

Research Proposal:

WATERPOCKET ECOLOGY/MACROINVERTEBRATE RESEARCH
CAPITOL REEF NATIONAL PARK, UTAH

Submitted to:

National Park Service
Capitol Reef National Park
Torrey, Utah 84775

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by:

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INTRODUCTION

Water-filled rock pools are ephemeral aquatic habitats, appearing wherever expansive areas of rock containing depressions are exposed. These natural depressions are eroded into bedrock primarily by stream action, wind and solution processes (Bryan 1920). A variety of terms are used worldwide for these aquatic habitats when they occur in semi-arid and arid climates (Elston 1917, 1918), but those in most common use in the arid western U. S. include: rock pool, rock tank, tank, scour depression, waterpocket and tinaja (Elston 1917, Bryan 1920). The latter term "tinaja", a Spanish word for bowl or jar, is in most common use in deserts of the southwest U. S.

Tinajas are major resources in arid regions where water is a crucial limiting factor. In deserts of the American southwest they provide important water reservoirs for water-dependent terrestrial invertebrates and vertebrates and were historically critical to survival of aboriginals and explorers (Brown and Johnson 1983). Much research has been conducted on the ecology of generic temporary waters (see recent reviews by Wiggins et al. 1980 and Williams 1985). These are defined by Williams (1985) as any waterbody occupying a discrete inland basin, containing fresh or saline water and which dries out for some time each year. Vernal ponds and playas are examples of this type of water. Consequently, it is their location in bedrock and their absence of persistent sediments which differentiates tinajas from other temporary pools.

In contrast to other temporary waters, much less is known about the ecology of rock pools (Dodson 1987), due largely to their location in remote regions (MacLachlan 1981). Three "centers" of rock pool research are the fresh-to-saline pools on Baltic Sea islands (Ranta 1982), rain-filled rock pools in Malawi, Africa (McLachlan and Cantrell 1980, McLachlan 1983) and southern South Australia (Bayly and Williams 1973, Bayly 1982). Research on tinajas in the arid southwest U. S. is even more scant, limited to less than a dozen journal articles (referenced in Brown and Johnson 1983 and Dodson 1987).

Limnological interest in temporary pools has focused mainly on the severe ecological stresses assailing their biota (Williams 1985). Physical/chemical factors associated with permanence are the most apparent stressors to the biota of temporary waters in arid climates. Stressors put forth by Williams (1985) as the most significant include: desiccation, chemical variation (high and ionically variable salinity), high temperature, low dissolved oxygen, high light intensity, habitat isolation, astatic (fluctuating) water levels, and general short-term instability and long-term unpredictability of environmental factors. Along with these factors, I include flooding as an additional stress or disturbance to the biota of tinajas in drainage channels. Fisher et al. (1982) and Fisher (1986) demonstrated flooding and its scouring effect to be the most frequent and severe natural disturbance in desert stream drainages. The thrust of this proposed research will be to examine the influence of these stressors on tinaja ecology in Capitol Reef National Park.

In addition to "natural" stressors, tinajas in Capitol Reef National Park are subjected to the additional "non-natural" disturbance of livestock (Capitol Reef National Park 1984). Because most tinajas contain scant permanent sediment, they have little riparian vegetation to be grazed by cattle or lateral banks to be eroded by livestock trampling. Consequently, livestock impacts on tinajas are anticipated to be somewhat different than reported for streams, ponds and marshes, where cattle impacts have been better researched. The most significant negative influences of livestock on streams and ponds are destruction of riparian vegetation, alteration of channel morphology, bank erosion, increases in suspended sediment and turbidity, fertilization by excretory products and reductions in populations of resident fishes (Meehan and Platts 1978). Cattle use tinajas primarily for drinking, not grazing; indeed, tinajas often provide the only source of water available to range livestock. Fouling of tinajas by livestock feces and urine, therefore, presents the most obvious impact of their presence. Unlike streams where livestock excrement is diluted by upstream flow, gradual desiccation of effectively closed-basin tinajas concentrates salts, nutrients, organic matter and potential toxicants present in livestock excrement.

