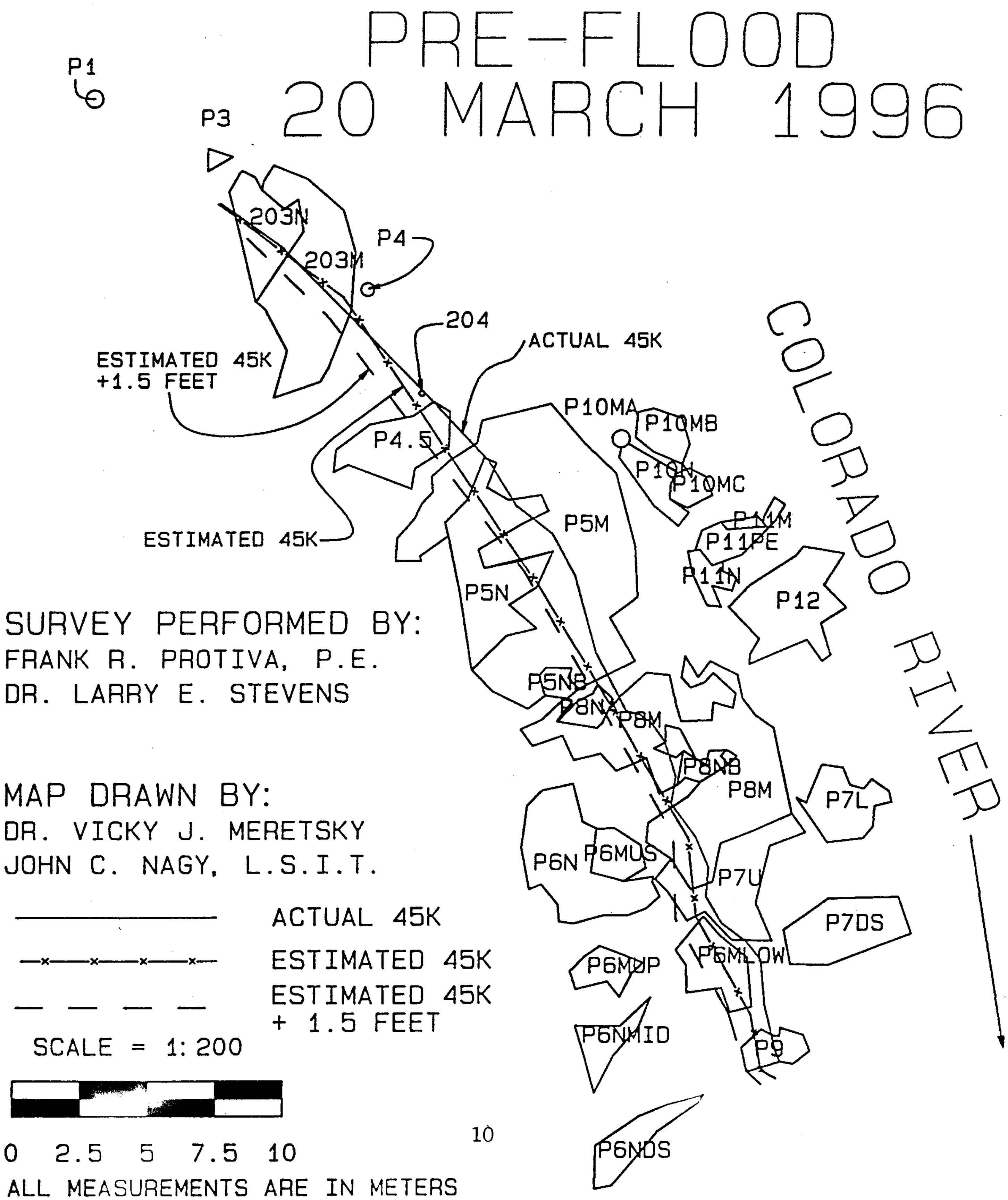

PRE-FLOOD
20 MARCH 1996
P1
P3
203N
203M
P4
204
ESTIMATED 45K
+1.5 FEET
ACTUAL 45K
P4.5
ESTIMATED 45K
P10MA
P10MB
P10N
P10MC
P5M
P11M
P11PE
P11N
P12
P5N
COLORADO RIVER
SURVEY PERFORMED BY:
FRANK R. PROTIVA, P.E.
DR. LARRY E. STEVENS
P5NB
P8N
P8M
P8NB
P8M
P7L
MAP DRAWN BY:
DR. VICKY J. MERETSKY
JOHN C. NAGY, L.S.I.T.
P6N
P6MUS
P7U
ACTUAL 45K
ESTIMATED 45K
ESTIMATED 45K
+ 1.5 FEET
P7DS
P6MUP
P6MLOW
SCALE = 1:200
P6NMID
P9
P6NDS
0 2.5 5 7.5 10
ALL MEASUREMENTS ARE IN METERS

Figure 2.

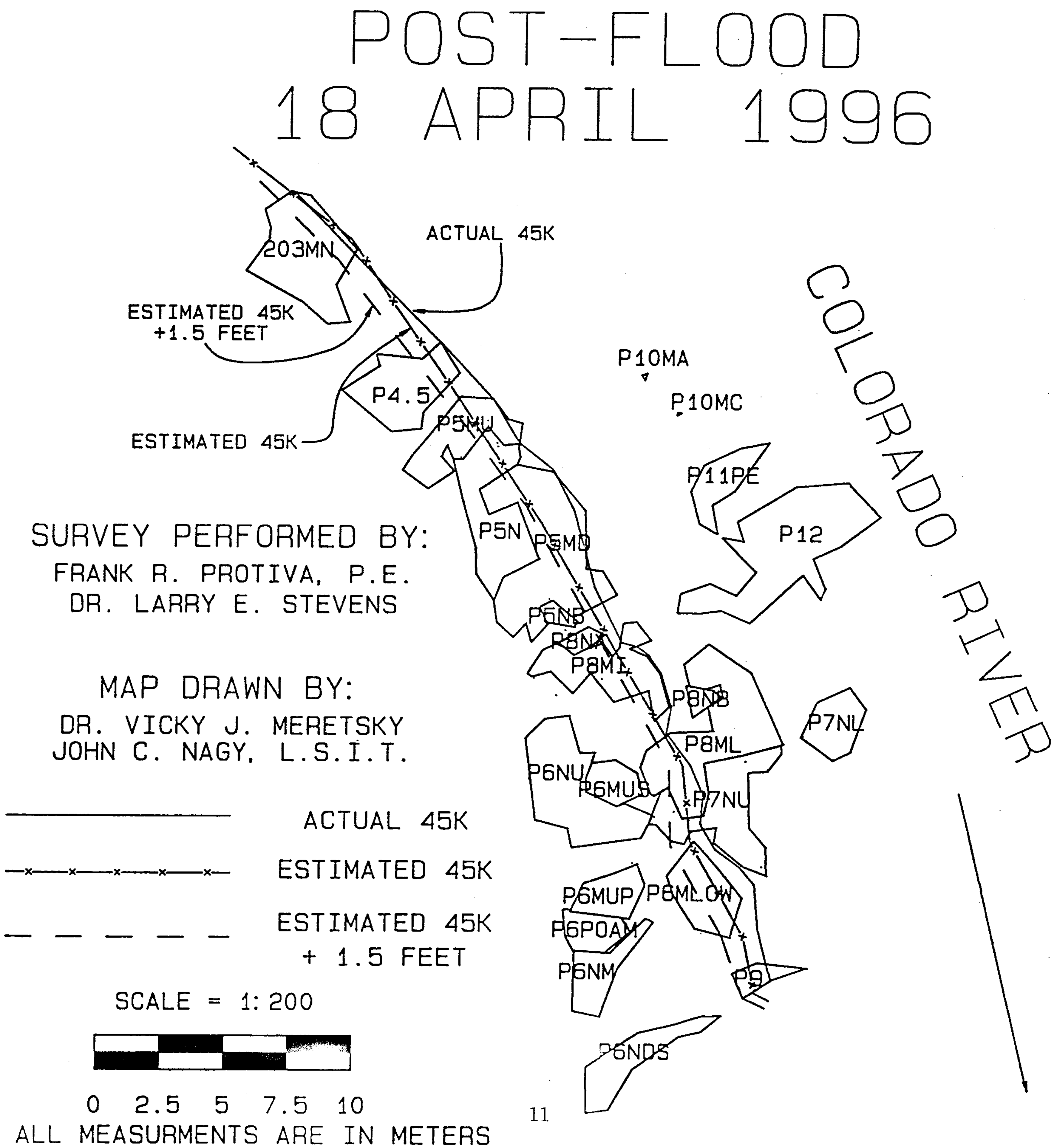
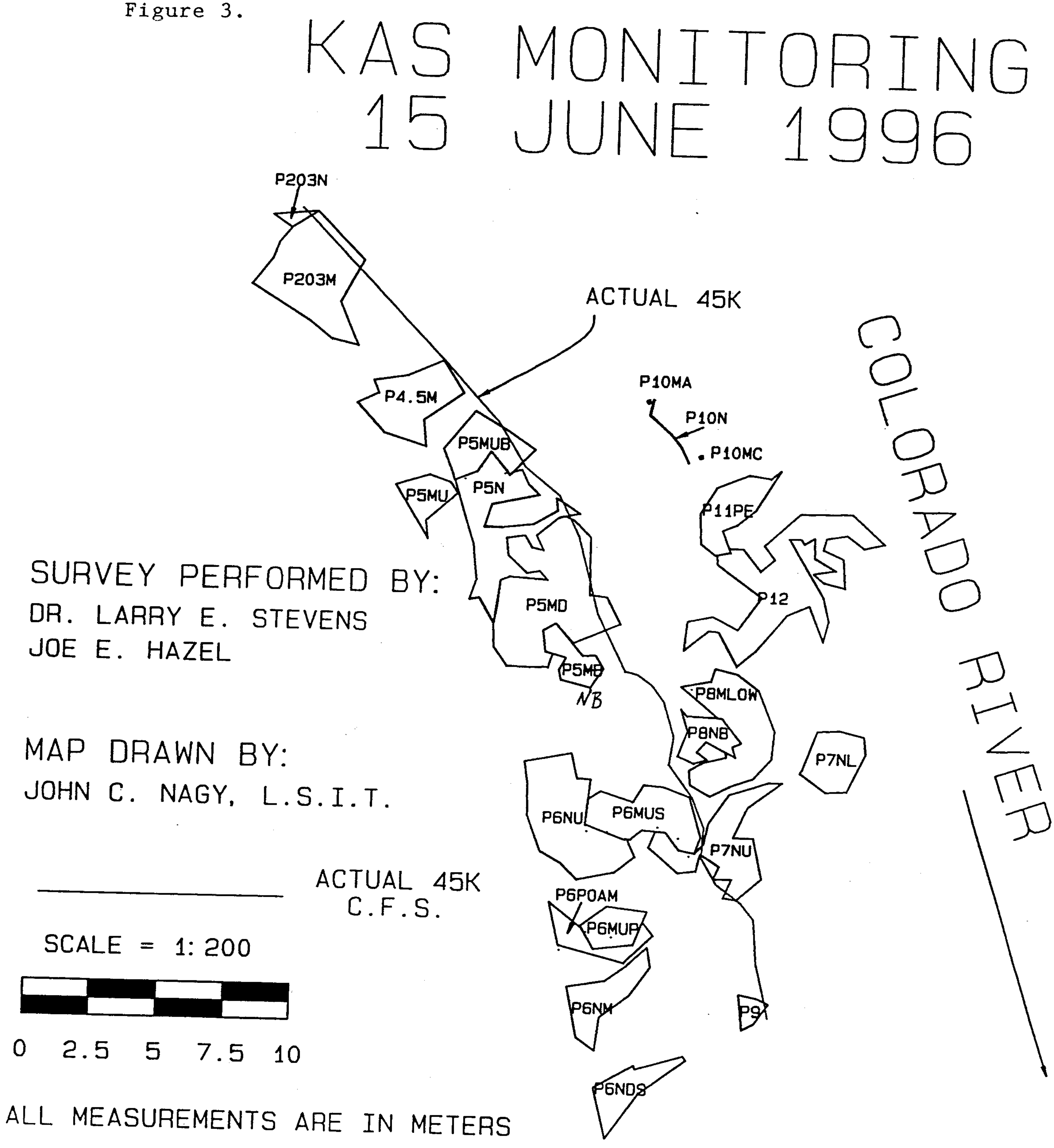

POST-FLOOD
18 APRIL 1996
ACTUAL 45K
203MN
ESTIMATED 45K
+1.5 FEET
ESTIMATED 45K
P4.5
P5MU
P10MA
P10MC
COLORADO RIVER
P11PE
P12
P5N
P5MD
SURVEY PERFORMED BY:
FRANK R. PROTIVA, P.E.
DR. LARRY E. STEVENS
P6NB
P8NX
P8MI
MAP DRAWN BY:
DR. VICKY J. MERETSKY
JOHN C. NAGY, L.S.I.T.
P8NB
P7NL
P8ML
P6NU
P6MUS
P7NU
ACTUAL 45K
ESTIMATED 45K
ESTIMATED 45K
+ 1.5 FEET
P6MUP
P6MLOW
P6POAM
P6NM
P9
SCALE = 1: 200
P6NDS
0 2.5 5 7.5 10
ALL MEASURMENTS ARE IN METERS

Figure 3.


