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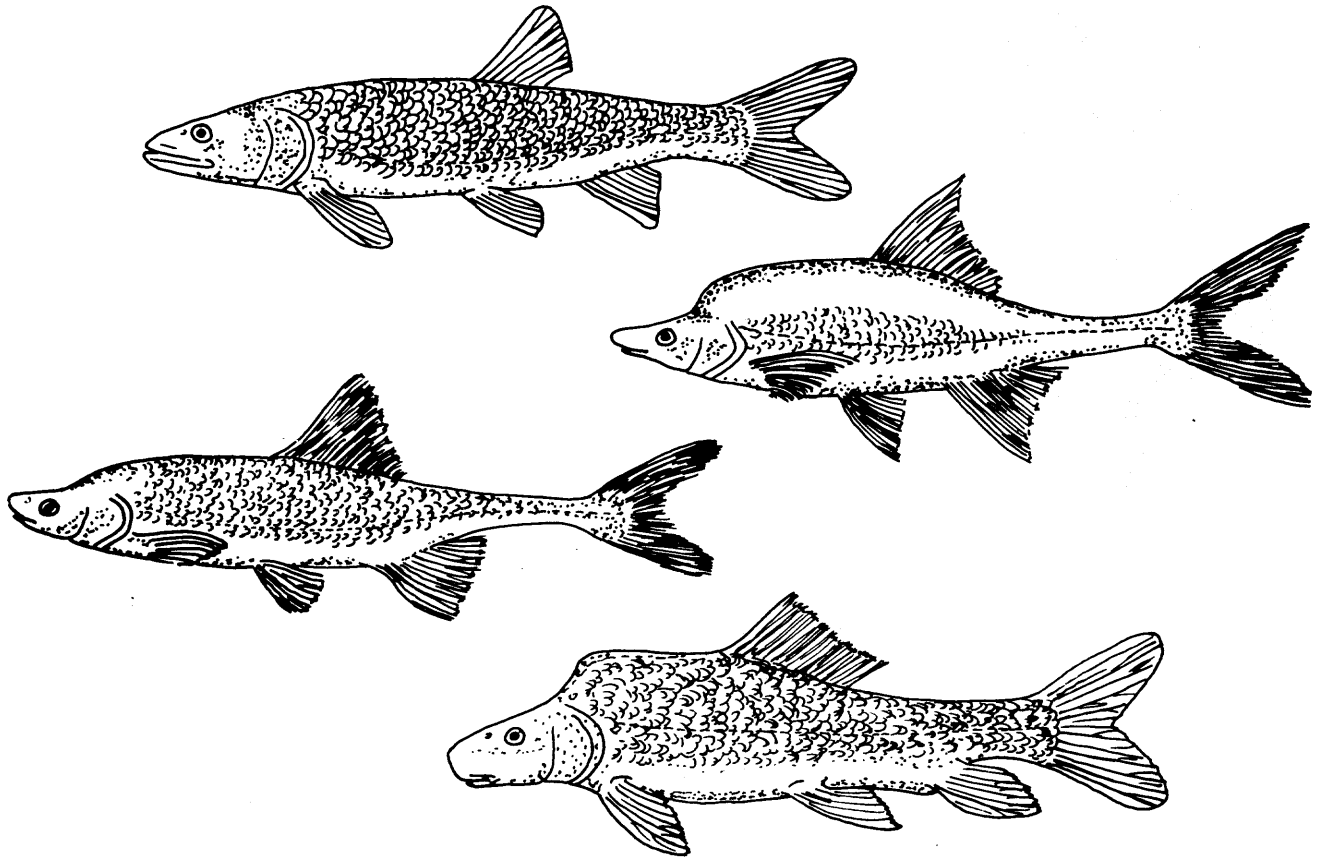
# Part 3

## Colorado River Fishery Project

# FINAL REPORT
# CONTRACTED STUDIES



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**Bureau of Reclamation**
**Salt Lake City, Utah**
**April 1982**

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# COLORADO RIVER FISHERY PROJECT

~~PART III~~

~~Summary Report~~

Submitted in fulfillment of Contract ~~No.~~ 9-07-40-L-1016 with the Bureau of Reclamation.


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# PREFACE

This is Part 3, Contracted Studies of a three-volume final report on the endangered Colorado River fishes. Part 1 is a Summary Report and Part 2 is a report on Field Investigations. This three-volume report was prepared primarily for the Bureau of Reclamation (Reclamation) in accordance with Memorandum of Understanding (MOU) No. 9-06-40-L-1016 between the Fish and Wildlife Service (FWS) and Reclamation. Some additional funding for various parts of this total work was provided by FWS and the Bureau of Land Management.

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For details of the total scope of study including objectives and areas of investigation see Part 1, Summary Report.

Opinions and conclusions expressed in the individual studies presented in this document represent the views of the authors and not necessarily those of the FWS or Reclamation.

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REPORT NO. 1

# IFG STUDY OF PHYSICAL-CHEMICAL HABITAT CONDITIONS ON THE GREEN AND COLORADO RIVERS IN COLORADO AND UTAH

by

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# INTRODUCTION

This report documents completion of the Instream Flow Group (IFG) phase of the Colorado River Fisheries Project (CRFP) as directed by an Amendment to a Memorandum of Understanding (MOU) agreed upon by U.S. Bureau of Reclamation (Reclamation) and U.S. Fish and Wildlife Service (FWS) in January of 1981.

As outlined in the original MOU, the overall objective of the CRFP was to gather and interpret data for use in resolving Endangered Species Act (Section 7) consultations regarding several proposed Reclamation projects or operations. The CRFP became a multiple project study with diverse objectives generally outlined in the executive summary. The IFG phase of the study was contracted to compliment the biologic phases by providing certain analytic tools to aid in determining past, present, and future habitat conditions. To provide these general capabilities, IFG, in 1980, began a project component with the following objectives:

1. To gather physical habitat data at selected locations on the Green and Colorado Rivers;

2. To gather and compile temperature and other water quality related data for use in a system based water temperature model, and

3. To provide the capabilities of a physical habitat and water quality simulation system as a partial analytic framework which might aid FWS and others in resolving current endangered species problems.

This completion report primarily describes the tools and capabilities available as of November 1981. Additional refinements in the model components and a more comprehensive representation of the basin's physical habitat distribution are to be expected in the future.

# THE SIMULATION MODELS - GENERAL

## PHABSIM

Two forms of habitat simulation were used during this period of the project. First, the PHABSIM model, developed by the IFG, was applied to six reaches, three each on the Green and Colorado River mainstems. This technique was applied as a component of the Instream Flow Incremental Methodology (IFIM) which is a systematic approach to solution of water allocation problems for stream resources. Proper use of the IFIM requires consideration of the watershed, food base, water quality and flow regime components of a river system, noting probable changes in each and determining the effects of such changes. Given reasonable assurance that changes in these components will be minimal or predictable, the effects

upon physical habitat (depth, velocity, substrate and cover) of altered flow regimes are determined using the PHABSIM system.

In this system, depth, velocity, substrate and cover at stream study sites characterized by multiple transects are predicted using hydraulic simulation techniques. Values for these parameters are compared with habitat suitability curves for each species in question, to obtain relative preferences or weighting factors. The product of the weighting factors is applied to the surface area of the study reach to obtain a Weighted Usable Area (WUA) for the given species at the modeled flow level.

WUA is an approximation of the relative usability of the stream reach; in some cases (notably for certain salmonids) it correlates well with the actual adult biomass. In most cases, changes in WUA should be thought of as an indicator of the amount of preferred physical habitat combinations, and as such a guideline for evaluation of various flow levels or regimes.

The specific regimes to be analyzed for this report were to depict present and past flow regimes and resulted in:

1. WUA for flows during some past period (before measurable depletions) to be known as "natural" flows:

2. WUA for a time period under present depletion levels, to be known as "present" flow levels, and

3. WUA for actual measured flows for the period between 1960 and 1980 (to be known as "actual" flow levels).

Each of the analyses were to be of mean monthly flows. The "present" and natural flows were to be simulated using the Bureau of Reclamation Colorado River Simulation System (CRSS) model.

## Instream Water Temperature Model

Because water temperature changes in the Green and Colorado Rivers were considered significant factors in the decline of the endangered fish species, a model was developed to determine effects of altered flow and reservoir release temperatures upon water temperatures throughout the Upper Colorado River Basin (UCRB). The desired capabilities were to 1) determine steady-state basin-wide temperature patterns which might result from various monthly flow levels; 2) determine site specific temperature regimes resulting from predicted flow regimes and 3) determine expected monthly maximum temperatures at various observation points.

The original Statement of Work specified use of the temperature component of the SSAM IV water-quality model developed jointly at the IFG and Utah State University. As discussed later, this model served as a basis for development of a temperature model which allowed accounting for several data deficiencies unique to the UCRB. Specifically, these were 1) scarcity of meterologic monitoring stations; 2) extensive shading due

to canyon topographies; 3) lack of certain headwater and tributary temperature data and 4) lack of certain temperatures against which model output might be validated.

The description, development, calibration and validation aspects of the temperature model are presented in this report. A temperature screening for suitable Colorado squawfish spawning is also presented. Continued refinement of the model would be facilitated by careful review of and comment upon the material in this report.

## Flow-Habitat Linkages

Because BR intended to conduct PHABSIM analysis of its future project operations, and because a BR model known as the Colorado River Simulation System (CRSS) had been used in the past to simulate basin-wide flow effects of these project operations, a linkage system between CRSS output and the PHABSIM system was developed. The intent was to provide a more comprehensive evaluation of project analyses by utilizing the water budgeting model to provide flow regimes expected at key points in the basin as a result of single or multiple BR water depletions.

The output of the CRSS model was in the form of monthly flow sequences for time periods from 10 to as many as 70 years at single or multiple points in the basin. The computer linkages between CRSS (or other sources of flow time-series) and PHABSIM were developed as components of a program library; structure and use of this library is described in Appendix II.

# MATERIALS AND METHODS

## PHABSIM Site Selection

From the meeting on March 17 and 18, 1980, in Grand Junction, Colorado, it was determined that the rationale for initial consideration of segments (called "strata" by CRFP personnel) would be Colorado squawfish nursery areas. Based upon this criterion, Segments, A, C, and F from the CRFP study were suggested on the Green River and the strata enclosed by river miles 0-48, and 71-86 were suggested for the Colorado River. In addition, the Black Rocks and Westwater Canyon areas were suggested, based on the captures of humpback chubs at those areas. Further, it was suggested that the upper- and lower-most five miles of each segment be considered "transitional" and removed from consideration as potential sampling sites.

Because of logistic problems involved in measurement of a reach in Westwater Canyon, no commitment was made to study that area during summer 1980.

Of the remaining five segments, each was considered representative of its entire stratum (after elimination of transitions) except those areas noted as being entirely anomalous, such as Black Rocks or certain

limited areas within major reaches. Anomalous reaches in their respective segments are listed below.

| Stratum or river segment (miles) | Analomous miles |
|---|---|
| Green River | |
| A | None |
| C | 12-20 (below Nefertiti) |
| F | Horseshoe bend (164, 175-176) |
| Colorado River | |
| 0-48 | The loop (5-11) |
| 71-86 | Mile 35 and miles 77-86 |

The remaining river miles were then randomized, and four random miles selected at each stream. These were to be evaluated both on aerial photographs (1:31,680 Color Infra Red from BLM) and on-site during the April 14-19 reconnaissance trip.

The following river miles were drawn randomly for each segment on the Green and Colorado Rivers:

| Stratum or river segment (miles) | Randomly selected miles | | | |
|---|---|---|---|---|
| Green River | | | | |
| A | 24 | 52 | 56 | 73 |
| C | 20 | 21 | 24 | 29 |
| F | 135 | 144 | 148 | 160 |
| Colorado River | | | | |
| 0-46 | 24 | 27 | 36 | 38 |
| 71-86 | 73 | 75 | 79 | 80 |

In-the-field observation of the Colorado River reaches led to preferences for stations at mile 39 in the downstream reach (hereafter called "Potash") because it corresponded with a good hydraulic control point and because it was considered accessible by boat during the high flow regime. This reach was characterized by steep sandstone cliffs or slopes along approximately 2/3 of the right bank. The left bank was a sandbar separated from the floodplain by a dense bank of tamarisk.

Upstream from Moab, Utah, site selection was strongly influenced by accessibility because the recurrent rapids were probably not navigable by aluminum boats at high water. The reach beginning at mile 72 was selected because it was within boat motoring distance of the boat launch and terminated downstream at a marginal flow control point.

Field reconnaissance of the Green River study strata led to the selection of three potential study site locations.

Within stratum (segment) "A", river mile 56 was chosen to represent the Labyrinth Canyon segment. This study site is located 4 miles above Mineral Bottom and is characterized by alluvial bars, islands, cliff areas, and a meandering thalweg. Six transects were established over flow control points and existing aquatic habitat.

Stratum (segment) "C" was represented by river mile 21. This site was chosen both because it was located upstream from Nephertiti rapids

and because it was thought to represent the typical hydraulic environment of Gray's Canyon. In addition, Rattlesnake Rapids restricted upstream movement at a relatively low flow and was not passable at high flow. This study site had a cobble/boulder substrate, high cliffs on the right bank and a small floodplain on the left. Included within the section were riffles and pool hydraulic features, characterized by six cross sections.

Stratum (segment) "F" was represented by river mile 143 between Jensen and Ouray, Utah. Features at this site included sand substrate and no vegetated alluvial islands; the reach was suspected to have a rather shifting bed. Six transects were used to describe the hydraulic and habitat conditions. Access was through the Ouray National Wildlife Refuge.

## PHABSIM Data Collection, General

Field measurements were conducted at all stations based upon established techniques (Bovee and Milhous 1978: Trihey and Wegner 1980). Velocities were obtained with a Marsh-McBirney direct-readout current meter. All differential leveling was performed with either Nikon or Geotech automatic levels. Depths were determined either with a calibrated topset wading rod or using a sounding weight and a USGS A-55 calibrated reel mounted on a 14 or 16 foot aluminum boat.

Measurements of the channel geometry velocity distribution and water surface elevations were used as input to either the IFG-2 (Dooly 1975) or IFG-4 (Main 1978) hydraulic simulation computer programs. In short, the IFG-2 program used predictable backwater relationships to compute stage (water surface elevation) at flows other than the measured flow. From the stage and known stream geometry, depths, velocities and wetted substrate were determined for each of the measured points and/or verticals.

The IFG-4 program also predicted depths, velocities and substrates but required a minimum of three measurements of stage and velocities to develop flow vs. stage and flow vs. velocity regressions.

All field measurements were taken so that they could serve as input to either the IFG-2 or IFG-4 programs.

### Colorado River

Depth, velocity, substrate and overbank condition data were collected at the Moab and Potash reaches during the weeks of July 1, July 14, and October 20. These measurements were successful in determining velocities and depths at all preselected cross-sections and verticals. The Black Rocks reach was sampled during the week of July 1 at a flow of 15,000 cubic feet per second (cfs) and was found unworkable because of excessive velocities. Water surface elevations and some moderate velocities were determined there, but collection of a complete data set was not possible.

Subsequently, a high flow level of about 7,000 cfs was measured on July 13 and a total of 5 cross-sections were completed. On July 22, a middle flow measurement (4200 cfs) was completed and the low flow was measured on October 23.

### Green River

The Mineral Bottom reach was measured at average flows of 9,700, 5,000 and 2,400 cfs. Between the second and third measurements, a large thunderstorm caused considerable input of sediment and debris into the river, resulting in aggradation across the lower transect.

At Gray's Canyon, flows of 9,500, 5,000, and 2,800 cfs were measured. The initial six transects were reduced to five because the uppermost transect was unmeasurable at the high flow. Two major tributaries occur between this reach and the Ouray site.

The study site at the Ouray National Wildlife Refuge (called the Ouray Reach) was measured at discharges of 6,000, 3,300, and 2,200 cubic feet per second. This study site is located above confluences of the Duchesne and White River which account for the large difference in flows between this site and Gray's Canyon.

## Hydraulic Simulation Model Calibration

Details of the data reduction, correction and review process are presented in Appendix I. The hydraulic simulation results for IFG-2 and IFG-4 presented in this report are considered adequate for the present purposes, and no further refinements are expected prior to use of the simulation models in actual analyses.

Calibration, predicted and target velocities, and water surface elevations for the IFG-2 (WSP) runs (Potash, Mineral Bottom, Ouray) are also presented in Appendix I as are stage regressions and velocity adjustment factors for the IFG-4 runs (Black Rocks, Moab, Gray's Canyon).

Review of Appendix I will show that results of the calibration processes were quite successful for all reaches after only minimal input adjustments. The calibration flow range was acceptable for all study sites except Black Rocks and a fourth sampling trip was planned for that reach in March 1981.

## Habitat Suitability Curves

At the time of this writing, habitat suitability curves for young-of-the-year (YOY) Colorado squawfish and adult humpback chubs at the Black Rocks reach were completed. Because it was felt that much of the variability in the habitat preferences of adult Colorado squawfish was attributable to available habitat distributions at the different collection points, a more thorough analysis was necessary.

Since YOY squawfish were captured only in a restricted range of depth, velocity, and substrate conditions, it was assumed that habitat

availability had been accounted for. The humback chub adult curves were to be applied only at the Black Rocks PHABSIM study site, thus eliminating the need to account for available habitat.

The YOY squawfish curves were derived from all YOY data from both Colorado and Green Rivers. This combination was made after examination of major data partitions and determination of significant differences. While statistically significant differences may have occurred among small data partitions, neither the preferences expressed in the Colorado River sample nor those from the Green River collections differed significantly from those of the combined Colorado-Green sample. A major subsample of Green River data (derived from collections from strata A, D, and E) also did not differ significantly from the Colorado, Green, or Colorado-Green data sets (Table 1). In all cases, there were very few collections at velocities greater than .5 fps, with the greatest number of collections at less than .1 fps. In all cases, depths were less than 2.5 feet, with the peak preference consistently in the .6 to .7 feet range. Substrate preferences varied among the samples but only with respect to sand preference. The final YOY curves reflected an average preference based on Colorado and Green River differences (Figure 1).

The humpback chub adult curve was derived from fish captured at both the Black Rocks reach and in Westwater Canyon on the Colorado River. Data from original histograms were smoothed to create a rather broad velocity curve and an extremely broad depth curve (Figure 2). The substrate curve was a step function (non-continuous) which is usually more suitable for use in PHABSIM analyses because of the integer nature of substrate values from the hydraulic simulation program.

## Water Temperature Modeling

The instream water temperature model described in this report was developed after careful consideration of available technology. It was basically a physical process model, but used certain regression techniques to calculate initial water temperatures and those temperatures used in validation checks.

Analysis of certain components of the SSAM IV temperature model (specified in the initial SOW) showed that missing or inadequate components were used under a wide range of conditions. This model had certain retainable features, however, and served as a basis for further development. A literature search was conducted and modeling components from several sources were extracted and tested (Cinquemani et al. 1978; Pluhowski 1970; Tennessee Valley Authority 1972). Resulting model components were modified and synthesized into an instream water temperature model suitable for use in predicting temperatures in an entire river basin. A prototype model was developed on a HP-41C hand calculator to test components and to verify the final main frame computer model.

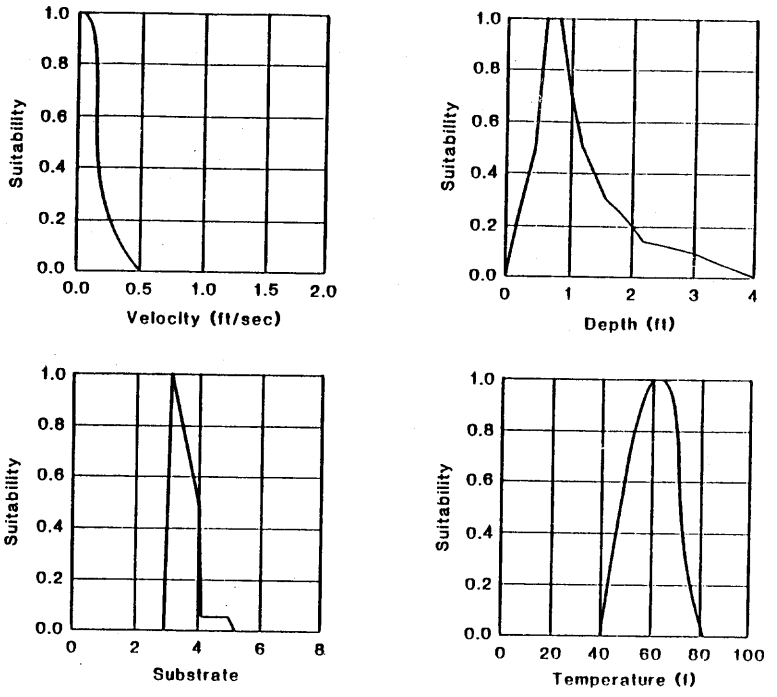
The instream water temperature model required three basic subsets of input data: 1) stream system structure, 2) hydrology, and 3) meterology. The stream system structure for the computer model was specific to selected sites in the UCRB. The meteorology data consisted of historical records from 1964 through 1980 and was similarly site specific.

Table 1
Comparisons of Colorado squawfish YOY preferences based on total catch (CSY), total Colorado River catch (CCSYC3F), total Green River catch (GRSSY) and partial Green River catch (GRCSYOY)

| Item | Colorado River squawfish YOY (CCSYC3Y) | Green River squawfish YOY (GRCSYCC) | Partial Green River squawfish YOY (GRCSYOY) | Total Colorado and Green River squawfish YOY (CSYCSYY) |
|---|---|---|---|---|
| Velocity | | | | |
| Mean | .041033 | .076298 | .078065 | .071109 |
| Standard deviation | .09684 | .25937 | .24659 | .24270 |
| Peak | 0 | 0 | 0 | 0 |
| Range min-max | 0-0.5 | 1/ 0-2.4 | 0-1.5 | 1/ 0-2.4 |
| Frequency | 329 | 1,907 | 465 | 2,236 |
| Depth | | | | |
| Mean | .96170 | .81017 | .69957 | .83247 |
| Standard deviation | .68640 | .42944 | .34944 | .47885 |
| Peak | .61 | .86 | .74 | .78 |
| Range min-max | 0.3-3 | 0.1-3.6 | 0.2-1.9 | 0.1-3.6 |
| Substrate | | | | |
| Mean | 3.4286 | 3.237 | 3.2172 | 3.2652 |
| Standard deviation | .54261 | .47435 | .43316 | .48959 |
| Peak | 3. | 3. | 3. | 3 |
| Range min-max | 3-5 | 3-6 | 3-5 | 3-6 |

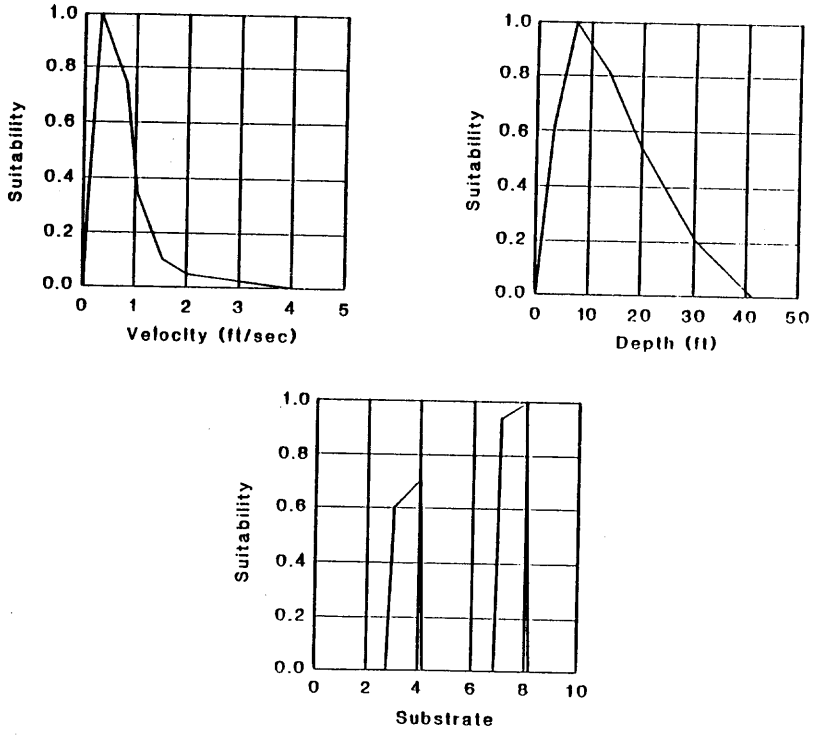
1/ Indicates one collection only at this velocity.

Figure 1




Habitat suitability curves for Colorado squawfish YOY based upon CRFP data.

Figure 2




Habitat suitability curves for adult humpback chubs based upon CRFP data from Black Rocks and Westwater Canyon, Colorado River.

The hydrology included historical flows for purposes of developing regression models both to predict initial headwaters and water temperatures and to aid in validating the model. The hydrologic data also provided the ability to "game" with the flows to determine the effect of flow regimes on the temperature regimes. Much of the computer modeling effort was devoted to generation of the input files. Obviously, such site specific orientation required a unique development effort which could not be obtained from other sources even if the "processing" components were sufficiently accurate.

## Stream System Structure

The temperature model was applied to the Green and Colorado River networks and their major tributaries (Figure 3). The Green River was modeled from below Flaming Gorge Dam using the Greendale Wyoming gage for estimates of initial flows and temperatures. Most of the tributaries emptying into the Green River were modeled as point loads; these included all of those tributaries with flows recorded near the confluence with the Green River (the Duchesne, Price, and San Rafael Rivers). The White River was modeled from the gage near Watson, Utah. The Yampa River was modeled from above the confluence with the Little Snake River; recorded flows and temperatures from the Little Snake gage near Lily, Colorado and the Yampa River gage near Maybell, Colorado were combined to approximate initial conditions on a pseudo tributary with a headwater 22 miles above the Little Snake/Yampa confluence.

The Colorado River was modeled from the gage near Cameo, Colorado. The Gunnison River was modeled as a point load to the Colorado and its effect was estimated from flows and temperatures recorded near Grand Junction, Colorado. The Dolores River was also modeled as a point load.

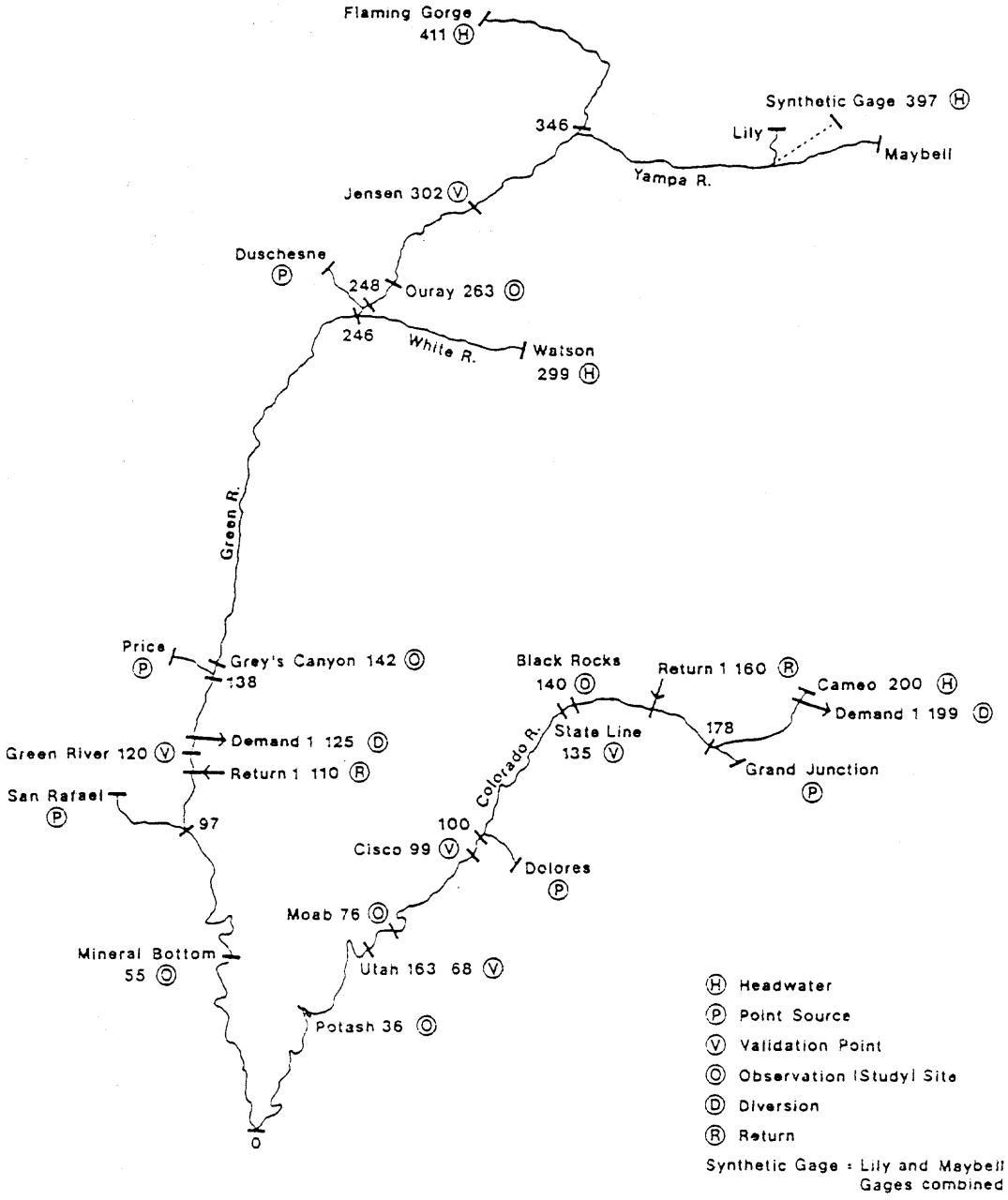
The current data preprocessing computer program allows for one diversion upstream of Green River, Utah, on the Green River (and subsequent return flow below Green River) and one diversion upstream of Grand Junction, Colorado, on the Colorado River with the return flow below Grand Junction.

USGS topographic maps (7.5 and 15 min) and Reclamation profile plots were used to determine elevations, stream slopes, site locations (river miles and latitude/longitude), and the extent of solar shading due to canyon walls.

## Meterology

Climatological data were developed from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration records for Grand Junction, Colorado. Local Climatological Data, Annual Summary, 1949-1980 were used for the daily information of temperature, wind speed and relative humidity. Normals for the period of record were also taken from the Annual Summary.

Figure 3




System structure used in Instream water temperature model of the Upper Colorado River Basin.

## Hydrology

The data file of gage discharges was developed from the U.S. Geological Survey, Water Resources Data for Colorado and Water Resources Data for Utah. The discharges for each location were obtained from the Surface Water Records. Water temperatures at each location were obtained from Water Quality Records. Additional water temperature and discharge information was obtained through the use of the USGS WATSTOR system.

## Published Temperature Data Smoothing

Fifteen USGS gages within the study area provided some useful instream water temperature data. However, none of the gage data were developed from accurate 24-hour averages. The published temperatures were assumed to represent water temperatures somewhere between the minimum/maximum on the day recorded. Frequently, published temperature data were missing for several days a month at each gage. Therefore, monthly means of the average daily water temperature for a specific year at any given gage were difficult to obtain directly.

A second-order, multiple regression model was used at each gage to generate estimates of the missing data. The published water temperature was treated as the dependent variable. Discharges at the selected sites and prevailing meterological parameters (obtained from published data for the Grand Junction weather station) were the independent variables. The meterologic parameters were based upon those used in the physical process model. Data from 1964 through 1977 was used for the regression.

## Water Temperature Screening, Black Rocks and Jensen Reaches

The water temperature model was used to predict mean monthly temperatures across a range of discharges at the Black Rocks (Colorado River) and Jensen (Green River) observation points. The Black Rocks flow-temperature relationships were to be used in screening flow levels for temperature suitability for humpback chub and Colorado squawfish spawning. The Jensen predictions were to be used 1) to determine differences between Green and Colorado River temperatures and 2) to screen various flow levels during critical spawning months for temperature suitability. On both rivers the months of May, June July, and August were selected as potential spawning months for both species (May and June primarily for humpback chubs, June, July and August for Colorado squawfish).

## Flow Time Series Generation

Mean monthly flow data for the six CRFP PHABSIM study sites were obtained for the three flow conditions (actual, present, and natural) specified in the Amendment to the MOU.

The "actual" flows were based upon USGS gage records adjusted to the study sites by addition or subtraction of tributary flows between the

study site to or from those at the gage location. Unrecorded inflows and losses between the gage locations and the study sites were assumed to be negligible. The gage records were obtained for the period of record; the gage with the shortest period of record determined the length of the adjusted period of record.

The simulated "natural" flows were obtained directly from CRSS output files. Reclamation defined these flows as those that might have occurred at a particular observation point if there were no human impacts on the basin. These flows were adjusted to the locations of the six study sites using the technique described above. Natural flow calculations were performed only through 1978. These calculations were a major effort and are only updated once every five years due to the costs and time involved.

Flows simulated for the 1980 level of development also came from the CRSS model. Natural flows were calculated for the period 1907 to 1974 (this was the period for which Reclamation has prepared the input data base). The natural flow series was then run with the water demands held constant at the 1980 level of development. This produced an output time series reflecting the probable range and frequency of flows at selected sites under 1980 conditions given historic hydrologic conditions.

These flow time series may be translated to habitat time series using the library of procedures and programs described below as soon as final WUA vs flow relations for each species and life stage at each study site are prepared by CRFP.

## RESULTS AND DISCUSSION

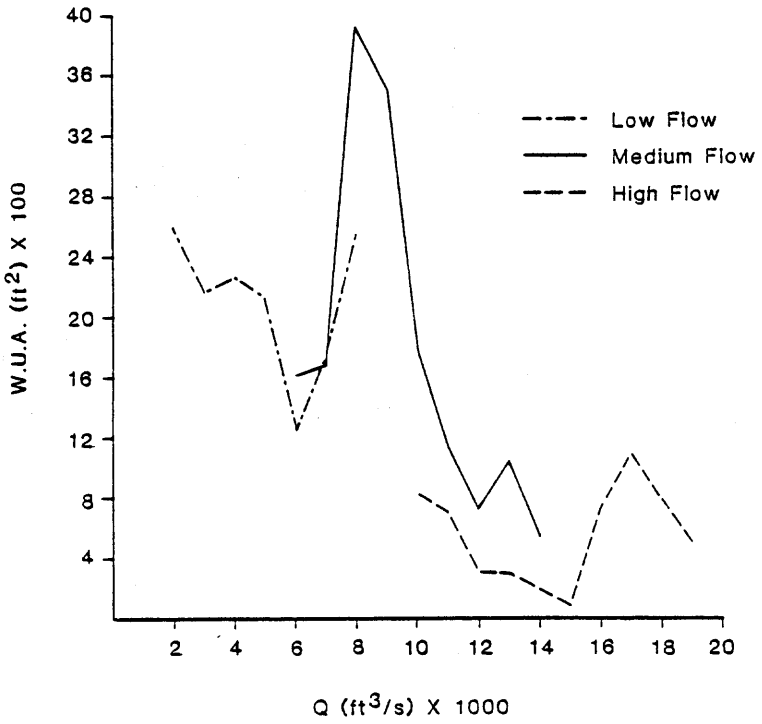
### Analyses of WUA

Because of extreme changes in bed elevations between low and high measured flows, three separate IFG-2 HABITAT simulations were used at the Potash, Ouray and Mineral Bottom reaches. In such instances, WUA was calculated for a range of flows within the predictive range of each simulation model for the reach. For example, at the Potash reach, simulation models were calibrated against data collected at approximately 4400, 8000 and 16000 cfs. Because of sand transport and scour, distinctly different bed elevations existed at these three flows. Predictions made using one simulation model therefore were limited to a small range of flows around the calibration flow.

To allow a broader range of simulations under these conditions, the WUA values for a range of flows around each calibration flow were calculated. At points of obvious discontinuity the WUA's were adjusted to form a continuous curve for the entire range of flows (Figures 4 and 5).

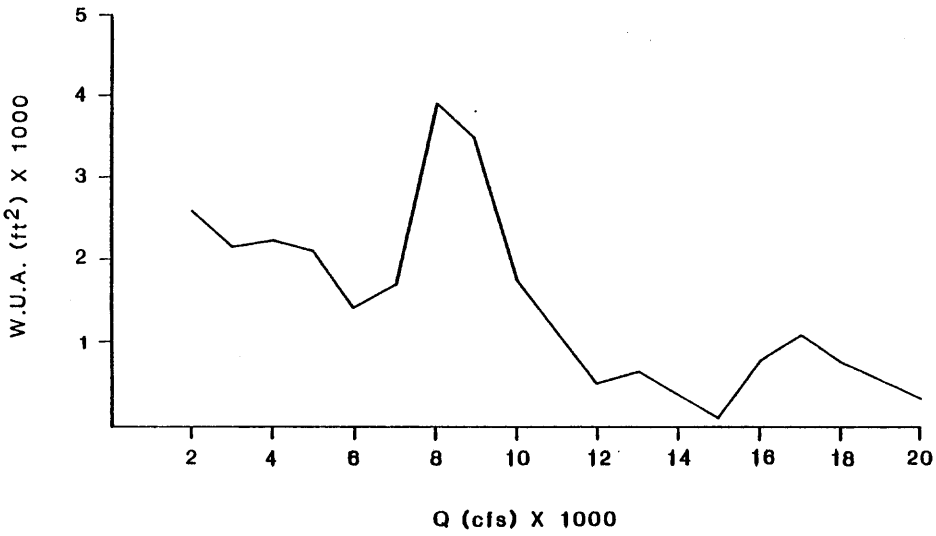
To calculate WUA for a time series of flows, these final WUA vs. flow curves were digitized and the coordinate pairs input to the computer. An interpolation program was then used to calculate WUA for any requested flow within the range of the initial curve. This process

Figure 4




Original WUA vs ascending flow relationship, Potash reach (Colorado River) derived from three separate HABITAT runs based on IFG-2 (WSP) output.

Figure 5




WUA vs flow relationship at Potash reach (Colorado River) after combining and smoothing curves from Figure 5.

provided the capability to quickly calculate WUA for a time series of monthly discharges without running the HABTAT program with its high associated computer cost.

## WUA vs. Ascending Flow

The WUA vs. flow graphs presented here are primarily for use in describing general relationships and cover only one life history stage of two species. They are best interpreted as indicators of general flow ranges, i.e., as aids in determining whether low, medium, or high regime discharges are most suitable for a life history stage. They should serve as tools in the development of flow recommendations, not as sources of inviolable "minimum" flow requirements.

### Green River

The two sand-substrate reaches, Mineral Bottom and Ouray refuge provided dramatically higher WUA for YOY squawfish than did the Gray's Canyon reach (Figures 6 through 8). Mineral Bottom and Ouray were quite consistent in offering high WUA in the 2000-3000 cfs range both for squawfish YOY. The Gray's Canyon reach, probably because of its large substrate and severe velocity conditions offered far less habitat, most of which was probably around the edges of the wetted area.

The selection of a site below a major rapids was influenced strongly by access and measurability. The more distinctive Gray's Canyon aquatic habitats were the deep, rather slow reaches where steep cliffs bordered one channel margin and broad sandbars the other. Measurement of such a site (several of which are accesible below Rattlesnake Rapids) is suggested as a valuable addition to the current sites.

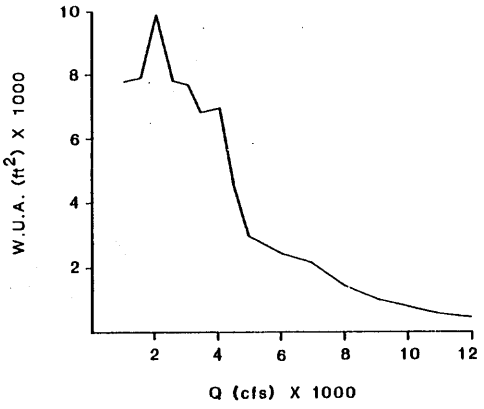
### Colorado River

As on the Green River, two Colorado River sites (Black Rocks and Potash) provided good WUA for Colorado squawfish YOY while the Moab site had significant WUA only for a limited range of low flows (Figures 9 through 11). The Black Rocks reach gained in adult humpback chub habitat as flow increased, probably because of the large secondary channel area which became inundated at higher flows. The same effect was probably true for squawfish YOY, in this case resulting in two peaks of WUA.

At Potash, a similar bimodal relationship was apparent; this condition has been noted in other large rivers in the basin and probably resulted from the stepped cross-sectional configuration and the establishment of two distinct habitats and different flow levels.

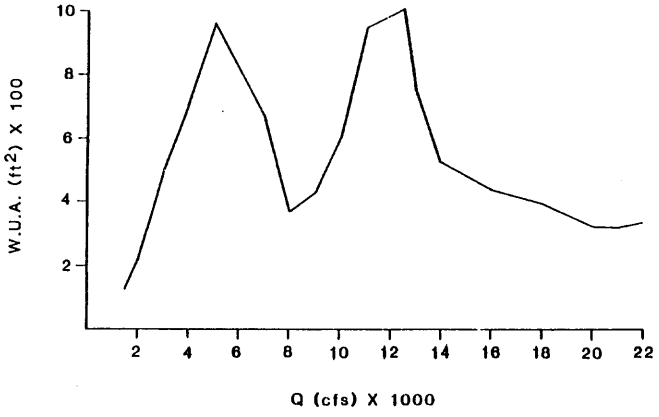
The Moab reach, because of its simple, incised channel characteristics, provided little shallow, slow water and subsequently, very little YOY habitat. The center channel areas were of uniformly high velocity, however, and provided good adult habitat only at very low flows.

Figure 6



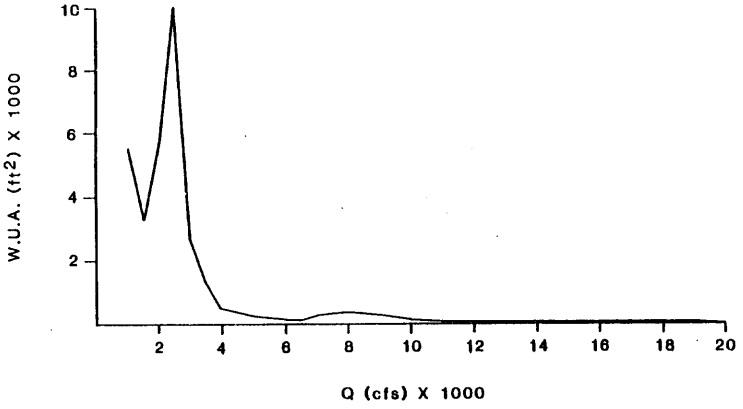

WUA for 1000 linear ft. of stream vs. ascending flow for Colorado squawfish YOY at the Ouray Refuge physical habitat sampling site.

Figure 7



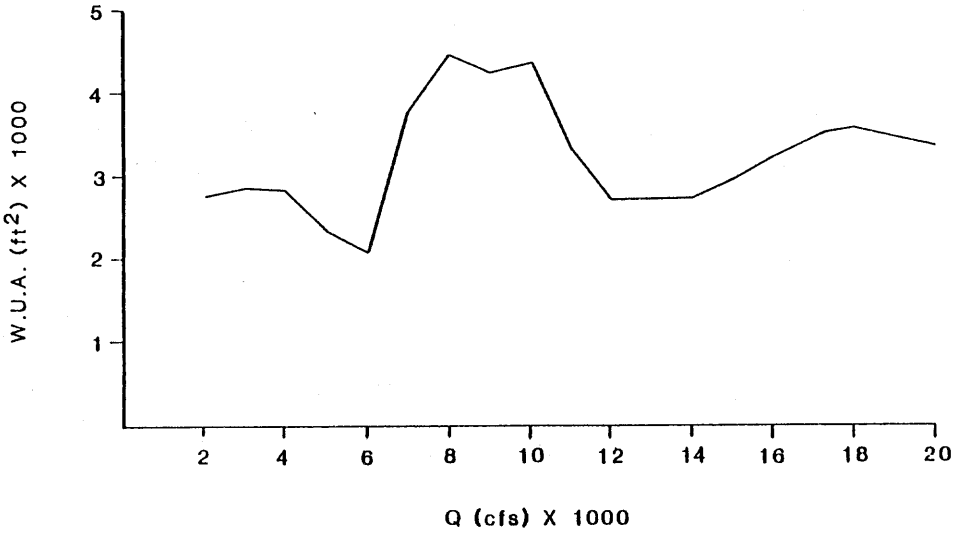

WUA 1000 linear ft. of stream vs. ascending flow for Colorado squawfish YOY at the Grays Canyon physical habitat sampling site.

Figure 8



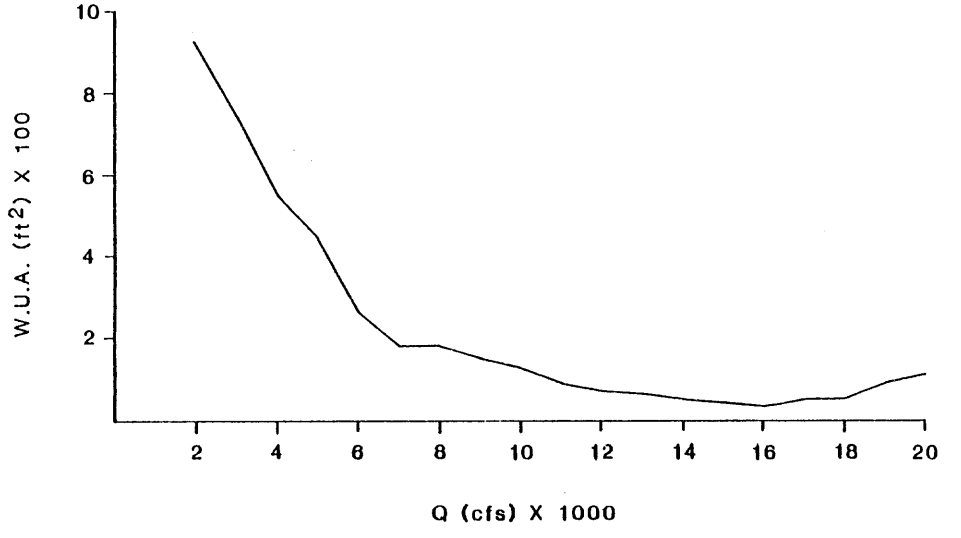

WUA for 1000 linear ft. of stream vs. ascending flow for Colorado squawfish YOY at the Mineral Bottom physical habitat sampling site.

Figure 9



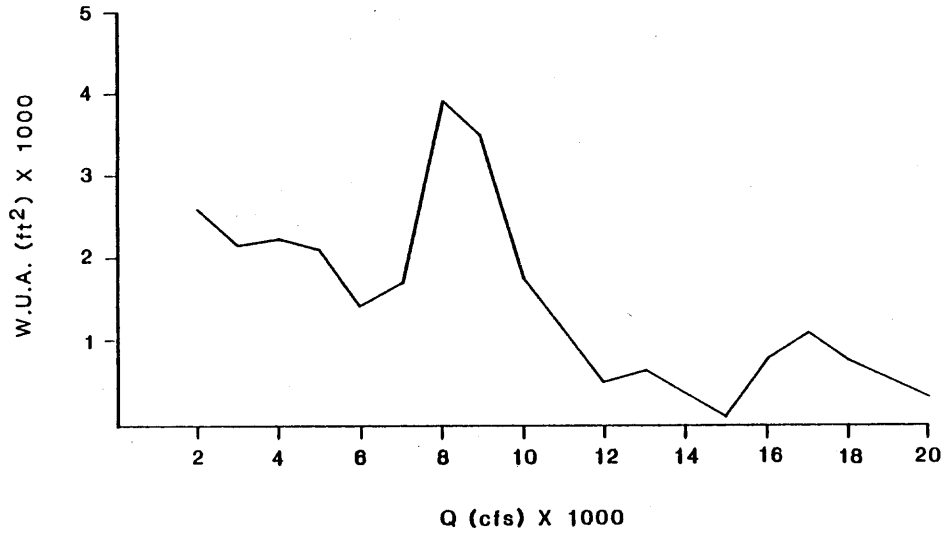

WUA for 1000 linear ft. of stream vs. ascending flow for Colorado squawfish YOY at the Black Rocks physical habitat sampling site.

Figure 10



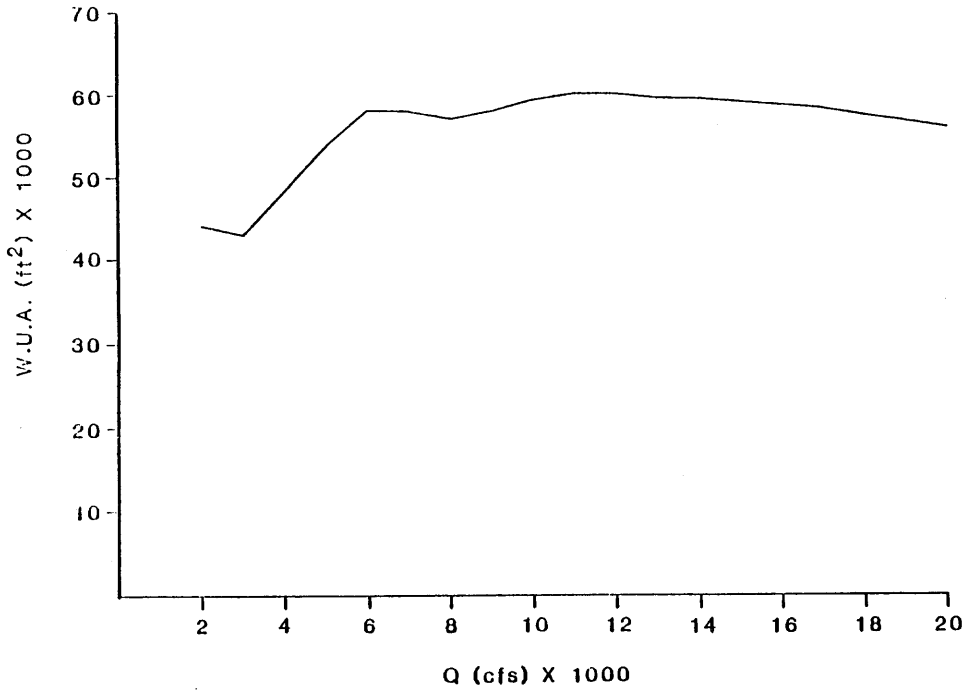

WUA for 1000 linear ft. of stream vs. ascending flow for Colorado squawfish YOY at the Moab physical habitat sampling site.

Figure 11




WUA for 1000 linear ft. of stream vs. ascending flow for Colorado squawfish YOY at the Potash physical habitat sampling site.

Figure 12




WUA for 1000 linear ft. of stream vs. ascending flow for adult humpback chubs at the Black Rocks physical habitat sampling site.

Humpback Chub Adults at Black Rocks

WUA at Black Rocks varied by a factor of less than 2 throughout the entire flow range (Figure 12). The Black Rocks hydraulic simulation model was only run to a low flow of 2000 cfs (a very low recurrence flow at the Colorado-Utah State line USGS gage). Even at this flow the Black Rocks reach offered more than 40,000 $ft^2$ of WUA for every 1000 linear feet of stream, which is nearly half the total surface area of the reach. At flows between 8,000 and 15,000 cfs, over 60,000 $ft^2$ of WUA was available. Clearly, based on the rather broad habitat suitability curves for depth and velocity and the fact that the substrates represented in the curves are essentially the only ones available at the Black Rocks reach, flow changes are not likely to have a major effect upon adult humpback chub WUA at Black Rocks.

## Analysis of Flow Time Series

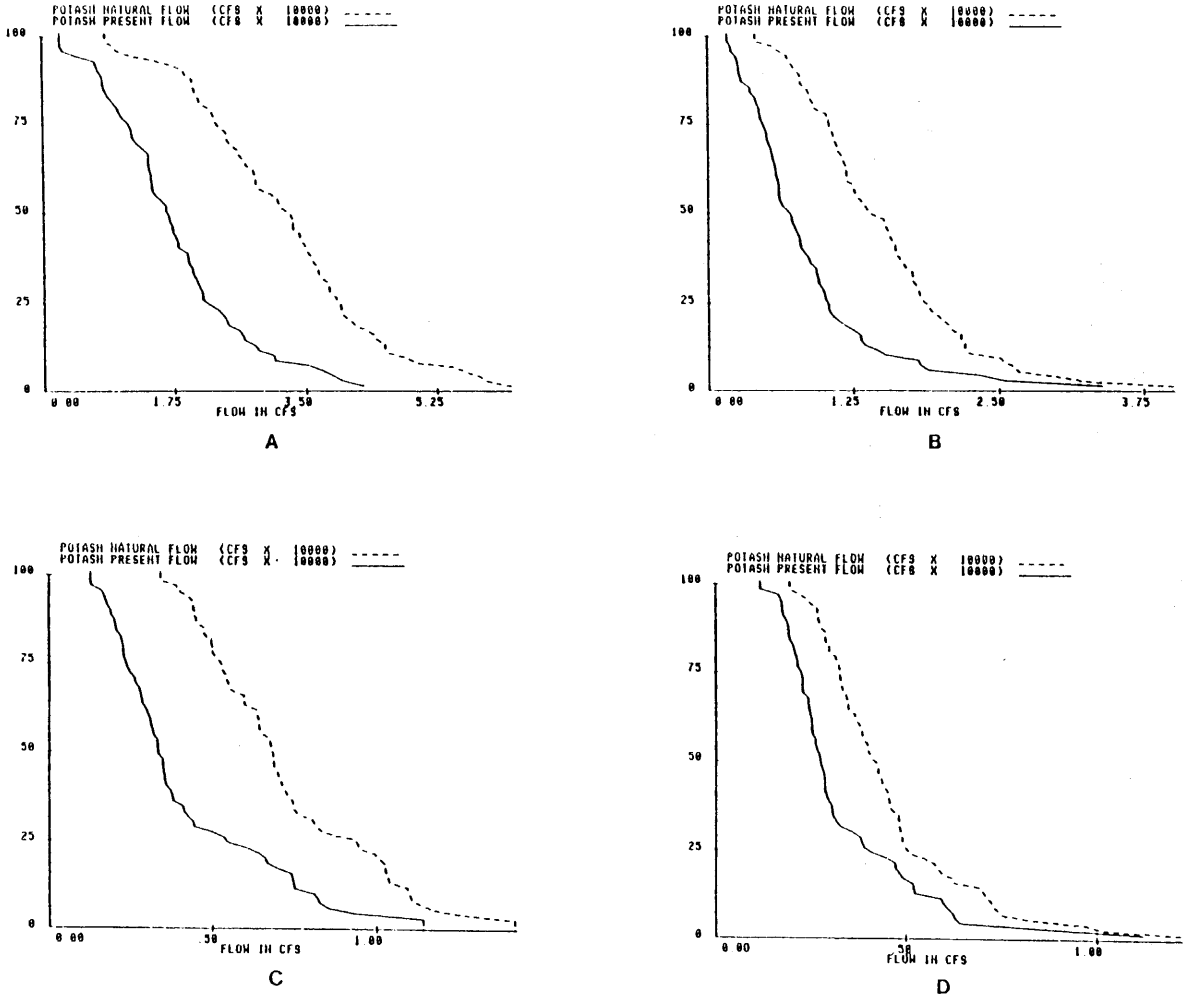
The Colorado and Green Rivers have been influenced quite differently by water developments. The present vs. natural comparisons (using percent exceedence plots) show a proportional reduction in the occurrence of all flow levels on the Colorado river (Figure 13). In contrast, the Green River has experienced a similar reduction in flow, with proportionally greater losses in the high flow range (Figure 14).

The timing of depletions on the Colorado River appears to have changed slightly with present level peak flows occurring more often in May than in June, an event expected with major reservoir storage taking place on the runoff peak (Figure 13). Peak flow on the Green River simulation appears to have been shifted from June to July (Figure 14) during about half the simulated years. These timing shifts may simply be the result of simulation techniques in the CRSS model, but could in actual occurrence cause significant impacts upon reproductive life history of the endangered fishes.

WUA times series for YOY squawfish were produced at the Ouray, Mineral Bottom, and Potash sites because these habitats had been identified as good rearing locations. The results from the Ouray and Potash reaches were probably more reliable than those from Mineral Bottom because of the latter's very low and narrow range of suitable discharges.

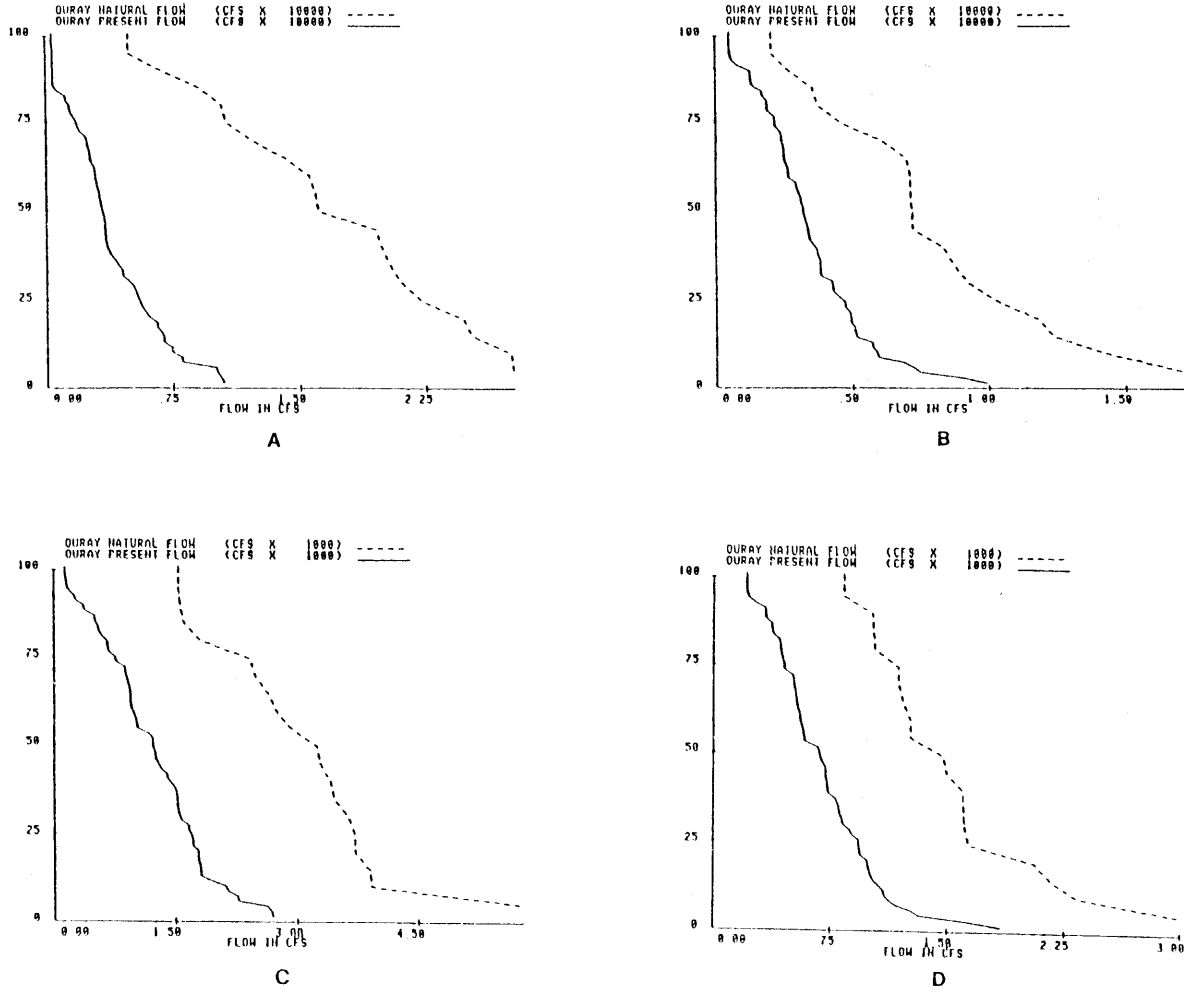
The effects of severe water depletion upon YOY habitat at the Ouray reach were variable among months from May through September (Figure 15). May, June, and July YOY habitat appears to have been profoundly improved by reduction in flow during those months. August and September results, however, indicate habitat depletions due to flow reductions in the lower range of suitable flows. During August, the depletions caused little change in physical habitat, but during September, reductions were typically so severe that the pre-development regime provided almost 50 percent more habitat at the 50th percentile exceedence levels and 300 percent more at the 80th percentile level. While these results were based on simulated data, they did clearly demonstrate that, even for immature fish which preferred slow, shallow water, flow levels must be maintained within a prescribed range if suitable habitat is to be provided.

Figure 13



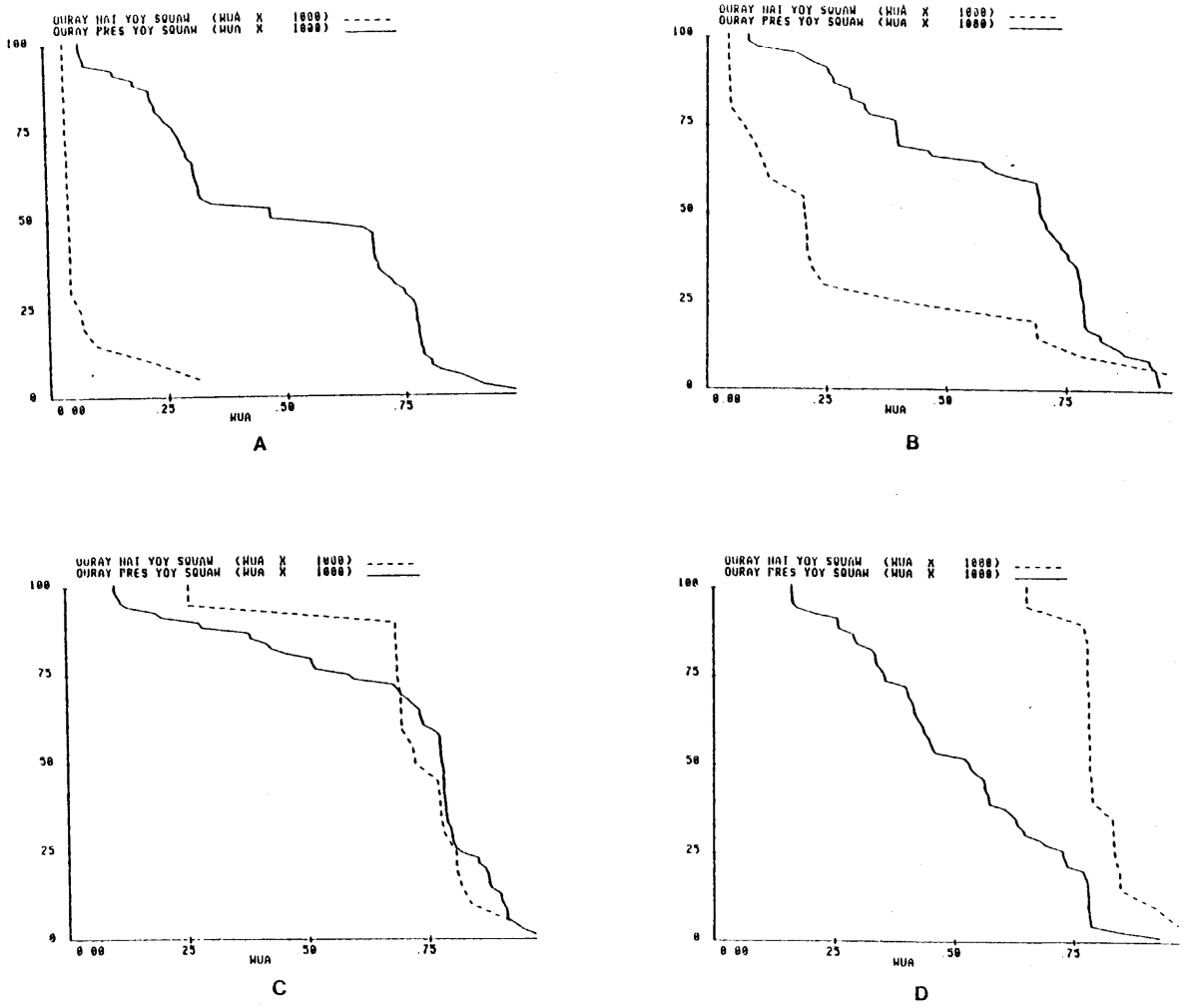

Percent exceedence plots for natural and present flow levels at Potash reach, Colorado River, as predicted by the CRSS program. (A=June, B=July, C=August, and D=September).

Figure 14




Percent exceedence plots for natural and present flow levels at Ouray reach Green River, as predicted by the CRSS program. (A-June, B=July, C-August, and D-September).

Figure 15




Percent exceedence plots for YOY squawfish WUA at Ouray reach, Green River, (from flows predicted by CRSS model). (A=June, B=July, C=August, and D=September).

The Mineral Bottom results reflected the extremely restricted range of suitable flows for YOY at that study site (Figure 16). While flow reductions have not been so severe as those upstream at Ouray (because of intervening tributaries and ground water effects), they appear to have provided some positive physical habitat effect. Oddly, at the 50% percentile exceedence level (noting those habitat values expected to occur during one-half of the months of record) the depletions have caused very little change in habitat except during August. Depletions during August appear to have brought the flows within the range of suitability, whereas depletions during the runoff months were still not great enough to result in suitable low flow levels.

Results at the Potash site somewhat reflected those at Mineral Bottom (Figure 17). Again, while reductions in flow were somewhat uniform, they had not been as great as those in the Upper Green River. Also, the reductions were proportionally greatest during runoff months; during September, the percentage reduction was quite low.

Only during July was YOY physical habitat effected significantly by flow reductions; again, a positive effect was noted. In general the effects of flow depletions upon the nursery habitats of both rivers appear to be either neutral or positive, with respect to depth, velocity, and substrate.

The actual flow times series (1960-1980) were completed for use in further refinements of flow recommendations and determinations of effects of recent flow events upon endangered fish populations. This report does not provide an in-depth analysis of the actual flow time series; more will be done with this information when more detailed life history information is made available.

## Temperature Model Results

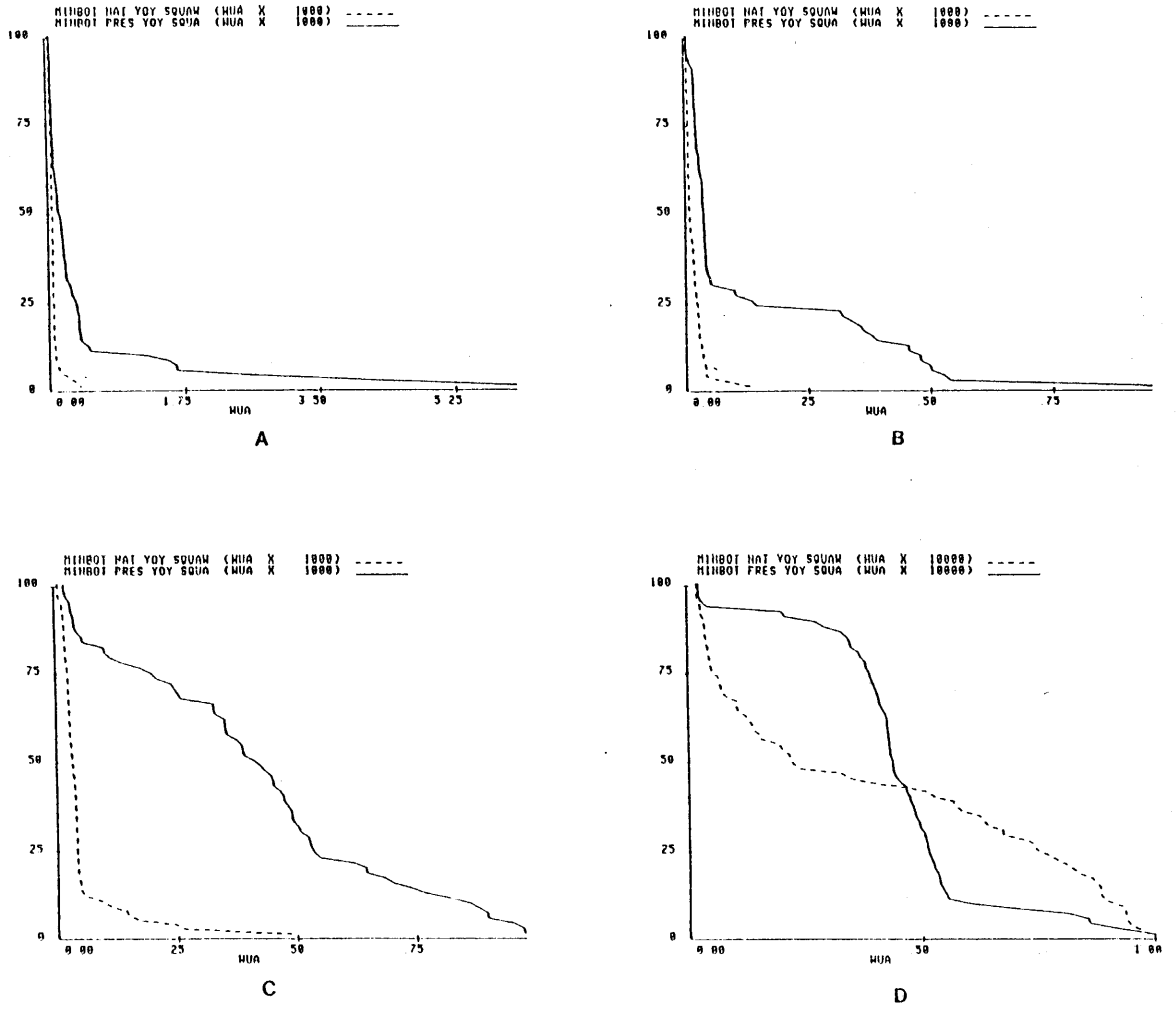
Table 2 identifies the respective gages and their associated adjusted multiple correlation coefficients (r) and probable difference (d). The correlation coefficient was the ratio of explained variation of the predicted temperature to the total variation of the published temperature. The probable error was the expected difference range of the published temperature with respect to the predicted temperatures; i.e., 50 percent of the published temperatures fall within the probable difference limits of the predicted temperature.

