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To: Joel Wagner, Kevin Berghoff, Norm Henderson, Sandy Borthwick,
Superintendent, Capitol Reef National Park

From: Jill Baron, USGS-BRD

Subject: Draft final report for chemical and biological characterization of CARE
rock pools

Here is our draft summary of ecological processes in Capitol Reef tinajas, along with an assessment of how robust they seem to be. Being a member in good standing of the Order of the Squeaky Wheel, this report has taken a good year longer to produce than I intended. I would be most appreciative if you would review it. If you have comments and criticisms, please send them to me by the end of March. I'll revise and send the final back. Unless you have a better suggestion, I would also like to submit it as a manuscript to Great Basin Naturalist. Thank you all for your patience.

A handwritten signature in cursive script that reads "Jill Baron".

cc: Toben LaFrancois, Boris Kondratieff, Alan Covich, Clifford Martinka

DRAFT

CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF DESERT ROCK POOLS IN INTERMITTENT STREAMS OF CAPITOL REEF NATIONAL PARK, UTAH

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Abstract

Chemical variability and biological communities of rock pools found in small desert drainage basins of Capitol Reef National Park were characterized over eight months in 1994. Neither flooding, drying, or the presence or absence of surrounding wetlands had much effect on chemical composition, which was very dilute and fluctuated in response to rain events. Neither flooding nor drying had much effect on biological communities. Close spatial association of the rock pools, and high numbers of predators in small systems dampened the community structure expected to result from abiotic factors or competition. Summer storms affected only a few drainages at a time, and only a few study pools of significant volume dried completely during the hot and dry summer. This suggests only a portion of the Waterpocket Fold aquatic community is ever disturbed at a time, leaving undisturbed areas as a source of recovery. Pools that were components of wetlands supported greater numbers of species throughout the year, but all pools appeared to benefit from these refugia. In summary, rock pools in Capitol Reef National Park appear to be resilient to climatic variability, and this resilience may also transfer to protection against other disturbances, including atmospheric deposition of strong acid anions and increased visitor use.

Introduction

Because of their scarcity, aquatic environments in the arid Colorado Plateau are extremely important resources for the maintenance of desert ecosystems. Many aquatic resources are ephemeral, characterized by spatial and temporal discontinuities in flow (Stanley and Valett 1992). Ephemeral streams may have running water after storms and snowmelt, but surface water rapidly becomes confined to pools as the running water evaporates or is transpired (Poff and Ward 1989).

Drainages of the Waterpocket Fold in Capitol Reef National Park represent an extreme example of ephemeral stream. Cut directly into sandstone bedrock, these

drainages function as streams only a few days each year. Stream flow occurs during and immediately after rain or snowmelt events. In between precipitation events, water resides in rock pools, many of which are large enough that they rarely dry out. Pools are of two morphologies: those cut directly into sandstone with no surrounding vegetation; and those with riparian borders. The sandy alluvial deposits that allow development of vegetation also allow for groundwater storage. The vegetation surrounding these pools has been characterized by Spence and Henderson (1993), and grades from obligate riparian species such as cattails, willows, and reeds, to upland species common to surrounding desert shrub, pinyon-juniper, and slickrock communities. Spence and Henderson (1983) found an increase in the number and abundance of non-native species associated with pools where cattle grazing had previously occurred, suggesting that these systems are vulnerable to disturbances.

Limited information has been collected on desert rock pools along the Waterpocket Fold in Capitol Reef National Park. Previous investigations have addressed questions regarding the role of disturbance by flooding on aquatic organisms (Haefner and Lindahl 1988, 1991). Similar systems of the Colorado Plateau have received more attention, including a chemical characterization of rock pools in northern Arizona (Van Haverbeke 1990), biological characterizations of temporary pools near Moab, UT (Dodson 1987), and ecosystem-scale studies in Sycamore Creek, AZ (Grimm and Fisher 1992, Fisher et al. 1982, Fisher and Grimm, 1985, 1988, Gray and Fisher 1981). Because assessing the status of physical and biological resources is the essential first step in managing natural resources (Stohlgren 1996), we conducted a six-month intensive study. This study complemented a park-wide

survey of the of 460 rock pools in 80 major drainages (Berghoff 1994). We explored the temporal and spatial variability of pools, and asked the following questions: how variable is pool chemistry and ecology over time and space; does the presence of surrounding vegetation influence water quality, pool volume, or ecology; how important are flooding and drought as disturbances to both water quality and aquatic invertebrate community composition; and how vulnerable are these waters to human-caused disturbances such as increased visitor use, long-range transport of atmospheric pollutants, and global climate change?

Site Description

The Waterpocket Fold, also known as the Capitol Reef, is a north-south trending monocline of Navajo Sandstone that extends some 70 miles north from Lake Powell in southern Utah (Figure 1). The Waterpocket Fold is specifically named for the more than 460 waterpockets, or rock pools that have been carved through water and scouring action in the many small west-east drainages cut into the sandstone. Drainages are typically less than 2 km long, and are made up of a series of pools connected with a drainage depression that conducts water during and after precipitation events. Because there is no upwelling of groundwater in the Navajo Sandstone (Kimball 1988), precipitation is the only source of new water to these drainages. Rock pools range in volume from a few liters to more than one thousand cubic meters of water holding capacity. Some wetlands adjacent to pools can have sediments up to two meters thick.

Mean annual precipitation ranges from 183 mm at Fruita (Capitol Reef NP

headquarters) in the north to 140 mm near Lake Powell. The maximum mean July temperature is 33 °C, while the minimum mean January temperature is -8 °C (Spence and Henderson 1993).

Chemical samples were collected from Cottonwood, Muley, and Fountain Tank drainages in the southern part of Capitol Reef National Park (Figure 1). Two additional drainages, Miahana Tanks and Gil-Scott Gulch, were sampled for aquatic fauna, so that a total of five drainages were characterized biologically. The drainages ranged from broad and open at Muley Tanks, to long and narrow at Cottonwood. The headwaters of Cottonwood Tanks originate in a narrow slot canyon. An attempt was made to select drainages along a broad length of the Waterpocket Fold, and pools were chosen from among the larger, more permanent water bodies.

Methods

Precipitation and Pool Volume

Rain gages were placed near the top and bottom of each drainage, and were monitored weekly. Gages were made from a funnel connected to a coiled tygon tube that ran into a plastic liter bottle. There were slight differences in the amounts collected by each pair of gages; the gage that reported the greatest total precipitation for the summer was arbitrarily chosen to represent rain for each drainage. The volume of each rock pool was measured weekly by geometrical approximation using a half ellipsoid formula.

Chemical analyses

Samples were collected approximately every other week from pools with and without surrounding wetlands in Cottonwood, Muley, and Fountain Tanks between

March and August 1994. Samples were collected for pH and specific conductance in 125 mL HDPE bottles that had been acid-washed in 10% HCl solution, rinsed, and stored full of de-ionized water prior to sampling. Samples collected for major ion analyses were stored in 250 mL HDPE bottles that had also been acid washed with the same procedures. Because access to refrigeration was only weekly, major ion samples were fixed with 0.5 mL chloroform. Samples were filtered in the field with a Nalgene hand pump and Whatman GF/C filters into baked dark-colored borosilicate glass bottles for analysis of dissolved organic carbon. Water temperature was recorded at time of sampling.

Specific conductivity and pH were determined weekly at park headquarters using an Amber Science Inc. model 604 conductivity meter and a Beckman Model 21 pH meter. Samples for major ions were stored refrigerated until transport to Fort Collins, CO, where aliquots were filtered (Whatman GF/C filters) for cation analyses. Major ions were analyzed with ion chromatography, and alkalinity was analyzed with a Gran titration at the USFS Rocky Mountain Forest and Range Experiment Station in Fort Collins, CO (O'Deen et al. 1993). Dissolved organic carbon was analyzed by the USGS Water Resources Division in Boulder, CO using an Oceanography International Model 700 Carbon Analyzer. Sample quality was assessed by calculating the ion percent difference (IPD) between positively and negatively charged ions. All but two of the samples met 15% cutoff criteria for acceptable IPD at ionic strengths of greater than 200 $\mu\text{eq/L}$; these data were discarded (Stensland and Bowersox 1984, O'Deen et al. 1994). Eight DOC samples were collected in duplicate; they compared within 10% over a range of 3-32 mg C/L.

Comparisons of mean chemical characteristics between the three drainages were made using a Student-Newman-Keuls test for studentized range. The studentized range is the difference between the largest and smallest treatment means divided by an estimate of the standard error of each single treatment mean. The size of the difference required for significance changes with the separation of the means in the rank order (Ferguson 1981).

Comparison of the chemistry of pools adjacent to wetlands with pools surrounded by sandstone was done with a Wilcoxon Matched Pairs Signed-Rank Test. Because the test assumes independence between the two groups being compared, we used a reduced data set. Connection of the pools during flooding events invalidates the assumption of independence. No vegetated vs. unvegetated comparisons were run for Cottonwood drainage, since rain events caused observed flow between the Cottonwood pools through July and August. Pools in Muley drainage were separated all summer, as no rain event was strong enough to cause spillage from the top pools, and pools in Fountain drainage overflowed only once, in late July. Chemical analyses from after the flooding event in Fountain were excluded from the analysis.