KAS MONITORING
15 JUNE 1996
P203N
P203M
ACTUAL 45K
P10MA
P10N
P10MC
P4.5M
P5MUB
P5N
P5MU
P11PE
P12
COLORADO RIVER
SURVEY PERFORMED BY:
DR. LARRY E. STEVENS
JOE E. HAZEL
P5MD
P5MB
NB
P8MLOW
P8NB
P7NL
MAP DRAWN BY:
JOHN C. NAGY, L.S.I.T.
P6NU
P6MUS
P7NU
ACTUAL 45K
C.F.S.
P6POAM
P6MUP
SCALE = 1: 200
0 2.5 5 7.5 10
P6NM
P9
P6NDS
ALL MEASUREMENTS ARE IN METERS

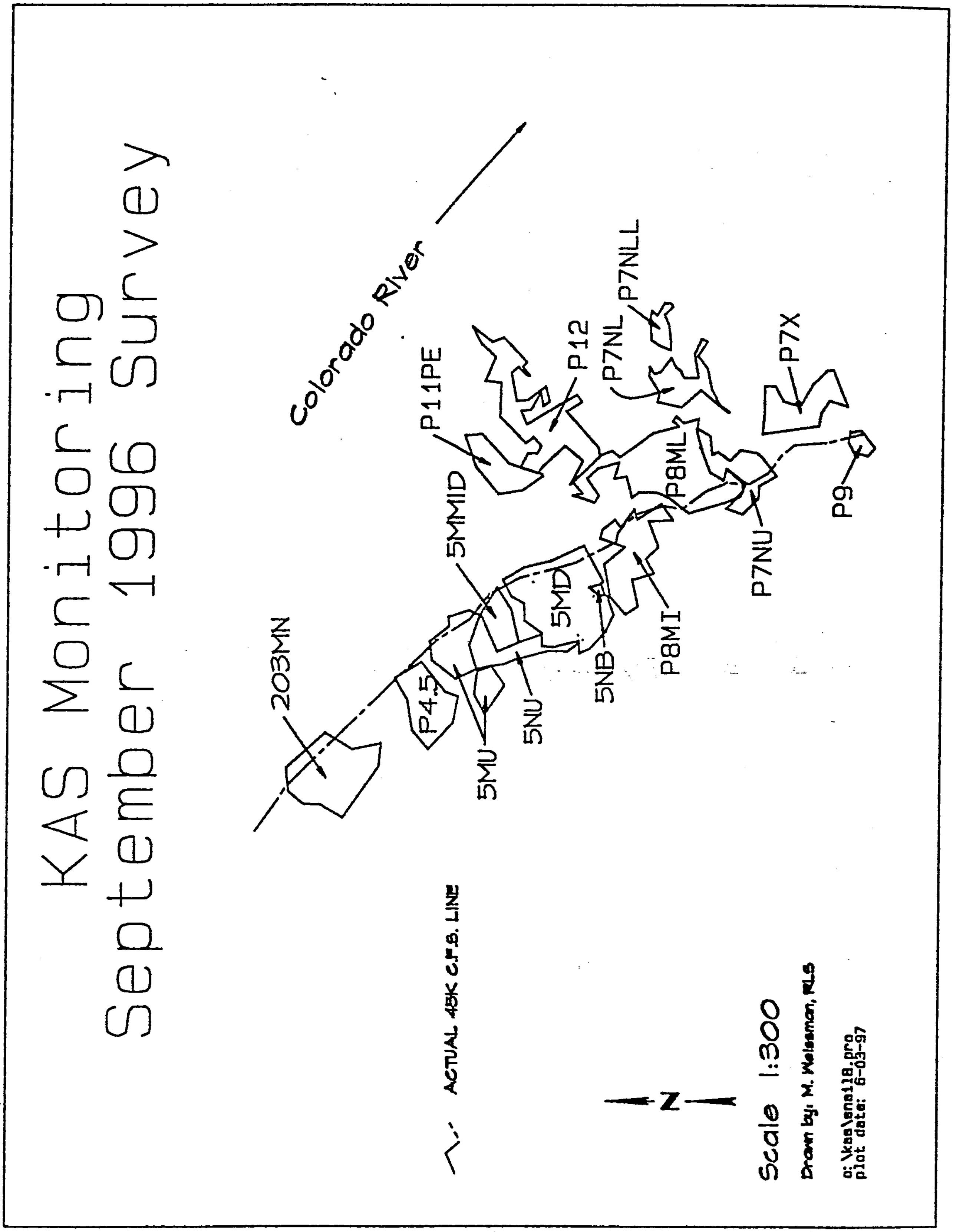


Figure 4: September 1996 KAS habitat survey at Vaseys Paradise.

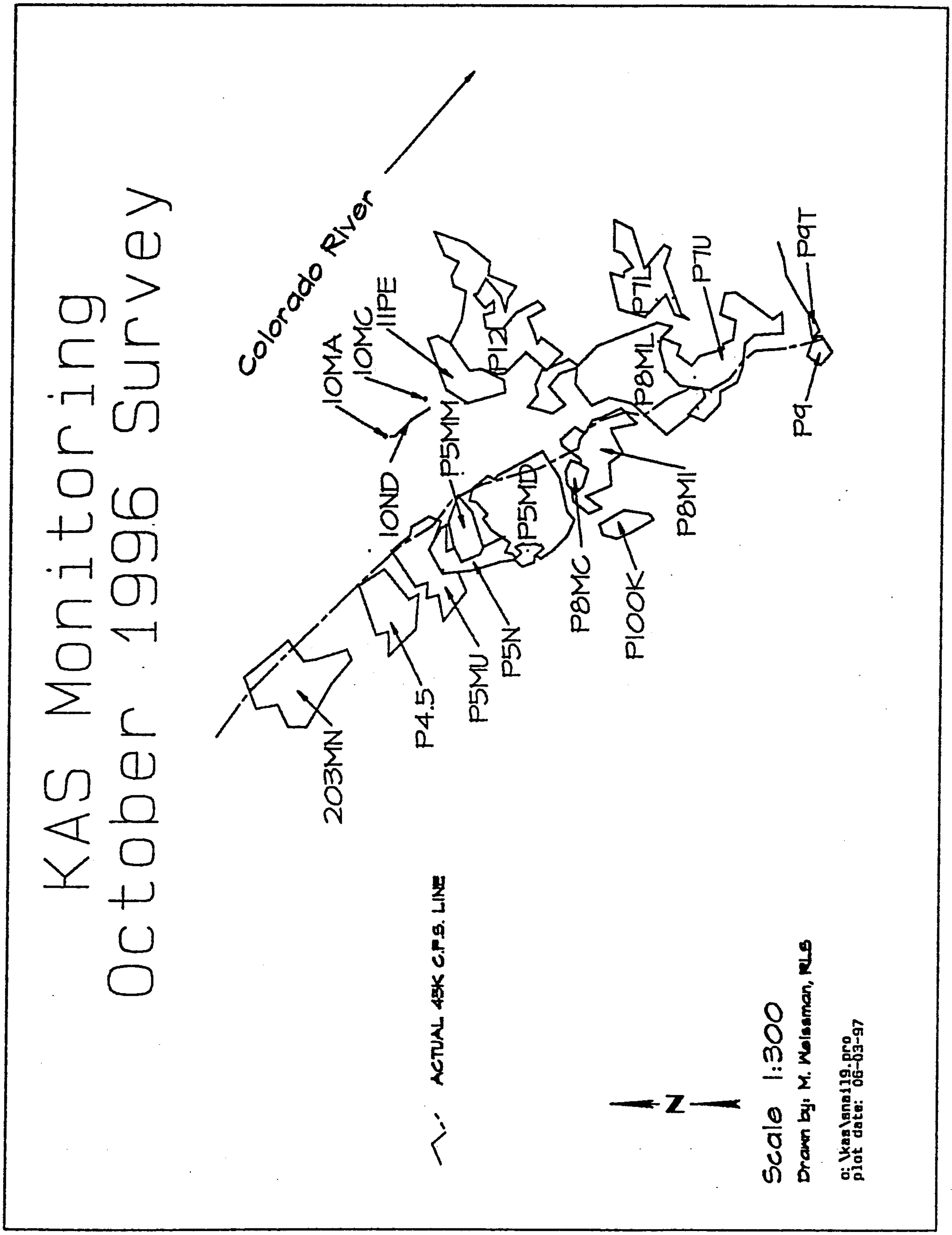


Figure 5: October 1996 KAS habitat survey at Vaseys Paradise.

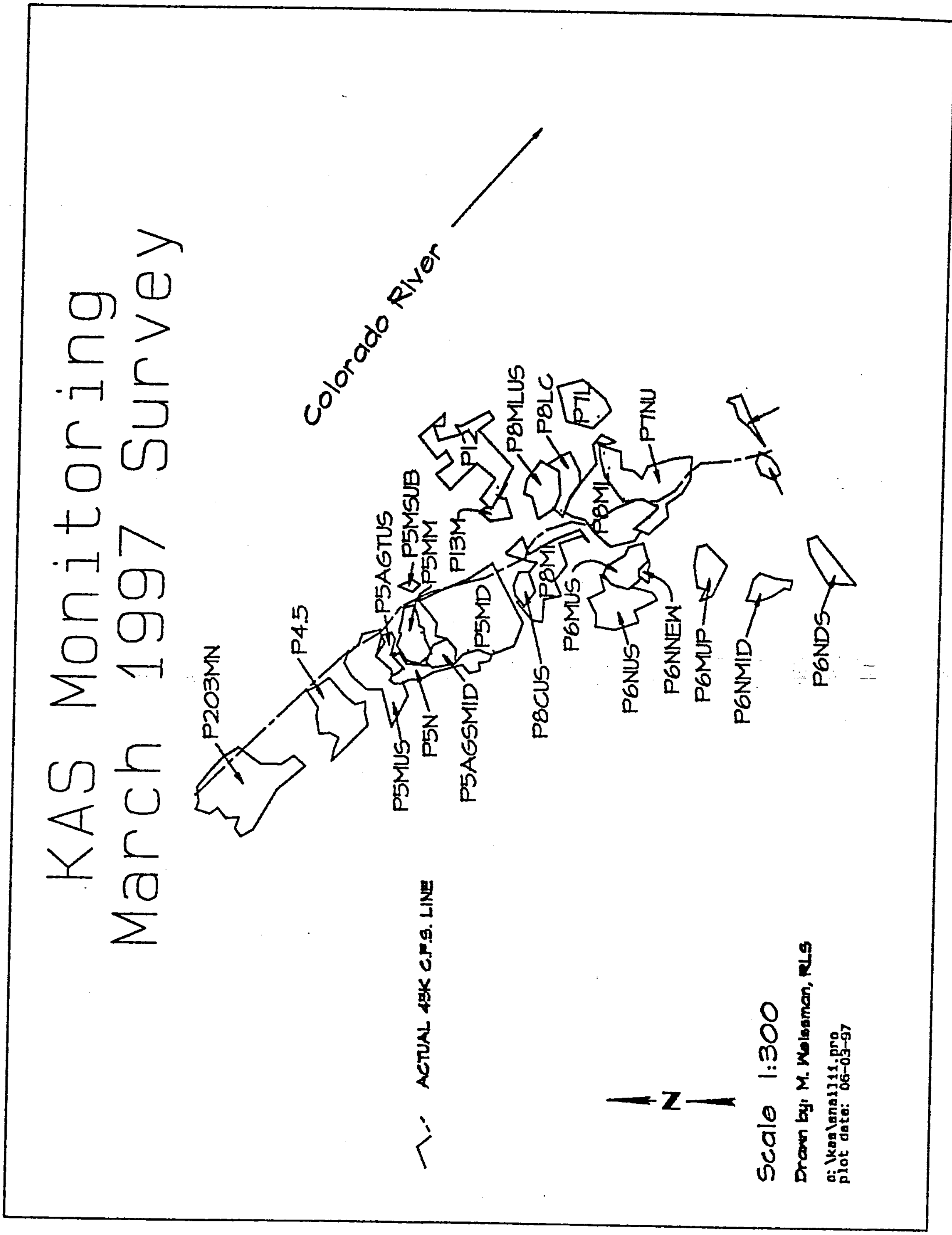


Figure 6: March 1997 KAS habitat survey at Vaseys Paradise.

Table 2. In-field estimate of the KAS population below the estimated 45,000 cfs + 1.5' stage on 22 March 1996.

PatchID	Plant sp.	<45k +1.5' Area (m2)	No. of 20cm Diam Plots	20cm Raw Mean KAS/m2	Estimated No. of KAS <45k+1.5'
P203M	Mica	12.81	6	15.9	204
P5M	Mica	39.75	8	17.8	708
P6MLower	Mica	4.97	4	27.6	137
P8M	Mica	18.882	23	31.5	594
P10M	Mica	5.11	All	17.8	91
P203N	Naof	6.66	6	31.8	212
P5N	Naof	4	8	31.8	127
P7Lower	Naof	6.64	8	23.4	155
P7Upper	Noaf	11.43	10	31.8	364
P7Dnstrm	Naof	9.12	All	5.5	50
P8N	Naof	1.94	All	31.8	62
P9N	Naof	3.37	7	54.4	183
P10N	Naof	3.33	9	23.4	78
P11N	Naof	1.94	9	23.4	45
P1	Dila	0.33	All	0.0	0
TOTAL	**All**	**130.282**	**102**	**29.5**	**3011**

Table 3. Recalculation (out of field) of estimated pre-flood KAS habitat and population size below the 45,000 cfs + 1.5' stage, 22 March 1996.