The regression models for the headwater and point source gages were used to predict the initial (headwater) water temperatures necessary for the physical process instream water temperature model. The regression models for the validation gages were used to predict temperatures against which to measure the performance of the physical process model.

## Temperature Simulations at Black Rocks and Ouray

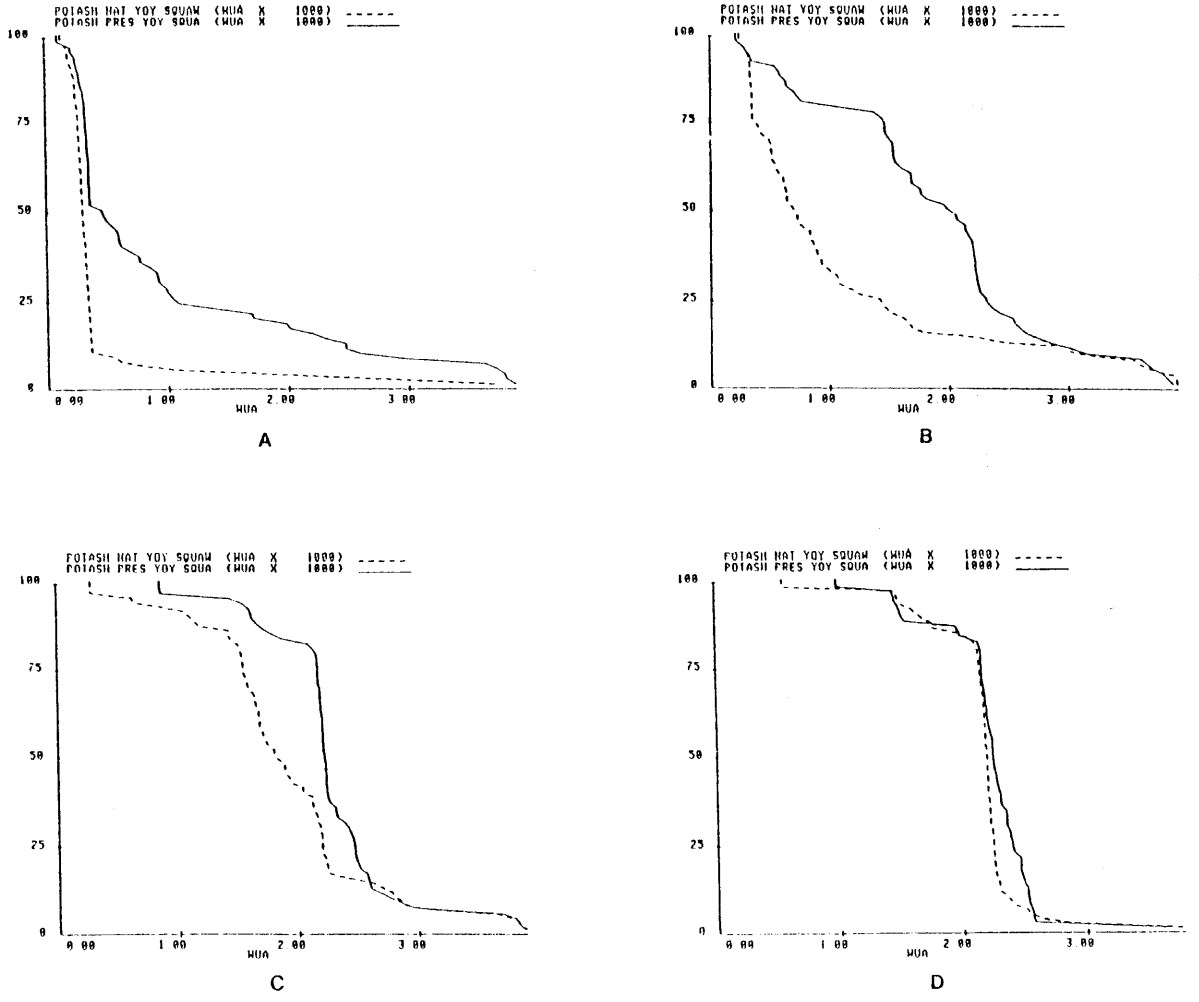
At Black Rocks, the May flows ranging from 7,000 to 13,500 cfs were associated with temperatures ranging from 15° C to 13° C (Figure 18). The mean annual May flow (10,000 cfs) was sufficiently high to maintain

Figure 16




Percent exceedence plots for YOY squawfish WUA at Mineral Bottom reach, Green River (from flows predicted by CRSS model). (A=June, B=July, C=August, D=September).

Figure 17



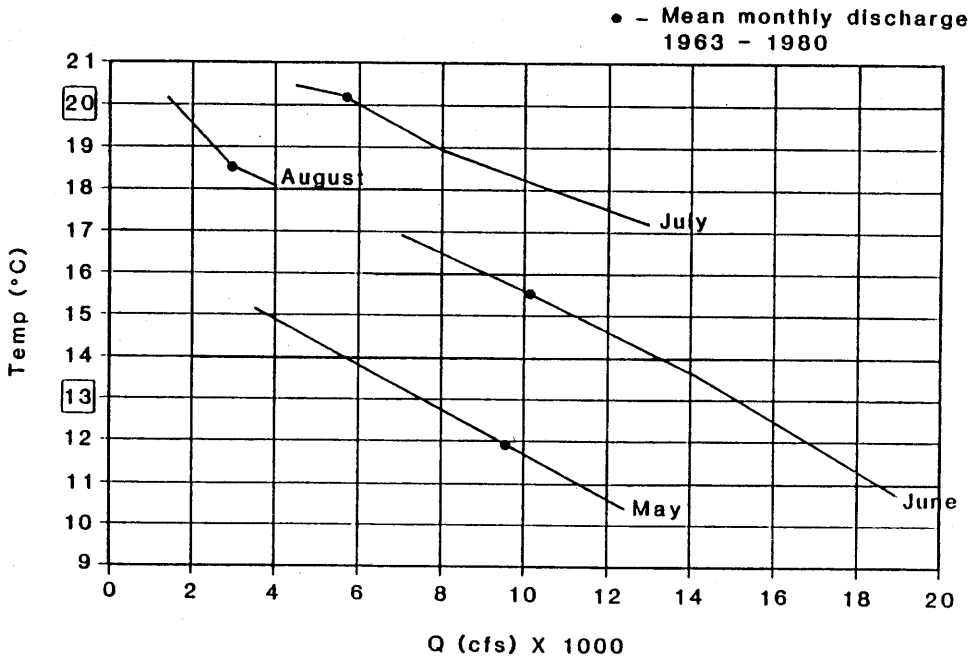

Percent exceedence plots for YOY squawfish WUA at Potash reach, Colorado River (from flows predicted by CRSS model). (A=June, B=July, C=August, and D=September).

Table 2
Results of regression analysis used
in development of validation temperatures

| Report name | Location | USGS gage number | R | d (C) |
|---|---|---|---|---|
| Headwater and point source gages | | | | |
| Flaming Gorge | Green River near Greendale, Utah | 09234500 | 0.789 | ± 0.93 |
| Yampa | Yampa River | Combined[1/] | 0.954 | ± 1.32 |
| Duschesne | Duschesne River near Randett, Utah | 09302000 | 0.956 | ± 1.30 |
| Watson | White River near Watson, Utah | 09306500 | 0.965 | ± 1.23 |
| Price | Price River at Woodside, Utah | 09314500 | 0.877 | ± 2.76 |
| San Rafael | San Rafael River near Green River, Utah | 09328500 | 0.955 | ± 1.66 |
| Cameo | Colorado River near Cameo, Colorado | 09095500 | 0.987 | ± 0.65 |
| | Dolores River near Cisco, Utah | 09180000 | 0.984 | ± 0.94 |
| Grand Junction | Gunnison River near Grand Junction, Colorado | 09152500 | 0.977 | ± 0.97 |
| Validation gages | | | | |
| Jensen | Green River near Jensen, Utah | 09261000 | 0.978 | ± 0.89 |
| Green River | Green River near Green River, Utah | 09315000 | 0.977 | ± 1.16 |
| State line | Colorado River near Colorado-Utah State line | 09163530 | 0.978 | ± 1.02 |
| Cisco | Colorado River near Cisco, Utah | 09180500 | 0.985 | ± 0.87 |
| UT163 | Colorado River at UT163 near Moab, Utah | 09182880 | 0.951 | ± 1.60 |

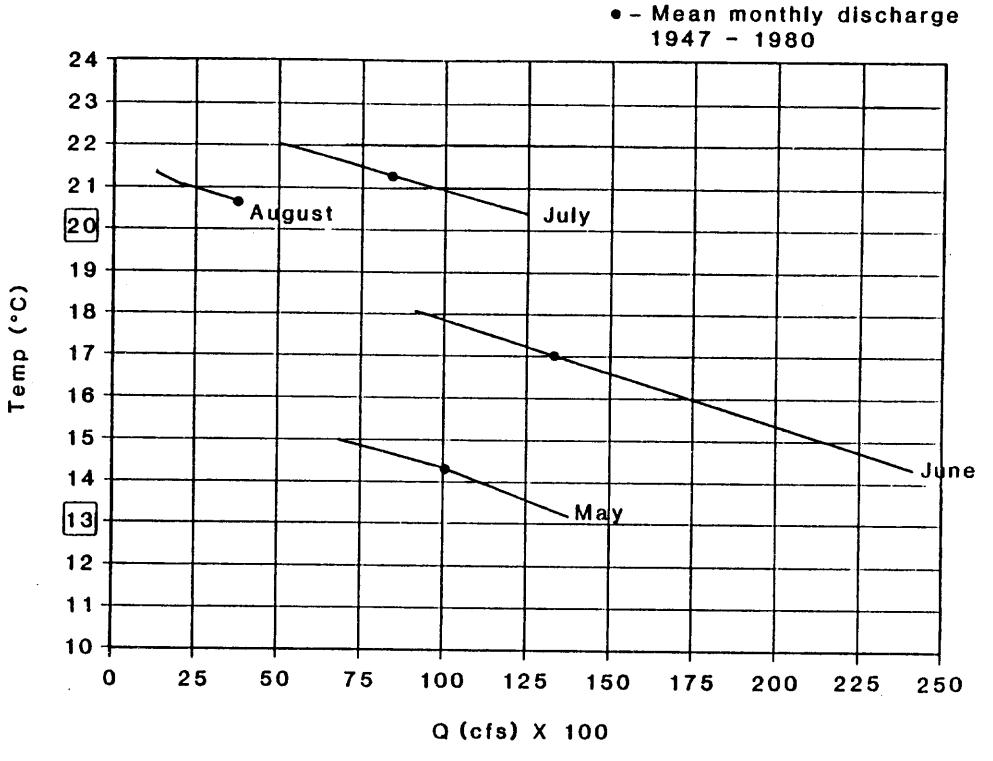
1/ Yampa was simulated using flow-weighted temperatures from the Little Snake River near Lily, Colorado (09260000) and the Yampa River near Maybell, Colorado (09251000) gage.

Figure 18




Mean monthly discharge-temperature relationships for May-August at Black Rocks reach, Colorado River, (temperatures expected under normal meteorlogic conditions).

Figure 19




Mean monthly discharge-temperature relationships for May-August at Jensen reach, Green River, (temperatures expected under normal meteorlogic conditions).

temperatures in the spawning range of humpback chubs. June flows, however, were necessarily quite high to maintain humpback spawning temperatures, especially if reproductive isolation between humpback and roundtail chubs was to be maintained. The normal July and August squawfish spawning requirements were easily met at the mean monthly discharge levels for those 2 months.

The Jensen reach Green River temperatures indicate suitable squawfish spawning temperatures only at flows less than the July mean monthly discharges, during July (Figure 19). Even at the July mean monthly discharge, temperatures at Jensen only exceed squawfish spawning criteria by 1° C.

The temperature depression here, relative to downstream Green River reaches and to the Colorado River during similar periods, is due to Flaming Gorge releases during the period of record. It is likely that cooling to this extent is no longer apparent, because of increased Flaming Gorge release temperatures.

## Validation

Results of the regression models for the validation gages were compared to results of the physical process model using the mean difference, $\delta$, probable difference range, d, by months for the years 1964 to 1977 (Table 3). The same statistics were calculated for "normal" discharges and meterological conditions. (Table 4). The probable difference range is the 50 percent confidence limits about the mean difference; i.e., 50 percent of the data from the validation gage regression model will fall within $\delta \pm d$ of the physical process model.

One must not assume that the differences represent errors. Where there is a difference, it can only be said that both temperatures cannot be correct. Errors probably exist in both the regression and physical process models. It has been pointed out that the published water temperature data does not represent the average daily water temperatures. Therefore, it can only be expected that the regression model predictions generally fall within the minimum/maximum daily water temperatures.

## Calibration

It was possible to calibrate the physical process model to exactly match water temperature data at any of the validation gages by either modifying the regression models at the headwater and point sources or adjusting certain stream channel geometry variables (e.g., stream width). Assuming that the validation gage regression models were accurate, another calibration technique involved adjusting the wind speed to account for both the transposition from the weather station to each reach in the basin and to possibly better determine the evaporation coefficient used in the heat flux components.

Table 3
Results of validation process for UCRB sites
($\bar{\delta}$ = mean difference, d = probable difference) 1964-1977

| Month | | Jensen | Green River | State line | Cisco | UT163 |
|---|---|---|---|---|---|---|
| January | $\bar{\delta}$ | 0.78 | 0.21 | - 0.04 | 0.05 | - 0.60 |
| | d | ± 0.57 | ± 0.41 | ± 0.29 | ± 0.11 | ± 0.51 |
| February | $\bar{\delta}$ | 0.44 | 0.27 | - 0.16 | - 0.04 | - 0.31 |
| | d | ± 0.59 | ± 0.51 | ± 0.57 | ± 0.54 | ± 0.92 |
| March | $\bar{\delta}$ | 0.70 | 0.46 | 0.21 | - 0.08 | 0.30 |
| | d | ± 0.59 | 0.37 | ± 0.51 | ± 0.35 | ± 0.53 |
| April | $\bar{\delta}$ | 0.10 | 0.19 | - 0.13 | - 0.10 | 0.82 |
| | d | ± 0.74 | ± 0.37 | ± 0.90 | ± 0.68 | ± 0.54 |
| May | $\bar{\delta}$ | - 1.96 | - 1.01 | 0.00 | 0.39 | - 0.73 |
| | d | ± 0.91 | ± 0.57 | ± 0.49 | ± 0.48 | ± 0.78 |
| June | $\bar{\delta}$ | - 1.46 | - 1.48 | - 0.55 | - 0.11 | - 1.77 |
| | d | ± 0.80 | ± 0.57 | ± 0.43 | ± 0.41 | ± 0.94 |
| July | $\bar{\delta}$ | 0.12 | - 1.78 | - 0.74 | - 0.35 | - 1.23 |
| | d | ± 1.03 | ± 0.52 | ± 0.53 | ± 0.55 | ± 0.66 |
| August | $\bar{\delta}$ | - 0.26 | - 1.67 | - 0.66 | - 0.56 | - 0.75 |
| | d | ± 0.94 | ± 0.32 | ± 0.41 | ± 0.52 | ± 0.63 |
| September | $\bar{\delta}$ | - 0.01 | - 0.97 | - 0.58 | - 0.70 | - 1.03 |
| | d | ± 0.80 | ± 0.38 | ± 0.68 | ± 0.63 | ± 0.62 |
| October | $\bar{\delta}$ | - 0.13 | - 0.91 | - 0.28 | - 0.72 | - 0.79 |
| | d | ± 0.47 | ± 0.45 | ± 0.38 | ± 0.51 | ± 1.03 |
| November | $\bar{\delta}$ | 0.06 | - 0.90 | - 0.86 | - 1.17 | - 1.84 |
| | d | ± 0.53 | ± 0.34 | ± 0.37 | ± 0.44 | ± 0.78 |
| December | $\bar{\delta}$ | ± 0.76 | - 0.21 | - 1.03 | - 0.97 | ± 2.64 |
| | d | ± 0.71 | ± 0.36 | ± 0.35 | ± 0.35 | ± 0.86 |
| Annual | $\bar{\delta}$ | - 0.08 | - 0.65 | - 0.40 | - 0.35 | - 0.84 |
| | d | ± 0.91 | ± 0.67 | ± 0.56 | ± 0.55 | ± 0.92 |

Table 4
Validation statistic for normal year
meterologic and hydrologic input

| Month | | Jensen | Green River | State line | Cisco | UT163 |
|---|---|---|---|---|---|---|
| January | $\delta$ | 1.11 | 0.00 | 0.27 | 0.25 | - 0.88 |
| February | $\delta$ | 0.76 | 0.52 | 0.02 | - 0.14 | - 1.01 |
| March | $\delta$ | 0.92 | 0.65 | 0.25 | - 0.10 | - 1.03 |
| April | $\delta$ | 0.61 | 0.39 | 0.18 | 0.11 | 0.45 |
| May | $\delta$ | - 1.19 | - 0.49 | 0.15 | 0.63 | - 0.46 |
| June | $\delta$ | - 1.36 | - 1.24 | - 0.13 | 0.55 | - 1.63 |
| July | $\delta$ | 0.52 | - 1.48 | - 0.18 | 0.19 | - 1.05 |
| August | $\delta$ | 0.52 | - 1.49 | - 0.26 | - 0.70 | - 0.49 |
| September | $\delta$ | 0.36 | - 1.13 | - 0.64 | - 1.03 | - 1.50 |
| October | $\delta$ | 0.17 | - 0.71 | - 0.32 | - 0.99 | - 1.85 |
| November | $\delta$ | - 0.10 | - 1.07 | - 0.96 | - 1.46 | - 2.64 |
| December | $\delta$ | 0.54 | - 0.65 | - 1.11 | - 1.26 | - 3.38 |
| Annual | $\bar{\delta}$ | 0.24 | - 0.56 | - 0.23 | - 0.33 | - 1.21 |
| | d | ± 0.53 | ± 0.53 | ± 0.31 | ± 0.49 | ± 0.73 |

Changes in wind speed factor could be used to reduce or entirely eliminate the monthly mean differences, $\bar{\delta}$, at validation gages (Tables 5 and 6). No attempt was made to calibrate UT163 because the data is considered unreliable. Obviously, if the mean differences for all months were reduced or eliminated at a specific gage, the annual mean difference was also reduced or eliminated. However, a probable difference range for each month would generally remain. In other words, calibration could only reduce the bias, not necessarily remove all differences.

Table 5
Wind calibration statistics: 1964-1977

| Month | | Jensen | Green River | State line | Cisco | UT163 |
|---|---|---|---|---|---|---|
| January | $\bar{\delta}$ | 0.01 | 0.09 | - 0.04 | 0.05 | - 0.60 |
| | d | ± 0.31 | ± 0.22 | ± 0.29 | ± 0.11 | ± 0.51 |
| February | $\bar{\delta}$ | 0.00 | 0.01 | - 0.01 | - 0.04 | - 0.30 |
| | d | ± 0.59 | ± 0.47 | ± 0.57 | ± 0.54 | ± 0.92 |
| March | $\bar{\delta}$ | 0.00 | 0.01 | 0.02 | - 0.01 | 0.62 |
| | d | ± 0.55 | ± 0.38 | ± 0.51 | ± 0.34 | ± 0.57 |
| April | $\bar{\delta}$ | 0.01 | - 0.04 | 0.03 | - 0.01 | 0.88 |
| | d | ± 0.73 | ± 0.37 | ± 0.90 | ± 0.67 | ± 0.54 |
| May | $\bar{\delta}$ | - 1.37 | - 0.01 | 0.00 | 0.05 | - 1.43 |
| | d | ± 1.19 | ± 0.82 | ± 0.49 | ± 0.65 | ± 0.61 |
| June | $\bar{\delta}$ | - 0.46 | - 0.02 | 0.00 | - 0.00 | - 2.04 |
| | d | ± 1.46 | ± 0.67 | ± 0.53 | ± 0.44 | ± 0.80 |
| July | $\bar{\delta}$ | 0.01 | 0.06 | - 0.01 | 0.04 | - 1.10 |
| | d | ± 0.99 | ± 0.48 | ± 0.55 | ± 0.51 | ± 0.65 |
| August | $\bar{\delta}$ | 0.00 | - 0.04 | - 0.02 | 0.01 | - 0.21 |
| | d | ± 1.12 | ± 0.30 | ± 0.44 | ± 0.52 | ± 0.65 |
| September | $\bar{\delta}$ | - 0.01 | 0.00 | - 0.03 | - 0.02 | - 0.17 |
| | d | ± 0.80 | ± 0.38 | ± 0.70 | ± 0.64 | ± 0.66 |
| October | $\bar{\delta}$ | 0.06 | - 0.00 | - 0.02 | - 0.04 | 0.42 |
| | d | ± 0.47 | ± 0.35 | ± 0.36 | ± 0.46 | ± 0.92 |
| November | $\bar{\delta}$ | 0.02 | 0.00 | - 0.02 | 0.02 | - 0.16 |
| | d | ± 0.54 | ± 0.29 | ± 0.34 | ± 0.38 | ± 0.69 |
| December | $\bar{\delta}$ | 0.00 | - 0.04 | 0.00 | - 0.05 | - 1.52 |
| | d | ± 0.76 | ± 0.36 | ± 0.28 | ± 0.27 | ± 0.69 |
| Annual | $\bar{\delta}$ | - 0.15 | 0.00 | - 0.01 | 0.01 | - 0.47 |
| | d | ± 0.87 | ± 0.44 | ± 0.51 | ± 0.47 | ± 0.89 |

Table 6 shows the monthly mean differences at each validation gage for the normal (mean monthly average) calibrated conditions. One could have just as easily calibrated on the normals and compared the results to the historical temperatures.

Table 6
Calibration wind factors used to adjust mean differences between predicted and simulated validation temperatures

| Month | Jensen | Green River | State line | Cisco |
|---|---|---|---|---|
| January | 1.85 | 1.6 | 1 | 1 |
| February | 1.22 | 1.05 | 0.94 | 1.05 |
| March | 1.3 | 1.08 | 1.06 | 0.8 |
| April | 1.06 | 1.07 | 0.95 | 1 |
| May | 0 | 0.83 | 1. | 1.7 |
| June | 0 | 0.75 | 0.7 | 1.5 |
| July | 1.08 | 0.505 | 0.79 | 1.05 |
| August | 0.76 | 0.65 | 0.85 | 0.9 |
| September | 1 | 0.715 | 0.85 | 0.78 |
| October | 0.9 | 0.62 | 0.9 | 0.4 |
| November | 1.02 | 0.34 | 0.6 | 0 |
| December | 1.3 | 0.48 | 0.4 | 0.6 |

## Maximum Daytime Water Temperatures

The computer model currently calculates only the average daily water temperatures. The water temperatures actually vary from a minimum just before sunrise to a maximum just before sunset. The maximum daytime water temperature model was used for the normal monthly discharges and meterological conditions and was solved using the HP-41C (Table 7). The results can be interpreted to be indicative of the anticipated rise in water temperatures above the average daily temperature for any year. For example, the month of June shows an increase in water temperature of 1.81 to 2.12C above the average daily for the normal June conditions. Therefore, the month of June in any year can be expected to show a similar increase.

Table 7
Maximum daytime temperature increments (C)

| | Study sites | | | | | |
|---|---|---|---|---|---|---|
| Month | Ouray | Grey's Canyon | Mineral Bottom | Black Rocks | Moab | Potash |
| January | 1.09 | 1.33 | 1.47 | 1.37 | 1.24 | 1.27 |
| February | 1.46 | 1.75 | 1.88 | 1.82 | 1.71 | 1.67 |
| March | 1.85 | 2.15 | 2.24 | 2.28 | 2.08 | 2.04 |
| April | 1.95 | 2.22 | 2.38 | 2.43 | 2.15 | 2.10 |
| May | 1.91 | 2.02 | 2.26 | 2.22 | 1.97 | 1.94 |
| June | 1.81 | 1.86 | 2.12 | 2.05 | 1.82 | 1.82 |
| July | 1.87 | 2.04 | 2.13 | 2.05 | 1.79 | 1.78 |
| August | 2.08 | 2.35 | 2.39 | 2.30 | 2.06 | 2.05 |
| September | 2.10 | 2.44 | 2.46 | 2.35 | 2.16 | 2.10 |
| October | 1.72 | 2.03 | 2.08 | 2.25 | 1.80 | 1.75 |
| November | 1.26 | 1.54 | 1.60 | 1.48 | 1.36 | 1.27 |
| December | 0.97 | 1.21 | 1.37 | 1.20 | 1.12 | 1.11 |

If there are serious depletions of flow in any month over the current normal discharges, the anticipated rise will be greater because the water temperature would more closely approach the equilibrium water

temperature. The average daily water temperatures would rise under these conditions and the daily water temperature cycle would be exaggerated. The computer model could be easily modified to include the maximum daytime water temperature model.

## CONCLUSIONS

In general, the Green River reaches offered more physical habitat for squawfish YOY than did those on the Colorado River. Also, at the Black Rocks and Potash reaches, considerable YOY habitat was available across a broad range of flows. Considering the downstream location of the Potash reach, it was advantageous that higher flows there were required to provide maximum squawfish YOY habitat.

Squawfish YOY habitat at the Potash reach was highest between 7,000 and 10,000 cfs and again at 15,000 cfs. At Black Rocks humpback chub adult habitat was insensitive to changes in flow with high WUA at low flows increasing as flow increased.

The Green River reaches did not respond similarly to changes in flow. First, maximum squawfish YOY habitat at the Mineral Bottom reach was attained at a lower flow than that which provided maximum YOY habitat at the upstream Ouray reach. Second, at all Green River reaches, either very low YOY habitat (at Grey's Canyon) or appreciable habitat across only a narrow range of flows was demonstrated. At the identified nursery sites (Ouray and Mineral Bottom) flows in the 2000-4500 cfs range were most suitable for squawfish YOY. At Mineral Bottom, this range was restricted to less than 3500 cfs.

In contrast, at the Moab and Greys Canyon reaches, very little habitat was available at any discharges except those within an extremely narrow range.

The results presented here may be used to formulate certain hypotheses regarding the effects of changes in discharge, especially upon preferred habitats of Colorado squawfish YOY. They should not be construed as flow recommendations or standards against which projects should be evaluated. Within the limitations of the data it is possible to make some valuable conclusions.

1. To a low discharge level of 2000 cfs, changes in discharge at the Black Rocks reach of the Colorado River do not cause significant changes in available physical habitat for ~~or~~ adult humpback chubs.

2. At the sand-substrate reaches, such as the Moab, Ouray and Mineral Bottom reaches, changes in discharge within the normal range may have profound results upon available physical habitat, especially for squawfish YOY. Because these reaches have been identified as prime habitats for rearing of squawfish young, and because they represent a very prevalent UCRB habitat type, it would seem highly

desirable to determine the flow requirements within these reaches for YOY squawfish. Such flow requirements result from analysis of both physical habitat and biologic data; the results presented in this phase of the report only define the species requirements with respect to depth, velocity, and substrate.

3. Certain habitat types, based both on PHABSIM results and actual fish captures, offer little suitable habitat at any normal flow, but may serve as refugia during extremely low-flow periods. In such cases, passage from normally suitable reaches to these areas might allow short-term survival during such severe conditions as were seen in 1977 or 1981. Also, such habitats, usually characterized by poor physical diversity, may be selected as potential habitat improvement locations.

4. To assure reproductive isolation between humpback and roundtail chubs at Black Rocks, May mean monthly discharges should be maintained in the 10,000 to 13,000 cfs range; June flows, at least at the historic mean monthly level, appear to be desirable.

5. The analyses of flow and WUA time series for natural vs present level depletions demonstrated a generally positive effect upon squawfish YOY. However, the apparently narrow range of suitable discharges at the Green River nursery sites (especially Mineral Bottom) resulted in effects ranging from high positive to high negative, depending upon the month involved. It is quite possible that further unspecified depletions in either river might result in generally negative effects. At present, the discharge ranges suggested should be adhered to.

6. The apparent suitability of low-regime flows for YOY should not encourage neglect of temperature and sediment transport consequences. The 3,500 cfs flow found to provide excellent YOY habitat at Ouray and Mineral Bottom would not be a suitable peak flow to ensure maintenance of sand-transport equilibrium throughout the Green River. Similarly, the 7000-8000 portion of the suitable Potash YOY range, if allowed to become peak flow in the Colorado, would not ensure sand-transport equilibrium, and might alter the Black Rocks-Westwater temperature regime enough to cause loss of reproductive isolation between humpback and roundtail chubs.

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Appendix I, continued

Calibration details for Green Colorado IFG-4 and WSP Models

| Transect 1 | | Transect 2 | | Transect 3 | | Transect 4 | | Transect 5 | | Transect 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Predicted | Measured $(\frac{V_1 \quad V_2}{2})$ 1/ | Predicted | Measured $(\frac{V_1 \quad V_2}{2})$ 1/ | Predicted | Measured $(\frac{V_1 \quad V_2}{2})$ 1/ | Predicted | Measured $(\frac{V_1 \quad V_2}{2})$ 1/ | Predicted | Measured $(\frac{V_1 \quad V_2}{2})$ 1/ | Predicted | Measured $(\frac{V_1 \quad V_2}{2})$ 1/ |
| | | | | Predicted and measured velocities at Mineral Bottom for 2403 cfs | | | | | | | |
| .42 | .39 | .55 | .46 | .89 | .85 | .59 | .58 | .15 | 0.0 | .58 | .58 |
| .94 | .90 | 1.16 | 1.14 | 2.07 | 1.90 | 1.41 | 1.39 | .12 | 0.6 | 1.31 | 1.40 |
| 1.50 | 1.41 | 1.70 | 1.67 | 1.94 | 1.84 | 1.82 | 1.77 | .59 | .56 | 1.89 | 1.90 |
| 2.36 | 2.10 | 2.10 | 1.98 | 1.50 | 1.37 | 1.90 | 1.82 | 1.50 | 1.43 | 1.96 | 1.93 |
| 2.28 | 2.19 | 1.92 | 1.87 | 1.43 | 1.34 | 2.04 | 1.98 | 2.26 | 2.14 | 2.23 | 2.18 |
| 2.15 | 2.02 | 1.95 | 1.85 | 2.29 | 2.16 | 1.98 | 1.99 | 2.11 | 2.02 | 2.25 | 2.27 |
| 1.97 | 1.78 | 2.21 | 2.11 | 2.32 | 2.29 | 1.35 | 1.35 | 1.87 | 1.80 | 2.08 | 1.98 |
| 1.48 | 1.38 | 1.75 | 1.76 | 2.12 | 1.97 | .67 | .66 | 1.68 | 1.59 | 1.78 | 1.78 |
| .37 | .33 | 1.75 | 1.67 | 1.35 | 1.28 | .34 | .33 | .59 | .56 | .81 | .77 |
| | | 1.11 | 1.08 | .45 | .42 | | | | | | |
| | | .29 | .21 | | | | | | | | |
| | | | | Predicted and measured velocities at Mineral Bottom for 5088 cfs | | | | | | | |
| .66 | .62 | 1.03 | .99 | 1.07 | 1.08 | 1.43 | 1.42 | .60 | .59 | .50 | .45 |
| 1.30 | 1.22 | 2.04 | 1.93 | 2.18 | 2.21 | 1.88 | 1.86 | 1.73 | 1.68 | 1.26 | 1.13 |
| 2.01 | 1.89 | 1.81 | 1.73 | 2.21 | 2.22 | 2.16 | 2.10 | 2.11 | 2.06 | 1.71 | 1.65 |
| 2.84 | 2.66 | 2.14 | 2.09 | 2.36 | 2.39 | 2.19 | 2.14 | 2.51 | 2.52 | 2.25 | 2.19 |
| 3.11 | 2.94 | 2.62 | 2.58 | 2.41 | 2.46 | 2.22 | 2.21 | 2.44 | 2.40 | 2.42 | 2.33 |
| 3.06 | 3.02 | 2.81 | 2.74 | 2.70 | 2.79 | 2.29 | 2.27 | 2.23 | 2.16 | 2.60 | 2.55 |
| 3.14 | 3.06 | 2.56 | 2.52 | 2.90 | | 1.90 | 1.80 | 1.89 | 1.89 | 3.05 | 2.93 |
| 2.99 | 2.94 | 2.35 | 2.36 | 2.39 | 2.43 | 1.15 | 1.13 | .93 | .91 | 3.33 | 3.15 |
| 2.67 | 2.56 | 2.70 | 2.56 | 1.59 | 1.62 | .57 | .42 | | | 1.23 | 1.11 |
| 1.11 | 1.04 | 2.05 | 1.97 | .52 | .52 | | | | | | |
| | | .60 | .57 | | | | | | | | |
| | | | | Predicted and measured velocities at Mineral Bottom for 10285 cfs | | | | | | | |
| 1.33 | 1.35 | 1.21 | 1.21 | .84 | .84 | 1.86 | 1.80 | 1.29 | 1.34 | 1.22 | 1.15 |
| 2.87 | 2.92 | 2.58 | 2.57 | 1.97 | 1.99 | 3.09 | 3.08 | 2.55 | 2.62 | 2.62 | 2.47 |
| 3.01 | 3.07 | 2.61 | 2.67 | 2.64 | 2.51 | 2.89 | 2.86 | 2.91 | 3.00 | 2.91 | 2.75 |
| 2.83 | 2.90 | 2.33 | 2.32 | 3.66 | 3.66 | 4.42 | 4.48 | 4.27 | 4.36 | 3.15 | 2.95 |
| 4.54 | 4.56 | 3.78 | 3.64 | 4.83 | 5.02 | 5.29 | 5.22 | 5.20 | 5.30 | 4.48 | 4.18 |
| 5.66 | 5.80 | 5.26 | 5.19 | 5.54 | 5.30 | 4.03 | 4.18 | 4.41 | 4.47 | 5.05 | 4.83 |
| 6.12 | 6.30 | 5.59 | 5.80 | 4.92 | 4.94 | 2.28 | 2.32 | 3.03 | 3.12 | 5.71 | 5.40 |
| 5.82 | 5.92 | 5.66 | 5.49 | 3.47 | 3.51 | 2.33 | 2.40 | 2.92 | 3.03 | 5.25 | 5.0 |
| 4.85 | 4.93 | 4.37 | 4.43 | 1.65 | 1.65 | 1.58 | 1.65 | 1.44 | 1.46 | 2.37 | 2.26 |
| 2.59 | 2.59 | 2.08 | 2.08 | .43 | .43 | | | | | | |
| | | .49 | .48 | | | | | | | | |
| | | | | Predicted and measured velocities at Ouray Refuge for 2194 cfs | | | | | | | |
| .14 | .01 | .94 | .96 | .13 | .01 | .14 | .01 | .09 | .01 | .14 | .01 |
| .72 | .79 | 2.88 | 2.93 | 1.44 | 1.51 | 2.32 | 2.10 | 1.44 | 1.39 | .41 | .16 |
| 2.92 | 2.94 | 2.72 | 2.69 | 3.09 | 3.15 | 3.19 | 3.10 | 2.34 | 2.32 | 2.28 | 2.17 |
| 3.05 | 3.08 | 2.40 | 2.48 | 2.59 | 2.61 | 2.71 | 2.58 | 2.29 | 2.28 | 2.87 | 2.69 |
| 1.62 | 1.69 | 2.57 | 2.64 | 2.23 | 2.29 | 2.69 | 2.55 | 2.30 | 2.20 | 1.67 | 1.63 |
| .77 | .85 | 2.48 | 2.47 | .89 | .93 | .54 | .63 | 2.68 | 2.55 | .45 | .24 |
| .21 | .01 | 2.11 | 2.11 | .30 | .13 | .22 | .01 | 1.79 | 1.75 | .37 | .06 |
| .46 | .52 | 1.02 | 1.03 | .25 | .01 | .33 | .01 | | | .28 | 0.0 |
| 1.85 | 1.90 | .04 | .01 | .15 | .01 | .30 | .03 | | | .26 | 0.0 |
| 2.89 | 3.03 | | | | | | | | | .33 | .13 |
| 1.30 | 1.45 | | | | | | | | | .37 | .22 |
| | | | | Predicted and measured velocities at Ouray Refuge for 3283 cfs | | | | | | | |
| .31 | .31 | .26 | .25 | .23 | .01 | .50 | .49 | .21 | .05 | .19 | 0.0 |
| 1.36 | 1.36 | 1.44 | 1.40 | 1.41 | 1.39 | 1.96 | 1.92 | 1.33 | 1.26 | .47 | .36 |
| 2.33 | 2.32 | 1.73 | 1.66 | 2.58 | 2.60 | 2.82 | 2.76 | 3.36 | 3.18 | 2.54 | 2.45 |
| 2.11 | 2.10 | 2.31 | 2.24 | 2.30 | 2.32 | 2.63 | 2.59 | 2.99 | 2.92 | 2.90 | 2.82 |
| 2.15 | 2.17 | 2.30 | 2.20 | 1.92 | 1.94 | 2.33 | 2.35 | 2.48 | 2.28 | 2.63 | 2.51 |
| 2.13 | 2.16 | 2.03 | 1.94 | 1.76 | 1.74 | 2.19 | 2.18 | 1.28 | 1.04 | 2.27 | 2.17 |
| 2,24 | 2.24 | 1.63 | 1.55 | 1.24 | 1.24 | 2.13 | 2.11 | .28 | .05 | 1.38 | 1.26 |
| 1.96 | 1.95 | 1.17 | 1.13 | .64 | .64 | 2.15 | 2.16 | | | 1.00 | .77 |
| 1.71 | 1.70 | .48 | .46 | .17 | .17 | 2.21 | 2.18 | | | .36 | .29 |
| 1.46 | 1.46 | .03 | .01 | .08 | .01 | .98 | .96 | | | 1.24 | 1.16 |
| .70 | .69 | | | | | .11 | .11 | | | 1.18 | 1.14 |
| | | | | Predicted and measured velocities at Ouray Refuge for 6357 cfs | | | | | | | |
| .84 | .84 | .67 | .63 | .43 | .41 | .81 | .70 | .79 | .63 | .31 | 0.0 |
| 1.99 | 2.17 | 2.30 | 2.13 | 2.10 | 1.99 | 2.37 | 2.29 | 2.51 | 2.25 | .87 | .75 |
| 2.87 | 2.66 | 2.76 | 2.81 | 3.24 | 3.12 | 2.93 | 2.87 | 2.96 | 2.63 | 2.75 | 2.90 |
| 2.62 | 2.61 | 2.83 | 2.91 | 2.94 | 2.87 | 2.93 | 2.90 | 3.90 | 3.76 | 3.42 | 3.52 |
| 2.83 | 2.72 | 2.72 | 2.79 | 2.79 | 2.65 | 2.76 | 2.69 | 3.64 | 3.45 | 2.78 | 2.98 |
| 2.83 | 2.86 | 2.70 | 2.71 | 2.81 | 2.70 | 2.68 | 2.60 | 2.84 | 2.53 | 2.15 | 2.37 |
| 2.85 | 2.85 | 2.57 | 2.49 | 2.40 | 2.58 | 1.79 | 1.77 | 1.40 | 1.33 | 2.17 | 2.09 |
| 2.75 | 2.73 | 2.20 | 2.07 | 2.27 | 2.19 | 1.03 | 1.00 | .59 | .46 | 2.56 | 2.63 |
| 2.29 | 2.39 | .98 | .93 | 1.43 | 1.40 | .91 | .73 | .62 | .47 | 2.27 | 2.46 |
| 1.14 | 1.13 | .12 | .11 | 1.08 | 1.03 | .36 | .35 | .26 | .07 | 1.44 | 1.43 |
| | | | | .48 | .47 | | | | | | |

1/ Corrected for stage.

Appendix I

Calibration details for Green Colorado IFG-4 and WSP models

| Transect 0 | | Transect 327 | | Transect 678 | | Transect 1315 | | Transect 1836 | |
|---|---|---|---|---|---|---|---|---|---|
| Predicted | Measured $(\frac{V_1 \quad V_2}{2})$ 1/ | Predicted | Measured $(\frac{V_1 \quad V_2}{2})$ 1/ | Predicted | Measured $(\frac{V_1 \quad V_2}{2})$ 1/ | Predicted | Measured $(\frac{V_1 \quad V_2}{2})$ 1/ | Predicted | Measured $(\frac{V_1 \quad V_2}{2})$ 1/ |
| | | | | Predicted and measured velocities at Potash for 5562 cfs | | | | | |
| 0 | 0 | .01 | 0 | .05 | 0 | .85 | .85 | | |
| 1.21 | 1.2 | .01 | 0 | .15 | 0 | 1.93 | 1.90 | | |
| 2.56 | 2.6 | .98 | .875 | .41 | .40 | 2.21 | 2.15 | | |
| 2.80 | 2.825 | 2.25 | 2.00 | .52 | .50 | 2.23 | 2.15 | | |
| 2.81 | 2.85 | 2.72 | 2.50 | .35 | .35 | 2.12 | 2.05 | | |
| 3.00 | 3.075 | 3.02 | 2.725 | .25 | .25 | 2.18 | 2.15 | | |
| 3.09 | 3.15 | 3.06 | 2.775 | .36 | .35 | 2.20 | 2.20 | | |
| 2.96 | 2.975 | 2.95 | 2.75 | .52 | .50 | 2.08 | 2.05 | | |
| 2.83 | 2.875 | 2.93 | 2.725 | .73 | .70 | 2.03 | 1.95 | | |
| 2.75 | 2.775 | 3.15 | 2.85 | 1.48 | 1.40 | 1.89 | 1.85 | | |
| 2.63 | 2.725 | 3.09 | 2.825 | 1.58 | 1.50 | 1.65 | 1.60 | | |
| 2.65 | 2.7 | 3.12 | 2.875 | 1.78 | 1.70 | 1.52 | 1.45 | | |
| 2.58 | 2.65 | 3.12 | 2.95 | 1.73 | 1.65 | 2.12 | 2.025 | | |
| 2.72 | 2.825 | 3.40 | 3.05 | 1.48 | 1.40 | 2.74 | 2.625 | | |
| 2.87 | 2.9 | 3.51 | 3.10 | 1.41 | 1.40 | 2.82 | 2.70 | | |
| 2.80 | 2.87 | 3.36 | 3.00 | 1.68 | 1.60 | 2.68 | 2.575 | | |
| 2.95 | 3.0 | 3.21 | 3.025 | 1.75 | 1.65 | 2.50 | 2.40 | | |
| 2.92 | 2.95 | 3.42 | 3.075 | 1.91 | 1.80 | 2.28 | 2.175 | | |
| 2.88 | 2.97 | 3.54 | 3.15 | 1.98 | 1.875 | 1.04 | 1.00 | | |
| 2.91 | 3.025 | 3.46 | 3.225 | 2.19 | 2.075 | | | | |
| 3.10 | 3.15 | 3.35 | 3.125 | 2.49 | 2.35 | | | | |
| 3.04 | 3.125 | 3.37 | 3.00 | 2.76 | 2.625 | | | | |
| 3.19 | 3.20 | 1.94 | 1.70 | 3.09 | 2.9 | | | | |
| 2.95 | 2.95 | .25 | .225 | 3.30 | 3.125 | | | | |
| 2.73 | 2.75 | .11 | 0 | 3.48 | 3.30 | | | | |
| 2.35 | 2.375 | | | 3.41 | 3.20 | | | | |
| .17 | 0 | | | 3.29 | 3.125 | | | | |
| | | | | 3.36 | 3.175 | | | | |
| | | | | 2.88 | 2.725 | | | | |
| | | | | 2.24 | 2.125 | | | | |
| | | | | 1.07 | 1.0 | | | | |
| | | | | Predicted and measured velocities at Potash for 7751 cfs | | | | | |
| .01 | 0 | 12 | .05 | .18 | .20 | .87 | .85 | .02 | 0 |
| .19 | .05 | .37 | .40 | 1.21 | 1.25 | 2.09 | 1.95 | 1.31 | 1.125 |
| .94 | .925 | 1.55 | 1.55 | 2.21 | 2.15 | 2.38 | 2.20 | 3.11 | 2.65 |
| 2.09 | 2.075 | 2.37 | 2.30 | 2.28 | 2.20 | 2.31 | 2.10 | 3.57 | 3.05 |
| 2.65 | 2.625 | 2.45 | 2.35 | 2.30 | 2.20 | 2.35 | 2.125 | 3.34 | 2.925 |
| 3.08 | 3.05 | 2.71 | 2.575 | 2.47 | 2.35 | 2.63 | 2.45 | 3.24 | 2.825 |
| 3.28 | 3.225 | 2.82 | 2.70 | 2.65 | 2.50 | 2.72 | 2.475 | 3.28 | 2.85 |
| 3.33 | 3.20 | 3.12 | 2.925 | 2.76 | 2.575 | 2.46 | 2.275 | 3.37 | 2.825 |
| 2.26 | 2.20 | 3.45 | 3.20 | 3.07 | 2.80 | 2.52 | 2.30 | 2.31 | 2.00 |
| .68 | .675 | 3.67 | 3.40 | 3.12 | 2.85 | 2.37 | 2.175 | .83 | .75 |
| .39 | .375 | 3.70 | 3.45 | 3.23 | 2.95 | 2.54 | 2.275 | .21 | .20 |
| .04 | 0 | 3.88 | 3.575 | 3.59 | 3.25 | 2.77 | 2.50 | .12 | .05 |
| | | 2.31 | 2.025 | 3.35 | 3.05 | 2.48 | 2.275 | .01 | .05 |
| | | .39 | .20 | 3.43 | 3.125 | 2.51 | 2.25 | .09 | .10 |
| | | .09 | .05 | 3.71 | 3.325 | 2.79 | 2.55 | 1.24 | 1.10 |
| | | | | 2.81 | 2.575 | 3.05 | 2.75 | 1.60 | 1.35 |
| | | | | 1.06 | 1.00 | 3.15 | 2.875 | 3.46 | 2.95 |
| | | | | | | 3.84 | 3.425 | 3.26 | 2.70 |
| | | | | | | 3.02 | 2.725 | 2.61 | 2.175 |
| | | | | | | 2.41 | 2.15 | 3.02 | 2.55 |
| | | | | | | 2.10 | 1.875 | 1.76 | 1.525 |
| | | | | | | .18 | .05 | .13 | 0 |
| | | | | Predicted and measured velocities at Potash for 15805 cfs | | | | | |
| .04 | 0 | 1.16 | .965 | .04 | 0 | .03 | 0 | .06 | 0 |
| .05 | 0 | 2.57 | 2.435 | 1.28 | 1.21 | 1.26 | 1.395 | 1.31 | 1.305 |
| .74 | .625 | 2.95 | 2.90 | 2.98 | 2.95 | 2.61 | 3.01 | 3.01 | 3.085 |
| 1.76 | 1.625 | 3.20 | 3.145 | 2.99 | 3.135 | 2.94 | 3.23 | 3.34 | 3.49 |
| 1.92 | 1.88 | 3.29 | 3.375 | 3.13 | 3.19 | 3.03 | 3.25 | 3.40 | 3.57 |
| 2.05 | 2.205 | 3.26 | 3.295 | 3.23 | 3.305 | 3.16 | 3.435 | 3.25 | 3.375 |
| 2.90 | 3.06 | 3.14 | 3.155 | 2.97 | 3.12 | 3.27 | 3.63 | 3.21 | 3.275 |
| 3.17 | 3.435 | 3.22 | 3.29 | 3.18 | 3.375 | 3.62 | 3.755 | 3.20 | 3.335 |
| 3.20 | 3.47 | 3.35 | 3.43 | 3.31 | 3.53 | 3.27 | 3.60 | 3.16 | 3.35 |
| 3.25 | 3.57 | 3.42 | 3.495 | 3.37 | 3.44 | 2.99 | 3.415 | 2.80 | 2.92 |
| 3.42 | 3.66 | 3.42 | 3.49 | 3.25 | 3.385 | 2.88 | 3.345 | 2.51 | 2.595 |
| 3.40 | 3.61 | 3.30 | 3.42 | 3.29 | 3.355 | 2.75 | 3.025 | 2.87 | 2.85 |
| 3.21 | 3.515 | 2.93 | 3.055 | 3.17 | 3.355 | 2.61 | 2.935 | 2.81 | 2.805 |
| 3.19 | 3.495 | 1.88 | 1.895 | 3.32 | 3.475 | 2.57 | 2.985 | 2.61 | 2.64 |
| 2.11 | 2.26 | .61 | .565 | 3.49 | 3.565 | 2.62 | 2.985 | 2.70 | 2.81 |
| .53 | .53 | .04 | 0 | 3.23 | 3.275 | 2.78 | 3.19 | 2,96 | 3.075 |
| .02 | 0 | | | 1.80 | 1.855 | 2.71 | 3.20 | 3.40 | 3.535 |
| | | | | .44 | .38 | 2.94 | 3.385 | 3.55 | 3.815 |
| | | | | .03 | 0 | 3.24 | 3.69 | 3.44 | 3.71 |
| | | | | | | 3.07 | 3.505 | 3.54 | 3.775 |
| | | | | | | 2.41 | 2.795 | 3.20 | 3.365 |
| | | | | | | 1.54 | 1.725 | 1.88 | 1.885 |
| | | | | | | .61 | .605 | .51 | .475 |
| | | | | | | .03 | 0 | .13 | 0 |

1/ Corrected for stage.

APPENDIX I (continued)

Summary of IFG-4 input stage and discharge with computed slopes and intercepts

| Site and transect | Input stage | Discharge | Slope | Intercept |
|---|---|---|---|---|
| Black Rocks | | | | |
| Transect 1 | 87.07 | 3800 | .0777 | 24.40 |
| | 87.38 | 4600 | | |
| | 89.05 | 6850 | | |
| Transect 2 | 87.07 | 3800 | .2505 | 4.801 |
| | 87.39 | 4600 | | |
| | 89.09 | 6850 | | |
| Transect 3 | 87.07 | 3800 | .6661 | .0701 |
| | 87.42 | 4600 | | |
| | 89.29 | 6850 | | |
| Transect 4 | 87.30 | 3800 | .3104 | 1.360 |
| | 87.59 | 4600 | | |
| | 89.49 | 6850 | | |
| Transect 5 | 87.28 | 3800 | .2910 | 1.597 |
| | 87.60 | 4600 | | |
| | 89.49 | 6850 | | |
| Moab | | | | |
| Transect 1 | 63.94 | 3743 | .4188 | .2549 |
| | 67.04 | 7758 | | |
| | 70.52 | 16335 | | |
| Transect 2 | 63.99 | 3743 | .4575 | .1605 |
| | 66.97 | 7758 | | |
| | 70.52 | 16335 | | |
| Transect 3 | 64.00 | 3743 | .4854 | .1216 |
| | 67.08 | 7758 | | |
| | 70.63 | 16335 | | |
| Transect 4 | 64.17 | 3743 | .4708 | .1336 |
| | 67.17 | 7758 | | |
| | 70.57 | 16335 | | |
| Transect 5 | 64.20 | 3743 | .4244 | .2132 |
| | 67.23 | 7758 | | |
| | 70.68 | 16335 | | |
| Grays Canyon | | | | |
| Transect 1 | 90.56 | 8990.96 | .29006 | .660997 |
| | 89.05 | 5115.40 | | |
| | 87.75 | 2577.40 | | |
| Transect 2 | 91.21 | 8935.1 | .328997 | .430266 |
| | 89.53 | 4977.2 | | |
| | 88.17 | 2566.8 | | |
| Transect 3 | 92.37 | 9430.43 | .299286 | .630508 |
| | 90.65 | 5049.40 | | |
| | 88.91 | 2392.30 | | |
| Transect 4 | 92.67 | 10351.16 | .306310 | .599433 |
| | 90.99 | 5367.84 | | |
| | 89.35 | 2753.30 | | |
| Transect 5 | 93.17 | 10009.70 | .268163 | .925106 |
| | 91.19 | 5767.70 | | |
| | 90.59 | 2877.80 | | |

APPENDIX I (continued)

Summary of IFG-4 velocity adjustment factors
for a range of flows at Black Rocks, Moab, and Grays Canyon

| Q (cfs) | Velocity adjustment factors by transect | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| | | Black Rocks | | | |
| 1,600.00 | .9518 | 1.051 | .9147 | .9708 | .9597 |
| 2,000.00 | .9728 | 1.049 | .9352 | .9581 | .9765 |
| 3,000.00 | .9983 | 1.033 | .9763 | .9728 | .9992 |
| 4,000.00 | 1.006 | 1.017 | .9960 | .9800 | 1.005 |
| 5,000.00 | 1.007 | 1.002 | 1.005 | .9827 | 1.005 |
| 6,000.00 | 1.003 | .9891 | 1.004 | .9824 | 1.001 |
| 7,000.00 | .9981 | .9770 | .9966 | .9803 | .9950 |
| 8,000.00 | .9911 | .9661 | .9830 | .9771 | .9873 |
| 9,000.00 | .9834 | .9561 | .9647 | .9737 | .9789 |
| 11,000.00 | .9672 | .9386 | .9185 | .9662 | .9609 |
| 13,000.00 | .9509 | .9237 | .8640 | .9583 | .9424 |
| 15,000.00 | .9349 | .9106 | .8056 | .9503 | .9239 |
| 17,000.00 | .9195 | .8991 | .7464 | .9422 | .9059 |
| | | Moab | | | |
| 2,000.00 | 1.107 | 1.050 | 1.067 | .9597 | .9249 |
| 3,000.00 | 1.026 | 1.011 | 1.017 | .9832 | .9644 |
| 4,000.00 | 1.003 | .9983 | 1.002 | .9958 | .9876 |
| 5,000.00 | .9939 | .9937 | .9983 | 1.003 | 1.001 |
| 6,000.00 | .9903 | .9926 | .9941 | 1.007 | 1.010 |
| 7,000.00 | .9897 | .9932 | .9942 | 1.008 | 1.014 |
| 8,000.00 | .9906 | .9946 | .9934 | 1.009 | 1.014 |
| 9,000.00 | .9924 | .9963 | .9938 | 1.009 | 1.013 |
| 11,000.00 | .9946 | 1.000 | .9965 | 1.008 | 1.007 |
| 13,000.00 | .9986 | 1.003 | 1.000 | 1.006 | .9989 |
| 15,000.00 | 1.003 | 1.006 | 1.004 | 1.003 | .9878 |
| 20,000.00 | 1.011 | 1.005 | 1.010 | .9930 | .9535 |
| 25,000.00 | 1.019 | 1.004 | 1.015 | .9811 | .9152 |
| 30,000.00 | 1.027 | 1.001 | 1.019 | .9689 | .8756 |
| 40,000.00 | 1.039 | .9909 | 1.025 | .9457 | .7973 |
| | | Grays Canyon site Green River | | | |
| 20,000.00 | .7070 | .8378 | 1.0056 | .9117 | .8902 |
| 17,500.00 | .7765 | .8733 | 1.0047 | .9367 | .9157 |
| 15,000.00 | .8467 | .9082 | 1.0035 | .9596 | .9415 |
| 13,500.00 | .8874 | .9285 | 1.0020 | .9830 | .9718 |
| 9,543.00 | .9805 | .9777 | .9985 | .9980 | .9942 |
| 8,500.00 | .9987 | .9884 | .9969 | 1.0029 | 1.0020 |
| 6,500.00 | 1.0218 | 1.0048 | .9941 | 1.0089 | 1.0122 |
| 5,255.00 | 1.0259 | 1.0111 | .9931 | 1.0096 | 1.0130 |
| 3,500.00 | 1.0114 | 1.0123 | .9939 | 1.0036 | .9996 |
| 2,633.00 | .9919 | 1.0084 | .9993 | .9953 | .9801 |
| 2,000.00 | .9721 | 1.0008 | 1.0100 | .9853 | .9557 |

# APPENDIX II

## Linkage of CRSS with PHABSIM

In general, the linkage of the CRSS water management model with PHABSIM was accomplished by coupling the WUA vs. flow data (contained on TAPE 8 of the normal PHABSIM output or in a formatted permanent file) with flow time series obtained from a run of CRSS to generate a WUA series for the site(s) of interest as described in the library documentation below.

The steps required to accomplish this linkage are described below. Note only a limited number of values may be obtained as output from a single run of CRSS so more than one run under the same set-up assumptions may be required if data are to be extracted for a large number of sites in the river system. Due to the complexity of CRSS, users are advised to work closely with USBR in performing CRSS runs and these linkages. At present, CRSS is run only by USBR personnel for planning and operations purposes. The linkages presented in this report facilitate development of habitat values associated with the flow series output from CRSS. A more convenient method accessing the CRSS program is being developed. The required final operation sequence is:

Step 1. Run CRSS in association with qualified USBR personnel. CRSS will only output data for specified points which may not be the same points of interest to the fishery biologist in determining habitat impacts of alternative management schemes.

Step 2. Run the procedure RCVTRSM (see library documentation below) to convert the CRSS output on file T61OUT to the Northwest Data Center (NWDC) format used by the programs used in the linkage system. Individual records are extracted from that file using the GTR command and saved under the appropriate file names.

Step 3. The flow units in these files are then converted from acre-feet per month to cfs using the unit conversion procedure known as CHGUNT.

Step 4. WUA time series are then generated for each life stage of interest at each site using the WUA time series generation program in the library.

## Documentation of the Procedure File PCOL that Accesses the Time Series Program Library COLLIB

Use of the program library COLLIB is possible by users trained in the CDC NOS operating system. The following description is intended to aid such users; others should become familiar with NOS 1.4 before attempting the system.

Generally, the library consists of a group of computer programs giving the user the following capabilities: (1) conversion of a monthly flow time series at a point to a monthly habitat time series by interpolating habitat values from a WUA vs. Q curve obtained from running PHABSIM for an ascending range of discharges. Given monthly flow values, a habitat value is extracted for each month and entered in the habitat time series file; (2) analysis of one or several habitat time series on the basis of critical life stage, aggregation of several sites into a summary index, plotting of time series, plotting of habitat duration curves, extraction of summary statistics and comparative plots of time series and habitat duration curves under two or more conditions.

WUA time series may be produced for the following specified combinations:

1. Single life stage at a single site.
2. Critical life stage at a single site.
3. Multiple life stages at a single site.
4. Single life stage weighted sum at several sites.
5. Multiple life stages weighted sum at several sites.

The program library COLLIB which contains the CRFP program is accessed using the procedure file PCOL (see Appendixes A and C of the Use's Guide to the Physical Habitat Simulation System for a description of procedure file use). Each procedure in PCOL is described in the following format:

a) Procedure name.
b) Example of the execution command.
c) Description of the execution command file substitutions.
d) Description of what the procedure does.

## Routines in PCOL

The following procedure files are presented by name followed by an example of an execution statement for the file.

Note: When inputting a two-line title be sure to include information that uniquely identifies the data in the file including units. Do not repeat file titles exactly. It will not help for future reference or report writings.

RTIN

-RTIN,PCOL,HAB,TAPE8.

Where: RTIN - name of the procedure
PCOL - the procedure file name
HAB - The habitat time series input file name you are creating (you may substitute your own name here.)

TAPE8 - TAPE8 output from PHABSIM for the study site and species you have selected (this is optional as WUA vs. Q may be input directly in this procedure.)

CAUTION: You must have the TAPE8 file local (get it if needed) before executing this procedure.

RTIN executes the HABTIN program that creates the input file for the habitat time series generation program HABT. If the habitat (WUA) vs. flow relationship for the species of interest is on a TAPE8 as produced by PHABSIM the user may use that information automatically by including the file name of the TAPE8 in the procedure command. If a TAPE8 is not available, the WUA vs. flow information may be entered directly from the terminal. Use of RTIN and RHABTS is the starting point in any analysis of habitat time series using this set of programs.

Notes: 1) Each file generated by RTIN is good for one life stage only. 2) The user must ensure that the flow range in the WUA vs. flow function is larger than the range of values in the flow time series. If in doubt, run the flow time series data through the procedure RHSSTS to set summary statistics including max and min flows. It may be necessary to directly enter the WUA vs. Q data if TAPE8 does not cover the desired range.

RHABTS

-RHABTS,PCOL,HAB,FLW,NWHAB.

Where: HAB - file produced by RTIN
FLW - flow time series file for the study site
NWHAB - habitat time series for one live stage at that site
All of these files may be substituted.

CAUTION: File FLW must be in Northwest Data Center Format (see RNWDC and RCNVRT below) and the units must be in cfs (see RUNITS below).

RHABTS executes the HABT program that generates a habitat time series. File HAB (i.e., the user's substituted file name) from RTIN and a flow time series (file FLW) must be supplied. If these files are not local, the procedure will attempt to GET files of those names (the user's substitution file names.) The output file will contain a habitat value for each month of the year for all years in the time series. Procedure RMLSTS (see below) may be used to select the months each life stage is important or to merge several life stages into one time series.

Note: The habitat time series will cover the same period of record as the flow time series input in file FLW. The user should extend or reduce the length of FLW to match the period of the analysis.

RNWDC

-RNWDC,PCOL,QTS.

Where: F - NWDC format flow in one set of units
G - same data in altered set of units

CAUTION: Use the editor to change the units in the title line of the output file.

RUNITS allows conversion of the units in a flow time series from acre-feet per month (AF/mo) to average cubic feet per second (CFS), from CFS to AF/mo, from 1000 AF/mo to CFS, or from CFS to 1000 AF/mo. These conversions are useful in manipulating various data sources to provide flow time series to use in generating habitat time series. Be sure the units in your file title are correct.

RHBTMP

-RHBTMP,PCOL,F,G,C,HBMOD

Where: F - habitat time series from RHABTS for a given study location.
G - temperature time series in NWDC format for the same site.
C - suitability-of-use criteria values for temperature
MODTP - temperature modified habitat time series file for specified location in the stream system

Files F,G,C,and HBMOD may be substituted.

CAUTION: The temperature suitability curve values should exceed the range of temperatures anticipated at the study site. Extend the curve as needed.

RHBTMP modifies a single life stage fcs for a specified location by adding another multiplicative suitability-of-use factor based on temperature. This assumes a uniform temperature distribution across the width and depth of the stream at the selected site. The effect of this temperature modification will be to reduce habitat area during the months when adverse temperature conditions exit for the selected life stage at the study site. The file containing coordinates of a temperature suitability-of-use curve may be input using procedure RTPREF.

RTPREF

-RTPREF,PCOL,F

Where: F - file of the coordinates of a temperature suitability-of-use curve created by this procedure

RTPREF allows the user to interactively build a suitability-of-use curve file for temperature.

RMLSTS

-RMLSTS,PCOL,T1,T2,T3,T4,T5,T6,T7,T8,T9,T10,CLSTS

Where: T1-T10 - are up to 10 separate habitat time series files for various life stages of one or more species.
CLSTS - output file containing merged habitat time series.

CAUTION: File T1 through T(N) must be local before using this program. T(N) is the last file you wish to merge, N may be less than 10.

RMLSTS allows the user to generate a merged time series of several life stages. The user has two options in selecting the months of the year that are of importance to a given species-life stage.

1. If a single life stage file is input and the months considered important selected, the non-selected months in the habitat time series will be set to a large negative number; thereby removing them from the time series.

2. If more than one life stage file is input, a single output time series in which the user selected life stages are displayed in the user selected months is generated.

RCOMBTS

-RCOMBTS,PCOL,T1,T2,T3,T4,T5,T6,T7,T8,T9,T10,COMBD

Where: T1-T10 - Habitat time series files for up to 10 study sites.
COMBD - File containing time series of sums of WUA for the input study sites.

CAUTION: Files T1-T(N)-N as in RMLSTS above - must be local before using this procedure.

RCOMBTS allows the user to produce a weighted sum time series at up to 10 study sites. This allows development of basin indexes of total habitat availability under alternate management approaches. The input time series should all represent the same phenomena, i.e., if one time series is temperature adjusted, they all should be; if one time series has merged life stages, they all should have the same life stage merged in the same months, etc.

RCOMB

-RCOMB,PCOL,F,G,COMBD

Where: F - a time series file
G - a second time series file
COMBD - resultant combined time series

RCOMB may be used to add, subtract, multiply, or divide two time series files. It is useful for adjusting flow files to an ungaged site and developing ratios of habitat or flow values.

RTSPT

-RTSPT,PCOL,T1,T2,T3,T4,T5,TAPE21,TAPE22

Where: T1-T5 - up to 5 time series may be plotted on the same plot
TAPE21 - printer plot output file which may be routed to line printer
TAPE22 - table of exceedence values

CAUTION: Files T1-T5 must be local before executing this procedure.

RTSPT allows the user to generate a line printer plot up to 5 time series (input must be in NWDC format). It may be used to plot several life stages, study sites or combinations of same over time. Pre- and post-change conditions of the same variables may also be plotted. For long time series the output may be voluminous so the user may wish to use the editor to adjust the input files to the period of interest.

RXCDPLT

-RXCDPLT,PCOL,T1,T2,T3,T4,T5,TAPE22,.....

Where: T1-T5 - up to 5 time series in NWDC format may be input

CAUTION: Files T1-T5 must be local before executing this procedure.

RXCDPLT produces printer plotted habitat duration curves for the input monthly time series. Tables of the habitat exceedence values are also obtained on TAPE22. Time duration plots and exceedence values provide a summary reference of the proportion of times a given habitat value is equalled or exceeded over the period of observation.

RHSSTS

-RHSSTS,PCOL,F,G

Where: F - a time series file
G - summary statistics output file

RHSSTS calculates summary statistics for a time series. The output can be either for monthly or annual values. Both flow and habitat time series may be input. The output is formatted for a 130 line printer. Values of the mean, variance, standard deviation, skew, range, maximum, minimum, and standard error of estimate of the mean are calculated. For some large values, the variance may overflow the format and print asterisks. A hand calculator may be used to square the standard deviation if variance is needed.

RMCHY

-RMCHY,F,NWFIL

Where: F - calculated natural flow file in output format used by USBR UC400 division
NWFIL - same file converted to NWDC format

Caution: Check with the UC400 division to be sure of file contents.

RMCHY allows linkage of the calculated natural flow and extended USGS record data bases used the UC400 division to habitat time series analysis. The user must coordinate with UC400 for permission to access those files.

RCVTRSM

-RCVTRSM,PCOL,T61OUT,SITES

Where: T61OUT - output file for selected sites from CRSS run
SITES - same information converted to multi-record

CAUTION: Make sure you understand the assumptions in the CRSS run when using this data.

RCVTRSM provides the linkage of the USBR CRSS model with PHABSIM. The entire output file from CRSS is converted to NWDC format and may include data that is not of interest in a fishery analysis. The user must extract the appropriate records from file SITES for habitat analysis as the output file associated with CRSS may vary. Users are advised to work closely with USBR when making this linkage.

REPORT NO. 2

# SPAWNING BEHAVIOR, HABITAT SELECTION, AND EARLY LIFE HISTORY OF NORTHERN SQUAWFISH WITH INFERENCES TO COLORADO SQUAWFISH

by

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## INTRODUCTION

Results of a study of selected aspects of the life history and behavior of the northern squawfish (Ptychocheilus oregonensis) are summarized in this report. This project was initiated as part of a contract entered into in April 1980, between the Idaho Cooperative Fishery Research Unit, University of Idaho, and the U.S. Fish and Wildlife Service, Colorado River Fisheries Project.