Biological Analyses

Aquatic fauna from macrozooplankton to vertebrates were sampled weekly from March through August 1994. Additional collections were made in September 1993, January, March, and September 1994. Macrofauna were defined as any animal larger than the mesh size (1 mm²) of a standard dip net. Organisms were field identified to the lowest practical taxon, usually species, based upon previous laboratory

identifications, and their life history stage (juvenile or adult) was noted. Bottle trap and light trap collections were used for precise identification of adult insects. A voucher collection of the invertebrate samples has been deposited in the C.P. Gillette Museum of Arthropod Diversity, Department of Entomology at Colorado State University.

Semi-quantitative measures of abundance were recorded as a rank based upon three standard dip net sweeps of each pool. The sweeps were taken from different sides of the pool, and the sample were combined in a single white pan. Organisms were then counted for ordination into the following ranks: 0 - no individuals; 1 - 1-10 individuals; 2 - 11-50 individuals; 3 - 51+ individuals. Three additional sweeps were then taken to insure consistent monitoring of rare species, and any taxa found that were not present in the first three sweeps were given an abundance rank of 1. Organisms were returned to the pool after enumeration and identification.

Common methods for quantitatively sampling the pools were field tested in February and March 1994. These were found to be unreliable and destructive. In such small systems it was important to sample non-destructively to avoid affecting pool communities through direct removal of pool organisms. Both a 30-micron plankton tow and standard Ekman dredge produced variance as large as population means. The rock pool organisms do not, however, fit other characteristics expected of a Poisson distribution that would exhibit this variance. (Ott 1984). Rock pool communities can not be assumed to be independent events, but are affected by the previous community. Standard sampling methods were also subject to other problems, such as not accounting for clustering of pool organisms and escape tactics by most adult beetles and hemipterans. The portable box method of quantification

was found suitable only for shallow pools of less than 1.2 m, and was ineffective for quantifying the more abundant benthos such as chironomid midge larvae.

Cluster analysis and a transformed Pearson correlation matrix using the 17 most common species were used to examine the biological structure of rock pool communities. Species chosen represent the major functional groups as well as the most abundant pool fauna. Pearson correlation coefficients between each species' abundance for a given period were transformed into a distance measure, and the data were then treated as distances in a cluster analysis to determine whether or not groups or organisms could be considered non-randomly associated. Groups of species that appeared together as clusters between zero and 0.3 were considered non-random associations. This analysis was performed three times, using data from weeks of March 15, June 10, and July 14.

A repeated measures, nested design ANOVA was used to analyze differences between pools in wetlands and those in bedrock through time. Drainage was treated as a random variable to allow inference from the statistical model to the population of all drainages in the Waterpocket Fold. Between subject factors were drainage, pool, and type. Period was the only within subject factor.

The effect of disturbance, defined as flooding, on the number of species present and ratio of juvenile to adult life history stages was evaluated with t-tests. The effect of pool volume and temperature on biological parameters was examined with Pearson correlation coefficients.

Results

Hydrology

The summer of 1994 was unusually dry, even for Capitol Reef National Park. The total precipitation at Cottonwood, Muley, and Fountain Tanks was 66.1, 27.2, and 31.0 mm, respectively (Figure 2). According to the 38-yr record analyzed by Spence and Henderson (1993) one third of the annual precipitation, 46-60 mm, usually falls as thunderstorms in July and August (Julian dates 182-243). In 1994 the July and August combined precipitation was 22.7, 5.0, and 31.9 mm at Cottonwood, Muley, and Fountain Tanks, respectively.

The volumes of all pools with vegetation increased with rain events, although only five events over the entire sampling period caused flooding, defined as overflow from the pools. Flooding was observed in Cottonwood and Fountain Tanks, but not in Muley Tanks. Normalized values (against maximum measured volume) with time showed that pool volumes covaried with rain events for pools with and without surrounding vegetation (Figure 2). There appeared to be less variation in volume in pools with surrounding vegetation and soils, presumably because of the dampening effects of evapotranspiration and soil water storage.

Pool water temperatures warmed over the summer from lows in March to mid-April of 4-18 °C to highs of 32-35 °C in June, July and August (Figure 3). Most pool waters after mid-April had temperatures in the 22-25 °C range, regardless of whether they were within wetlands or bedrock. Pools were sampled at different times of day. Since there was probably a wide diurnal variability in temperature the values in Figure 3 should be interpreted as within a range of measured temperatures for any given week.

Chemical Characterization

Fountain Tanks solutes were two to three times more concentrated than either

Cottonwood or Muley Tanks (Table 1). Exceptions were the major plant nutrients potassium, nitrate, and phosphate. The mean pH, 7.6, of Fountain Tanks was slightly higher than the pH of Cottonwood and Muley Tanks, 7.0 and 7.3, but the difference between Fountain and Muley Tanks was not significant. Similarly, chloride concentrations were slightly higher for Fountain Tanks, but significantly different only for Fountain and Cottonwood Tanks. Ammonium was lower and less variable in Fountain Tanks than the other two drainages. Concentrations in Cottonwood and Muley Tanks were not significantly different from each other, with the exception of dissolved organic carbon (DOC), which was significantly higher at 10.6 mg C/L, and more variable, in Muley Tanks than in either of the other two drainages. Concentrations of DOC averaged 6.3 and 4.3 for Cottonwood and Fountain Tanks, respectively.

Solutes became more concentrated in both vegetated and unvegetated pools over the summer, as can be seen in Figure 4. Dissolved organic carbon at Muley Tanks reached concentrations as high as 13.2 mg C/L, possibly because a small rain storm flushed organic material into the pools from the surrounding watershed. There was no significant difference in concentrations within each drainage between pools surrounded by rock or vegetation. A plot of conductance versus normalized pool volume using all pools shows a negative relation (Figure 5). Drying accounted for only 0.29% of the change in measured conductance for the entire data set, but there was variability by drainage. In the Fountain Tanks 68% of conductance variability was explained by pool drying, while 30% and 27% was explainable for Muley and Cottonwood Tanks, respectively.

Biological Characterization

There were 59 separate macroinvertebrates and vertebrate taxa found (Table 2). These included fathead minnows, *Pimephales promelas* (Rafinesque), in the bottom Miahana pool that terminates close to Hall's Creek, a stream in which this species is common. Anurans were represented by spadefoot toad, *Scaphiopus intermontanus* Cope, the canyon treefrog, *Hyla arenicolor* Cope, and two other toads, *Bufo woodhousei* Girard, and *Bufo punctatus* Baird and Girard. Fairy shrimp, *Branchinecta lindahli*, were observed in pools within the park, but not in any of the study pools. Another crustacean, *Streptocephalus texanus* Packard, occurred in all pools. A snail, *Physella* sp., was observed in all of the drainages. The remainder of the taxa were arthropods, present in both larval and adult forms.

Larvae of the caddisfly *Limnephilus taloga* Ross, were common throughout the winter and spring months, and larval activity was even observed under ice in January. The mayfly *Callibaetis pictus* Eaton was found as larvae throughout spring, summer and fall.

Aquatic beetles were well represented in all pools. The diverse assemblage included predaceous dytiscid diving beetles from the minute *Liodes affinis* Say to the larger *Dysticus* sp. Common hydrophilid water scavenger beetles included *Berosus punctatissimus* LeConte and *Tropisternus ellipticus* LeConte. The water scavenger beetles are predaceous as larvae, but collector-gatherers as adults (Merritt et al. 1984).

Water bugs, Notonectidae and Corixidae, were common throughout the year. The crawling water bug family Naucoridae was also found in late summer. The

neuston complex consisted of water striders *Aquarius remigis* Say, *Microvelia torquata* Champion, and the whirligig beetle *Gyrinus plicifer* LeConte. Dipterans were represented by one species of tabenid, various common chironomids, and a few mosquito species.

Most species in the rock pools were also common to other aquatic habitats of the Colorado Plateau. Probably for this reason, no significant clusters of species were found, indicating no non-random associations between species in the pools (Figure 6a-c). This implies all species were closely related to each other, which is likely the result of close ecological association and proximity and similarity of the rock pools. The alternative, which was not observed, would have shown clusters of species beginning between 0.0 and 0.4 and remaining distinctly clustered to the point of least correlation, which was $\pi/2$ on the scale used. Many coleopterans and hemipterans have highly mobile aquatic adult stages, enabling long distance dispersal from pool to pool. Other organisms have terrestrial adult mating and dispersal stages, such as the mayflies, caddisflies, dragonflies, and anurans. Crustaceans such as the anostracans rely on dispersal of eggs by animal or wind vectors. Most organisms in the pools, 62%, were predators. Thirty four percent were herbivorous collector/gatherers and scrapers, while the remainder were collector/filter feeders.