PatchID	Plant sp.	Estimated Area (m2) <45k+1.5'	Estimated Area (m2) >45k+1.5'	Act.. Area <45K (m2)	Act.. Area >45K (m2)	Actual Total Area (m2)	PLOT DATA No. of 20cm Plots	20cm Raw Mean KAS/m2	20cm Raw 1 sd KAS/m2	No. of KAS<45k	No. of KAS>45k	Total No. KAS/patch	No. KAS Markd & Removed	*	BOOTSTRAPPED DATA Mean No. KAS/ptch	1 sd KAS/ptch	5% Quant.	95%Quant.	Estim'd No. KAS <45k cfs	Estim'd No. KAS >45k cfs	Estim'd Total No. KAS
P3	Mica	0.46	0.00	0.46	0.00	0.46	Tot. Count	0.0		0	0	0	0	*	0		0	0	0	0	0
P203M	Mica	12.81	12.06	7.31	17.56	24.87	6	15.9	26.630	116	280	396	4	*	398	247.05	0	792	117	281	398
P4	Mica	0.20	0.00	0.20	0.00	0.20	Tot. Count	0.0		0	0	0	0	*	0		0	0	0	0	0
204	Mica	0.03	0.00	0.00	0.03	0.03	Tot. Count	0.0		0	0	0	0	*	0		0	0	0	0	0
P4P5	Mica	2.37	8.98	0.09	11.26	11.35	6	27.0	51.830	2	304	306	0	*	306		0	306	2	304	306
P5M	Mica	39.75	16.49	28.94	27.30	56.24	8	18.0	19.930	522	492	1015	191	*	1013	202.18	716	1372	521	492	1013
P6MUP	Mica	0.00	3.14	0.00	3.14	3.14	6	15.9	17.430	0	50	50	0	*	50	20.50	17	83	0	50	50
P6MUS	Mica	0.00	3.30	0.00	3.23	3.23	6	15.9	17.430	0	51	51	0	*	51	20.93	17	86	0	51	51
P6MLower	Mica	4.97	1.54	0.00	6.60	6.60	0	27.6		0	182	182	0	*	182				0	182	182
P8M	Mica	31.47	5.80	23.51	13.76	37.27	23	19.4	42.640	456	267	722	125	*	719	312.80	258	1290	454	265	719
P10M	Mica	5.11	0.00	5.11	0.00	5.11	Tot. Count	52.3		267	0	267	267	*	267				267	0	267
P11M	Mica	0.61	0.00	0.61	0.00	0.61	4	15.9	31.830	10	0	10	0	*	10	8.45	0	29	10	0	10
P203N	Naof	6.66	1.82	4.98	3.50	8.48	6	26.5	42.310	132	93	225	0	*	224	133.50	0	450	132	93	224
P5N	Naof	4.00	14.07	0.06	18.01	18.07	8	31.8	77.970	2	573	575	18	*	569	468.18	0	1510	2	567	569
P6NDS	Naof	0.00	4.64	0.00	4.64	4.64	6	15.9	26.630	0	74	74	0	*	74	46.34	0	148	0	74	74
P6N	Naof	0.00	14.35	0.00	14.96	14.96	12	5.3	12.390	0	79	79	0	*	80	51.49	0	159	0	80	80
P6NMid	Naof	0.00	3.10	0.00	3.10	3.10	7	59.1	85.070	0	183	183	0	*	183	92.08	42	338	0	183	183
P7Lower	Naof	6.64	0.00	6.64	0.00	6.64	8	15.9	29.470	106	0	106	52	*	106	65.23	0	211	106	0	106
P7Upper	Noaf	11.43	0.00	8.73	2.70	11.43	10	6.4	20.130	56	17	73	26	*	73	68.93	0	218	55	17	73
P7Dnstrm	Naof	9.12	0.00	9.12	0.00	9.12	Tot. Count	0.0		13	0	13	13	*	13		0	13	13	0	13
P8NA	Naof	0.59	1.20	0.00	1.79	1.79	Tot. Count	105.6		0	189	189	189	*	189		0	189	0	189	189
P8NB	Naof	1.43	0.00	1.43	0.00	1.43	Tot. Count	14.7		21	0	21	21	*	21		0	21	21	0	21
P9N	Naof	3.37	0.00	1.77	1.60	3.37	7	59.1	116.850	105	95	199	179	*	200	137.81	15	475	105	95	200
P10N	Naof	3.33	0.00	3.33	0.00	3.33	9	36.3	34.030	121	0	121	121	*	121				121	0	121
P6Poam	Poam	0.00	3.26	0.00	3.26	3.26	6	58.4	42.310	0	190	190	0	*	190	51.09	104	277	0	190	190
P6Rem	Mix	0.00	63.46	0.00	63.46	63.46	0	0.0		0	0	0	0	*	0		0	0	0	0	0
P1	Dila	0.33	0.00	0.33	0.00	0.33	Tot. Count	109.1		36	0	36	36	*	36		0	36	36	0	36
201	Dila	0.05	0.00	0.05	0.00	0.05	Tot. Count	0.0		0	0	0	0	*	0		0	0	0	0	0
202	Dila	0.05	0.00	0.05	0.00	0.05	Tot. Count	0.0		0	0	0	0	*	0		0	0	0	0	0
P11PE	Phau/Eqhy	3.23	0.00	3.23	0.00	3.23	7	4.6	12.030	15	0	15	0	*	15	13.70	0	44	15	0	15
P11N	Naof	1.94	0.00	1.94	0.00	1.94	9	0.0	0.000	0	0	0	0	*	0		0	0	0	0	0
P12	Eqhy	13.75	0.00	13.75	0.00	13.75	5	12.7	28.470	175	0	175	0	*	177	157.52	0	525	177	0	177
Subtotal	Mica	97.78	51.31	66.23	82.88	149.11	63	17.3	18.939	1373	1622	2995	587	*	2992	811.92	1008	4136	1371	1625	2996
Subtotal	Naof	46.57	39.18	36.06	50.30	86.36	76	29.0	35.983	555	1303	1858	619	*	1852	1063.56	58	3732	555	1297	1852
Subtotal	Other	19.35	66.72	19.35	66.72	86.07	30	26.4	15.882	226	190	416	36	*	418	222.32	104	882	228	190	418
TOTAL	All	183.70	157.21	121.63	199.90	321.54	169	24.0	28.025	2154	3120	5274	1242	*	5077	708.74	3949	6298	2154	3113	5266

Table 4. Estimates of KAS population at Vaseys Paradise, 22 March 1996.

PatchID	Plant sp.	Area <1275 m3/s (m2)	Area >1275 m3/s (m2)	Total Area (m2)	20 cm PLOT DATA No. of 20cm Diam Plots	Raw Mean KAS/m2	Raw sd KAS/m2	Est'd No. KAS <1275m3/s	Est'd No. KAS >1275m3/s	Est'd. Tot. No. KAS/ patch	No. KAS Marked& Removed	*	BOOTSTRAPPED DATA Estim'd No.KAS <1275m3/s	Estim'd No.KAS >1275m3/s	Estim'd Tot. KAS	5%Quant.	95%Quant.
P3	Mica	0.46	0.00	0.46	Tot. Count	0.0		0	0	0	0	*	0	0	0	0	0
P203M	Mica	7.31	17.56	24.87	6	15.9	26.63	116	280	396	4	*	117	281	398	0	792
P6MUS	Mica	0.00	3.23	3.23	6	15.9	17.43	0	51	51	0	*	0	51	51	17	86
P4	Mica	0.20	0.00	0.20	Tot. Count	0.0		0	0	0	0	*	0	0	0	0	0
204	Mica	0.00	0.03	0.03	Tot. Count	0.0		0	0	0	0	*	0	0	0	0	0
P4P5	Mica	0.09	11.26	11.35	Control	27.0	51.83	2	304	306	0	*	2	304	306	0	306
P5M	Mica	28.94	27.30	56.24	30	18.0	19.93	522	492	1015	191	*	521	492	1013	716	1372
P6MUP	Mica	0.00	3.14	3.14	6	15.9	17.43	0	50	50	0	*	0	50	50	17	83
P6MLower	Mica	0.00	6.60	6.60	4	27.6		0	182	182	0	*	0	182	182		
P8M	Mica	23.51	13.76	37.27	23	19.4	42.64	456	267	722	125	*	454	265	719	258	1290
P10M	Mica	5.11	0.00	5.11	Tot. Count	52.3		267	0	267	267	*	267	0	267		
P11M	Mica	0.61	0.00	0.61	4	15.9	31.83	10	0	10	0	*	10	0	10	0	29
P203N	Naof	4.98	3.50	8.48	6	26.5	42.31	132	93	225	0	*	132	93	224	0	450
P5N	Naof	0.06	18.01	18.07	8	31.8	77.97	2	573	575	18	*	2	567	569	0	1510
P6NDS	Naof	0.00	4.64	4.64	6	15.9	26.63	0	74	74	0	*	0	74	74	0	148
P6N	Naof	0.00	14.96	14.96	12	5.3	12.39	0	79	79	0	*	0	80	80	0	159
P6NMid	Naof	0.00	3.10	3.10	7	59.1	85.07	0	183	183	0	*	0	183	183	42	338
P7Lower	Naof	6.64	0.00	6.64	8	15.9	29.47	106	0	106	52	*	106	0	106	0	211
P7Upper	Noaf	8.73	2.70	11.43	10	6.4	20.13	56	17	73	26	*	55	17	73	0	218
P7Dnstrm	Naof	9.12	0.00	9.12	Tot. Count	0.0		0	0	0	13	*	13	0	13	0	13
P8NA	Naof	0.00	1.79	1.79	Tot. Count	105.6		0	189	189	222	*	0	189	189	0	189
P8NB	Naof	1.43	0.00	1.43	Tot. Count	14.7		21	0	21	21	*	21	0	21	0	21
P9N	Naof	1.77	1.60	3.37	7	59.1	116.85	105	95	199	179	*	105	95	200	15	475
P10N	Naof	3.33	0.00	3.33	9	36.3	34.03	121	0	121	121	*	121	0	121		
P11N	Naof	1.94	0.00	1.94	9	0.0	0.00	0	0	0	0	*	0	0	0	0	0
P6Poam	Poam	0.00	3.26	3.26	6	58.4	42.31	0	190	190	0	*	0	190	190	104	277
P6Rem	Other	0.00	63.46	63.46	0	0.0		0	0	0	0	*	0	0	0	0	0
P1	Dila	0.33	0.00	0.33	Tot. Count	109.1		36	0	36	36	*	36	0	36	0	36
201	Dila	0.05	0.00	0.05	Tot. Count	0.0		0	0	0	0	*	0	0	0	0	0
202	Dila	0.05	0.00	0.05	Tot. Count	0.0		0	0	0	0	*	0	0	0	0	0
P11PE	Phau/Eqhy	2.98	0.00	2.98	7	4.6	12.03	14	0	14	0	*	14	0	14	0	41
P12	Eqhy	11.80	0.00	11.80	5	12.7	28.47	150	0	150	0	*	150	0	150	0	451
Subtotal	Mica	66.23	82.88	149.11	83	17.3	35.34	1373	1626	2999	587	*	1371	1625	2996		
Subtotal	Naof	38.00	50.30	88.30	85	29.0	45.64	542	1303	1845	652	*	555	1297	1852		
Subtotal	Other	15.21	66.72	81.93	21	26.4	34.50	200	190	390	36	*	200	190	390		
TOTAL	All	119.43	199.90	319.34	189.00	24.0	36.77	2115	3120	5235	1275	*	2126	3113	5239		

Table 5. Estimates of KAS habitat and population at Vaseys Paradise, 18 April 1996.

PatchID	Plant Sp.	Area <1275 m3/s (m2)	Area >1275 m3/s (m2)	Total Area (m2)	20 cm PLOT DATA No. of 20cm Diam Plots	Raw Mean KAS/m2	Raw 1sd KAS/m2	Est'd No. KAS <1275 m3/s	Est'd No. KAS >1275 m3/s	Est'd Total No. KAS/plot	No. KAS Marked	Est'd No. KAS <1275 m3/s	Est'd No. KAS >1275 m3/s	Est'd Tot. No KAS	5%Quant.	95%Quant.
P3	Mica	0	0	0	Tot. Count	0.0		0	0	0	0	0	0	0	0	0
P203MN	Mica	0.96	19.58	20.54	0	0.0		0	0	0	0	0	0	0	0	0
P4	Mica	0	0	0		0.0		0	0	0	0	0	0	0	0	0
204	Mica	0	0	0		0.0		0	0	0	0	0	0	0	0	0
P4P5	Mica	0	12.97	12.97	5	12.7	28.47	0	165	165	2	0	168	168	0	496
P5MU	Mica	0.38	9.3	9.68	3	0.0	0.00	0	0	0	0	0	0	0	0	0
P5MD	Mica	0.8	19.9	20.7	6	10.6	16.44	8	211	220	1	8	211	220	0	439
P6MUS	Mica	0	3.54	3.54	7	4.6	12.03	0	16	16	0	0	16	16	0	48
P6MUp	Mica	0	4.22	4.22	4	8.0	15.92	0	34	34	1	0	34	34	0	101
P6MLower	Mica	0	7.48	7.48	0	0.0	0.47	0	0	0	0	0	0	0	0	0
P8ML	Mica	11.4	5.7	17.1	2	5.3	12.99	61	30	91	0	84	42	126	0	375
P8MI	Mica	0.78	5.66	6.44	4	5.3	12.99	4	30	34	3	0	0	(Combined with 8ML)		
P10MA	Mica	0.03	0	0.03	Tot. Count	0.0		0	0	0	0	0	0	0	0	0
P10MB	Mica	0	0	0	Tot. Count	0.0		0	0	0	0	0	0	0	0	0
P10MC	Mica	0.01	0	0.01	Tot. Count	0.0		0	0	0	0	0	0	0	0	0
P5N	Naof	0	11.76	11.76	4	0.0	0.00	0	0	0	0	0	62	63	0	188
P5NB	Naof	0	0.81	0.81	Tot. Count	2.2		0	2	2	0	0	2	2	2	2
P6NDS	Naof	0	6.14	6.14	7	131.9	187.80	0	810	810	6	0	807	807	112	1508
P6N	Naof	0	13.28	13.28	8	71.6	153.84	0	951	951	17	0	953	953	106	2325
P6NMid	Naof	0	4.95	4.95	4	23.9	15.92	0	118	118	5	0	118	118	39	158
P7Lower	Naof	4.49	0	4.49	6	0.0	0.00	0	0	0	0	0	0	0	0	0
P7Upper	Noaf	8.21	2.76	10.97	13	19.6	44.14	161	54	215	8	161	54	215	54	457
P7Dnstrm	Naof	0	0	0	Tot. Count	0.0		0	0	0	0	0	0	0	0	0
P8NA	Naof	0	1.04	1.04	Tot. Count	2.2		0	2	2	0	0	2	2	2	2
P8NB	Naof	0.88	0	0.88	Tot. Count	0.0		0	0	0	0	0	0	0	0	0
P9N	Naof	0.59	1.24	1.83	6	281.2	210.58	166	349	515	60	166	349	515	272	757
P10N	Naof	0	0	0	Tot. Count	0.0		0	0	0	0	0	0	0	0	0
P1	Dila	0	0	0	Tot. Count	0.0		0	0	0	0	0	0	0	0	0
P201	Dila	0	0	0	Tot. Count	0.0		0	0	0	0	0	0	0	0	0
P202	Dila	0	0	0	Tot. Count	0.0		0	0	0	0	0	0	0	0	0
P6Poam	Poam	0	3.26	3.26	2	111.4	112.54	0	363	363	7	0	363	363	623	104
P6Rem	Other	0	60.4	60.4	0			0	0	0	0	0	0	0		
P11PEM	Phau/Eqhy	4.11	0	4.11	Tot. Count	0.0		0	0	0	0	0	0	0		
P11N	Naof	0	0	0	Tot Count	0.0		0	0	0	0	0	0	0	0	0
P12	Eqhy	19.56	0	19.56	Tot. Count	0.0		0	0	0	0	0	0	0	0	0
P8ADCA	Adca	2.78	0	2.78	0											
Subtotal	Mica	14.36	88.35	102.71	35	3.1	9.9	73	486	560	7	92	471	563		
Subtotal	Naof	14.17	41.98	56.15	53	44.4	68.0	327	2286	2613	96	327	2348	2675		
Subtotal	Other	26.45	63.66	90.11	8	13.9		0	363	363	7	0	363	363		
TOTAL	All	54.98	193.99	248.97	96	19.7	41.2	400	3135	3535	110	420	3181	3601		

Table 6. KAS population estimates at Vaseys Paradise, 18-19 May 1996.