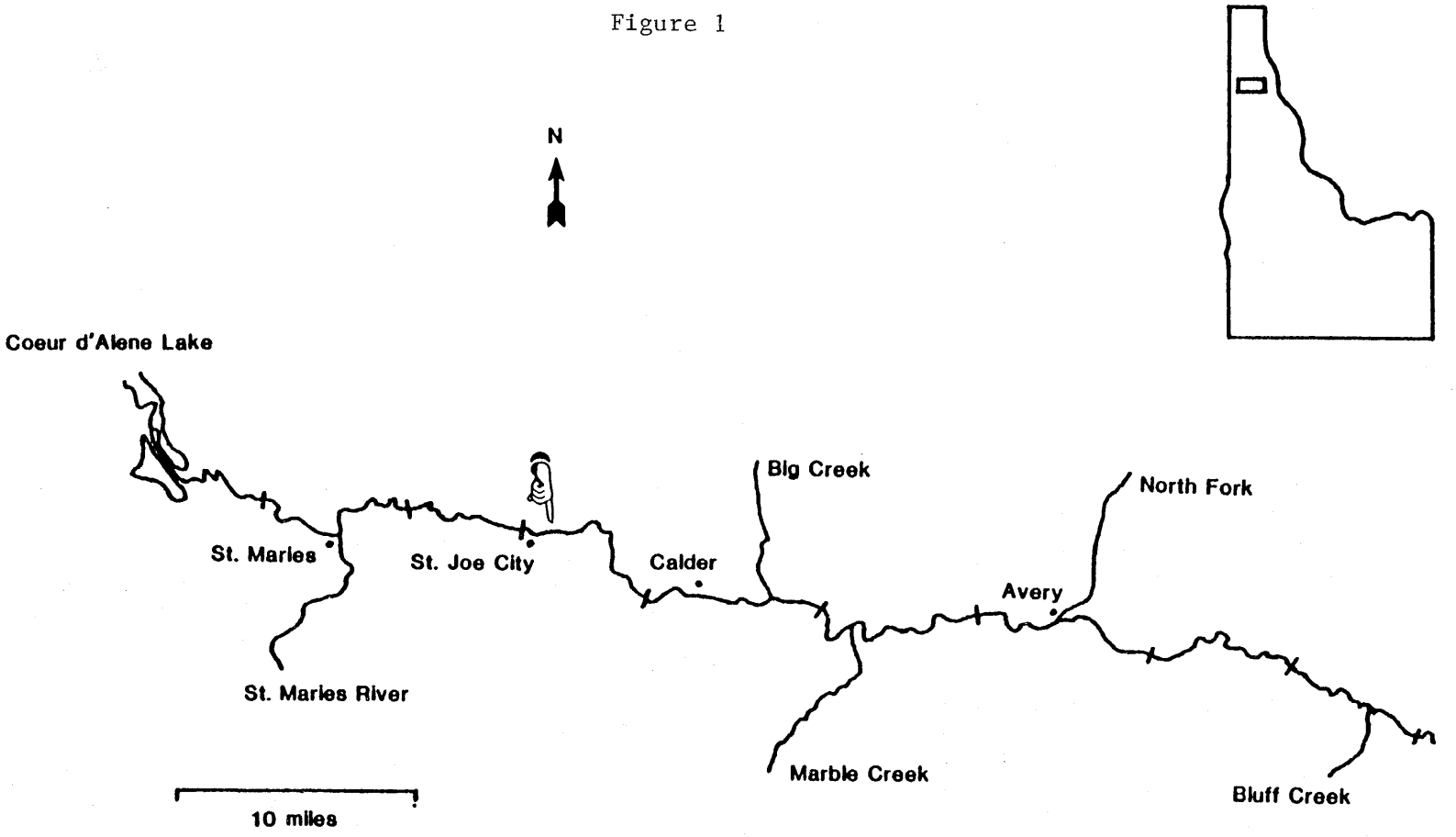
Study objectives were chosen to supplement areas on northern squawfish life history and behavior where information was found to be lacking in a thorough review of the literature. Problems considered are analogous to those of Colorado squawfish which might be useful in explaining past and present distribution patterns and in preventing further declines in the range and abundance of that species. Four topic areas are considered in this report: spawning biology, habitat selection, early life history, and laboratory behavioral comparisons.

## STUDY AREA

The St. Joe River, in the northern panhandle region of Idaho (Figure 1), was selected for this study because it contains a large reproducing population of northern squawfish in a river environment. It has the additional advantages of easy accessibility, water clear enough to allow direct observations of fish, a size small enough to work in without great difficulty, and a large body of information on its squawfish population. A forested watershed of approximately 1,900 square miles on the west slope of the Bitterroot Mountains is drained by the St. Joe River before it empties into the south end of Lake Coeur d'Alene at an elevation of 2,128 feet. Mean annual air temperature in the region is 8.5° C and annual precipitation averages 77.3 cm (Falter 1969). Mean annual flow at Calder is 2,364 cfs (USGS 1980). Flow regimes are characterized by a large spring peak in April and May and a smaller peak in November and December. Low flow for the 1980 water year occurred in November at 154 cfs and a high of 12,400 cfs was reached in April (USGS 1980). Large winter flood events are also common. A major tributary, the St. Maries River, enters the St. Joe near river mile 16 at a mean annual flow of 352 cfs.

Closure of the Post Falls Dam at the outlet of Lake Coeur d'Alene in 1906 raised the lake level and backed water into the lower 34 miles of the St. Joe River. This section, referred to as slackwater, consists of smooth-surfaced water flowing over a coarse silt and sand bottom (Falter 1969) at an average depth of 9.0 meters and an average width of 80 meters (Davis 1961) in a series of meanders through a broad, flat valley. Above the slackwater, in the fastwater, the gradient increases and riffles alternate with long pools. The substrate consists of well washed rubble and the maximum depth is 10 meters. The river valley in the lower reach of the fastwater remains fairly broad; meanders and

Figure 1




The St. Joe River, Idaho, below Bluff Creek, including major tributaries. Ten mile river mile increments are indicated with dashes across the river and the junction of slack and fastwaters is denoted with an arrow.

braided channels are common. Above Marble Creek the valley narrows, gradient increases further, braids and meanders cease, pools become infrequent, and riffles predominate. Temperature varies little between the fastwater and slackwater (Davis 1961).

Fish abundant in the St. Joe River fastwater include largescale suckers (Catostomus macrocheilus), bridgelip suckers (Catostomus columbianus), mountain whitefish (Prosopium williamsoni), cutthroat trout (Salmo clarki), redside shiners (Richardsonius balteatus), dace (Rhinichthys sp.), and sculpin (Cottus sp.). Northern squawfish range as far upriver as Bluff Creek at river mile 87, but are most abundant below Marble Creek (Reid 1971).

## SPAWNING BIOLOGY

### Methods

Fieldwork was conducted between June 10, 1980, and August 10, 1981, but was concentrated during June and July of both years. Trammel, trap, and experimental gill nets were set nightly in different areas of the St. Joe, St. Maries, and Clearwater Rivers in the late spring and early summer of 1980, during the period that literature information indicated spawning should be in progress. Capture success and general condition of fish taken in each areas were compared to determine which areas were used by spawming squawfish. Swimmers equipped with faceplates and snorkels then examined these areas to locate spawning sites. Spawning behavior was observed and described qualitatively by the snorkelers.

In 1981, fieldwork on spawning biology began on June 2 and was restricted to the St. Joe River. Transects were established at 4 sites where fish had been observed spawning in 1980. Counts of fish made by two snorkelers independently swimming standardized routes were averaged to give an index of fish abundance of each site. Counts were made only during days and hours when lighting and turbidity resulted in Secchi depth measurements of at least 5 meters. Counts were repeated at two-day intervals if conditions allowed. Fish behavior and appearence were also noted at the time of each count. Throughout the spawning period, river temperature (midmorning) and level were determined at one- or two-day intervals with a hand-held thermometer and a fixed, calibrated staff.

During the period of peak spawning activity, areas where spawning had been observed the previous year were checked by snorkelers. Each spawning site located was outlined with painted rocks placed on the stream bottom and then mapped from a baseline established with a calibrated line along one bank. Calibrated transect lines (at least four per site) were extended across the river perpendicular to the baseline at measured intervals. Baseline length and transect number and spacing were chosen to give accurate and complete coverage of each site and its immediate surroundings. Velocity profiles, depths, and substrate compositions were determined at stations along each transect line, and the presence or absence of spawning or holding fish was noted. The number

of stations on each transect line and their spacing was selected to accurately represent the area and at least 10 sets of observations were made along each transect.

Current velocities were measured with a Marsh-McBirney Model 201 electromagnetic flow meter at points 5 cm above the substrate and 3 cm below the surface. Measurements were also made at one or more points to estimate mean velocity. In depths less than 1 meter, mean velocity was measured at 0.6 of the depth; in depth greater than 1 meter, velocities were measured at 0.2 and 0.8 of the depth.

Snorkelers visually estimated substrate composition by assigning approximate proportions to each of four particle size-classes. Particles less than 0.1 cm in diameter were classed as sand, those between 0.1 and 10 cm as gravel, those between 10 and 30 cm as cobble, and particles larger than 30 cm were boulder or bedrock. Estimates of substrate composition at actual spawning sites were compared with photos taken with an underwater camera to insure accuracy.

During the spawning season and for several weeks before and after, gill and trammel nets were set each evening and checked the following morning. Nets included a sinking trammel net (6 feet deep by 100 feet long with 1 square-inch nylon mesh and 10 inch panels), a sinking experimental gill net (6 feet deep by 125 feet long with 3/4, 1, and 1 1/4 square-inch nylon mesh), and a floating experimental gill net (6 feet deep by 50 feet long with 1 1/4 and 2 square-inch monofilament mesh). Because net effectiveness was highly dependent on both net type and set location, the same nets were always set in the same manner at the same five sites. Three sites were in the fastwater area at river miles 38-1/2, 36-1/2, and 35-1/2, and the other two sites were in the slackwater at river miles 30-3/4 and 29-1/2. Sets were made parallel to shore and were anchored to the bottom in low velocity areas. The floating monofilament gill net was always set at river mile 38-1/2, while the other pair of nets was set alternately in the fastwater and the slackwater.

Fish removed alive and in good condition from nets were Floy-tagged beneath the dorsal fin and released. Tag color and location (left or right side) were specific to date and area of capture. Thus, a fish with a yellow tag on the left side was tagged in the slackwater between June 2 and 10. This was done to enable snorkelers to identify time and location of capture of fish sighted on spawning sites without having to recapture the fish. Fish were also tagged on one spawning site. Fish to be tagged were captured by angling or by drifting a 30-foot section of monofilament gill net through the site (swimmers held the ends of the net apart). Fish were marked over a 2-day period soon after spawning began. After this effort, snorkelers counted numbers of tagged fish while swimming standardized transects.

All fish that were not tagged and released after capture were sacrificed, weighed to the nearest gram, and measured (fork length) to the nearest 5 cm increment. Sex and general development were determined, and gonads were removed and weighed to the nearest 0.1 gm. Scales were

removed and acetate impressions were made for age determination. Fish which were tagged and released were measured and sexed on the basis of external characteristics, which were readily apparent during the spawning season.

## Results

### Spawning behavior

Spawning in the St. Joe River occurred in aggregations of fish ranging in size from a hundred to a few thousand individuals. Spawning fish were apparently unconcerned with swimmers, but maintained a minimum distance of 1 to 2 meters and drifted away if approached too closely. Males outnumbered females by 50-100:1, and swarmed in a dense mass within a meter of the substrate. Individual males generally faced the current, but did not maintain a position at any single locus. No aggressive interactions between males were noted. Females cruised slowly along the fringes of the aggregation and in nearby areas or swam about quickly just above the males. Slowly cruising females were ignored by males or were followed half-heartedly by one or two. Rapidly moving females were followed closely by up to 8 males, who stayed below or to the side of the female with their heads even with or slightly ahead of the female's vent.

Spawning occurred when a female and her entourage of males dipped to within a few centimeters of the substrate. Acts lasted 1 second or less and eggs and milt were only momentarily visible. Females arched their backs with vents close to the substrate, gaped their mouths, and vibrated. Males ducked alongside the female and vibrated. Spawners were besieged by a mass of darting males and all fish moved quickly away afterwards. Females typically veered away downstream, still followed by a few males. This action usually took them out of the observer's field of vision, but on one occasion a female was seen spawning three times at 4- to 6-second intervals in the same general area.

Inspection of an area after spawning revealed many eggs adhering to the substrate or drifting into interstices. Further examination revealed eggs up to 15 cm below the substrate surface. Spawning was observed on both clear and rainy days. Activity seemed low until late morning, but continued at least until dust.

Dark lateral bands were usually seen on spawning squawfish of both sexes. These bands were especially apparent of fish viewed underwater, but were also evident of fish removed from the river. Few fish observed or captured in portions of the river other than spawning sites were colored in this manner. Almost all fish in spawning aggregations exhibited this coloration and the few that did not were usually on the fringes of the activity.

Limited observations made in the Clearwater River in 1980 revealed behavior similar to that noted in the St. Joe River. One difference was

that spawning squawfish in the Clearwater River mixed with similar numbers of spawning chiselmouth chubs (Acrocheilus alutaceus). some hybridization apparently results, as fish were collected with appearances and meristic characteristics intermediate between the two species.

Large aggregations of spawning squawfish have been reported by a number of authors. In Cooper's Lake, Montana, Hill (1962) observed a school of several hundred adult northern squawfish, believed to be a spawning group, concentrated within a few yards of shore. Most activity consisted of slow mass movements back and forth along the shore, but no activity interpreted as actual spawning was noted. Jeppson and Platts (1959) observed vigorous splashing and vibrations among fish spawning in congregations in Hayden and Cocolalla lakes in north Idaho. In tributaries to Cascade Reservoir, Idaho, Casey (1962) observed schools consisting of several hundred squawfish and noted each female was attended by several males. In the St. Joe River, Idaho, large schools of squawfish accompanied by solitary females were thought by Reid (1971) to represent spawning populations.

The spawning behavior observed in the St. Joe River is virtually identical to that observed by divers in Merwin Reservoir, Washington (Patten and Rodman 1969). As many as 5 to 8 thousand fish were observed congregating on one spawning site and the male to female ratio was estimated at between 50-200:1. Behavior was classed as swarming or chasing. Swarming was restricted to males and consisted of a dense aggregation of slowly swimming fish, milling within 30 cm of the substrate. Chasing consisted of pursuit of females passing near the swarm. From 1 to 6 males chased each female. Females did not swarm and approached the site only for spawning. Females move faster than males and it was thought this movement elicited the chase response in males. Any fish including male squawfish and largescale suckers (Catostomus macrocheilus) were chased when they attained a threshold speed of about 60 cm per second. Spawning acts occurred within 3 cm of the substrate and were often observed by the swarm. As in the St. Joe River, Merwin squawfish on the spawning grounds had a dark lateral band from their snout to the base of their caudal fin.

### Seasonal timing

No squawfish were observed on June 23, 1981, on any of the sites where fish were seen spawning in 1980. Two days later, a total of over 700 fish were counted and by June 27 at least 2,000 fish were present. June 27 was the first day when spawning acts were observed and when the majority of fish on spawning sites had lateral bands. Spawning activity remained high for approximately 1 week, but was interrupted abruptly between July 5 and 7 when counts declined from highs of 3,000 fish to less than 200. This decline in numbers coincided with cessation of spawning activity and an absence of lateral bands on most fish remaining at spawning sites. By July 14, large numbers of fish returned and spawning activity and lateral banding were again common, although numbers never reached those recorded prior to the interruption. Spawning was completed by July 28, following a gradual decline through the preceding 2 weeks.

The onset of spawning closely followed an increase in river temperature from 9 to 12° C over a 2-day period (Figure 2). Cool, rainy weather prior to June 24 resulted in water temperatures in the 7 to 10° C range. The temperature increase associated with spawning resulted from clear, sunny weather on June 24 and 25. Spawning activity was interrupted on July 7 when river temperature fell from 15 to 11° C and level increase 10 cm overnight following cold rains. Temperature rose to 14° C by the time spawning resumed and 18° C was reached by the completion of spawning. Increasing temperatures through the spawning period were accompanied by decreasing river discharge and a drop in river level of 30 cm.

The dates of the beginning and ending of spawning and of peak activities varied between sites, although the same pattern was followed at all sites (Figure 3). Spawner counts increased and peaked 1 week earlier at the lowermost site than at the 3 upriver sites. At the upriver sites fish appeared and began spawning at about the same time. Spawning activity at the lower and uppermost sites ended a week earlier than at the other sites.

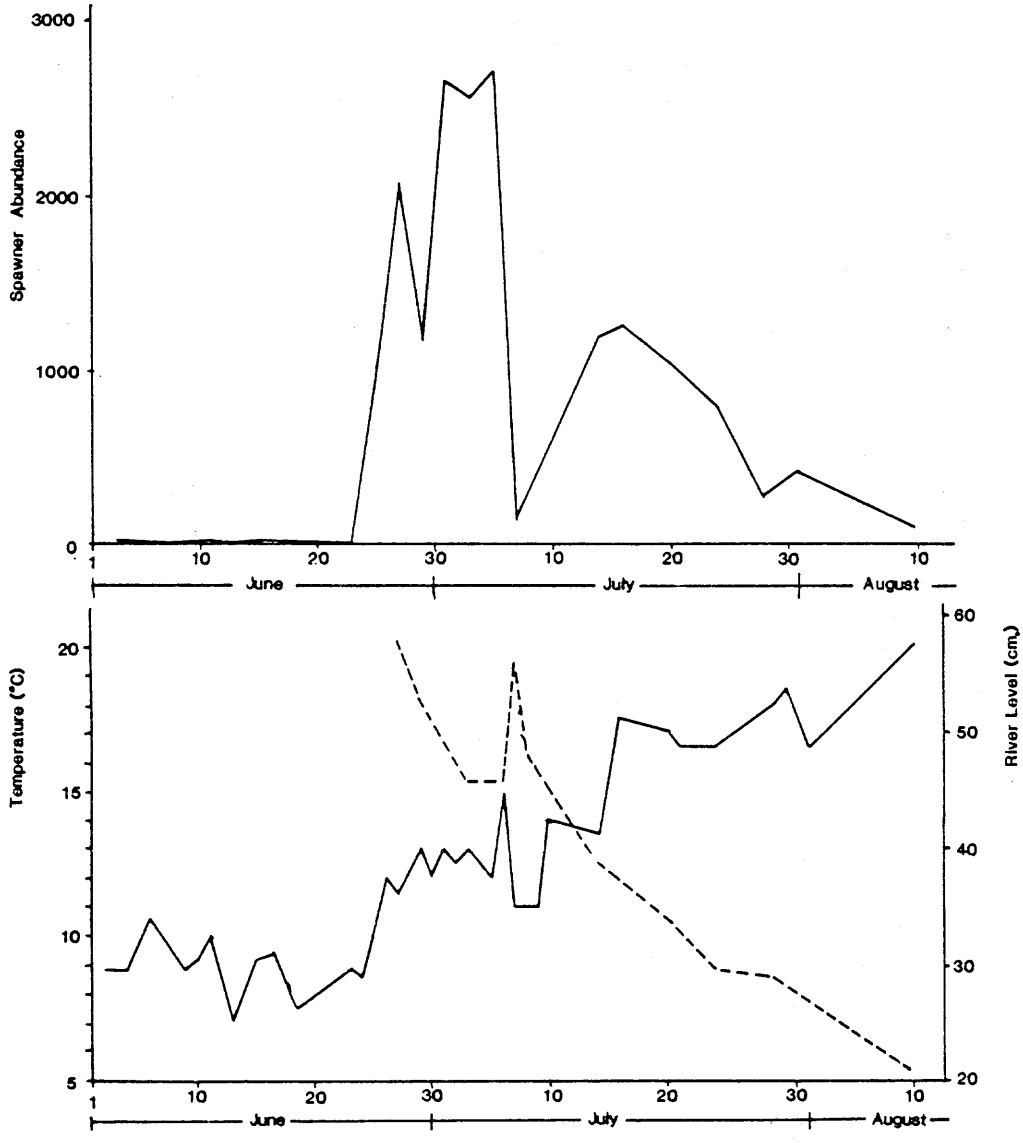
Dates and water temperatures associated with spawning in the St. Joe, St. Maries, and Clearwater Rivers in 1980 were comparable with those documented in the St. Joe in 1981. Spawning was already in progress on the St. Joe River in 1980 when the first site was located on July 1. River temperature increased from 11° C on that date to 16° C by July 12, when spawners had dispersed. Spawners were not observed in the St. Maries River, but netting information indicated spawning was in progress on June 10, 1980, at a river temperature of 10° C. Fish were apparently still spawning on June 26, when water temperature was 12° C, but was suspended by June 27 when river temperature fell 7° C in 2 days following heavy rains. Whether activity resumed when favorable temperatures were again reached is unknown. A school of 500 to 600 spawners located in the Clearwater River on June 20, 1980, when the water temperature was 18° C, had dispersed by the following day.

Table 1 summarizes dates and water temperatures associated with spawning by northern squawfish in this and other studies. In all cases spawning occurred in June or July at temperatures between 10 and 20° C. Dates of spawning varied within this context as the required water temperature were reached at different times. In Cooper and Seeley Lakes (Hill 1962) and in Cascade Reservoir, spawning dates also varied in successive years as conditions varied. Different temperature regimes in tributaries to Cascade Reservoir were thought to explain the variable spawning dates in that system. The variations in times of spawning recorded in this study can also be explained by different temperature regimes in successive years and in the different systems.

## Site preference

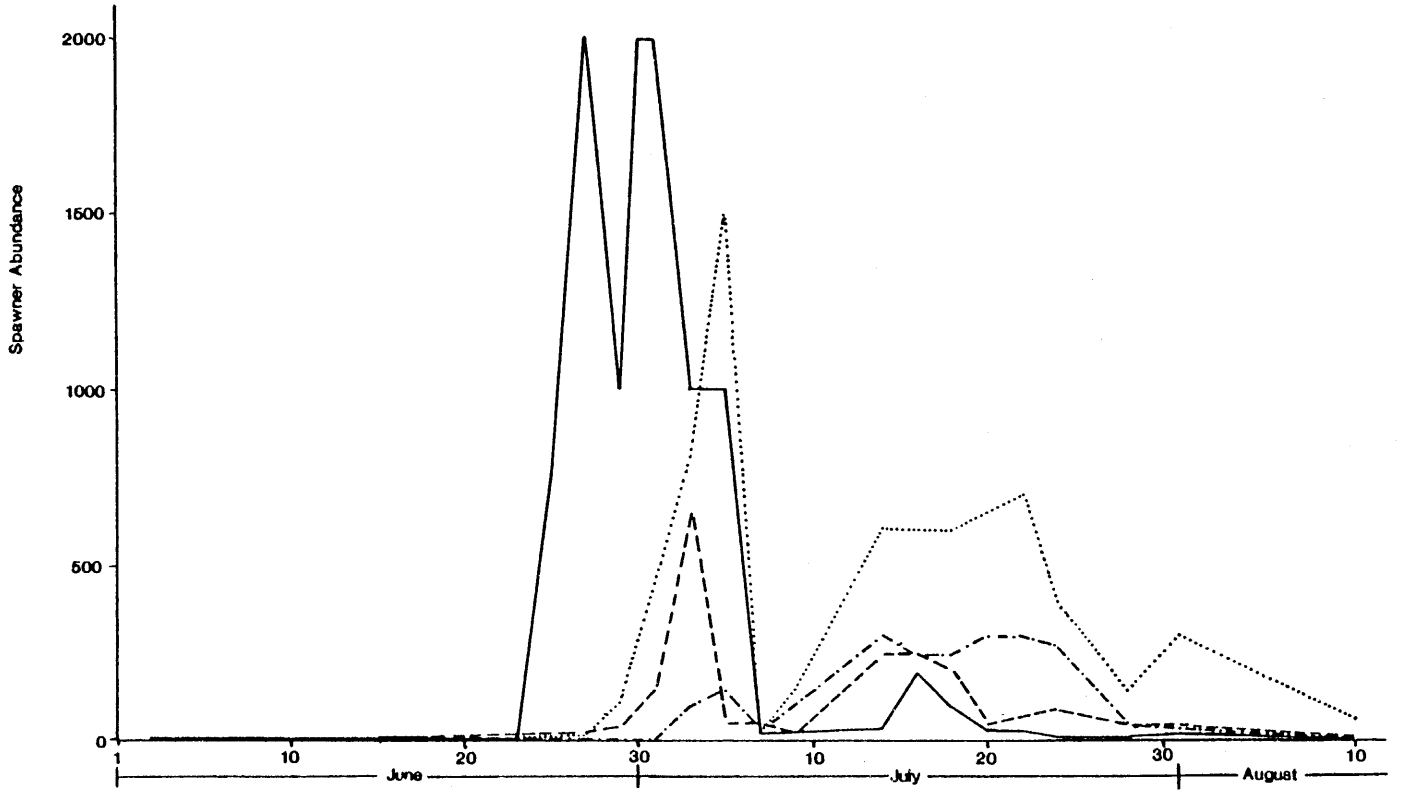
A total of 9 spawning sites were scattered throughout an 18 mile section of the lower fastwater of the St. Joe River (Figure 4). Physical conditions at the locations of egg deposition at each site are summarized in Figures 5 and 6. Relatively deep areas in the river were favored by

Figure 2




Comparison over time of index of the abundance of northern squawfish on four spawning sites in the St. Joe River, Idaho, with river temperature and level (above an arbitrarily chosen zero).

Figure 3

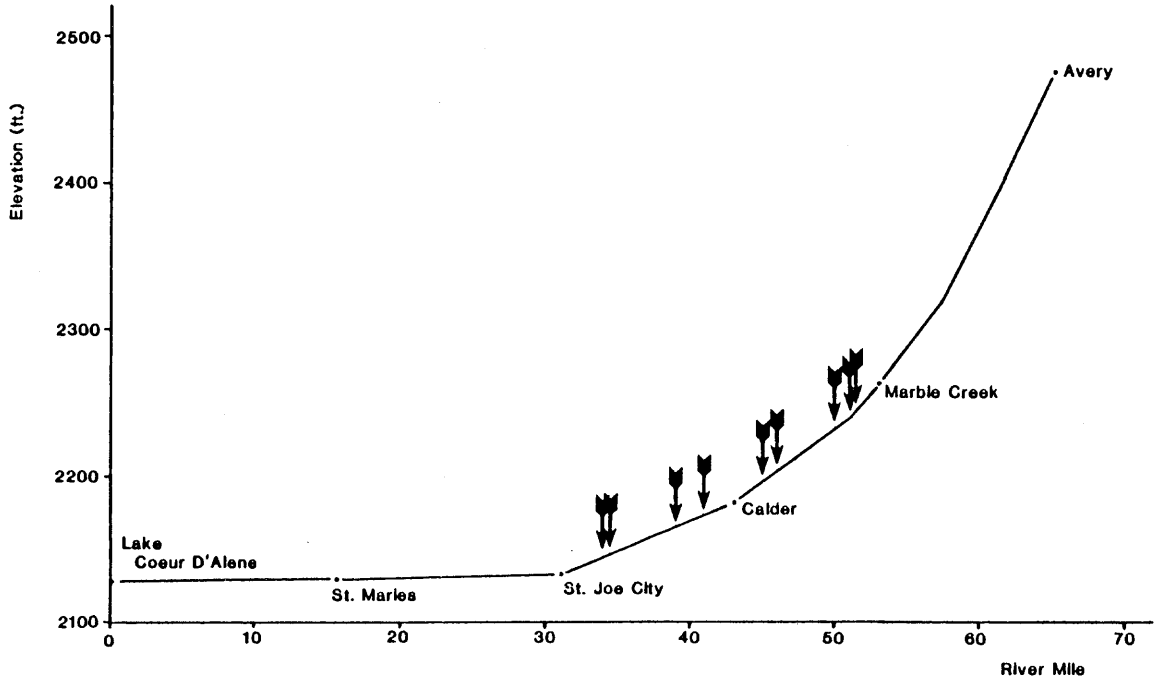



Comparison over time of index of abundance of northern squawfish on each of four spawning sites in the St. Joe River, Idaho. Sites at river miles 39½, 41, 46¼, and 51½ are denoted by solid alternating dot and dash, dotted and dashed lines, respectively.

Table 1
Dates and temperatures reported to coincide with spawning by northern squawfish

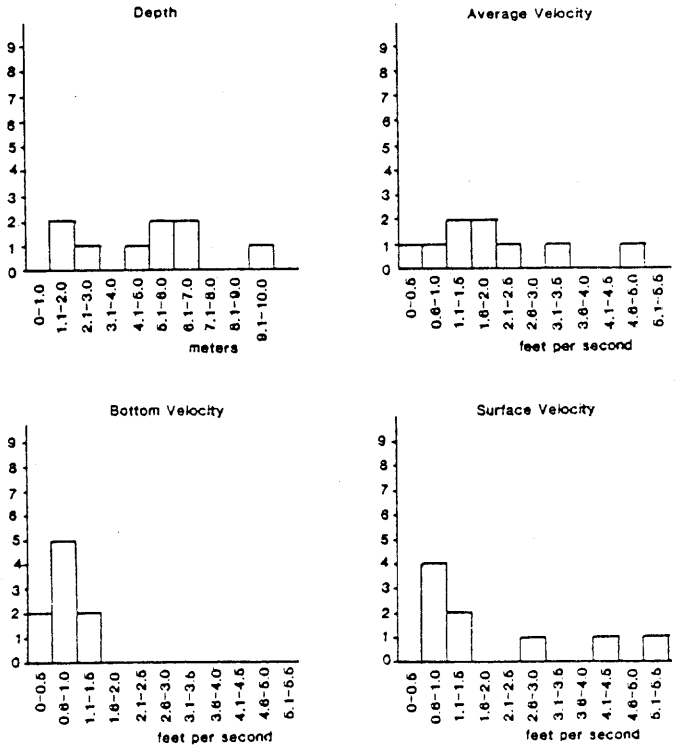
| Location | Dates | Temperature(s) | Citation |
|---|---|---|---|
| Anderson Ranch Reservoir, Idaho | June | | Pollard 1970 |
| Cascade Reservoir tributaries, Idaho | June | 10-20° C | Casey 1962 |
| Clearwater River, Idaho | ?-late July | ?-18° C | This study |
| Columbia River (lower) | -- | 18° C | LaRivers 1962 |
| Cooper and Seeley Lakes, Montana | June | 12-20° C | Hill 1962 |
| Cultus Lake, British Columbia | April-early June | | Foerster and Ricker 1941 |
| Hayden Lake, Idaho | Mid-June-mid-July | 14-20° C | Jeppson 1957 |
| Lake Merwin, Washington | Late June-early July | 17° C | Patten and Rodman 1968 |
| Payette Lake tributaries, Idaho | June-July | 10° C | Casey 1962 |
| St. Joe River, Idaho | Mid-June-mid-July | 10-20° C | Reid 1971 |
| St. Joe River, Idaho | Late June-mid- or late July | 11-18° C | This study |
| St. Maries River, Idaho | June | 10-12° C | This study |
| Lake Washington, Washington | June-July | 13.5-20° C | Olney 1975 |

Figure 4



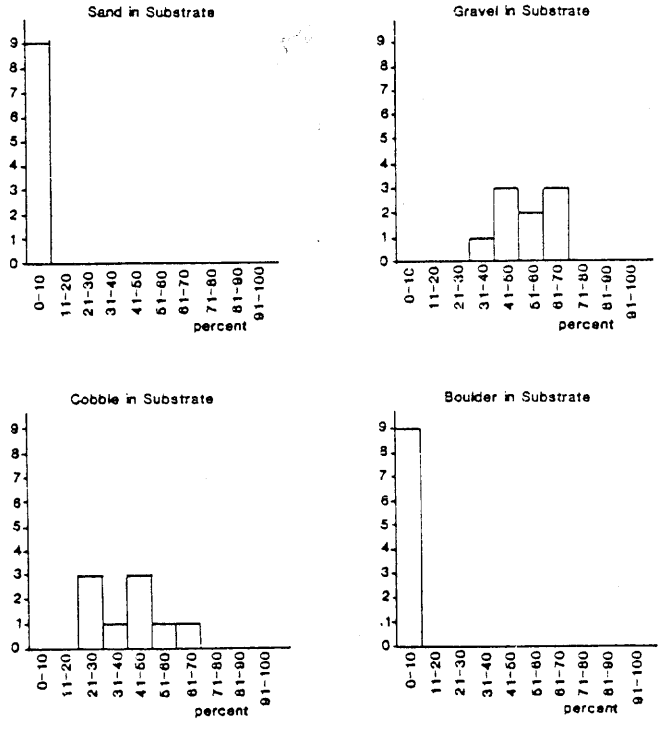

Locations of 9 northern squawfish spawning sites in the St. Joe River, Idaho relative to river mile (above Lake Coeur d-Alene) and gradient.

Figure 5




Depth, average velocity, bottom velocity (5 cm above substrate) and surface velocity (3 cm below surface) for nine sites in the St. Joe River, Idaho, where northern squawfish were observed depositing eggs.

Figure 6




Frequency histograms for properties of substrates at nine sites in the St. Joe River, Idaho, where northern squawfish were observed depositing eggs.

spawners. Five of the 9 spawning sites were in depths of 5 meters or greater, although such areas comprised a small proportion of the river. One site in 9.5 meters of water was at the deepest place anywhere in the fastwater. A preference for deep water spawning sites is seemingly indicated; however, areas as shallow as 1.3 meters were also used. Deeper areas may have been used more often because they were more likely to present proper substrate and velocity conditions than because of a depth preference.

Average and surface velocities were apparently not a consideration in site selection as spawning occurred over the range of average and surface velocities available in the river. Low bottom velocities were clearly preferred by spawning northern squawfish. No site where bottom velocity was grater than 1.4 ft/s (or less than 0.2 ft/s) were utilized. Bottom velocities were low even where surface velocities were high. Downwelling may have been an important characteristic of spawning sites; however, vertical velocity components were not measured.

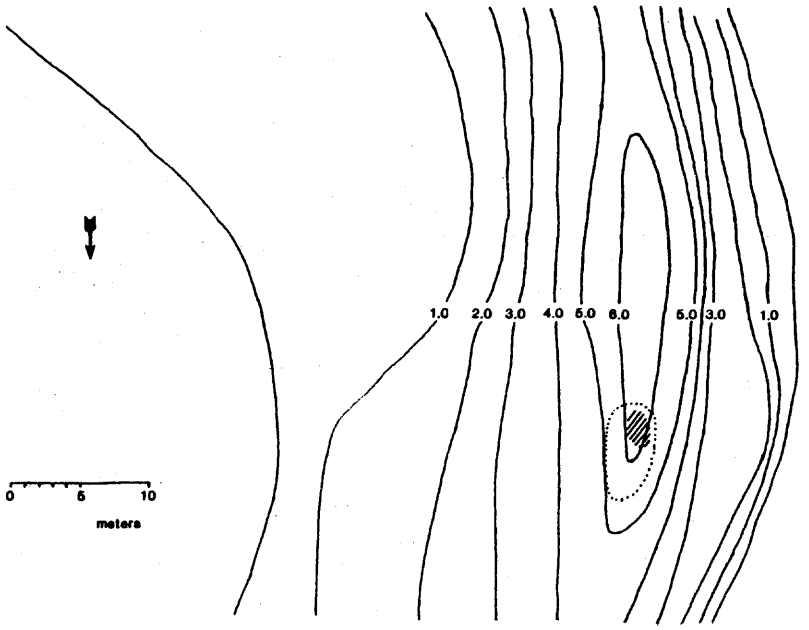
Substrate preferences by spawning squawfish were distinct. The substrate at all spawning sites consisted of a mix of large gravel and small cobble, 3 to 30 cm in diameter, in which no smaller particles were present. Rocks larger in diameter than 30 cm were scarce or absent.

Combinations of the appropriate bottom velocities and substrate were rare in the St. Joe River. Sediment deposition occurred in most areas of low velocity, so that the substrate consisted of fine material. On the other hand, in areas where the substrate was free of fines, velocities were often too great for squawfish to hold position. This may account for the low number of areas used by squawfish for spawning.

All sites on which squawfish spawned were in areas where river morphology resulted in scouring of the substrate. These features, including converging channels, bends in the river, and jutting cliffs or boulders, acted alone or in combination to produce one of two types of suitable areas. High velocity flows were directed along the surface by rock or gravel shelves in type I areas, resulting in low velocities near the substrate. Type I areas tended to be relatively shallow. Type II areas were in relatively deep water, where surface and bottom velocities were similar. Planimetric maps of depths, surface velocity, and bottom velocity are shown in Figures 7 through 12 as examples of the types of areas in which northern squawfish spawned. Sections from river miles 34-3/4, 46-1/4, and 51 represent, respectively, a type II site in a river bend, a type I site where two channels converge, and a type II site next to a jutting rock outcrop.

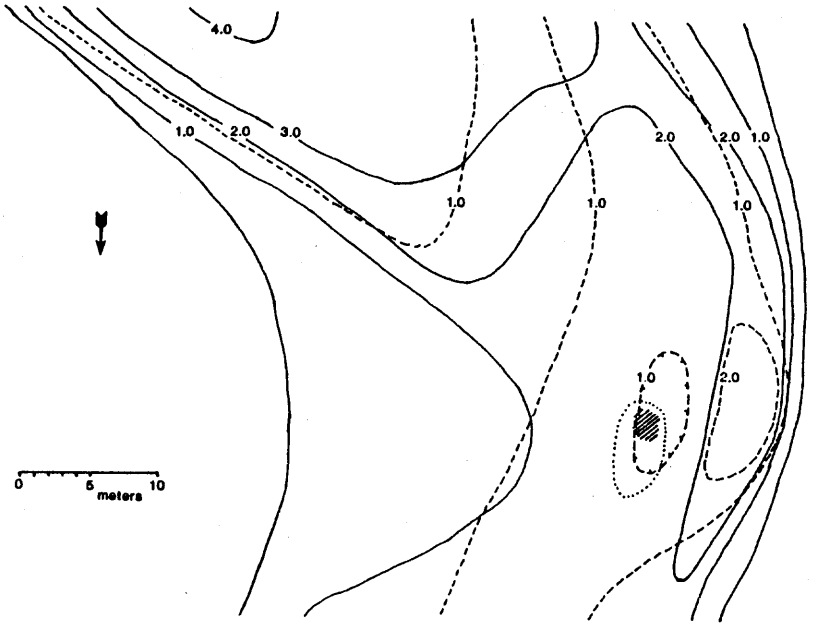
Sites used for spawning by a number of other northern squawfish populations have been described in the literature. Fish spawned over rubble or upon rocks in riffle areas between pools in tributaries to Cascade Reservoir (Casey 1962). In Fish Lake, Chelan County, Washington, squawfish spawned over granite rubble in an outlet stream (Patten and Rodman 1969). In Merwin Reservoir, Washington, spawning occurred on 20 to 45 degree slopes over angular shale talus (38 to 51 cm in diameter) from the edge of a shoreline shelf in 3 meters of water down to the

Figure 7



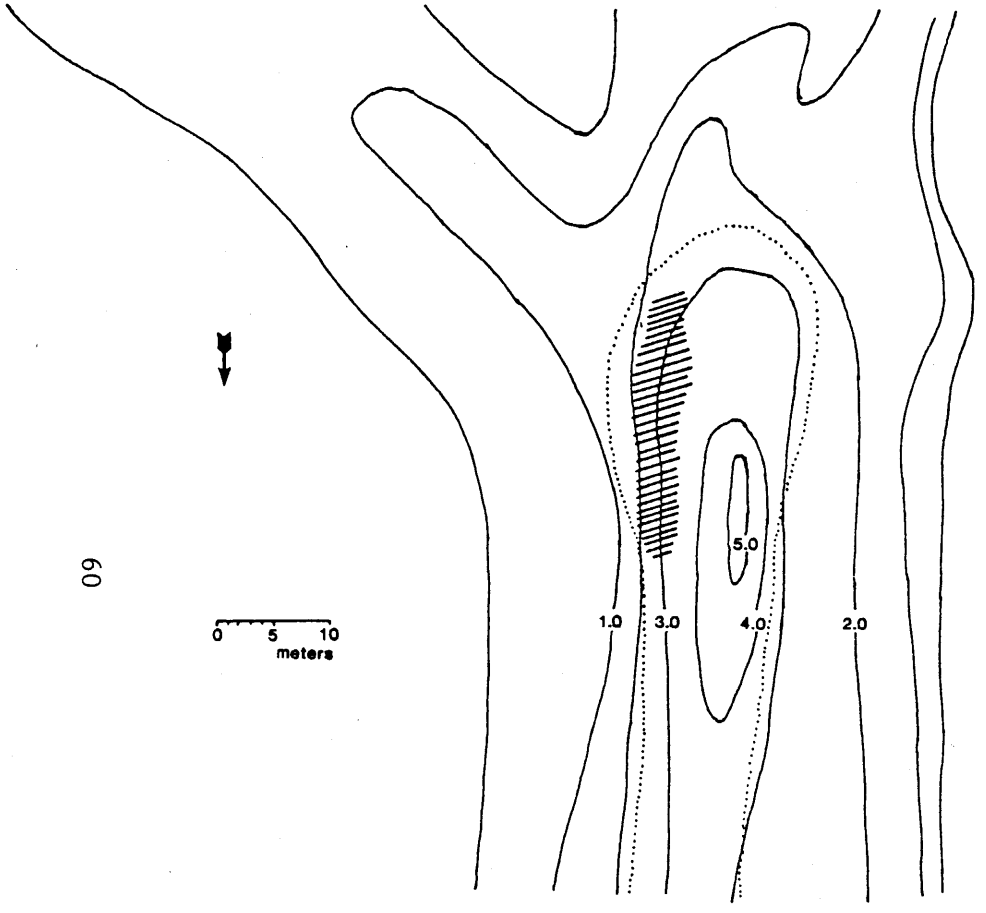

Depth-contour map (depth in meters) of area surrounding northern squawfish spawning site at river mile 34 3/4, St. Joe River. The area of egg deposition is cross-hatched, the area where large numbers of spawning fish were present is outlined by a dotted line, and direction of flow is indicated by an arrow.

Figure 8



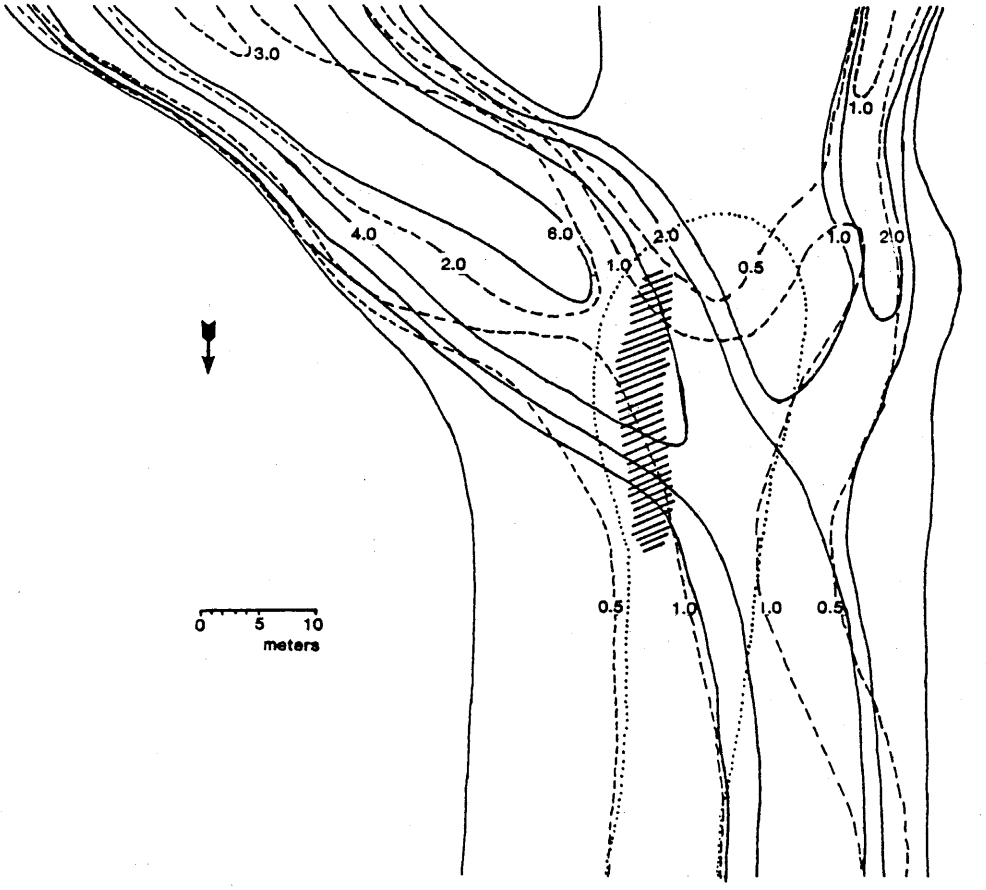

Surface and bottom velocities (in feet per second; solid and dashed lines, respectively) in the immediate vicinity of a northern squawfish spawning site at RM 34 3/4 in the St. Joe River, Idaho. The area of egg deposition is cross-hatched, the location of the spawning aggregation is outlined by a dotted line, and the direction of flow is indicated by an arrow.

Figure 9



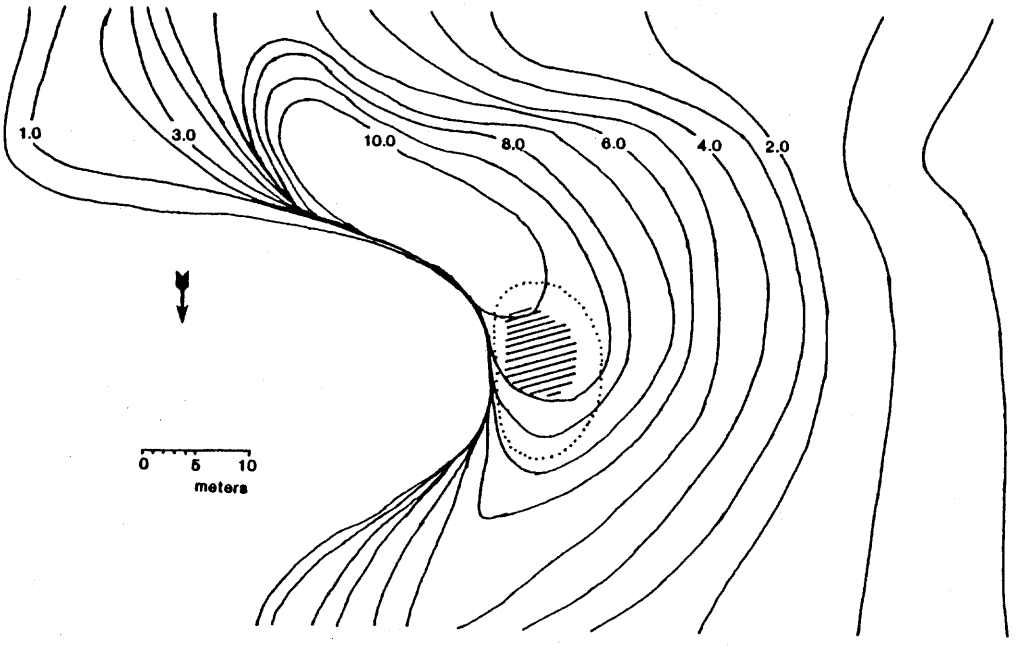

Depth-contour map (depth in meters) of area surrounding northern squawfish spawning site at river mile 46¼, St. Joe River. The area of egg deposition is cross-hatched, the area where large numbers of spawning fish were present is outlined by a dotted line and direction of flow is indicated by an arrow.

Figure 10



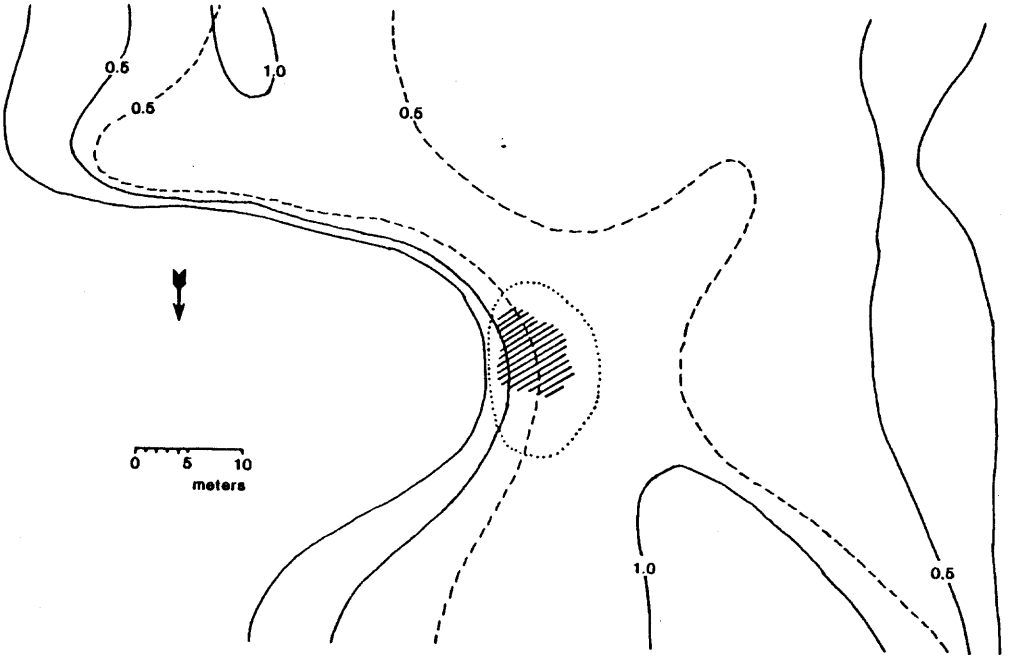

Surface and bottom velocities (in feet per second; solid and dashed lines, respectively) in the immediate vicinity of a northern squawfish spawning site at RM 46¼ in the St. Joe River, Idaho. The area of egg deposition is cross-hatched, the location of the spawning aggregation is outlined by a dotted line, and the direction of flow is indicated by an arrow.

Figure 11




Depth-contour map (depth in meters) of area surrounding northern squawfish spawning site at river mile 51, St. Joe River. The area of egg deposition is cross-hatched, the area where large numbers of spawning fish were present is outlined by a dotted line, and direction of flow is indicated by an arrow.

Figure 12




Surface and bottom velocities (in feet per second; solid and dashed lines, respectively) in the immediate vicinity of a northern squawfish spawning site at RM 51 in the St. Joe River, Idaho. The area of egg deposition is cross-hatched, the location of the spawning aggregation is outlined by a dotted line, and the direction of flow is indicated by an arrow.

thermocline at 15 meters (Patten and Rodman 1969). Angular rubble (2.5 to 20 cm) in wave washed shoreline areas 5 to 30.5 cm deep were used by spawners in Hayden Lake, Idaho (Jeppson 1957). Wave washed clay and sand embedded, 5 to 25 cm cobbles in water less than 30 cm deep was used in Cocolalla Lake, Idaho (Jeppson 1957). Rubble bottoms within a few feet of shore were preferred by spawners in Cooper Lake, Montana (Hill 1962), while gravel beaches in "quite shallow water" were utilized in Cultus Lake, British Columbia (Foerster and Ricker 1941).

In all populations, the common denominator of preferred spawning sites is some type of clean, rocky substrate similar to that utilized in the St. Joe River. A wide variety of sites satisfying this description are used, including lake tributaries, outlet streams, and shallow and deep littoral areas. Velocity preference appear less rigid than substrate preferences. Upper limits are apparently set by the fish's ability to maintain position against the current. Squawfish did spawn in moderately high velocity riffle areas in Cascade Reservoir tributaries, but they aggregated in adjacent pools (Casey 1962). At least some water movement was associated with spawning at all sites located during this study or reported elsewhere. In lakes this movement was the result of wave action or turbulence caused by swimming fish. In Lake Merwin this turbulence was sufficient to clear the talus of sediment and to drive eggs into interstices (Patten and Rodman 1969). The variety of depths used by spawning squawfish implies depth preferences do not exist or are subordinate to substrated and velocity preferences.

Fish in lake-dwelling populations of northern squawfish may spawn in the lake or may enter tributary streams. Of the seven lake populations previously mentioned, five spawned in the lake and two in associated streams. Squawfish in Anderson Ranch Reservoir (Pollard 1970) and Lake Washington (Olney 1975) were also reported to spawn in the lake. Fish spawning in the St. Joe and St. Maries Rivers originate in Lake Coeur d'Alene (Reid 1971). The suitability of existing areas appears to determine whether lake or stream spawning occurs. Jeppson and Platts (1959) surmised that migration into streams occurs when lakeshores are unsuitable for spawning. A limited amount of spawning occurred in Cascade Reservoir in 1958, when tributaries were rotenoned blocked with an electric barrier trap. This spawning occurred on road fills where a narrow bridge across an arm of the reservoir impeded flow, resulting in a current. The success of these spawning activities is unknown.

### Spawning related movements

Comparisons of catch per unit effort for nets set in the St. Joe River during spawning added no significant information to the understanding of squawfish movements near spawning areas. The use of a variety of net types and differences in net effectiveness at different sites precluded between-site comparisons. Comparisons of catch rates of individual nets over time were also inconclusive because of low rates and high variation.

Mark and recapture studies of fish movements also yielded little information as a result of the low numbers of fish captured. Only

134 fish were tagged and 111 of those were collected on one spawning site. Fifteen of 16 tagged fish later recaptured or sighted were from the group tagged on the spawning site. Figure 13 shows the locations and date of recaptures or sightings. Most fish tagged on the spawning site apparently left soon after. Within a week only 4 tagged fish were observed there by snorkelers. It is unlikely many tags were overlooked, as they were highly visible and the site was small. Two tagged fish were recaptured within 10 days downstream with spent gonads and a few others were later observed on other spawning sites. Two males were observed on spawning sites one month after tagging and one female was seen on an upstream site three weeks after being tagged. Whether fish behaved normally after being captured and tagged is unknown. Attempts to seine fish from the spawning site interrupted spawning activity and the majority of fish left the site after a few passes with the seine, although most returned by the following day. Attempts to monitor movements of radio-tagged fish failed because of insufficient transmitter range.

Observations made during this study were consistent with the general pattern of movements of St. Joe River squawfish described by Reid (1971). Mature fish move into the slackwater during April from deep water areas of Coeur d'Alene Lake, where they have spent the winter. Fish disperse both upstream and downstream after spawning in the lower fastwater in June and July. The majority return to slackwater and the lake, but some move upstream as far as 80 miles above the lake. Movements through areas at the mouth of the river into the lake during early summer have been documented by Howse (1966). All mature northern squawfish emigrate from the river during October.

Spawning migrations similar to those of squawfish in the St. Joe River have been reported from Cascade Reservoir (Casey 1962). Males moved into tributaries in late May or early June. Females ripened later than males and moved into tributaries during June in large schools. Females drifted rapidly back to the reservoir after spawning, but males migrated downstream more slowly.

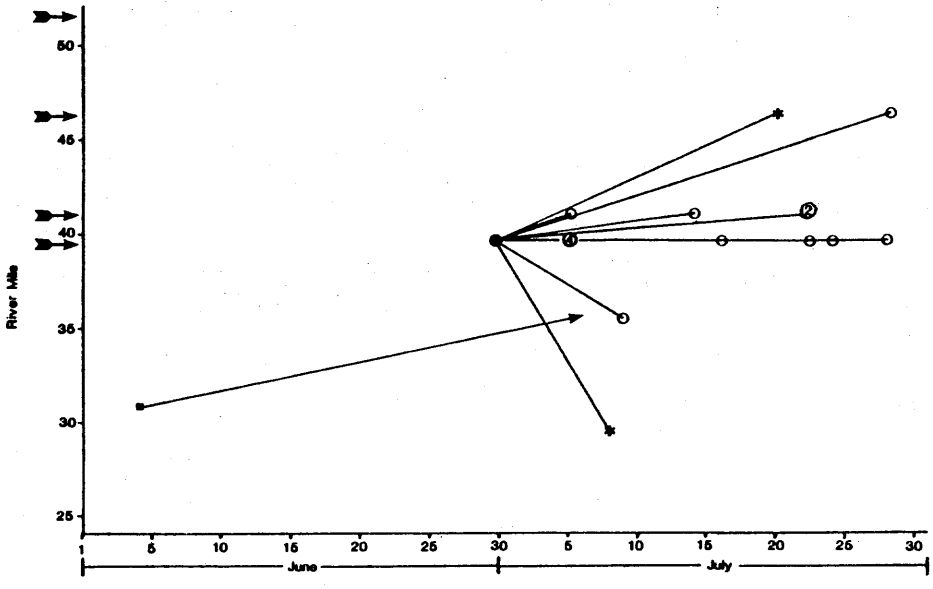
### Spawning population characteristics

The length frequency distribution of fish collected by gill and trammel net during this study is depicted in Figure 14. The majority of fish in the upper end of the distribution were females. Mature females reached greater lengths than males and averaged almost 80 mm longer (Table 2). Females matured at greater lengths than males (Figure 15). The shortest matured females were in the 251 to 275 mm range, a majority were mature by 325 mm, and all were mature by 400 mm. Males first matured at 201 to 225 mm, a majority were mature by 275 mm, and all were mature by 300 mm.

The relationship between fork length and net weight of all fish collected in the St. Joe River during this study may be expressed by the equation:

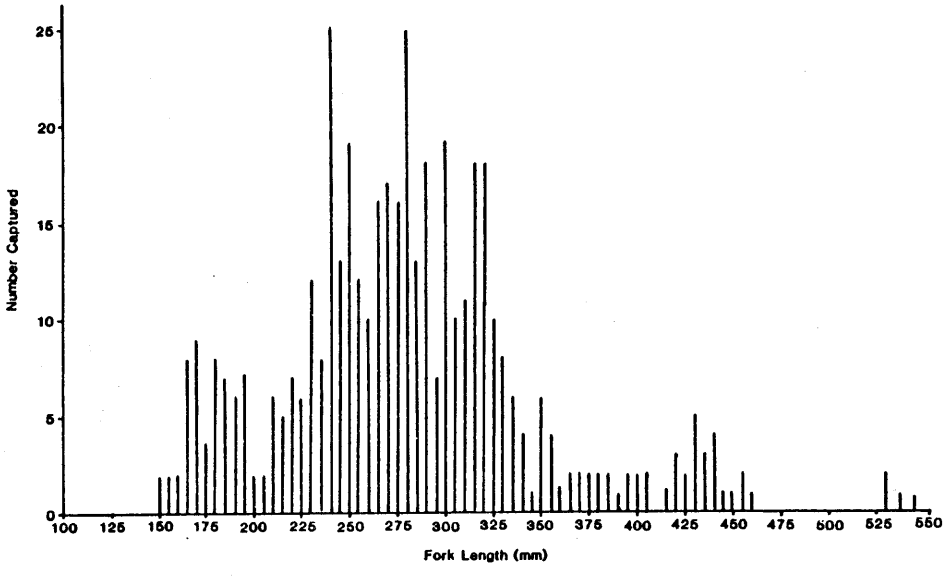
$$\text{Log } W = (3.17 \text{ Log } L - 5.36)$$

Figure 13




Movements of tagged northern squawfish in a portion of the St. Joe River between dates of tagging and recapture or observation. Arrows along the river mile axis denote locations of spawning site transects. The long arrow on the graph refers to the movement of a single recaptured male tagged at R.M. 31. The solid circle represents the tagging of squawfish on a spawning site at R.M. 39 in late June; lines are drawn to points indicating the date and location where tagged individuals were later observed. The time and location where fish were tagged on a spawning site are indicated with a star and lines are drawn to points where these fish were later observed. Sightings of more than one fish are indicated with a figure enclosing the number seen. Sightings of males are indicated by circles and of females by triangles.

Figure 14



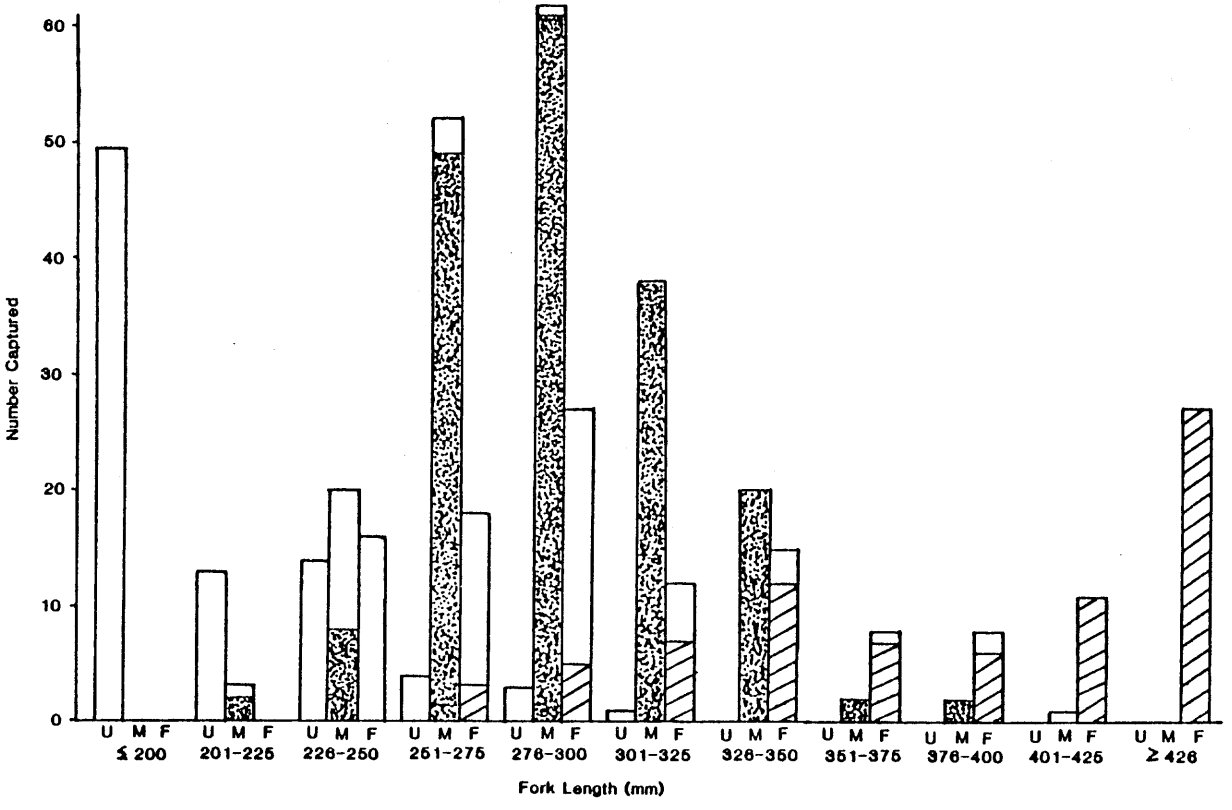

Length-frequency distribution of northern squawfish collected by gill and trammel net from the St. Joe River in 1980 and 1981.

Table 2

Length data (fork lengths in mm) for the mature male and female northern squawfish collected in the St. Joe River in 1980 and 1981

| Description | Male | Female |
|---|---|---|
| Largest mature individual | 425 | 530 |
| Smallest mature individual | 210 | 270 |
| Mean lengths of mature individuals | 291 | 368 |
| Sample size | 210 | 114 |
| 95% confidence intervals for difference in mean lengths, male vs female | (65.8, 88.2) | |

Figure 15




Length-frequency distribution of northern squawfish collected from the St. Joe River during spawning seasons in 1980 and 1981. Frequencies are broken down by sex (unidentified, male, female) and maturity status (immature-blank, mature male-strippled, mature female-hatched).

where W is weight in grams, L is length in millimeters, and constants were calculated with a least squares regression. Ninety-three percent of the variation in fish weight is accounted for by length in this regression. Gonad weights of fish collected just prior to spawning were also closely correlated with fish length (Figure 16). With slight increases in length, male gonadal weights increased little but female gonadal weights increased greatly.

Secondary sexual characteristics clearly differentiated mature and immature northern squawfish during the spawning season. Dorsal surfaces darkened and ventral surfaces and fins became yellow in mature fish of both sexes. Males developed large number of tubercles, especially about the head. Females developed fewer tubercles and their vents became enlarged and inflamed.

Gonads of unripe males were solid and pinkish in color. Gonads of green females were yellow, orange, green, or gray and eggs were easily distinguished. Sex products in both sexes ripened in small increments. Ripened products (white milt in males and translucent eggs in females) were contained in the anterior end of the gonad. After spawning the gonads of both sexes were flaccid and reddened. Partially developed eggs were visible in the ovaries of spent females. Partially developed eggs were also visible in the gonads of larger immature females about the time of spawning.

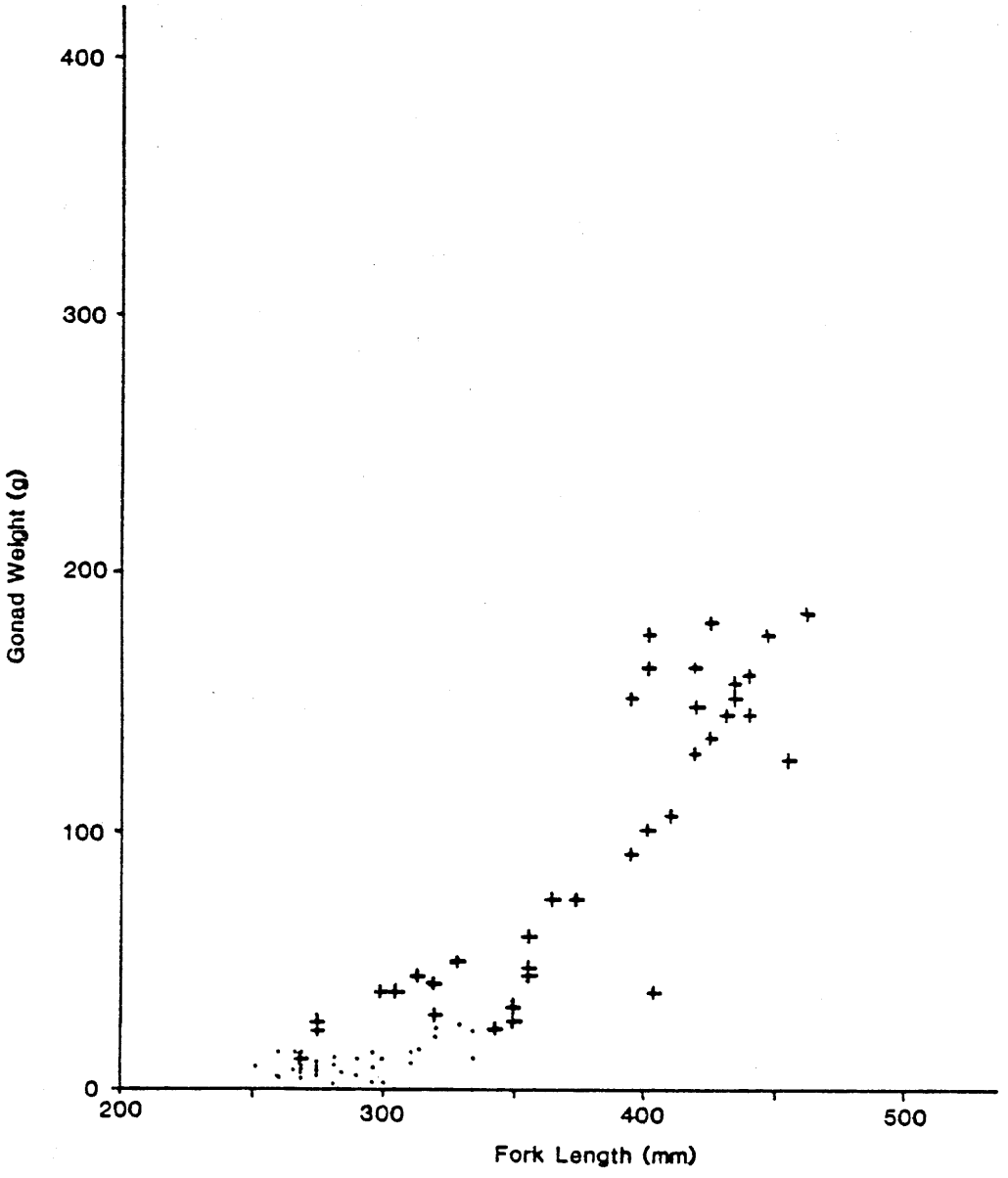
Information on population characteristics of other squawfish populations similar to the St. Joe population are summarized in Table 3. For all cases, females reached larger sizes than males due to greater longevity. Olney (1975) noted that age of sexual maturity in northern squawfish varied with location but appeared related to fish length. Hill (1962) also observed fish with partially developed ovaries during the spawning season. Large increases in the fecundity of females accompanying slight increases in length, such as were seen in this study, have been reported by Casey (1962), Hill (1962), Jeppson and Platts (1959), Olney (1975), and Reid (1971).

## HABITAT SELECTION

### Methods

A reach of the St. Joe River including the lower fastwater below Marble Creek (river miles 34 to 54) was delineated and divided into 10 2-mile sections. A quarter mile subsection was selected at random from each section and was marked on a topgraphic map from which it was located in the field. During summer low flows in August and September of 1980, fish were located in each subsection by two snorkelers floating downstream in midchannel, where velocities were high, then swimming quietly upstream near shore, where velocities were lower. Swimmers worked on opposite sides of the river to completely cover the section.

Figure 16




Gonad weights as a function of fork length for male (dats) and female (pluses) northern squawfish collected just prior to spawning in the St. Joe River during 1980 and 1981.

Table 3
Maximum ages, lengths and ages at first reproduction, and length-weight relationships of five populations of northern squawfish

| | St. Joe River (Reid 1971) | Lake Washington (Olney 1975) | Cascade Reservoir (Hill 1962) | Alva Lake (Hill 1962) | Round Lake (Howse 1966) |
|---|---|---|---|---|---|
| Maximum age (year) | | | | | |
| Males | 10 | 16 | 5 | 22 | -- |
| Females | 17 | 21 | 11 | 14 | -- |
| Length at first reproduction (mm) | | | | | |
| Males | ?-310 | 251-275 | 250-? | -- | -- |
| Females | ?-280 | 301-350 | 310-? | -- | -- |
| Age at first reproduction (year)[1/] | | | | | |
| Males | 5-6 | 4-6 (5) | 4 | 6-? | -- |
| Females | 6-7 | 4-7 (6) | 4-5 (5) | 7-9 | -- |
| Length-weight relationship[2/] | | | | | |
| Measurement | Fork | Total | Standard | -- | -- |
| Sample size | 96 | 933 | 132 | -- | -- |
| a | 2.94 | 3.20 | 2.67 | -- | 2.91 |
| b | -1.54 | -5.56 | -3.92 | -- | -4.75 |

1/ Ages when most fish reproduce are enclosed in parentheses.
2/ Log W = a Log L + b where W = weight in grams and L = length in millimeters.

Shallow shoreline areas of each subsection were checked by walking along each bank. Observations were made no sooner than 2 weeks after spawning was completed to avoid including spawning fish or fish emigrating after spawning.

After a brief period of observation of each fish located, snorkelers recorded general descriptions of behavior and of the surrounding area, estimates of distances to the substrate, to the bank, and to overhead cover, estimates of substrate composition and numbers, and types of fish within 1 and 3 meters. The site was then marked with a small, weighted float. After each fish in the subsection was located, depths and velocity profiles at each marker were determined from a boat with a calibrated line and a Marsh-McBirney Model 201 portable water current meter. Additional information on the types of observations made is included in Appendix B. Sections were snorkeled only on bright or sunny days at least one day after rain to insure optimal visibility.