The proportion of juveniles in the rock pools decreased significantly throughout the spring and summer (Figure 7a), but there was no difference in the proportion of juvenile versus adult stages between pools with vegetation versus those surrounded by rock ($p=0.586$). There were more species in pools that were components of wetlands (mean of 10.5, std. dev of 4.4, $n=116$) than pools situated in bedrock only

(mean of 7.2, std. dev. of 3.2, $n=116$), although numbers of species declined in both types of pools from the spring through the summer (Figure 7b). Neither pool volume ($p=0.54$) nor temperature ($p=0.74$) affected the number of species present.

The effects of flooding on species numbers was not significant, either when comparing numbers of species within all pools before and after flood events ($p=0.54$), or when rock pool species numbers were treated separately from those surrounded by vegetation ($p=0.87$). Data were normalized by taking their square roots. The two middle flooding events in Cottonwood drainage (see Figure 2) were not used to eliminate the potential for autocorrelation. The first and last storms were considered sufficiently separate events to satisfy conditions of independence.

A similar test was performed to examine the responses of pools to drying as a disturbance. Such disturbances were relatively infrequent (compared with pools studied by Dodson 1987). Pre-drying numbers of species and juvenile to adult ratios were tested against post-drying parameters directly after the first filling event. Both variables were normalized with square root transformations. Neither were significantly different as a result of drying (species numbers, $p=0.16$; life history stage ratio, $p=0.49$).

Discussion

Neither flooding nor drying had much effect on biological communities. Close spatial association of the rock pools, and high numbers of predators in small systems dampened the community structure expected to result from abiotic factors or competition (McLachlan 1985, Morin 1987, Schneider and Frost 1996). Summer

storms affected only a few drainages at a time, and only a few study pools of significant volume dried completely during the hot and dry summer. This suggests only a portion of the Waterpocket Fold aquatic community is ever disturbed at a time, leaving undisturbed areas as a source of recovery. Pools that were components of wetlands supported greater numbers of species throughout the year, but all pools appeared to benefit from these refugia.

The rapidity of recovery suggests these systems display great variability, but also great resilience, a conclusion also reached in a study of macroinvertebrate recovery of flash floods in Sycamore Creek, AZ (Grimm and Fisher 1989). Flood events introduce nutrients from precipitation and upstream. This new food supply for primary production and consumption allows for rapid re-establishment of macroinvertebrates. Grimm and Fisher (1989) hypothesize flood events are necessary to the maintenance of macroinvertebrate populations because they refresh the food supply for fast-growing organisms.

Some chemical constituents, such as acid-neutralizing capacity, increased over an order of magnitude during the study period, concurrent with declining pool volume, but rapidly decreased after a rain event (Figure 4). Other solutes were not as dynamic as we assumed they would be as a result of evaporation- and transpiration-caused concentration. Pool chemistry was very dilute, and was not significantly influenced by the presence or absence of wetlands.

The chemical composition and biological communities of Capitol Reef National Park rock pools appear to be adapted to climatic disturbances, but predisposition to floods or droughts may not mean equal adaptation to other types of stress. Increased

visitor use and atmospheric deposition of pollutants are two additional disturbances that may lead to different responses of tinaja ecosystems; we discuss these below.

Effects of increasing numbers of visitors/tourists to these remote sites include increased trampling, introduction of non-native plants and animals, eutrophication, and possibly development of soap and oil films on pools if people bathe in the water. We expect consequences to rock pool systems from infrequent visitor disturbances will be transient, at most lasting until the next major flood. Films on water surfaces probably pose the greatest threat by preventing gas exchange and coating organisms with residue. More frequent exposure to visitor use may lead to population depletions, but given the life histories of most organisms and the proximity of more pools, communities should return to normal if visitor use is restricted.

Nitrate and phosphate were somewhat lower in concentration in the study pools than reported for an ephemeral stream in Arizona (Fisher and Grimm 1983). Alkalinity and conductivity were similar in concentration to those reported by Fisher and Grimm (1983) for the desert ephemeral stream, and conductivity was similar to that reported by Van Haverbeke (1990) for ephemeral rock pools. Nitrate concentrations of 4.8-6.5 $\mu\text{mol/L}$ were much lower than was measured in summer wet precipitation from the two nearest National Atmospheric Deposition Program sites, Green River and Bryce Canyon, UT. Summer volume weighted mean nitrate concentrations at these two sites were 29.1 $\mu\text{mol/L}$ and 43.4 $\mu\text{mol/L}$, respectively (NADP/NTN 1996). Wet deposition of nitrogen species has increased in some western states as a result of increased urban, agricultural and industrial activities (Lynch et al. 1995, Baron and Campbell in press), but the threats to aquatic ecosystems occur mainly where extremely low acid-

neutralizing capacity leads to acidification (Stoddard 1994). Rock pool ANC values were greater than 500 $\mu\text{mol/L}$, so acidification from nitrate deposition is not a threat. Eutrophication is another outcome of elevated nitrate deposition, but the pools were already eutrophic, so this, also, is not a possible threat. Although we did not measure algal productivity (to assess trophic status), filtration of 125 ml water for DOC analyses sometimes took more than five hours due to algae clogging the filter paper (LaFrancois, personal observation).

Sulfate concentrations in Cottonwood and Muley Tanks (21.9 $\mu\text{mol/L}$, and 27.1 $\mu\text{mol/L}$, respectively) were similar to sulfate measured in precipitation (10.7 $\mu\text{mol/L}$ at Bryce Canyon, 25.1 $\mu\text{mol/L}$ at Green River). Sulfate was higher in the Fountain Tanks, with a mean concentration of 38.5 $\mu\text{mol/L}$. Fountain Tanks is the southernmost set of pools for which we analyzed chemical composition, and closest to regional industrial centers that are dominant sources of sulfur oxides to the region (Eatough et al. 1996). Although it is possible that the higher sulfate values in Fountain Tanks are due to deposition, and deposition certainly contributes to the solute load of the pools, it is more likely that a slight change in bedrock mineralogy is the source of solutes. The highest concentrations of ANC, Ca, Na, Mg, and Cl of all the pools sampled were also found in Fountain Tanks, and this suggests the difference in water quality is due to different bedrock composition rather than a deposition problem. Deposition of sulfate has decreased significantly throughout the United States (Lynch et al. 1995). It is our opinion that unless sulfur emissions increase again, atmospheric deposition does not pose a threat to the integrity of Capitol reef rock pools.

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Figure Captions

Figure 1. Map showing location of Capitol Reef National Park, and enlargements of the three study drainages where both chemical and biological analyses were conducted: A) Cottonwood Tanks; B) Muley Tanks; and C) Fountain Tanks.

Figure 2. Precipitation (bars) and pool volumes (lines) for Cottonwood, Muley, and Fountain Tank drainages during the period of study, March through August 1994.

Rain events that caused flooding are marked with an asterisk. Flooding was defined as overflow from one pool to another.

Figure 3. Pool temperatures ($^{\circ}\text{C}$) during the study period. Circle represent temperatures of pools with wetlands, triangles are pools surrounded by bedrock.

Figure 4. Dynamics of specific conductance ($\mu\text{S}/\text{cm}^2$), acid neutralizing capacity

(ANC, in $\mu\text{eq/L}$), and dissolved organic carbon (DOC, in mg C/L) over time in a) Cottonwood Tanks, b) Muley Tanks, and c) Fountain Tanks.

Figure 5. Relation of specific conductance ($\mu\text{S/cm}^2$) with normalized pool volume. Volume was normalized by dividing weekly volumes by the maximum pool volume measured during the study period.

Figure 6. Average linkage cluster analysis for aquatic species collected in a) April, b) late June, and c) August of 1994. On a scale of 0.00 to 3.14 (π), groups that form near 0.00 and remain distinct to 1.57 ($\pi/2$) would be considered non-random associations of species abundances.

Figure 7. Characteristics of aquatic organisms in Capitol Reef rock pools over time: a) Average ratio of juvenile to adult stages; and b) species numbers. Circles are numbers in pools with vegetation, and triangles are numbers in pools surrounded by bedrock.

Table 1. Mean concentrations (and standard deviations) of major ions from three drainages of Capitol Reef National Park, Utah. Means with the same letter are not significantly different. Solutes are reported as $\mu\text{mol/L}$ unless otherwise indicated.