		PLOT DATA							*	BOOTSTRAPPED DATA				
Patch ID	Plant Sp.	Area (m2) <45k cfs	Area (m2) >45k cfs	Total Area m2	No. of Plots	Raw Mean KAS/patch	Raw sd KAS/patch	Raw Mean KAS/m2	*	Est. Total KAS/Patch <45k cfs	Est. Total KAS/Patch >45k cfs	Est. Total No. KAS/ Patch	5% Quantile	95% Quantile
P203M	Mica	0.92	22.07	22.99	5	0.4	0.80	12.7	*	12	281	293	0	843
P4.5M	Mica	0	12.97	12.97	6	0.0	0.00	3.0	*	0	39	39	0	0
P5M	Mica	1.18	29.2	30.38	20	25.5	64.92	20.7	*	24	604	629	48	1257
P6MUS	Mica	0	3.54	3.54	6	0.5	0.00	15.9	*	0	56	56	0	113
P6MUP	Mica	0	4.22	4.22	6	0.8	0.00	26.5	*	0	112	112	45	201
P6MLOW*	Mica	0	7.48	7.48	0	0.7	0.00	21.2	*	0	159	159	nav	nav
P8MI	Mica	0.78	13	13.78	4	0.5	0.00	15.9	*	12	207	219	0	829
P8ML*	Mica	11.4	5.7	17.1	0	2.5	0.00	79.6	*	907	454	1361	nav	nav
P10MA	Mica	0.03	0	0.03	All	0.0	0.00	0.0	*	0	0	0	0	0
P10MC	Mica	0	0	0	All	0.0	0.00	0.0	*	0	0	0	0	0
P203N	Naof		1.2	1.2	3	1.7	1.25	53.1	*	0	64	64	25	102
P5N	Naof	0	12.88	12.88	20	1.0	1.56	30.2	*	0	389	389	164	635
P5NB*	Naof	0	0.81	0.81	0	7.6	0.00	247.8	*	0	201	201	nav	nav
P6NU	Naof	0	13.28	13.28	12	0.0	0.00	0.0	*	0	0	0	0	0
P6NMID	Naof	0	4.95	4.95	6	0.7	1.11	21.2	*	0	105	105	0	236
P6NDS	Naof	0	6.14	6.14	6	0.3	0.47	15.9	*	0	98	98	33	163
P7NUP	Naof	7.21	2.76	9.97	9	0.2	0.00	7.1	*	51	20	71	0	155
P7NLOW	Naof	4.54	0	4.54	6	0.0	0.00	0.0	*	0	0	0	0	0
P8NA	Naof	0	1.04	1.04	5	0.0	0.00	0.0	*	0	0	0	0	0
P8NB	Naof	0.88	0	0.88	5	0.2	0.40	6.4	*	6	0	6	0	17
P9N	Naof	0.59	1.24	1.83	5	3.8	1.17	121.0	*	71	150	221	175	268
P6POAM	Poam	0	3.26	3.26	6	0.2	0.37	5.3	*	0	17	17	0	52
P8CA	Caaq	0	Not done	0	None	na	na	na	*	na	na	0	na	na
P10MB	Mix	0	Not done	0	None	na	na	na	*	na	na	0	na	na
P10ND	Mix	0	0	0	All	0.0	0.00	0.0	*	0	0	0	0	0
P11PE	Phau/Eqhy	4.11	0	4.11	8	0.0	0.00	0.0	*	0	0	0	0	0
P12E	Eqhy	18.56	0	18.56	6	0.2	2.65	5.3	*	98	0	98	0	295
Subtotal	Mica	14.31	98.18	112.49	49	11.1	65.72	19.6	*	956	1912	2867	93	3244
Subtotal	Naof	13.22	44.3	57.52	77	1.9	5.95	45.7	*	128	1026	1154	397	1576
Subtotal	Other	22.67	>3.26	>25.93	21	0.1	3.03	1.8	*	98	17	116	0	347
TOTAL	**All**	**50.2**	**>144.54**	**>194.74**	**147**	**4.0**		**26.3**	*	**1182**	**2955**	**4137**	**490**	**5205**

Table 7. KAS population estimates at Vaseys Paradise, 15 June 1996.

Patch ID	Plant Spp.	Area (m2) <1275 m3/s	Area (m2) >1275 m3/s	Total Area (m2)	20 cm PLOT DATA: No. of 20cm Plots	Raw Mean KAS/Plot	Raw sd KAS/Plot	Raw Mean KAS/m2	Est'd. No. KAS <1275m3/s	Est'd. No. KAS >1275m3/s	Est.d Tot. No. KAS	BOOTSTRAPPED DATA: Est. Total KAS/Patch >1275 m3/s	Est. Total KAS/Patch <1275 m3/s	Est. Total KAS/Patch	5% Quantile	95% Quantile
203M	Mica	0.56	20.2	20.76	5	0.0	0.00	0.0	0	0	0	0	0	0	0	0
4.5M	Mica	0	11.07	11.07	6	0.2	0.41	5.3	0	59	59	59	0	59	0	177
5MU	Mica	0.66	8.76	9.42	7	0.1	0.38	4.5	3	39	42	39	3	42	0	129
5MD	Mica	1.5	17.08	18.58	17	0.5	1.01	16.9	25	288	313	288	25	313	104	557
6MUS	Mica	0	8.14	8.14	6	0.0	0.00	0.0	0	0	0	0	0	0	0	0
6MUP	Mica	0	3.14	3.14	6	0.0	0.00	0.0	0	0	0	0	0	0	0	0
6MLOW	Mica															
8MI	Mica	0.5	12.5	13.00	5	0.2	0.45	6.4	3	80	83	80	3	83	0	249
8ML*	Mica	9.96	0	9.96	0	0.0	0.00	0.0	0	0	0	0	22	22		nav
10MA	Mica	0.018	0	0.02	Tot. Count	0.0		0.0	0	0	0	0	0	0		na
10MC	Mica	0.018	0	0.02	Tot. Count	0.0	0.00	0.0	0	0	0	0	0	0	0	0
203N	Naof	0.04	0.61	0.65	2	1.0	1.41	31.8	1	19	21	19	1	21	0	42
5N	Naof	0.14	11.26	11.40	7	0.4	0.79	13.7	2	154	156	154	2	156	0	312
5NB+8NA*	Naof	0	2.71	2.71	0	0.0	0.00	0.0	0	0	0	38	0	38	0	0
6NU	Naof	0	11.97	11.97	8	0.5	0.76	15.9	0	191	191	191	0	191	48	334
6NMID	Naof	0	4.67	4.67	6	0.3	0.52	10.5	0	49	49	49	0	49	0	100
6NDS	Naof	0	3.8	3.80	6	0.3	0.52	10.5	0	40	40	40	0	40	0	81
7NUP	Naof	6.52	2.05	8.57	12	0.2	0.58	5.1	33	10	44	33	33	66	0	253
7NL	Naof	4.54	0	4.54	6	0.0	0.00	0.0	0	0	0	0	0	0	0	0
8NB*	Naof	2.7	0	2.70	0			0.0	0	0	0	0	8	8		
9N	Naof	0.03	1.1	1.13	7	3.0	2.39	95.5	3	105	108	105	3	108	63	158
6POAM	Poam	0	2.52	2.52	6	0.0	0.00	0.0	0	0	0	0	0	0	0	0
8CA	Caaq/Adca	0	7.5	7.50	3	0.0	0.00	0.0	0	0	0	0	0	0	0	0
10MB	Mix		0					0.0	0	0	0	0	0	0		
10ND	Mix	0.155	0	0.16	Tot. Count	0.0	0.00	0.0	0	0	0	0	0	0	0	0
11PE	Phau/Eqhy	4.56	0	4.56	7	0.0	0.00	0.0	0	0	0	0	0	0	0	0
12E	Eqhy	15.86	0	15.86	7	0.0	0.00	0.0	0	0	0	0	0	0	0	0
Subtotal	Mica	13.216	80.89	94.11	54	0.1	0.20	3.0	33	468	499	468	56	521		
Subtotal	Naof	13.97	38.17	52.14	54	0.6	0.70	18.3	39	568	608	629	47	676		
Subtotal	Other	20.575	10.02	30.60	24	0.0	0.00	0.0	1	1	1	1	1	1		
TOTAL	All	47.761	129.08	176.84	132	0.3	0.34	8.0	74	1037	1108	1097	104	1198		

Table 8. KAS population estimates at Vaseys Paradise, 20 July 1996.

Patch ID	Plant Spp.	Area <1275 m3/s (m2)	Area >1275 m3/s (m2)	Total Area (m2)	20 cm PLOT DATA No. of Plots	Raw Mean KAS/Plot	Raw sd KAS/Plot	Raw Mean KAS/m2	Est'd. No. KAS >1275 m3/s	Est'd. No. KAS <1275 m3/s	Est'd. Tot. No. KAS	BOOTSTRAPPED DATA Est. No. KAS/Patch >1275 m3/s	Est. No. KAS/Patch <1275 m3/s	Est'd. Tot. No. KAS	5%Quant.	95%Quant
203M	Mica	0.56	20.2	20.76	5	0.20	0.45	6.4	129	4	132	128.6	3.6	132.2	0	397
4.5M	Mica	0.00	11.07	11.07	6	0.00	0.00	0.0	0	0	0	0.0	0.0	0.0	0	0
5MU*	Mica	0.66	8.76	9.42	0				0	0	0	122.7	8.3	131.0		
5MD	Mica	1.50	17.08	18.58	11	1.27	3.26	40.4	690	61	751	690.5	60.6	751.1	108	1882
6MUS*	Mica	0.00	8.14	8.14	1	0.00		0.0	0	0	0	104.0	0.0	104.0		
6MUP	Mica	0.00	3.14	3.14	3	0.00	0.00	0.0	0	0	0	0.0	0.0	0.0	0	0
6MLOW	Mica								0	0	0					
8MI	Mica	0.00	13	13.00	5	0.40	0.89	12.7	166	0	166	165.5	0.0	165.5	0	497
8ML	Mica	9.96	0	9.96	3	0.30	0.58	9.5	0	95	95	0.0	95.1	95.1	0	212
10MA	Mica	0.02	0	0.02	Tot. Count	0.00	0.00	0.0	0	0	0	0.0	0.0	0.0	0	0
10MC	Mica	0.02	0	0.02	Tot. Count	0.00	0.00	0.0	0	0	0	0.0	0.0	0.0	0	0
203N	Naof	0.04	0.61	0.65	2	2.50	3.54	79.6	49	3	52	48.5	3.2	51.7	0	104
5N	Naof	0.14	11.26	11.40	10	2.40	6.57	76.4	860	11	871	860.2	10.7	870.9	37	2323
5NB+8NA	Naof	0.00	2.71	2.71	4	0.75	0.96	23.9	65	0	65	64.7	0.0	64.7	13	136
6NU	Naof	0.00	11.97	11.97	6	10.00	6.10	318.3	3810	0	3810	3810.2	0.0	3810.2	2477	5208
6NMID	Naof	0.00	4.67	4.67	6	1.50	2.07	47.7	223	0	223	223.0	0.0	223.0	50	422
6NDS	Naof	0.00	3.8	3.80	6	0.33	0.52	10.5	40	0	40	39.9	0.0	39.9	0	81
7NUP	Naof	6.51	2.05	8.56	6	0.16	0.41	5.1	10	33	44	10.4	33.2	43.6	0	137
7NLOW	Naof	4.54	0	4.54	6	0.16	0.41	5.1	0	23	23	0.0	23.1	23.1	0	73
8NB	Naof	2.70	0	2.70	4	2.25	2.63	71.6	0	193	193	0.0	193.4	193.4	43	344
9N	Naof	0.03	1.1	1.13	6	5.17	7.94	164.6	181	5	186	181.0	4.9	186.0	42	396
6POAM	Poam	0.00	2.52	2.52	6	1.67	1.37	53.2	134	0	134	134.0	0.0	134.0	67	201
8MCA	Caaq/Adca	0.00	7.5	7.50	2	0.00	0.00	0.0	0	0	0	0.0	0.0	0.0	0	0
10MB	Mix			0.00					0	0	0			0.0	0	0
10ND	Mix	0.16	0	0.16	Tot. Count	0.00	0.00	0.0	0	0	0	0.0	0.0	0.0	0	0
11PE	Phau/Eqhy	4.56	0	4.56	6	0.00	0.00	0.0	0	0	0	0.0	0.0	0.0	0	0
12E	Eqhy	15.86	0	15.86	4	0.00	0.00	0.0	0	0	0	0.0	0.0	0.0	0	0
Subtotal	Mica	12.72	81.39	94.11	36	0.2	0.47	6.3	987	161	1146	1213	170	1381		
Subtotal	Naof	13.96	38.17	52.13	56	2.5	3.11	80.3	5238	268	5506	5238	268	5506		
Subtotal	Other	20.58	10.02	30.60	19	0.3	0.23	8.9	135	1	135	135	1	135		
TOTAL	All	47.25	129.58	176.83	111	1.1	1.40	34.3	6359	431	6787	6586	439	7022		

Table 9: KAS densities at Vaseys Paradise, 27 August 1996.

Patch ID	Plant Sp/.	Rough Estimate of Total Patch Area (m2)	No. of 20 cm Plots	Raw Mean No. KAS/ plot	Raw sd KAS/plot	Est'd. Tot. KAS/m2	Est'd Tot. No. KAS/ patch	*	BOOTSTRAPPED DATA Est'd. Tot. KAS/patch	5% Quant.	95% Quant
P5MD	MICA	22.18	7	1.1	1.73	36.4	807	*	806.9	101	1614
P5MU	MICA	10.74	6	2.8	2.11	90.2	969	*	968.6	456	1425
P8MI	MICA	12	5	0.0	0.00	0.0	0	*	0.0	0	0
P8ML	MICA	22.81	6	0.5	0.76	15.9	363	*	363.0	0	623
P4.5M	MICA	12.8	6	0.3	0.47	10.6	136	*	135.8	0	272
P8ML	MICA		1	0.0		0.0	0	*			
P6MUS	MICA	6.74	3	0.0		9.6	64	*	64.4	0	144
P100K	MICA	3.03	9	0.7	1.05	21.2	64	*	64.3	11	129
P10A	MICA	0.032	1	0.0		0.0	0	*	0.0	0	0
P10C	MICA	0.015	1	0.0		0.0	0	*	0.0	0	0
P10N	MICA	0.22	1	0.0		0.0	0	*	0.0	0	0
								*			
P5N	NAOF	9.59	7	4.3	4.43	136.4	1308	*	1308.3	480	2181
P5NB	NAOF	0.28	4	4.3	1.30	135.3	38	*	37.9	27	47
P6NU	NAOF	9.85	7	17.2	5.81	477.5	4703	*	4703.0	3181	6137
P7NU	NAOF	7.7	7	0.0	0.00	0.0	0	*	0.0	0	0
P8NB	NAOF	2.7	1	1.0		31.8	86	*	85.9		
P9N	NAOF	1.5	6	4.2	4.71	132.6	199	*	198.9	64	359
								*			
P7NL	Mix	3.3	6	0.0	0.00	0.0	0	*	0.0	0	0
P11PE	PHAU	5.9	6	0.2	0.37	5.3	31	*	31.3	0	94
P12	EQHY	15	6	0.0	0.00	0.0	0	*	0.0	0	0
								*			
Subtotal	Mica	90.567	46	0.8	0.77	190.2	2403	*	2403		
Subtotal	Naof	31.62	32	5.6	2.71	1046.3	6334	*	6334		
Subtotal	Mix	24.2	18	0.1	0.12	5.3	31	*	31		
TOTAL	All	146.387	96	0.3	1.34	1241.8	8768	*	8768		

Table 10. Estimates of KAS habitat area and numbers < and > the 1275 m3/s stage, 15-16 Sept. 1996.