Effects of animal excrement on rock pool ecology have been reported in the literature. Feces from birds (Ganning and Wulff 1969) and from wild felids (Osborne and McLachlan 1985) were shown to be the largest source of nutrients and terrestrial organic matter to otherwise undisturbed rock pools. In general, standing waters in arid environments are impoverished in both nutrients and terrestrial organic matter (Galat et al. 1981, Galat 1986). Nevertheless, potential impacts to aquatic biota from small inputs of wild bird and small mammal feces are certainly much less than excrement from moderate densities of large ungulates. A second purpose of this proposed research will, therefore, be to evaluate impacts of livestock on ecology of tinajas in Capitol Reef National Park.

Due to the severe environmental stressors acting on natural temporary pools, their faunas are distinctive and often less diverse than those of permanent standing waters (Wiggins et al. 1980). The scientific value of research on temporary pool faunas has been primarily in unraveling evolutionary and ecological adaptations and life-history strategies which permit survival in these harsh, ephemeral habitats. Life-cycles of rock pool faunas are closely geared to cycles of drying and refilling and also the spatial distribution of habitats (McLachlan 1983). Three principal strategies for survival in rock pools are: 1. physiological adaptations to withstand the stresses of low oxygen, high salinity and desiccation (Belk and Cole 1975); 2. rapid growth and development so that the aquatic life-cycle is completed quickly before the pool evaporates (Wiggins et al. 1980); and, 3. wide dispersal of adults to assure colonization of isolated habitats (Belk and Cole 1975).

Survival during desiccation is usually accomplished physiologically as a resting stage or diapause. Resistant eggs of many branchiopod crustaceans (fairy, tadpole and clam shrimps) are the best described adaptations of aquatic macroinvertebrates to survive desiccation (Pennak 1978). Larval and adult stages of several crustacean copepods (Cole 19688), cladocerans (Ranta and Nuutinen 1985), dipteran insects (Tribby 1965, Cantrell and McLachlan 1982) and

amphibians (Mayhew 1968) are among the taxonomic groups which survive desiccation by estivation. Physiological responses of aquatic macroinvertebrates to salinity are well studied (egs. Bayly 1972, Hammer 1986, Galat, in press). Most are osmoregulators, able to control their internal salt concentration in the face of changes in environmental salinity. Well known examples of macroinvertebrate osmoregulators include brine shrimp, Artemia salina and tadpole shrimp, Triops longicaudatus. A few macroinvertebrates are osmoconformers, at least during part of their life-cycle. The snail, Coxiella exhibits little or no osmoregulation, so that salinity of body fluids follows changes in salinity of the environment (Williams 1985).

Rapid growth and development are exhibited by many crustaceans (fairy and tadpole shrimps), dipteran insects and anuran amphibians. Most temporary pond organisms also have remarkable powers of dispersal (Bayly and Williams 1973). Passive dispersal is enhanced by presence of drought resistant stages which are distributed primarily by wind (Belk and Cole 1975). Active dispersal, most often by winged adults, is well developed in insects (egs. corixids, notonectids, coleopterans, anisopterans and dipterans). A final purpose of this proposed research on tinajas in Capitol Reef National Park will be to document life-history survival strategies of dominant aquatic macroinvertebrates in permanent versus temporary rock pools.

Ecosystems are predicted to respond to disturbances in expected ways whether the stressors are natural, such as seasonal desiccation of a tinaja, or artificial, such as deposition of cattle excrement into a tinaja. Odum (1985) summarized general trends expected in ecosystems subjected to severe stress and his analysis should also be applicable to tinajas. His general categories include: 1. energetics, 2. nutrient cycling, 3. community structure, and, 4. general system-level trends. It is our intent to use this framework (emphasizing categories 2. and 3.) to evaluate responses of aquatic communities, and macroinvertebrates in particular, in tinajas of Capitol Reef National Park to the natural and artificial stresses outlined above.