ANALYTE	COTTONWOOD TANKS		MULEY TANKS		FOUNTAIN TANKS	
	Mean (s.d.)	Sig.	Mean (s.d.)	Sig.	Mean (s.d.)	Sig.
pH	7.0 (0.4)	A	7.3 (0.9)	A	7.6 (0.5)	B/A
Conductivity, $\mu\text{S/cm}$	52.5 (34.3)	A	62.1 (41.5)	A	114.8 (49.5)	B
Calcium	192.1 (157.2)	A	217.1 (152.2)	A	524.0 (279.4)	B
Magnesium	57.6 (41.2)	A	65.8 (49.4)	A	135.8 (61.7)	B
Sodium	17.4 (13.1)	A	17.4 (17.4)	A	34.8 (13.1)	B
Potassium	32.25 (23.0)	A	43.5 (38.4)	A	28.1 (15.3)	A
Ammonium	22.2 (33.3)	A	33.3 (44.4)	A	5.5 (11.1)	B
Chloride	16.9 (11.3)	A	19.7 (22.6)	A	31.0 (11.3)	B/A
Nitrate	4.8 (12.9)	A	4.8 (9.7)	A	6.5 (8.1)	A
Sulfate	21.9 (13.5)	A	27.1 (3.1)	A	38.5 (15.6)	B
Phosphate	0.0 (0.0)	A	0.0 (0.0)	A	0.0 (0.0)	A
ANC	502.8 (436.0)	A	555.3 (458.4)	A	1226.8 (729.8)	B
Silica	13.3 (1.7)	A	8.3 (1.7)	A	23.3 (18.3)	B
DOC, mg C/L	6.3 (2.6)	A	10.6 (9.5)	B	4.3 (1.7)	A

Table 2. Species list of macroinvertebrate and vertebrate rock pool species collected September 11, 1993 to September 23, 1994, and October 25 1995 in Capitol Reef National Park, Utah. The most abundant taxa (marked with *) were included in a cluster analysis for community assemblages.

Vertebrata:

Cyprinidae:

Pimephales promelas Rafinesque

Anura:

Scaphiopus intermontanus (Cope)*

Bufo punctatus Baird and Girard*

Bufo woodhousei Girard*

Hyla arenicolor Cope*

Gastropoda:

Physella sp.*

Nematomorpha:

Arthropoda:

Class Anostraca:

Streptocephalus texanus Packard*

Class Conchostraca:

Eulimnida texana Packard

Class Notostraca:

Triops longicaudatus LeConte

Class Arachnida:

Hydrachnida*

Class Hexapoda:

Collembola:

Isotomidae

Ephemeroptera:

Baetidae

Callibaetis pictus Eaton*

Odonata:

Aeshnidae

Aeschna multicolor Hagen*

Aeschna palmata Hagen*

Anax junius (Drury)*

Libellulidae

Sympetrum obstrusum (Hagen)

Libellula saturata Uhler

Lestidae

Archilestes grandis (Rambur)*

Coenagrionidae

Enallagma cyathigerum (Charpentier)

Argia sp.

Table 2 (continued).

Hemiptera:	
Notonectidae	<i>Notonecta kirbyi</i> (Hungerford)* <i>Notonecta undulata</i> (Say) <i>Buenoa margaritacea</i> (Torre-Bueno)
Naucoridae	<i>Ambrysus mormon mormon</i> Montandon
Gerridae	<i>Aquarius remigis</i> (Say)
Veliidae	<i>Microvelia torquata</i> (Champion)
Corixidae	<i>Graptocorixa abdominalis</i> (Say)*
Belostomatidae	<i>Lethocerus americanus</i> (Leidy)
Trichoptera:	
Limnephilidae	<i>Limnephilus taloga</i> Ross*
Coleoptera:	
Gyrinidae	<i>Gyrinus plicifer</i> LeConte*
Hydrophilidae	<i>Hydrophilus triangularis</i> (Say) <i>Tropisternus ellipticus</i> (LeConte) <i>Hydrochara lineata</i> (LeConte) <i>Berosus punctatissimus</i> LeConte* <i>Laccobius</i> sp.
Dytiscidae	<i>Agabus disintegratus</i> (Crotch) <i>Agabus tristis</i> Aube <i>Agabus lugens</i> LeConte <i>Agabus semivittatus</i> LeConte <i>Rhantus gutticollis</i> (Say)* <i>Laccophilus maculosus decipiens</i> LeConte* <i>Stictotarsus striatellus</i> (LeConte) <i>Liodessus affinus</i> (Say)* <i>Neoclypeodytes discretus</i> (Sharp) <i>Hygrotus collatus</i> (Fall) <i>Thermonectus marmoratus marmoratus</i> (Hope) <i>Uvarus</i> sp. <i>Dytiscus</i> sp.
Haliplidae	<i>Peltodytes</i> sp.

Table 2 (continued).

Diptera:

Tabanidae

Tabanus sp.

Chironomidae

Chironomus sp.*

Polypedilum sp.

Phaenopsectra dyari (Townes)

Phaenopsectra sp.

Micropsectra sp.

Alotanypus sp.

Ceratopogonidae

Bezzia sp.

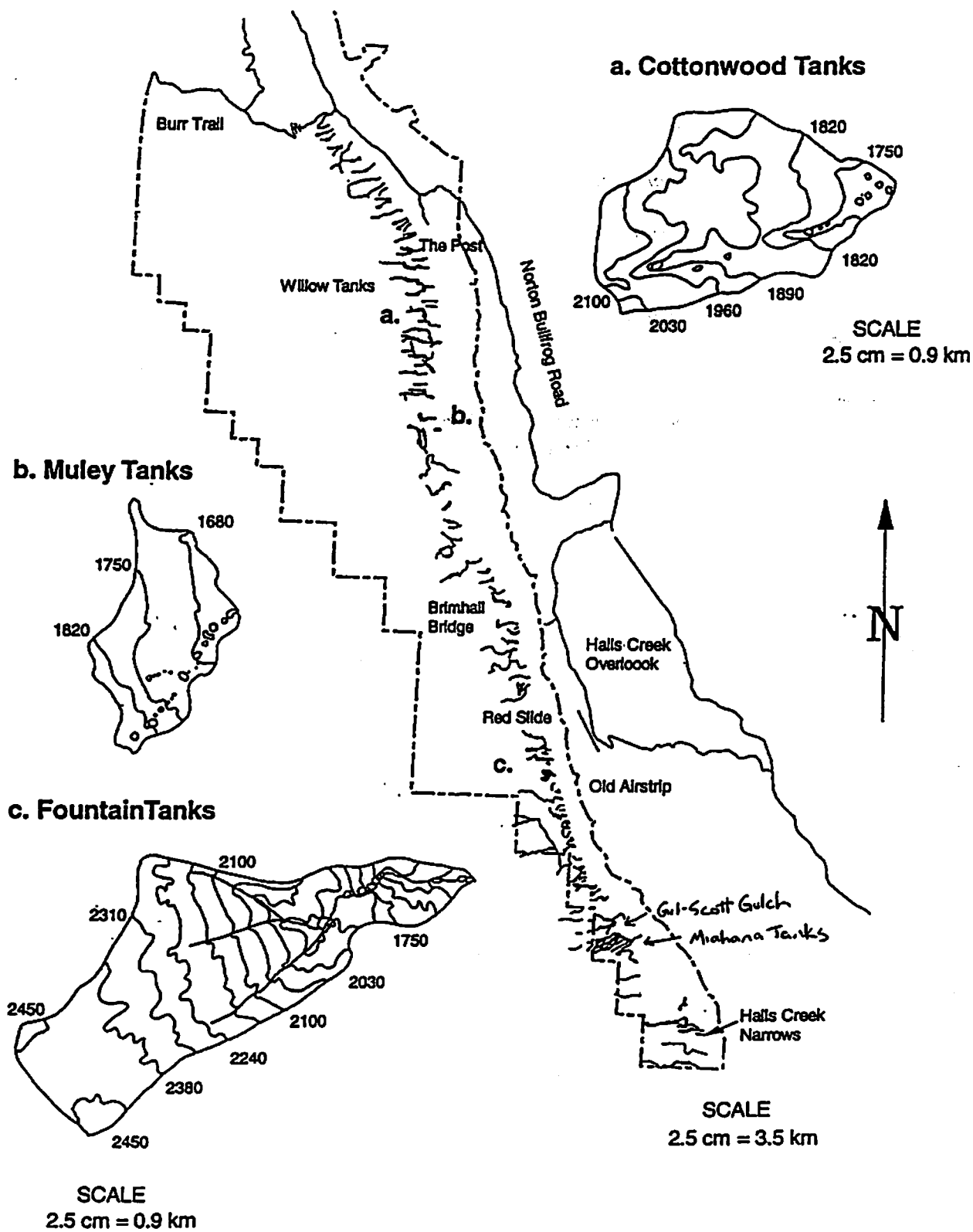
Culicidae

Anopheles fransiscans (McCracken)