					20cm PLOT DATA						*	BOOTSTRAPPED DATA				
PatchID	Plant Sp.	Area <1275m3/s (m2)	Area >1275m3/s (m2)	Tot. Area (m2)	No. of 20cm Diam Plots	Raw Mean KAS/m2	Raw 1sd KAS/m2	Est'd. No. KAS <1275m3/s	Est'd. No. KAS >1275m3/s	Est'd. Total No. KAS/patch	*	No KAS <45 k cfs	No KAS >45 k cfs	Total No. KAS/patch	5%Quant	95%Quant
P8ML	Mica	19.79	3.02	22.81	1	0.00	9.15	0	0	0	*	0	0	0	0	218
P8MI+Roll	Mica	1.13	9.9	11.03	10	25.46	39.76	29	252	281	*	29	252	281	59	439
P6MUP	Mica	0	6	6	1	0.00	0.00	0	0	0	*	0	0	0	0	144
P5MMID	Mica	0	4.67	4.67		24.51	0.00	0	114	114	*	0	0	114		
P5MD	Mica	2.32	19.86	22.18	14	22.74	56.98	53	452	504	*	53	452	504	122	1404
P5MUS	Mica	1.2	9.54	10.74	6	26.53	33.97	32	253	285	*	32	253	285	57	570
P4.5	Mica	0.03	11.77	11.8	6	5.31	11.86	0	62	63	*	0	62	63	0	204
P5N	Naof	0	5.92	5.92	8	23.87	26.39	0	141	141	*	0	141	141	42	209
P5NB	Naof	0	0.28	0.28	2	79.58	79.58	0	22	22	*	0	22	22	0	45
P6NDS	Naof	0	7	7	6	90.19	78.87	0	631	631	*	0	631	631	260	1003
P6NMid	Naof	0	1.5	1.5	3	509.29	170.43	0	764	764	*	0	764	764	558	971
P6NU	Naof-est'd	0	5.56	5.56	6	318.31	138.75	0	1770	1770	*	0	1770	1770	1239	2242
P7NU	Naof	4.82	2.27	7.09	6	5.31	11.86	26	12	38	*	26	12	38	0	113
P7NL	Naof	4.95	0	5.75	3	0.00	0.00	0	0	0	*	0	0	0	0	0
P7X	Naof	7.74	0	7.74	Tot. Count	0.00	0.00	0	0	0	*	0	0	0	0	0
P8NB	Naof-est'd	0.75	0	0.75	2	0.00	0.00	0	0	0	*	0	0	0	0	0
P9	Naof	0.28	1.22	1.5	5	210.08	86.82	59	256	315	*	59	256	315	151	374
P203MN	Mica/Naof	2.39	20.36	22.75	6	0.00	0.00	0	0	0	*	0	0	0	0	0
P6POAM	Poam	0	34	34	6	15.92	24.31	0	541	541	*	0	541	541	0	1083
P7NLL	Mix	2	0	2	Tot. Count	0.00	0.00	0	0	0	*	0	0	0	0	0
P10MA	Mix - est'd	0.045	0	0.045	Tot. Count	0.00	0.00	0	0	0	*	0	0	0	0	0
P10MC	Mix - est'd	0.012	0	0.012	Tot. Count	0.00	0.00	0	0	0	*	0	0	0	0	0
P10MD	Mix - est'd	0.63	0	0.63	Tot. Count	0.00	0.00	0	0	0	*	0	0	0	0	0
P11PE	Mix	5.9	0	5.9	8	11.94	31.58	70	0	70	*	70	0	70	0	211
P12	Mix	16.41	0	16.41	12	0.00	0.00	0	0	0	*	0	0	0	0	0
P28K	Mix	0.0157	0	0.0157	Tot. Count	0.00	0.00	0	0	0		0	0	0	0	0
P30K	Mix	0.0165	0	0.0165	Tot. Count	0.00	0.00	0	0	0		0	0	0	0	0
P42K	Mix - est'd	0.104	0	0.104	Tot. Count	0.00	0.00	0	0	0	*	0	0	0	0	0
Subtotal	Mica	24.47	64.76	89.23	38	13	35.25	114	1134	1247	*	114	1019	1247		
Subtotal	Naof	18.54	23.75	43.09	42	149	148.83	84	3597	3681	*	84	3597	3681		
Subtotal	Mix+Other	27.52	54.36	81.88	39	3	11.56	70	541	612	*	70	541	612		
TOTAL	All	70.53	142.87	214.20	119	47	114.05	268	5272	5540	*	268	5157	5540		

Table 11. Estimates of KAS habitat area above and below the 1275 m3/s stage post-flood, 24 October 1996.

Date	PatchID	Plant Sp.	Actual Area <1275 m3/ (m2)	Actual Area >45K (m2) (m2)	Actual Total Area (m2)
961024	P8ML	Mica	21	4.89	25.89
961024	P8MI	Mica	1.39	8.6	9.99
961024	P6MUP	Mica	1.2	10.64	11.84
961024	P100K	Mica	0	3.03	3.03
961024	P5MM	Mica	0	4.39	4.39
961024	P5MD	Mica	1.81	19.11	20.92
961024	P5MU	Mica	1.03	10.13	11.16
961024	P4.5	Mica	0	11.48	11.48
961024	P5N	Naof	0	6.86	6.86
961024	P5NB	Naof	0	0.28	0.28
961024	P6NDS	Naof	0	7	7
961024	P6NM	Naof	0	1.5	1.5
961024	P6NU	Naof	0	13.28	13.28
961024	P6POAM	Naof	0	20	20
961024	P8NB	Naof	0.75	0	0.75
961024	P9	Naof	0.08	1.28	1.36
961024	P9T	Naof	0.4	0	0.4
961024	P7U	Naof	13.08	2.77	15.85
961024	P7L	Naof	10.53	0	10.53
961024	P203MN	Mix	2.25	19.2	21.45
961024	P11PE	Mix	6.86	0	6.86
961024	P12	Mix	20.75	0	20.75
961024	P8C rollmat	Mix	0	1.41	1.41
961024	P42K	Mix	0.06	0	0.06
961024	P10MA	Mix	0.045	0	0.045
961024	P10MC	Mix	0.012	0	0.012
961024	P10MD	Mix	0.255	0	0.255
Subtotal		Mica	26.43	72.27	98.7
Subtotal		Naof	24.84	52.97	77.81
Subtotal		Other	30.232	20.61	50.842
TOTAL		All	81.502	145.85	227.352

Table 12. KAS habitat area and population estimates above and below the 1275 m3/s stage, 17-18 March 1997.

PatchID	Plant Sp.	Area <1275m3/s	Area >1275m3/s	Tot. Area (m2)	No. of # Plots	Est'd. No. KAS/m2	Est'd. KAS <1275m3/s	Est'd. KAS >1275m3/s	Est'd. Tot. No. KAS	Total KAS Counted	*	Est'd. KAS <1275m3/s	Est'd. KAS >1275m3/s	Est'd. Tot. No. KAS	5% Quant.	95% Quant
P4.5	MICA	0	9.41	9.41	7	0.0	0	0	0	0	*	0	0	0		
P5MU	MICA	0.42	8.29	8.71	6	21.2	9	176	185	4	*	9	176	185	47	324
P5MDS	MICA	0.71	18.07	18.78	12	18.6	13	336	349	7	*	14	336	350	50	698
P5MMID	MICA	0	4.21	4.21	5	12.7	0	54	54	2	*	0	54	54	0	108
P5MSUB	MICA	0.43	0	0.43	Tot. Count	0.0	0	0	0	0	*	0	0	0		
P6MUP	MICA	0	3.55	3.55	3	0.0	0	0	0	0	*	0	0	0		
P6MUS	MICA	0	3.71	3.71	3	10.6	0	39	39	1	*	0	40	40		
P8MI	MICA	0.82	4.22	5.04	9	7.1	6	30	36	2	*	6	30	36	0	79
P8ML	MICA	6.81	5.98	12.79	10	0.0	0	0	0	0	*	0	0	0	0	72
P8MLUS	MICA	4.41	0	4.41	3	0.0	0	0	0	0	*	0	0	0		
P203M	MICA	1.35	20.17	21.52	6	5.3	7	107	114	1	*	8	108	116	0	343
P13	MICA	1.67	0	1.67	3	0.0	0	0	0	0	*	0	0	0		
P5N	NAOF	0	3.77	3.77	3	0.0	0	0	0	0	*	0	0	0		
P6NUS	NAOF	0	6.39	6.39	6	5.3	0	34	34	1	*	0	34	34	0	93
P6NMID	NAOF	0	2.58	2.58	6	111.4	0	287	287	21	*	0	288	288	42	644
P6NDS	NAOF	0	2.89	2.89	6	21.2	0	61	61	4	*	0	62	62	0	123
P203N	NAOF	0.04	1.46	1.5	1	0.0	0	0	0	0	*	0	0	0		
P9N	NAOF	0.02	1.29	1.31	3	10.6	0	14	14	1	*	1	14	15	0	28
P9NL	NAOF	1.16	0	1.16	3	10.6	12	0	12	1	*	13	0	13	0	25
P5AGTUS	AGST-MIX	0	1.94	1.94	3	84.9	0	165	165	8	*	0	165	165	62	268
P5AGSMID	AGST-MIX	0	1.89	1.89	3	21.2	0	40	40	2	*	0	41	41	21	61
P6BACKG	CAAQ-MIX	7.59	83.41	91	5	25.5	193	2124	2317	4	*	194	2125	2319	579	4056
P7NU	NAOF-AGST	8.44	2.48	10.92	5	0.0	0	0	0	0	*	0	0	0		
P7NL	CAAQ-MIX	5.14	0	5.14	5	0.0	0	0	0	0	*	0	0	0		
P8CUS	CAAQ	0	1.48	1.48	4	15.9	0	24	24	2	*	0	24	24	0	48
P8LC	CAAQ	3.12	0	3.12	Tot. Count	0.0	0	0	0	0	*	0	0	0		
P8ADCA	ADCA	0	2.71	2.71	3	21.2	0	58	58	2	*	0	58	58	29	87
P12	EQ-MIX	10.85	0	10.85	5	0.0	0	0	0	0	*	0	0	0		
Subtotals	Mica	16.62	77.61	94.23	68	6.3	35	741	776	17	*	37	744	781		
Subtotals	Naof	1.22	18.38	19.6	28	22.7	13	396	409	28	*	14	398	412		
Subtotals	Other	35.14	93.91	129.05	34	18.7	193	2410	2603	18	*	194	2413	2607		
TOTAL	All	52.98	189.9	242.88	130	13.4	241	3547	3788	63	*	245	3555	3800		

1c. Determine the mechanism(s) of habitat loss during the high flow experiment.

Direct observation and measurement of scour (vegetation loss) were made during the rising hydrograph. We measured water velocity from a point between patches 4.5 and 5 during the upramp on 26 March. Velocities ranged from 0.5 m/sec to 1.5 m/sec at the surface, and from 0.6 m/sec to 1.5 m/sec at 0.5 m below the surface (Table 13). The portion of Vaseys's Paradise above the debris fan lies at a steep angle to the current and immediately upstream of a riffle. The current near the shore was turbulent, and the water level surged. Consequently, water velocities varied considerably over short periods of time. Vegetation and snails on the rock faces were exposed to turbulent, high velocity water forces.

Table 13. Water velocity (m/sec) measured at Vaseys's Paradise on the flood upramp, 26 March 1996.

TIME	Surface Velocity (m/s)	Velocity at 0.5 m depth (m/s)
1529	0.5	0.8
1639	0.8 - 1.5	0.6
1705	0.5	1.0
1847	1.0	1.5

1d. Determine the mechanisms and recovery rate of primary KAS habitat following the high flow experiment.

Vegetation losses were attributed to high velocity, scouring flows and impacts by coarse debris. We resurveyed the site in June, September and October of 1996 to document the rate of recovery of inundated vegetation patches that remain in the $<1{,}275$ m^3/s zone.

Vegetation recolonization of the lower zone (downslope from the 45,000 cfs stage) was slow in the 1996 growing season and in early 1997 (Tables 2-12). Low zone cover of *Mimulus* decreased from 66.2 m^2 on 22 March to 14.4 m^2 on 18 April, and to 13.2 m^2 on 15 June, and then increased to 24.5 m^2 on 16 September and to 26.4 m^2 on 24 October 1996. Low zone cover of *Nasturtium* decreased from 38.0 m^2 on 22 March to 14.2 m^2 on 18 April, and then increased from 14.0 m^2 on 15 June, to 18.5 m^2 on 16 September, to 24.8 m^2 on 24 October. Total KAS primary habitat cover was reduced by the test flow from 104.2 m^2 to 28.5 m^2 (a 72.6% reduction), and increased to 51.3 m^2 (49.2% of the pre-flood vegetated area) by the end of the 1996 growing season in late October. Normal cold conditions in the 1996-97 winter and a late winter, month-long constant discharge of 27,000 cfs resulted in die-back of overall KAS habitat below the 45,000 cfs stage to 53 m^2, with 16.6 m^2 of *Mimulus*, 1.2 m^2 of *Nasturtium*.

Seedling establishment of *Nasturtium* occurred on flood-scoured bedrock faces following the flood, and seedlings grew through the 1996 growing season, dying back in mid-winter, 1996-97. Germination has just begun in March 1997, accounting for the reduced *Nasturtium* cover at that time. Recovery of *Nasturtium* patches via seedling establishment was more rapid at VP than clonal expansion of *Mimulus*. No seedlings of the latter species were detected during any of our visits. *Mimulus* regrew from root masses that survived the test flow, and slowly expanded through the 1996 growing season.

1e. Determine historic development of KAS habitat, particularly colonization by water-cress.

We acquired several historic photographs of VP from Dr. Robert Webb (U.S. Geological Survey, Tucson, Arizona) since 1890, and from the National Park Service. These photographs demonstrate that KAS habitat at Vaseys Paradise increased by at least 20% as a result of flood control by Glen Canyon Dam. We surveyed recognizable rocks and vegetation scour lines, and related them to our stage discharge model. over time. Water-cress has been present at Vaseys Paradise since at least 1938 (Clover and Jotter 1938), and photographs reveal that it has expanded its range in the lower riparian zone (<1700 m^3/s stage) during post-dam time.

OBJECTIVE 2: High Flow Impacts on the VP KAS Population:

2a. Determine the proportion of the KAS population at risk to loss during the high flow experiment.