RESEARCH OBJECTIVES

The overall objectives of this research are detailed in RFP-1350-7-0001 and summarized as follows:

1. Characterize the physical, chemical and biological limnology and macroinvertebrate ecology of representative tinajas and tinaja systems in the southern section (Halls Creek region) of Capitol Reef National Park, Utah.
2. Determine temporal and spatial variability in the limnology and macroinvertebrate ecology of tinajas with particular emphasis on natural stressors and disturbance events (ie. precipitation, desiccation and flooding).

3. Determine the impact of non-natural livestock disturbance on the physical, chemical and biological limnology and macroinvertebrate ecology of tinajas.

SCOPE OF WORK

Ecological research proposed for the three year study of Capitol Reef National Park tinajas is framed as a series of hypotheses which address the National Park Service Scope of Work detailed in RFP-1350-7-0001 and incorporate topics presented in the Introduction. Hypotheses (H) to be examined are listed under three categories: A. Physical and Chemical Limnology, B. Biological Limnology, and C. Livestock Impacts. Following the section on hypotheses, study designs (D) are given to test each, including year during which research effort will be concentrated. Methodologies, composition of study team and time schedule are also outlined. Citations in the text are referenced and a budget is enclosed separately. Three years will be necessary to thoroughly evaluate all hypotheses, and, as is the nature of any scientific endeavor, several may be modified or falsified as a consequence of research results.

RESEARCH HYPOTHESES

A. Physical and Chemical Limnology.

H1. Permanence is the primary factor determining community structure of tinajas. It is correlated with and can be predicted by a suite of physical factors:

H1.1 Permanence is positively correlated with size of catchment area.

H1.2. Permanence is negatively correlated with surface area (A) to volume (V) ratio (A/V).

H1.3. Permanence is positively correlated with frequency and intensity of precipitation.

H1.4. Permanence is negatively correlated with evaporation rate.

H2. General inorganic water chemistry of tinaja systems is defined by geologic characteristics of catchment basin.

H3. Seasonal climatic influences on physical and chemical limnology of individual tinajas are dominated by water input expressed as variation in intensity, frequency and type (rain vs. snow) of precipitation and also evaporation rate which is influenced primarily by water temperature and wind.

H4. Temporal changes in chemistry of tinajas that desiccate are dominated by evaporative concentration processes. Predicted successional patterns from filling to desiccation are early precipitation of relatively insoluble carbonates and sulfates and subsequent precipitation of more soluble chlorides.

H5. Periodic wash-out (flushing) of tinajas during storm events acts as a resetting mechanism for chemical succession.

H6. Spatial factors influencing permanence and limnology of tinajas include:

H6.1. elevational gradient. Cooler temperatures at higher elevations reduce evaporation rate, thereby increasing permanence and maintaining lower salinity. Furthermore, within a tinaja drainage system higher elevation ("upstream") tinajas will generally be smaller and their chemistry more dilute immediately following filling than lower elevation ("downstream") tinajas. This is a consequence of a smaller catchment area and shorter residence time of mineral dissolving surface water in the upstream drainage network.

H6.2. aspect/shading. Northern exposure and/or shading of tinaja basin by surrounding topography reduce water temperature and evaporation rate, thereby increasing permanence and maintaining lower and less fluctuating salinity.

H6.3. wind exposure. High wind exposure increases mixing, evaporation and turbidity, thereby reducing stability of summer thermal stratification in deep permanent tinajas and increasing salinity and reducing permanence in small ephemeral tinajas.

H7. Dissolved nitrogen and phosphorus concentrations will initially be high following tinaja filling, will subsequently decline as nutrients are incorporated into plant and animal biomass and will increase again as desiccation proceeds and internal recycling from aquatic animal excretion and decomposition becomes important.

H7.1 Nitrogen and phosphorus concentrations in precipitation falling on tinajas will be relatively low. The major source of new nutrients to tinajas is predicted to be leaching from sediments following filling, and leaching from wild and domestic animal excretory products.

B. Biological Limnology

H8. Phytoplankton biomass in tinajas is negatively correlated with presence of herbivores (eg. tadpoles), positively correlated with nitrogen and phosphorus supply and negatively correlated with wash-out rate.

H9. Diversity and abundance of macroinvertebrates and amphibians in tinajas not impacted by livestock are positively associated with size, permanence and nutrient supply and negatively associated with salinity and frequency of natural disturbance (egs. flooding, desiccation).