Observations were repeated during August of 1981 in 10 additional quarter mile subsections of the lower fastwater reach of the St. Joe River. As in 1980, one subsection was selected at random from each 2 mile section of the reach (omitting subsections previously surveyed). Observations in shallow shoreline areas were also omitted in 1981.

## Results

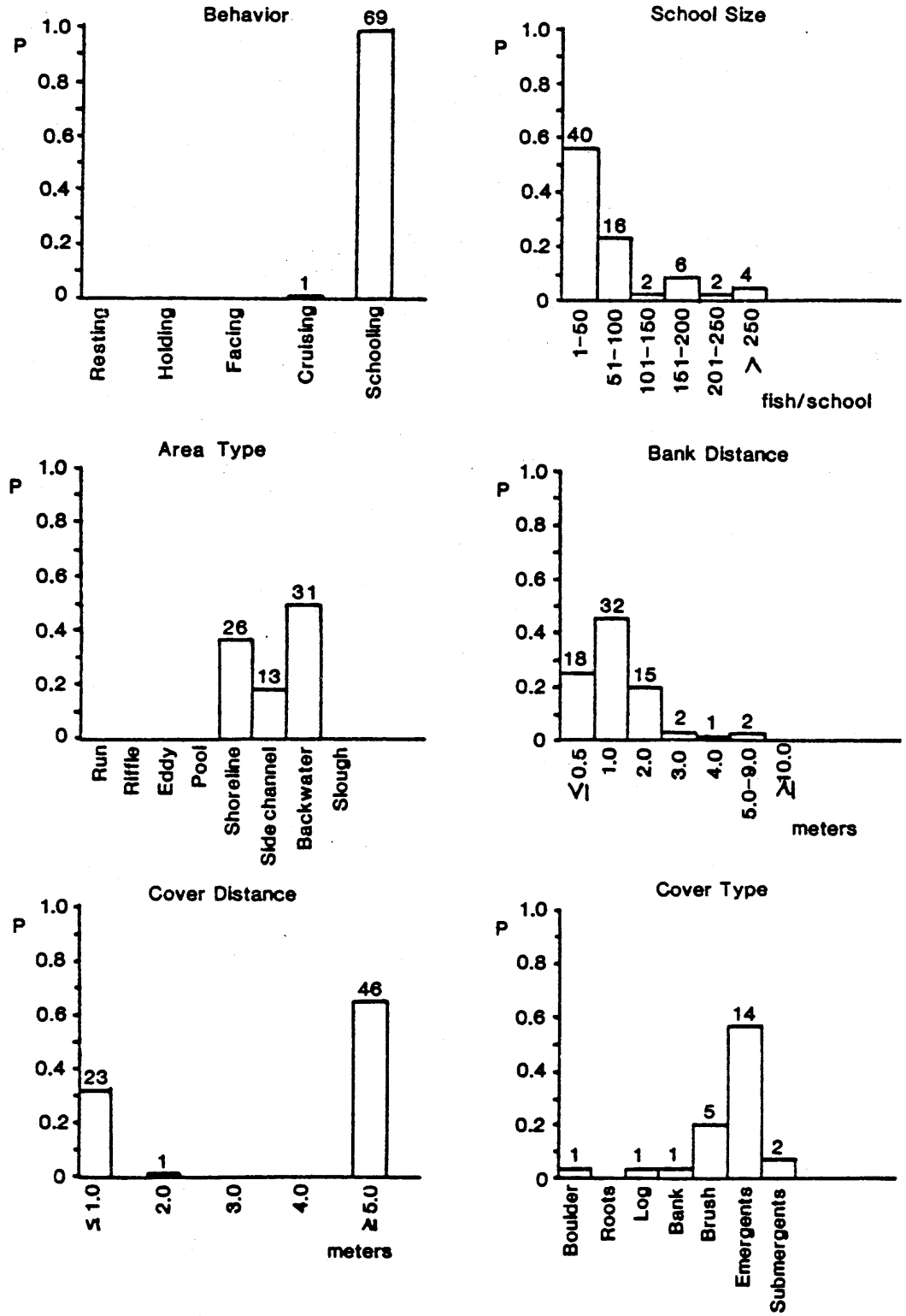
### Young-of-the-year

Age-specific differences in behavior and habitat preference were apparent. Preferences of fish less than 5 cm in length (young-of-the-year) are summarized in Figures 17 through 19 and in Table 4. Fish of this size schooled in shoreline pockets in low velocity areas of the river and in partially enclosed backwaters and side channels isolated from the main river during summer low flows. Most schools were of 50 or fewer fish although they ranged in size up to 2,500 fish. Individual squawfish within a school typically cruised very slowly with frequent changes of direction. The orientation of each fish appeared independent of other fish in the school and schools tended to remain stationary. Fish in a school ranged throughout the water column.

Areas preferred by young squawfish were characterized by very shallow water (usually less than 25 cm deep), close proximity to shore, no velocity, and a substrate consisting almost entirely of sand. Many schools were closely associated with overhead cover in the form of emergent vegetation but even more schools were seen in areas devoid of cover, indicating that cover is not a strict requirement. Almost all squawfish schools included redside shiner young-of-the-year. Young dace, sculpins, and suckers were also common in areas preferred by young squawfish. When suckers were present, they usually formed a discrete school close to the substrate on the offshore fringe of the cyprinid school.

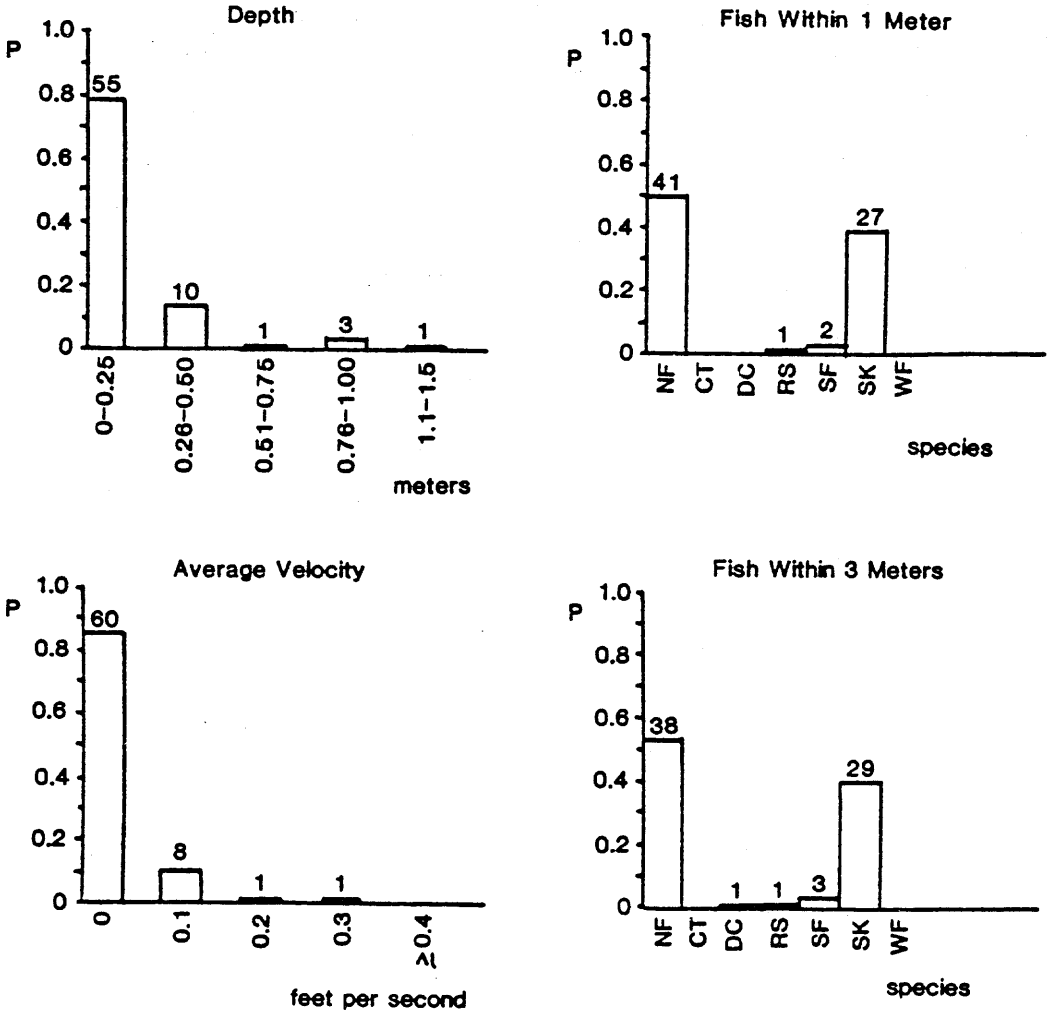
Young squawfish were observed in study subsections as far upstream as river mile 50-3/4 (Figure 20). This was immediately below the

Figure 17



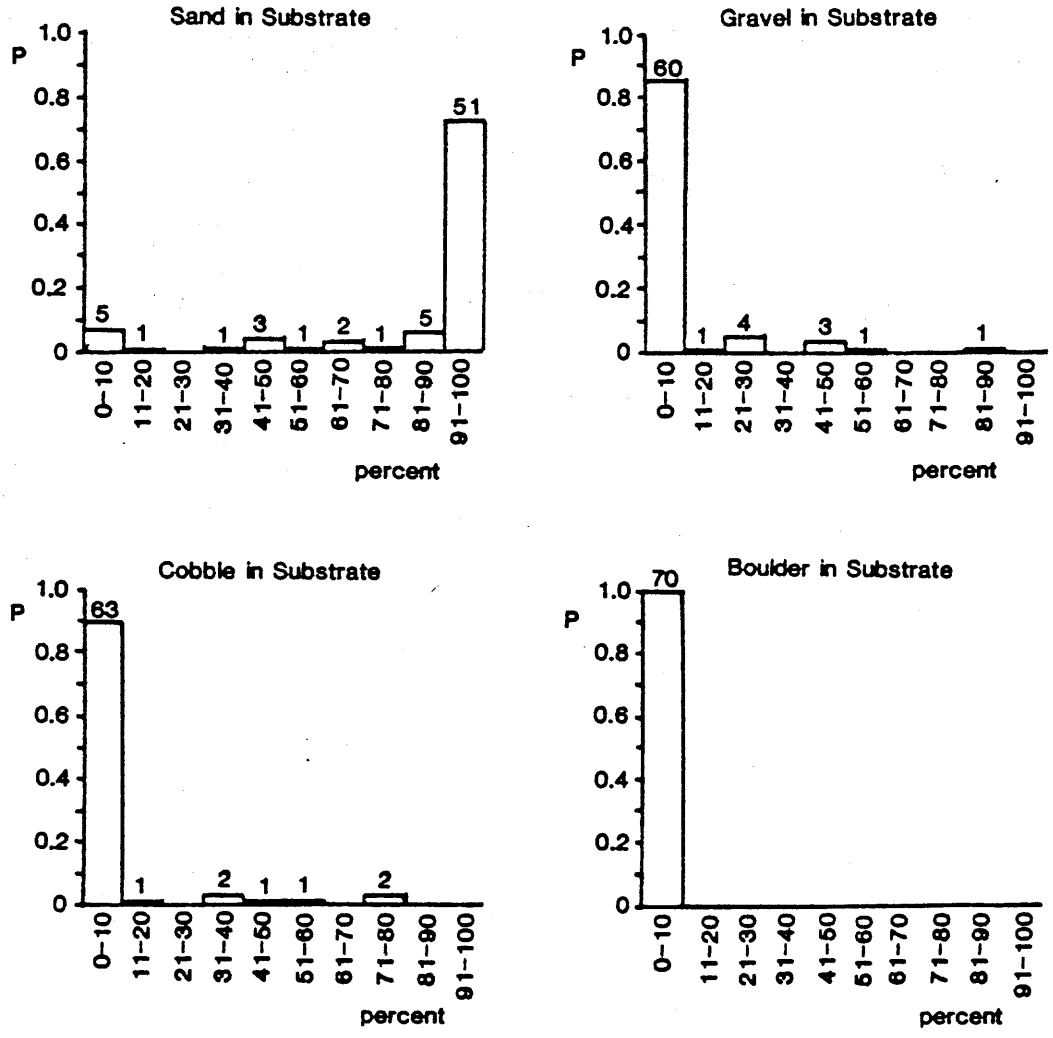

Frequency of occurrence histograms for observed habitat preferences and activity patterns of young-of-the-year northern squawfish. Observations were made in the lower fastwater portions of the St. Joe River during summer low flows in 1980. "P" refers to the proportion of all observations falling within a given habitat characteristic stratum. Numbers above histogram bars are the number of schools observed.

Figure 18



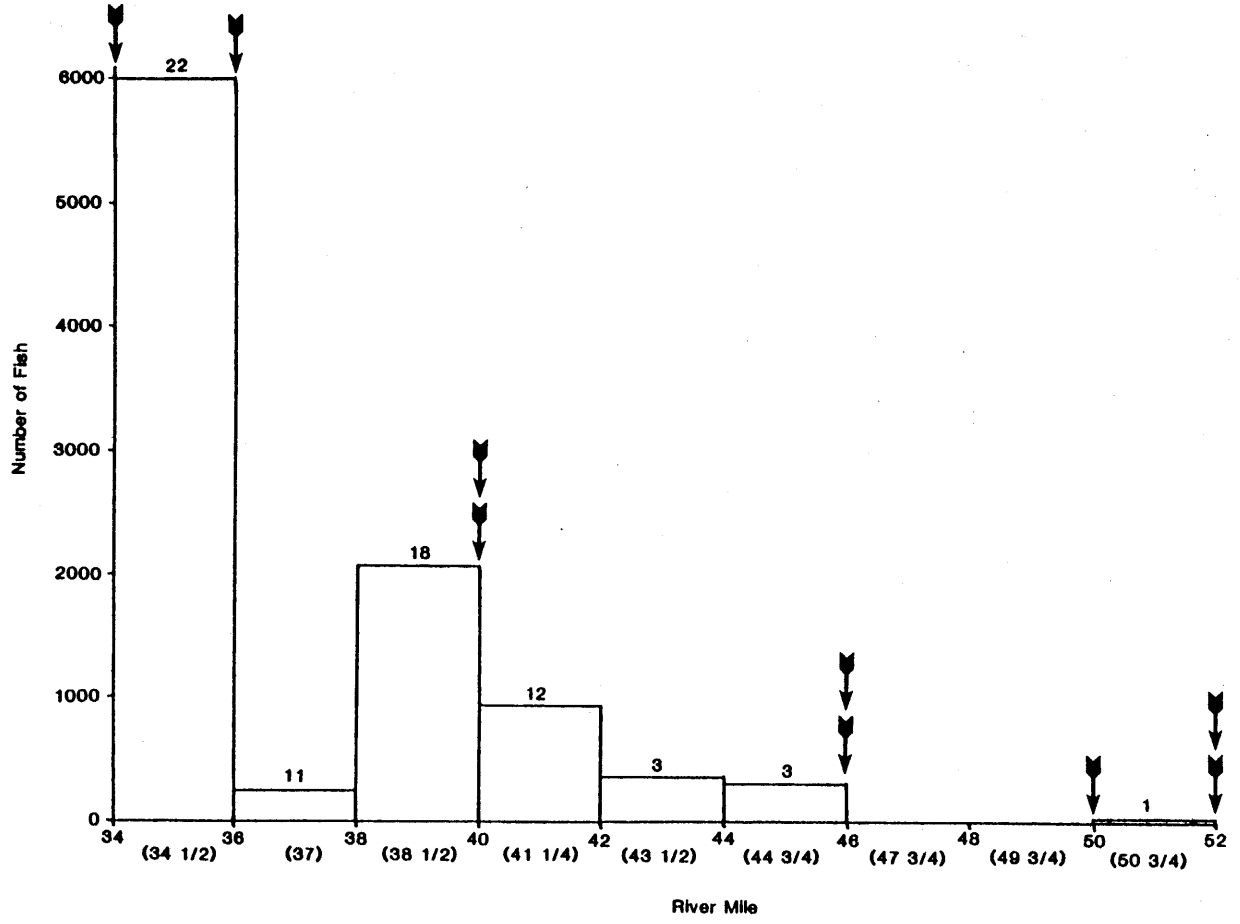

Frequency of occurrence histograms of schools of young-of-the-year northern squawfish over a range of depths and velocities and within given distances of other species of fish. Observations were made in the lower fastwater portion of the St. Joe River during summer low flows in 1980. NF refers to no fish while other species include cutthroat trout (CT), dace (DC), redside shiners (RS: juveniles and adults only), other squawfish (SF: juveniles, subadults, and adults only), suckers (SK), and whitefish (WF).

Figure 19




Frequency of occurrence histograms of schools of young-of-the-year northern squawfish over a range of proportions composed by each of four substrate particle size classes. Observations were made in the lower fastwater portion of the St. Joe River during summer low flows in 1980. Sand is less than 0.1 cm in diameter, gravel is between 0.1 and 10 cm in diameter, cobble is between 10 and 30 cm in diameter, and boulders are larger than 30 cm in diameter.

Figure 20




Distribution of young-of-the-year northern squawfish in the lower fastwater reach of the St. Joe River, Idaho, during summer low flows in August and September. River mile fractions (in parentheses) are those randomly-selected quarter-mile subsections in which fish abundance was estimated. Numbers above histogram bars are the numbers of schools observed and arrows depict the relative positions of spawning sites.

Table 4

Preferred habitat characteristics for different size classes of northern squawfish from the St. Joe River, Idaho. Shown are sample size, number of schools, mean preference with standard deviation and range, and area of maximum preference with the probability of occurrence within that area (from frequency distribution histograms)

| Fish size class | Habitat character | Number of schools | Mean | Standard deviation | Range | Maximum preference |
|---|---|---|---|---|---|---|
| <5 cm | Depth (meters) | 70 | 0.20 | 0.22 | 0.03-1.2 | 0-0.25 (0-79) |
| | Average velocity (ft/s) | 70 | 0.02 | 0.05 | 0-0.3 | 0 (.86) |
| | Facing velocity (ft/s) | 70 | 0.02 | 0.05 | 0-0.3 | 0 (.84) |
| | Sand in substrate (percent) | 70 | 86.5 | 27.6 | 5-100 | 91-100 (.73) |
| | Gravel in substrate (percent) | 70 | 7.2 | 16.4 | 0-85 | 0-10 (.86) |
| | Cobble in substrate (percent) | 70 | 5.9 | 17.2 | 0-80 | 0-10 (.90) |
| | Boulder in substrate (percent) | 70 | 0.4 | 1.8 | 0-10 | 0-10(1.00) |
| 5-15 cm | Depth (meters) | 23 | 0.64 | 0.63 | 0.09-2.0 | 0-0.25 (.39) |
| | Average velocity (ft/s) | 23 | 0.07 | 0.12 | 0-0.4 | 0 (.65) |
| | Facing velocity (ft/s) | 23 | 0.06 | 0.12 | 0-0.4 | 0 (.65) |
| | Sand in substrate (percent) | 23 | 58.7 | 41.2 | 0-100 | 91-100 (.35) |
| | Gravel in substrate (percent | 23 | 19.4 | 26.9 | 0-85 | 0-10 (.65) |
| | Cobble in substrate (percent) | 23 | 12.0 | 16.7 | 0-50 | 0-10 (.65) |
| | Boulder in substreat (percent) | 23 | 7.8 | 20.8 | 0-70 | 0-10 (.87) |
| 5-25 cm | Depth (meters) | 63 | 1.83 | 0.66 | 0.9-4.0 | 1.1-1.5 (.35) |
| | Average velocity (ft/s) | 53 | 0.39 | 0.25 | 0.1-1.2 | 0-0.2 (.36) |
| | Facing velocity (ft/s) | 53 | 0.32 | 0.21 | 0-1.0 | 0-0.2 (.42) |
| | Sand in substrate (percent) | 63 | 18.9 | 29.0 | 0-80 | 0-10 (.79) |
| | Gravel in substrate (percent) | 63 | 37.9 | 26.7 | 0-70 | 61-70 (.43) |
| | Cobble in substrate (percent) | 63 | 27.5 | 13.8 | 0-75 | 21.30 (.59) |
| | Boulder in substrate (percent) | 63 | 15.6 | 23.9 | 0-85 | 0-10 (.68) |
| >25 cm | Depth (meters) | 144 | 1.82 | 0.73 | 0.7-4.3 | 1.6-2.0 (.35) |
| | Average velocity (ft/s) | 142 | 0.67 | 0.58 | 0-3.3 | 0-0.2 (.30) |
| | Facing velocity (ft/s) | 142 | 0.40 | 0.36 | 0-1.7 | 0-0.2 (.44) |
| | Sand in substrate (percent) | 148 | 20.2 | 28.8 | 0-100 | 0-10 (.70) |
| | Gravel in substrate (percent) | 148 | 29.2 | 24.5 | 0-85 | 0-10 (.34) |
| | Cobble in substrate (percent) | 148 | 34.4 | 23.5 | 0-100 | 0-10 (.22) |
| | Boulder in substrate (percent) | 148 | 15.4 | 22.0 | 0-100 | 0-10 (.66) |

upstream limit of spawning by squawfish (river mile 51-1/2). Few young fish were present in these upstream areas, however. Most were located in the lower 10 miles of fastwater with abundance increasing progressively down river. This distribution pattern probably reflects the relative abundance of the preferred habitat type, as well as proximity to spawning areas. Many young squawfish were also observed in slackwater areas below river mile 34, although no attempt was made to determine distribution patterns there.

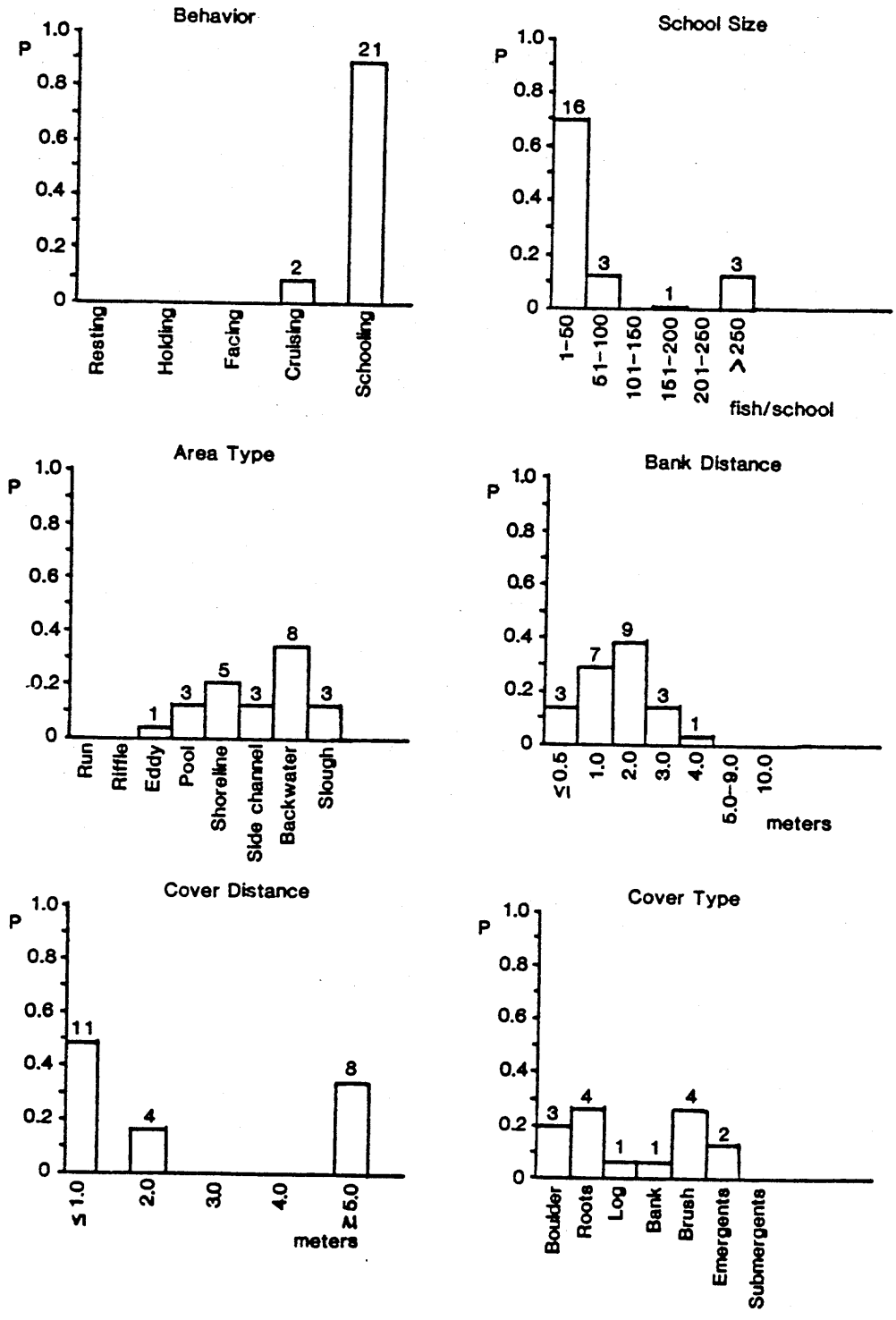
Other studies on both lake and stream-dwelling squawfish populations have documented young squawfish habitat preferences similar to those observed in this study. Hill (1962) found young squawfish in protected places near shore and in backwaters of the Big Blackfoot and Clearwater Rivers. Small squawfish school in large numbers in still water along the banks of spawning tributaries to Cascade Reservoir and in backwaters of the reservoir itself during July and August (Casey 1962). Schools in shallow littoral areas were also reported in Hayden and Cocolalla Lakes (Jeppson and Platts 1959) and in Lake Washington, Washington (Olney 1975). In Seeley Lake, preference shifts from water less than one foot deep along rubble or gravel shores during early summer to shoreline areas of submergent vegetation in depths less than three feet after August (Hill 1962). A similar midsummer shift in preference was noted in Nicola Lake, British Columbia, from sandy bottomed littoral areas to shallow sandy areas with some aquatic vegetation (Miura 1962).

Northern squawfish young-of-the-year were found in the same areas of Seeley Lake as peamouth chub young (Mylocheilus caurinum) (Hill 1962) and in the same areas of Cascade Reservoir as redside shiner and large-scale sucker young (Casey 1962). During the early summer in Nicola Lake (Miura 1962), young squawfish, largescale suckers, peamouth chubs, redside shiners, and prickly sculpins (Cottus asper) were often found in the same areas and schools formed by several different species were common. Some differences in habitat preference was noted, with suckers and chubs being most abundant in the sandy bottomed areas favored by squawfish and shiners and sculpins being most common in sandy areas where aquatic vegetation was present. By mid-summer, the preference of chubs shifted, along with those of squawfish, to weedy areas while the preference of shiners for areas of aquatic vegetation diminished. During the early summer, all cypriniform species avoided the bottom layer of the water column, while later in the year young suckers preferred the bottom layer, leaving the cyprinid species in the middle and upper layers.

### Juveniles

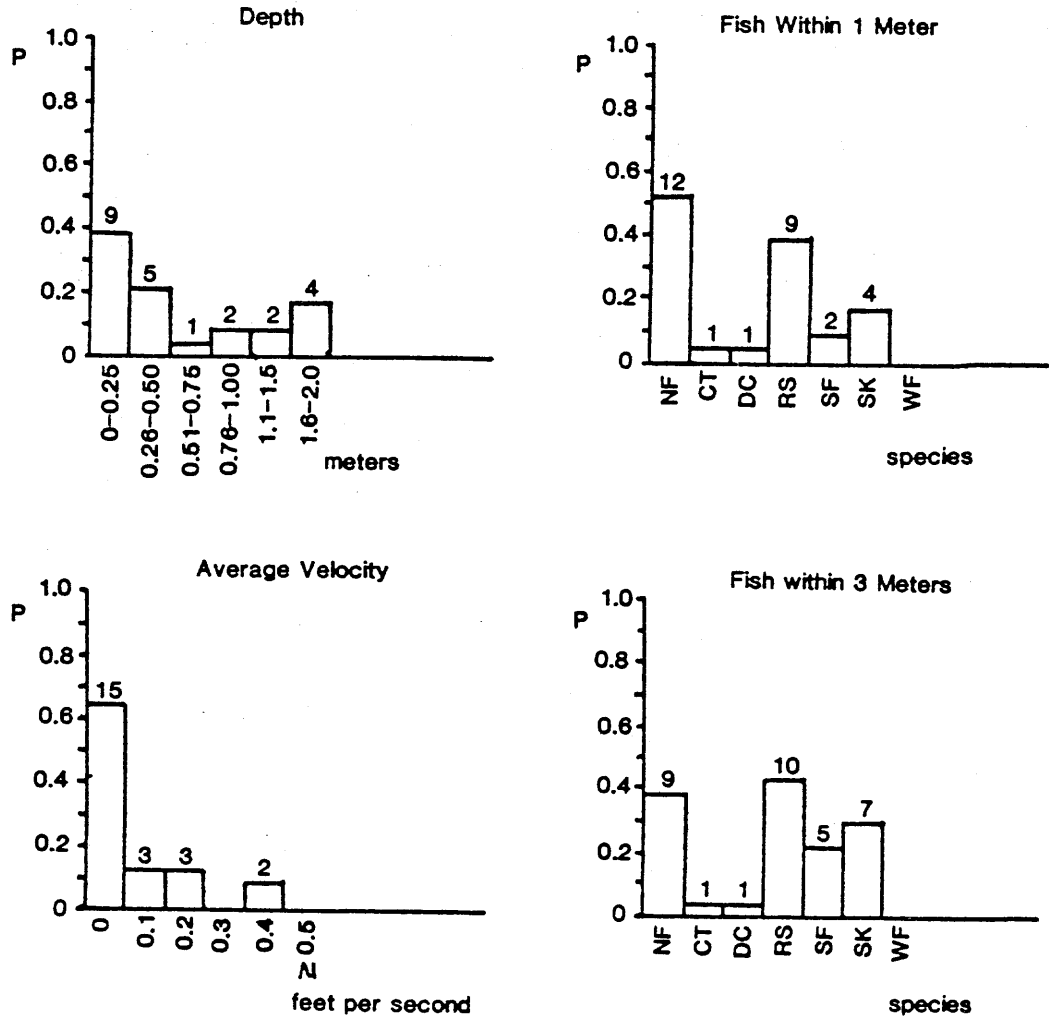
Squawfish between 5 and 15 cm in length are classed as junveniles and their habitat preferences are indicated in Table 4 and Figures 21 through 23. Like young squawfish, juveniles showed a strong tendency to school, although schools of juveniles were smaller than those of young. Schools of juveniles were observed cruising slowly or milling near cover. Juvenile squawfish showed a greater affinity for overhead cover than did young squawfish and preferred submerged boulders, roots, and brush over emergent vegetation.

Figure 21



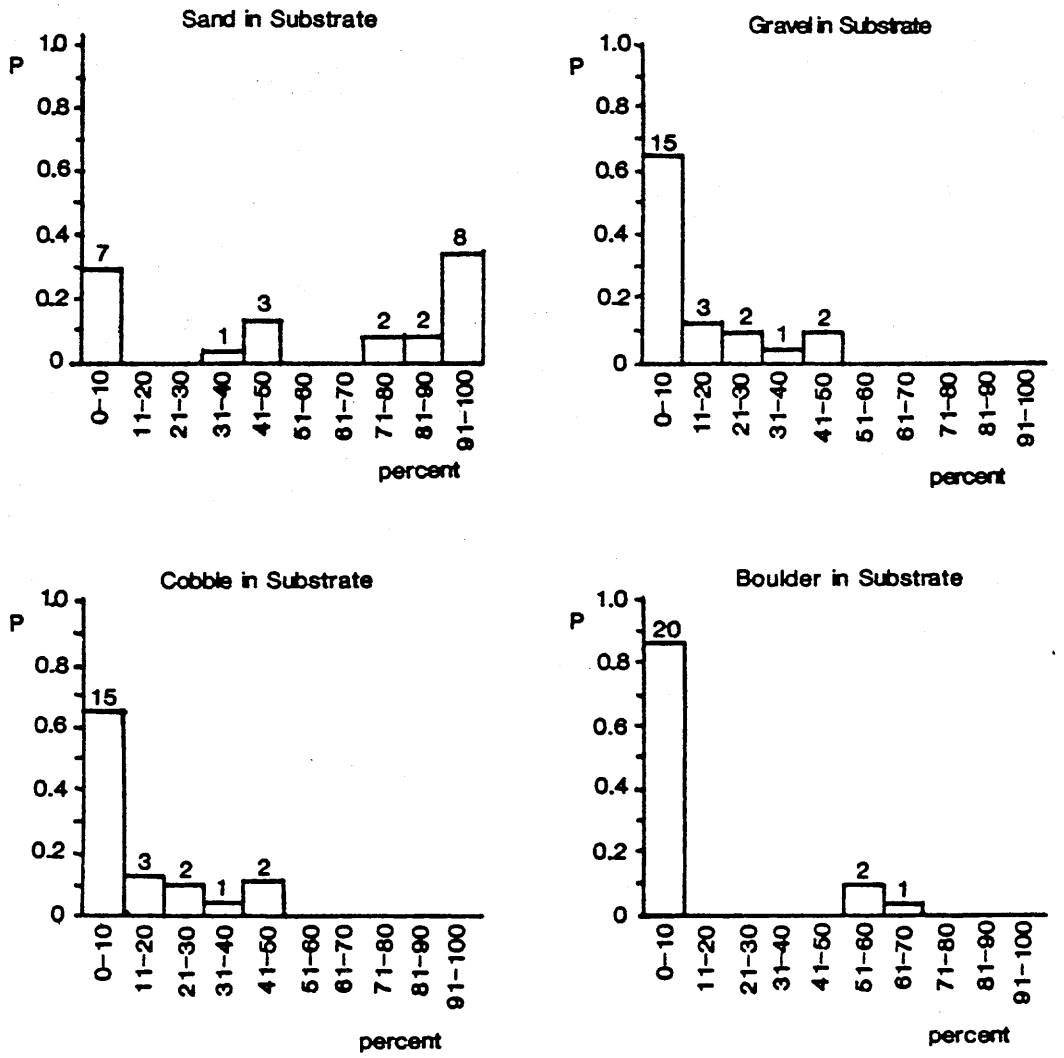

Frequency of occurrence histograms of schools of juvenile northern squawfish over a range of values for a series of behavioral and habitat characteristics. Observations were made in the lower fastwater portion of the St. Joe River during summer low flows in 1980 and 1981. "P" refers to the proportion of all observations falling within a given characteristic stratum. Numbers above histogram bars are the number of schools observed.

Figure 22




Frequency of occurrence histograms of schools of juvenile northern squawfish over a range of depths and velocities and within given distances of other species of fish. Observations were made in the lower fastwater portion of the St. Joe River during summer low flows in 1980 and 1981. NF refers to no fish while other species include cutthroat trout (CT), dace (DC), redside shiners (RS: juveniles and adults only), other squawfish (SF: young, subadults, and adults only), suckers (SK), and white-fish (WF).

Figure 23




Frequency of occurrence histograms of schools of juvenile northern Squawfish over a range of proportions composed by each of four substrate particle size classes. Observations were made in the lower fastwater portion of the St. Joe River during summer low flows in 1980 and 1981. Sand is less than 0.1 cm in diameter, gravel is between 0.1 and 10 cm in diameter, cobble is between 10 and 30 cm in diameter, and boulders are larger than 30 cm in diameter.

Juvenile squawfish were common in the shoreline, backwater, and sidechannel areas favored by young fish but, unlike young fish, also utilized pools and permanent sloughs. Areas preferred by juveniles tended to be deeper, farther from shore, and with a substrate including larger proportions of gravel and cobble than in areas preferred by young. Juveniles, like young-of-the-year, preferred areas of little or no velocity. Redsided shiner subadults and adults commonly formed schools with juvenile squawfish and schools of juvenile suckers were often found nearby.

Observations made by Reid (1971) on juvenile squawfish in the St. Joe River agree with the habitat preferences determined in this study. Reid noted the majority of juvenile squawfish congregated over silt and sand substrates in sloughs where water temperatures were 2 to 6° C warmer than in the main river and in shallow pools near cover (typically boulders). Larger juveniles preferred deeper areas than did smaller juveniles and young fish. Boulders have also been reported to shelter concentrations of juvenile squawfish in riffle areas of the Clearwater River, Montana (Hill 1962). In Lake Washington, schools of juvenile squawfish congregated near cover in protected bays and sloughs (Olney 1975).

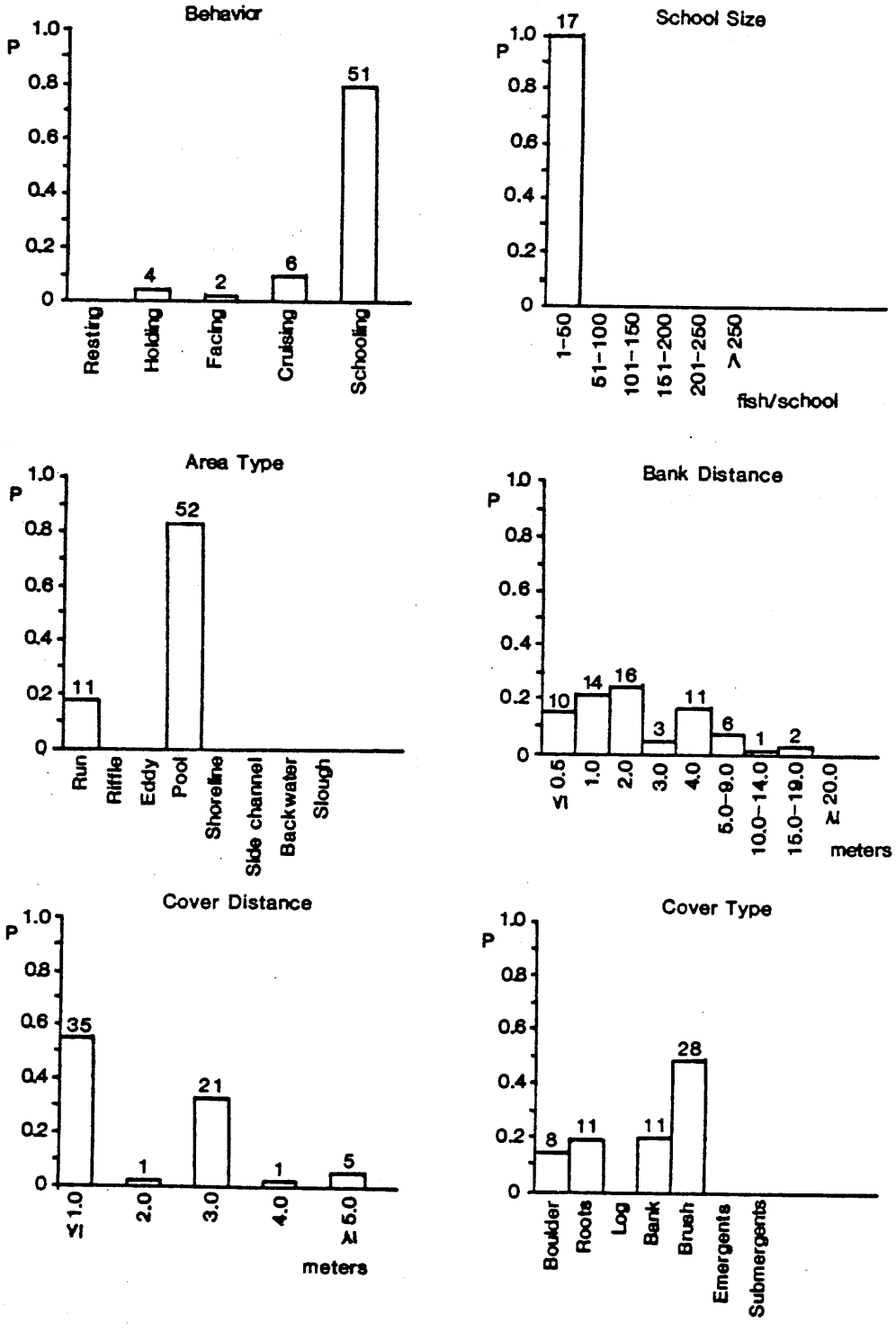
### Subadults

Subadults include fish in the 15 to 25 cm size range (Table 4 and Figures 24 through 26). Schooling tendency is reduced by the time fish reach this size. Eleven of 17 observations of subadults were of single fish. Schooling is still common, however, as most of the subadults seen were in the company of other subadults in groups of up to 15 fish. Most of the fish observed were cruising slowly, but a few were seen positioned into the current both about a fixed point (holding) and moving throughout a general area (facing).

While younger fish preferred backwater, side channel, shoreline, and slough areas, subadults preferred pools and slow runs in the main channel. Subadults were much less bank oriented than juveniles but a preference for overhead cover was still strong. Favored cover types included brush, roots, and boulders. In contrast to younger fish, subadults preferred areas of moderate depth, some velocity, and a substrate with large proportions of gravel, cobble, or boulder and little sand. Positions near but not on the substrate were preferred by subadults rather than in the middle and upper layers of the water column. Redside shiners and adult suckers were often observed in areas near subadult squawfish. Where those species were also present, squawfish were usually at least 1 meter away.

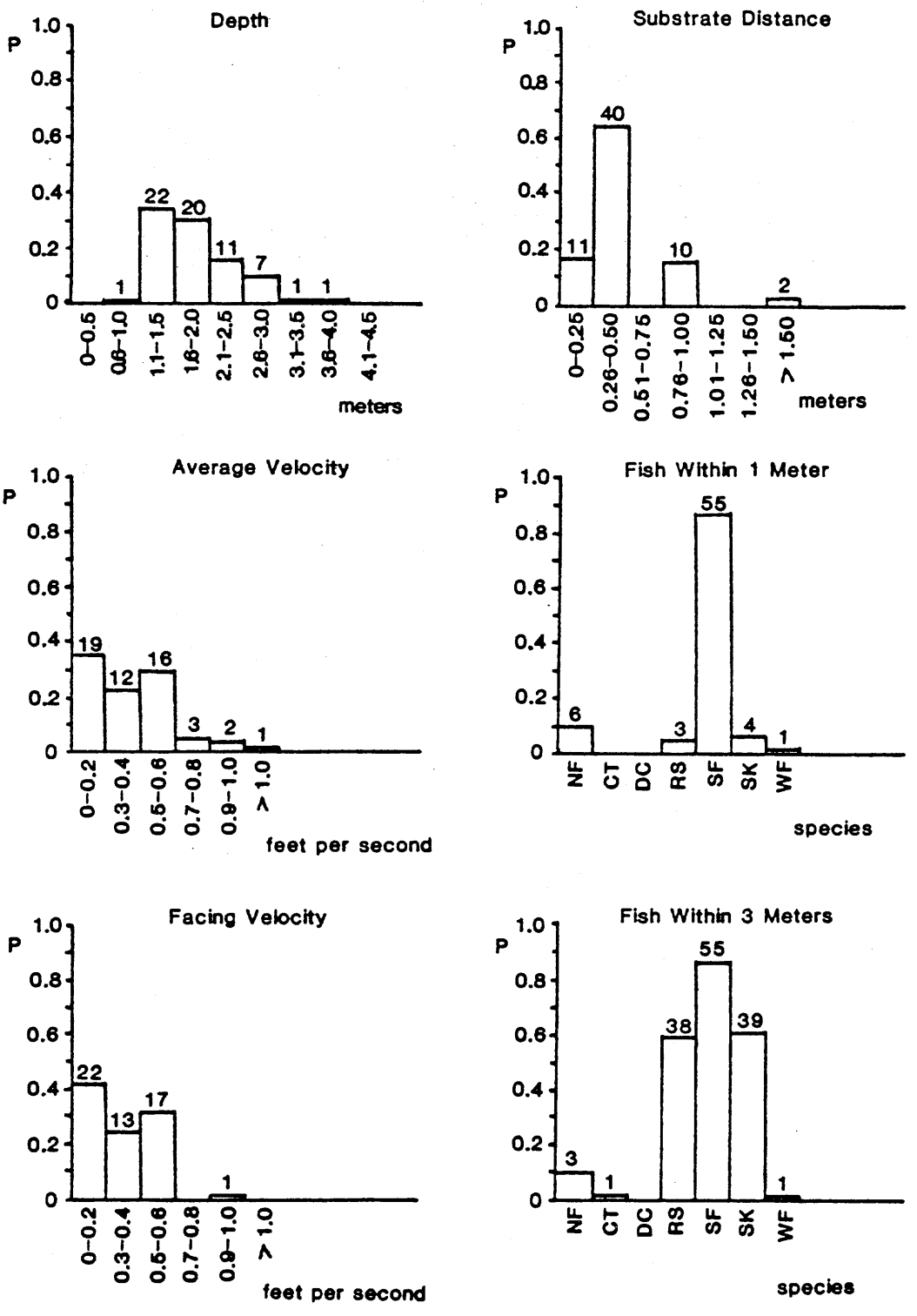
Observations of fish in the 15 to 25 cm size range were not common in the lower fastwater reach of the St. Joe River. Length frequency distributions of fish collected in the river by Reid (1971) with prima cord explosives and after chemical treatment (squoxin) in 1970 indicated subadults were scarce in the lower fastwater. Reid suggests these fish rear downstream in the slackwater and lakes of the Coeur d'Alene complex.

Figure 24



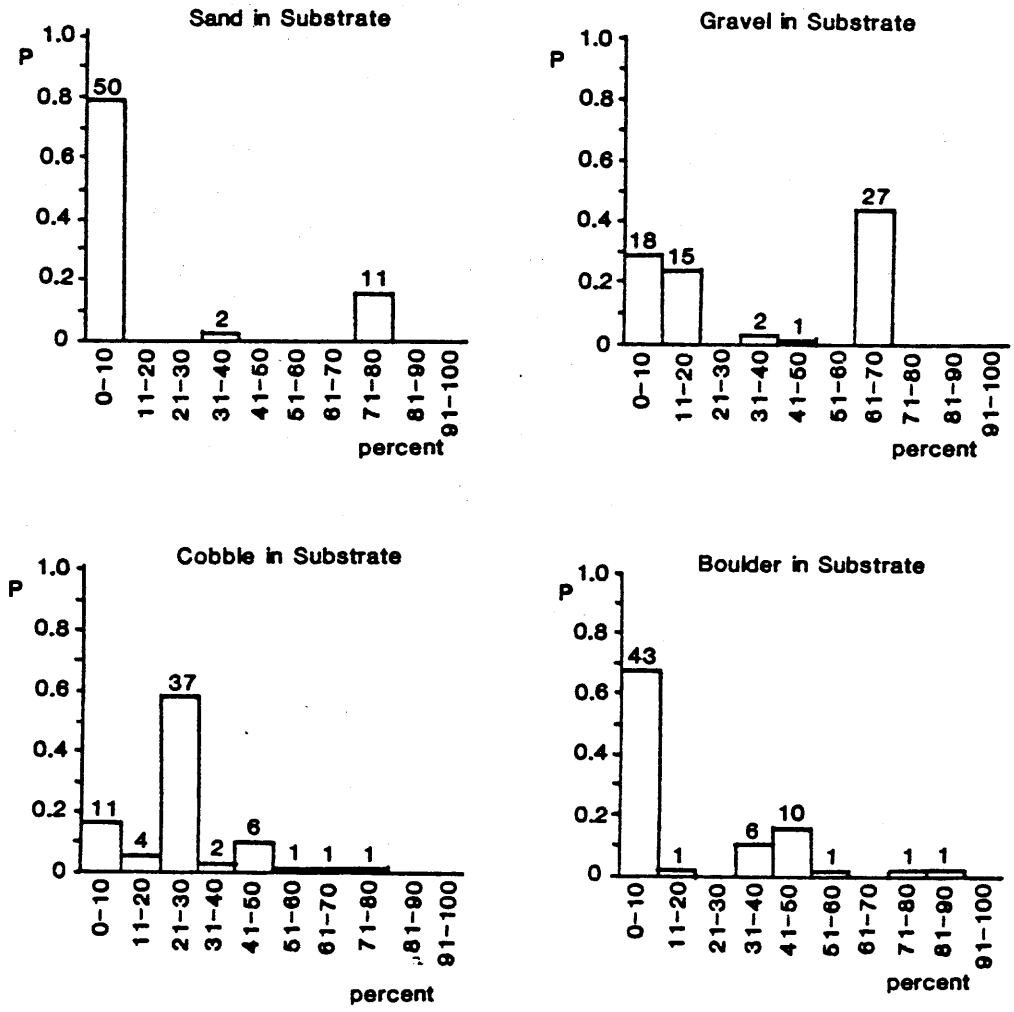

Frequency of occurrence histograms of subadult northern squawfish over a range of values for a series of behavioral and habitat characteristics. Observations were made in the lower fastwater portion of the St. Joe River during summer low flows in 1980 and 1981. "P" refers to the proportion of all observations falling within a given habitat characteristic stratum. Numbers above histogram bars are the number of individuals observed.

Figure 25




Frequency of occurrence histograms of subadult northern squawfish over a range of depths, velocities, and substrate distances and within given distances of other species of fish. Observations were made in the lower fastwater portion of the St. Joe River during summer low flows in 1980 and 1981. NF refers to no fish while other species include cutthroat trout (CT), dace (DC), redside shiners (RS: juveniles and adults only), other squawfish (all age groups), suckers (CK), and whitefish (WF).

Figure 26




Frequency of occurrence histograms of subadult northern squawfish over a range of proportions composed by each of four substrate particle size classes. Observations were made in the lower fastwater portion of the St. Joe River during summer low flows in 1980 and 1981. Sand is less than 0.1 cm in diameter, gravel is between 0.1 and 10 cm in diameter, cobble is between 10 and 30 cm in diameter, and boulders are larger than 30 cm in diameter.

One explanation for subadults rearing elsewhere is a lack of desireable habitat in the fastwater reach. In this case, the preferences noted in this study would be those of a small, nonrepresentative portion of the subadult population. Sampling bias may also have compounded the problem of a limited number of observations. Of all the types of areas in the river, snorkelers would be most likely to miss observations in the slow, deep pool areas near cover which most resemble the types of areas available downriver. Both of these factors must be considered when extrapolating the results of the subadults habitat preference portion of this study.

## Adults

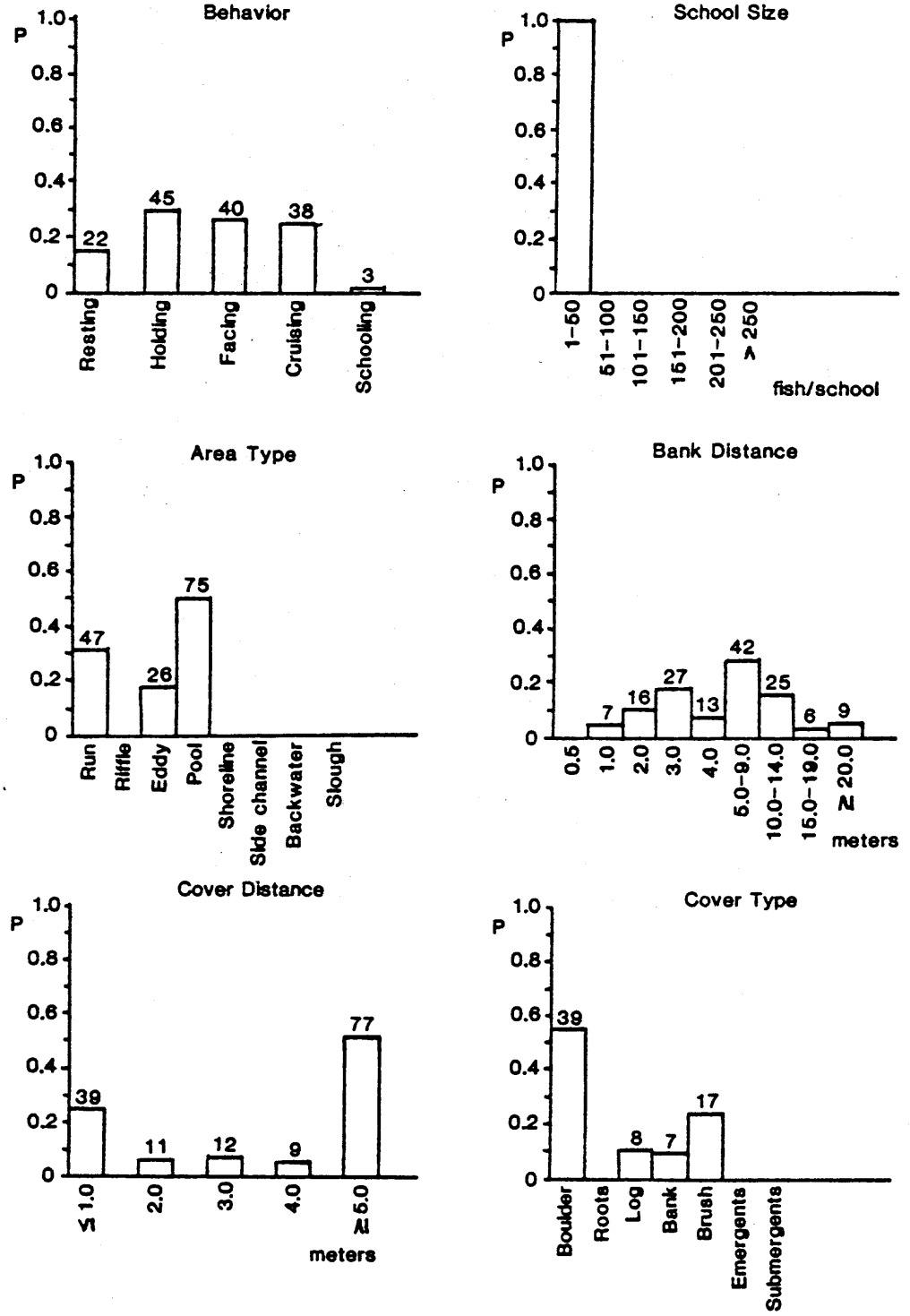
Most mature northern squawfish (Table 4 and Figures 27 through 29) were observed alone or in pairs. Fish sometimes aggregated in areas of favorable habitat but maintained discrete distances from one another. Behavior included holding, facing, slow cruising, and resting. Pools, slow runs, and eddies over a wide range of depths and average velocities were utilized but moderate depths and low to moderate velocities were preferred. A strong preference for the lower portion of the water column explains why facing velocities tended to be lower than average velocities. The substrate in preferred areas varied widely but usually consisted of a mix of gravel and cobble with smaller proportions of sand or boulder. Mature fish were much less likely to be found near shore or cover than were younger fish.

Adult suckers were almost always closely associated with mature northern squawfish. Adult whitefish were also common nearby, although areas preferred by whitefish appeared quite different than those favored by squawfish. Instances where whitefish and squawfish were associated occurred when areas preferred by each were adjacent. Other species of fish, including redside shiners and trout, were seldom associated with adult squawfish.

The preferences of adult northern squawfish reported in this study are similar to observations made by other authors. Reid (1971) found adult squawfish to be most abundant in deep, low velocity areas of the St. Joe River. Fish were captured in pools up to 12 feet (3.7 m) deep and in other areas of low gradient in the Big Blackfoot and Clearwater Rivers (Hill 1962). A preference for low gradient areas of the Willamette River has also been attributed to more optimum habitat conditions there than in areas of higher gradient (Buchanan et al. 1980).

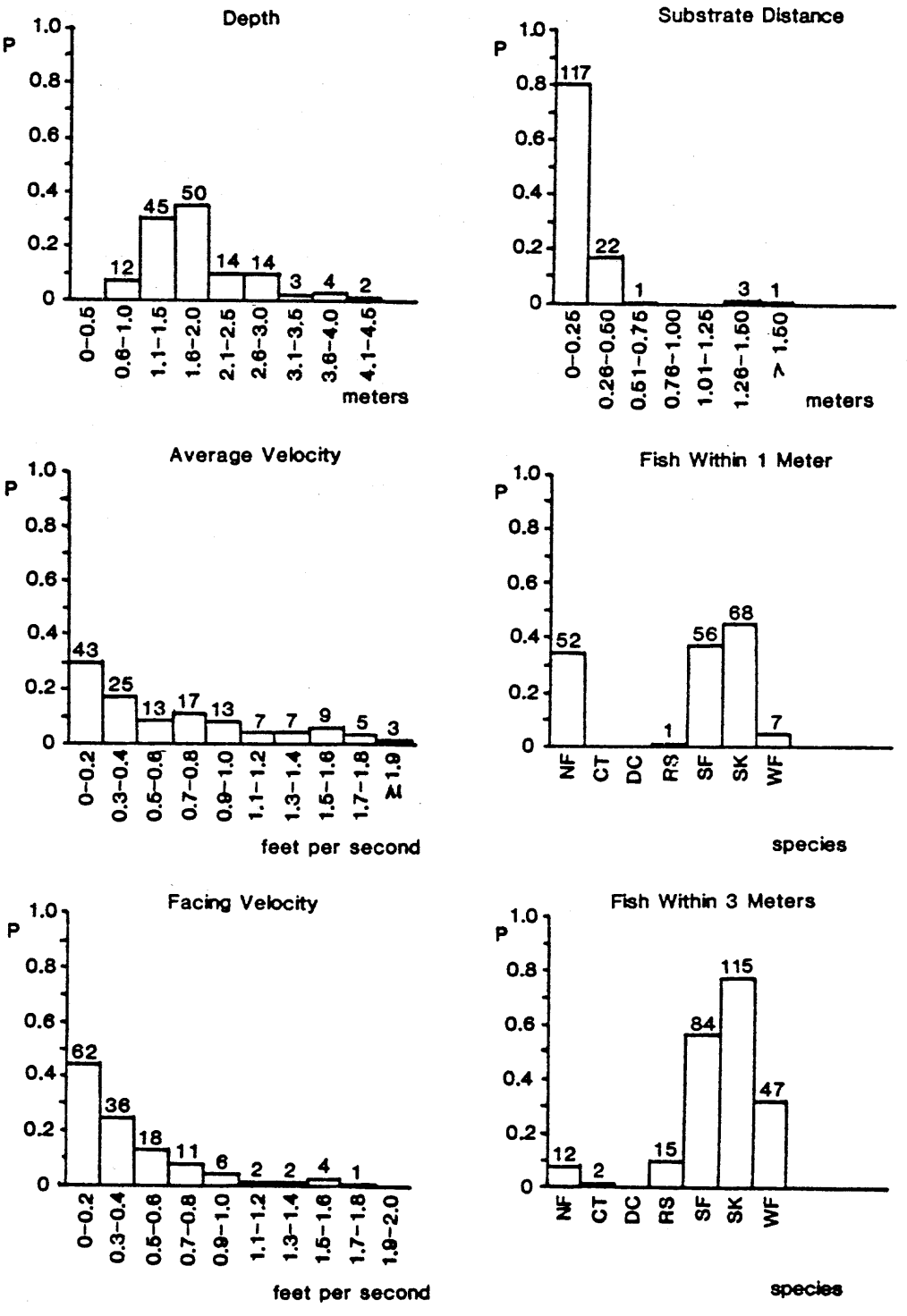
Preference determined here may be incomplete indicators of habitat utilization by northern squawfish. There is some evidence that habitats used during evening, night, and early morning hours are different from those frequented during the day. Gill nets set during this study in areas where fish were seldom seen during the day often took adults. Falter (1969) reported that squawfish moved into riffle areas to feed during the evening. Activity and feeding rates were both found to peak after dark in northern squawfish in two British Columbia lakes (Steigenberger and Larkin 1974).

Figure 27



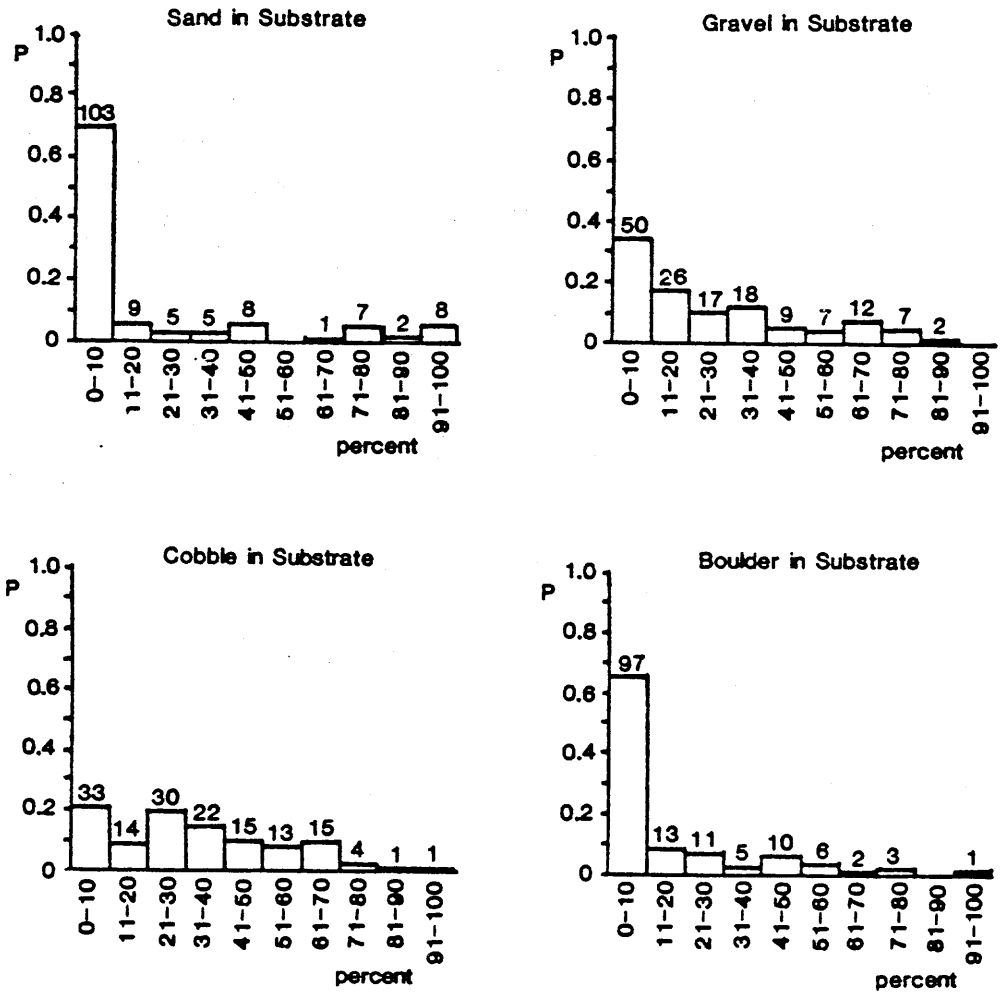

Frequency of occurrence histograms of adult northern squawfish over a range of values for a series of behavioral and habitat characteristics. Observations were made in the lower fastwater portion of the St. Joe River during summer low flows in 1980 and 1981. "P" refers to the proportion of all observations falling within a given habitat characteristic stratum. Numbers above histogram bars are the number of individuals observed.

Figure 28




Frequency of occurrence histograms of adult northern squawfish over a range of depths, velocities, and substrate distances and within given distances of other species of fish. Observations were made in the lower fastwater portion of the St. Joe River during summer low flows in 1980 and 1981. NF refers to no fish while other species include cutthroat trout (CT), dace (DC), redside shiners (RS: juveniles and adults only), other squawfish (SF: all age groups), suckers (SK), and whitefish (WF).

Figure 29




Frequency of occurrence histograms of adult northern squawfish over a range of proportions composed by each of four substrate particle-size classes. Observations were made in the lower fastwater portion of the St. Joe River during summer low flows in 1980 and 1981. Sand is less than 0.1 cm in diameter, gravel is between 0.1 and 10 cm in diameter, cobble is between 10 and 30 cm in diameter, and boulders are larger than 30 cm in diameter.

## EARLY LIFE HISTORY

### Methods

Areas of the lower fastwater of the St. Joe River where young squawfish were abundant were located at 1 to 2 month intervals beginning when fry first appeared in large numbers following the 1980 spawning. At each interval, at least 10 young-of-the-year squawfish were collected every 2 hours over a 24 hour period from an area deemed typical of habitat preferred by young at that time. Collections were initially made with fine meshed dip nets and later with a 30-foot by 4-foot beach seine (1/8-inch bar mesh). Fish were immediately preserved in 10 percent formalin. Complete samples were collected in July, August, September, and November of 1980 and June of 1981. Partial samples were collected in March and July of 1981. Sampling was suspended over the winter months because adequate numbers of fry could not obtained.

In the laboratory, approximately 200 of the preserved fish were measured (total length) and 100 were individually weighed (on a Mettler Balance to the nearest 0.0001 g wet weight) for each monthly sampling series. Ten fish were then selected from each complete sample according to the length-frequency distribution to give a sample representative of the sizes present in the population at the time of sampling. Hence, six fish of different lengths were selected from within one standard deviation of the mean length and two fish each were selected from lengths greater than and less than one standard deviation of the mean. Gut contents were removed and examined with a dissecting scope at a magnification of 20X.

Each food item was identified (according to Pennak 1978) and enumerated. The relative volume contributed by each prey item was estimated with a simple system adapted from Hynes (1950). A chydorid cladoceran 0.3 mm in length was taken as the standard for a volume of one unit or point. Larger prey items were assigned more points corresponding to the visually estimated difference in volume in comparison with the standard. Points were summed for each fish to provide an index of stomach content volume. The length of each prey item was also measured with an ocular micrometer.

### Results

#### Progression in habitat selection

Squawfish young-of-the-year first appeared along river margins near spawning areas while spawning was still in progress and became abundant by the time spawning ended. Within a month, young squawfish concentrated in the shallow, low velocity shoreline areas described under Habitat Selection. Many of these areas were isolated from the main channel as river discharge decreased through August, trapping large numbers of young squawfish, suckers, and shiners. Isolated pools were typically

maintained by subsurface flows but were warmer than the main river and developed substantial growths of filamentous algae.

In late November, increases in river discharge flooded temporary sloughs and reclaimed isolated pools. Ice formed and thickened on remaining low velocity areas. High turbidities and flooding combined with ice cover to make young squawfish difficult to find. A few fish were observed in permanent sloughs and among flooded vegetation near areas frequented during the summer.

Few young squawfish were located in the lower fastwater in early April when effective sampling was again possible. Repeated sampling in June or July failed to locate significant numbers of age 1 fish in any areas of the fastwater. Young fish were common in a permanent slough near the head of the slackwater in March, but these fish may represent a portion of the population that reared in the slackwater rather than the lower fastwater. Whether the apparent decline in abundance of young squawfish in the lower fastwater was due to purposeful or accidental movements into slackwater areas or to some other factors such as heavy winter mortalities is unknown.

Other studies confirm that the incubation period of northern squawfish eggs is relatively short. Eggs removed from lower Columbia River squawfish and incubated at 18° C required four days to hatch (LaRivers 1962). Eggs spawned in Cocolalla Lake hatched in 7 to 8 days at 16 to 21° C (Jeppson 1957) and Payette River eggs hatched in 9 to 10 days at 10 to 16° C (Casey 1962). After hatching it is probable that northern squawfish larvae remain in the gravel for a week or so while the yolk sac is being absorbed (Miura 1962). After emergence from the substrate, larval fish drift with the current for some distance (Gale and Mohr 1978). Small fish began to appear in still water along the bank of the Payette River about 2 weeks after hatching (Casey 1962). During July and early August, there was a rapid migration of these small fish downstream into Cascade Reservoir. Late summer movements were reported in Nicola Lake; young squawfish dispersed from areas where they spent the early part of the summer after first appearing in early July (Miura 1962).

### Growth and development

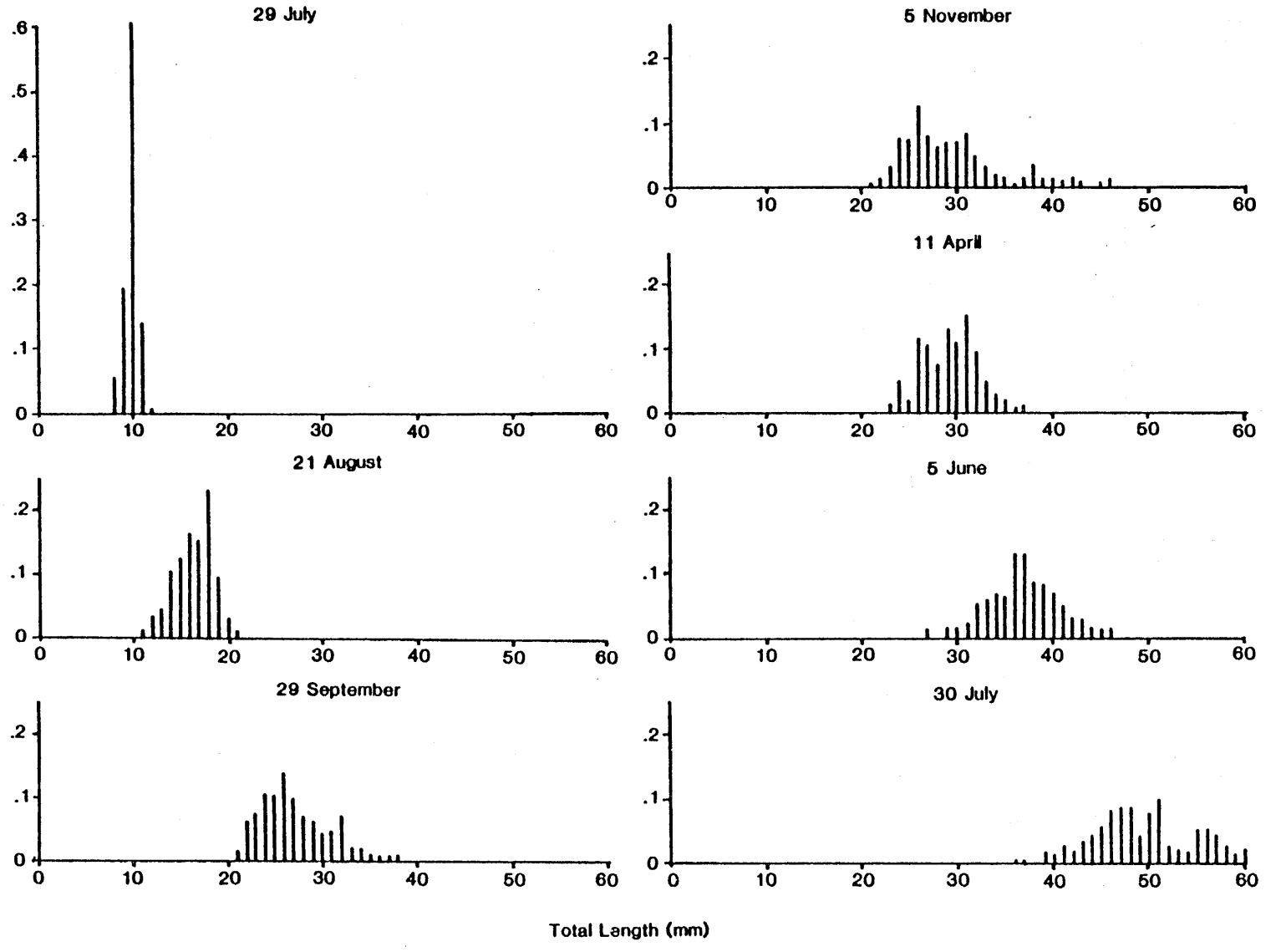
Young squawfish increased in length from an average of 10 mm on July 29, soon after they first appeared, to an average of almost 50 mm when one year old (Table 5). Frequency distributions gradually broadened as some fish grew more rapidly than others (Figure 30). By November, the largest young-of-the-year squawfish (45 mm) was over twice the length of the smallest (21 mm). The greatest rates of increase in length occurred early in the summer (Table 5). Rates remained high through September, but by November rates declined drastically. Increases in fish length again became apparent after April.