We measured KAS density using the techniques of Stevens et al. (1997) and estimated KAS abundance above and below the predicted inundation level. We sampled a total of 189 10 to 30 cm-diameter plots and total patches in March 1996 and estimated in the field that 3,080 to 3,120 KAS existed below the 45,000 cfs + 1.5' stage, and were at risk to loss during the flood (Tables 2 and 3). We subsequently estimated that 2,126 KAS existed below the actual 45,000 cfs (Table 4). The total estimated KAS population in the flood zone was 3.4-fold higher than that estimated from the March, 1995 data. We attributed this difference to the warmer, drier 1995-96 winter (i.e., lack of prolonged freezing and local floods), and considerable expansion of primary host plant patches. More thorough searching in 1996 may have accounted for a small part of the difference. On-site discussions with the FWS and NPS resulted in a modification of our marking and moving program (FWS Memorandum, 1996). This revised FWS prescription for the site directed us to:

> "Relocate and collect approximately 75% of the Kanab ambersnail individuals from 50% of the habitat expected to be inundated. Control polygons must not receive moved snails. Remaining vegetation should be dispersed and varied to maximize rejuvenation."

We marked and moved 1,275 KAS to other primary habitat at VP that lay above the estimated 45,000 cfs + 1.5' stage prior to the flood. This number was 105 more KAS than the 1,170 total recommended by the FWS memorandum.

2b. Determine the proportion of the KAS population lost during the high flow experiment.

Based on 83 20-cm-diameter plots from the mid-April postflood population survey, we estimated that 420 KAS existed downslope from the 45,000 cfs stage following the flood. If all KAS not removed by us from the flood zone were lost, then approximately 16.7% of the snails below the 1275 m^3 stage - the low-zone area surveyed prior to the flood - were lost. The uncertainty of the estimate is due to the fact that we removed snails from below the estimated 45,000 cfs + 1.5' stage, and we cannot be certain how many of the snails removed were from the area that was actually inundated.

2c. Determine the mechanisms of KAS loss due to high flow experiment.

Loss of KAS was attributed to immersion followed by molar action of the river. KAS were observed swept from the vegetation by rising water or floating debris as the flood waters rose. We observed three KAS which were being inundated by the rising hydrograph, and noted that KAS were lost to a combination of inundation and increasing velocity (4c below).

Four short (<24 h) and one long immersion experiment were run during the flood visit. The first four experiments confirmed that snails survived immersion for 12-17 h. The long immersion experiment began with 22 snails in a wire mesh cage submerged in a bucket which was submerged in the mainstream flow. Two snails were removed at a time, at roughly 5-h intervals. Removing snails exposed all cage occupants to air for 5-10 min. In addition, all snails were inadvertently exposed to air for 45-60 min, approximately 36 h into the experiment. All snails removed from the cage recovered to normal size and exhibited normal attachment to vegetation within 30 min of removal. The last snails were removed at 65 h, just prior to our departure. Immersed snails became bloated with water and lost their attachment to vegetation after prolonged inundation; however, they were resistant to drowning by immersion in cold, well-oxygenated water.

2d. Determine KAS population recolonization for six months post-flood.

We resurveyed KAS population density on monthly basis through the 1996 growing season (tables 4-12). During the post-flood survey in April, we observed that several KAS recolonized a low-lying *Nasturtium* patch (P7NU), probably carried there by a small rivulet that runs through the patch. All KAS found in the flood zone in April were located near the 45,000 stage elevation, and their presence below flood stage probably resulted from wash-down and other downslope movement, rather than persistence in inundated areas through the flood. We hypothesize that longer downslope movements, such as those into P7NU, were entirely due to wash-down as the newly occupied areas had sparse vegetation cover.

We monitored the recovery of the population through the 1996 growing season in the inundated zone (tables 4-12). The estimated KAS population there decreased from: 420 in April, to 391 on 19 May, to 104 on 15 June, and then increased to 439 on 20 July during emergence of young from egg sacks, and then decreased to 268 on 16 September. KAS were largely in dormant condition in October, and the population was not surveyed to prevent disturbance.

The flood zone KAS population did not recover in the 1996 growing season because of slow vegetation recovery; however, the total KAS population surveyed below the ca. 2000 m^3/s stage increased to levels comparable to those reported in mid-summer of 1995. In 1995 the estimated KAS population increased from 282 snails in the entire low zone in March, to 2328 in June. In 1996, the estimated KAS population size in the <2000 m^3/s stage ranged from 5239 in March (Table 4) to 3061 in April (Table 5), to 8768 in August (Table 9), to 5540 in September (Table 10), and to 3800 in March 1997. Whereas KAS had a single reproductive cycle centered in July in 1995, in 1996 there were two peaks of reproduction: one in June and a secondary peak in August (Figure 7). The warm winter and early spring apparently permitted snails to mature and reproduce twice within a single growing season. As a result, smaller size classes of snails overwintered in 1996-97, a phenomenon not previously observed for KAS.

The KAS habitat and population in the flood zone have been slow to colonize the areas scoured by the test flow. Vegetation recovery appears to require at least 1.5 yr at VP. As vegetation continues to recolonize this zone over the next several years, the KAS population is expected to increase accordingly.

OBJECTIVE 3: KAS Sampling and Protocol Assessment

3a. Refine the stage-discharge relationship at VP.

The stage-to-discharge relationship at VP has been greatly refined by photo-documentation and surveying (to within 0.1 m accuracy) of the stage elevation during the 8,000 cfs and 45,000 cfs constant flows, as well as during the up-ramp flows. As stage increased during the flood, we used leveling surveying to document the rising limb hydrograph and the 45,000 cfs stage elevation. This survey effort also serves as a verification and as a back-up for the electronic river stage data collection by the U.S.G.S at VP. The 45,000 cfs stage was used to refine stage estimation of habitat patches.

3b-d. Determine the accuracy of KAS density measurements made using the plot sampling method of Stevens et al. (1997), stem breakage and plot size.

We conducted surveys of 10-, 20-, 30-, and 50-cm-diameter plots in the flood zone, and then destructively sampled those plots to determine the accuracy of KAS sampling through follow-up sampling, as well as the effects of plot size on KAS density estimation (Table 4). Follow-up sampling revealed a complex relationship between plant species and plot size. The proportion of KAS found on follow-up increased with plot diameter in *Mimulus*, but not in *Nasturtium* (Table 14). In *Mimulus*, complete harvesting of 20-cm-diameter plots following the initial survey added, on average, 0.22 KAS/m^2, a 38.6% increase. In *Nasturtium*, follow-up harvesting added, on average, 0.35 KAS/m^2 (28.4%). Therefore, our existing plot-based analyses underestimate KAS abundance by as much as one third, but probably varies considerably between observers (a factor not tested in this analysis). Time expenditure and stem breakage during searches in 50-cm plots were prohibitive. The 10-cm plots were too small to allow for a well-defined perimeter. Stem breakage was increased with plot diameter for both host plant species, and increased 2.1-fold on *Mimulus* and 4.0-fold in *Nasturtium* on 30-cm-diameter plots as compared to 20-cm-diameter plots (Table 15). Consequently, we still favor the use of 20-cm-diameter study plots. Analyses of snail numbers presented in this document are consistent with those presented in earlier documents and do not incorporate the accuracy assessments described above.

3e. Compare KAS distribution and population estimation analysis techniques.

KAS population estimation techniques based on patch mean and variance may vary slightly under various distributional assumptions (i.e., Poisson, negative binomial, etc.) in relation to the bootstrapping methods used by Stevens et al. (1997). One of the largest determinants of accuracy in sampling is related to replication of sampling, and a minimum of three plots/patch were sampled in this study. More replication is likely to refine population estimates.

OBJECTIVE 4: Behavior and Movement Studies

4a. Determine the most appropriate marking technique for KAS survivorship and movement

We conducted a literature survey and contacted members of the malacological community to determine what marking techniques were available for snails with similar shell morphology and life habits to those of KAS. Bee-dots were overwhelmingly recommended. These are 2-mm diameter, colored plastic circles with printed numbers. We attached bee dots to 10 *Catinella vermeta* using cyanoacrylate glue (Superglue™) and observed the snails for > 2 weeks. The snails showed no ill effects from this experiment, and we concluded that this technique was appropriate for marking KAS.

4b. Develop a KAS ethogram.

We observed snails for approximately one hour and determined that the degree of emergence from shell, direction and distance of movement. orientation to vegetation, and movement of eyestalks were the major observable behaviors. Behavior in response to other invertebrates was recorded when applicable. The approximate position of the observed snail also was recorded on a site map. The data on KAS movement patterns discussed in 4c (below) obviates the need for a diurnal or seasonal ethogram for this snail on either host plant species.

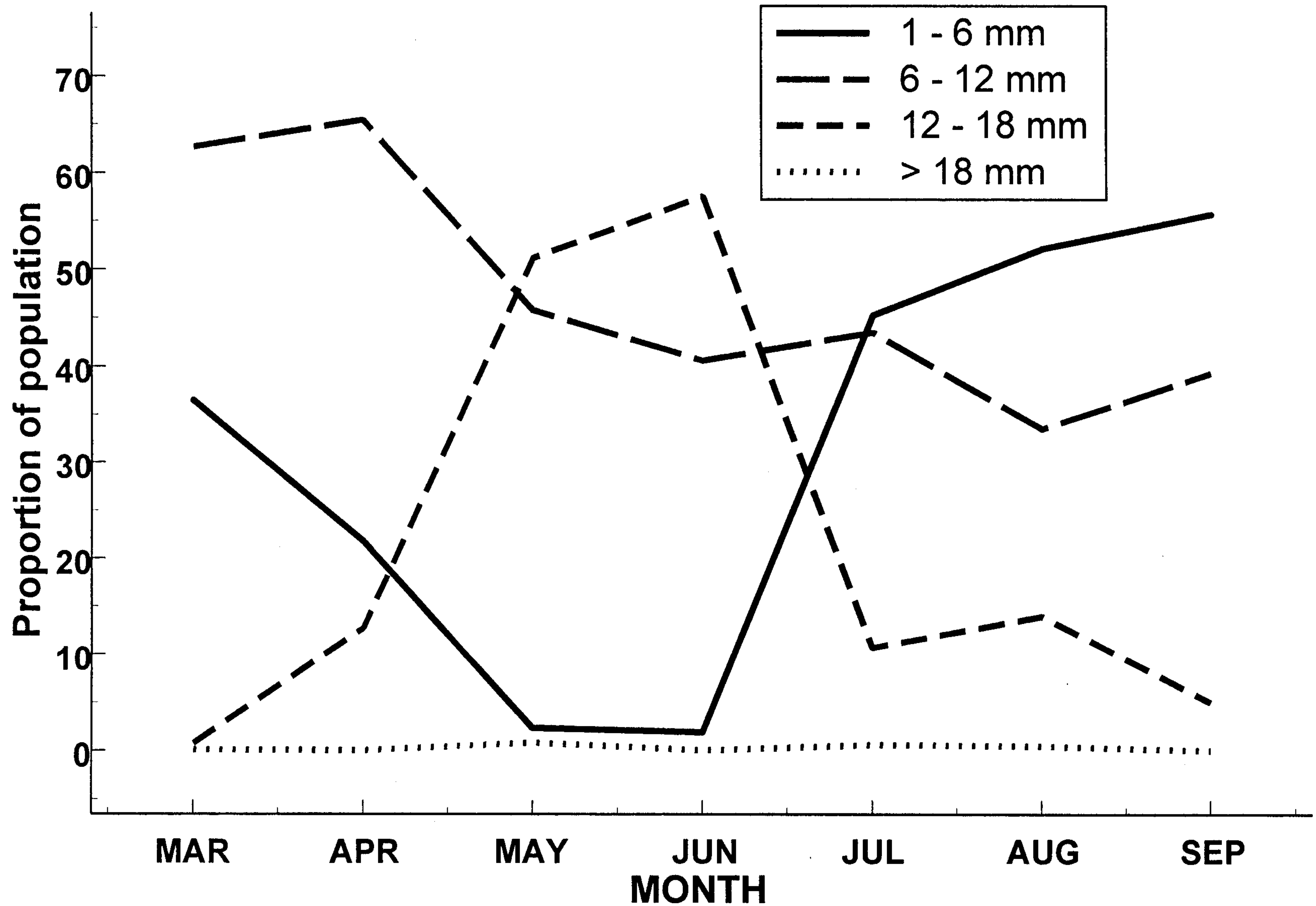


Figure 7. Proportion of four size classes of KAS at Vaseys Paradise in 1996.

Table 14: Effects of follow-up sampling and plot diameter (cm) on KAS density estimates.

Host plant	Plot diameter	N	Mean initial count	Mean followup	% found on followup
Mimulus	10	8	0.25	0	0
	20	23	0.35	0.22	38.6
	30	8	0.13	0.38	74.5
	50	2	0.00	0.50	100.0
Nasturtium	10	9	1.33	0.67	33.5
	20	17	0.88	0.35	28.4
	30	11	4.00	2.64	39.7

Table 15: Effects of plot diameter (cm) on count time, search time per snail (for plots containing snails) and number of host plant stems broken.

Host plant	Plot diameter	N	Count time	N	Time/snail	N	Stems broken
Mimulus	10	10	3.53	4	4.23	7	1.43
	20	65	4.29	28	4.01	80	2.83
	30	10	7.22	3	4.92	8	5.88
	50	2	12.79	1	3.05	2	45.00
Nasturtium	10	9	2.01	6	1.65	9	1.78
	20	44	3.67	11	2.54	62	2.26
	30	10	5.20	6	3.28	11	9.00

4c. Determine KAS movement behavior in relation to the high flow.

We made focal observations on KAS before and after the high flow and through the 1996 growing season. Observations were made in four time categories: 0000-0559, 0600-1159, 1200-1759, 1800-2359. We attempted to observe each focal snail for 15 min, noting direction and distance moved, use of eyestalks, substrate, orientation to substrate. interactions with other invertebrates, as well as length of snail and eyestalk damage. At the end of each observation, we estimated total distance moved.