H10. Diversity of macroinvertebrates is predicted to decrease, but density per unit area increase as an individual tinaja desiccates.

H11. Distinct faunal assemblages will be correlated with permanence of tinajas.

H12. Seasonal diversity and abundance of macroinvertebrates within an individual tinaja is predicted to be low during winter due to cold water temperatures and also low during the driest season due to desiccation. Highest seasonal diversity and abundance is predicted to occur following spring snowmelt and again during the summer rainy season.

H13. Diversity of macroinvertebrates is predicted to be higher at lower elevations and in downstream tinajas within one drainage system due to colonization from upstream, less severe winter conditions (H11.) and greater permanence (H6.1.).

H14. Permanence is also the dominant natural factor dictating life history strategies of aquatic macroinvertebrates in tinajas.

H14.1 More ephemeral tinajas should be dominated by taxa from lower trophic levels (ie. herbivores and detritivores), which exhibit short life cycles (eg. multivoltine insects), rapid growth, high reproductive potential, resistant life stages and/or highly mobile adults.

H14.2 Wash-out of permanent drainage channel tinajas during storm events and refilling of desiccated tinajas provide resetting mechanisms for macroinvertebrate community succession.

H14.3 Initial macroinvertebrate recolonization of tinajas where all sediments have been scoured (eg. summer thunderstorm) will be by aerial insects, in contrast tinajas refilled after desiccation (eg. following spring snowmelt) will initially be recolonized by resistant life stages of macroinvertebrates from sediments.

H14.4 Food chains are shorter and food webs less complex in temporary versus permanent tinajas.

C. Livestock Impacts.

H15. Tinajas severely impacted by livestock urine, feces, trampling and grazing, compared with natural tinajas similiar in other respects, are predicted to exhibit limnological conditions characteristic of aquatic ecosystems severely disturbed by human sewage effluent (James and Evison 1979, Hellawell 1986). Specific impacts on livestock versus control (no livestock) tinajas are hypothesized to include:

H15.1 Higher turbidity and reduced transparency as a result of physical disturbance of sediments by trampling and increased phytoplankton biomass due to greater nutrient supply.

H15.2 Larger diel variations in temperature, dissolved oxygen and pH.

H15.3. More frequent anoxia in bottom waters and sediments.

H15.4. Higher salinity and greater dominance of soluble salts (sodium, chloride) due to salts in livestock urine.

H15.5 Higher nitrogen and phosphorus concentrations.

H15.6. Higher total organic matter concentrations in water column and sediments.

H15.7 Higher total primary production and community metabolism due to biostimulation from nutrients contributed by livestock urine and feces.

H15.8. Reduced macroinvertebrate diversity as a result of toxic effects from nitrogenous compounds and anoxia.

H15.9 Greater abundance of macroinvertebrate taxa tolerant of low oxygen concentrations, high concentrations of toxic nitrogenous compounds, high turbidity, and high salinity.

H15.10. Shorter aquatic food chains and less complex macroinvertebrate and aquatic vertebrate food webs.

METHODS

STUDY SITES

To test these hypotheses a number of tinajas and tinaja systems will be examined during the three year study. They are divided into three groups and the hypotheses to be examined within each enclosed by parentheses (H).

Group 1: Survey tinajas (H1, 2, 11). Between 20 to 40 tinajas will be selected which encompass the range of physical, chemical, size, elevation, longitude, catchment basin geology and microclimatic features in the study area. Tinajas studied within the remaining two groups will be selected from Group 1.

Group 2: Drainage systems (H2, 6, 8, 9, 13). A minimum of two drainage systems, at least one each in the north and south areas of the Halls Creek region will be examined in more detail. Within each drainage system a minimum of three tinajas will be selected to evaluate effects of elevation within and between drainages.

Group 3: Intensive Study (H3, 4, 5, 7, 10, 12, 14, 15). A minimum of two tinajas (one seasonally temporary and one permanent) influenced by livestock and two others (one seasonally temporary and one permanent) not impacted by livestock (controls) will be selected from Group 1 or 2 tinajas for research on seasonality, dynamics of succession from filling to desiccation and analyses of livestock impacts. Except for differences in livestock presence each member of the pair will be selected to be similar in physical and chemical features.