Increases in fish weight accompanied increases in length but at different rates. Rates of increase in weight remained low in August when rates of increase in length were greatest. After August, weight increases reached a relatively high rate that was sustained into November,

Table 5
Nominal growth in length and weight and length-weight relationship (preserved specimens) for young northern squawfish in the St. Joe River

| | Date of sample | | | | | | |
|---|---|---|---|---|---|---|---|
| | 29 July | 21 August | 29 September | 5 November | 11 April | 5 June | 30 July |
| Fish age (days) | 0 | 23 | 62 | 99 | 256 | 311 | 366 |
| Mean length (mm) with 95% confidence intervals | 9.84 (9.74, 9.94) | 16.36 (16.06, 16.66) | 27.15 (26.64 27.66) | 29.98 (29.23, 30.73) | 29.94 (29.44, 30.44) | 36.83 (36.31, 37.35) | 49.26 (48.38, 50.14) |
| Length range (mm) | 8-12 | 11-21 | 21-40 | 21-45 | 23-37 | 27-46 | 36-60 |
| Sample size | 209 | 199 | 212 | 211 | 136 | 214 | 136 |
| Growth (mm) per day since last sample | -- | 0.2873 | 0.2767 | 0.0765 | -0.0003 | 0.1253 | 0.2369 |
| Mean weight (g) with 95% confidence intervals | 0.006 (0.006- 0.007) | 0.040 (0.037- 0.044) | 0.173 (0.156- 0.190) | 0.300 (0.271- 0.328) | 0.207 (0.197- 0.217) | 0.472 (0.443- 0.501) | -- -- -- |
| Weight range (g) | 0.002- 0.015 | 0.009- 0.082 | 0.059- 0.515 | 0.073- 0.690 | 0.109- 0.358 | 0.204- 0.856 | -- -- |
| Sample size | 67 | 79 | 115 | 112 | 99 | 112 | -- |
| Growth (g) per day since last sample | -- | 0.0015 | 0.0034 | 0.0034 | -0.0006 | 0.0048 | -- |
| Slope (b) of length-weight function (log W = b log L + a) | 2.90 | 3.44 | 3.06 | 3.10 | 2.45 | 3.21 | -- |
| Intercept (a) of length-weight function | -5.15 | -5.70 | -5.21 | -5.21 | -4.28 | -5.42 | -- |
| Coefficient of determination ($r^2$) | 0.53 | 0.88 | 0.90 | 0.94 | 0.92 | 0.96 | -- |

Figure 30




Total length (mm) frequency distributions of northern squawfish sampled from the St. Joe River at intervals between emergence and one year of age.

even after rates of increase in length had declined. As with length, weight rates were high by June of the following year. Changes in the slope of the allometric length-weight function reflect these varying rates of length and weight change.

While it appeared that no increase in length occurred between November and April and some weight may have been lost during that period, it is probably not valid to compare growth parameters between the two dates as different groups of fish were sampled on each. Fish were collected from the fastwater prior to April but in the following months samples were taken from a permanent slough in the slackwater. A comparison of the length-frequency distributions of fish collected in November and April supports the possibility of differences in growth between the two groups. The November distribution is skewed toward smaller fish, but the April distribution approaches normality and large fish are absent.

Fins differentiated from fin folds at 13 to 15 mm in length. The gut began to fold at 15 to 17 mm in length and by 18 to 20 mm a black spot appeared at the base on the caudal fin. Scales first became apparent when fish reached 20 to 25 mm. Newly emerged squawfish, redside shiners, and suckers were all of similar length but suckers emerged earlier than squawfish and shiners evidently grew slower so that, by late summer, squawfish were intermediate in length between the larger suckers and the smaller shiners.

Lengths at age 1 of fish collected during this study are lower than those reported by Reid (1971) for St. Joe River squawfish at age 1 and are near the lower end of the range of lengths reported by age 1 fish of other populations (Table 6). These apparent differences are likely a result of the different methods of estimation used. Other studies refer to lengths at second annulus formation rather than at 12 months of age. Length at the end of one summer (30 mm) was similar to that of fish from Cascade Reservoir (30 mm; Casey 1962) but less than that of Placid Lake fish (53 mm; Hill 1962). Changes in morphology with development are the same as those reported in detail by Miura (1962) and Casey (1962).

## Food and feeding

Food items utilized by squawfish during their first year in the St. Joe River included aquatic insects such as midge larvae, mayflies, caddisflies and stonefly nymphs, water boatmen, and springtails; terrestrial insects such as ants and midges; copepod, cladoceran, and amphipod crustaceans; water mites, bivalves, earthworms, and rotifers. Most of these items occurred in small amounts (Table 7) in only a few fish (Table 8) while a few others comprised the bulk of the diet. The dominant food items were benthic forms, particularly chironomid larvae, although terrestrial and pelagic forms were important in a few cases.

The importance of different food items varied over the course of the year (Figure 31) as changes in habitat use and prey abundance within habitats affected the availability of food organisms and as fish became larger and were able to utilize a wider range of prey sizes. Feeding

Table 6
Average lengths at age 1 for fish from a number of northern squawfish populations

| Location | Length (mm) | Citation |
|---|---|---|
| Cascade Reservoir, Idaho | 73 | Casey 1962 |
| St. Joe River (males) | 66 | Reid 1971 |
| Lake Washington, Washington | 64 | Olney 1975 |
| Clearwater River, Montana | 61 | Hill 1962 |
| St. Joe River (females) | 60 | Reid 1971 |
| Round Lake, Idaho | 60 | Howse 1966 |
| Seeley Lake, Montana | 56 | Hill 1962 |
| Alva Lake, Montana | 53 | Hill 1962 |
| St. Joe River | 49 | This study |
| Woods Lake, British Columbia | 49 | Clemens et al. 1939 |
| Okanogan Lake, British Columbia | 46 | Clemens at al. 1939 |

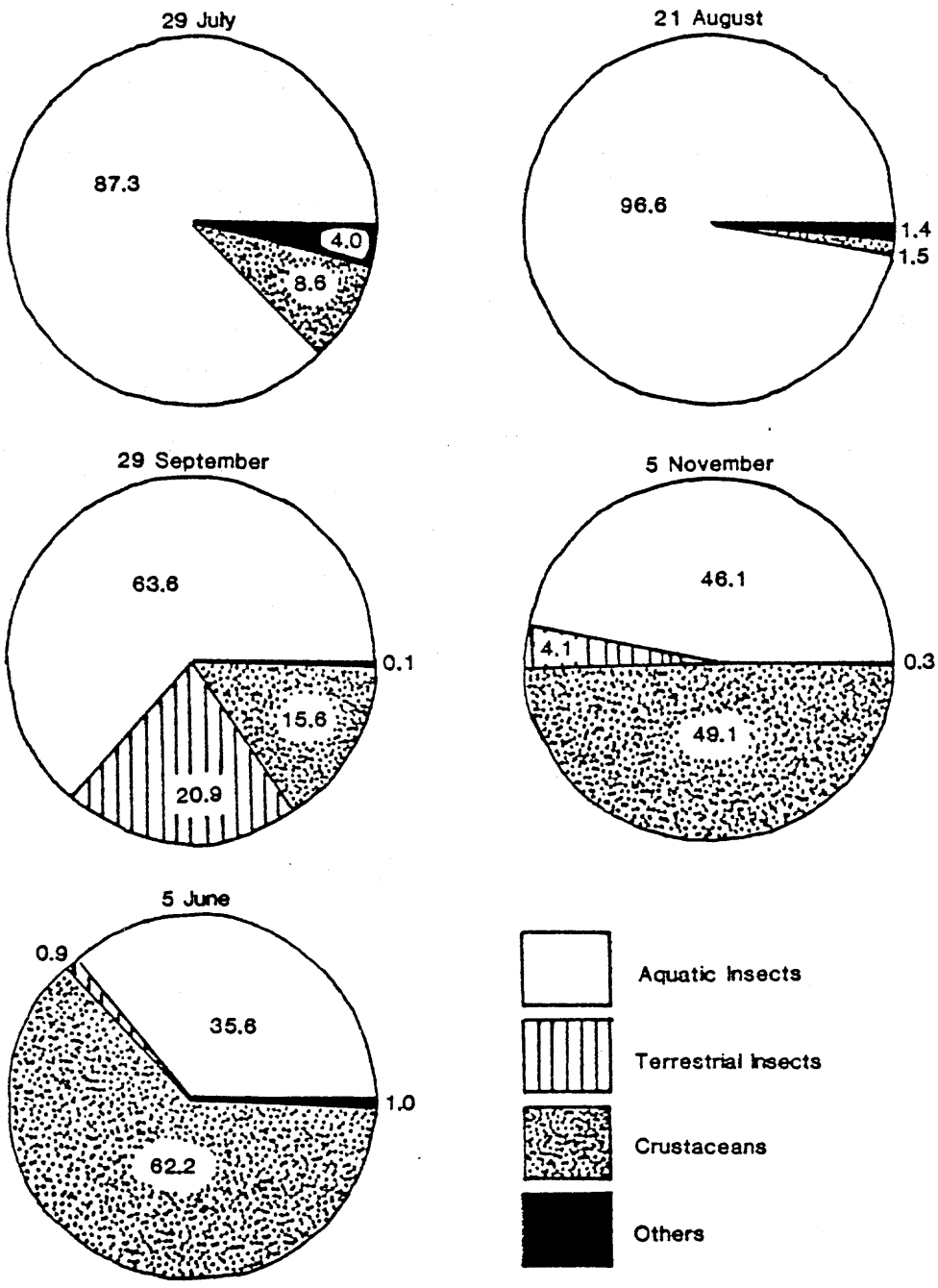
Table 7
Percentages by volume of food items of northern squawfish sampled from the St. Joe River during the first year of life

| | Date of sample | | | | |
|---|---|---|---|---|---|
| | July 29 | August 21 | September 29 | November 5 | June 5 |
| Aquatic insects | | | | | |
| Chironomidae (l) | 72.3 | 82.8 | 21.0 | 23.6 | 2.3 |
| Chironomidae (p) | 7.9 | 13.1 | 0.5 | 6.5 | 2.9 |
| Ceratopogonidae (l) | -- | 0.1 | 0.1 | -- | 0.6 |
| Unidentified lower dipteran (l) | -- | -- | -- | -- | 28.0 |
| Ephemerellidae (n) | -- | -- | 1.0 | 0.2 | -- |
| Leptophlebiidae (n) | -- | -- | 30.4 | 3.9 | -- |
| Leptoceridae (n) | -- | -- | 0.2 | 0.2 | -- |
| Unidentified plecopteran (n) | -- | -- | -- | 10.8 | -- |
| Corixidae | -- | -- | 0.8 | 0.1 | 0.2 |
| Others | 7.1 | 0.6 | 9.6 | 0.8 | 1.6 |
| Terrestrial insects | | | | | |
| Formicidae | -- | -- | 18.6 | 0.1 | -- |
| Chironomidae (a) | -- | 0.6 | 0.1 | 3.2 | -- |
| Others | -- | 0.1 | 2.2 | 0.8 | 0.9 |
| Crustaceans | | | | | |
| Copepod nauplii | 0.4 | -- | 0.0 | -- | 0.0 |
| Cyclopoid copepods | 4.6 | 1.2 | 4.0 | 13.0 | 1.9 |
| Calanoid copepods | -- | -- | 0.4 | -- | -- |
| Chydorus | 3.0 | 0.2 | 10.1 | 35.4 | 17.3 |
| Alonella | 0.6 | 0.1 | -- | 0.1 | 0.1 |
| Eurycercus | -- | -- | -- | -- | 5.4 |
| Ceriodaphnia | -- | -- | 1.1 | 0.6 | 36.3 |
| Daphnia | -- | -- | -- | -- | 0.0 |
| Scapholeberis | -- | -- | -- | -- | 1.2 |
| Amphipoda | -- | -- | -- | -- | 0.0 |
| Others | | | | | |
| Hydracarina | 3.4 | 0.2 | 0.0 | 0.0 | 1.0 |
| Pelecypoda | -- | -- | 0.0 | -- | -- |
| Oligochaeta | -- | 1.2 | -- | 0.3 | -- |
| Rotatoria | 0.6 | -- | 0.1 | -- | 0.0 |

Table 8
Percentage frequency of occurrence of food items in stomachs of northern squawfish sampled from the St. Joe River during the first year of life

| | Date of sample | | | | |
|---|---|---|---|---|---|
| | July 29 | August 21 | September 29 | November 5 | June 5 |
| Aquatic insects | | | | | |
| Chironomidae (l) | 86.7 | 77.5 | 54.2 | 75.8 | 35.8 |
| Chironomidae (p) | 6.7 | 25.8 | 1.7 | 18.3 | 17.5 |
| Ceratopogonidae (l) | -- | 0.8 | 2.5 | -- | 6.7 |
| Unidentified lower dipteran (l) | -- | -- | -- | -- | 30.8 |
| Ephemerellidae (n) | -- | -- | 1.7 | 0.8 | -- |
| Leptophlegiidae (n) | -- | -- | 20.0 | 5.8 | -- |
| Leptoceridae | -- | -- | 1.7 | 0.8 | -- |
| Unidentified plecopteran | -- | -- | -- | 19.2 | -- |
| Corixidae | -- | -- | 2.5 | 0.8 | 1.7 |
| Others | 13.3 | 1.7 | 26.7 | 8.3 | 10.8 |
| Terrestrial insects | | | | | |
| Formicidae | -- | -- | 22.5 | 0.8 | -- |
| Chironomidae (a) | -- | 0.8 | 1.7 | 12.5 | -- |
| Others | -- | -- | 4.2 | 1.7 | 7.5 |
| Crustaceans | | | | | |
| Copepod nauplii | 2.2 | -- | 1.7 | -- | 1.7 |
| Cyclopoid copepods | 15.6 | 10.8 | 39.2 | 81.7 | 34.2 |
| Calanoid copepods | -- | -- | 4.2 | -- | -- |
| Chydorus | 14.4 | 2.5 | 35.8 | 86.7 | 73.3 |
| Alonella | 2.2 | 0.8 | -- | 1.7 | 8.3 |
| Eurycercus | -- | -- | -- | -- | 30.8 |
| Ceriodaphnia | -- | -- | 5.8 | 6.7 | 80.0 |
| Daphnia | -- | -- | -- | -- | 0.8 |
| Scapholeberis | -- | -- | -- | -- | 3.3 |
| Amphipoda | -- | -- | -- | -- | 0.8 |
| Others | | | | | |
| Hydracarina | 18.9 | 3.2 | 0.8 | 1.7 | 23.3 |
| Pelecypoda | -- | -- | 0.8 | -- | -- |
| Oligochaeta | -- | 0.8 | -- | 0.8 | -- |
| Rotatoria | 2.2 | -- | 3.3 | -- | 1.7 |

Figure 31




Percentages of the diet contributed by different groups of organisms for northern squawfish sampled from the St. Joe River at intervals between emergence and one year of age.

began as soon as fish appeared along river margins in the spring and focused heavily on aquatic insects, predominantly chironomids. Mites and small crustaceans, including cyclopoid copepods and Chydorus, were also utilized to a limited extent. Diet remained similar through August until September, when terrestrial insects (mainly winged ants) and crustacean zooplankters, from the large populations which developed in the sloughs and pools frequented by young fish at that time, became important. The diet was much more varied in September than in previous months.

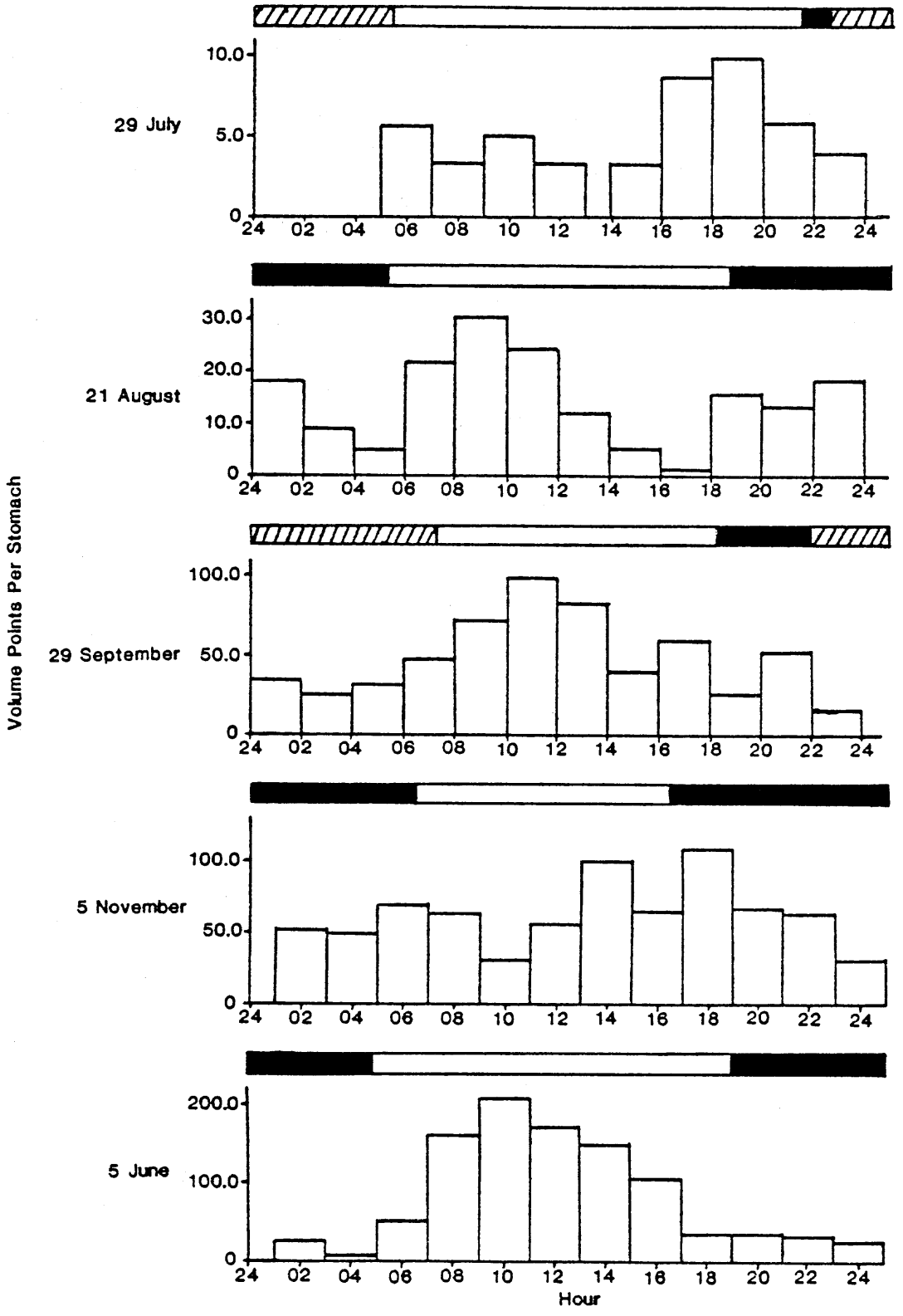
The diet was almost evenly divided between crustacean zooplankters and aquatic insects by November, with terrestrial insects and other organisms of little importance. As in September, the crustaceans were mainly cyclopoids and Chydorus, while a variety of aquatic insects was consumed. Crustaceans comprised the majority of the diet in June when fish were collected from among heavy growths of aquatic macrophytes in a permanent slough in the slackwater of the river. Aquatic insects made up the bulk of the remaining portion of the diet. A wide variety of crustaceans was consumed in June, including six genera of cladocerans. Only a few species of dipteran larvae were eaten, in contrast to the variety of insect species from different orders seen in the diet of fish from the fastwater during September and November.

Stomach fullness varied over the course of a diet cycle and different patterns were observed on different sampling dates (Figure 32). Fish taken in daylight collections contained more food than fish taken in night collections, although fish collected at night in August, September, and November contained significant amounts of food. As bright moonlight occurred on only one of those sampling dates, fish were apparently able to feed at night.

Peak fullnesses were observed in mid-morning and/or early to late evening. Only morning peaks were observed in the September and June samples while only evening peaks were apparent during July and November. Both morning and evening peaks occurred in August and the evening peak extended into the night. Feeding peaks coincided roughly with the daily formation and dispersal of schools of young squawfish. Schools broke up during hours of darkness and individual fish were often observed resting on or near the substrate. Schools reformed within a few hours of daybreak.

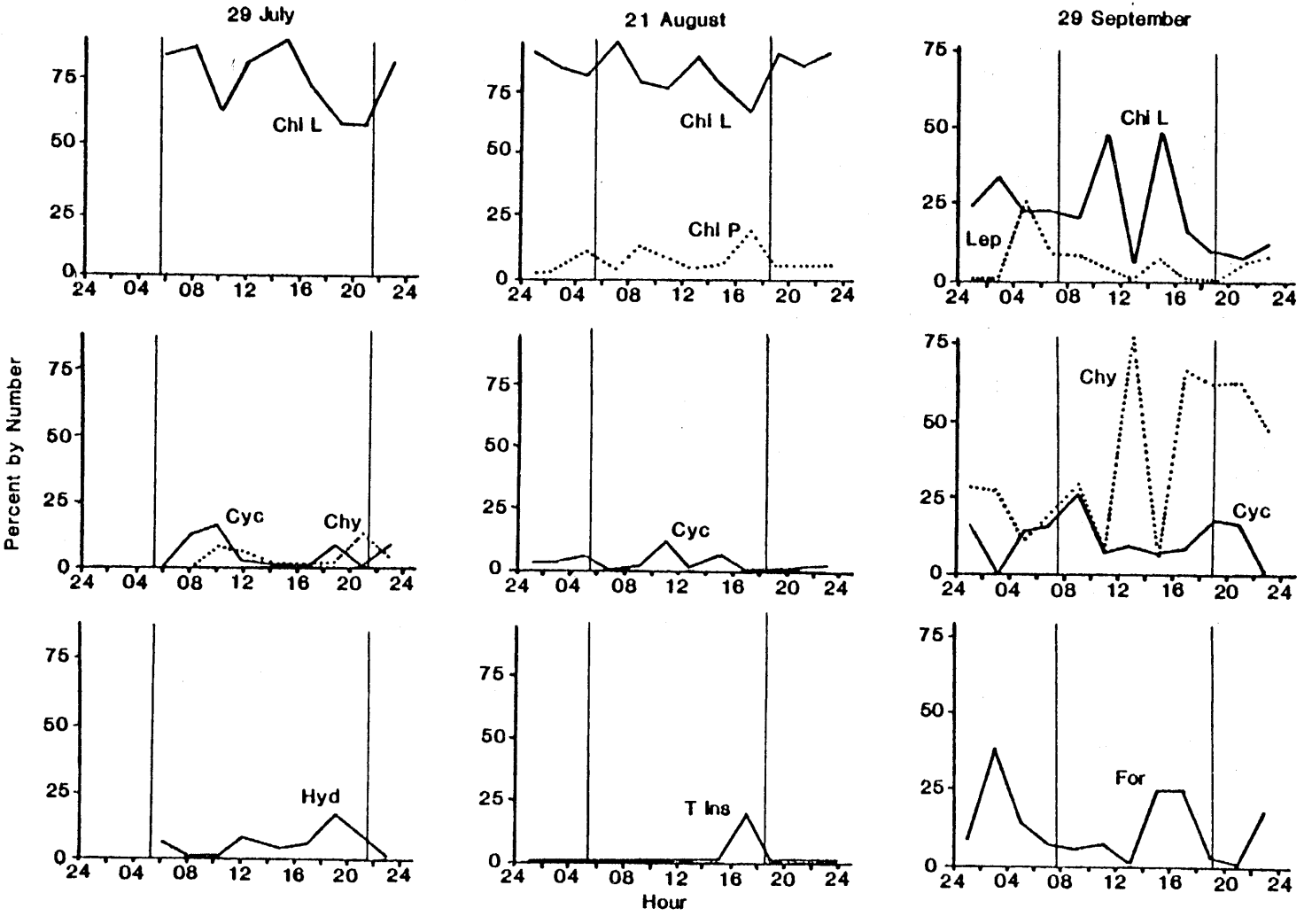
The numerical importance of diet items fluctuated widely over the course of each sampling date (Figures 33 and 34). Fluctuations followed discernible patterns during some sampling dates, as would be expected if fish ate different items as availability changed over the course of a day. On July 29, the importance of chironomid larvae declined in the early morning and evening when crustaceans and mites became significant. Seemingly random patterns were observed on other dates. For example, on September 29 peaks in abundance of chironomid larvae alternated from hour to hour with peaks in abundance of chydorids. Patterns of utilization of a given species also varied between sampling dates. On different dates chydorids were of greatest importance in the morning, evening, midday,

Figure 32



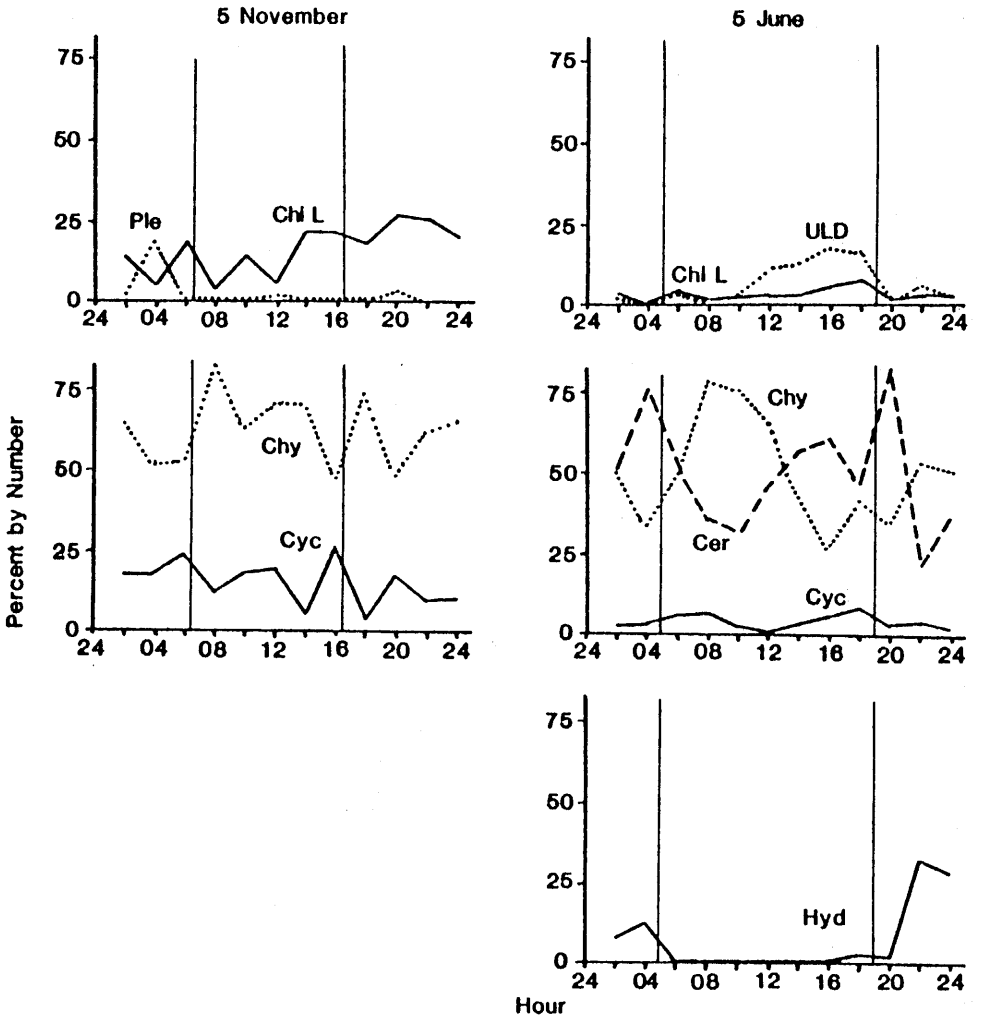

Stomach fullness expressed in volume points per stomach in comparison with hours of daylight (open bar), darkness (shaded bar), and bright moonlight (hatched bar) for samples collected at two-hour intervals on a series of dates between emergence and one year of age of northern squawfish from the St. Joe River

Figure 33




Fluctuations in the importance (expressed as a percentage by number) of major food items over the course of the day for St. Joe River squawfish on a series of dates between emergence and one year of age.

Figure 34




Fluctuations in the importance (expressed as a percentage by number) of major food items over the course of the day for St. Joe River squawfish on a series of dates between emergence and one year of age.

and after dark. These fluctuations may have resulted from a combination of small sample sizes and a tendency of individual fish to concentrate on a few items. A few fish gorging of a particular item could greatly alter the importance of that item in a 10-fish sample. This problem would be most acute later in the year, when larger fish were able to consume more items and diets were more diverse.

While the food habits of larger squawfish have been reported in the literature, few studies have included diet data for fish less than one year of age. Cladocerans, copepods, and chironomid larvae and pupae occurred most frequently in the digestive tracts of 15-to 50-mm squawfish from Lake Washington (Olney 1975). Cladocerans and copepods occurred less frequently in 50-to 100-mm fish while chironomids increased in importance. Fish appreared in the diet when squawfish were between 50 and 100 mm. The smallest squawfish containing another fish was a 55-mm individual containing an unidentified 10-mm fry.

Miura (1962) found copepods and cladocerands to be the dominant food items of squawfish young-of-the-year during the summer in Nicola Lake, although chironomid larvae were also present in appreciable numbers. Other insects, including both aquatics and terrestrials, were rare or absent. Pelagic rather than benthic organisms were most prevalent. The relative importance of different items changed over the course of the summer. Smaller, younger fish relied more heavily on smaller organisms including Bosmina, Chydorus, and copepod nauplii while larger, older fish preferred larger items such as Simocephalus and Leptodora. But contents of Nicola Lake squawfish reflected their behavior patterns: the total number of food items in the digestive tract increased during the day, when young squawfish moved into shallow water, and decreased at night, when fish moved offshore and remained inactive on the bottom. Plankton were eaten more frequently at dawn and early morning as fish consumed individuals that accumulated in the littoral zone during the night. Benthic organisms became more important later in the day after plankton supplies became depleted.

Nicola (1962) compared times of emergence, distribution and dispersal patterns, habitat preferences, and food habits of young-of-the-year of five species of fish which were commonly found in littoral areas of Lake Nicola during the summer. These species were northern squawfish, redside shiners, largescale suckers, peamouth chub (Mylocheilus caurinum), and prickly sculpins (Cottus asper). Competition for scarce planktonic crustaceans was thought to be severe among all species except sculpins during the few weeks in early summer when young-of-the-year concentrated in the same areas. All species had similar feeding habits, but competition was reduced somewhat by varying time of emergence. Shiners, for instance, did not appear until at least two weeks after squawfish. Dispersal and mortality decreased fry densities and differences in behavior and habitat preference increased spatial segregation as the summer progress. Rates of divergence between squawfish and shiners were high so that competition for food between these species was thought to be minimal by mid or late summer. By late summer, shiners preferred terrestrial organisms and upper portions of the water column rather than the planktonic organism and mid-column depths utilized by squawfish.

## LABORATORY BEHAVIORAL COMPARISONS

### Methods

Artificial stream channels already in place at the University of Idaho were used to compare habitat preferences, behavior, and response to potential competitors (redside shiners) of 1-year-old northern and Colorado squawfish. Two identical oval channels, 60 cm wide by 49 cm deep, each provided 10-meter sections of habitable area. Walls of clear plexiglass allowed observation of fish in the channels. Water from the channels was recirculated through a biological filter, where suspended solids and metabolites were removed, makeup water and oxygen were added, and temperature was adjusted to a constant 18° C (Figure 35). Flow through each channel was maintained by a paddlewheel rotated by a 0.5 horsepower electric motor. Each channel was illuminated for 12 hours daily.

Locations in each channel were described by coordinates based on distances from the upstream confinement screen and the inner channel wall. Upstream distances were marked for reference at 10 cm intervals on the inner wall of each channel. Distances from the inner wall were estimated in 15 cm increments. A grid of 425 points was thus described in each channel.

A variety of depths was provided by arranging substrate gravel (2- to 8-cm in diameter) into three 15- to 17-cm-high bars perpendicular to flow in both stream channels. Paddlewheel speed was fixed, but a range of velocities was provided by the varying depths. Shallower water resulted in increased velocity. Different arrays of depths and velocity combinations were presented in each channel by filling each with different amounts of water (Figure 36 and 37). Depths and average velocities (at 0.6 the depth) were measured with a calibrated rod and a Marsh-McBirney Model 201 electromagnetic flowmeter at each coordinate point in each channel.

Replicated observations of habitat preference were made under several sets of conditions (descibed below) by placing individuals of the same species (either northern squawfish or Colorado squawfish) in both channels; after all trials had been completed, fish were removed and individuals of the other species were introduced into the channels. Squawfish (northern squawfish n = 167, mean length = 61 mm; Colorado squawfish n = 140, mean length = 67 mm) were initially introduced in equal numbers into the upper and lower channels with paddlewheels turned off (zero velocity) and observed daily until they appeared to settle into a regular pattern of habitat use (10 to 14 days). The locations of all fish in each channel were then recorded on the coordinate grid during an arbitrarily chosen 20-minute observation period. The paddlewheels were then turned on, the fish were again observed until they had settled into a consistent pattern of habitat use, and a second set of observations was made by recording the locations of all fish as before. This two-step procedure was then repeated with the same squawfish after introducing

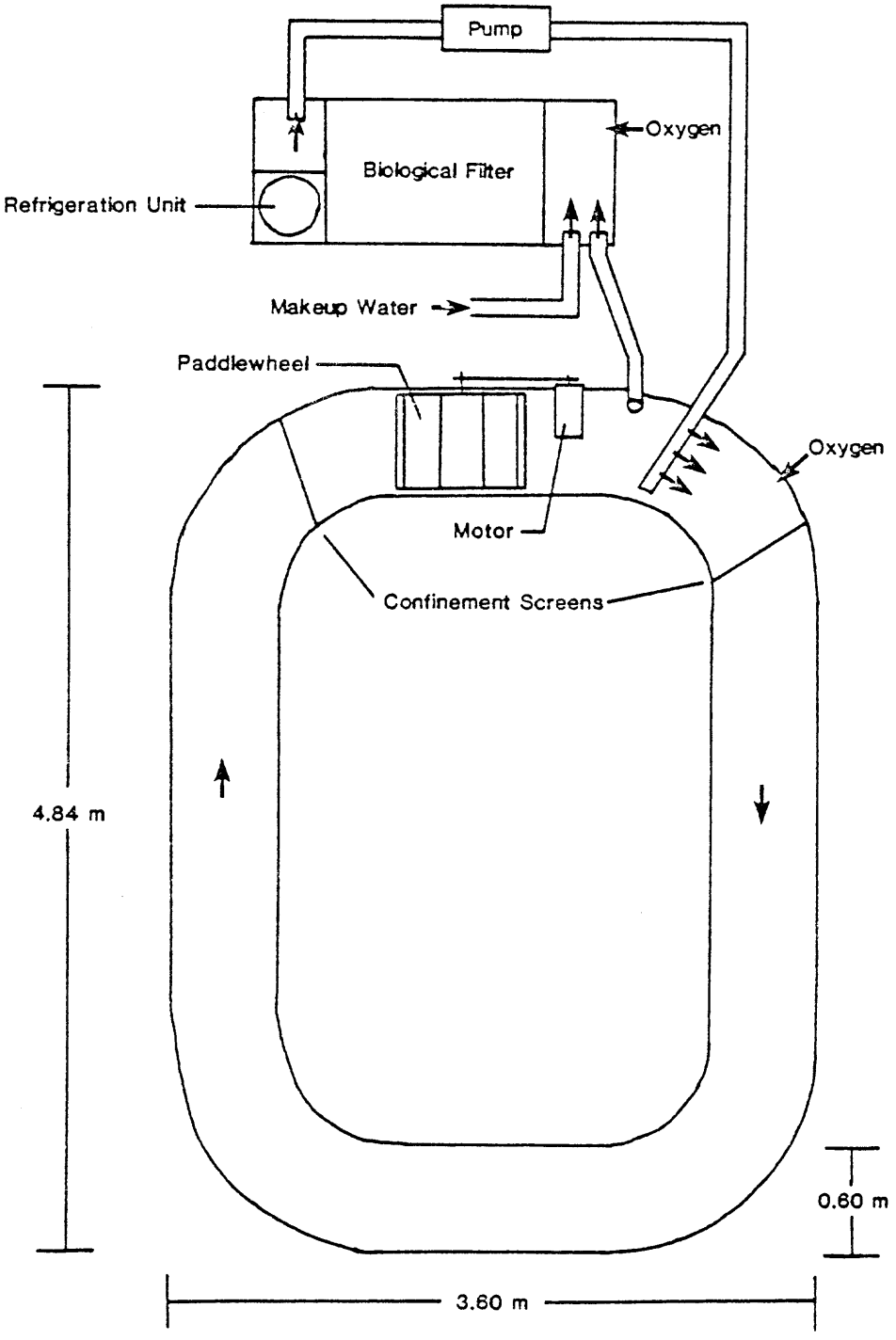



Figure 35

Configuration of the artificial stream channel system (only one channel shown). After Hahn 1977.

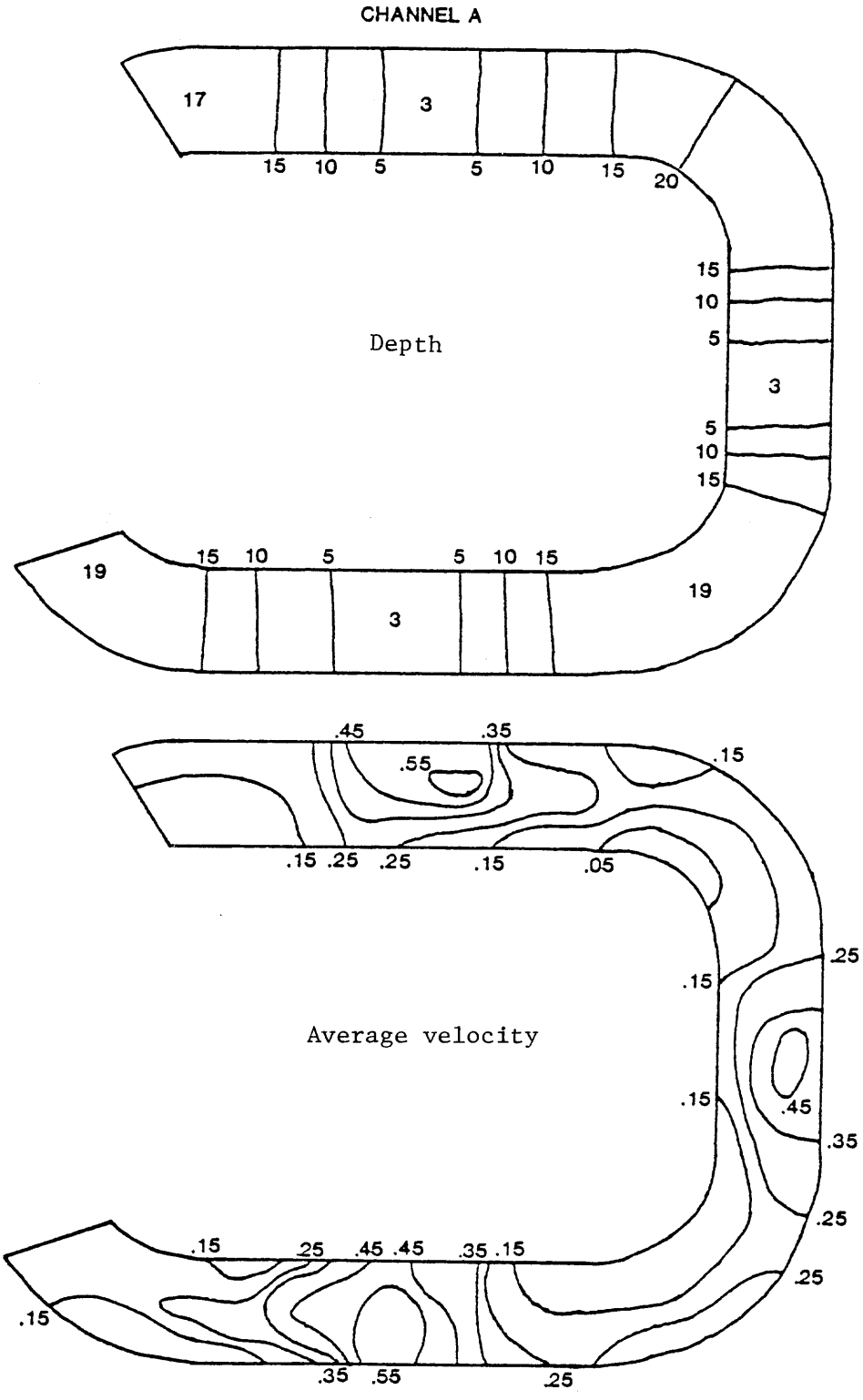



Figure 36

Depth (cm) and average velocity (fps) contours in artificial stream channel A.

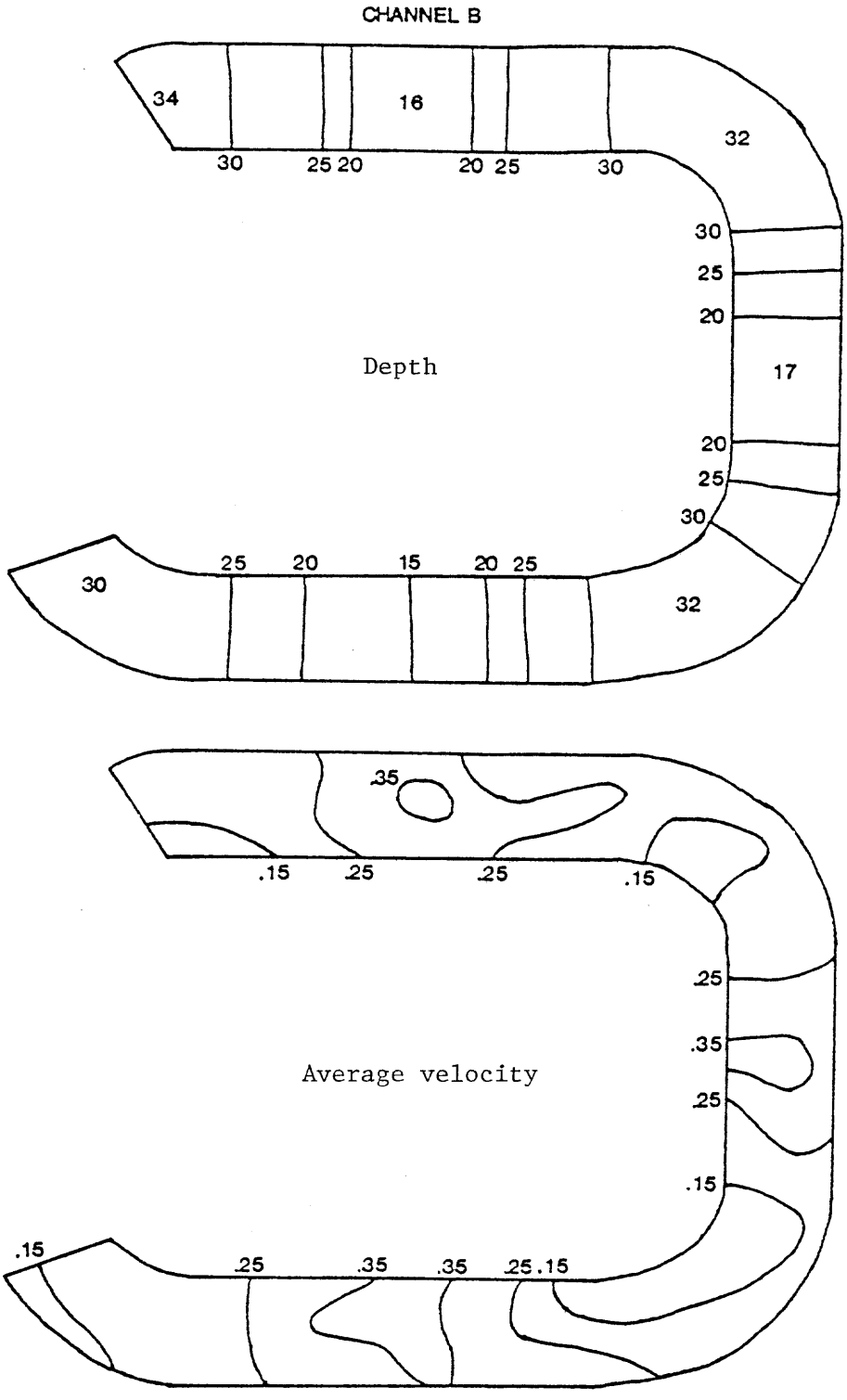



Figure 37

Depth (cm) and average velocity (fps) contours in artificial stream channel B.

redside shiners (55 age 0 shiners, $\bar{x}$ length 48 mm and 64 age 1 shiners, $\bar{x}$ length 78 mm) to the channels.

In summary, four sets of replicated observations (with and without) current; with and without redside shiners) were made with northern squawfish and then repeated with Colorado squawfish. The observations indicated the depths and velocities preferred by squawfish under each set of conditions, given the limited array of conditions available in the experimental channels. The preferences of northern and Colorado squawfish were compared to determine if they reacted similarly to the experimental conditions.

## Results

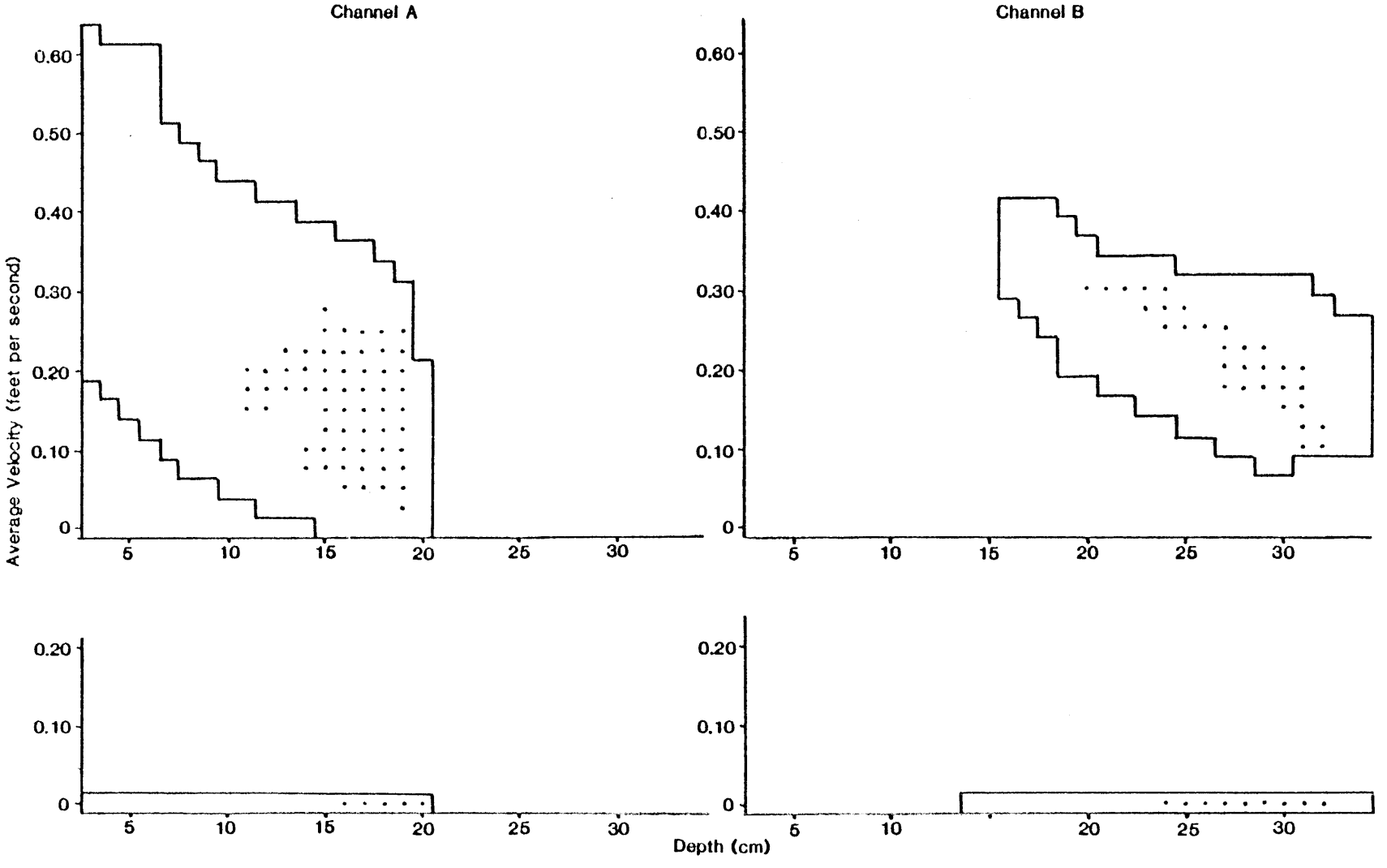
No important differences in habitat preference or behavior were observed between northern and Colorado squawfish. Both selected deeper areas in both channels when velocity was zero and both preferred deep, low velocity areas of each channel when paddlewheels were on (Figures 38 and 39). Northern squawfish may have been slightly more tolerant than Colorado squawfish of higher velocities in channel B when paddlewheels were on.

Both a northern and Colorado squawfish cruised in one or more schools back and forth between confinement screens when first introduced to channels and after paddlewheels were turned on. After acclimation, fish milled in schools near the substrate in fixed locations. Individual fish within the schools cruised slowly with frequent changes of direction, pausing often. No overt aggressive behavior was noted between fish in a school, but individual fish maintained discrete distances from each other, resulting in uniform spacing of fish within a school.

Very slight changes in habitat preference and behavior were noted in both northern and Colorado squawfish when redside shiners were also present (Figures 40 and 41). With shiners present, squawfish were less likely to be found in shallower, higher velocity areas. Squawfish of both species remained closer to the substrate than when alone and were more active and likely to cruise between pools rather than milling in one pool for long periods of time.

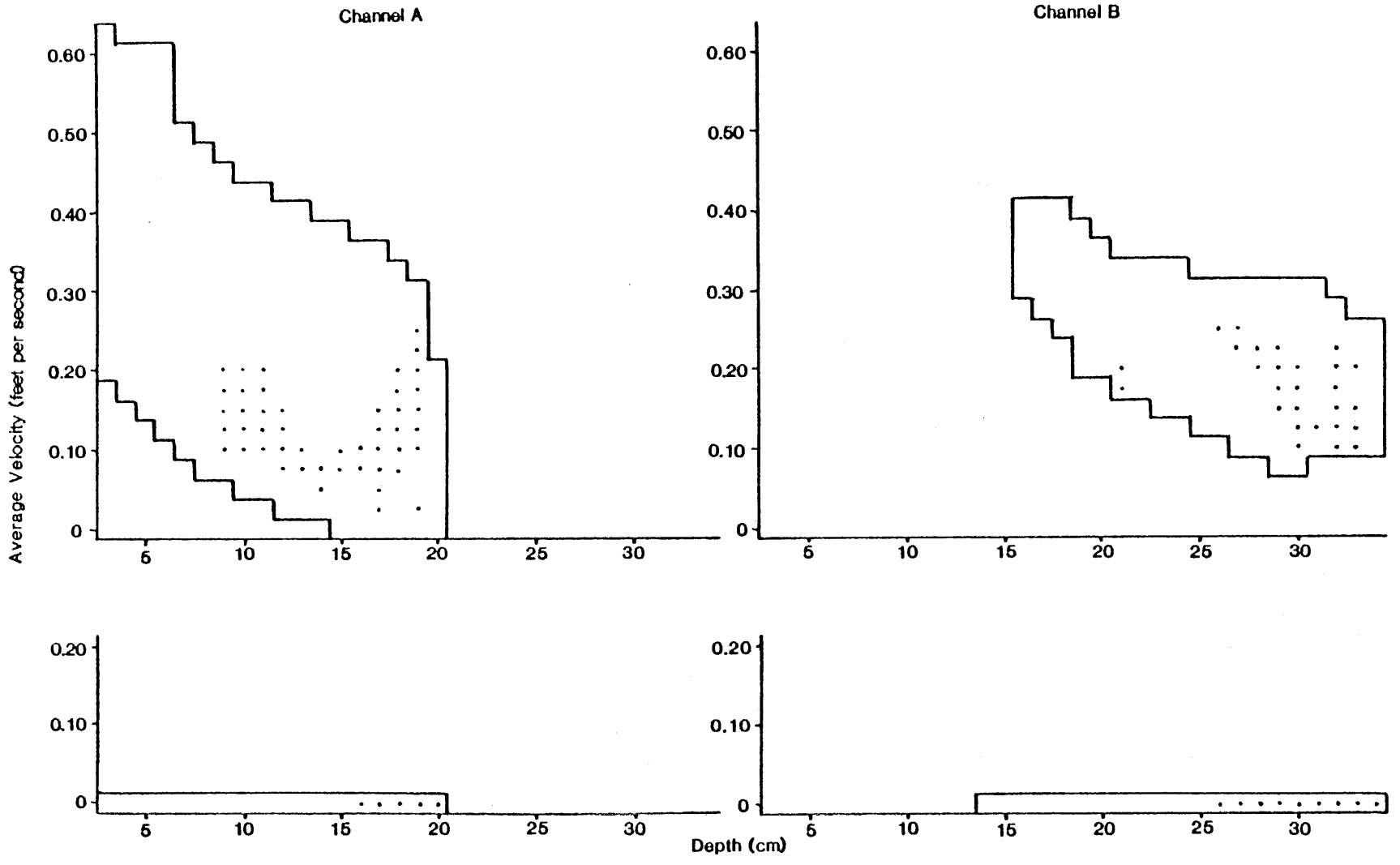
Redside shiners formed loose schools immediately above the squawfish schools. Larger shiners stayed a few centimeters above the squawfish; smaller shiners remained above the lateral to the larger redsides. Redsides also appeared to be more active than either species of squawfish. Age 0 shiners were likely to be found in the shallower, higher velocity areas, where squawfish were sometimes seen when no shiners were present.

Figure 38



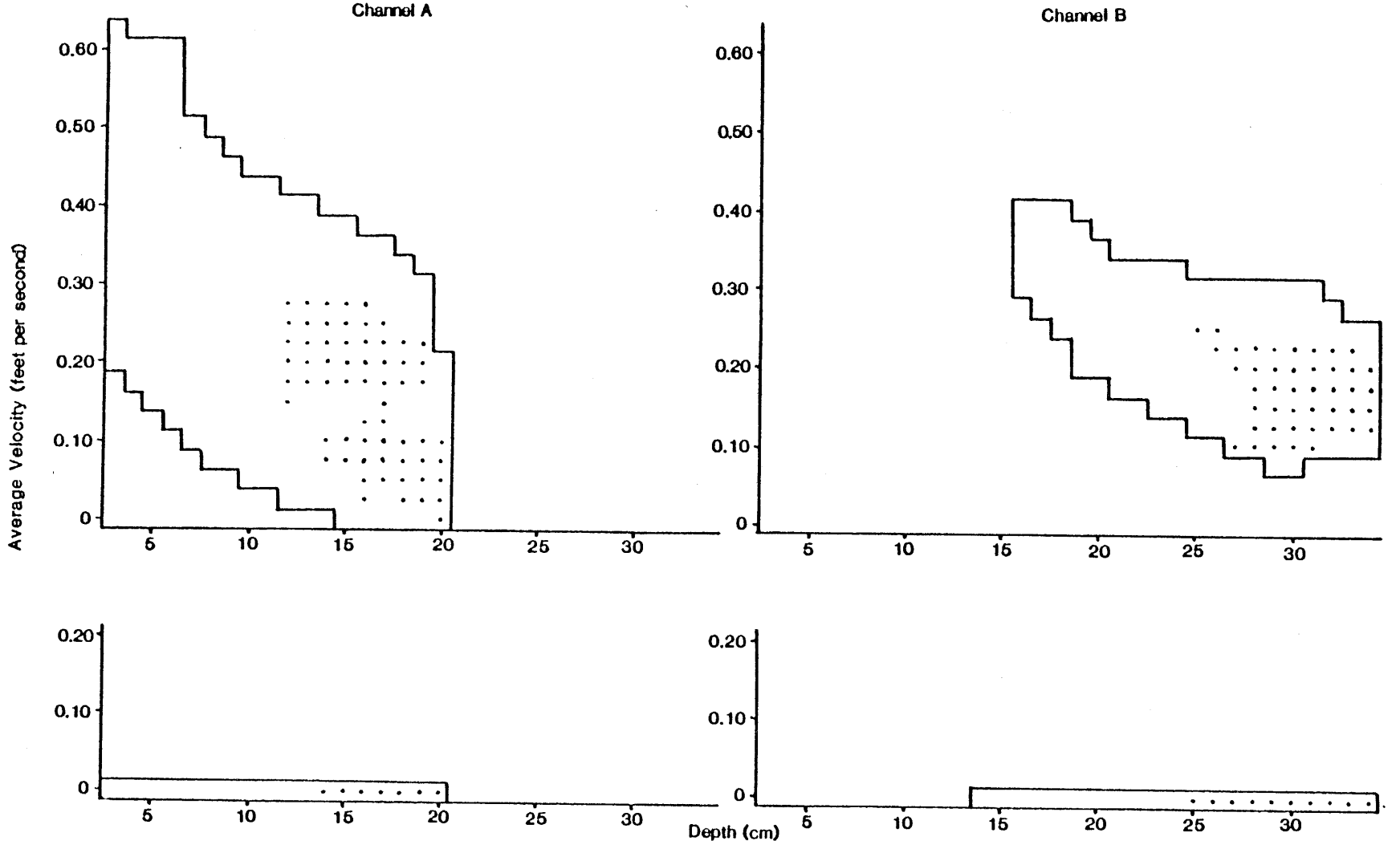

Depths and velocities (dots) preferred by northern squawfish in artificial stream channels. Depths and velocities available in each trial are outlined. Upper graphs refer to trials with paddlewheels on while lower graphs refer to trials with paddlewheels off.

Figure 39



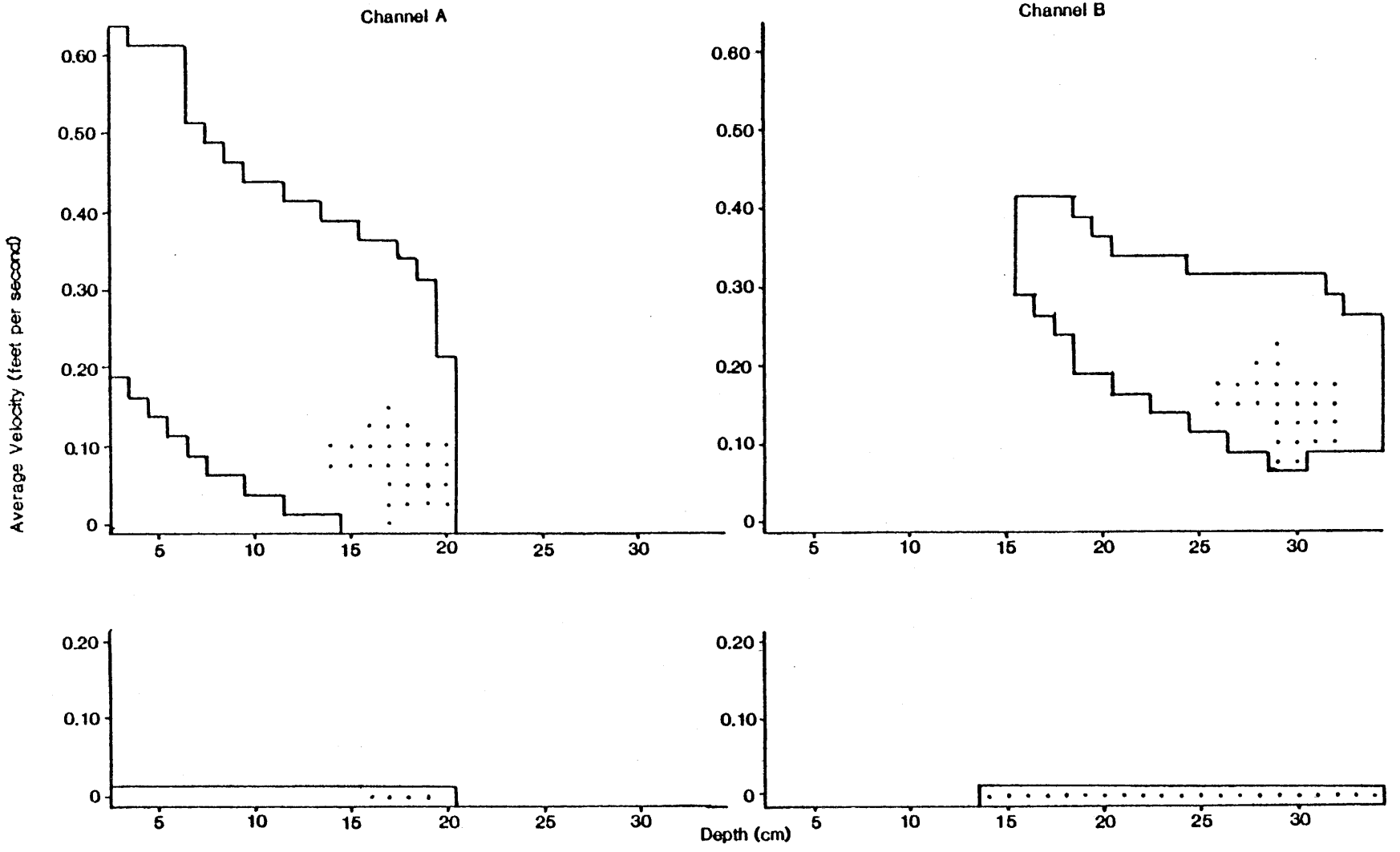

Depths and velocities (dots) preferred by Colorado squawfish in artificial stream channels. Depths and velocities available in each trial are outlined. Upper graphs refer to trials with paddlewheels on while lower graphs refer to trials with paddlewheels off.

Figure 40




Depths and velocities (dots) preferred by northern squawfish when redside shiners were also present in artificial stream channels. Depths and velocities available in each trial are outlined. Upper graphs refer to trials with paddlewheel on while lower graphs refer to trials with paddlewheels off.

Figure 41




Depths and velocities (dots) preferred by Colorado squawfish when redside shiners were also present in artificial stream channels. Depths and velocities available in each trial are outlined. Upper graphs refer to trials with paddlewheel on while lower graphs refer to trials with paddlewheels off.