We made focal observations on the behavior of 253 snails in 1996. Total distances moved per minute ranged from 0 to 2.48 cm/min, with values skewed toward slower movements (Figure 8). Differences between major host plants were not consistent among months (Table 16). Differences in distances moved during different times of day were not consistent on either host plant among months (Figures 9, 10). Lack of normality in the data precluded analysis by multiway ANOVA to detect higher order trends, but inspection of Table 16 and Figures 9 and 10 clearly show that snail speed is not clearly controlled by one or two simple patterns. The patterns we observed may be consistent from year to year (e.g., faster movements in July, perhaps), but we cannot determine long-term consistency from a single year's observations. Similarly, although we observed faster movements in March 1996 (before the flood) than in April 1996 (after the flood), we cannot determine whether this difference is usual at Vaseys's without data from other years.

```
TTLCMPM                                                  Cum.               Cum.
Midpoint                                                 Freq Freq Percent Percent

0.00   |**********************************                34   34  30.09    30.09
0.15   |*****************************                     29   63  25.66    55.75
0.30   |****************                                  16   79  14.16    69.91
0.45   |************                                      12   91  10.62    80.53
0.60   |*******                                            7   98   6.19    86.73
0-75   |********                                           8  106   7.08    93.81
0.90   |**                                                 2  108   1.77     5.58
1.05   |***                                                3  111   2.65    98.23
1.20   |**                                                 2  113   1.77   100.00
       -----+----+----+----+----+----+----
            5   10   15   20   25   30
```

Figure 8: Distribution of movement rates (cm/min) of unmarked resident snails at Vaseys's Paradise, March and April, 1996.

All researchers who observed snails at night noted that snails exposed to direct white light often moved into light-sheltered positions. As a result of these observations, we began using infrequent and/or strongly reduced light for observations. Therefore, we performed an additional analysis to confirm these informal observations of negative phototaxis during nighttime observations. Observations in March, and on the first night of observations in April were mostly performed in relatively bright light, while observations

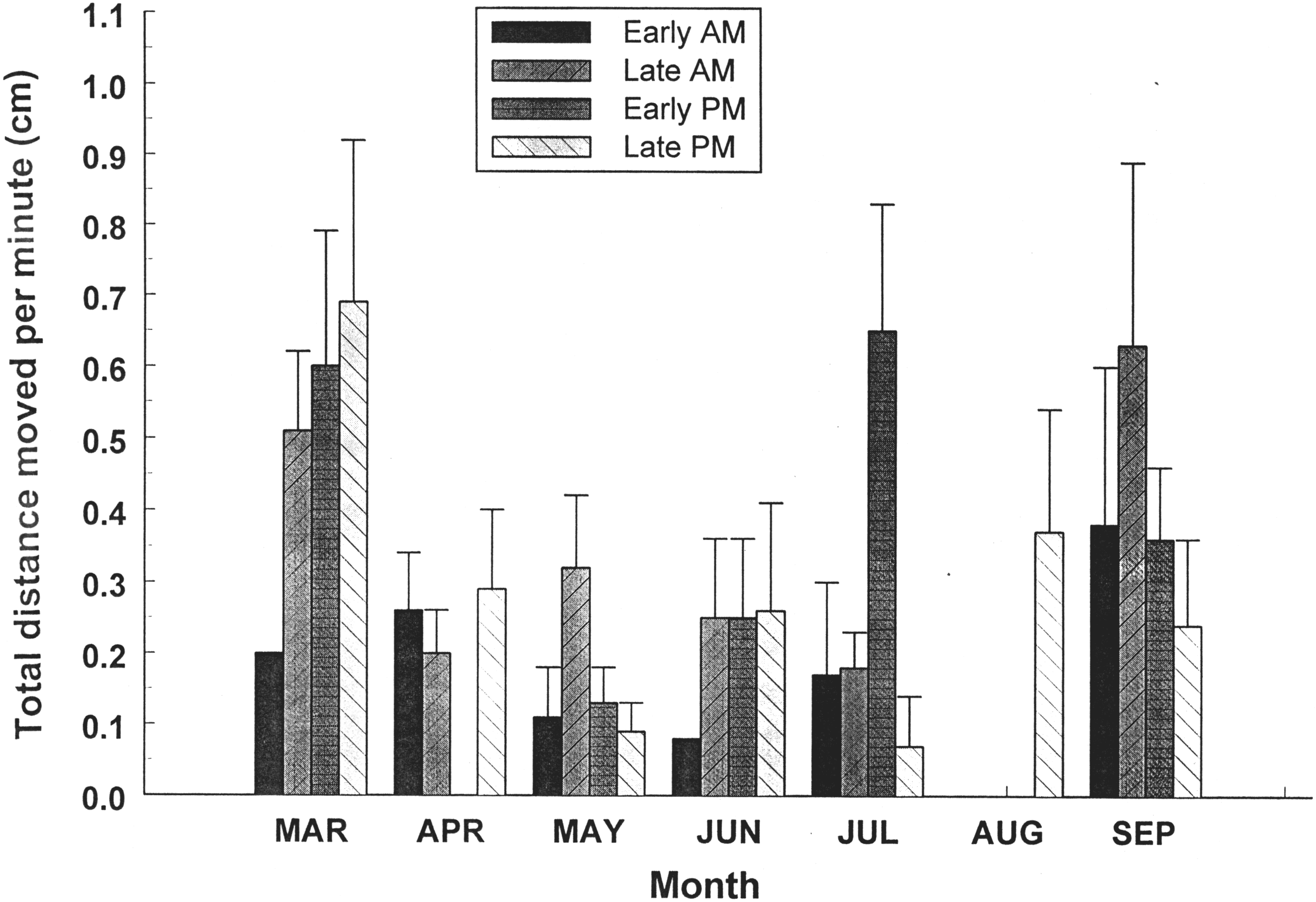


Figure 9. Total distances moved per minute by KAS on MICA. Data are means and standard errors from focal observations in 1996.

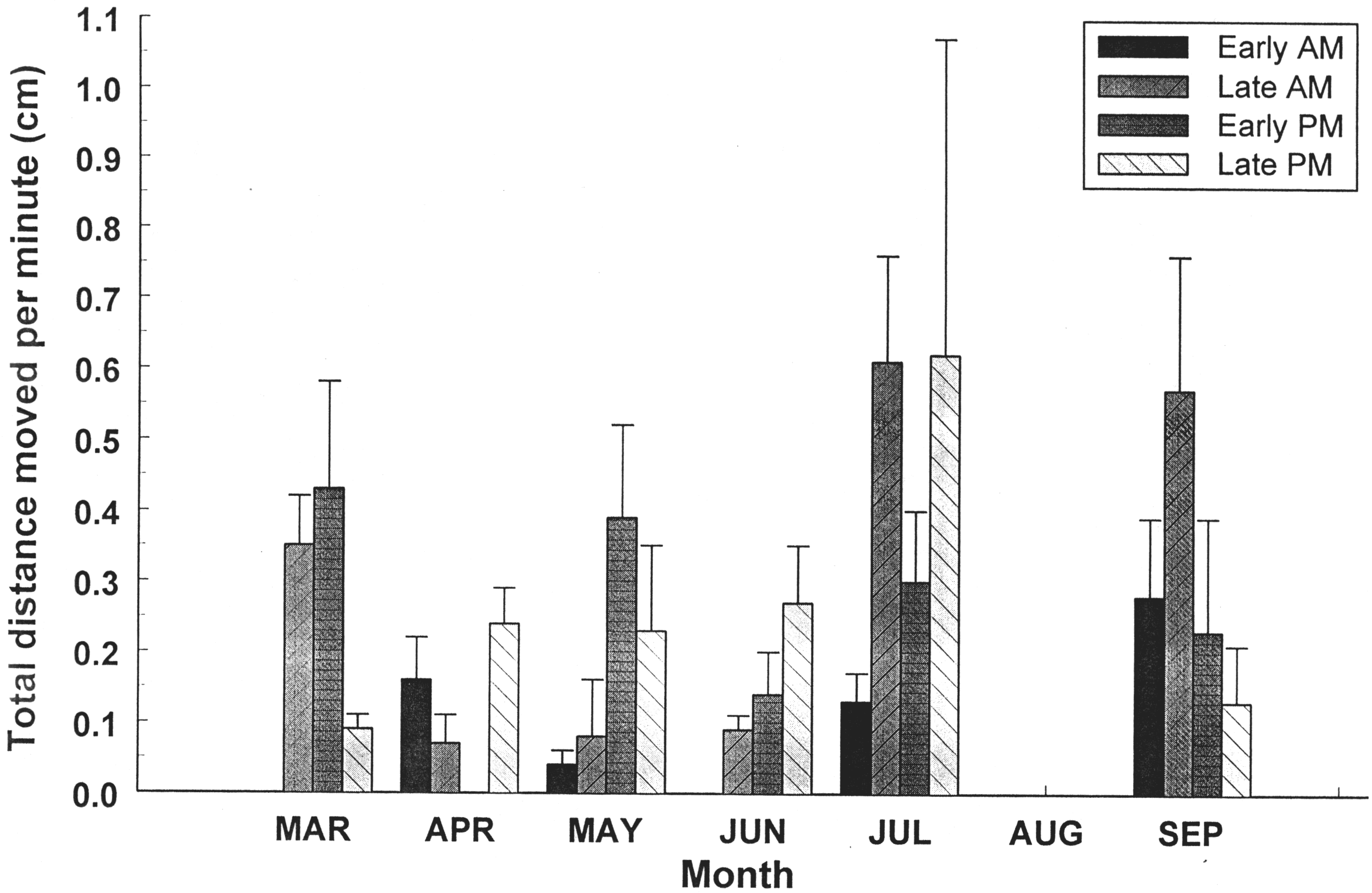


Figure 10. Total distance moved per minute by KAS on NAOF. Data are means and standard errors from observations in 1996.

Table 16: Mean movement rates (total cm/min) of unmarked resident KAS at Vaseys's Paradise from March 1996 to March 1997, broken down by host plant.

MONTH	PLANT	N	Mean	Std Error	Maximum
March	MICA	18	0.57	0.09	1.25
	NAOF	16	0.33	0.06	0.80
April	MICA	30	0.25	0.05	1.00
	NAOF	28	0.18	0.03	0.57
May	MICA	32	0.15	0.03	0.68
	NAOF	34	0.23	0.06	1.33
June	MICA	8	0.23	0.08	0.53
	NAOF	35	0.16	0.04	0.87
July	MICA	9	0.26	0.09	0.83
	NAOF	23	0.37	0.07	1.13
August	MICA	2	0.37	0.17	0.53
September	MICA	35	0.41	0.09	2.48
	NAOF	12	0.29	0.08	0.80

during the last two nights of observations in April were made using infrequent and/or indirect light. Snails observed at night (2030 - 0530) at lower light intensity moved less than snails observed at higher light intensity ($Z = 2.342$, $n_{bright} = 12$, $n_{dim} = 31$, $p = 0.019$).

We obtained additional information on snail movements from observations of unmarked snails in inundated areas soon after the flood, and from observations of marked snails during that survey and incidental observations. The lower area of patch P7NU, which was inundated to a depth of 15-20 cm for a week, was recolonized by KAS by our April visit two weeks postflood. See section 2d above for additional comments concerning recolonization.

Forty-three snails were resighted during the 1996 field season. Of these, 10 had changed patches (23%), and 3 of these (7% of all resightings) had changed vegetation type (Table 17). Thirty snails were found alive in the same patches to which they were returned; 22 were resighted within 33 days of the initial observation, initial sighting date was missing for four, and the remaining 4 were observed at 49, 77, 92, 120 days after initial marking. Information on initial patch was not available for three snails.

An additional 9 snails were found dead at least one visit after they were marked; the shells suggested three inter-patch movements (the patches in which the shells were found were not below the original patches - gravity did not cause a "false" move). Three shells were found in the patch in which the snail was originally marked, and three shells had insufficient data to determine movement.

We investigated snail movements near the rising water line by placing snails on vegetation above the water's edge and observing their actions. In all cases, snails were fully active when moved. The maximum time a snail remained on vegetation after the first contact of its stem or leaf with water was 4 min. Snails were removed by waves, or, in slack water, through flotsam impact. Survival through immersion is apparently less important than their inability to maintain their position in surging, debris-laden water.

Table 17. Summary of KAS resightings during 1996 in which snails changed patch.

ID	1st Patch	2nd Patch	Different 1° veg	Months between sightings
Blue12	P9	P7UP	N	1
Blue28	P8MUP	P100K	N	1
Blue60	P7Nup	P9apron	N	2
Blue88	P100K	P8M	N	1
Green37pink	P100K	P5MD	N	1
Red19pink	P9	P5MD	Y	3
White17pink	P5Nup	P5MDds	Y	1
White49pink	P8M	P5M	N	2
White89pink	P5Nlow	P5MDlow	Y	1
White91pink	P100K	P5Mlow	N	1

4d. Determine survivorship of marked and moved versus resident KAS.

Relocations of marked snails were too few to permit mark-recapture estimates of survivorship. In addition, early post-release mortality was probably higher than long-term, post-release mortality. Predator-related mortality (4g below) may have been initially high to due to local enhancement of snail densities caused by release of snails in small groups around the margins of patches. After initial mortality decreased densities in these areas, mouse-caused mortality probably declined. Mortality information from later months, when marked residents were returned to patches individually, allowed a more conclusive determination of the effects of release procedure on mouse-caused mortality.

Measurements from 26 marked snails allowed us to estimate growth rates. Growth rate did not seem to vary with size in snails over 7 mm (no snails smaller than 6 mm were marked with bee dots). Average growth rate was 2.09 mm per 30 days, with a standard error of 0.256. Growth rate did not change significantly with size in snails first observed at sizes from 7 to 17 mm in length.

4e. Determine activity budgets and habitat use of resident and immigrant KAS in the growing season.

Activity budgets and habitat use data of marked snails will be reported in the final 1997 report. Median KAS densities in 20-cm survey plots were statistically higher on *Mimulus* in March, whereas in all other months, densities were higher on *Nasturtium*, significantly so in April, July, August, and September (Table 18). Calculations use raw medians from survey plots where the survey plot, not the patch, is the unit of measure. Higher densities on *Nasturtium* may be linked to the phenology of the species. This *Nasturtium officinale* variety is an annual and cycled twice during the 1996 growing season, maturing by June, and germinating in July-September, and the second population matured in late autumn. KAS densities were greatest on *Nasturtium* seedlings, and densities on *Nasturtium* were near 0 on senescent plants.

4f. Determine KAS diet through the 1996 growing season.

Analysis of fecal pellets collected after focal observations is being used to determine KAS diet. Up to 12 replicated paired fecal pellet and adjacent surface scraped samples are being collected from each host plant

Table 18. Mean and median densities of KAS in 20-cm-diameter survey plots on the two major host species at Vaseys's Paradise in 1996. Mann-Whitney-Wilcoxon (MWW) results test differences between medians.

Month	Host Plant	Mean	N	Std. Error	Median	MWW p value
March	MICA	21.3	91	3.85	0	
	NAOF	16.1	82	5.13	0	0.0106
April	MICA	7.0	32	2.76	0	
	NAOF	57.8	49	18.32	0	0.0204
May	MICA	15.9	30	9.00	0	
	NAOF	19.3	33	7.32	0	0.4539
June	MICA	8.4	49	3.05	0	
	NAOF	22.5	51	6.45	0	0.0743
July	MICA	16.9	32	11.07	0	
	NAOF	78.8	61	20.11	0	0.0055
August	MICA	28.1	43	7.28	0	
	NAOF	199.2	27	45.89	95.5	0.0011
September	MICA	14.21	56	4.99	0	
	NAOF	163.98	33	32.07	95.5	0.0001

species on a seasonal basis, and preserved in 70% EtOH. These samples are being compared with laboratory-derived fecal samples at Northern Arizona University.