STUDY DESIGN

Proposed research designs (D) are outlined for each of the hypotheses (H) presented above. Although all hypotheses will be evaluated to some degree during each year, the year of major research thrust for each is indicated following its research design. In general, survey and single location dessication studies will be conducted in Year 1, spatial and seasonal patterns will be emphasized in Year 2, and livestock impacts will be stressed in Year 3. Completion of proposed research is contingent on availability of appropriate tinajas, graduate research assistant and suitable weather conditions.

A. Physical and Chemical Limnology.

- D1. Physical factors important in determining permanence will be evaluated on Group 1 tinajas a minimum of once during the summer thunderstorm season. Catchment area, maximum depth, mean depth, surface area and volume, temperature, conductivity, dissolved oxygen, precipitation frequency and intensity, and evaporation rate will be measured. Tinajas will be classified according to Byran's (1920) scheme or a modification of it. Significance of physical factors on permanence will be determined by Pearson correlation matrices and least squares multiple linear regression, multivariate principle components analysis or other suitable technique. (Year 1)
- D2. The importance of basin geology on tinaja chemistry will be assessed by field and literature determinations of dominant rock types within and among major tinaja drainage basins and their chemical composition. Concentrations of dominant cations and anions will be measured from selected Group 1 and 2 tinajas representative of geologic formations where tinajas concentrate (eg. Navajo Sandstone) a minimum of once during the study. Similarity of tinaja water chemistry to catchment basin geologic chemistry will be statistically evaluated by Chi-Square or other appropriate statistical test. (Year 1)
- D3. Seasonal climatic influences on physical and chemical limnology will be evaluated on one or more representative tinajas once during autumn, winter, spring and summer. Relevant methods outlined under D4 will be used. (Years 2 and 3)
- D4. Temporal changes in inorganic water chemistry during desiccation of tinaja water will be evaluated by four or more successive analyses of specific conductance and quantitative chemical measurements of dominant cations and anions within a single tinaja located in the major geologic formation (Navajo Sandstone). Should the relative ionic composition be similar to that of other waters for which evaporative concentration chemistry has been published, this information may be substituted if verified by a minimum of two analyses during a desiccation experiment using Capitol Reef National Park tinaja water. (Year 1)
- D5. The influence of wash-out on tinaja chemistry will be evaluated by monitoring specific conductance (an indirect measure of salinity, Williams 1968) during several filling and desiccation cycles of a single tinaja. Temporal variations in salinity will be used to test if the wash-out resetting hypothesis is valid. (Year 2)

D6. Effects of spatial factors on tinaja physical and chemical limnology will be evaluated on Group 2 tinajas one or more times during winter (minimum solar radiation and sun angle) and also summer (maximum solar radiation and sun angle). Surface area and volume, water temperature, dissolved oxygen and specific conductance profiles will be measured at each tinaja. Aspect, elevation, wind exposure, dominant wind direction and relative intensity, and shading (exposure) will also be quantified. Hypotheses will be statistically tested using parametric regression analysis or alternatively if parametric assumptions cannot be met a non-parametric correlation method (eg. Spearman rank correlation) will be applied. (Year 2)

D7. Nutrient dynamics and succession will be evaluated in permanent and ephemeral tinajas. Ammonia, nitrite plus nitrate, total nitrogen, soluble reactive phosphorus (SRP) and total phosphorus (TP) from integrated samples of the water column will be measured periodically (minimum of four times in conjunction with sampling to test hypothesis H4) between filling and desiccation of one or more ephemeral Group 3 tinajas and seasonally from one or more permanent tinajas. Attempts will be made to measure nutrients contained in precipitation from storm event filling of the ephemeral tinaja as well as surface water flowing into tinaja during storm event. These measurements will be conducted from tinajas also used to examine hypotheses H3, H4 and H15. (Years 1-3)