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# APPENDIX A

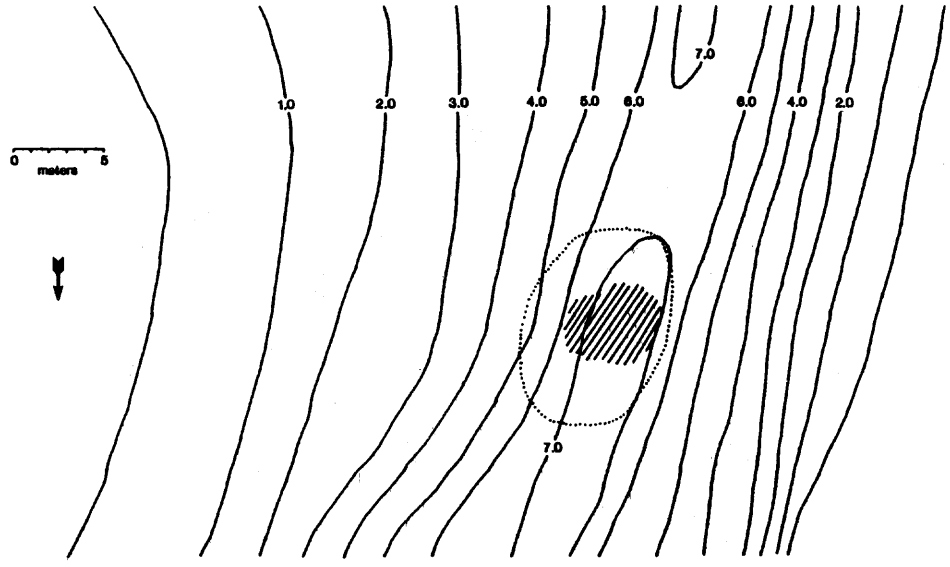
# ADDITIONAL SPAWNING SITE SELECTION INFORMATION

Table A-1

Average depth, current velocity, and substrate composition at nine northern squawfish spawning sites in the St. Joe River. Data were taken only from points on transects where spawning activity was observed

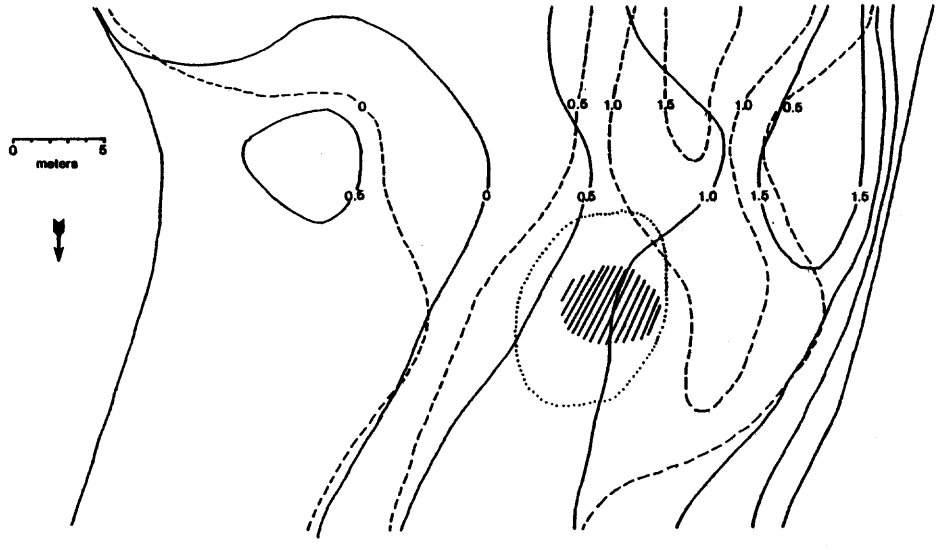
| Site number | River mile | Depth (m) | Velocity (f/s) | | | Substrate (percent) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Average | Bottom | Surface | Sand | Gravel | Cobble | Boulder |
| 1 | 34 1/4 | 7.0 | 1.8 | 0.8 | 1.0 | 0 | 70 | 30 | 0 |
| 2 | 34 3/4 | 6.1 | 1.5 | 0.8 | 1.1 | 0 | 70 | 30 | 0 |
| 3 | 39 1/2 | 1.3 | 2.1 | 0.6 | 2.8 | 0 | 47 | 49 | 0 |
| 4 | 41 | 1.7 | 4.7 | 0.2 | 5.4 | 0 | 50 | 50 | 0 |
| 5 | 45 | 6.0 | 1.1 | 0.4 | 1.0 | 0 | 60 | 40 | 0 |
| 6 | 46 1/4 | 3.0 | 3.3 | 1.4 | 4.5 | 0 | 53 | 47 | 0 |
| 7 | 50 | 3.2 | 1.6 | 1.3 | 1.5 | 0 | 35 | 65 | 0 |
| 8 | 51 | 9.5 | 0.4 | 0.6 | 0.7 | 0 | 70 | 30 | 0 |
| 9 | 51 1/2 | 5.6 | 0.7 | 0.6 | 0.6 | 0 | 43 | 57 | 0 |

Figure A-1




Depth (m) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 34¼

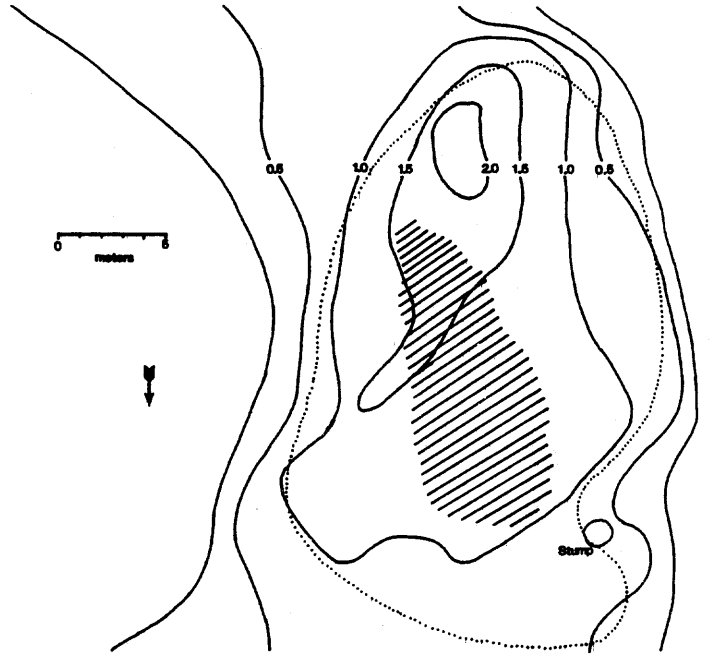
Figure A-2




Surface (solid lines) and bottom (dashed lines) velocity (feet per second) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 34¼

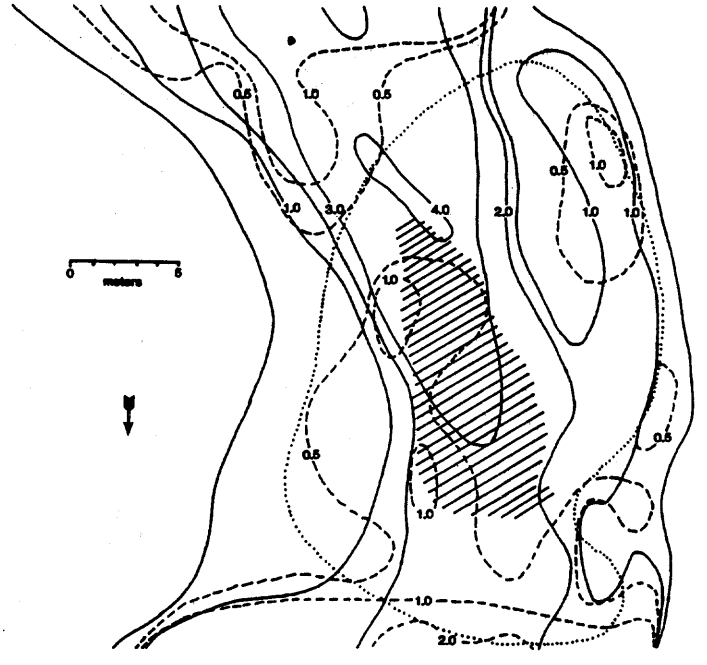
Figure A-3





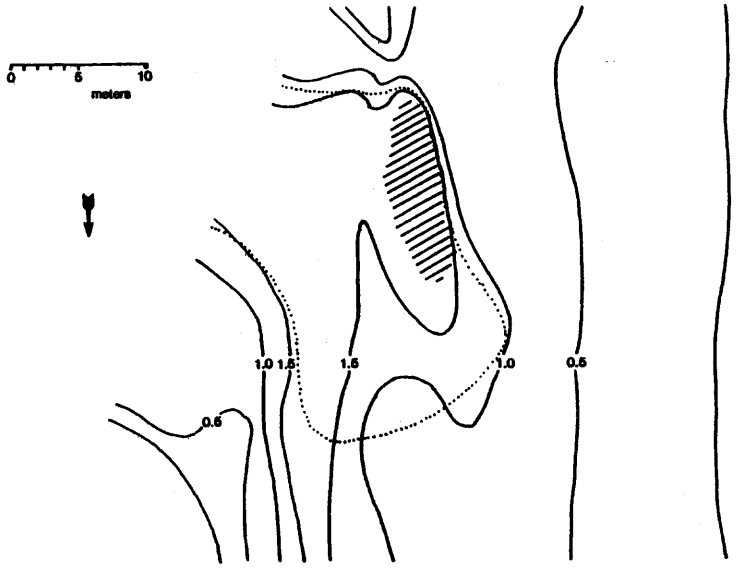

Depth (m) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 39½

Figure A-4



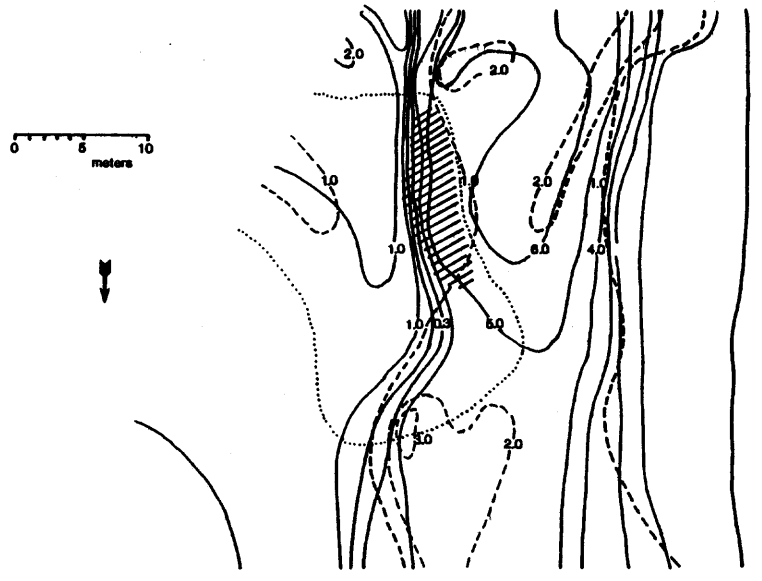

Surface (solid lines) and bottom (dashed lines) velocity (feet per second) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 39½

Figure A-5



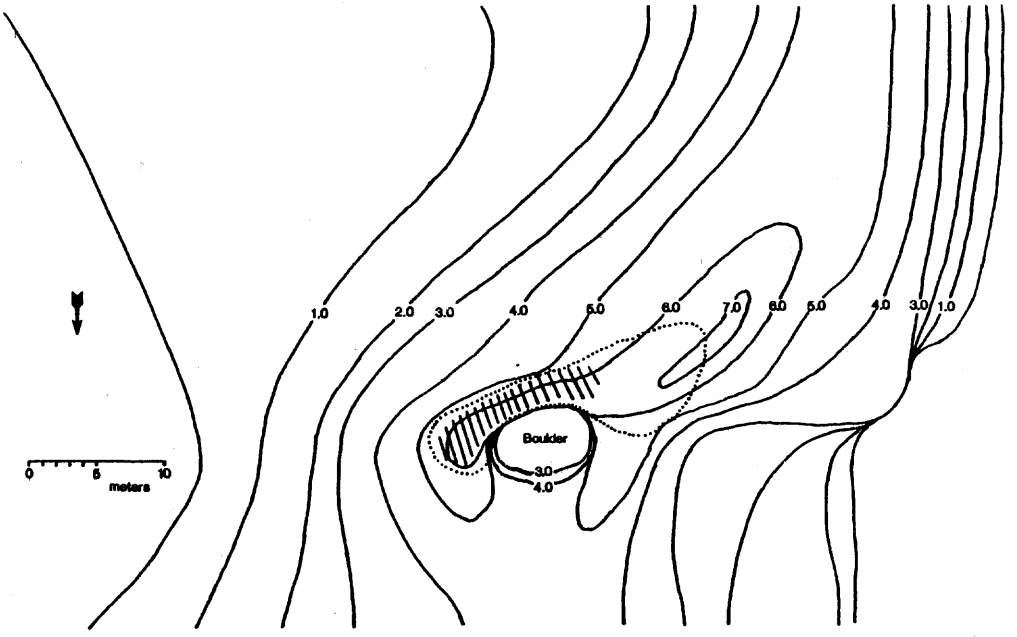

Depth (m) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 41

Figure A-6



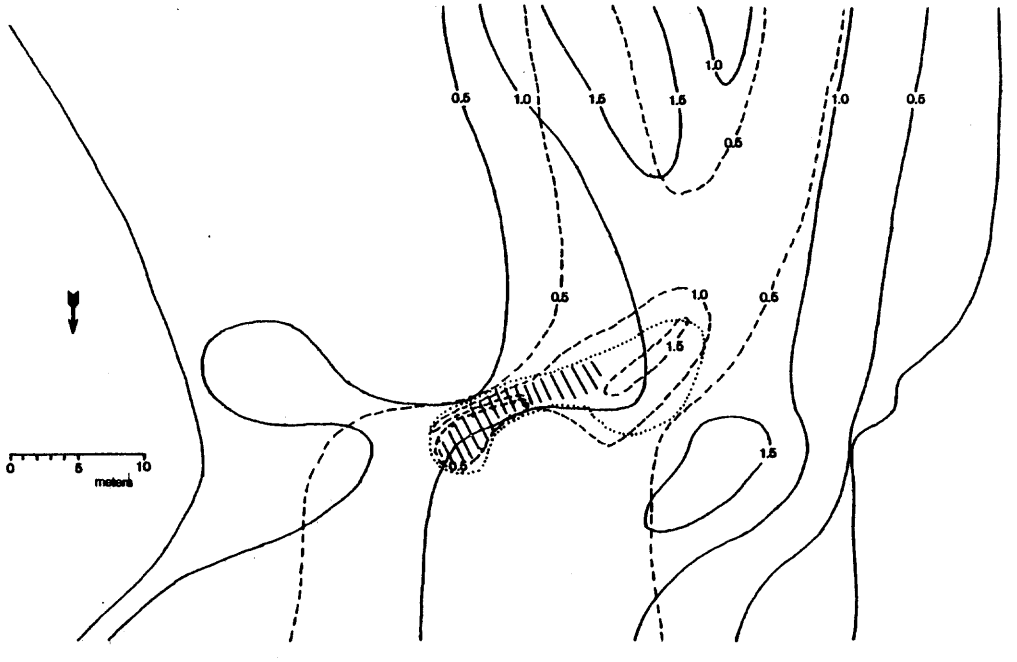

Surface (solid lines) and bottom (dashed lines) velocity (feet per second) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 41

Figure A-7



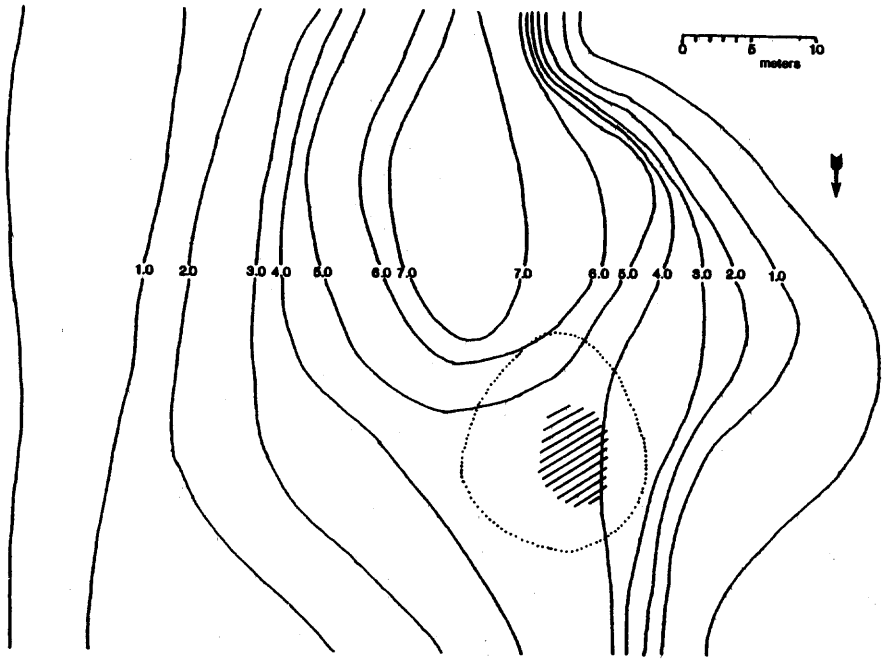

Depth (m) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 45

Figure A-8



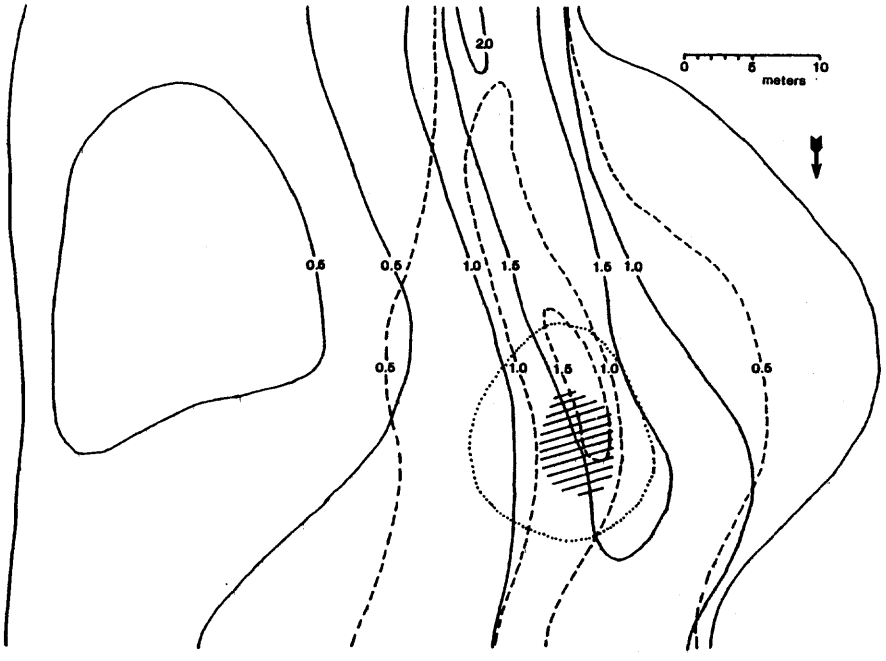

Surface (solid lines) and bottom (dashed lines) velocity (feet per second) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 45

Figure A-9



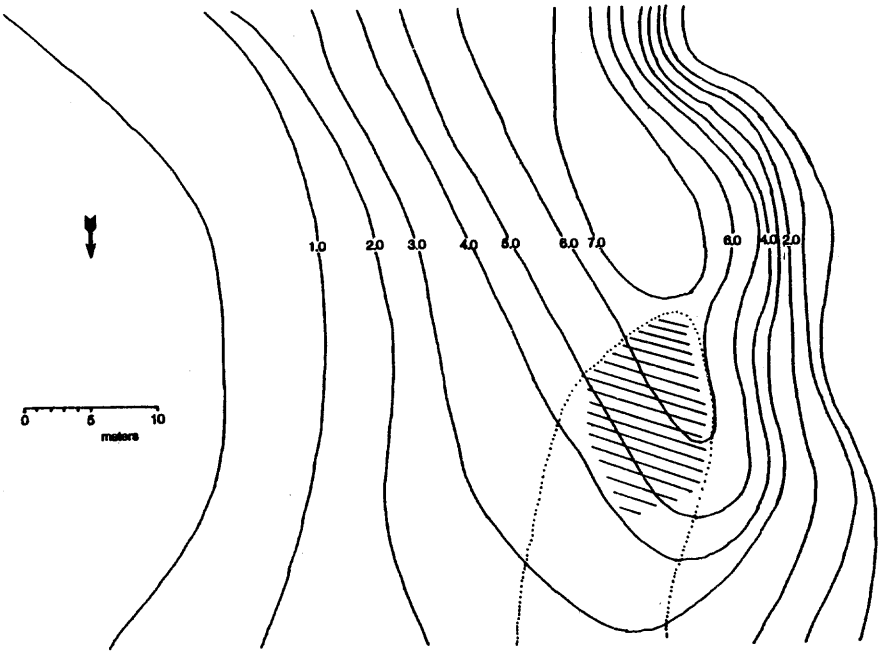

Depth (m) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 50

Figure A-10



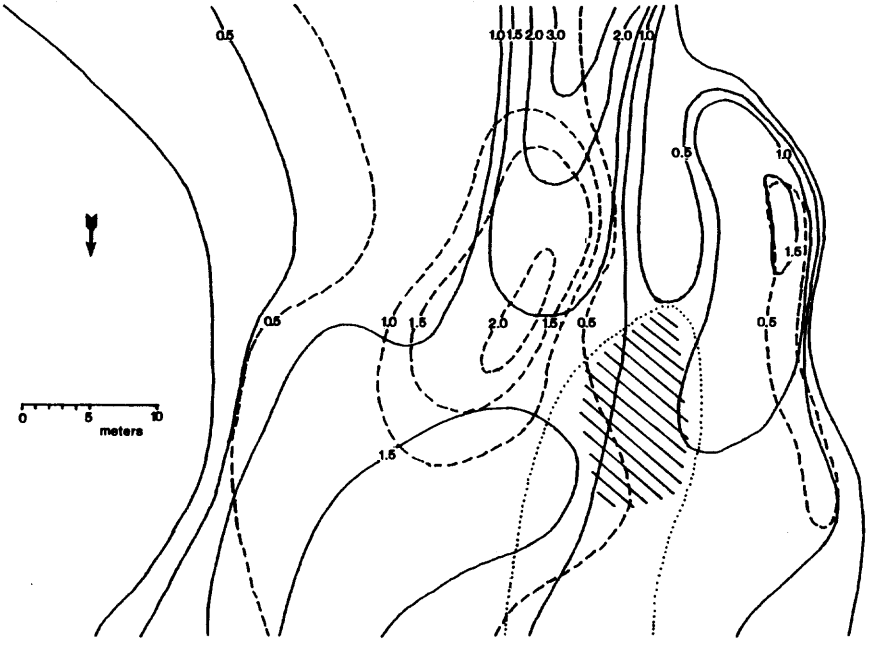

Surface (solid lines) and bottom (dashed lines) velocity (feet per second) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 50

Figure A-11




Depth (m) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 51½

Figure A-12




Surface (solid lines) and bottom (dashed lines) velocity (feet per second) contours in the vicinity of a squawfish spawning site at St. Joe River Mile 51½

# APPENDIX B

## HABITAT AND MICROHABITAT OBSERVATION DATA

Table B-1
Data conventions for northern squawfish microhabitat observations in the St. Joe River, Idaho, during summer low flows in 1980 and 1981

Size class - Estimated in 5 cm intervals.

Number of observations - Observations are by school for fish less than 15 cm in total length and by individual for fish 15 cm and longer.

Behavior includes:
- R - Resting with a minimum of activity on or near the substrate.
- H - Holding a position into the current about a fixed locus.
- F - Holding a position or a series of positions facing into the current in a general area without a single locus.
- C - Cruising within a general area.
- S - Cruising slowly with frequent changes of direction as part of a school.

Area type - Adapted from Archer, Tyus, and Valdez, these include:
- Run - A stretch of flowing water with a smooth, nonturbulent surface.
- Riffle - A shallow, fast flowing area where the water surface is broken into waves by obstructions wholly or partly submerged.
- Pool - A portion of the stream that is deep and slow-moving relative to the main current.
- Eddy - A portion of a pool where flow is reversed.
- Shoreline - Shallow, low-velocity waters next to shore.
- Side Channel - A channel which carries appreciable flow during high water and provides a low-velocity habitat during low flow.
- Backwater - A wholly or partially enclosed body of water off the main channel that exists only during low flows when former side channels or low lying areas are isolated.
- Slough - A wholly or partially enclosed body of water off the main channel that exists year round.

Substrate distance - Estimated in 0.05 meter increments. (Estimated only for fish 15 cm in length and longer.)

Overhead cover distance - Estimated in 1 meter increments for distances up to 5 meters. Greater distances are denoted by a capital N signifying no nearby cover.

Overhead cover type - Classifications include:
1. Boulders
2. Submerged root systems
3. Log
4. A steep, undercut, or heavily vegetated bank
5. Submerged brush
6. Emergent vegetation
7. Submergent vegetation

Bank distance - Estimated as one of the following distances or distance intervals (in meters): 0.5, 1, 2, 3, 4, 5-9, 10-14, 15-19, etc.

Table B-1, Continued
Data conventions for northern squawfish microhabitat observations in the St. Joe River, Idaho, during summer low flows in 1980 and 1981

Depth - Measured to the nearest 0.1 meter.

Average and facing velocities - Measured to the nearest 0.1 foot per second.

Substrate composition - Estimated by assigning approximate proportions (as a percentage) to each of four particle size classes:

| | |
|---|---|
| Sand | (<0.1 cm in diameter) |
| Gravel | (0.1 to 10 cm in diameter) |
| Cobble | (10 to 30 cm in diameter) |
| Boulder or bedrock | (>30 cm in diameter). |

Other fish - Estimates of fish numbers, age groups, and species within 1 and 3 meters of an observed squawfish. Three meter counts do not include any fish counted within 1 meter. Age groups include:

y - Young-of-the-year
j - Juvenile
a - Subadult or adult

Species include:
CT - Cutthroat trout
DC - Dace
RS - Redside shiners
SF - Squawfish (counts of squawfish in the same aggregation or school are included for adults and subadults but are not for young and juveniles)
SK - Suckers
WF - Whitefish

Table B-2
Microhabitat observations of northern squawfish in the St. Joe River during summer low flows in 1980 and 1981

| Size class | Number of fish | Behavior | Area type | Substrate distance | Overhead cover distance | Overhead cover type | Bank distance | Depth | Average velocity | Facing velocity | Substrate composition | Other fish within 1 meter | Other fish within 3 meters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| <5 | 50 | S | Backwater | -- | N | -- | 2.0 | 0.20 | 0 | 0 | 90,10,0,0 | 450 ySK | -- |
| | 5 | S | Backwater | -- | 0.6 | 7 | 0.3 | 0.10 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 10 | S | Backwater | -- | 0.3 | 5 | 0.3 | 0.03 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 10 | S | Backwater | -- | N | -- | 0.1 | 0.06 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 10 | S | Backwater | -- | 0.6 | 5 | 0.3 | 0.06 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 250 | S | Backwater | -- | N | -- | 1.0 | 0.09 | 0 | 0 | 100,0,0,0 | 250 ySK | -- |
| | 100 | S | Backwater | -- | N | -- | 3.0 | 0.15 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 2,500 | S | Backwater | -- | N | -- | 0.5 | 0.05 | 0 | 0 | 100,0,0,0 | 200 ySK | -- |
| | 1,800 | S | Backwater | -- | N | -- | 1.0 | 0.03 | 0 | 0 | 100,0,0,0 | 200 ySK | -- |
| | 200 | S | Shoreline | -- | 1.0 | 7 | 2.0 | 0.27 | 0.1 | 0.1 | 80,10,10,0 | -- | -- |
| | 100 | S | Shoreline | -- | N | -- | 2.0 | 0.24 | 0 | 0 | 85,5,10,0 | 10 ySK | -- |
| | 100 | S | Shoreline | -- | N | -- | 2.0 | 0.24 | 0 | 0 | 85,10,5,0 | -- | -- |
| | 200 | S | Backwater | -- | N | -- | 1.0 | 0.34 | 0 | 0 | 70,30,0,0 | | 100 ySK |
| | 20 | S | Shoreline | -- | 1.0 | 5 | 1.0 | 0.09 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 50 | S | Shoreline | -- | 1.0 | 6 | 1.0 | 0.06 | 0 | 0 | 100,0,0,0 | 10 ySK | -- |
| | 150 | S | Shoreline | -- | 0 | 6 | 1.0 | 0.15 | 0 | 0 | 100,0,0,0 | 10 ySK | -- |
| | 200 | S | Shoreline | -- | 1.0 | 6 | 1.0 | 0.15 | 0 | 0 | 100,0,0,0 | 10 ySK | -- |
| | 100 | S | Shoreline | -- | 1.0 | 6 | 1.0 | 0.21 | 0 | 0 | 100,0,0,0 | 10 ySK | -- |
| | 50 | S | Shoreline | -- | 1.0 | 6 | 1.0 | 0.43 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 50 | S | Shoreline | -- | 0.3 | 6 | 0.2 | 0.03 | 0 | 0 | 100,0,0,0 | 5 aRS | -- |
| | 30 | S | Shoreline | -- | 0.5 | 6 | 0.5 | 0.21 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 50 | S | Shoreline | -- | 1.0 | 6 | 1.0 | 0.27 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 10 | S | Shoreline | -- | 0.3 | 1 | 0.3 | 0.60 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 2 | C | Shoreline | -- | 1.0 | 4 | 1.0 | 0.40 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 10 | S | Shoreline | -- | 1.0 | 6 | 1.0 | 1.20 | 0.1 | 0.1 | 100,0,0,0 | 2 ySK | -- |
| | 30 | S | Backwater | -- | 1.5 | 6 | 2.0 | 0.12 | 0 | 0 | 10,85,5,0 | -- | -- |
| | 30 | S | Backwater | -- | 1.0 | 6 | 1.0 | 0.27 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 20 | S | Backwater | -- | N | -- | 1.0 | 0.15 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 30 | S | Backwater | -- | N | -- | 1.0 | 0.15 | 0 | 0 | 20,60,20,0 | -- | -- |
| | 20 | S | Shoreline | -- | N | -- | 1.0 | 0.12 | 0 | 0 | 100,0,0,0 | 8 jSF | -- |
| | 20 | S | Shoreline | -- | 1.0 | 6 | 1.0 | 0.05 | 0.1 | 0.1 | 70,25,5,0 | -- | -- |
| | 10 | S | Shoreline | -- | 0 | 6 | 0.5 | 0.06 | 0.1 | 0.1 | 97,0,5,0 | -- | -- |
| | 50 | S | Shoreline | -- | N | -- | 0.5 | 0.09 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 50 | S | Shoreline | -- | N | -- | 2.0 | 0.30 | 0.1 | 0.1 | 50,50,0,0 | -- | -- |
| | 250 | S | Side Channel | -- | N | -- | 1.0 | 0.12 | 0 | 0 | 100,0,0,0 | 250 ySK | -- |
| | 100 | S | Side Channel | -- | N | -- | 1.0 | 0.15 | 0 | 0 | 100,0,0,0 | 10 ySK | -- |
| | 150 | S | Side Channel | -- | N | -- | 2.0 | 0.12 | 0 | 0 | 100,0,0,0 | 150 ySK | -- |
| | 50 | S | Side Channel | -- | N | -- | 2.0 | 0.24 | 0 | 0 | 100,0,0,0 | 50 ySK | -- |
| | 100 | S | Side Channel | -- | N | -- | 1.0 | 0.24 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 30 | S | Side Channel | -- | 0 | 5 | 0.5 | 0.15 | 0 | 0 | 100,0,0,0 | 25 ySK | -- |
| | 30 | S | Side Channel | -- | N | -- | 1.0 | 0.15 | 0.3 | 0.3 | 100,0,0,0 | 35 ySK | -- |
| | 25 | S | Side Channel | -- | N | -- | 1.0 | 0.15 | 0.1 | 0.1 | 100,0,0,0 | -- | -- |
| | 35 | S | Backwater | -- | N | -- | 0.5 | 0.09 | 0 | 0 | 100,0,0,0 | 50 ySK | -- |
| | 50 | S | Backwater | -- | N | -- | 2.0 | 0.15 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 450 | S | Backwater | -- | N | -- | 1.0 | 0.18 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 100 | S | Backwater | -- | N | -- | 2.0 | 0.09 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 500 | S | Side Channel | -- | N | -- | 2.0 | 0.15 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 40 | S | Side Channel | -- | 1.0 | 3 | 5.0 | 0.80 | 0 | 0 | 50,50,0,0 | -- | -- |
| | 10 | S | Side Channel | -- | N | -- | 5.0 | 1.0 | 0.2 | 0.2 | 100,0,0,0 | -- | -- |
| | 50 | S | Side Channel | -- | N | -- | 4.0 | 0.85 | 0 | 0 | 60,30,0,10 | -- | -- |
| | 100 | S | Side Channel | -- | N | -- | 3.0 | 0.43 | 0 | 0 | 5,25,60,10 | -- | -- |
| | 100 | S | Backwater | -- | N | -- | 0.5 | 0.10 | 0 | 0 | 5,45,50,0 | 50 ySK | -- |
| | 20 | S | Backwater | -- | N | -- | 1.0 | 0.05 | 0 | 0 | 100,0,0,0 | 20 ySK | -- |
| | 50 | S | Backwater | -- | 0 | 5 | 2.0 | 0.10 | 0 | 0 | 100,0,0,0 | 50 ySK | -- |
| | 30 | S | Shoreline | -- | N | -- | 0.5 | 0.05 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 50 | S | Shoreline | -- | N | -- | 0.3 | 0.05 | 0 | 0 | 100,0,0,0 | 25 ySK | -- |
| | 20 | S | Backwater | -- | N | -- | 1.0 | 0.04 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 100 | S | Backwater | -- | N | -- | 2.0 | 0.08 | 0 | 0 | 90,10,0,0 | 10 ySK | -- |
| | 50 | S | Backwater | -- | N | -- | 0.5 | 0.06 | 0 | 0 | 100,0,0,0 | -- | 50 ySK |
| | 100 | S | Backwater | -- | N | -- | 0.2 | 0.03 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 200 | S | Backwater | -- | N | -- | 2.0 | 0.20 | 0 | 0 | 100,0,0,0 | 50 ySK | -- |
| | 100 | S | Backwater | -- | N | -- | 0.5 | 0.05 | 0.1 | 0.1 | 100,0,0,0 | 300 ySK | -- |
| | 100 | S | Backwater | -- | N | -- | 1.0 | 0.10 | 0.1 | 0.1 | 90,10,0,0 | -- | -- |
| | 100 | S | Shoreline | -- | N | -- | 1.0 | 0.15 | 0 | 0 | 95,0,5,0 | 20 ySK | -- |
| | 70 | S | Shoreline | -- | 0.5 | 6 | 1.0 | 0.30 | 0 | 0 | 5,10,80,5 | -- | -- |
| | 200 | S | Shoreline | -- | N | -- | 2.0 | 0.30 | 0 | 0 | 10,10,80,0 | -- | -- |
| | 30 | S | Shoreline | -- | N | -- | 1.0 | 0.20 | 0 | 0 | 40,20,40,0 | -- | -- |
| | 200 | S | Backwater | -- | N | -- | 1.0 | 0.15 | 0 | 0.1 | 100,0,0,0 | 20 ySK | 5 jSF |
| | 100 | S | Backwater | -- | N | -- | 1.0 | 0.15 | 0 | 0 | 50,10,40,0 | 200 ySK<br>2 jSF | -- |
| | 10 | S | Backwater | -- | N | -- | 1.0 | 0.15 | 0 | 0 | 100,0,0,0 | 4 ySK | 10 jDC |
| 5+ | 30 | S | Side Channel | -- | 0 | 5 | 2.0 | 2.0 | 0 | 0 | 100,0,0,0 | 100 aRS<br>1 aCT | -- |
| | 60 | S | Side Channel | -- | 0 | 5 | 2.0 | 0.20 | 0 | 0 | 50,0,0,0<br>(50% wood) | 50 aRS<br>10 ySK | -- |
| | 500 | S | Backwater | -- | N | -- | 3.0 | 0.10 | 0 | 0 | 75,20,5,0 | 100 aRS<br>10 jDC | -- |
| | 10 | S | Backwater | -- | 2.0 | 4 | 2.0 | 0.12 | 0 | 0 | 10,85,5,0 | -- | -- |
| | 300 | S | Slough | -- | N | -- | 2.0 | 0.18 | 0 | 0 | 5,80,15,0 | -- | -- |
| | 8 | S | Shoreline | -- | N | -- | 2.0 | 0.30 | 0.1 | 0.1 | 100,0,0,0 | 20 ySF | -- |
| | 20 | S | Shoreline | -- | N | -- | 2.0 | 0.09 | 0 | 0 | 50,50,0,0 | -- | -- |
| | 80 | S | Backwater | -- | 0 | 6 | 1.0 | 0.09 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 200 | S | Slough | -- | 0 | 6 | 1.0 | 0.09 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 50 | S | Slough | -- | N | -- | 1.0 | 0.09 | 0 | 0 | 100,0,0,0 | 50 jSK | -- |
| | 100 | S | Eddy | -- | 1.0 | 1 | 1.0 | 0.85 | 0.2 | 0.2 | 0,0,30,70 | -- | -- |
| | 20 | S | Backwater | -- | 1.0 | 3 | 1.0 | 0.30 | 0 | 0 | 95,5,0,0 | -- | -- |
| | 20 | S | Backwater | -- | 0 | 5 | 2.0 | 0.35 | 0 | 0 | 100,0,0,0 | -- | -- |
| | 40 | S | Backwater | -- | 2.0 | 2 | 2.0 | 0.50 | 0 | 0 | 40,10,50,0 | -- | -- |
| | 5 | S | Side Channel | -- | N | -- | 2.0 | 0.30 | 0 | 0 | 100,0,0,0 | -- | 200 ySF |
| | 2 | C | Backwater | -- | N | -- | 1.0 | 0.15 | 0 | 0 | 50,10,40,0 | -- | 200 ySK |
| | 4 | C | Shoreline | -- | 1.0 | 2 | 0.5 | 1.0 | 0.1 | 0.1 | 90,10,0,0 | 4 jSF | -- |
| | 2 | S | Pool | -- | 2.0 | 1 | 3.0 | 1.6 | 0.2 | 0.1 | 5,20,20,55 | 3 jSF<br>1 aSF<br>10 aRS | 1 aSF<br>3 aSK<br>-- |
| 10+ | 6 | S | Shoreline | -- | 1.0 | 5 | 1.0 | 1.8 | 0.4 | 0.4 | 5,65,30,0 | 100 aRS<br>2 aSK | -- |
| | 40 | S | Pool | -- | 1.0 | 2 | 0.5 | 1.2 | 0.4 | 0.4 | 80,10,10,0 | -- | 150 aRS<br>10 jSF |
| 25+ | 1 | C | Pool | 0.25 | N | -- | 5.0 | 2.5 | 0.2 | 0.2 | 45,40,15,0 | 1 aSF | -- |
| | 1 | C | Pool | 0.25 | N | -- | 5.0 | 2.5 | 0.2 | 0.2 | 45,40,15,0 | 1 aSF | -- |
| | 8 | H | Eddy | 0.50 | 0 | 5 | 2.0 | 1.2 | 0.1 | 0.1 | 5,70,25,0 | 20 jSK<br>-- | 100 aRS<br>2 aSK |
| | 2 | H | Eddy | 0.50 | 2.0 | 5 | 4.0 | 1.5 | 0.4 | 0.4 | 5,65,30,0 | 20 jSK<br>-- | 100 aRS<br>2 aSK |
| | 2 | H | Eddy | 1.5 | 1.0 | 5 | 3.0 | 3.0 | 0.9 | 0.6 | 80,20,0,0 | 20 jSK | 15 aSK |
| | 1 | H | Run | 0.10 | N | -- | 4.0 | 1.3 | 1.6 | 1.5 | 5,40,55,0 | 15 aSK<br>1 aSF | --<br>-- |
| | 1 | C | Run | 0.10 | N | -- | 5.0 | 1.1 | 1.2 | 0.8 | 10,85,5,0 | 15 aSK | -- |
| | 1 | H | Run | 0.05 | N | -- | 20.0 | 1.6 | 2.7 | 1.4 | 0,50,50,0 | 5 aSK | 5 aSK |
| | 1 | C | Pool | 0.10 | N | -- | 10.0 | 1.9 | 0.1 | 0.2 | 100,0,0,0 | 3 aSK | 5 aSK |
| | 1 | H | Run | 0.10 | N | -- | 5.0 | 1.9 | 1.3 | 0.8 | 5,50,30,15 | 2 aSK<br>1 aSF | 2 aSK<br>1 aWF |
| | 1 | H | Eddy | 0.20 | N | -- | 2.0 | 0.90 | 0.3 | 0.3 | 0,0,100,0 | -- | 1 aWF |
| | 2 | C | Pool | 0.10 | N | -- | 20.0 | 1.2 | 0.9 | 0.4 | 10,30,60,0 | --<br>--<br>-- | 5 aWF<br>3 aSK<br>1 aSF |

Table B-2 (Continued)
Microhabitat observations of northern squawfish in the
St. Joe River during summer low flows in 1980 and 1981

| Size class | Number of fish | Behavior | Area type | Substrate distance | Overhead cover distance | Overhead cover type | Bank distance | Depth | Average velocity | Facing velocity | Substrate composition | Other fish within 1 meter | Other fish within 3 meters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25+ | 1 | F | Pool | 0.20 | 2.0 | 3 | 3.0 | 1.3 | 0.8 | 0.4 | 80,10,10,0 | -- | 1 aCT |
| | | | | | | | | | | | | | 1 aWF |
| | 1 | F | Run | 0.05 | 1.0 | 1 | 3.0 | 2.0 | 0.8 | 0.4 | 5,10,55,30 | -- | 2 aWF |
| | 1 | F | Pool | 0.02 | N | -- | 15.0 | 2.1 | 0.8 | 0.7 | 50,40,10,0 | -- | 1 aSK |
| | | | | | | | | | | | | | 1 aWF |
| | 1 | F | Pool | 0.05 | N | -- | 10.0 | 2.8 | 0.8 | 0.6 | 40,40,20,0 | 1 aSK | 8 aSK |
| | | | | | | | | | | | | -- | 1 aSF |
| | 1 | F | Pool | 0.05 | N | -- | 10.0 | 2.8 | 0.8 | 0.6 | 40,40,20,0 | 1 aSK | 8 aSK |
| | | | | | | | | | | | | | 1 aSK |
| | 1 | H | Pool | 0.30 | N | -- | 3.0 | 2.0 | 0.2 | 0.1 | 0,0,30,70 | 1 aSK | -- |
| | | | | | | | | | | | | 1 aSF | -- |
| | 1 | H | Pool | 0.30 | N | -- | 3.0 | 2.0 | 0.3 | 0.2 | 0,0,30,70 | 1 aSK | -- |
| | | | | | | | | | | | | 1 aSF | |
| | 1 | F | Run | 0.20 | N | -- | 10.0 | 1.1 | 2.2 | 1.5 | 10,10,70,10 | 2 aSK | 6 aSK |
| | 1 | C | Run | 0.05 | N | -- | 10.0 | 3.7 | 0.7 | 0.4 | 5,20,75,0 | 3 aSK | 15 aSK |
| | | | | | | | | | | | | | 1 aWF |
| | 400 | S | Backwater | -- | N | -- | 4.0 | 0.60 | 0 | 0 | 0,50,50,0 | 50 aRS | -- |
| | | | | | | | | | | | | 20 jSK | -- |
| | 4 | S | Shoreline | -- | 1.0 | 2 | 0.5 | 1.1 | 0.1 | 0.1 | 90,10,0,0 | 15 aRS | -- |
| | | | | | | | | | | | | 4 jSF | -- |
| | 2 | S | Pool | -- | 2.0 | 1 | 3.0 | 1.6 | 0.2 | 0.1 | 5,20,20,55 | 3 jSF | 1 aSF |
| | | | | | | | | | | | | 1 aSF | 3 aSK |
| | | | | | | | | | | | | 10 aRS | -- |
| 15+ | 1 | C | Pool | 0.05 | N | -- | 6.0 | 2.1 | 0.9 | 0.1 | 40,20,40,0 | -- | -- |
| | 2 | H | Pool | 0.40 | 0 | 5 | 1.0 | 1.2 | 0.1 | 0.1 | 5,70,25,0 | 20 jSF | -- |
| | | | | | | | | | | | | 2 aSK | -- |
| | | | | | | | | | | | | 100 aRS | -- |
| | 15 | S | Pool | 0-1.0 | 3.0 | 5 | 2.0 | 1.8 | 0.5 | 0.5 | 5,65,30,0 | -- | 100 aRS |
| | | | | | | | | | | | | -- | 2 aSK |
| | 10 | S | Pool | 0.50 | 1.0 | 2 | 0.5 | 1.2 | 0.4 | 0.4 | 80,10,10,0 | -- | 150 aRS |
| | | | | | | | | | | | | -- | 10 jSF |
| | 1 | S | Pool | 0.35 | 2.0 | 1 | 3.0 | 1.6 | 0.2 | 0.1 | 5,20,20,55 | 4 jSF | 1 aSF |
| | | | | | | | | | | | | 1 aSF | 3 aSK |
| | | | | | | | | | | | | 10 aRS | -- |
| 20+ | 1 | C | Pool | 0.50 | 3.0 | 1 | 3.0 | 2.8 | 1.2 | 1.0 | 40,40,20,0 | -- | 2 aSK |
| | 1 | C | Pool | 0.25 | 1.0 | 4 | 1.0 | 3.3 | 0.4 | 0.1 | 0,0,15,85 | -- | -- |
| | 10 | S | Run | 0.50 | 0 | 5 | 1.0 | 1.2 | 0.1 | 0.1 | 5,70,25,0 | 20 jSF | 100 aRS |
| | | | | | | | | | | | | -- | 2 aSK |
| | 1 | C | Pool | 1.5 | 1.0 | 5 | 2.0 | 3.0 | 0.9 | 0.6 | 80,20,0,0 | -- | 15 jSK |
| | 1 | F | Run | 0.10 | 4.0 | 2 | 4.0 | 0.90 | 0.8 | 0.5 | 5,20,70,5 | -- | 1 aCT |
| | | | | | | | | | | | | | 1 aSK |
| | 10 | S | Pool | 1.0 | 1.0 | 4 | 4.0 | 2.2 | -- | -- | 5,20,25,50 | -- | 1 aSF |
| | 1 | C | Pool | 2.5 | N | -- | 3.0 | 4.0 | 0.2 | 0.1 | 0,0,60,40 | 1 aSK | -- |
| | 1 | F | Pool | 0.05 | N | -- | 15.0 | 1.6 | 0.8 | 0.3 | 5,45,50,0 | -- | -- |
| | 1 | C | Pool | 0.10 | N | -- | 10.0 | 1.9 | 0.6 | 0.4 | 5,15,75,5 | 1 aSF | 3 aSK |
| | 1 | H | Pool | 0.10 | N | -- | 15.0 | 1.7 | 0.8 | 0.4 | 0,40,40,20 | 3 aSK | 2 aSK |
| | | | | | | | | | | | | 3 aWF | -- |
| | 5 | S | Pool | 0.20 | 3.0 | 1 | 5.0 | 3.0 | 0.2 | 0.1 | 5,10,45,40 | 2 aSF | 1 aSK |
| | 1 | H | Pool | 0.30 | 1.0 | 1 | 1.0 | 1.9 | 0.3 | 0 | 0,5,20,75 | 1 aSF | 6 aSK |
| | 1 | C | Run | 0.10 | N | -- | 2.0 | 3.6 | 0.6 | 0.4 | 15,30,50,5 | 2 aSK | 8 aSK |
| | 1 | C | Pool | 0.20 | N | -- | 3.0 | 1.9 | 0.4 | 0.4 | 10,20,65,5 | -- | 2 aSK |
| | | | | | | | | | | | | | 1 aWF |
| | 1 | C | Run | 0.10 | N | -- | 10.0 | 1.0 | 1.8 | 0.9 | 5,25,70,0 | -- | -- |
| | 1 | F | Run | 0.10 | N | -- | 10.0 | 1.6 | 1.7 | 0.9 | 5,25,70,0 | 4 aSK | 10 aSK |
| | | | | | | | | | | | | -- | 1 aSF |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | F | Run | 0.25 | N | -- | 10.0 | 1.6 | 1.7 | 1.6 | 5,25,70,0 | 1 aSK | 4 aSK |
| | | | | | | | | | | | | -- | 1 aSF |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | F | Run | 0.10 | N | -- | 5.0 | 1.6 | 1.5 | 0.8 | 5,25,70,0 | 1 aSK | 4 aSK |
| | | | | | | | | | | | | -- | 1 aSF |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | H | Run | 0.05 | N | -- | 10.0 | 1.3 | 1.5 | 0.7 | 5,25,70,0 | 1 aSK | 4 aSK |
| | | | | | | | | | | | | -- | 1 aCT |
| | 1 | H | Run | 0.10 | N | -- | 5.0 | 1.1 | 1.8 | 0.9 | 5,15,70,10 | -- | 2 aSK |
| | 1 | F | Run | 0.10 | N | -- | 5.0 | 1.0 | 1.6 | 0.9 | 5,15,70,10 | -- | 1 aSK |
| | 1 | F | Run | 0.15 | N | -- | 10.0 | 1.1 | 1.5 | 1.4 | 5,10,75,10 | -- | -- |
| | 1 | H | Run | 0.05 | N | -- | 15.0 | 1.2 | 1.4 | 0.7 | 0,10,80,10 | 1 aSK | 1 aSK |
| | 1 | R | Run | 0.05 | N | -- | -- | -- | -- | -- | 10,80,0,10 | -- | 3 aSK |
| | | | | | | | | | | | | -- | 2 aSK |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | R | Run | 0.05 | N | -- | -- | -- | -- | -- | 10,80,0,10 | -- | 3 aSK |
| | | | | | | | | | | | | -- | 2 aSF |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | R | Run | 0.05 | N | -- | -- | -- | -- | -- | 10,80,0,10 | -- | 3 aSK |
| | | | | | | | | | | | | -- | 2 aSF |
| | | | | | | | | | | | | | 1 aWF |
| | 1 | H | Run | 0.10 | N | -- | 10.0 | 1.4 | 1.6 | 1.0 | 10,40,45,5 | 1 aSK | 3 aSK |
| | | | | | | | | | | | | 1 aWF | 1 aWF |
| | 1 | F | Run | 0 | N | -- | 10.0 | 1.2 | 1.6 | 0.4 | 5,10,60,25 | -- | -- |
| | 1 | F | Run | 0.10 | N | -- | 10.0 | 1.1 | 1.4 | 0.6 | 5,5,30,60 | 2 aSF | -- |
| | | | | | | | | | | | | 1 aSK | -- |
| | 1 | F | Run | 0.05 | N | -- | 10.0 | 1.1 | 1.4 | 0.4 | 5,5,30,60 | 2 aSF | -- |
| | | | | | | | | | | | | 1 aSK | -- |
| | 1 | C | Eddy | 0.20 | 3.0 | 1 | 4.0 | 1.4 | 0.2 | 0.2 | 80,10,10,0 | -- | 2 aSF |
| | | | | | | | | | | | | -- | 1 aSK |
| | 1 | C | Eddy | 0.75 | 3.0 | 1 | 3.0 | 1.9 | 0.2 | 0.2 | 95,0,5,0 | 3 aSF | 6 aSK |
| | | | | | | | | | | | | 2 aSK | 4 aSF |
| | 1 | C | Eddy | 0.50 | 3.0 | 1 | 3.0 | 1.9 | 0.2 | 0.2 | 95,0,5,0 | 3 aSF | 6 aSK |
| | | | | | | | | | | | | 2 aSK | 4 aSF |
| | 1 | R | Eddy | 0.20 | 0 | 1 | 1.0 | 1.9 | 0.2 | 0.2 | 65,0,5,30 | -- | 6 aSK |
| | | | | | | | | | | | | -- | 4 aSK |
| | 1 | C | Eddy | 0.30 | 2.0 | 3 | 3.0 | 1.6 | 0.1 | tr | 40,20,5,35 | 1 aSK | 4 aSK |
| | 1 | C | Run | 0.20 | 5.0 | 1 | 10.0 | 2.9 | 0.7 | 0.4 | 0,5,90,5 | -- | 5 aSK |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | R | Run | 0.20 | 1.0 | 1 | 2.0 | 1.2 | tr | tr | 10,25,25,40 | -- | 3 aSK |
| | 1 | R | Pool | 0.05 | 1.0 | 1 | 3.0 | 2.7 | 0.2 | 0.2 | 0,80,0,20 | 1 aSF | 2 aSF |
| | | | | | | | | | | | | -- | 2 aSK |
| | 1 | R | Pool | 0.05 | 1.0 | 1 | 2.0 | 2.1 | 0.1 | 0 | 0,0,0,100 | -- | 2 aSF |
| | | | | | | | | | | | | -- | 2 aSK |
| | 1 | F | Pool | 0.10 | 4.0 | 1 | 5.0 | 1.7 | 0.4 | 0.3 | 0,60,40,0 | 3 aSK | 10 aSK |
| | | | | | | | | | | | | 1 aSF | 2 aSF |
| | 1 | F | Pool | -- | 4.0 | 1 | 5.0 | 2.1 | 0.8 | 0.3 | 0,60,40,0 | -- | 20 aSK |
| | | | | | | | | | | | | -- | 3 aSF |
| | | | | | | | | | | | | -- | 3 aWF |
| | 1 | F | Pool | -- | 4.0 | 1 | 5.0 | 2.1 | 0.8 | 0.3 | 0,60,40,0 | -- | 20 aSK |
| | | | | | | | | | | | | -- | 3 aSF |
| | | | | | | | | | | | | -- | 3 aWF |
| | 1 | C | Pool | 0.10 | 1.0 | 1 | 4.0 | 1.7 | 0.3 | 0.3 | 0,50,50,0 | -- | -- |
| | 1 | S | Pool | 0.20 | 3.0 | 1 | 5.0 | 3.0 | 0.2 | 0.1 | 5,10,45,40 | 6 aSF | 1 aSK |
| | 1 | C | Pool | 0.20 | 2.0 | 1 | 4.0 | 2.1 | 0.1 | 0.2 | 0,10,40,50 | 3 aSK | 12 aSK |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | F | Pool | 0.10 | 8.0 | 1 | 5.0 | 1.4 | 0.4 | 0.2 | 0,20,60,20 | -- | 1 aSF |
| | 1 | F | Pool | 0.10 | 8.0 | 1 | 5.0 | 1.4 | 0.4 | 0.2 | 0,20,60,20 | -- | 1 aSF |
| | 1 | H | Pool | 0.10 | 6.0 | 1 | 5.0 | 2.0 | 1.0 | 0.7 | 0,10,40,50 | -- | 3 aWF |

Table B-2 (Continued)
Microhabitat observations of northern squawfish in the St. Joe River during summer low flows in 1980 and 1981

| Size class | Number of fish | Behavior | Area type | Substrate distance | Overhead cover distance | Overhead cover type | Bank distance | Depth | Average velocity | Facing velocity | Substrate composition | Other fish within 1 meter | Other fish within 3 meters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20+ | 1 | F | Pool | 0.10 | N | -- | 5.0 | 1.8 | 0.8 | 0.2 | 0,10,40,50 | 1 aSK | 1 aSK |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | C | Pool | 0.20 | N | -- | 5.0 | 1.6 | 0.6 | 0.5 | 0,30,50,20 | -- | -- |
| | 1 | R | Pool | 0.05 | 1.0 | 1 | 2.0 | 1.6 | 0.2 | 0,1 | 5,20,20,55 | 10 aRS | 3 aSK |
| | | | | | | | | | | | | 15 jSF | 1 aSF |
| | 1 | F | Pool | 0.10 | N | -- | 5.0 | -- | -- | -- | 10,10,40,40 | -- | -- |
| | 1 | H | Pool | 0.15 | N | -- | 5.0 | 1.6 | 0.8 | 0.3 | 5,5,30,60 | -- | 2 aWF |
| 30+ | 1 | C | Pool | 0.20 | 5.0 | 1 | 5.0 | 1.8 | 0 | 0 | 40,35,25,0 | -- | 3 aSK |
| | | | | | | | | | | | | -- | 1 aWF |
| | 2 | R | Run | 0 | 0 | 3 | 5.0 | 1.8 | 0 | 0 | 80,5,15,0 | -- | 200 aRS |
| | 1 | R | Run | 0 | 1.0 | 4 | 1.0 | 0.70 | 0.5 | 0.3 | 5,85,10,0 | -- | 6 aSK |
| | 1 | C | Pool | 0.05 | N | -- | 15.0 | 2.8 | 0.5 | 0.6 | 5,50,45,0 | -- | 4 aSK |
| | 1 | H | Pool | 0.05 | 2.0 | 5 | 4.0 | 1.8 | 0.4 | 0.4 | 5,65,30,0 | 10 jaSF | 100 aRS |
| | | | | | | | | | | | | -- | 10 jaSF |
| | | | | | | | | | | | | -- | 2 aSK |
| | 1 | H | Pool | 1.5 | 1.0 | 5 | 3.0 | 3.0 | 0.9 | 0.6 | 80,20,0,0 | 10 jaSF | 10 jaSF |
| | | | | | | | | | | | | -- | 10 aSK |
| | 1 | C | Pool | 0.10 | 1.0 | 5 | 3.0 | 2.5 | 0 | 0 | 95,5,0,0 | 1 aSF | -- |
| | 4 | H | Eddy | 0.20 | N | -- | 5.0 | 1.1 | 0.1 | 0.1 | 50,20,30,0 | -- | 1 aSK |
| | 1 | R | Pool | 0 | N | -- | 10.0 | 1.4 | 0.9 | 0.5 | 5,20,35,0 | 3 aSK | 6 aSK |
| | | | | | | | | | | | | 1 aWF | 2 aWF |
| | | | | | | | | | | | | -- | 1 aSF |
| | 1 | H | Pool | 0.10 | N | -- | 10.0 | 1.8 | 1.2 | 0.6 | 0,20,70,10 | -- | 6 aSK |
| | | | | | | | | | | | | -- | 2 aWF |
| | | | | | | | | | | | | -- | 1 aSF |
| | 1 | F | Pool | 0.20 | N | -- | 10.0 | 2.1 | 1.2 | 0.5 | 10,40,40,10 | 1 aSK | 4 aSK |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | R | Pool | 0.05 | 1.0 | 3 | 1.0 | 0.80 | 0.2 | 0 | 90,20,0,0 | -- | -- |
| | 1 | C | Pool | 0.20 | 1.0 | 1 | 3.0 | 1.9 | 0.4 | 0.1 | 5,75,5,15 | 2 aSK | 7 aSK |
| | | | | | | | | | | | | -- | 1 aSF |
| | 1 | H | Pool | 0.05 | 5.0 | 1 | 5.0 | 1.7 | 1.6 | 0.7 | 5,20,50,25 | 2 aSK | 8 aSK |
| | | | | | | | | | | | | 1 aWF | 6 aWF |
| | | | | | | | | | | | | -- | 1 aSF |
| | 1 | C | Run | 0.40 | 1.0 | 1 | 2.0 | 1.6 | 1.1 | 0.4 | 5,20,70,5 | -- | 1 aWF |
| | 1 | C | Pool | 0.10 | N | -- | 20.0 | 1.2 | 0.9 | 0.4 | 10,30,60,0 | -- | 5 aWF |
| | | | | | | | | | | | | -- | 3 aSK |
| | | | | | | | | | | | | -- | 2 aSF |
| | 2 | F | Pool | 0.10 | N | -- | 20.0 | 1.4 | 0.9 | 0.4 | 5,5,40,50 | -- | 10 aSK |
| | 1 | C | Pool | 0.10 | 15.0 | 1 | 15.0 | 1.5 | 1.3 | 1.0 | 10,80,10,0 | 2 aSK | 6 aSK |
| | 1 | H | Pool | 0.30 | 2.0 | 1 | 4.0 | 1.6 | 0.1 | 0.2 | 20,0,0,80 | -- | 1 aSK |
| | 1 | C | Run | 0.20 | N | -- | 3.0 | 1.5 | 0.5 | 0.3 | 25,25,25,25 | 2 aSK | 11 aSK |
| | 1 | C | Run | 0.05 | N | -- | 10.0 | 1.5 | 1.7 | 0.8 | 5,25,70,0 | -- | 4 aSF |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | C | Run | 0.05 | 3.0 | 4 | 3.0 | 1.6 | 0.7 | 0.3 | 10,80,10,0 | -- | -- |
| | 1 | F | Run | 0.15 | 3.0 | 4 | 3.0 | 1.0 | 0.6 | 0.6 | 25,35,40,0 | 3 aSF | -- |
| | 1 | F | Run | 0.10 | N | -- | 10.0 | 1.1 | 1.4 | 0.6 | 5,5,30,60 | 2 aSF | -- |
| | | | | | | | | | | | | 1 aSK | -- |
| | 1 | F | Run | 0.20 | N | -- | 15.0 | 1.7 | 1.6 | 1.5 | 5,40,40,15 | 2 aSK | 8 aSK |
| | 1 | C | Eddy | 0.20 | 3.0 | 1 | 3.0 | 1.9 | 0.2 | 0.2 | 95,0,5,0 | 3 aSF | 4 aSK |
| | | | | | | | | | | | | 2 aSK | 1 aSF |
| | 1 | R | Run | 0.10 | 0 | 1 | 1.0 | 1.0 | 0.1 | 0.1 | 5,20,20,55 | -- | -- |
| | 1 | C | Run | 0.50 | 2.0 | 1 | 3.0 | 3.3 | 0.2 | 0.2 | 5,10,55,30 | 5 aSK | 8 aSK |
| | | | | | | | | | | | | -- | 1 aSF |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | C | Run | 0.30 | 1.0 | 1 | 3.0 | 3.3 | 0.2 | 0.2 | 5,10,55,30 | 5 aSK | 8 aSK |
| | | | | | | | | | | | | -- | 1 aSF |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | R | Pool | 0.05 | 1.0 | 1 | 3.0 | 4.3 | 0.7 | 0.4 | 20,0,10,20 | -- | -- |
| | 1 | H | Pool | 0.10 | 1.0 | 3 | 5.0 | 2.7 | 0.5 | 0.2 | 20,30,50,0 | 15 aSK | -- |
| | | | | | | | | | | | | 1 aSF | -- |
| | 1 | H | Pool | 0.20 | 1.0 | 3 | 5.0 | 2.7 | 0.5 | 0.2 | 20,30,50,0 | 15 aSK | -- |
| | | | | | | | | | | | | 1 aSF | -- |
| | 1 | F | Pool | -- | 4.0 | 1 | 5.0 | 2.1 | 0.4 | 0.3 | 0,60,40,0 | -- | 20 aSK |
| | | | | | | | | | | | | -- | 3 aSF |
| | | | | | | | | | | | | -- | 3 aWF |
| | 1 | C | Run | 0.15 | N | -- | 5.0 | 0.80 | 0.5 | 0.4 | 0,50,40,10 | 10 aSK | -- |
| | 1 | R | Pool | 0 | 1.0 | 1 | 10.0 | 3.9 | 0.9 | 0.5 | 0,50,0,50 | -- | 1 aSF |
| | | | | | | | | | | | | -- | 1 aSK |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | R | Pool | 0 | 1.0 | 1 | 10.0 | 3.9 | 0.9 | 0.5 | 0,50,0,50 | -- | 1 aSF |
| | | | | | | | | | | | | -- | 1 aSK |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | F | Pool | 0.05 | 5.0 | 1 | 10.0 | 2.0 | 0.7 | 0 | 10,30,50,10 | -- | 3 aSK |
| | | | | | | | | | | | | -- | 2 aWF |
| | 1 | S | Pool | 0.20 | 3.0 | 1 | 5.0 | 3.0 | 0.2 | 0.1 | 5,10,45,40 | 6 aSF | 1 aSK |
| | 1 | S | Pool | 0.10 | 1.0 | 1 | 3.0 | 3.1 | 0.2 | 0.1 | 20,50,20,10 | 2 aSK | 6 aSF |
| | 1 | R | Pool | 0.05 | N | -- | 10.0 | 1.8 | 0.6 | 0.1 | 5,50,40,25 | 1 aSK | -- |
| | | | | | | | | | | | | 1 aWF | -- |
| | 1 | H | Pool | 0.40 | 1.0 | 1 | 1.0 | 1.9 | 0.3 | 0 | 0,5,20,75 | 1 aSF | 6 aSK |
| | 1 | C | Pool | 0.15 | N | -- | 4.0 | 1.5 | 0.3 | 0.1 | 20,20,30,30 | 1 aSF | 8 aSK |
| | 1 | H | Pool | 0.10 | N | -- | 5.0 | 1.3 | 0.9 | 0.7 | 5,5,45,45 | 2 aWF | -- |
| | 1 | R | Pool | 0.05 | N | -- | 5.0 | 1.7 | 0.4 | 0.2 | 5,5,70,20 | 1 aSF | -- |
| | 1 | R | Pool | 0.05 | N | -- | 5.0 | 1.7 | 0.4 | 0.2 | 5,5,70,20 | 1 aSF | -- |
| | 1 | H | Pool | 0.15 | N | -- | 4.0 | 1.8 | 0.4 | 0.4 | 50,20,20,10 | 2 aSK | -- |
| 35+ | 1 | C | Pool | 0.15 | N | -- | 15.0 | 3.0 | -- | -- | 80,0,20,0 | -- | -- |
| | 1 | C | Pool | 0.10 | 1.0 | 5 | 1.0 | 2.5 | 0 | 0 | 95,5,0,0 | 1 aSF | -- |
| | 1 | H | Run | 0.20 | N | -- | 5.0 | 1.8 | 1.2 | 0.7 | 5,70,25,0 | -- | 10 aSK |
| | 1 | H | Pool | 0.05 | 0 | 1 | 5.0 | 2.0 | 0.3 | 0 | 0,20,70,0 | -- | 4 aSK |
| | | | | | | | | | | | | -- | 2 aWF |
| | | | | | | | | | | | | -- | 1 aSF |
| | 1 | F | Pool | 0.10 | 4.0 | 1 | 4.0 | 1.3 | 1.2 | 0.4 | 40,40,20,0 | -- | 5 aSK |
| | 1 | C | Pool | 0.50 | 2.0 | 5 | 5.0 | 2.3 | -- | -- | 5,20,25,50 | -- | 10 aSF |
| | I | F | Eddy | 0.05 | 5.0 | 1 | 5.0 | 1.9 | 1.1 | 1.1 | 5,10,55,30 | -- | 4 aWF |
| | | | | | | | | | | | | -- | 2 aSK |
| | 1 | H | Pool | 0.15 | 2.0 | 1 | 2.0 | 1.4 | 0.3 | 0.3 | 10,10,0,80 | -- | -- |
| | 1 | R | Pool | 3.0 | 1.0 | 4 | 3.0 | 4.3 | 0.2 | 0.1 | 100,0,0,0 | 2 aSK | -- |
| | 1 | F | Run | 0.15 | 3.0 | 4 | 3.0 | 1.0 | 0.7 | 0.6 | 25,35,40,0 | 3 aSF | 3 aSK |
| | | | | | | | | | | | | 1 aSK | 1 aWF |
| | 1 | R | Eddy | 0.05 | 0 | 3 | 1.0 | 1.0 | 0.4 | 0.1 | 20,0,20,10 | 2 aSK | 1 aSF |
| | 1 | C | Eddy | 0.20 | 3.0 | 1 | 3.0 | 1.9 | 0.2 | 0.2 | 95,0,5,0 | 3 aSF | 4 aSK |
| | | | | | | | | | | | | 2 aSK | 1 aSF |
| | 1 | F | Run | 0.05 | N | -- | 25.0 | 1.3 | 0.7 | 0.4 | 5,40,45,10 | -- | 2 aSK |
| | | | | | | | | | | | | -- | 1 aWF |
| | 1 | F | Pool | 0.10 | 4.0 | 1 | 5.0 | 1.7 | 0.3 | 0.1 | 0,60,40,0 | 3 aSK | 7 aSK |
| | | | | | | | | | | | | 1 aSF | 2 aSF |
| | 1 | F | Pool | 0.10 | 4.0 | 1 | 5.0 | 1.7 | 0.3 | 0.1 | 0,60,40,0 | 3 aSK | 7 aSK |
| | | | | | | | | | | | | 1 aSF | 2 aSF |
| | 1 | F | Pool | -- | 4.0 | 1 | 5.0 | 2.1 | 0.4 | 0.2 | 0,60,40,0 | 20 aSK | -- |
| | | | | | | | | | | | | 3 aSF | -- |
| | | | | | | | | | | | | 3 aWF | -- |
| | 1 | C | Pool | 0.15 | N | -- | 4.0 | 1.5 | 0.2 | 0.1 | 20,20,30,30 | 1 aSF | 3 aSK |
| 40+ | 1 | H | Pool | 0.10 | N | -- | 10.0 | 1.4 | 3.3 | 1.7 | 5,20,55,20 | 1 aSK | 4 aSK |
| | | | | | | | | | | | | 1 aWF | 1 aSF |
| | 1 | F | Run | 0.15 | 3.0 | 4 | 3.0 | 1.0 | 0.6 | 0.6 | 25,35,40,0 | 3 aSF | 4 aSK |
| | 1 | F | Run | 0.15 | 3.0 | 4 | 3.0 | 1.0 | 0.6 | 0.6 | 25,35,40,0 | 3 aSF | 1 aWF |
| | | | | | | | | | | | | | 4 aSK |
| | | | | | | | | | | | | -- | 1 aSF |
| | 1 | F | Run | 0.15 | N | -- | 20.0 | 1.8 | 1.4 | 1.2 | 5,35,40,20 | 5 aSK | 5 aSK |
| | 1 | H | Pool | 0.40 | 1.0 | 1 | 2.0 | 2.0 | 0.4 | 0.3 | 90,0,0,10 | 3 aSK | 5 aSK |
| | 1 | H | Pool | 0.50 | 2.0 | 1 | 5.0 | 2.8 | 0.5 | 0.4 | 0,25,25,50 | -- | 2 aSF |
| | | | | | | | | | | | | -- | 2 aSK |
| | 1 | H | Pool | 0.05 | 4.0 | 1 | 4.0 | 2.2 | 0.4 | 0.1 | 0,0,80,20 | 3 aSK | 10 aRS |
| | | | | | | | | | | | | -- | 10 aSK |
| | | | | | | | | | | | | -- | 5 jSF |
| | | | | | | | | | | | | -- | 1 aSF |
| 45+ | 1 | F | Run | 0.05 | N | -- | 25.0 | 2.0 | 0.7 | 0.3 | 5,40,45,10 | 3 aSK | 8 aWF |
| | | | | | | | | | | | | | 2 aWF |

REPORT NO. 3

# CULTURE OF ENDANGERED COLORADO RIVER FISHES

## SECTION I

## INDUCED SPAWNING AND CULTURE OF THE HUMPBACK CHUB AND BONYTAIL CHUB HYBRIDS

by

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## INTRODUCTION

The humpback chub (Gila cypha) and the bonytail chub (Gila elegans) are both classified as endangered species by the U.S. Department of the Interior (1980) and by several western states. Ostensibly pure and remnant populations of G. cypha and G. elegans exist in the lower Colorado River Basin in the Little Colorado River and Lake Mohave respectively (Smith, Miller, Sable 1979). The upper basin contains these two species plus the roundtail chub (Gila robusta) and so called "intergrades" between the three (Holden and Stalnaker 1978). The systematics of the "Gila complex" are still in dispute.

A decline of the Gila spp. has been reported by various workers (USFWS 1979). Impoundments with their cold tail waters, habitat destruction and a fish poisoning program by state and Federal biologists in 1962 have been blamed for the demise of these species.

Willow Beach NFH responding to recommendations by the Colorado River Endangered Fish Recovery Teams has been working on culture methods for the Colorado squawfish (Ptychocheilus lucius) and razorback sucker (Xrauchen texanus) since 1973. In 1979-80 the humpback chub and bonytail chub were added to the program. With the advent of the Colorado River Fishery Project in 1979, the hatchery's program was stepped up to develop technology for the culture of these species of chubs and to produce them for test fish for various laboratory research programs.

The spawning habits and early life history of these fish are little known because of the difficulty of obtaining exact data in the field due to the remote habitat and the swift and turbid water. The hatchery program was designed to supply some of this information. The first objective was to induce captive adults to spawn in the hatchery using various cultural techniques. The second objective was to hatch and rear the progeny of these fish to 2-3 inches in size and to produce about 50,000 of each species for transfer to research laboratories. An alternate objective was to produce bonytail hybrids if a male bonytail was not captured to cross with the females on hand at the hatchery.

## METHODS

### Broodstock

The humpback broodstock consisted of 33 wild adults, of which 18 were collected from the Colorado River, at Black Rocks, Utah, November 5, 1979, and the remaining 15 from the Little Colorado River, Grand Canyon National Park, Arizona, May 17, 1978 and November 17, 1980.

Five bonytail females were collected in Lake Mohave, near Cottonwood Cove, on April 30 to May 1, 1979, and April 29 to May 3, 1980. Eight roundtail chubs were collected from the Colorado River, near Black Rocks, on November 5, 1979. Lengths varied from 457 to 559 mm (bonytail), 298 to 352 mm (roundtail) and 304 to 381 mm (humpback). Weights varied from 850 to 1300g (bonytail), 240 to 420g (roundtail) and 275 to 590g (humpback).

### Hatchery System

The incoming water for Willow Beach National Fish Hatchery is 12 to 13° C. Spawning temperature for Gila spp. ranges from 18 to 21° C (U.S. Fish and Wildlife Service 1979). To obtain the necessary water temperature within the hatchery building, a 45,000 BTU/hr. liquid propane gas water heater was used, capable of heating 23 liter/min of 12 to 13° C water to 20 to 21° C. This was considered a sufficient amount of water for hatching eggs and holding 15 adult chubs for a short time.

The heated water entered the first of two adjacent concrete tanks (6 m x .75 m x .75 m) that were connected at both ends to allow recirculation and settling of suspended matter and aeration. At the lower end of the first tank water was pumped to the second by a 1/20 hp fresh-flo pump at the rate of 132 liter/min. At the opposite end it circulated back into the first tank. When the water depth in the system exceeded .70 m, excess water was allowed to escape over a 7.5 cm in diameter stand pipe. After at least one pass through both tanks, a 1/3 hp automatic sump pump delivered water from the second tank to each of two egg incubation troughs at 8 liter/min and to the broodstock holding facilities at 5 liter/min via a system of 1.73 cm pvc pipe and brass valves.