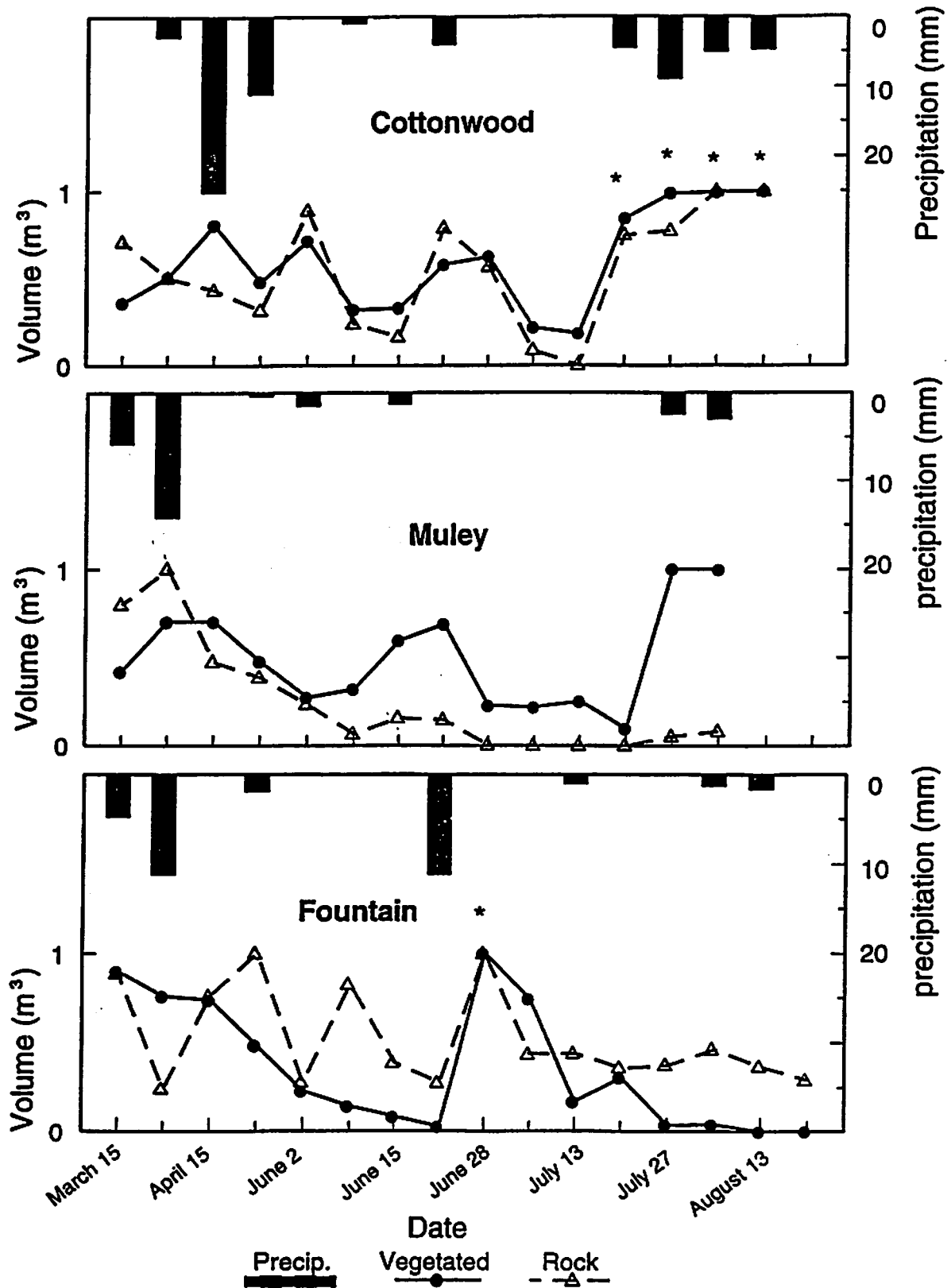
Culex tarsalis Coquillett

Culiseta inornata (Williston)

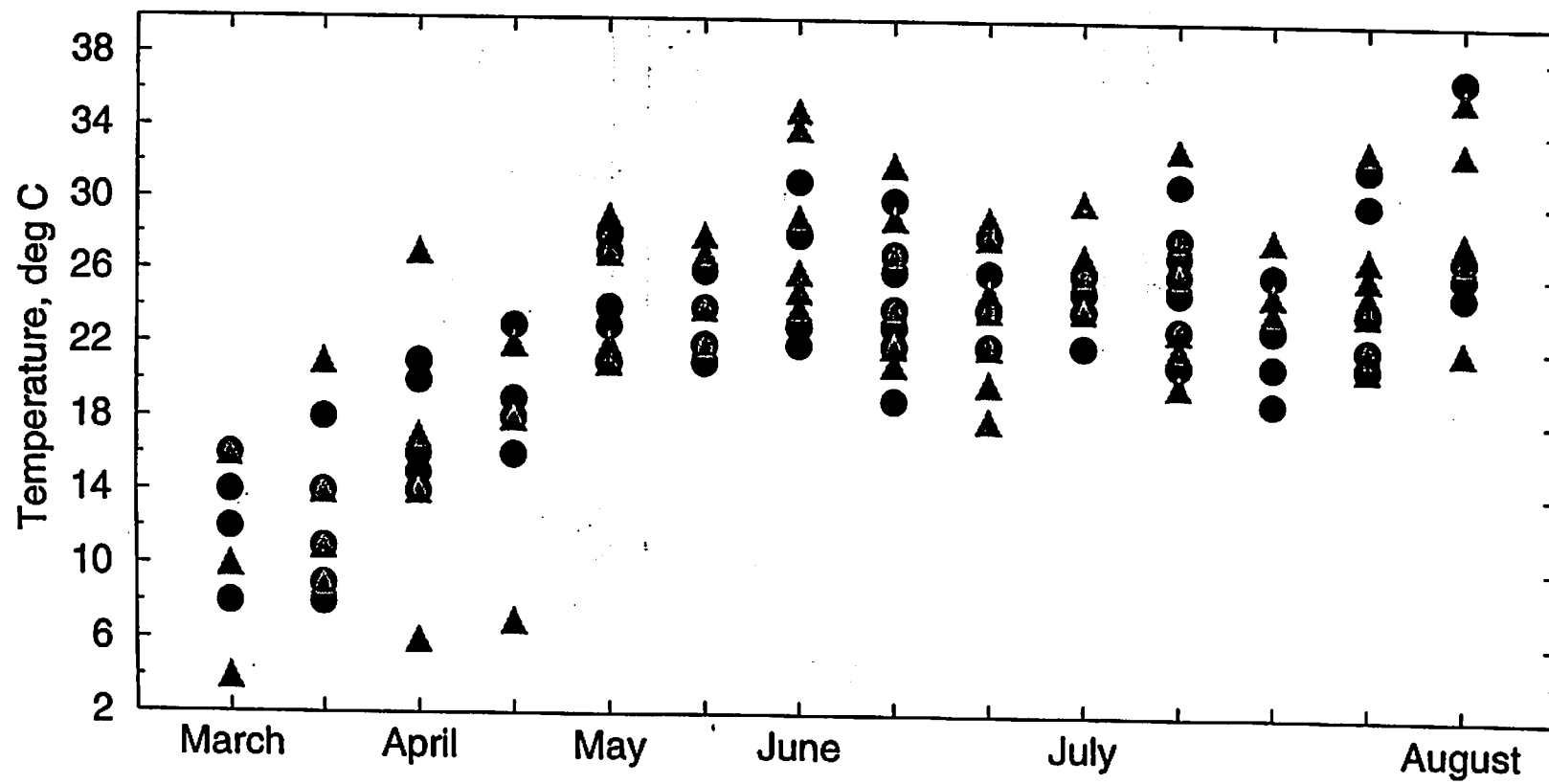
Culiseta sp.