Leaching of nutrients from sediments and feces will be determined from separate laboratory experiments where known weights of dried sediments and dried feces are placed into distilled water or sterilized tinaja water (minimum of two replicates) and nutrient concentrations measured over time until they cease to increase. (Year 3)

B. Biological Limnology

D8. The influence of herbivores, nutrients and wash-out on phytoplankton in tinajas will be evaluated from six or more representative Group 2 tinajas containing a range of herbivore densities. Phytoplankton biomass will be quantitatively measured as chlorophyll *a* from whole water and, if considered important, also sediment samples. Vertically and horizontally integrated water samples will be collected for nutrient (D7) analyses when phytoplankton is sampled. Benthic macroinvertebrate and larval amphibian composition and abundance will be quantitatively estimated from three or more replicate water column and/or benthic samples per tinaja. Taxa identified will be placed into Merritt and Cummins' (1978) functional feeding groups. Wash-out rate will be estimated using results from H1 test. Spearman rank correlations or other appropriate statistical technique will be used to test predictions. (Year 2).

D9. The effect of permanence, nutrients and salinity in tinajas on macroinvertebrate composition and abundance will be evaluated using data collected during test of hypothesis H8. In addition, conductivity will be measured and macroinvertebrate species richness and Shannon diversity indices (Hellawell 1986) will be calculated and also statistically compared as outlined in D8. (Year 2)

D10. Macroinvertebrate succession during desiccation of a single Group 3 tinaja will be examined in conjunction with testing H4 and H7 by quantifying abundance, community composition, and Shannon diversity a minimum of four times as the system evaporates. (Year 1)

D11. The association of distinct macroinvertebrate and amphibian assemblages with permanence of tinajas will be evaluated by collecting and identifying animals from waterpockets at the same time physical and chemical data for Hypotheses H1 and H6 are obtained. Collection techniques will emphasize documenting the variety of taxa present, rather than quantifying population densities. However, densities of dominant taxa will be qualitatively estimated. Patterns of association of dominant taxa will be statistically evaluated from presence-absence data and multivariate cluster analysis using methods similar to those Dodson (1987) applied to temporary rock pool animal assemblages. (Year 1)

D12. Seasonal influences on macroinvertebrate diversity and abundance will be evaluated from one or more Group 3 tinajas once during autumn, winter, spring and summer concurrent with evaluation of seasonal effects on physical and chemical limnology (H3 and D3). (Year 2)

D13. Effects of elevation on macroinvertebrate species diversity in tinajas will be assessed in conjunction with testing hypotheses H6 and H11. Macroinvertebrates will be quantitatively sampled from Group 2 tinajas once in winter or spring and again in summer, identified, enumerated and Shannon diversity calculated. Elevation will be statistically compared with diversity using Spearman rank correlation, linear regression or other statistical techniques. (Year 2)

D14. The influence of tinaja permanence on macroinvertebrate life-history strategies will be examined by comparing community structure and succession seasonally and during desiccation and refilling of two or more Group 3 tinajas (one permanent, one temporary). Information collected from D15 and throughout this study will provide much of the data for this hypothesis. Field observations and reference to published literature will be used to obtain life-history and dispersal information for dominant taxa. (Years 2 and 3)

C. Livestock Impacts.

During the second year of study livestock impacts on the four Group 3 tinajas will be examined once during summer. However, most of the emphasis on this phase will be in Year 3. Additional control and livestock impacted pools will be included if funding and logistics permit. Cattle effects will be evaluated seasonally (autumn, winter, spring and summer) and a minimum of four times during one summer evaporation cycle of the temporary pools. All measurements will be made on both livestock impacted and control tinajas. Livestock exclusion will be considered in consultation with Park personnel as a technique to create control systems if reasonably accessible, tinajas unimpacted by livestock cannot be located. To test hypothesis H15 the following parameters will be measured during each sample period:

Physical/chemical Limnology: Maximum and mean depths, surface area, volume, total solar radiation and/or shading, air temperature; water temperature, water transparency, dissolved oxygen, pH and conductivity vertical profiles at the deepest location of pools >1 m depth or at surface and bottom of pools <1 m depth; integrated and/or discrete depth water samples analyzed for turbidity, inorganic ions (D2), nutrients (D7), and water column and sediment organic matter. Experiment D7 to measure rate of nutrient leaching from cattle feces is also appropriate to evaluate H15.