The indoor broodstock holding facilities consisted of recirculation system with two adjacent concrete tanks as described above. The adult chubs were held in the first tank, which contained cobble stones ranging in size from 50 to 75 mm in diameter in the upper half through which recirculated water flowed at 132 liter/min to create an artificial spawning environment. The water temperature was held at 20 to 21° C.

The egg incubators consisted of three aluminum troughs (3.5 x 0.55 x 0.30 m). Two received heated water (20 to 21° C) and third unheated river water (12 to 13° C) at 8 liter/min. Hatching trays 55- x 53-cm covered with 1.4 mm hardware cloth slanted at a 30 degree angle into the incoming water were used to hold the eggs.

## Injecting Procedures

Hormone-induced spawning has been widely used for the propagation of certain fish species (Ihering 1937; Ball and Bacon 1954; Clemens and Sneed 1962). Acetone dried carp pituitary was selected to induce spawning of the three Gila species.

The carp pituitary (40 mg) was suspended in 10 ml of a 5 percent solution of oxytetracycline hydrochloride. Therefore, 1 ml of the mixture contained 4 mg of carp pituitary and 50 mg of antibiotic.

Before the injection, each fish was anesthetized with Tricaine Methanesulfonate at 1:20,000 to 1:10,000 (Leitritz 1960). Injections were administered with 1 cc plastic hypodermic syringe using a No. 23 gauge needle. The fish were weighed and injected at a rate of 4 mg of pituitary and 50 mg of antibiotic per kg of body weight. Injections were repeated at 24 hour intervals until the fish were ripe with a maximum of two injections. All injections were made intraperitoneally from the ventral surface under the pelvic fin (Ball and Bacon 1954). Afterward, the fish were placed in the broodstock holding facility and held until hand stripping was attempted.

## Egg Stripping Procedures

When eggs could be expelled from the female with slight pressure, the fish was hand stripped. The female was anesthetized, wiped dry with a cloth, and the eggs stripped into a plastic pan. Three to four males were anesthetized, wiped dry and the milt added to the eggs. Eggs and sperm were mixed for 15 seconds using a swirling motion. Water was added at this time, causing the eggs to clump and adhere. The eggs were then stirred with a feather and washed for 60 minutes. The majority of the eggs separated after water hardening.

Egg samples were taken to determine size, volume and numbers and were placed on screen trays for hatching at the warm and cold temperatures. They were left in the incubator troughs through hatching to swim up. Humpback fry were transferred to an outside recirculating system consisting of two concrete raceways B1 and B2 (30.5 x 2.4 x 1.2 m) described below for the squawfish in Section II. Bonytail hybrid fry were transferred to a cage within a recirculating raceway. The cage measured 1.0 x 1.0 x 1.0 m and was covered with 0.5 mm saran filter to prevent escape into Lake Mohave.

The fry were fed a starter trout diet several times a day along with zooplankton, predominately cladocerans, that produced in the raceway.

## Transportation Procedures

Shipping fish in plastic bags is a fish culture technique used for many years. Bayless (1972) used sealed plastic bags containing water and oxygen to transport striped bass larvae and eggs. Snow et al. (1978) successfully used plastic bags for shipping largemouth bass fry.

Fry were shipped at a density of 500-1,000/liter and fingerlings at a density of 60 to 120 per liter of water. They were removed from the holding facilities and placed in square-bottomed plastic bags 76 cm x 38 cm x 56 cm containing 8 liters of water. The bags were inflated with oxygen, sealed with rubber bands and placed in insulated styrofoam containers 42 cm x 42 cm x 24 cm. A small amount of ice was placed in the containers and they were sealed in cardboard boxes (125 psi, bursting test) for shipment by airline.

## RESULTS

### Humpback Chub

The Colorado River, Black Rocks strain, were injected at 24 hour intervals with 4 mg/kg carp pituitary. Ten were injected May 13 and eight on May 20. One female partially spawned May 15 producing 100 eggs which resulted in only 70 progeny.

The Little Colorado River strain was injected at 24-hour intervals beginning on June 4. Eggs could be expelled from the females after 24 hours, while the males ripened only after 48 hours.

All males produced clear milt of low viscosity after two pituitary injections. Three females ovulated June 5 after the first injection, while three ovulated June 6 after the second injection. Egg diameter varied from 2.0-2.5 mm; the volume was 50 eggs/ml.

Fecundity was 100, 4,850, 4,000, 4,200, 5,760, and 250 eggs per female. Fertility was less than 1 percent. A total of 750 fry were later transferred to the University of Idaho at Moscow.

On June 4, 18,000 humpback chub eggs were shipped to Willow Beach for hatching. These eggs were collected by CRFP personnel from wild fish at Black Rocks.

When the eggs arrived, the water temperature was 8.5° C in the container. They were slowly tempered to water temperatures of 13 and 20° C for incubation. On arrival they were 80-85 percent fertilized and measured 2.5-3.0 mm in diameter. Their volumetric measurement was 48 egg/ml.

Eggs placed in the cold water (12 to 13° C) never completed development. This was unusual, since these eggs were taken at 11 to 12° C. Hatching of eggs placed in warm water (20° C) began at 120 hours, peaked at 135 hours, and was complete after 160 hours. Newly hatched fry averaged 6.5 to 7.5 mm in length.

In 96 hours, the yolk-sac had been absorbed and the fry began swimming to the surface. Approximately 13,000 fry were transferred to an outside recirculating raceway system B1-B2.

During the first 2 weeks, the fry were very active feeding on plankton. A schooling behavior was observed which continued throughout the next 2 months.

When the fry reached approximately 20.0 mm in length, a commercial trout starter diet was offered to supplement their diet of plankton. All fish appeared to accept the dry diet, as most were observed feeding near the surface.

Fry doubled their length in 10 days and attained a size of 55-65 mm by day 72 (Figure 1). Survival was lower than expected, approximately 6,200 fingerlings were recovered from the pond.

A total of 5,200 juveniles were transferred to University of Idaho and 1,000 to Utah Fishery Experimental Station at Logan, Utah, in August.

## Bonytail x Roundtail

### Spawning

Three bonytail chub females and eight roundtail chub males were used for this hybridization. Roundtail males were injected April 30 at 24-hour intervals with 4 mg/kg carp pituitary. Two injections and 48 hours later, all males were producing milt of a low viscosity. Two bonytail females were injected May 3 with 4 mg/kg carp pituitary. Twenty-four hours later, both females ovulated. The other bonytail female already had ovulated naturally, but her eggs appeared over-ripe judging from their light opaque appearance.

Each female was hand stripped individually and the eggs fertilized using 3 to 4 males. After water hardening, egg samples were taken to determine size, volume, and numbers. The size varied from 1.5-2.0 mm in diameter, with a volume of 103 eggs/ml.

The three females produced 15,862; 20,806 and 7,216 eggs which were incubated separately at 20, 20, and 13° C. respectively.

### Egg and fry development

Over-ripe eggs placed in a water temperature of 20° C, failed to develop. Good eggs placed in a water temperature of 20° C, developed rapidly. The first cleavage occurred at 36 hours and the embryo could be seen vigorously moving at 60 hours. Hatching began 86 hours after fertilization. Newly hatched fry averaged 5.5 to 6.5 mm in length. Hatching was completed 95 hours after fertilization.

Good eggs placed in a water temperature of 13° C developed very slowly. The embryo was forming at 96 hours, but all eggs died after 110 hours. The cold water temperature is believed to have contributed to their death.

Seventy-two hours after hatching at 20° C, all fry had absorbed the yolk-sac and after 96 hours were swimming. The average length of the fry

was 6.5 to 7.5 mm. The following day, fry were transferred to a cage in an outside recirculating raceway.

The average length of the elegans-robusta reached 12 to 13 mm in 16 days.

Approximately 12,000 fry were shipped to Dexter National Fish Hatchery on May 29 and 30, 1980. Dexter has placed these in warm water ponds and is collecting some periodically for a developmental series to do taxonomic work.

## Bonytail x Humpback

### Spawning

Two bonytail chub females and five humpback chub males from Black Rocks were used for this hybridization. The humpback males were injected May 13 at 24-hour intervals with pituitary. Two injections and 48 hours later, all males were producing milt of a low viscosity. The bonytail females were injected May 19 and ovulated 24 hours after injection.

Only one female was hand stripped. The eggs were fertilized using milt from three males. After water hardening, egg samples were taken to determine size, volume, and numbers. The size varied from 1.5 to 2.0 mm in diameter, with a volume of 103 eggs/ml. The female produced 22,660 eggs that were light yellow in color.

A total of 18,540 eggs were placed on four trays at a water temperature of 21° C. The remaining 4,120 eggs were placed on two trays at a water temperature of 12° C.

### Egg and Fry Development

Eggs placed in a water temperature of 12° C failed to complete development. As with the elegans-robusta, the embryo formed at 96 hours, but all eggs were dead after 110 hours.

Eggs placed in a water temperature of 21° C developed slower than the elegans-robusta. The first cleavage occurred at 48 hours and the embryo could be seen vigorously moving at 72 hours. Hatching began 101 hours after fertilization. Newly hatched fry averaged 5.5 to 6.5 mm in length. All eggs were hatched 172 hours after fertilization.

By 96 hours, all fry had absorbed the yolk-sac and after 120 hours, all fry were able to swim freely. The average length of the fry was 6.5 to 7.5 mm. The following day, all fry were transferred to a cage in an outside recirculating raceway. Average length of the elegans-cypha hybrids reached 13 to 14 mm in 15 days.

Approximately 8,000 fry were transferred to Dexter National Fish Hatchery June 17, 1980, as was done with the roundtail chub.

## DISCUSSION

Humpback eggs incubated at water temperatures of 12 to 13° C succumbed after 110 hours, while 80 to 85 percent hatched at 20° C. Further, all hybrid eggs incubated at water temperatures of 12 to 13° C, succumbed after 110 hours. The fact that embryos died at cooler temperatures suggests one cause for the decline of such endangered species. Thus, eggs may not survive the colder water temperatures now found in parts of the lower Colorado River. The lack of pre-dam temperature regimes (18 to 21° C) may be an important cause of present reproduction failure in that area.

When propagating the bonytail x roundtail and bonytail x humpback, natural hybridization was attempted in the broodstock holding facility. The efforts were futile. All females had to be hand stripped and the eggs artificially fertilized. While hybrids or intergrades have been observed in the Upper Colorado River Basin (Holden and Stalnaker 1970), under these controlled conditions natural hybridization did not occur.

Results were encouraging: (1) the use of acetone-dried carp pituitary to produce viable sex products was successful; (2) chub females were hand stripped and the eggs artificially fertilized; (3) transporting hybrids and humpback chubs in plastic bags was successful; and (4) both hybrid crosses and humpback chubs are doing well at Dexter National Fish Hatchery, University of Idaho, and Utah FES.

It appears that with additional research, these techniques may be applied for culturing bonytail chubs, humpback chubs, and roundtail chubs in the future.

## ACKNOWLEDGEMENTS

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REPORT NO. 3

# CULTURE OF ENDANGERED COLORADO RIVER FISHES

## SECTION II

## SPAWNING AND CULTURE OF COLORADO SQUAWFISH IN A RACEWAY ENVIRONMENT

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## INTRODUCTION

The Colorado squawfish (Ptychocheilus lucius) is considered an endangered fish species by the states of Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming (Deacon et al. 1979). It is also listed as endangered by the U.S. Department of the Interior (1980).

The Colorado Squawfish Recovery Plan (1978) has three major goals: (1) preserve, protect, and manage existing populations and habitats of Colorado squawfish; (2) restore Colorado squawfish populations to their range; (3) acquire, propagate, and maintain captive reserve gene pools.

The purpose of this project was to test and develop techniques for the spawning and culture of Colorado squawfish and produce test fish for research. Only one other paper discusses propagation and rearing of this species (Toney 1974). This paper reports on the successful spawning of hatchery-reared and wild broodstock, and presents culture data for the progeny during 1980 at Willow Beach National Fish Hatchery, Arizona.

## METHODS

### Broodstock

The broodstock consisted of 13 wild adults from the Colorado River, 14 wild adults from the Green River, and 130 hatchery-reared adults from the Yampa River. The hatchery-reared fish were progeny from the first squawfish to be propagated at Willow Beach National Fish Hatchery (Toney 1974).

The Colorado River fish were collected November 18, 1975, April 24, 1978, and November 2, 1979. All were captured between Grand Junction, Colorado, and Moab, Utah. The Green River fish were collected May 13, 1976, May 10, 1978, and November 26, 1979, and were captured between Ouray National Wildlife Refuge and Jensen, Utah. The Yampa River hatchery-reared fish have been reared at Willow Beach since July 1, 1974.

### Holding Facilities

Broodstock holding and spawning facilities consisted of five concrete raceways 30.5 x 2.4 x 1.2 m. These raceways are referred to as A3-A4, A9-A10, and A2. About 95 percent of the water in A3-A4, A9-A10, and A2 was recirculated to reach spawning temperatures. Colorado squawfish begin spawning when the water temperature reaches 21 to 22° C. (Vanicek and Kramer 1969; Toney 1974). At the upper end of raceways A3, A9, and A2, brass valves 6.35 cm were installed to allow for introduction of river water. Fresh water was needed to maintain proper temperatures and to compensate for evaporation. Water was recirculated between

adjacent raceways A3 through A4 and A9 through A10 by 1 hp fresh-flo pumps at the rates of 46.8 cf/min. In raceway A2, a 1/4 hp fresh-flo pump moved water from the middle of the raceway toward both ends via a T connection at the rate of 23.4 cfm creating a recirculation system within this raceway.

Spawning substrate was placed in the first 10 m of raceways A3 and A9. It was divided into two layers; the bottom layer consisted of boulders 30 to 40 cm in size, while the top layer consisted of cobble stones 4 to 10 cm in diameter. Water depth over the substrate ranged from 10 to 76 cm. Water introduced at this end flowed through the substrate creating an artificial spawning environment based on observation of the spawning behavior of Colorado squawfish (Toney 1974) and northern squawfish (Jeppson 1957; Patten and Rodman 1969). Instead of a gravel spawning bed, three mats of Spanish moss 1.2 x 2.0 m were placed in Raceway A2. These mats, commonly used in Cyprinid culture, were constructed with 2.5 x 10 cm pine lumber covered with 10 x 10 cm heavy gauge wire screen to which the moss was attached.

Eight wild females and 19 males were placed in raceway A9 in an attempt to promote natural spawning and make observations. Following this, all females that had not spawned and 12 males were transferred to raceway A3 to be spawned artificially.

Raceway A2 was used as a holding and spawning facility for the 130 hatchery-reared adults.

## Artificial Spawning

Spawning was induced by carp pituitary injection (Ball and Bacon 1954; Clemens and Sneed 1962) in the manner described above for the humpback chub (Section I).

The squawfish were given intraperitoneal injections of 4 or 8 mg/kg body weight which were repeated at 24-hour intervals with a maximum of two injections per female.

Five wild females were injected at 4 mg/kg body weight and placed in raceway A3 to spawn on the cobble stone substrate. Thirty-nine hatchery-reared females were injected at 4 mg/kg and 39 at 8 mg/kg body weight. Eggs were hand stripped and fertilized using procedures described for the humpback chub. Milt from four males was used to fertilize all these eggs. They were hatched in facilities described in Section I at both the cold (12 to 13° C) and warm (20 to 21° C) temperatures.

## Fry and Juvenile Rearing

When the fry swam to the surface, they were removed by seines and transferred to rearing facilities outdoors. The fry rearing facilities consisted of three recirculating systems or six raceways A9-A10, C1-C2, and B1-B2. Water was recirculated by a 1/4 hp fresh-flo pump at the rate of 23.4 cfm through each system.

The fry rearing raceways were filled 2 weeks in advance to obtain warmer water temperatures and a zooplankton bloom. Small amounts of inorganic (ammonium phosphate) and organic (commerical trout starter) fertilizers were added to the raceways to produce the plankton bloom. Ten days after the fertilization, cladocerans appeared. When the zooplankton could no longer sustain the fish, trout feed was introduced until they were completely converted to it.

On several occasions, river water at a temperature of 12 to 13° C was introduced to the systems to compensate for evaporation, and to control water quality and temperature. This cold water would normally lower the water temperature from 23 to 24° C to 17 to 18° C in 30 minutes but on one occasion the temperature dropped 10° C in 10 minutes.

## RESULTS

### Prespawning

In late April, as water temperature reached 15° C due to recirculation, males began acquiring small tubercles on the head, operculars, pectoral, and pelvic fins. In May, with the water temperature approaching 18° C, males began producing seminal plasma with active sperm. By June, when the water temperature reached 20° C, tubercles spread over the entire surface of the males, except the abdominal area and caudal fin.

Females showned no spawning characteristics until June (20° water temperature). A few females acquired small tubercles on the head, operculars, and pectoral and pelvic fins, but most had no tuberculation. Females were mostly larger than males (Table 1). The abdominal region started to soften and distend as females became gravid. Genital papillae became swollen and inflamed just prior to spawning.

Table 1
Total length-weight comparison of Colorado squawfish being held at Willow Beach National Fish Hatchery, Arizona, 1980

| Fish | | Length (mm) | | Weight (g) | |
|---|---|---|---|---|---|
| | | Average | Range | Average | Range |
| Domestic females | 78 | 429 | 390-441 | 681 | 530-830 |
| Domestic males | 52 | 402 | 381-425 | 590 | 450-750 |
| Wild females | 8 | 681 | 619-756 | 2824 | 2315-3872 |
| Wild males | 19 | 578 | 466-633 | 1862 | 862-2393 |

### Natural Spawning

Three females started spawning in raceway A9 at 1800 hours, June 24. Two to three males pursued each female, appearing to guide her to the selected spawning site. The female slowly settled to the bottom while two males, one on each side, nudged her genital papillae. The female responded with a rapid opercular movement, followed by a body vibration or shudder and released some eggs. The males fertilized the eggs and all fish swam off. Three to four minutes later, the females and males

reappeared and repeated the behavior. Spawning was observed over a 48 hour period. Evidently, a Colorado squawfish must spawn a number of times to deplete her egg supply. Patten and Rodman (1969) observed similiar spawning behavior for the northern squawfish. The eggs were distributed over an area of 1.2 x 3.0 m in a water depth of 25 to 45 cm. The spawning temperatures were 20 to 21° C.

## Artificial Spawning

Wild fish transferred to raceway A3 were checked for ripeness and observed daily. One female spawned July 2, 1980, 24 hours after the first carp pituitary injection. This female was also hand stripped, but only 1,000 eggs could be expelled. The eggs were placed in the hatchery system (Section I) at a water temperature of 20 to 21° C. Three females spawned July 3, 1980, 24 hours after the second injection.

The spawning areas covered 1.2 x 1.2 and, 1.2 x 5.0 m in water depths of 10 cm and 20 to 55 cm. The water temperatures were 23° C and 24° C.

One female spawned on July 26, 1980, 24 days after the second injection. This last spawn resulted after a sudden fluxation in water temperature. The raceway had been flushed with 12 to 13° C river water for 24 hours, then refilled and the temperature allowed to rise naturally. The spawning area covered 1.0 x 1.0 m in a water depth of 20 to 25 cm. The water temperature was 22° C.

Ten out of 78 hatchery-reared females ranging in total length from 425 to 441 mm and weights of 675 to 830 g ovulated after receiving one carp pituitary injection. Five received 4 mg/kg and five 8 mg/kg body weight. No difference in maturity or fecunity was noted between the two treatments. The 10 hatchery-reared females produced 78,540 eggs, averaging 7,854 eggs/female. The egg size varied from 1.5 to 2.0 mm in diameter. The water temperatures were 18 to 19° C.

## Incubation and Hatching

The estimated number of eggs spawned by the three non-injected females in raceway A9 was 25,000. The egg size varied from 1.5 to 2.0 mm in diameter. Eggs were allowed to hatch in this raceway on the cobblestone substrate. Hatching began at 96 hours and was completed at 144 hours. This extended incubation period was due to the three females spawning over a 48 hour period. Newly hatched fry average 6.5 to 7.0 mm in total length. An estimated 7,500 fry were hatched from the 25,000 eggs. The water temperatures were 20 to 21° C.

The estimated number of eggs produced by the five injected females in raceway A3 was 55,000. These were 1.5 to 2.5 mm in diameter. All except 5,000 eggs which were brought into the hatchery for incubation, were allowed to hatch where they were layed, on the cobble stone substrate. Hatching began in raceway A3 at 90 hour and was completed at 130 hours at 23 to 24° C. Newly hatched fry averaged 6.5 to 7.5 mm in

length. An estimated 32,500 fry hatched of the 50,000 thought to be in the raceway.

Of the 5,000 eggs incubated in the hatchery at 20 to 21° C approximately 4,500 hatched. They started hatching at 90 hours, peaked at 100 hours, and were finished by 120 hours.

The eggs stripped from the first injected and partially spawned female developed as described above, but only 500 eggs hatched out of the 1,000 eggs hand stripped and fertilized. That is, only 50 percent of the artificially spawned eggs hatched compared to a 90 percent hatch for the 5,000 eggs deposited and fertilized by the fish themselves.

Less than 3 percent of the eggs obtained from the hatchery-reared adults showed any signs of development. A total of only 2,000 fry hatched from the 78,540 eggs taken. These poor results may be attributed to first time spawners, improper egg collecting techniques or improper diet. Eggs placed in the warm water (20 to 21°C) began hatching at 96 hours, peaked after 105 hours, and were finished at 121 hours. Newly hatched fry averaged 6.0 to 6.5 mm in length. Eggs placed in cold water (12 to 13° C) began hatching at 145 hours, and were finished by 180 hours. Newly hatched fry averaged 6.0 to 6.5 mm.

## Fry and Juvenile Rearing

A total of 19,000 swim-up fry were placed in A9-A10 System One, 14,000 in C1 & C2 System Two, and 10,000 in B1 & B2 System Three, 72 to 96 hours after hatching. During the first seven days, the fry were very active and swam from the surface to the bottom feeding on the cladocerans. A schooling behavior was observed, but later the fry scattered throughout the recirculation systems.

On Day 28, zooplankton were noted to be declining and a dry diet, commercial trout starter, was supplemented. The fry were fed three to four times daily or about 0.5 kg of feed per system per day. By Day 35, most fish were readily accepting the prepared diet. In response to a 10° C drop in water temperature when introducing freshwater to the system, the feeding behavior became benthic. And when the water temperature increased the fish returned to feeding near the surface.

Weekly samples were collected to determine growth rates (Table 2). On Day 63, canabalism was observed, probably resulting from overcrowding. A small number juveniles could be seen swimming with caudal fins extending from their mouths.

On Day 93, an oxygen depletion down to 1.5 mg/L occurred in one recirculating system C1 & C2. An immediate flushing of the system held mortalities down to only 60 fish. However, the water temperatures were reduced to 12-13° C stopping further growth. Throughout the growth period, ammonia nitrogen ($NH_3$-N) varied from 0.03 to 2.0 mg/L, carbon dioxide ($CO_2$) to 2.5 to 15.0 mg/L, pH from 7.5 to 9.0 units and dissolved oxygen ($O_2$) 9.9 to 1.5 mg/L. Highest concentrations of metabolites and the lowest oxygen reading reflect the oxygen depletion.

Table 2
Growth rate for larval Colorado squawfish reared in three recirculating systems

| Age days | | Average total length (mm) Recirculating System 1 | | Recirculating System 2 | | Recirculating System 3 |
|---|---|---|---|---|---|---|
| 1 | 10 | 6.8 | 10 | 7.1 | 10 | 6.7 |
| 7 | 10 | 7.5 | 10 | 8.0 | 10 | 7.6 |
| 14 | 10 | 9.0 | 10 | 10.1 | 10 | 9.2 |
| 21 | 10 | 14.2 | 10 | 15.0 | 10 | 14.0 |
| 28 | 10 | 18.7 | 10 | 19.5 | 10 | 19.1 |
| 35 | 10 | 21.4 | 10 | 23.8 | 10 | 23.0 |
| 42 | 10 | 24.8 | 10 | 25.1 | 10 | 25.2 |
| 49 | 10 | 26.9 | 10 | 27.8 | 10 | 27.3 |
| 56 | 10 | 28.2 | 10 | 30.6 | 10 | 29.9 |
| 63 | 10 | 30.3 | 10 | 32.2 | 10 | 33.0 |
| 70 | 10 | 33.6 | 10 | 35.3 | 10 | 34.5 |
| 77 | 10 | 36.5 | 10 | 37.4 | 10 | 36.0 |
| 84 | 10 | 41.8 | 10 | 44.0 | 10 | 38.4 |
| 91 | 10 | 44.3 | 10 | 45.7 | 10 | 39.1 |
| 98 | 10 | 47.4 | 10 | 48.3 | 10 | 41.2 |
| 105 | 10 | 48.5 | 10 | 50.1 | 10 | 42.2 |
| 107 | 10 | 48.5 | 10 | 50.1 | 10 | 42.2 |

On day 98, all juveniles were removed from the three systems and the survival rate determined (Table 3). A total of 34,843 squawfish juveniles, 42 to 50 mm in total length, were then transferred to other stations for culture and experimental bioassay studies.

Table 3
Survival rate for Colorado squawfish reared from fry to 42-50 mm in three recirculation systems

| Recirculating system | Numbers of fry stocked | Number of juveniles harvested | Percent survival |
|---|---|---|---|
| 1 | 19,000 | 16,156 | 85 |
| 2 | 14,000 | 11,075 | 79 |
| 3 | 10,000 | 7,612 | 76 |

## DISCUSSION

An important discovery during this study was the age at which Colorado squawfish may become sexually mature. Vanicek and Kramer (1969) found nearly all squawfish age VII and older are sexually mature. Seethaler (1978) found sexual maturity to occur only after squawfish exceeded a total length of 400 mm and an age of VI year. Hatchery-reared squawfish, at Willow Beach National Fish Hatchery, began becoming sexually mature at age V (males) and age VI (females). Poor fertilization resulted at this early age, so dependable broodstock will probably require 10 years to become fully mature.

Vanicek and Kramer (1969) determined Colorado squawfish spawning occurred after the water temperature reached 21.1° C. This was based on ripe fish, spawned out fish, and appearance of juvenile fish in the Green River. Toney (1974) reported captive squawfish spawned when the water temperature was 22.2° C. During this study, noninjected females spawned at water temperature of 20 to 21° C, while injected females spawned at temperatures of 18 to 24° C. Induced spawning can occur at a lower water temperature (18° C), however, the ideal spawning and egg incubation temperature must be considered between 20 to 22° C.

Several techniques were used to spawn Colorado squawfish: (1) non-injecting and natural spawning on cobble stone substrate; (2) injecting and natural spawning on cobble stone substrate; (3) injecting, hand stripping, and artificial fertilization; (4) injecting and natural spawning on Spanish moss matts. Comparing the four techniques used, injecting and natural spawning on cobble stone substrate proved superior. Noninjected females produced 25,000 eggs, 7,500 fry, or a 30 percent hatch; injected females that spawned naturaly on cobble stone substrate produced 55,000 eggs, 37,000 fry, or a 67.3 percent hatch; injected females that were hand stripped produced 78,540 and 1,000 eggs, 2,000 and 500 fry, or a 2.5 percent and 50 percent hatch; and injected females which spawned on Spanish moss mats produced 5,000 eggs, 0 percent yolk sac fry or a 0 percent hatch.

Survival of squawfish progeny was excellent in the modified raceways. The fish were able to endure culture conditions such as: low dissolved oxygen (1.5 mg/L); high ammonia nitrogen (2.0 mg/L); high carbon dioxide (15.0 mg/L); high pH (9.0 units); overcrowding; and sudden fluxations in water temperatures, up to 10° C in 10 minutes. Raceway culture may not be the ideal environment for rearing fry but until other culture techniques are achieved it must be considered feasible.

By developing spawning and rearing techniques today, the Colorado squawfish may again inhabit the waters of the upper and lower Colorado River basin. If this endangered species is to survive, hatchery propagation and culture will be beneficial for the survival of the species.

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REPORT NO. 3

# CULTURE OF ENDANGERED COLORADO RIVER FISHES

## SECTION III

## SPAWNING OF RAZORBACK SUCKERS

by

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1981

## INTRODUCTION

Razorback suckers (Xyrauchen texanus) were transferred from Lake Mohave and arrived on the RDU on January 16, 1981. The fish arrived in an overall fair to good condition. Five fish were in bad condition, 28 fish had large areas of thick white mucous on body and caudal peduncle. The 136 fish were placed in eight tanks and treated with 1:6,000 formalin for one hour to remove external parasites. Most of the males were fluid. Many of the females flowed a few eggs during the unloading process. Fish remained in tanks for 24 hours before being stocked in ponds or spawned in tanks. Twenty fish were held in the holding house for spawning and 15 fish were held in a holding house tank to be treated for the heavy mucous spots on the body.

## METHODS AND MATERIAL

### Pond Spawning

Two 0.1 surface acre ponds were prepared by placing about 6 yards of rock, ranging in size from 1/4 inch to 3 inch diameter, in one corner area of each pond covering an area about 15 feet by 15 feet. When ponds were filled to normal level the water depth over the rocks ranged from 1.5 to 3 feet deep. The water temperature was 60±1° F and the ponds were about one-third full when fish were stocked on the day following arrival. The ponds were full within 48 hours after stocking. Pond C6 received 26 females and 24 males, whereas C5 received 26 females and 23 males. Fish were added to Pond C5 after they had been utilized in tank spawning and stripping, also stocked were those treated for disease. Observations of the rock areas were periodically made to ascertain spawning activity.

### Spawning in a Flow-Through Pond

Pond D was prepared by placing two overlapping sheets of pressed fiberglass cloth, 16 feet wide and 27 feet long, across the shallow end of the pond making a liner about 31 by 27 feet. About 6 yards of rock ranging from 1/2 inch to 4 inch in diameter was scattered evenly over the liner. The pond was filled to a level that covered the rock area from 8 inches to 24 inches. A 3-inch pump was used to wash the rocks as the pond was being drained. The pond was refilled and stocked with five females and five males. The adults were seined on March 5 or 48 days after they had been stocked in C5. The females did not appear to be as gravid as would have been desired, and it was questionable if spawning would occur.

## Circular Tank Spawning

Three ripe females and males were placed in each of two 6-foot circular tanks, with a water depth of 22 inches. The females in tank No. 1 were injected intraperitoneally with dried carp pituitary at 2 mg/1b body weight. The males were injected with 800 IU human chorionic gonadotropin per pound of body weight. The females were injected daily for three days whereas the males were injected only once. The fish in tank No. 2 received no hormone and served as a control. Each tank had about 20 gallons of rock, from 1/2 inch to 3 inch diameter, covering the bottom of the tank. A flow of 10 liters per minute of well water ($62 \pm 1^{\circ}$ F) was delivered under pressure and aimed at about a 45 degree angle to cause a circular flow.

## Tank (Holding House) Spawning

A bed of rocks and gravel 4 inches deep was placed in the upper one-quarter of each of four (30 inch by 24 inch by 10 feet) holding house tanks. Water was flowed at 15 gmp through the tank. The water was delivered through an outlet that was below the level of rock bed. Each tank was stocked with one pair of razorback suckers. One pair of fish served as controls, two pair of fish were injected with 2 mg carp pituitary per pound, and one pair of fish was injected intraperitoneally with 800 IU chorinoic gonadotropin. Each female was reinjected the second and fourth day with the initial dosage.

## Hormone Injections and Stripping

Four females were injected with 500 IU chorionic gonadotropin and four females with a carp pituitary 2 mg/1b. Each fish was checked daily for ripeness. When eggs were available they were stripped, fertilized, and placed in hatching equipment. These fish had been held in the holding house tanks for about 17 days before injections were started.

Males were held in a separate tank and injected with 300 and 500 IU chorionic gonadotropin intermuscularly. Injections were made whenever the males appeared to be losing fluidity.

Fish were seined in Pond C5 about 30 days after stocking and four gravid females were moved to a holding house tank. One female was injected intermuscularly with 500 IU chorionic gonadotropin before being placed in a 6-foot circular tank with 3 fluid males that were injected with 300 IU hormone intermuscularly.

One female was injected with 300 IU hormone and one female was injected with 500 IU hormone in the muscle. The last female was injected with 2 mg carp pituitary per pound of body weight daily. A total of three injections were given each female. The females were held in a holding house tank separate from males and were checked daily for ripeness.

## Egg Hatching

Eggs were incubated utilizing five methods: McDonald jars; in the circular tank on rocks after natural spawning; in a circular tank after stripping; on a fine mesh net suspended in holding house tank; and in a Heath incubator. Egg measurements were taken from six females reproduction.

## Fungus Studies

Bioassays of formalin were performed in 1 gallon jars containing 3 leters of water. Eggs were treated at 1:600; 1:500; 1:400; 1:300; 1:200 for 10 and 15 minutes; 1:100; 1:75 and 1:50 for 5 and 10 minute tests. The eggs were held in the gallon jars for 24 hours after which eggs were checked for viability. Two, 3, and 4 day old eggs were tested. All tests were performed in triplicate.

## Fry Feeding

One thousand fry were placed in a 1 x 1 x 4-foot tank and offered a trout starter diet. The fish were fed for two weeks, were counted and stocked in a rearing pond. These fry were hatched in McDonald hatching jars. The fish were offered food at least six times daily. Tanks were cleaned each day by gently brushing all excess food on the bottom to the lower end of the tank and siphoning off. Any fry siphoned from the tank during cleaning were netted and replaced in the tank.

A total of 28,500 swim-up fry were caught when they swam out of 6-foot circular hatching tanks and placed in a 30 inch by 30 inch by 10 foot holding house tank. A regular screen was covered with saran material to retain the fry in the tank. A 3 to 6 gpm flow of $62 \pm 1^{\circ}$ F well water was maintained through the test. A trout starter diet was offered at least four times daily. Food was administered with a jar with holes in the lid to alleviate excessive over-feeding. All the water surface of the tank was covered with feed at each feeding. The tank was cleaned in the same manner as in the first test.

The fish were moved to a rearing pond after 17 days on feed. The rearing pond had developed a zooplankton bloom that would support the fry at the time of stocking.

## RESULTS AND DISCUSSION

### Pond Spawning

The temperature of the two ponds that received brood razorback suckers ranged from 44° F to 61° F for the first 68 days that the fish were stocked. The temperatures were in the 50's for all but about 8 days during the early part of this period.

Spawning activity was noted the 12th day after the fish were stocked in the pond. There were three swept areas in C5 and five areas in pond C6. The areas that were cleaned were from 2 to 3 feet in diameter. Fish were observed over these and other cleaned areas on several occasions. Observations from a boat with an underwater viewer confirmed that nest areas were being prepared. On three occasions eggs were observed on the rocks in the two ponds. The difficulty of seeing the almost transparent eggs made any estimation of numbers impossible. Another observation of a few fungused eggs adhered to rocks in pond C6 gave evidence that spawning had taken place on at least a total of four occasions in the two ponds.

The ponds developed a phytoplankton bloom that limited clear observations for the last 30 days of the spawning period. It appeared that rock sweeping was evident until March 25, at the time of the preparation of this report.

The C series ponds proved to be a poor choice for spawning ponds. The ponds were new, with no vegetation on the dikes to reduce erosion. Any strong wind caused the water to become turbid which resulted in silt on the rock spawning beds. Also the water action caused a general erosion of the dikes over parts of the rocks. Should older ponds have been available for use with dikes settled and stabilized, the problem of settleable solids would have been lessened. The strong winds during this time of year will cause some dike erosion and siltation in all ponds, thus may limit the success of pond spawning.

The stage of maturity of razorback sucker fry at hatching will greatly influence their ability to survive in a pond spawning operation. When hatched, the larvae are very helpless and it takes almost twice as long to advance to the swim-up stages as for development of the embryo and hatching. The larvae are incapable of any swimming action thus are unable to move from any adverse environment. When hatching, the fry will settle in the rocks and invariably come to rest on a silt substrate. The probability for suffocation from silt would be extremely high.

Close observations throughout the last 45 days gave no indications of fry in the two spawning ponds. On four occasions a fry seine was utilized to seine two areas in each of the ponds. There were no fry captured. The author concludes that the silt problem was the limiting factor for reproduction.

The stocking program that has been proposed for this species will necessitate spawning and rearing large numbers of fry. Observations of fry and spawning in ponds give strong indications that this method will

never provide enough reproduction to fulfill the proposed stocking program unless specialized spawning ponds can be developed.

## Spawning in Flow-Through Type Pond

The fish placed in Pond D were observed over the rocks 12 days after stocking. Observations with an underwater viewer showed that some areas had been cleaned as if nests were being prepared. There were cleaned areas observed until March 31, but no eggs had been observed on the cleaned areas. The fish were left in the pond until about the middle of April before they were moved to a holding pond.

This technique needs to be attempted next year with better quality fish and during the time when the females appear to be the ripest. The rock bed will need to be washed to remove settled silt and organic material. A problem of slime algae was encountered this year growing on rocks and pond bottom, the use of an herbicide in the pond would greatly reduce this problem and will aid in keeping the rocks clean.

## Circular Tank Spawning

The use of circular tanks in conjunction with injections of 2 mg carp pituitary per pound of female brood fish appeared to be a technique that would be successful. Nest preparation was evident after 24 hours. There were eggs found in the tank with injected females after being in the tank 8 hours. Eggs were observed in the 2-, 4-, 8-, and 16-cell stage. The female fish were reinjected with carp pituitary 48 hours after the first injection. The adult fish were removed after 96 hours in the spawning tank. There appeared to be eggs deposited on at least two of the four nights. Spawning occurred during the hours of darkness. There were indications of nest preparation in the control tank but no spawning occurred after 12 days. When the fish were removed from each tank two females from the injected and all three females in the control tank yielded a small amount of eggs when stripped. These eggs all appeared to be overripe and could not be fertilized.

The number of eggs in the No. 1 tank were estimated by five people and an average taken. It was estimated that there were 50,000 eggs in the tank. It appeared that about 30 percent of the eggs were water hardened, the remainder of the eggs either did not water harden or the yolk was broken down.

After the adult fish were removed from tank No. 1 the eggs were left in the gravel to hatch. Samples of the gravel and rock to obtain and check eggs gave indications that there was a heavy fungal infestation and that the water exchange through the rocks was low. There were many dead eggs and water in rock area was very sour. The 24-inch standpipe was replaced with a 6-inch standpipe to cause a greater current over and through the rocks.

When a sample of gravel was taken 5 days after stocking fish larvae was found but later was determined to be prematurely hatched. The movements of sampling probably caused premature hatching.

The fry started swimming up on the 15th day after brood fish had been stocked in spawning tank. A total of 838 fry were harvested from tank No. 1 whereas no fry were harvested from the control tank. The low number of fry from this tank is attributed to a suspected loss of eggs from low oxygen in the rocks although there were no samples taken to ascertain the percentage of good eggs.

Another trial utilizing one female and three fluid males was initiated in a circular tank after the fish were seined from the 0.1 surface acre pond. The female was seined from the pond, injected intermuscularly with 500 IU HCG and placed in the tank. The female was caught 48 hours after the first injection; she released about 3,000 eggs that were fertilized by stripping milt from a male and stirring with a feather. These eggs were placed in a Heath incubator. The female was reinjected 24 hours later with the same dosage. When this female was caught 48 hours after the first injection she released about 3,000 eggs that were fertilized by stripping milt from a male and stirring with a feather. These eggs were placed in a Heath incubator. The female was injected with 2 mg carp pituitary per pound and returned to the tank. There were very few eggs in the circular spawning tank at this time. The following morning there were many eggs in the tank and the female was still flowing eggs. She was hand stripped, the eggs fertilized and the eggs scattered on the rocks in the tank after the males were removed. The 24-inch standpipe was replaced by one 6 inches long, and four air stones were added to the tank. It was estimated that well over 50 percent of the eggs incubating in the tank had been hand stripped. Previous sample counts and observations of the eggs released by the female in the tank gave indications that less than 50 percent water hardened correctly and less than 10 percent of the eggs were developing embryos. A sample of the eggs that were hand stripped were held for observation and 81 percent had water hardened. Hatching had started by early the 5th day.

Fry were caught in a small tank from the drain of the circular tank. Fry started swimming out of the circular tank on the 14th day after spawning. A total of 11,000 fry was obtained from the spawning of this female.

## Holding House Tank Spawning

There were no eggs deposited on rocks in any of the tests utilizing holding house tanks for spawnings. Some of the females had ovulated eggs that were lost when fish were handled for reinjections. There was little or no indication of nest building activity in any of the tanks. This technique is not recommended for retrial in future years. The females that received 800 IU chorionic gonadotropin had ovulated all the eggs in her ovary by the morning after the third treatment but no eggs were deposited on the bed of rocks. This female was stripped and eggs placed in a jar for hatching.

## Hormone Injections

Hormone injections of chorionic gonadotropin that was administered to females and males held in tank in some cases caused the expected

reaction and in other cases no response was evident. Males fluidity could be maintained with 300 to 500 IU with injections every 3rd to 5th day. Males that were dry at the first injections were brought to fluidity with injections of 300 IUs daily for 3 or 4 days. The response of the females that was held in tanks for a period of 14 days before injections were initiated gave a very poor response. The females would give a few eggs daily but all were nonviable. It appeared that the reabsorbtion process has started. The female that received 800 IU for three, every other day, injections had strippable eggs 24 hours after the third injection. The eggs that were stripped and fertilized from this female gave strong evidence that this dosage was too strong. Over half of the eggs were immature and would not even water harden. About 10 percent of the eggs appeared to be viable after water hardening. The remainder were eggs that appeared to be overripe. This female yielded 139,000 eggs. The eggs were one of the lots that were placed in jars for hatching. Premature hatching made fry enumeration and hatching success impossible.

Female No. 1 that injections started with 5 days after arrival and injected every other day with 500 IU yielded 9,000 eggs the day following second injection. All eggs water hardened. These eggs were not coated with clay but were placed in a McDonald jar and allowed to stick to the jar and were incubated. A total of 1,800 fry were hatched from this lot of eggs. Any eggs that lost their adherence were prematurely hatched. The eggs appeared to loose much of their adherence at about two days of age. Injections continued with this female and from 1,000 to 5,000 eggs could be stripped but all eggs were nonviable.

Female No. 2 was injected with 300 IU every other day and the day after the third injection had ovulated eggs that were stripped and water hardened. This female yielded a total of 32,300 eggs. These eggs all water hardened correctly, but less than 10 percent (9.9) started embryo development. These eggs were incubated on screens in tanks with a water flow over the eggs. Fungus problems and piling of eggs made this technique less than optimum. A total of 1,315 fry were obtained from this female. Additional injections yielded only nonviable eggs.

Females Nos. 3 and 4 - These two females received 300 and 500 IU respectively, and although each yielded a few eggs every day or two there were no viable eggs.

Injections of 2 to 8 mg carp pituitary injected every other day into four females gave no results.

Four females that were seined from the pond. One was injected with 2 mg carp pituitary/lb. daily, and after four injections the female died before any eggs were ovulated. One female was used in the circular tank spawning test. The two remaining females were injected with 300 IU and 500 IU intermuscularly daily for 2 days and the 3rd day injected with the same dosage rate but in the body cavity. These two females were ripe and running eggs on the morning of the 4th day. Eggs were not enumerated to reduce handling. Estimated numbers were 60,000 eggs each. Eggs were placed in trays in a Heath incubator. A total of 28,500 swim-up fry was obtained from these two females. All eggs water hardened but 2- and

3-day-old egg samples showed that 32 percent were developing. Fungus in the incubator reduced the number of fry obtained.

## Egg Measurements

Eggs were enumerated using Von Bayer's method. Egg counts were made from both water hardened eggs and non-water hardened eggs. The eggs from the females during the first part of the spawning tests were of various stages. In some instances over 50 percent of the eggs would absorb no water. The data presented here will be from lots of eggs that all had water hardened. The data from non-water hardened eggs will not be presented due to the changing size of the eggs and their size depending on the amount of time between fertilization and counting.

| | | | |
|---|---|---|---|
| Female | #1 | egg diameter | 0.089 inch or 95990/qt. |
| | #2 | | .091 inch or 89800/qt. |
| | #3 | | .090 inch or 92826/qt. |
| | #4 | | .088 inch or 99297/qt. |
| | #5 | | .091 inch or 89800/qt. |
| Mean Size | | | .089 inch or 93542/qt. |

Samples of 1- and 2-day-old eggs were comparable in size to the measurements taken within 1 to 4 hours after fertilization.

The water hardening process was completed within a 1 hour time period.

## Egg Incubation

Egg incubation was attempted by five different methods.

Eggs were placed in McDonald hatching jars after water hardening. The eggs developed normally until about the 48-hour stage. At this time the percentage of eggs with developing embryos started decreasing. The shell is so delicate that almost any movement will cause it to break. A high percentage of premature hatched embryos either died or were malformed. Samples of one lot of the larvae that were jar hatched and held in a tank revealed that 62 percent had abnormalities. The abnormality that was most prevalent was a body curvature ventrally into almost a complete circle.

Three trials with McDonald jars gave the same results, premature hatched eggs.

Egg hatching in the 6-foot circular tank where the water was 22 inches deep proved less than satisfactory. There was not enough flow through the rock bed, which resulted in a putrid area where eggs were incubating. Another problem in the first trial was the heavy growth of fungus that probably further reduced the flow of water through the rocks. The lowering of the water with a 6-inch standpipe helped to alleviate the problem. The non-aeration of eggs was not encountered in the second trial with the lowered standpipe. The problem of fungus was still present. The hatching success of viable eggs could not be measured due

to the unknown total number of eggs. Observations of and counts of viable versus nonviable eggs gave indications that the hatching success of viable eggs in the second test was as high as could be expected. The circular tank hatching is one method that is recommended even though fungal growths will be hard to control. Another disadvantage is not being able to determine what is happening and the culturist has very little control over the eggs while in the tank.

The tray suspended in a tank hatching attempt gave indications that this may be a method that could be utilized. Water exchange and aeration was not what would be desired. Water flows piled some of the eggs. Fungus problems were encountered and will be difficult to control utilizing this method. The percentage of viable eggs was low that were utilized in this test. This technique needs further testing with air stones added to increase aeration of water.

The hatching method that gave the best results was the Heath incubator. The one drawback was the heavy fungal infestation that developed on the 3rd 4th and 5th day. The fry go through the screen and can be removed from the trays through the clean-out hole. Even though fungus may be controlled in the future, the large percentage of bad eggs will cause problems of hatching eggs regardless of the method used. The non-fertile eggs start to break down at about the 4th day or just prior to the start of eggs hatching. Water quality from the decaying eggs may pose a problem to hatching larvae.

A great advantage to the Heath incubator will be the ease in treating eggs for fungus, and the availability of the incubating eggs for observations. Although the number of eggs that can be hatched per tray has not been determined the suggested starting point is 10,000 to 20,000 per tray.

The heavy fungal growth that developed in the incubator just prior to hatching prompted an attempt to separate good eggs from bad eggs that were fungused. After the eggs had started hatching, the eggs on the trays were placed in a McDonald hatching jar. The bad eggs and fungused eggs were lighter than viable eggs or hatched fry, thus the fungused and bad eggs were carried out of the jar with the water flow and the viable products were retained. During the separation process of 4 hours, more than 90 percent of the eggs hatched. After the separation process, the eggs and larvae were placed in a 6-foot circular tank, as previously described, to allow the fry to develop to the swim-up stage.

The fry started swimming out of the circular tank drain on the 14th day. They were caught in a 12-inch by 16-inch by 15-foot tank with a fine screen of saran cloth to retain the fry. Fry were removed daily from this tank and transferred to a holding house tank to be offered a prepared ration. Fry swam out of the circular tank for 4 days. A total of 28,500 swim-up fry were obtained from the eggs that incubated in the Heath incubator or an average of 14,250 per female.

## Fungus Studies

The viable 3- and 4-day-old eggs that were treated with formalin at 1:75 to 1:600 for 5, 10, and 15 minutes showed no mortalities from the treatment. Eggs treated with 1:50 formalin for 10 minutes had a 54 percent mortality rate for 3-day-old eggs and a 33 percent loss of the 4-day eggs. A 5-minute treatment of 1:50 formalin of 3-day-old eggs sustained a 21 percent loss and 4-day-old eggs had a 7 percent loss.

It appears that the $LD_0$ lies between 1:50 and 1:75 formalin for 5 to 10 minutes. The length of treatment time also affected the survival rate of eggs.

Tests were also performed on 2-day-old eggs, but viable and nonviable eggs were hard to seperate. The reduction of viable eggs was extremely difficult to ascertain, but it appeared that 1:75 for 5 and 10 minutes caused no egg mortality.

The efficacy tests of formalin on the fungi growing on eggs was tested after the fungi had been transplanted to hemp seed. After treatment of developing fungal infections the effect was noted after 5 days and 16 days. The rationale of these two time periods was to correspond to hatching and fry swim-up time. If eggs are incubated in Heath trays the fry would hatch and be removed from fungus in about a 5-day period but if eggs were incubated in the circular tank method the fry would be exposed to expanding fungus until they could swim up or about 14 days.

After 5 days from treatment the fungus appeared to be dead at concentrations of 1:75 and 1:100 for both 5- and 10-minute treatments; also at 1:200 for 10- and 15-minute treatments. There were no new growth of mycelia nor had any of the uninfected hemp seed in the tests developed any fungal growths.

The treatment at 1:300 for 10 minutes did not show that the fungus had been killed but its growth had been delayed to where it would not have proliferated to other areas. Only one test showed reproductive organs developing on the 10-minute treatment and no development of reproductive products on the 15-minute treatment.

All treatments above 1:300 regardless of length of time treated showed growth of the mycelia and reproduction of the fungi. The positive controls showed growth and reproduction in all tests. The negative controls showed no growth.

After 16 days there was no growth or reproduction of the 1:75 or 1:100 formalin treatment. Only minimal growth was observed in one of three 1:200 formalin for 15 minutes and only one of three 1:200 formalin for 10 minutes showed growth and reproduction.

This study shows that viable eggs can be treated with a formalin solution as strong as 1:75 for 10 minutes and not harm eggs. The fungi can be killed or retarded with 1:200 formalin for 10 minutes. The treatment recommended is a constant flow treatment in 1:100 for 10 minutes on the 2nd and early on the 4th day after hatching.

## Maintenance of Adults in Pond

The adults in the two C ponds received 5 pounds of catfish rations on work days. The fish ate the rations readily and when moved to a holding pond were in good body condition. The rate of feeding will be increased as temperatures increase to the rate of 2 to 2.5 percent of body weight.

## Starting Fry on a Prepared Ration

The fry fed in the 4 x 1 x 1-foot tank were first observed feeding the 3rd day after the fry were swimming continuously. A considerable loss occurred during the first week, but most were abnormal fry. This lot of fry had been jar hatched, and although actual counts of abnormal fry were not made, the poor survival rate is attributed to fry quality. The fish were stocked in a rearing pond after 17 days on feed. A survival rate of 60.6 percent was achieved in this test.

Samples showed that all fish had food in their digestive tracts at stocking.

The feeding test in the 10 x 2.5 x 2-foot tank appeared to be more successful as to the number of fry that died in a 2-week feeding period. Estimations and counts of dead fry removed when tanks were cleaned ranged from 0 to 50 per day. Most generally mortalities ranged from 8 to 20 per day. The major problem encountered was the saran cloth that covered the screen plugged easily and quickly. Only once did the screen plug and overflow. An estimate of 5,000 to 10,000 fry were lost down the drain. When fry were enumerated and stocked, about 8,500 were missing from the tank. This method of starting fry worked well, with the exception of the plugged screen, to hold the fry until adequate zooplankton had developed in the pond for the fry to be stocked. Hopefully, this method will not be necessary in the future years.

## Rearing Ponds for Fry

A 0.1 surface-acre pond was started filling on Febuary 27. Fertilization used was 100 pounds of manure and 80 pounds of 18-46-0 on the pond bottom before filling, and weekly treatments of 20 pounds manure and 30 pounds 18-46-0. Water temperatures were in the low 50° range which was not conducive to plankton production.

The fry were fed in a holding house tank on 50 percent protein trout starter diet until March 23 at which time plankton samples showed that there was enough plankton to support the fry. After stocking, samples were taken and stomach analysis showed that the majority of food items eaten for the first 3 weeks were rotifers.

# GENERAL OBSERVATIONS

Razorback sucker adults are very docile and present little problem in handling. The method of grasping the fish on the caudle peduncle area

and cradling the head is a technique that seems to quiet channel catfish during handling but works adversely with razorback sucker adults. When suckers are grasped by the "tail" they immediately struggle. The method that seemed to work best was to cradle the fish under the head and under the peduncle area.

The adults are susceptable to seining, the fish are docile and can be circled with a seine without difficulty.

This test gave indications that razorback suckers may be intermittent spawners during the late winter and early spring. Observations and microscopic examinations of the ovaries showed no clear-cut differences in eggs with the exception of one female that clearly showed two sizes of eggs. The results from hormone injections and observations of eggs is the major basis for this hypothesis. The eggs obtained from females would contain eggs that were overripe, eggs that were viable, and eggs that appeared to be too green to be fertilized.

There were two factors that may have influenced the spawning and egg viability in a negative manner. The transport of the fish from Lake Mohave when they were ripe. Observations of the eggs that were ovulated on arrival showed that these eggs were overripe. The trauma of capture and transfer may have influenced abnormal spawning and egg viability. The age of the fish most probably influenced the spawning success of these fish. Five females were dissected after death that exhibited ovaries that were atrophied and most probably would never spawn again. Experience with other species have shown that old broodfish do not perform well.

The time of year that ripe fish were obtained most probably had an effect on their spawning in the ponds. The water temperatures in our ponds vary greatly during this time of year, and temperatures as much as 10 to 12° F below that of the water from which they were removed could only have had a negative effect on spawning. It is hopeful that the maintenance of the remaining brood fish on Dexter National Fish Hatchery will retard spawning and eliminate the transport and temperature problems when fish are spawned next year. Adults reared on this culture station will most probably enhance the propagation program of razorback suckers.

The time of year that this species spawn makes it difficult to prepare rearing ponds. When water temperatures are in the lower 50° F it is difficult to develop predictable zooplankton blooms in the ponds. The timing of the blooms with the advent to fry will continue to be a problem.

## RECOMMENDATIONS FOR 1982 SPAWNING SEASON

a. The flow through pond with a gravel bed placed on a liner needs to be tried with ripe females.

b. Injections of chorionic gonadotropin at 300, 400, and 500 IU per pound with hand stripping and fertilization of eggs.

c. Circular tank spawning with ripe females in conjunction with daily injections of chorionic gondadotropin of 300, 400, and 500 IU per pound.

d. Egg hatching in Heath incubators, circular tanks and/or trans suspended in tanks.

e. Fungus control of eggs in Heath incubator with 10 minute flow through treatments of 1:100 formalin daily for the first 4 days or at least the 2nd and early on the 4th day after fertilization.

f. Start preparing rearing ponds at least 2 weeks to 1 month in advance, depending on temperature, of anticipated spawning to have zooplankton available for swim-up fry.

g. Closer measurement and monitoring of viable vs nonviable eggs during hatching.

h. Start a year class in 1981 to be held for future brood fish.

REPORT NO. 3

# CULTURE OF ENDANGERED COLORADO RIVER FISHES

## SECTION IV

## SPAWNING AND CULTURE OF HUMPBACK CHUB

by

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## INTRODUCTION

The humpback chub (Gila cypha) was one of the last freshwater fishes to be discovered in North America (Miller 1946). Although endemic to the Colorado River Basin, before 1950 it was known only to the Grand Canyon of Arizona.

The humpback chub can now be found sporadically in canyon areas of rivers in the upper (Joseph et al. 1977; Behnke and Benson 1980) and lower (Suttkus et al. 1976; Suttkus and Clemmer 1977) basin; however, it is considered in danger of extinction. The humpback chub is listed as an endangered species by the states of Arizona, Colorado, Utah, and Wyoming (Deacon et al. 1979), and by the U.S. Department of the Interior (1980).

The purpose of the present study was to test and develop techniques for the spawning and culture of humpback chub, and to supply hatchery-reared test fish for scientific studies. This study reports on the successful spawning of wild brood stock, and presents culture data for the progeny during 1981 at Willow Beach (Arizona) National Fish Hatchery.

## METHODS

### Brood Stock

The brood stock consisted of 14 wild adults from the Little Colorado River (LCR) and 16 wild adults from the Colorado River (CR). The LCR fish were collected May 17, 1978, October 17, 1979, and June 13, 1980, near the confluence with the Colorado River, Grand Canyon National Park, Ariz. The CR fish were collected November 5, 1979, at Black Rocks, near Grand Junction, Colo.

### Spawning (Hand Stripping)

A total of 16 humpback chubs (CR) were used in this spawning trial. Ripening of sex products was induced by injections of carp pituitary (Ball and Bacon 1954; Clemens and Sneed 1962). Acetone-dried carp pituitary (40 mg) was mixed with a solution of oxytetracycline hydrochloride (10 mL) and injected 4 mg/kg body weight at 24 h intervals (Hamman 1981). Before the intraperitoneal injection, fish were anesthetized with tricaine methanesulfonate at 50-100 mg/L (Leithritz 1960), and afterwards placed in a holding tank (6.0 X 0.75 X 0.75 m) until hand stripping was attempted. Warm water (21-22° C) flowed through the tank at the rate of 23 L/min. Spawning of humpback chubs is believed to occur when the water temperature reaches 18° C (U.S. Fish and Wildlife Service 1979).

When eggs could be expelled from a female with slight pressure, she was anesthetized and wiped dry before the eggs were stripped into a plastic pan. Milt from one male was added to the eggs, and water was added to activate the sperm. To prevent clumping, eggs were stirred and washed for 45 minutes, until water hardening occurred. Eggs were then poured on screen trays (53 x 53 cm) covered with 1.4-mm hardware cloth which were, in turn, placed in four aluminum troughs (3.5 x 0.55 x 0.3 m) and slanted at a 30 degree angle into the incoming water. Warm water (21-22° C) entered two troughs, cool water (16-17° C) entered one trough, and cold water (12-13° C) entered the fourth trough, all at 8 L/min.

## Spawning (Natural)

Spawning facilities consisted of two concrete raceways (30.5 x 2.4 x 1.2 m) and were designated as A9 and A10. These raceways were connected to allow water recirculation to obtain the warmer temperatures (at least 18° C) believed to be necessary for spawning. Water was pumped to the upper end of A9 from the adjacent raceway (A10) by a 1-hp fresh-flo pump at 0.02 $m^3/s$, flowed to the lower end, and returned to A10 by gravity. Two layers of spawning substrate were placed in the uppermost 10 m of raceway A9. The bottom layer consisted of boulders (30-40 cm) and the top layer cobble (4-10 cm in diameter). Water introduced at the upper end flowed through the substrate, creating an artificial spawning environment. Water depth over the substrate ranged from 10 to 76 cm. A total of 14 humpback chubs (LCR) were injected with 4 mg carp pituitary per kilogram of body weight, and allowed to spawn natural on the cobble substrate. Adults were removed from the raceway as soon as the eggs began hatching.

## Rearing Facilities

Swim-up fry were transferred to two recirculating systems or four concrete raceways (30.5 x 2.4 x 1.2 m) and were designated as A9 and A10, and C1 and C2. Water was recirculated by a 1/3-hp fresh-flo pump at 0.01 $m^3/s$. These raceways were filled one week before spawning (except A9 and A10) to obtain warmer water temperatures; small amounts of inorganic (ammonium phosphate) and organic (commercial trout starter) fertilizers were added to produce a plankton bloom. Zooplankton, predominately cladocerans, were observed in 10 days.

Measurements of egg diameter, newly hatched larvae, and fingerlings were to the nearest 0.1 mm, and weights were to the nearest 0.1 mg. The number of eggs spawned naturally by wild fish on the cobble substrate were estimated by visual observations, while the number of larvae hatched were based on the fertility rate of eggs.

# RESULTS

Males exhibited orange to red-orange breeding colors on the pectoral and pelvic fins, anal fin, and entire lower sides when spawning began May 5, 1981, water temperature 19° C). Females were light orange on the

sides and at the base of the pectoral and pelvic fins, and anal fin. Females were normally larger than the males (Table 1). Males and females also possessed fine tubercles on the head, operculars, and paired fins. All males were producing seminal plasma with active sperm, however, no sex products could be expressed from the females until after hormonal injections.

## Natural Spawning

The humpback chubs in raceway A9 were closely observed. Nine females spawned (May 5-6, 1981) within 24 h of receiving the carp pituitary injection. The spawning area covered 1.0 x 2.4 m in a water depth of 35 to 45 cm; water temperatures were 19-20° C. An estimated 30,000 eggs were spawned naturally by the nine females. Egg diameters varied from 2.6 to 2.9 mm (mean, 2.8 mm). Since all the eggs were adhering to the cobble, they were allowed to hatch on the substrate.

## Hand Stripping

Eight females ovulated (June 1-4, 1981) 20 h after receiving the first injection and one female failed to ovulate after receiving three injections. Egg diameters ranged from 2.6 to 2.8 mm (mean, 2.7 mm); volumetric measurements varied from 51 to 58 eggs/mL (mean, 55 eggs/mL). Total fecundity was 20,185 (mean, 2,523/female) or 5,262 eggs/kg of body weight (Table 2).

## Incubation and Hatching

Hatching began in raceway A9 (water temperature 19-20° C) at 115 h and was completed at 160 h; total lengths of newly hatched fry averaged 7.1 mm (Table 3). Eggs placed on the slanted screen trays in water temperatures of 21-22° C, 16-17° C, and 12-13° C began hatching at 102, 167, and 340 h, respectively, and hatching was completed at 146, 266, and 475 h, respectively; total lengths of these newly hatched fry averaged 6.9 mm (Table 3).

## Culture

When the fry started swimming to the surface in the hatching troughs, about 72 h after hatching, a total of 12,381 were transferred to raceways C1 and C2. The fry (23,940) which hatched on the cobble substrate were cultured in raceways A9 and A10.

During the first 2 weeks the fry were very active and could be seen feeding near the surface on zooplankton. A schooling behavior was observed and continued through the duration of the present study.

Continuous water temperature recordings and weekly carbon dioxide, ammonia nitrogen, dissolved oxygen, and pH analysis were taken to determine water quality during culture conditions (Table 4). With the

Table 1

Comparison of total lengths and weights of wild humpback chubs being held at Willow Beach (Arizona) National Fish Hatchery as of May 5, 1981

| Fish (ages unknown) | Number | Length (mm) | | Weight (g) | |
|---|---|---|---|---|---|
| | | Mean | Range | Mean | Range |
| Little Colorado River | | | | | |
| Females | 9 | 395 | 372-425 | 588 | 494-730 |
| Males | 5 | 355 | 315-378 | 329 | 260-470 |
| Colorado River | | | | | |
| Females | 9 | 382 | 355-409 | 507 | 350-730 |
| Males | 7 | 357 | 327-378 | 370 | 268-460 |

Table 2

Summary of data for hand stripping female humpback chubs during 1981 at Willow Beach (Arizona) National Fish Hatchery

| Total length (mm) | Weight (grams) | Dosage (mg/kg[1/] at 24-hour intervals) | Number of injections | Fecundity (number) | Fertility (percent) |
|---|---|---|---|---|---|
| 409 | 730 | 4.0 | 3 | 0 | 0 |
| 387 | 540 | 4.0 | 1 | 3,520 | 80 |
| 406 | 690 | 4.0 | 1 | 5,445 | 77 |
| 401 | 560 | 4.0 | 1 | 3,795 | 92 |
| 361 | 400 | 4.0 | 1 | 1,485 | 46 |
| 390 | 500 | 4.0 | 1 | 2,805 | 83 |
| 372 | 416 | 4.0 | 1 | 1,925 | 85 |
| 355 | 350 | 4.0 | 1 | 880 | 57 |
| 359 | 380- | 4.0 | 1 | 330 | 0 |

1/ Milligrams of acetone-dried carp pituitary per kilogram wet weight of fish.

Table 3
Summary of data for incubating eggs of humpback chub at four different water temperatures

| Incubation data | Water temperature (°C) 21-22 | 19-20 | 16-17 | 12-13 |
|---|---|---|---|---|
| Mode of fertilization | | | | |
| Artificial (A) | A | | A | A |
| Natural (N) | | N | | |
| Number of eggs | 1/ 19,910 | 2/ 30,000 | 165 | 110 |
| Egg size (mm) | 2.7 | 2.8 | 2.7 | 2.7 |
| First cleavage (hours) | 3 | 3 | 4 | 6 |
| Embryo developed (hours) | 70 | 75 | 105 | 205 |
| Hatching began (hours) | 102 | 115 | 167 | 340 |
| Size of fry (mm) | 6.9 | 7.1 | 6.9 | 6.9 |
| Hatching ended (hours) | 146 | 160 | 266 | 475 |
| Percent hatch | 79 | 84 | 62 | 12 |
| Numbers hatched | 3/ 15,207 | 4/ 25,200 | 102 | 13 |
| Age of swim-up fry (hours) | 72 | 72 | 120 | 168 |
| Percent swim-up | 99 | 95 | 91 | 17 |
| Numbers of fry | 12,381 | 2/ 23,940 | 4/ 93 | 4/ 2 |

1/ A total of 660 eggs were transferred to Utah State University at Logan.

2/ These numbers were estimates and not actual counts.

3/ A total of 2,700 fry were transferred to University of Idaho at Moscow.

4/ Fry were preserved in 10% formalin for developmental series.

Table 4
Water analysis summary for culturing larval humpback chubs in two recirculating systems

| Water analysis | Month (1981) A9 and A10 May | A9 and A10 June | C1 and C2 June | C1 and C2 July |
|---|---|---|---|---|
| Temperature (°C) | | | | |
| Mean | 18.40 | 21.80 | 21.70 | 22.30 |
| Range | 17.20-20.50 | 18.30-25.50 | 20.00-23.90 | 12.80-23.90 |
| Dissolved oxygen (mg/L) | | | | |
| Mean | 9.87 | 9.35 | 9.82 | 8.96 |
| Range | 9.10-10.40 | 9.10- 9.60 | 8.55-10.60 | 8.75- 9.25 |
| Carbon dioxide (mg/L) | | | | |
| Mean | 2.73 | 2.57 | 2.73 | 3.00 |
| Range | 2.24- 3.65 | 2.11- 3.43 | 2.20- 3.12 | 2.24- 4.00 |
| Ammonia nitrogen (mg/L) | | | | |
| Mean | 0.02 | 0.25 | 0.03 | 0.08 |
| Range | 0.01- 0.04 | 0.01- 0.59 | 0.02- 0.04 | 0.04- 0.13 |
| pH (units) | | | | |
| Mean | 8.35 | 8.24 | 8.68 | 8.03 |
| Range | 8.15- 8.70 | 8.05- 8.40 | 8.55- 8.75 | 7.90- 8.15 |

exception of the pH exceeding 8.5 units on numerous occasions, water quality was not a problem.

On day 28, zooplankton began declining and a dry diet (commercial trout starter) was supplemented. The fry were fed 4 to 5 times daily (0.25 to 0.50 kg per system per day). By day 35 most fish were accepting this prepared diet. On several occasions, river water (12-13° C) was introduced to the recirculating systems to compensate for evaporation. This addition of cold water would normally lower the temperature 7° C in 2 h. A benthic feeding behavior was observed as the water temperature decreased, and as the water temperature increased, the fish began feeding near or at the surface.

Weekly samples of fish were collected to determine growth rates (Table 5). On day 56, a total of 19,857 fingerlings (30.3-44.2 mm and 361.6-923.2 mg) were removed from raceways A9 and A10, and 9,318 fingerlings (43.2-51.1 mm and 720.5-1 006.4 mg) were removed from raceways C1 and C2; survival rates were 83 and 75 percent, respectively. The fish had attained a 5.2 to 6.9-fold increase in total length during 56 days.

## DISCUSSION

Several important reproductive and early life history characteristics were documented in the present study: (1) estimated fecundity rate for female humpback chub (5,262 eggs/kg of body weight); (2) egg size after water hardening (2.6 to 2.9 mm in diameter); (3) incubation periods for eggs (102-146 h at 21-22 C, 115-160 h at 19-20° C, 167-266 h at 16-17° C, and 340-475 h at 12-13° C); (4) size of newly hatched larvae (6.7 to 7.4 mm total length and 2.8 to 4.2 mg weight); and (5) growth rate for larval fish cultured in a recirculating system (29.8-40.6 mm and 584.6-883.9 mg gain during 56 days at Willow Beach National Fish Hatchery).

Suttkus and Clemmer (1977) stated that humpback chubs probably spawn during June and July in the Grand Canyon, while Holden (1978) indicated that spawning may occur during May and June in the Desolation Canyon; this was based on gravid females, ripe males, and YOY individuals collected from the Little Colorado River, Arizona, and the Green River, Utah. During the present study, spawning occurred in May (Little Colorado River) and June (Colorado River) when the water temperatures were 19-20° C and 21-22° C. This study indicates that lower basin (Little Colorado River) humpback chubs spawn earlier (May) than upper basin (Colorado River) humbpack chubs (June). Spawning temperatures probably range from 19-22° C.

The present study established two techniques which may be used for the propagation of humpback chub: (1) injecting and natural spawning; and (2) injecting, hand stripping, and artificial fetilization. Comparing the two techniques, natural spawning produced 23,940 swim-up fry and 19,857 fingerlings for a 83 percent survival, while artificial spawning produced 12,381 swim-up fry and 9,318 fingerlings, for a 75 percent survival.