Capitol Reef National Park Pool Volumes and Precipitation, 1994

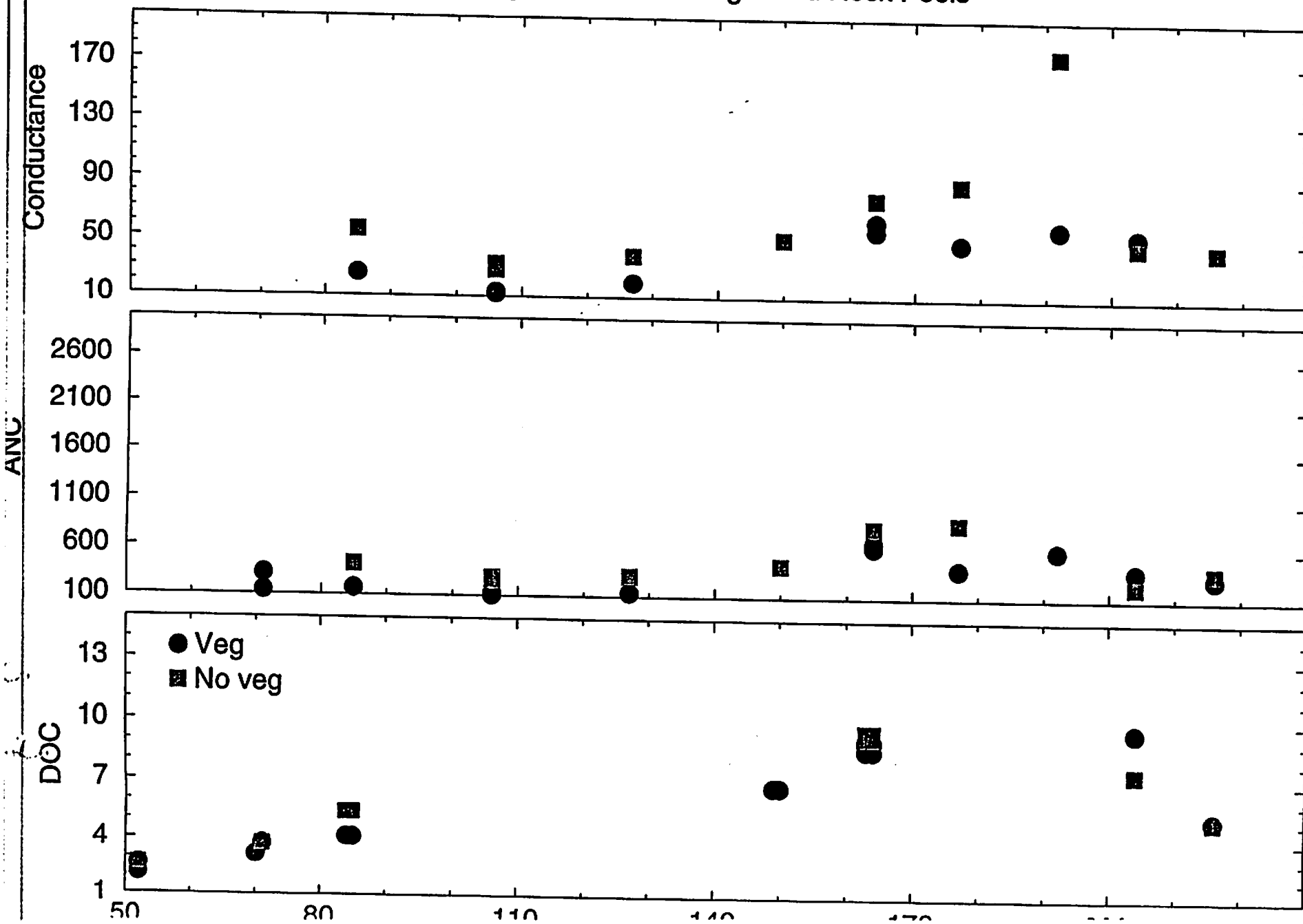


Temperature of Pools



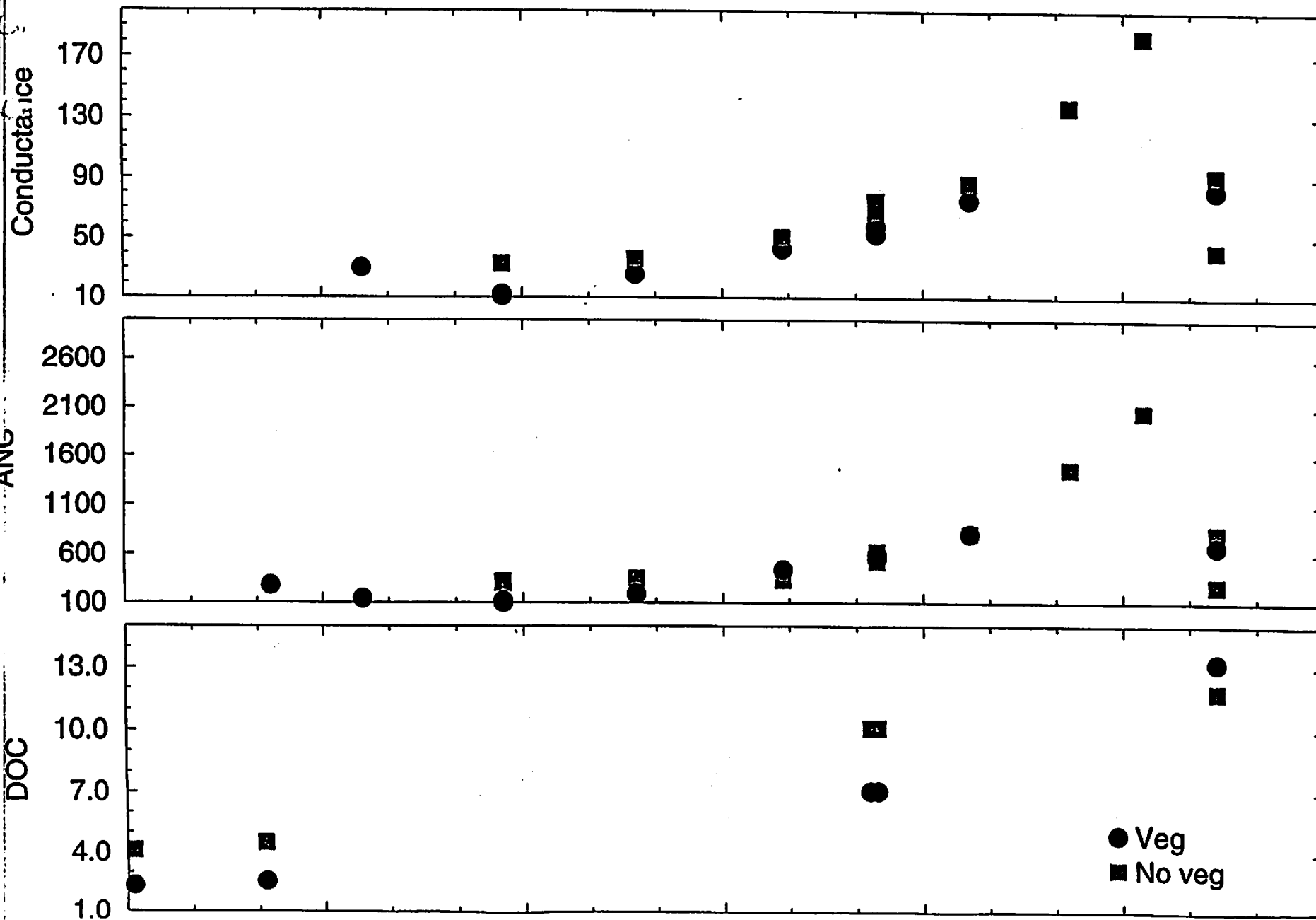
Cottonwood Tanks

Vegetated and Unvegetated Rock Pools



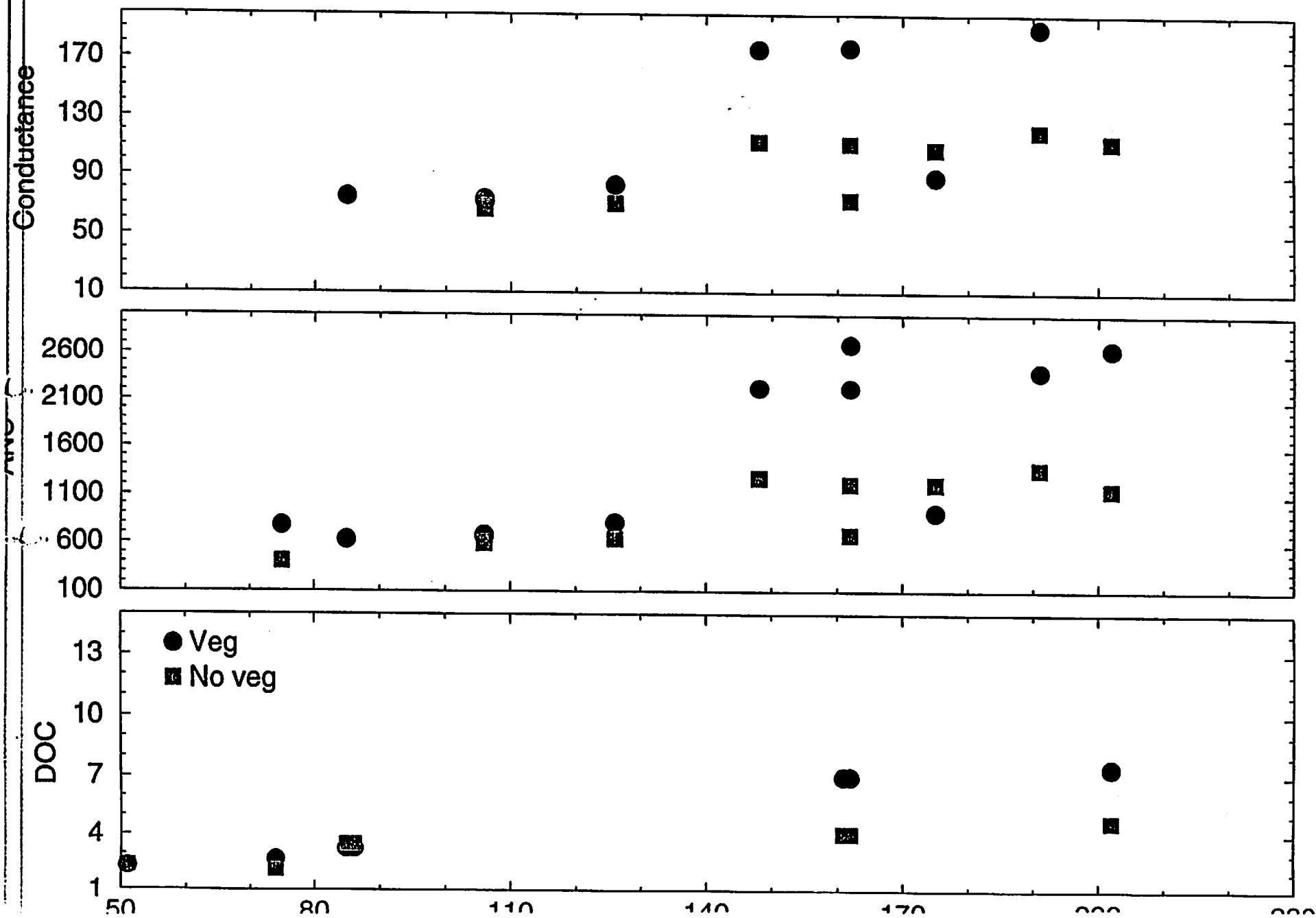