Biological Limnology: Integrated and/or discrete depth quantitative samples for chlorophyll *a*, phytoplankton and zooplankton; quantitative benthic samples for macroinvertebrates; Composition, abundance and Shannon diversity of phytoplankton, zooplankton and macroinvertebrate samples; community gross and net photosynthesis and respiration. Differences in dispersal mechanisms among pools will also be evaluated. Attempts will be made to conduct a controlled bioassay on one or more susceptible invertebrate or amphibian species if toxic effects of nitrogenous compounds are suspected. Specific design for this experiment will be outlined in Year 3 proposal.

Location and number of samples collected for physical, chemical and biological variables will depend on basin morphometry and observed pattern of vertical stratification within individual tinaja.

Miscellaneous: Record livestock density and quantify density of fecal material within a defined area surrounding study pool.

Early during the study a detailed morphometric map of each Group 3 tinaja will be made to facilitate morphometric measurements. Catchment area and aspect of each tinaja will also be determined at this time.

Non-parametric Mann-Whitney or other appropriate tests will be used to statistically compare results of livestock impacted tinajas with controls.

FIELD SAMPLING AND ANALYSIS METHODS

All collection and analysis methods will follow standard procedures (eg. APHA et al. 1985). Sufficient replicates will be collected and analyzed to assure representative samples and quality control. Methods outlined here may be modified or replaced if site characteristics indicate other more suitable approaches. Taxonomic keys will be used for identifications, selected specimens may be sent to experts for verification. A reference collection of representative macroinvertebrates and amphibians inhabiting waterpockets will be made.

A. Physical and Chemical Limnology

1. Catchment area and elevation of tinaja. Measured from existing USGS topographic maps, aerial or satellite photos or determined in the field for small catchment basins.

2. Maximum depth, mean depth, maximum surface area, maximum volume. Measured in the field following procedures in Lind (1979) and Wetzel and Likens (1979). Maximum volume of Group 1 and 2 tinajas will be approximated from maximum surface width and length measurements and reference to approximate geometric shapes of basins. Maximum volume of Group 3 tinajas will be determined from hypsographic curves generated from surveyed data (Lind 1979).
3. Aspect. Compass direction of basin slope.
4. Shading. Measurement of total daily solar radiation by recording pyranograph or integrating photometer. Alternatively, shading may be approximated as time per day >50 of tinaja surface area is in basin shadow.
5. Wind exposure, direction and intensity. Wind exposure will be ranked on a scale from 0 to 4, where 0 is complete protection from wind (eg. tinaja encircled by steep bedrock walls) and 4 is total exposure to wind. Seasonal wind direction and intensity will be obtained from Park Service meteorological data and/or a portable anemometer.
6. Precipitation. Obtained from Park Service meteorological records and from rain gages placed at selected Group 3 tinajas.
7. Evaporation. Estimated from decrease in depth at staff gage or by water evaporation from standard surface area pans placed at selected sites.
8. Catchment geology. Obtained from USGS Miscellaneous Geologic Investigations maps of study area or other published sources and field observations.
9. Water temperature. Thermistor, Hydrolab surveyor and/or calibrated pocket thermometer.
10. Dissolved oxygen. Polarographic oxygen electrode and oxygen meter, Hydrolab surveyor and/or Winkler technique.
11. Conductivity. Conductivity bridge and/or Hydrolab surveyor.
12. pH. Electrometric pH meter and/or Hydrolab surveyor.
13. Transparency. Underwater photometer and/or Secchi disk
14. Turbidity. Measured from whole water sample using turbidimeter or spectrophotometer.
15. Inorganic chemistry. Concentrations of dissolved ions will be determined from filtered water using U. S. EPA (1979), APHA et al. (1985) or other established techniques. Cations (sodium, potassium, calcium, magnesium) will be measured by atomic absorption spectrometry. Bicarbonate plus carbonate will be measured as total alkalinity, chloride determined from colorimetric titration, and sulfate measured turbidometrically.