4g. Observe interactions between KAS, parasites, potential competitors and potential predators.

Eighty-nine marked, dead snails (shells without snails) were found during the 1996 field season. The first empty, marked shells were found the day after the first releases in March 1996. The following day we used a softer release technique, individually placing snails on substrates, rather than simply placing them into new positions within patches. However, the day after soft release, we found additional snail shells from both release efforts. We began a series of experiments to try to determine the agent of mortality.

To examine possible invertebrate predator behavior, we caged *Catinella* and *Physella* with three different invertebrates commonly found on the site: a carabid beetle, a hydrophilid beetle, and a common, web-spinning spider species. Ten snails were observed for 108 h. During this time, one *Catinella* died, with a crushed shell. It was caged with an etiolate, web-spinning spider which seemed unable to exert the pressure necessary to crush a snail shell. Furthermore, other snails in the container were uninjured during the remainder of the experiment. We concluded that none of these invertebrates was a major source of KAS mortality. We also observed KAS near other invertebrates during focal and incidental observations, but no observations have suggested any strong reaction to other invertebrates by KAS. One snail was observed "flinching" from small Diptera that were crawling under its shell.

We used a series of three experiments to try to observe post-release mortality of marked KAS:

1) To determine whether mortality was associated with the mark/release process, we placed 10 marked KAS in each of two wire mesh cages with living plants, litter and soil. We placed one cage in a *Mimulus* patch and one in a *Nasturtium* patch. Both cages were observed for 48 h. At the end of 48 h, 19 snails were alive and active, and one snail had disappeared (escaped, or thoroughly hidden in substrate material). From this experiment and the fact that none of the 1,275 KAS that were handled died. We concluded that marking and handling snails were not direct causes of snail mortality.

2) The next experiment allowed more predator access to snails. We placed 5 marked KAS, 1 marked *Catinella* and one unmarked *Catinella* in a glass jar with living plant material, litter and soil, and placed the jar on its side in a *Mimulus* patch, under the canopy. The jar was monitored for 48 h. At the end of the experiment, the snails were alive and healthy.

3) Finally, we created a 10-cm high, 20-cm diameter wire arena. The first such enclosure was placed in a *Mimulus* patch, at the border of untouched and clipped plants. Seven marked snails and 3 unmarked, locally-resident snails were enclosed during the afternoon. At 1900 that evening, we removed the enclosure and observed the snails at intervals through the night and early the following morning. All snails survived the entire period of observation. We repeated the enclosure experiment in a *Nasturtium* patch in which we had found empty, marked snail shells. While removing litter from the enclosure, we also observed and removed mouse droppings. Six marked KAS were placed in the enclosure during the afternoon. When we returned to the site at 1920, a *Peromyscus* was observed in or very near the enclosure. Upon reaching the enclosure, we found two empty, marked shells and fresh mouse droppings. We surmised that *Peromyscus* at VP forage on KAS, which explains, in part, the large number of intact shells of all sizes observed on the site. High *Peromyscus*-related mortality may be attributed to naturally high densities (below) and possibly local enhancement of snail densities because we initially released marked snails in small groups around patch margins.

We obtained permission from NPS to trap and mark small mammals at VP, and we live-trapped small mammals in April, May, June, July and September 1996, and March 1997 (a total of 267 trap nights; Table 19). *Peromyscus crinitus* and *P. maniculatus* were the only rodents captured at VP during the 1996 growing season. A *Spermophilus spilosoma* was repeatedly seen near the site during the day, but was not observed engaged in KAS predation. Mammal trapping success of the two mice in KAS habitat patches was highest in 1996 in April (18.8%), and decreased to 0% by 20 July, then increased in September to 9.7%, and increased slightly in March 1997 to 10.5%. This pattern generally follows the abundance of large KAS. During the March, we observed a *P. maniculatus* nest in P6MUS, and we trapped two immature *P. maniculatus* in April, additionally confirming that *Peromyscus* are successfully reproducing in the area inhabited by KAS.

In 1996 only a single KAS was found expressing sporocysts of *Leucochloridium cyanocittae*. This represents nearly an order of magnitude decrease in parasitism between 1995 and 1996.

Several fecal pellets were collected from each live-trapped *Peromyscus* at VP. In the laboratory, 2-3 pellets from each of 8 mice were soaked in dilute bleach and dissected under 60x magnification to determine whether any snail radulae were present. None of the approximately 30 *Peromyscus* fecal pellets examined revealed any KAS or other snail radulae. Mouse diet was found to consist of vegetation and various arthropods, and appeared to be consistent between vegetation types and different sampling periods. These results do not support the contention that *Peromyscus* is a major predator on KAS.

Table 19. Rodent trapping data at Vaseys Paradise in 1996.

Date	Species	No. Trapped	No Traps Set	Trap Success (%)
April 1996	*Peromyscus crinitus*	11	80	18.8
	Peromyscus maniculatus	4	(2 nights)	
May 1996	*Peromyscus crinitus*	3	43	7.0
	Peromyscus maniculatus	0		
June 1996	*Peromyscus crinitus*	1	37	2.7
	Peromyscus maniculatus	0		
July 1996	*Peromyscus crinitus*	0	38	0
	Peromyscus maniculatus	0		
September 1996	*Peromyscus crinitus*	3	31	9.7
	Peromyscus maniculatus	0		
March 1997	*Peromyscus crinitus*	4	38	10.5
	Peromyscus maniculatus	0		

OBJECTIVE 5: Recovery and Longterm Studies

5a. Determine potential for growing KAS primary host plant species in controlled environments.

A prerequisite for establishing captive breeding KAS populations is understanding propagation potential of primary host plants. Although *Nasturtium officinale* is grown commercially, VP stock may have specific microhabitat requirements that are not matched in commercial production. We removed 6 batches each of *Mimulus* and *Nasturtium* from VP, and propagated them in the Northern Arizona University greenhouse. Propagation of these species was also attempted using seed from the VP stock in mid-summer. Seed establishment of *Nasturtium* has been successful. All *Mimulus* seeds failed to germinate under standard greenhouse conditions; however, *Mimulus* root stock are readily transplanted and our experience with these samples indicates that this species can be used to establish additional habitat for KAS.

5b. Determine use of alternate host plant food sources.

Nasturtium officinale is commercially available, but the utility of other strains of this species as a food source for KAS is unknown. We obtained *Nasturtium* seed to evaluate its potential as a KAS food source.

5c. Move low-zone KAS to non-inundated habitat at VP.

The FWS Biological Opinion on the planned flood originally requested that the Bureau of Reclamation move 90% of the KAS occurring downslope from the 45.000 cfs + 1.5' stage to higher elevation primary habitat at VP. This measure was requested to limit undue losses of KAS at VP during the experiment, as well as providing insight into snail dispersal, survivorship and essential life history characteristics. On-site discussions with FWS and NPS officials were conducted immediately prior to the test flow regarding the advisability of leaving some low zone KAS habitat in place in case it was not scoured. These consultations resulted in a modification of the original request. The revised FWS recommendation involved removing 75% of the KAS from 50% of the habitat lying downslope from the 45,000 cfs + 1.5' stage (U.S. Fish and Wildlife Service Memorandum, March, 1996).

We marked 1,275 KAS and moved them to higher elevation just prior to the high flow event. Using the unadjusted 20-cm-diameter plot analysis, this number represented 40.9% of the total estimated KAS population that existed downslope from the 45,000 cfs + 1.5' stage, 105 more KAS than the 1,170 KAS which the revised FWS guidelines directed the Bureau of Reclamation to move.

Mark-recapture techniques are traditionally used for population estimation, but we are using them to determine behavioral parameters and to estimate dispersal behavior of moved snails. Because of the large KAS population at VP, with numerous snails on the upper slopes, a mark recapture technique was not considered to be appropriate for this population, and analyses of that nature have been abandoned. In contrast, much information on *in situ* snail growth rates, and fidelity to host plants and individual patches can be gained by marking KAS. We marked all KAS collected in 20-cm-diameter plots from March through July 1996, and analyzed the data to determine movement rates and host plant species and patch fidelity (above).

5d. Determine fate of moved KAS.

See 4c and 4d above.

5e. Investigate comparable habitats in Grand Canyon for possible introduction sites.

In compliance with the Endangered Species Act, Arizona Game and Fish Department completed its three-year Section 6 studies of potential secondary KAS population establishment sites (Sorensen and Kubly 1997). We assisted AGFD staff in this effort by providing logistical and equipment support. State and federal criteria for secondary population establishment are defined in the KAS recovery plan (U.S. Fish and Wildlife Service 1995), and potential alternate population sites are suggested Sorensen and Kubly (unpublished 1997). Continued cooperative discussion, planning, and implementation by the Kanab Ambersnail Working Group is recommended.

MANAGEMENT AND FUTURE MONITORING RECOMMENDATIONS

The results presented in this report demonstrate that KAS has an approximately annual life cycle, and the snail is influenced by host plant availability, interseasonal and interannual variation, and Colorado River flows. The extent of parasitism by *Leucochloridium cyanocittae* diminished in the 1996 growing season, as compared to the 1995 growing season, and the parasite's role in VP KAS population dynamics remains unclear. While underestimating KAS density to some extent, the approach used here is conservative and can be clearly and consistently applied to monitor population development of this species without undue damage to the host plants. Therefore we recommend continuing to employ the protocol used in this study to monitor this population. Additional marking of KAS may provide additional insight into movement and host plant patch fidelity. Additional small mammal trapping may determine the extent of mouse predation on KAS.

Because of the above uncertainties, we recommend continuing to monitor the VP KAS population, at least at bimonthly intervals in the future, and at least until laboratory experiments have been conducted to determine the potential for establishment of secondary populations in neutral habitats (e.g., in propagated habitat at Glen Canyon Dam), in natural sites, or until other wild populations have been located, in accord with the KAS recovery plan (U.S. Fish and Wildlife Service 1995). After these experiments are complete, and additional populations have been established or discovered, the monitoring schedule should be revisited.

Genetic distinctiveness of all 4 known *Oxyloma* populations in the Four Corners area has been discussed by Miller et al. (in Sorensen and Kubly, unpublished 1997), and indicates the need for a full review of taxonomic and administrative status of this genus.

LITERATURE CITED

Anonymous. 1992. Kanab ambersnail (*Oxyloma haydeni kanabensis*). Endangered Species Technical Bulletin 17(1-2):6.

Blinn, D.W., L.E. Stevens and J.P. Shannon. 1992. The effects of Glen Canyon Dam on the aquatic food base in the Colorado River corridor in Grand Canyon, Arizona. Bureau of Reclamation Glen Canyon Environmental Studies Report II-02, Flagstaff, AZ. Northern Arizona University.

Clarke. A.H. 1991. Status survey of selected land and freshwater gastropods in Utah. U.S. Fish and Wildlife Service Report, Denver, CO.

Clover, E.U., and L. Jotter. 1944. Floristic studies in the canyon of the Colorado and tributaries. American Midland Naturalist 32:591-642.

England, J.L. 1991a. Endangered and threatened wildlife and plants; emergency rule to list the Kanab ambersnail as endangered. Federal Register 56(153):37668-37671.

England, J.L. 1991b. Endangered and threatened wildlife and plants; proposal to list the Kanab ambersnail as endangered and designate critical habitat. Federal Register 56(221):5802058026.

England, J.L. 1992. Endangered and threatened wildlife and plants; final rule to list the Kanab ambersnail as endangered . Federal Register 57(75): 13657- 13661.

Harris, S.A. and L. Hubricht. 1982. Distribution of the species of the genus Oxyloma (Mollusca, Succineidae) in southern Canada and the adjacent portions of the United States. Canadian Journal of Zoology 60:1607-1611.

Huntoon, P.W. 1974. The karstic ground water basins of the Kaibab Plateau, Arizona. Water Resources Research 10:579-590.

Pilsbry, H.A. 1948. Land Mollusca of North America. The Academy of Natural Sciences of Philadelphia Monographs II:521-1113.

Pilsbry, H.A. and J.H. Ferriss. 1911. Mollusca of the southwestern states, V: the Grand Canyon and northern Arizona. Proceedings of the Academy of Natural Sciences of Philadelphia 63:174199.

Randle, T.J. and Pemberton, E.L. 1988. Results and analysis of STARS modeling efforts of the Colorado River in Grand Canyon. National Technical Information Services Report PB88183421/AS .

Sellers, W.D. and Hill, R.H., editors. 1974. Arizona climate 1931-1972. 2nd edition. University of Arizona Press, Tucson, AZ.

Sorensen, J. A. and D.M. Kubly. 1997. Investigations of the endangered Kanab ambersnail: monitoring, genetic studies, and habitat evaluation in Grand Canyon and Northern Arizona, draft report. Arizona Game and Fish Department, Phoenix. Unpublished.

Spamer, E.E. and A.E. Bogan. 1993. Mollusca of the Grand Canyon and vicinity, Arizona: new and revised data on diversity and distributions, with notes on Pleistocene-Holocene mollusks of the Grand Canyon. Proceedings of the Academy of Natural Sciences of Philadelphia 144:21-68.

Stevens, L.E., D.M. Kubly, J.R. Petterson, F.R. Protiva and V.J. Meretsky. 1995. A proposal to assess, mitigate and monitor the impacts of an experimental high flow release from Glen Canyon Dam on the endangered Kanab ambersnail at Vaseys Paradise, Grand Canyon, Arizona. U.S. Bureau of Reclamation Glen Canyon Environmental Studies, Flagstaff, AZ.

Stevens, L.E., F.R. Protiva, D.M. Kubly, V.J. Meretsky and J.R. Petterson. 1997. The ecology of Kanab ambersnail (Succineidae: *Oxyloma haydeni kanabensis* Pilsbry, 1948) at Vaseys Paradise, Grand Canyon, Arizona: 1997 final report. Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Turner, R.M. and M.M. Karpiscak. 1980. Recent vegetation changes along the Colorado River between Glen Canyon Dam and Lake Mead, Arizona. U.S. Geological Survey Professional Paper 1132.

U.S. Fish and Wildlife Service. 1995. Kanab ambersnail (*Oxyloma haydeni kanabensis*) recovery plan. U.S. Fish and Wildlife Service, Denver, CO.

U.S. Fish and Wildlife Service. 1996. Interagency memorandum revising reasonable and prudent measures regarding Kanab ambersnail mitigation prior to the planned high flow from Glen Canyon Dam. U.S. Fish and Wildlife Service Memorandum, Phoenix, AZ.