Muley Tanks

Vegetated and Unvegetated Rock Pools

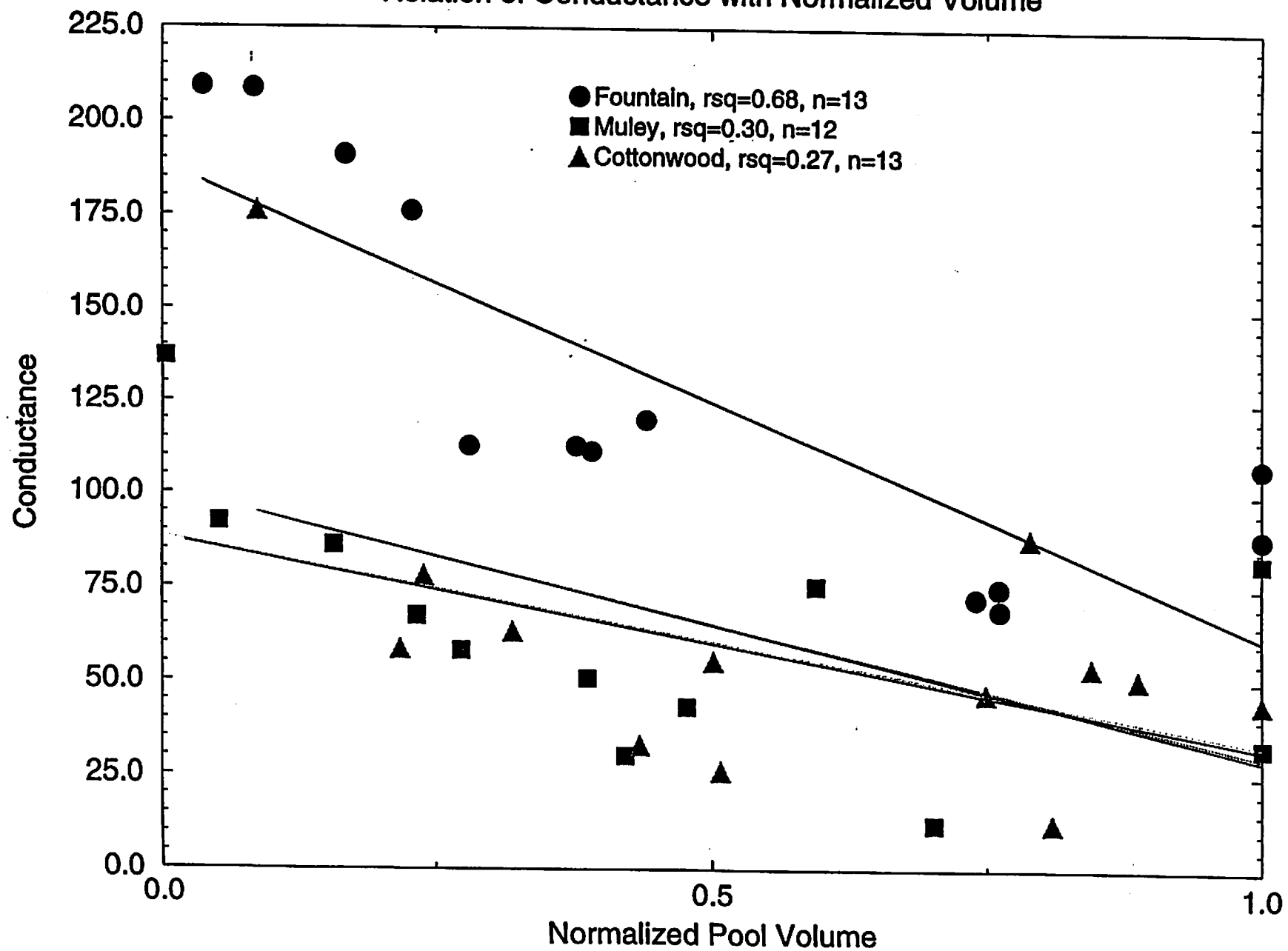


Fountain Tanks

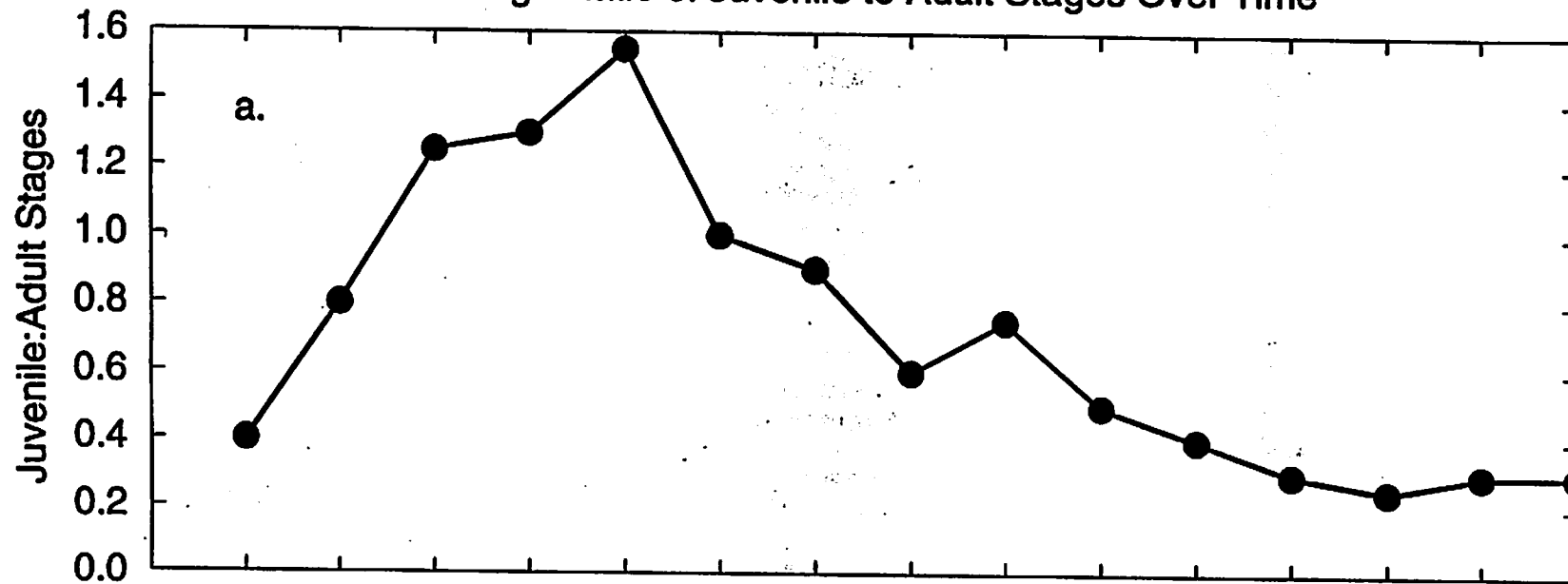
Vegetated and Unvegetated Rock Pools



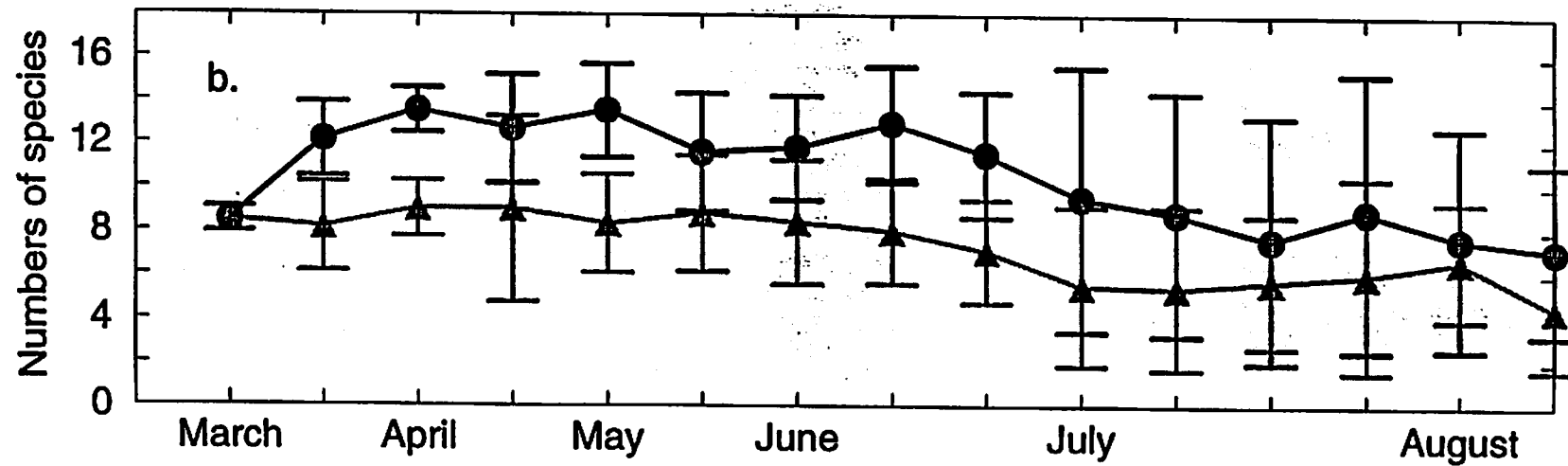
Relation of Conductance with Normalized Volume