STUDY TEAM

Principle Investigator: David L. Galat, Ph.D, Assistant Professor, Department of Zoology, Arizona State University, Tempe AZ 85287-1501

Project Assistants:

Graduate Research Assistant: ASU MS or Ph.D. program. Dalaine Roark (tentative). Final selection of individual will be made as soon as possible following award. Most of the proposed research will be conducted by this person under supervision of PI.

Hourly student labor (Work Study Program) for sorting samples, dishwashing, data entry, etc.

Consultants:

Desert limnology and crustacean taxonomy: Gerald Cole, Ph.D, Emeritus Professor, Arizona State University (vitae enclosed)

Statistics, taxonomy of temporary pool algae and invertebrates: Dennis Kubly, MA, Mankato State University (vitae enclosed)

Additional taxonomic expertise as needed.

FIELDWORK SCHEDULE

Principal Investigator (PI) will meet with Contracting Officer's Representative (COR) for briefing and orientation soon after contract is awarded, hopefully, in early October 1987. At this time a reconnaissance of the study area will also be made. Five field trips are planned to Capitol Reef National Park each fiscal year (Oct-Sep). Three will be of about one week's duration, including travel (ca. 3 days roundtrip), and will occur in approximately in October, January (weather permitting), March or April (depending on snowmelt). Two field trips will be made each summer, each lasting about two to three weeks. This schedule may be modified as field conditions, tinaja ecology and ASU commitments dictate.

During fieldwork temporary housing will be provided by the sponsor. It is anticipated project personnel will also camp at, or near, study sites during extended periods of fieldwork. Limited use of laboratory space and storage at Park Headquarters is requested. Occasionally, use of a 4X4 vehicle may be requested. It is anticipated field assistance from park staff will also be available as indicated in the RFP.

BUDGET

Project budget is enclosed separately. Year 1 budget is fixed as per RFP. Budgets for Year 2 and 3 are tentative and may be revised prior to each year's contract renewal.

16. Nutrient chemistry (U. S. EPA 1979, APHA et al. 1985, Parsons et al. 1984 and others).

Soluble reactive phosphorus (SRP): filtered sample, colorimetric, ascorbic acid, phosphomolybdate technique.

Total phosphorus: whole water, acid persulfate digestion followed by analysis for SRP.

Total ammonia: whole water, phenolhypochlorite method.

Nitrite plus nitrate: filtered water, cadmium reduction.

Total nitrogen: whole water, persulfate oxidation to nitrate then nitrate measured by cadmium reduction.

B. Biological Limnology

17. Phytoplankton biomass. Measured as chlorophyll *a* following APHA et al. (1985) procedures.

18. Gross and net photosynthesis and community respiration. Measured from diel changes in dissolved oxygen in tinajas (Lind 1979, APHA et al. 1985)

19. Organic Matter (OM). Water column OM. Determined as ash free dry weight of residue from filtered sample, dichromate oxidation of evaporated sample or infrared gas analysis of persulfate digested whole water sample. Sediment OM. Determined from sediment cores or benthic grabs as ash free dry weight.

20. Phytoplankton. Determined from Lugol's preserved whole water grab or integrated samples. Taxa identified to genus or species under compound microscope in counting chamber. Sample concentration may be required.

21. Zooplankton. Collected quantitatively using Schindler trap, Wisconsin net, integrating tubes or other appropriate samplers. Identified to genus or species from formalin preserved samples using compound microscope and counting chamber.

22. Macroinvertebrates. Various life-stages collected using kick nets, bottom grabs, suction dome samplers, emergence traps, drop-in traps or other qualitative and quantitative methods depending on substrate composition and life-stage of interest. Preserved in formalin or alcohol. Identified to genus or species using dissecting microscope. Dense samples may be subsampled for counting.

23. Vertebrates (Amphibians). Collected using macroinvertebrate methods, preserved in formalin or alcohol. Identified to species.

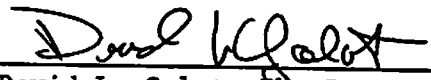
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APPROVALS


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