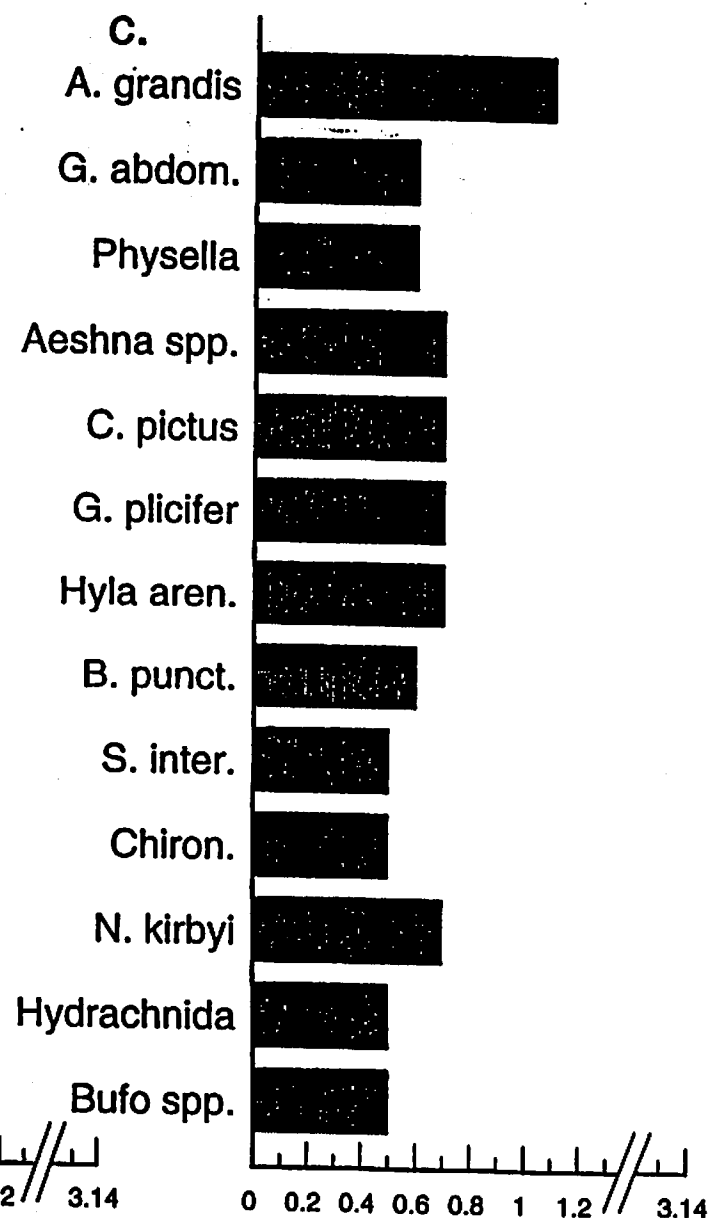
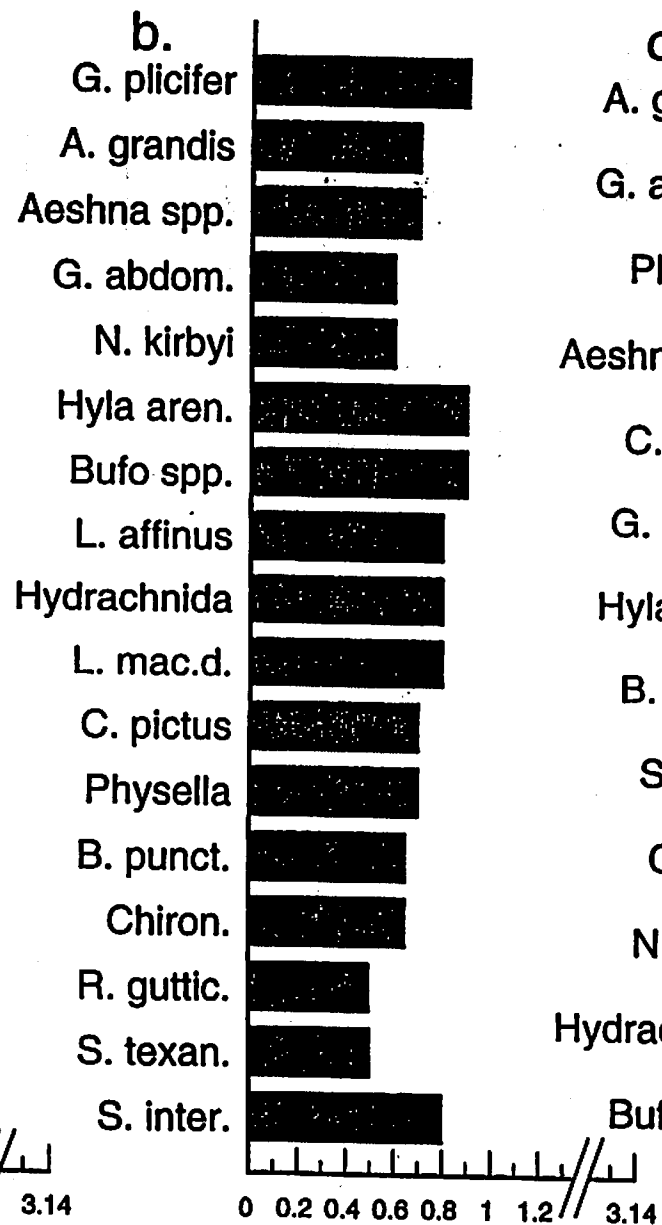
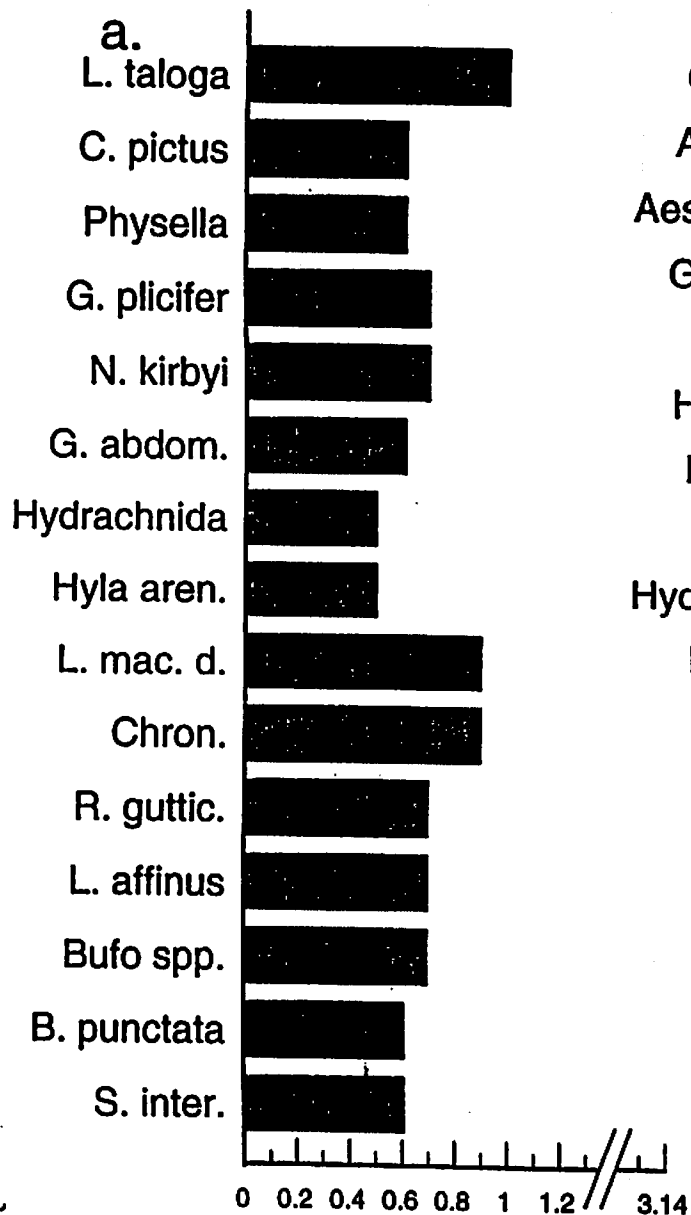


Average Ratio of Juvenile to Adult Stages Over Time



Species Numbers over Time





Average distance between clusters