Table 5
Growth rate for larval humpback chubs cultured during 1981
at Willow Beach (Arizona) National Fish Hatchery

| | Little Colorado River progeny | | | | Colorado River progeny | | | |
|---|---|---|---|---|---|---|---|---|
| | Total length (mm) | | Weight (mm) | | Total length (mm) | | Weight (mg) | |
| Day | Mean[1/] | Range | Mean[1/] | Range | Mean[1/] | Range | Mean[1/] | Range |
| [2/] 1 | 7.1 | 6.8- 7.4 | 3.9 | 3.8- 4.2 | 6.9 | 6.7- 7.3 | 3.5 | 2.8- 3.7 |
| 7 | 10.2 | 10.0-10.6 | 5.1 | 4.7- 5.7 | 9.6 | 9.0- 9.8 | 4.7 | 4.0- 5.4 |
| 14 | 10.7 | 10.0-11.8 | 6.9 | 5.5- 10.6 | 11.5 | 10.8-12.9 | 9.7 | 7.2- 15.4 |
| 21 | 12.0 | 10.8-14.8 | 14.3 | 9.6- 21.4 | 17.1 | 13.6-18.4 | 43.2 | 15.6- 54.0 |
| 28 | 15.2 | 10.8-19.8 | 33.8 | 18.6- 78.2 | 24.9 | 22.7-27.2 | 144.9 | 115.8- 188.3 |
| 35 | 22.4 | 18.9-25.7 | 101.0 | 59.0-152.1 | 32.9 | 30.0-35.1 | 358.3 | 298.4- 448.4 |
| 42 | 30.3 | 22.9-35.7 | 309.1 | 140.4-427.9 | 38.6 | 34.0-40.9 | 525.8 | 397.6- 649.2 |
| 49 | 33.3 | 30.1-37.7 | 393.2 | 304.6-531.8 | 41.4 | 35.9-45.9 | 670.6 | 540.0- 920.1 |
| 56 | 36.9 | 30.3-44.2 | 588.5 | 361.6-923.2 | 47.5 | 43.2-51.1 | 887.4 | 720.5-1,006.4 |

1/ Mean total length and weight of 10 fish per sample.
2/ Age of newly hatched larvae.

The decline of the humpback chub has been attributed to loss of habitat created by dams (Vanicek et al. 1970; Holden and Stalnaker 1975; Suttkus and Clemmer 1977; Smith et al. 1979), reduced flows below cold and fluctuating tailwaters of dams (Joseph et al. 1977), and hybridization (Holden and Stalnaker 1970; Minckley 1973). The fact that 88 percent of the eggs and 83 percent of the larvae incubated at water temperatures of 12-13° C died suggests that cold water temperatures below dams may be one cause for the decline of the humpback chub. Hybridization may also occur in the natural environment since bonytail chubs (Gila elegans) have been artificially hybridized with humpback chubs at Willow Beach (Arizona) National Fish Hatchery (Hamman 1981).

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REPORT NO. 3

# CULTURE OF ENDANGERED COLORADO RIVER FISHES

## SECTION V

## INDUCED SPAWNING AND CULTURE OF BONYTAIL CHUB

by

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1982

## INTRODUCTION

Little is known about the biology of the bonytail chub (Gila elegans), a species of cyprinid endemic to the Colorado River basin. Once abundant throughout the upper and lower basin (Cope and Yarrow 1875), the bonytail chub has experienced the most abrupt decline of any fish native to the mainstreams.

In the upper basin, the only bonytail chubs reported in recent years were from the Green River in Utah (Behnke and Benson 1980); although it can occasionally be found in the reservoir areas of Lakes Havasu and Mohave in the lower basin (Minckley 1973), it is considered in danger of extinction. The bonytail chub is listed as an endangered species by the states of Arizona, California, Colorado, Nevada, Utah, and Wyoming (Deacon et al. 1979), and by the U.S. Department of the Interior (1980).

The purpose of the present study was to develop and test techniques for the spawning and culture of bonytail chub. This study reports on the first successful spawning of genetically pure bonytail chub in captivity and presents culture data for the progeny during 1981 at Willow Beach (Arizona) National Fish Hatchery.

## METHODS

The brood stock consisted of six wild females and five wild males collected from Lake Mohave, near Cottonwood Cove, April 30 - May 1979, April 29 - May 3, 1980, and March 11-12, 1981. Total lengths and weights of the captured specimens were 487-564 mm and 956-2,500 g (females), and 454-480 mm and 728-870 g (males).

Ripening of sex products was induced by injections of carp pituitary (Ball and Bacon 1954; Clemens and Sneed 1962). Acetone-dried carp pituitary (42 mg) was mixed with a solution of oxytetracycline hydrochloride (10 mL) and injected 4 mg/kg body weight at 24 h intervals (Hamman 1981). Before the intraperitoneal injection, fish were anesthetized with tricaine methanesulfonate at 50-100 mg/l (Leitritz 1960), and afterwards placed in a holding tank (6.0 X 0.75 X 0.75 m) until hand stripping was attempted. Warm water (22° C) flowed through the tank at the rate of 23 L/min. Spawning of bonytail chubs is believed to occur when the water temperature reaches 18° C (Vanicek and Dramer 1969; U.S. Fish and Wildlife Service 1979).

When eggs could be expelled from a female with slight pressure, she was anesthetized and wiped dry before the eggs were stripped into a plastic pan. Milt from one male was added to the eggs, and diluent (Billard 1977) at 12,000 mg/L was added to activate sperm. To prevent clumping, eggs were stirred and washed for 45 min until water hardening

occurred. Eggs were then poured on screen trays (53 x 53 cm) covered with 1.4 mm mesh hardware cloth which were, in turn, placed in four aluminum troughs (3.5 x 0.55 x 0.3 m) and slanted at a 30 degree angle into the incoming water. To determine incubation periods at different water temperatures, warm water (20-21° C) entered two troughs, cool water (16-17° C) entered one trough and cold water (12-13° C) entered the slanted at a 30 degree angle into the incoming water. To determine incubation periods at different water temperatures, warm water (20-21° C) entered two troughs, cool water (16-17° C) entered one trough and cold water (12-11° C) entered the fourth trough, all at 7.5 L/min.

The day after swim-up, fry were transferred to an outside recirculating system consisting of two concrete raceways (30.5 x 2.4. 1.2 m) and were designated as B1 and B2. These raceways were connected to allow water recirculation necessary for obtaining warmer temperatures. Water was pumped to the upper end of B1 from the adjacent raceway (B2) by a 1/3-hp fresh-flo pump at 0.01 $m^3/s$, flowed to the lower end, and returned to B2 by gravity. The raceways were filled 1 week before spawning; small amounts of inorganic (ammonium phosphate) and organic (commercial trout starter) fertilizers were added to produce a plankton bloom. Ten days after the fertilizers were added, zooplankton (predominately cladocerans) began appearing.

## RESULTS

Males and females were possessing fine tubercles on the head, operculars, and pectoral and pelvic fins when spawning began (May 4, 1981) water temperature 20° C. Breeding males also had a light orange coloration at the base of the pectoral and pelvic fins; breeding colors were not present on the females. All males were producing seminal plasma with active sperm; however, no sex products could be expressed from any female until after hormonal injections.

Five females ovulated 18 to 20 h after receiving the first injection, while one female failed to ovulate after receiving three injections. Egg diameter ranged from 2.0 to 2.3 mm (mean 2.2 mm); volumetric measurements varied from 103 to 151 eggs mL (mean 130 eggs mL). Total fecundity was 125,450 (mean, 25,090 female) or 21,514 eggs/kg of body weight (Table 1).

### Incubation and Hatching

Eggs placed in the warm water (20-21° C) began hatching at 99 h and were completely hatched by 174 h; total length of newly hatched fry averaged 6.8 mm (Table 2). During the incubation period at 20-21° C, dissolved oxygen ranged from 9.25 to 9.50 mg/L, ammonia nitrogen from 0.03 to 0.04 mg/L, carbon dioxide from 2.77 to 2.95 mg/L, pH from 8.00 to 8.05 units and water hardness from 325 to 355 mg/L.

Eggs placed in the cool water (16-17° C) began hatching at 170 h and hatching was completed by 269 h; newly hatched fry averaged 6.8 mm

in total length (Table 2). Eggs placed in the cold water (12-13° C) began hatching at 334 h and were finished by 498 h; total length of these newly hatched fry also averaged 6.8 mm (Table 2).

## Culture

When the fry began swimming to the surface 48 to 120 h after hatching, a total of 26,438 were placed in raceways B1 and B2; the remaining 80,000 fry were transferred to Dexter National Fish Hatchery at Dexter, New Mexico.

During the first 14 days the fry were very active and could be seen feeding near the surface. These small fish (9.7 mm TL) were observed swimming in schools, but by day 21 (11.5 mm TL) the fry scattered throughout the recirculating system. This nonschooling behavior was believed due to the decline in zooplankton which also occurred by the third week.

Fry were fed a supplemental diet (commercial trout starter) beginning on day 21. The fish were fed four to five times daily (0.25 to 0.50 kg of feed per day). By day 28, most fish were readily accepting this prepared diet. A schooling behavior was again observed on day 28 (18.1 mm TL) and continued through day 70.

Through the duration of the present study, carbon dioxide ($CO_2$), ammonia nitrogen ($NH_3$-N), dissolved oxygen ($O_2$), and pH analysis were recorded (weekly) to determine water quality during culture conditions (Table 3). With the exception of the pH exceeding 8.5 units and ammonia nitrogen exceeding 0.50 mg/L on several occasions, water quality was not a major problem.

On day 42 (31.1 mm TL), Ichthophthirius multifiliis was microscopically observed on two dead fish. To prevent further losses, this protozoan was controlled using multiple treatments of formalin at 15 mg/L (Allison 1957). By day 49, the parasite was believed to be eliminated, however weekly prophylactic treatments were contined to prevent unnecessary outbreaks.

Weekly samples of fish were collected to determine growth rates (Table 4). On day 70, a total of 18,775 fingerlings (mean, 49.5 mm and 974.6 mg) were removed from raceways B1 and B2; survival rate was 71 percent. The fish had exhibited a 7-fold increase in total length and a 348-fold increase in weight during 70 days.

## DISCUSSION

The present study was able to document several reproductive and early life history characteristics not previously reported: 1) estimated fecundity rate for female bonytail chub (21,514 eggs/kg of body weight); 2) egg size after water hardening (2.2 mm in diameter); 3) incubation periods (99-174 h at 221° C, 170-269 h at 16-17° C, and 334-498 h at

Table 1
Summary of data for spawning female bonytail chubs during May 1981 at Willow Beach (Arizona) National Fish Hatchery

| Total length (mm) | Weight (grams) | Dosage mg/kg[1/] at 24-hour intervals) | Number of injections | Fecundity (Numbers) | Fertility (percent) |
|---|---|---|---|---|---|
| 533 | 1,280 | 4.0 | 3 | 0 | 0 |
| 487 | 1,160 | 4.0 | 1 | 27,300 | 97 |
| 492 | 1,065 | 4.0 | 1 | 22,100 | 94 |
| 564 | 1,500 | 4.0 | 1 | 32,500 | 95 |
| 518 | 1,150 | 4.0 | 1 | 37,700 | 91 |
| 511 | 956 | 4.0 | 1 | 5,850 | 98 |

1/ Milligrams of acetone-dried carp pituitary per kilogram wet weight of fish.

Table 2
Summary of data for incubating eggs of bonytail chub at three different water temperatures

| Incubation data | Water temperature (°C) | | | |
|---|---|---|---|---|
| | 20-21 | 20-21 | 6-17 | 12-13 |
| Number of eggs | 80,600 | 37,700 | 5,850[1/] | 1,300 |
| Egg size (mm) | 2.2 | 2.2 | 2.2 | 2.2 |
| First cleavage (hours) | 3 | 3 | 4 | 5 |
| Embryo forming (hours) | 22 | 24 | 29 | 52 |
| Embryo developed (hours) | 68 | 69 | 101 | 162 |
| Pigmented eyes (hours) | 76 | 79 | 133 | 222 |
| Hatching began (hours) | 4.1 | 4.45 | 7.08 | 13.9 |
| Size of fry (mm) | 6.8 | 6.8 | 6.8 | 6.8 |
| Hatching ended (hours) | 6.87 | 7.25 | 11.2 | 20.75 |
| Percent hatch | 91 | 88 | 55 | 4 |
| Numbers hatched | 73,346 | 33,176 | 1,787 | 52 |
| Age of swim-up fry (hours) | 48 | 48 | 72 | 120 |
| Percent swim-up | 98 | 99 | 96 | 25 |
| Numbers of fry | 71,879 | 32,844 | 1,715 | 13 |

1/ A total of 2,600 eggs were transferred to Utah State University at Logan.

Table 3
Water analysis summary for culturing larval bonytail chubs in a recirculating system

| Water analysis | Month (1981) May | June | July |
|---|---|---|---|
| Temperature | | | |
| Mean | 19.50 | 22.20 | 21.90 |
| Range | 18.30-21.10 | 19.40-24.40 | 12.80-24.40 |
| Carbon dioxide (mg/L) | | | |
| Mean | 2.85 | 3.19 | 2.66 |
| Range | 2.02-4.40 | 1.80-3.92 | 2.17-3.17 |
| Ammonia nitrogen (mg/L) | | | |
| Mean | 0.03 | 0.22 | 0.44 |
| Range | 0.01-0.07 | 0.01-0.58 | 0.16-0.81 |
| Dissolved oxygen (mg/L) | | | |
| Mean | 9.08 | 8.50 | 9.35 |
| Range | 7.95-10.00 | 7.60-9.50 | 9.15-9.65 |
| pH (units) | | | |
| Mean | 8.49 | 8.06 | 8.27 |
| Range | 8.15-9.00 | 7.80-8.75 | 8.05-8.40 |

Table 4
Growth rate for larval bonytail chubs cultured in a recirculating system at Willow Beach (Arizona) National Fish Hatchery

| Age (days) | Total length (mm) Mean 1/ | Range | Weight (mg) Mean 1/ | Range |
|---|---|---|---|---|
| 2/ 1 | 6.8 | 6.7-6.9 | 2.8 | 2.3-3.4 |
| 7 | 8.2 | 7.3-9.1 | 3.6 | 2.8-4.5 |
| 14 | 9.7 | 8.4-12.6 | 6.4 | 4.6-14.4 |
| 21 | 11.5 | 10.2-14.1 | 8.7 | 5.7-16.8 |
| 28 | 18.1 | 16.3-20.1 | 48.0 | 33.1-70.7 |
| 35 | 20.2 | 19.1-21.6 | 76.4 | 62.8-89.0 |
| 42 | 31.1 | 26.7-35.9 | 278.2 | 179.4-397.3 |
| 49 | 36.1 | 30.6-43.9 | 448.7 | 853.3-746.2 |
| 56 | 38.8 | 33.3-46.7 | 692.8 | 341.8-839.9 |
| 63 | 43.6 | 36.7-47.8 | 740.7 | 466.1-910.3 |
| 70 | 49.5 | 42.9-54.3 | 974.6 | 714.1-1,326.8 |

1/ Mean total length and weight of 10 fish per sample.
2/ Age of newly hatched larvae.

12-13° C); 4) total length and weight of newly hatched larvae (6,8 mm and 2.8 mg); and 5) growth rate for larval fish cultured in a recirculating system (42.7 mm and 971.8 mg gain during 70 days at Willow Beach National Fish Hatchery).

Vanicek and Kramer (1969) determined that bonytail chubs apparently spawn in June and July when the water temperature reaches 18° C; this was based on the collection of gravid females, ripe males, and the appearance of juvenile fish in the upper Green River. During the present study, spawning occurred in May at water temperatures of 20-21° C. Although spawning was induced by hormonal injections, natural spawning of bonytail chub has been observed in Lake Mohave during May (Jonez and Sumner 1954). Based on the three different egg incubation temperatures used in this study (Table 2), the optimum reproductive temperature is probably 20-21° C.

The decline of the bonytail chub is believed to revolve around the construction of dams which created cold water temperatures and reductions in water flows (Joseph, et al. 1977), and loss of habitat (Smith, et al. 1979). The fact that 96 percent of the eggs incubated at cold water temperatures (12-13° C) failed to hatch suggests one cause for the decline of this species--thus eggs may not survive the low water temperatures below dams.

Another reason for the decline of the bonytail chub is the possibility of hybridization between the roundtail chub (Gila robusta) and humpback chub (Gila cypha) in the upper Colorado River (Holden and Stalnaker 1970; Minckley 1973). It is apparent natural hybridization may occur because bonytail chubs have been artificially hybridized with roundtail and humpback chubs at Willow Beach (Arizona) National Fish Hatchery (Hamman 1981).

The future of the bonytail chub may depend on hatchery propagation as the key role in the restoration of the species. In addition to providing specimens for the restocking of selected former habitats and supplementing current populations, these culture efforts provide an opportunity to study the fish under hatchery conditions. Based on captive and cultured specimens, much can and is now being learned about the reproductive, early life history and preferences of the fish. This information may be necessary to insure the survival of the species.

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REPORT NO. 4

# DISEASE SURVEY OF THE COLORADO RIVER FISHES

by

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1981

## INTRODUCTION

A two-year survey of the pathogens of the fishes of the Colorado River drainage was conducted. Three objectives were pursued in this study: (1) determine the health status of endangered fish populations; (2) determine whether disease agents associated with exotic fish species have adversely affected endangered fishes, and (3) identify potential problems for hatchery propagation of endangered fishes.

## METHODS

Collection and anlysis methods employed were those outlined by the Fish Health Section of the American Fisheries Society (1979).

## RESULTS

### Pathogens of Endangered Fishes

Ninety-one endangered fishes were examined during the two-year survey. Apendix A lists the pathogens recovered and the endangered fish species in which they were found. Appendix B lists the individual specimens and the pathogens recovered. No virus was detected from any specimen. Several species of bacteria were isolated but all were of a saprophytic nature ubiquitous in the aquatic environment. An unidentified protozoan of the genus Myxobolus was detected in several organs (gill, liver, spleen, kidney, intestine, and skin) from all species of endangered fishes. This Myxobolus is probably an undescribed species (Hoffman, personal communication). A Myxidium sp. was recovered from the gall bladder on one Gila elegans and is probably an undescribed species (Hoffman, personal communication). This same Myxidium sp. was found in the gall bladder of one Gila robusta. Tetrahymena sp., a ciliated protozoan, was found on the skin and gills of hatchery held G. cypha. Amoebae were found on the gills of a number of G. cypha specimens. The common hatchery protozoan parasites Apiosoma, Ambiphrya, and Chilodonella were found on hatchery held G. cypha. Trichodina sp. was recovered from one Ptychocheilus lucius specimen. The only trematode recovered was one larval specimen of Ornithodiplostomum from two P. lucius. The tapeworm Proteocephalus ptychocheilus was found in six P. lucius specimens and occasionally was abundant in the intestine. The nematode Philometra was found in the body cavity of one G. cypha. Lernaea cyprinacea was frequently encountered in all endangered species.

### Pathogens of Exotic and Other Endemic Fishes

A total of 97 specimens of exotic and other endemic fishes were examined. Exotic and other endemic fishes harbored a greater variety of

disease agents (Appendix A). Perhaps this results from greater species diversity. The only virus identified in the study was recovered from Lepomis cyanellus. The virus was Lymphocystis and it is neither highly pathogenic nor highly contagious. Bacterial isolates were similar to those of the endangered species but again common in aquatic environments. Noteworthy in the protozoan category was the recovery of the same undescriber Myxobolus sp. Gila robusta, Catostomus latipinnis, and Catostomus Discobolus and the same undescribed Myxidium sp. in G. robusta the larval genus Neascus was represented by Posthodiplostomum minimum and Uvulifer ambloplitis in five fish species. The larval cestode Ligula was found in Micropterus dolomieui and L. cyanellus. Adult Corallobothrium was recovered from Ictalurus punctatus and the caryophyllaeid genera Hunterella and Isoglaridaeris from C. latipinnis. Nematodes encountered were Capillaria sp. from M. dolomieui, Rhabdochona pellucida in G. robusta and Philometra cylindracea in the body cavity of Notropis lutrensis. Lernaea cyprinacea appeared to be common to many fish species.

## Health Status of Endemic Fishes

Endemic fishes were a relatively healthy group of fishes. The absence of any detectable virus is not surprising in that most viruses are enzootic in feral populations and rarely are expressed in an epizootic form. These findings do not preclude the possibility of the existence of an enzootic virus in some form but do indicate that virus is not a limiting factor in the endemic fish populations.

Bacterial isolates most frequently encountered were Aeromonas hydrophila and Pseudomonas spp. These organisms are often found as residents of the normal flora of fish and cause mortality when the host-pathogen relationship is tilted to favor the pathogen. These bacterial species were found as systemic pathogens in spawning G. cypha, hatchery held Gila spp. and other fishes net captured and held in live boxes. The existence of recovery of these bacterial species was expected and does not pose any threat to the general health of the feral endemic fishes.

Sparolegnia was the only fungus found associated with endemic species in the study period. Saprolegnia is a facultative pathogen that attacks necrotic tissues and/or breaches in the integrity of the host's skin. Stressful conditions in hatcheries often predispose fish to Saprolegnia invasion and evidence of this was found in the Gila sp. may have resulted from osmotic imbalances due to Saprolegnia invasion. Abrasions from net capture and tagging were also prime targets for Saprolegnia but no mortalities could be attributed to this alone.

The most interesting recoveries were the protozoans. The undescribed Myxobolus sp. was found in most endemic species but not in exotic species. The undescribed Myxidium sp. was found only in the gall bladder of G. robusta and G. elegans. There appeared to be some question about the species identification of the G. elegans so it could be only G. robusta that harbors this myxosporidean. These myxosporideans appear to be species or group specific and this indicates a long-term existence with the host fishes. The Myxobolus sp. was found in nearly every

endemic specimen and a number of different organs. No pathology could be associated with the presence of the myxosporidean and this presence probably does not adversely impact on the survival and propagation of the endemic species. Tetrahymena sp. found in the hatchery reared G. cypha are generally commensal organisms unless unfavorable conditions exist for the host or the numbers of Tetrahymena become too great. Apiosoma and Ambiphrya are also common hatchery related commensal organisms and cause problems only during poor water quality conditions. Chilodonella is a protozoan that has the potential to cause significant mortalities in a hatchery situation but rarely does so in feral populations.

The Neascus of Ornithodiplostomum was recovered from two specimens of P. lucius. The species of this larval trematode has not yet been determined (Hoffman, personal communication). The larval trematodes, Posthodiplostomum minimum and Uvulifer sp., were found G. robusta. Both of these organisms are quite common and have little impact on feral fish. Since the final hosts of all three of these larval trematodes are birds, it seems unlikely that the stocking of exotic fish species would have introduced these organisms into the Colorado River system.

Perhaps the most host specific organism encountered was the cestode Proteocephalus pytchocheilus. P. lucius was the only host for this organism. It is not known if indeed this parasite is so host specific or if numbers of fish sampled were inadequate to detect the cestode in other fish species. This same parasite is known to occur in the northern squawfish Ptychocheilus oregonensis.

The only nematode recovered from an endangered species was Philometra sp. from G. cypha. Rhabdochona pellucida was found in endemic fish species G. robusta and probably does exist in some of the endangered fish species.

Lernaea cyprinacea was found in almost all species of fish sampled in the study period. This is not surprising considering Lernaea sp. are almost world-wide in distribution and have been reported from most fish species. On-site samplings seem to indicate P. lucius had greater infestations than other endemic species. This may be a result of habitat preference. Warm and sluggish waters would tend to favor Lernaea multiplication and attachment. Direct mortalities due to Lernaea infestation are rare, but do occur. Evidence gathered on site and in the laboratory indicate Lernaea is not a limiting factor in the survival of the endangered fishes.

The reproductive status and potential of the endangered fishes were not a part of this study, but on a few occasions assistance in this area was requested. Ovaries of one G. elegans from Willow Beach NFH were examined and vesicle-like structures filled with clear fluid were present on the surface of the gonads. Examination of the vesicles revealed no parasites and the formalin fixed state of the ovaries did not allow virus and bacteria sampling. One parasitologist and two other pathologists were consulted and no explanation could be found. The significance of this finding is unknown. The spawning status of one P. lucius was checked and one ovary was immature and the other degenerative and dysfunctional. Another P.lucius female (Tag #165) was examined in October

1980 for spawn status and the ovaries were found to be in a state of development but would not have spawned until the 1981 season. A sex determination was requested for a P. lucius (Tag #064) and the fish was found to be a male. Five young-of-the-year G. cypha with lordosis were submitted. No infectious basis could be found for the condition.

## Impact of Exotic Species Disease Agents on Endemic Species

As previously implied, disease agents associated with exotic species do not appear to have impacted adversely on endemic fishes. The findings indicate that a high degree of loose host specificity is involved. The endemic fishes harbor a distinctly different pathogen group than do the exotic fishes. Considering the biology of the various host specific pathogens associated with the endemic fishes, disease is likely not a factor in the demise of the endangered fish populations.

## Intensive or Extensive Culture of Endangered Fishes and Disease Implications

Extrapolation of disease data from feral populations to a hatchery situation is difficult. Certainly the type of cultural methods employed and the quality of management will have a greater effect on the success or failure than will infectious agents. The amplification of the pathogenicity of infectious agents usually occurs in a cultural situation. Many of the same problems encountered in widely cultured fish species will occur in the endangered fishes. Motile aeromonads (Aeromonas hydrophila) and pseudomonads (Pseudomonas sp.) are frequently related to significant mortalities in present cultural systems and will most likely pose a threat to the culture of endangered fishes. Saprolegnia will probably be a limiting factor in the rearing and propagation of these fishes. Many of the external protozoans, ciliates especially, already associated with hatchery fishes, may cause mortalities. Doubtless, pathogens that have existed in a successful host-pathogen relationship for thousands of years could be of consequence in a cultural situation. Although no virus was detected, if one does exist in the endangered fishes, problems will likely occur in the hatchery. Enviromental control and manipulation will be the key in maintaining healthy fish populations. This goal can only be met if the biology of the subject is known and understood.

## References Cited

American Fisheries Society, Fish Health Section, 1979. Procedures for the detection and identification of certain fish pathogens. American Fisheries Society. 118 pp.

APPENDIX A

Table A-1
Pathogens recovered from endangered fish species

| Pathogen | Code | Fish species |
|---|---|---|
| Bacteria | | |
| *Aeromonas hydrophila* | B1 | *P. Lucius, G. cypha* |
| *Pseudomonas fluorescens* | B2 | *P. lucius, G. cypha, G. elegans* |
| *Pseudomonas putrifaciens* | B3 | *P. lucius, G. cypha* |
| *Pseudomonas sp.* | B4 | *G. cypha* |
| *Pseudomonas II-$K_2$* | B5 | *G.cypha* |
| *Acinetobacter calcoaceticus* | B6 | *P. lucius, G. cypha* |
| *Aeromonas punctata* | B7 | *P. lucius* |
| *Morganella morganii* | B8 | *P. lucius, G. cypha* |
| *Escherichia coli* | B9 | *P. lucius, G. cypha* |
| *Enterobacter agglomerans* | B10 | *P. lucius, G. cypha* |
| *Enterobacter liquefaciens* | B11 | *P. lucius* |
| *Bacillus mycoides* | B12 | *G. cypha* |
| *Erysipelothrix rhysiopathiae* | B13 | *G. cypha, X. texanus* |
| *Corynebacterium equi* | B14 | *G. cypha* |
| *Bacillus sp.* | B15 | *G. cypha* |
| Fungi | | |
| *Saprolegnia* | F1 | *P. lucius, G. cypha, G. elegans* |
| Protozoa | | |
| *Myxobolus sp.* | P1 | *P. lucius, G. cypha, G. elegans, S. texanus* |
| *Myxidium sp.* | P2 | *G. elegans* |
| *Trichodina sp.* | P3 | *P. lucius* |
| *Apiosoma* | P4 | *G. cypha* |
| *Tetrahymena* | P5 | *G. cypha* |
| Gill amoebae | P6 | *G. cypha, G. elegans* |
| *Ambiphrya* | P7 | *G. cypha* |
| *Chilodonella* | P8 | *G. cypha* |
| Trematoda | | |
| *Neascus* of *Ornithodiplostomum* | T1 | *P. lucius* |
| Cestoda | | |
| *Proteocephalus ptychocheilus* | C1 | *P. lucius* |
| Nematoda | | |
| *Philometra sp.* | N1 | *C. cypha* |
| Crustacea | | |
| *Lernaea cyprinacea* | W1 | *P. lucius, G. cypha, G. elegans, X. texanus* |

Table A-2
Pathogens recovered from exotic and other endemic fish species

| Pathogen | Fish species |
|---|---|
| Virus | |
| *Lymphocystis* | *L. cyanellus* |
| Bacteria | |
| *Aeromonas hydrophila* | *M. salmoides, M. dolomieui, I. puntatus, I. melas, G. robusta, C. latipinnis* |
| *Pseudomonas fluorescens* | *G. robusta, C. latipinnis* |
| *Pseudomonas putrifaciens* | *G. robusta* |
| *Pleisomonas shigelloides* | *M. dolomieui* |
| Protozoa | |
| *Epistylis* | *M. salmoides, M. dolmieui* |
| *Henneguya sp.* | *I. puntatus* |
| | *I. puntatus* |
| *Myxobolus sp.* | *G. robusta, C. latipinnis, C. discobolus* |
| *Myxidium sp.* | *G. robusta* |
| Trematoda | |
| *Posthodiplastomum minimum* | *M. dolomieui, L. cyanellus, I. punctatus, I. melas, G. robusta* |
| *Uvulifer ambloplitis* | *L. cyanellus, G. robusta* |
| Cestoda | |
| *Ligula* | *M. dolomieui, L. cyanellus* |
| *Corallobothrium* | *I. punctatus* |
| *Hunterella* | *C. latipinnis* |
| *Isoglaridacris* | *C. latipinnis* |
| Nematoda | |
| *Capillaria sp.* | *M. dolomieui* |
| *Rhabdochona pellucida* | *G. robusta* |
| *Philometra cylindracea* | *N. lutrensis* |
| Crustacea | |
| *Lernaea cyprinacea* | *M. salmoides, L. cyanellus, I. punctatus, I. melas, G. robusta, N. lutrensis, C. latipinnis, C. discobolus* |

APPENDIX B

Table B-1
Pathogens recovered from individual fish

| Fish species and tag number | Pathogen codes (see Table A-1) |
|---|---|
| *Ptychocheilus lucius* | |
| 001 | B1, B2, B3, B7, B10, B11, F1, P1, W1 |
| 064 | B1, B3, B8, B11, F1, P1, C1 |
| 138 | B1, B6 |
| 141 | B1, F1, P1, C1 |
| 165 | B1, B3, P1, T1 |
| 09001 | P1, C1, W1 |
| 09002 | C1, W1 |
| 09003 | P1, C1, W1 |
| None (Utah State University Co-op) | P1, W1 |
| None (Colorado River) | P1, P3, T1, C1, W1 |
| None (Walter Walker Wildlife Area) | W1 |
| *Gila cypha* | |
| 948, 994 | B2, F1, P4, P7, P8 |
| 996, 968, 955, 970, 963 | B1, F1, P1, P4, P5, W1 |
| 975, 957 | B2, B8, F1, P5 |
| L0000 | NP |
| L0001 | NP |
| L0045 | NP |
| L0060 | B1, B15 |
| L0072 | NP |
| L0085 | NP |
| L0086 | B1 |
| L0087 | NP |
| L0094 | NP |
| L0115 | NP |
| L0116 | NP |
| L0143 | NP |
| L0147 | NP |
| L0154 | NP |
| L0155 | NP |
| L0175 | NP |
| L0183 | NP |
| L0203 | NP |
| L0207 | P1, P6 |
| L0210 | P6 |
| L0232 | P1, P6 |
| L0235 | NP |
| L0253 | P6 |
| L0262 | P1, B4 |
| L0332 | NP |
| L0340 | NP |
| L0346 | NP |
| L0351 | NP |
| L0355 | NP |
| C2024 | NP |
| C2025 | B5 |

Table B-1, continued
Pathogens recovered from individual fish

| Fish species and tag number | Pathogen codes (see Table A-1) |
|---|---|
| *Gila cypha*, continued | |
| C2031 | NP |
| C2033 | NP |
| C2034 | NP |
| C2036 | P1 |
| C2049 | NP |
| C2050 | B5 |
| C2051 | B10, B13 |
| C2052 | B1, B13 |
| C2054 | P6 |
| C2056 | P1 |
| C2058 | P1 |
| C2060 | B1, B3, B4, B5, B6, B9 |
| C2062 | P6 |
| C2105 | B1, B3, B9, B12 |
| C2106 | P1 |
| C2110 | NP |
| C2121 | B1, N1 |
| C2122 | NP |
| C2123 | B1 |
| C2127 | B5 |
| C2131 | B14 |
| C2156 | NP |
| C2158 | P1, P6 |
| C2170 | NP |
| C2188 | NP |
| *Gila elegans* | |
| Lot 80WMOWB | F1, P6 |
| Lot 81WGRWB | B2, F1, P1, W1 |
| Lot 81WGRWB | P2, W1 |
| *Xyrauchen texanus* | |
| Colorado River | W1 |
| 051 | B13, P1, W1 |
| Walter Walker Wildlife Area | P1 |
| Walter Walker Wildlife Area | NP |
| Walter Walker Wildlife Area | W1 |

REPORT NO. 5

# TOLERANCE AND PREFERENCES OF COLORADO RIVER ENDANGERED FISHES TO SELECTED HABITAT PARAMETERS

by

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## INTRODUCTION

The Colorado River drainage contains several species of endangered and threatened fishes. Very little information is available on the habitat requirements of these fishes to assist water development agencies in assessing and thereby minimizing the effect of their project(s) on species protected by state and federal endangered species regulations. Habitat factors most likely to be altered by development projects include water temperature and velocity and concentrations of total dissolved solids.

Objectives of our study were to (1) determine temperature and total dissolved solids preferences of juvenile and adult Colorado squawfish (Ptychocheilus lucius), humpback chub (Gila cypha), bonytail chub (Gila elegans), and razorback sucker (Xyrauchen texanus), (2) determine baseline hematological parameters for each species, (3) determine swimming stamina for each species at various water velocities and temperatures, and (4) determine effects of swimming and transport stress on certain blood parameters.

## METHODS

### Fish History

Razorback suckers (Xyrauchen texanus) used in all experiments were from a single female spawned in 1974 at the Willow Beach National Fish Hatchery (WBNFH). The progeny were reared in concrete outdoor raceways where they were fed commercial trout feed. Approximately 100 of the largest specimens (30-40 cm in length) were shipped to California in the spring, 1980. Remaining fish (n = 700, 15-30 cm in length) were transported to the Utah Water Research Laboratory (UWRL), Logan, Utah, on June 17, 1980. Fish were held in circular 833-liter tanks under controlled photoperiod (14L x 10D) and acclimated to 8°, 14°, 20°, 26° ± 1° C. Fish were fed Silver Cup trout chow (3 mm pellets) ad libitum once per day. Terramycin was added to the feed (4-10 mg/L) for two 7-day periods to control columnaris infection. Diseased fish were not subjected to testing of any kind during treatment or for 7 days thereafter.

Juvenile Colorado squawfish (Ptychocheilus lucius) that were used in temperature preference, blood analysis, and swimming stamina studies were hatched on July 1, 1979, from hatchery-reared adults at the WBNFH. The progeny were held in concrete outdoor raceways and fed commercial trout feed. The fish were transported to the Fisheries Experiment Station (FES), Logan, Utah, in February 1980, and then on July 17, 1980, they were moved to the UWRL facility. At UWRL, they were held in circular 225-liter tanks, fed Silver Cup commercial trout food (#3 crumbles) ad libitum twice per day, kept on a 14L x 10D photoperiod, and were acclimated to 14°, 20°, 26° ± 1° C. The fish ranged in length from 7.5 to 10 cm (n = 1000) when received and appeared to grow best at 20° C

(after 1 year, 20° C fish were 4X larger than 14° C fish and 2X larger than 26° C fish). We experienced no difficulty in holding the squawfish; no diseases or signs of stress were noticed.

Adult Colorado squawfish used in temperature preference, blood analysis, and swimming stamina studies were hatched at WBNFH in 1974. They were held in concrete outdoor raceways and fed commercial trout pellets. The fish were transported (n = 120, 30-50 cm in length) to the FES in February of 1980. They were held in concrete outdoor ponds and fed Silver Cup trout pellets (6 mm) and fingerling rainbow trout (Salmo gairdneri) ad libitum. In December 1980, 25 of the squawfish were transferred to URWL and were held in 833-liter circular tanks at 20° ± 1° C. The photoperiod was 14L x 10D and they were fed in the same manner as at FES. Within 2 weeks of transfer, the fish contracted a columnaris infection. They were treated with abdominal injections of Terramycin (250 mg/kg) and the following day with a nitrofurazone dip (10 mg/L for 1 hr). Tank temperature was lowered from 20° C to 14° C (1° C per day). Nine fish were lost to the disease; the remaining fish had no further problems. In August 1981, 35 additional adult squawfish (40-55 cm in length) were transferred from FES. These fish were acclimated to 14°, 20°, 26° ± 1° C, kept on a 14L x 10D photoperiod, and fed fingerling rainbow trout ad libitum.

Juvenile Colorado squawfish used in total dissolved solids (TDS) experiments were hatched at WBNFH in July 1980, held in concrete outdoor, recirculating raceways, and fed commercial trout feed. They were transported to FES in April 1981, and held in the same manner as at WBNFH. They were transferred by 114-liter covered plastic garbage cans to UWRL on the morning of each TDS experiment (experiments started in June 1981) and placed directly into the experimental apparatus. The fish were held at UWRL after the experiments in 450-liter circular tanks, on Logan River water and at ambient temperatures and photoperiod.

Humpback chubs (Gila cypha) used in all experiments were hatched at WBNFH in June 1980, from wild fish caught at Black Rocks, Colorado. They were held in concrete outdoor recirculating raceways and fed commercial trout feed. They were transported to the University of Idaho, Moscow, in September 1980, where they were held in 225-liter rectangular tanks and fed Biodiet trout feed. They were transferred to UWRL (n = 300, 8-12 cm in length) in February 1981, where they were held in 833-liter circular tanks and fed Silver Cup trout pellets (#3 crumbles) ad libitum twice per day. They were acclimated to 14°, 20°, 26° ± 1° C and kept on a 14L x 10D photoperiod.

Bonytail chubs (Gila elegans) used in temperature and TDS preference experiments were hatched at WBNFH in May 1981, held in concrete outdoor recirculating raceways, and fed commercial trout feed. They were transported to UWRL (n = 800, 2.5-5 cm length) on August 7, 1981. A second group of bonytails (n = 300, 8.5-12 cm in length) was transferred to UWRL on August 27, 1981, for blood analysis and swimming stamina experiments. These fish were from the same group hatched at WBNFH in May 1981, but were held at Dexter National Fish Hatchery (DNFH) in earthen ponds and on natural food supplemented with commercial trout feed. Both groups of bonytail chubs were held together in 225-liter circular tanks

and fed Silver Cup trout feed (#3 crumbles ad libitum twice per day. They were acclimated to 14°, 20°, 26° ± 1°C and kept on a 14L x 10D photoperiod.

Hybrid chubs (bonytail x humpback) used in temperature preference experiments were hatched at WBNFH in May 1980, and sent to DNFH where they were reared in outdoor earthen ponds and fed natural food supplemented with commerical trout feed. They were transported (n = 31, 12 cm in length) to UWRL in November 1980, where they were held in 833-liter circular tanks at 20° ± 1°C, fed Silver Cup trout pellets (3 mm) ad libitum twice per day, and kept on a 14L x 10D photoperiod.

All fish held at UWRL were kept in flow-through systems of heated, dechlorinated city water with supersaturation removed from the water before it entered the tanks. Dissolved oxygen was maintained in the tanks at 90-100 percent of saturation, ammonia was kept below 0.2 ppm (direct Nesslerization method, Hach Kit), and pH was kept at 8.0. All fish were acclimated to the various water temperatures in accordance with procedures outlined by Richards et al. (1977).

## Temperature Preference

The final temperature preferendum is defined by Fry (1947) as that temperature toward which a fish will finally gravitate regardless of previous thermal history and at which acclimation and preferred temperature are equal. Final preferendum has been generally assumed to be an innate and species-specific measure of thermal behavior (Reynolds and Casterlin 1976, Magnuson and Beitinger 1978). Final preferendum for razorback suckers acclimated to four temperatures (8°,14°, 20°, 26° C) was determined using an electronic shuttle box adapted from Neill et al. (1972). This device is basically a plexiglass chamber in which individual fish were allowed to regulate water temperatures by triggering photocells controlling warm and cold water flow (Figure 1). The shuttlebox was filled with water from tanks in which the fish were being held and an individual fish was placed in the device. After a 1-hour acclimation period, the photocells were activated and water temperature was recorded (Honeywell Thermographs) for the next 47 hours. The final preferendum during light and dark hours was determined with data from 15-minute intervals of the last 24 hours of testing for 20-23 specimens. The mode, instead of the mean or median, was used to describe the final preferendum of individual fish because it best corresponds to the definition of (modal) preferendum as that temperature occupied most frequently by a fish (Pitt et al. 1976, Richards et al. 1977). In addition to individual modes, a mean of the individual modes, a pooled mode and mean, and Pearson's coefficient of skewness were calculated for day and night for fish of each acclimination temperature. Data were collected in degrees Fahrenheit but were not converted to degrees Centigrade for statistical analysis.

Because of their small size, humpback, bonytail, and hybrid chubs were unable to operate the shuttle box and no final preferendum could be directly determined. Acute preferendum (measured in the first 3 hours and affected by prior thermal history) was measured for humpback and bonytail chubs acclimated to 14°, 20°, 26° C and hybrid acclimated

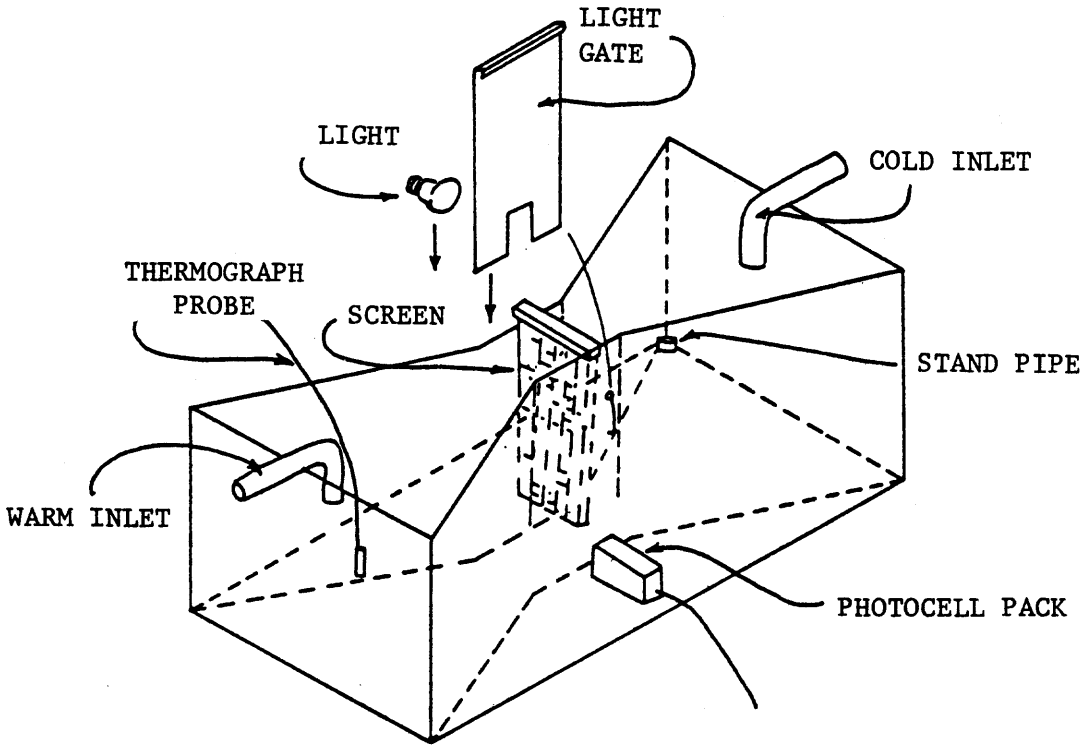



Figure 1

Electronic shuttlebox for thermal preference studies
(after Neill et al. 1972)

to 20° C using a horizontal gradient trough (234 cm x 33 cm). The range of temperature in the gradient was ca. 14-34° C but varied slightly with each fish. The range was maintained by adjusting the flow of hot and cold water at opposite ends of the trough. Temperature probes (YSI tele-thermometer) recorded temperatures in degrees Fahrenheit at 26-cm intervals along the trough bottom. The device was supplied with aeration by five air stones 40 cm apart and was enclosed by a curtain. Fish were observed through a small aperture in the side of the curtain. A fish was placed in the gradient device at a position that approximated its acclimation temperature and was allowed to explore the trough for 1-hour before observations began. Temperature and location of the fish were observed at 1-minute intervals for 2 hours. During the second hour hot water was turned off to alter the gradient and check for positional effects (Stauffer et al. 1975). An additional test for positional effects (i.e. as a control) was done by placing a fish in the trough with a uniform temperature (14° C) and observing it in the same manner as above. Twenty to 30 fish for each acclimation temperature were tested and 10 additional fish, acclimated to 14° C, were tested in the control experiment. All temperature data were converted to degrees centrigrade before statistical analysis. Data were analyzed similarly to that recorded for the razorback sucker.

Preliminary tests were conducted for juvenile squawfish. At least 10 fish from three acclimation temperatures (14°, 20°, and 26° C) were tested in the horizontal thermal gradient (234 cm x 33 cm) used for humpback chubs to determine acute temperature preference. Several squawfish were left in the gradient overnight to estimate final temperature preferendum.

Additional juvenile squawfish (10-18 cm in length) were tested in a horizontal trough, 5 m x 25 cm with variable depth (5-10 cm). Seven air stones and 13 thermistor probes were attached at uniform intervals along the bottom of the trough. Air stones used to prevent gas supersaturation and vertical temperature stratification helped to maintain an even temperature gradient. The thermistor probes were attached to a tele-thermometer on the observation platform. Uniform, low-level lighting (1 lux) was provided, and the area surrounding the trough was covered in black plastic with a small opening for observation.

Twenty squawfish from each acclimation temperature (14°, 20°, and 26° C) were tested in the larger gradient trough. Range of temperatures in the gradient was varied according to the acclimation temperature of the fish; 13-33° C for 14° C fish, 16-35° C for 20° C fish, and 14-34° C for 26° C fish. A single fish was placed in the trough at a point where the temperature corresponded to the fish's acclimation temperature (Richards and Ibara 1978, Hall et al. 1979). Observations of fish position and temperature at that position were recorded at 1-minute intervals for 3 hours, beginning as soon as the fish was placed in the trough. Only the last hour was used in the analysis of temperature preference. At the end of 3 hours, either the hot or cold water was turned off to shift the gradient. The fish was observed in a similar manner for 30 minutes to see if it remained in a particular preferred area of the trough (e.g., corner or end), or if it followed its selected temperature down the trough (Richards and Ibara 1978, Erlich et al. 1979, Hesthagen 1979).

Frequently the gradient did not shift significantly, particularly near the end of the trough where the water remained on, therefore additional criteria were used to determine if those fish were actually selecting temperature over other physical factors of the trough. Five fish from each acclimation temperature were individually tested in the trough with the water held at a uniform temperature equal to their respective acclimation temperature (Richards and Ibara 1978, Hesthagen 1979). Fish position was recorded at 1-minute intervals for 3 hours; only the last hour was used in data analysis.

Testing procedures of adult squawfish were essentially identical to those of the juveniles, though an even larger gradient trough (5.3 m long x 61 cm wide x 13 cm deep) was constructed after testing 10 of the smaller adults (38-42 cm in length). The large gradient provided ample room for the larger adults (42-50 cm in length). Two air stones were added and slightly higher flows were required; otherwise conditions were the same. Ten adults per acclimation temperature (14°, 20°, and 26° C) were tested with a thermal gradient. Fish acclimated to 20° C and 26° C were offered a range of 16-32° C, those acclimated to 14° C were offered 13-26° C. Five fish per acclimation temperature were tested at a uniform temperature equal to their acclimation temperature. The 10 smaller adults were tested in April 1981, the remaining adults were tested in April 1981, the remaining adults were tested in August and early September 1981.

Individual modes, a mean of individual modes, a pooled mean and mode, and Pearson's coefficient of skewness were calculated for juvenile and adult squawfish at each acclimation temperature. Effects of acclimation temperature and age on selected temperature were tested by analysis of variance. If differences were significant, means were further compared with Fisher's (protected) least significant difference test (Steel and Torrie 1960).

## Egg Temperature Tolerance

Eggs were initially held at the water temperature of spawning or if shipped, at the water temperature of the water in which they arrived. They were gradually tempered to test temperatures. Eggs were placed in water in plastic cups supported by styrofoam, ten eggs per cup and three or four replicates per temperature. The eggs were initially checked with a dissecting scope to see if they were viable and if in the same stage of development (usually four-celled). They were then checked for viability every 24 hour.

## Total Dissolved Solids Preference

The preference of Colorado squawfish, humpback chub, and bonytail chub to various levels of total dissolved solids (TDS) was tested in an enlarged version of a salinity gradient device designed by Staaland (1960). The apparatus was designed to test marine snails and later modified by Reynolds and Thomson (1974) for use with fish. The device consisted of a long trough (243 cm x 30 cm x 45 cm) with series of staggered partitions 20-cm high that enable the establishment of a

salinity gradient by using the difference in densities of water at different levels of TDS to keep them from mixing (Figure 2). Chamber 1 contained dechlorinated Logan city water to which the fish were acclimated and chamber 2 contained the major ions found in the Colorado River at Moab, Utah, (U.S. Geological Survey 1978, mean of 1978 water year August-March). Chambers 3-8 contained the same ions as chamber 2 except levels of $mg^{++}$, $SNa^{+}$,$SO_4^{=}$ were raised a combined total of 1 g/L/chamber (Table 1). These three ions are considered to be the major constituents of the saline input from oil shale processing (Wagenet el al. 1980). A group of fish (30 squawfish, 20 humpbacks, or 40 bonytails) were placed in chamber 1 at the start of the experiment and allowed to migrate throughout the trough for 24 hours. Positions were recorded every 0.5 hours for the first 7-hours (to insure that all chambers were sampled by the fish) and again at 24 hours for the distribution used as data. TDS was measured (YSI conductivity meter) before and after the experiment because the concentration in each chamber would slowly change over time, but only the last measurement was used for data (see Table 1 for conversion of TDS to conductivity). Three treatments and three controls (all chambers filled with city water) were performed for each species. Because of the schooling tendency of these fish, independence could not be assumed for their distributions and no statistics could be performed. Pooled distributions, however, were made for comparisons between controls and treatments, and between species.

Black plastic was used to shield the apparatus from light and to minimize external disturbance. Photoperiod was maintained at ambient (14L x 10D). Temperature of the gradient was 16-18° C. Water was changed after each experiment. Dissolved oxygen and $NH_3$ (first controls only) were measured before and after each experiment and were never found to be a problem (D.O. > 7.2 mg/L, $NH_3$ < 0.2 mg/L).

## Baseline Hematology and Stress

Hematological analysis for glucose, chloride, hematocrit, red and white blood cell counts, and white blood cell differentials were determined using methods of Wedemeyer and Yasutake (1977). Instruments routinely used by aquaculturists to monitor fish health were used to determine total protein (refractometer) and hemoglobin (homoglobinometer). Razorback sucker were sampled for baseline data on June 14-16, 1980, while held at WBNFH. They were moved to the UWRL on June 17. Other species were sampled for blood analysis after being held for 1 month at 14° C at the UWRL. Comparison between sex (razorbacks), age (squawfish), and fish length (all species) was conducted by analysis of variance.

The effect of transporting the razorback suckers from WBNFH to Logan was examined by analysis of blood chloride and glucose levels. About 700 razorback suckers (15-30 cm in length) were transported in a 1,000-liter hauling tank. Density was not determined exactly but was less than 65 g/L. Fish were transported in hatchery water with aeration. Temperatures were controlled by adding ice to maintain 12° $\pm$ 2° C. No salt or anesthetic was added; 5 mg/L Furacin (4.59 percent active ingredient) was added to prevent bacterial infection. Total hauling time was 15 hours. Fish were loaded and unloaded by netting. Fish resided in

SALINITY GRADIENT

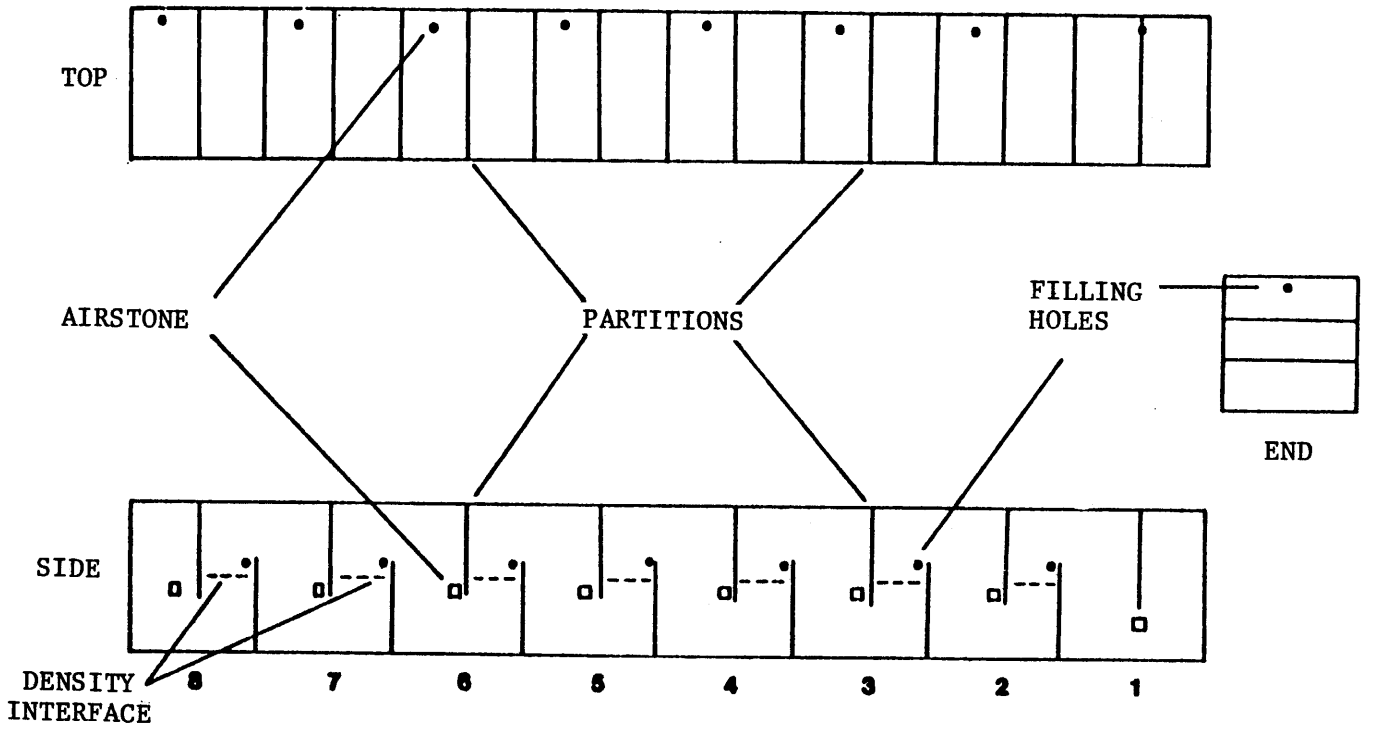



Figure 2

The TDS gradient device with positions of density/TDS interfaces and location of airstones. Length = 2.4 m, width = 45.7 cm, height = 30.5 cm.

Table 1

Initial concentrations of ions in each compartment of TDS preference chamber

| Compartment | Ionic concentration (mg/l) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1/ | 2/ 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| $Ca^{++}$ | 47 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| $Mg^{++}$ | 16 | 82 | 170 | 250 | 330 | 420 | 500 | 580 |
| $Na^{+}$ | 1.0 | 170 | 360 | 550 | 740 | 930 | 1,100 | 1,300 |
| $K^{+}$ | 0.0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| $Cl^{-}$ | 4.0 | 220 | 220 | 220 | 220 | 220 | 220 | 220 |
| $SO_4^{=}$ | 6.2 | 590 | 1,300 | 1,200 | 2,800 | 3,500 | 4,200 | 4,900 |
| $HCO_3^{-}$ | 200 | 210 | 210 | 210 | 210 | 210 | 210 | 210 |
| | 274 | 3/ 1,438 | 2,426 | 3,396 | 4,466 | 5,446 | 6,396 | 7,376 |

1/ Logan city water.

2/ Approximate composition of Colorado River water at Moab, Utah (U.S. Geological Survey 1978).

3/ mmhos of conductivity = 0.618 + 0.00068 mg/l TDS; $r^2 = 0.91$.

Table 2

Water quality of Willow Beach National Fish Hatchery and Utah Water Research Laboratory

| Parameter | Willow Beach National Fish Hatchery 1/ | Utah Water Research Laboratory 2/ |
|---|---|---|
| Dissolved oxygen (mg/l) | 7.5-9.0 | 9.0-9.3 |
| Ammonia | 0.1 mg/l | 0.05 mg/l |
| Carbon dioxide (mg/l) | 2.0-4.0 | --- |
| pH | 7.5-8.0 | 8.2 |
| Alkalinity (mg/l as $CaCO_3$) | 127.0 | 138.0 |
| Calcium (mg/l) | 92.0 | 47.0 |
| Magnesium (mg/l) | 31.0 | 14.0 |
| Total hardness (mg/l as $CaCO_3$) | 358.0 | 174.0 |
| Total dissolved solids (mg/l) | 730.0 | 164.0 |
| Sulfate (mg/l) | 317.0 | 4.0 |
| Nitrate (mg/l) | 1.0 | 0.2 |
| Floride (mg/l) | 0.45 | 0.02 |
| Chloride (mg/l) | 104.0 | 1.0 |
| Iron (ug/l) | 0.07 | 76.0 |

1/ Ground water well at Willow Beach National Fish Hatchery.

2/ Utah Water Research Laboratory, city water after charcoal filtration. Only trace amounts (less than 1 ug/l) of arsenic, cadmium, chromium, copper, and lead were found; 131 ug/l zinc was found.

water of somewhat similar quality to that of the hatchery (Table 2) at the UWRL for 17-21 hours. Blood was then collected to determine effects of hauling stress. The effect of stress on the suckers was determined for each sex and for fish of various lengths by analysis of variance.

## Swimming Ability

Swimming ability was determined in a stamina tunnel (Thomas et al. 1964). Fish were tested at temperatures of 14°, 20°, and 26° C, at various water velocities. A standard testing protocol was used. Fish were acclimated for at least 1 week to the temperature at which they were tested. Acclimated fish were netted and introduced in pairs into the stamina tunnel. Fish were allowed to swim for 5 minutes in a water velocity of 0.15 m/sec, and were then immediately subjected to the test velocity. Swimming fish which retreated to the rear of the tunnel were subjected to mild electric shock (5-10 volts). Time of fatigue was defined as the time at which a fish could no longer avoid the electric field. Fatigued fish were removed from the tunnel, measured for length, and returned to holding tanks for post-test observation. Data were analyzed by analysis of variance with temperature and velocity as main effects, and fish length as a covariate.

# RESULTS

## Temperature Preference

Razorback suckers acclimated to 8° C had considerable trouble in working the shuttleboxes. Of 20 fish tested, only 4 could regulate the shuttlebox correctly (10 raised their temperature so fast they died, the rest just sat in one chamber or the other). Fish acclimated to 14° C had similar problems in regulating their temperature as did 8°C fish, but to a lesser degree (10 out of 21 fish tested were able to operate the shuttlebox). Beitinger (1974) had a similar problem with bluegill sunfish (Lepomis macrochirus) unless maximum temperature was limited to 19° C for the first 24 hours. This limitation evidentially allowed bluegill acclimation rate to catch up with their thermal preference (Beitinger and Magnuson 1976). Mean of the individual razorback modes and pooled modes were similar both day and night for fish acclimated to 8° C (x modes = 25.4° C D, 25.6° C N; pooled mode = 26° C D, 26° C N) whereas razorbacks acclimated to 14°, 20°, 26° C had higher night pooled modes than day (Table 3, Figure 3).

The means of indivdual modes for 14° C fish were similar for day and night (28.9° C D, 28.8° C N, Table 3), whereas pooled modes showed a slightly higher night temperature (29° C D, 30° C N, Figure 3). This same trend of higher night-time selected temperature was noted for razorbacks acclimated to 20° C (x modes = 22.9° C D, 22.2° C N; pooled mode - 24° C D, 27° C N, Table 3, Figure 3) and to 26° C (x modes 23.3° C D, 23.3° C N; pooled mode = 22° C D, 24° C N, Table 3, Figure 3). Reynolds and Casterlin (1976) found that mean values did not describe differences in day and night temperature preferendum of bluegill sunfish, smallmouth bass (Micropterus dolomieui), or largemouth bass (M. salmoides), whereas

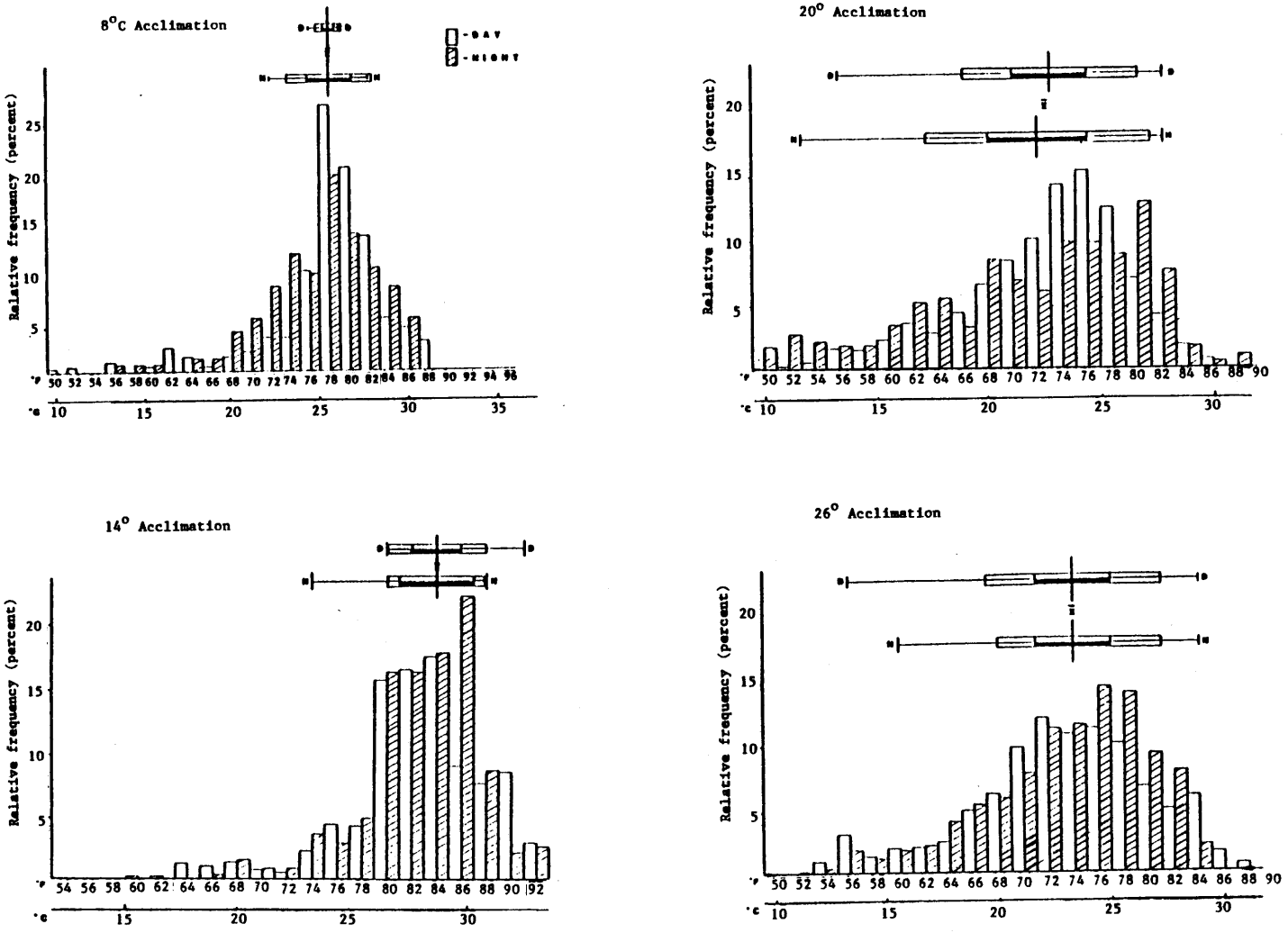
Table 3
Temperature distribution statistics for razorback suckers, comparison of day and night values

| Acclimation temperature °C | Razorback suckers | Day/night | Range of individual modes | Mean of modes[1/] | Pooled data | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Mode | Mean | Standard deviation | Skewness[2/] |
| 8 | 4 | D | 24 - 26 | 25.4 ± 0.35 | 26 | 24.7 | 4.2 | -0.3 |
| | | N | 22 - 28 | 25.6 ± 1.39 | 26 | 25.1 | 1.9 | -0.5 |
| 14 | 10 | D | 27 - 32 | 28.9 ± 0.64 | 29 | 28.2 | 2.8 | -0.3 |
| | | N | 23 - 31 | 28.8 ± 0.75 | 30 | 28.4 | 1.9 | -0.8 |
| 20 | 20 | D | 13 - 28 | 22.9 ± 0.89 | 24 | 22.7 | 3.0 | -0.4 |
| | | N | 12 - 28 | 22.2 ± 1.12 | 27 | 22.3 | 2.1 | -2.2 |
| 26 | 20 | D | 13 - 29 | 23.3 ± 0.90 | 22 | 22.8 | 2.9 | 0.3 |
| | | N | 16 - 29 | 23.3 ± 0.73 | 24 | 23.3 | 2.1 | -0.3 |

1/ ± standard error of the mean.

2/ Pearson's skewness coefficient = (mean-mode)/standard deviation. A negative value indicates a longer tail on the low temperature side of the distribution curve.

Figure 3




Relative frequency distribution of temperatures selected by razorback suckers. Pooled 15-minute data during second day and night for fish acclimated to 8, 14, 20, and 26°C. Figures above vertical bars provide day (D) and night (N) range of individual modes, mean of individual modes ± 2 standard errors (darkened box) and ± 1 standard deviation (clear box).

pooled frequency distributions indicated differences. They believed that the skewness in their distributions accounted for the lack of agreement. Our data were also skewed for razorbacks acclimated to 14°, 20°, 26° C (Table 3) but in the opposite direction (i.e. warmer temperature selected at night) than the data of Reynolds and Casterlin. This difference may be a reflection of the differences in biological requirements of centrarchids and catostomids. The small lamp used to trigger the photocells may also have lowered sensitivity of razorbacks to day and night changes.

Final preferenda for razorbacks acclimated to different temperatures were compared using analysis of variance on the combined night and day individual modes. Difference in preferenda were significant ($P > 0.005$), and analysis with Fisher's LSD test (Steele and Torrie 1960) showed that 14° C fish selected significantly higher temperatures than did 20° C or 26° C fish (Table 4). There is some evidence that cold-acclimated fish (<15° C) may initially overshoot their final preferendum, but by the third or fourth day of testing their preferenda equal those of warm-acclimated fish (Beitinger and Magnuson 1976, Reynolds 1978). Final preferendum of 8° C suckers was also higher than those of 20° C and 26° C fish (Table 4), but the difference was not significant perhaps due to the small sample size of the 8° C fish.

Data from 8° C and 14° C acclimated razorback suckers were not used to estimate final preferendum because of small sample size (8° C fish) and possible overshoot as mentioned above. Data from 20° C and 26° C acclimated razorbacks, however, agreed well with Fry's (1947) definition of final preferendum as that temperature where fish will finally gravitate regardless of previous thermal history. Use of average day and night x modes and pooled modes for 20° C and 26° C acclimated fish (Table 3 and 4) indicated that the best estimate of razorback suckers final preferendum was 23-24° C. The geometric mean (24.9° C) of the means of individual modes for all four acclimation temperatures (8°, 14°, 20°, 26° C) as an indication of central tendency agreed closely with the estimated final preferendum of 23-24° C by the above method even with the small sample size of the 8° C and 14° C fish.

Testing thermal preference in a horizontal gradient device tends to produce more variable data than that obtained from the shuttlebox but gives comparable results (Magnuson and Beitinger 1978, Huggins 1978). There is also the problem of fish selecting for a particular position in the trough rather than the temperature associated with that position. Ten 14° C acclimated humpback chubs were tested in the horizontal gradient with a uniform temperature (14° $\pm$ 1° C) to detect preferred positions. The results indicated that the ends of the chambers were the most preferred positions (Figure 4). (Future horizontal gradients should be constructed long enough to insure thermal avoidance temperatures at each end of the gradient to eliminate this problem.) As an additional test for positional effects, hot water was shut off to the gradient during the second hour of observation. This change allowed the gradient to shift and eventually be eliminated (Stauffer et al. 1975, Cherry et al. 1975, Richards et al. 1977). Use of these two tests effectively screened fish for positional effects and allowed us to eliminate those fish that were influenced by the chamber. Data of fish were rejected for analysis if location modes of an individual were the same during the first and the second hour of observation, or if their location mode during the first

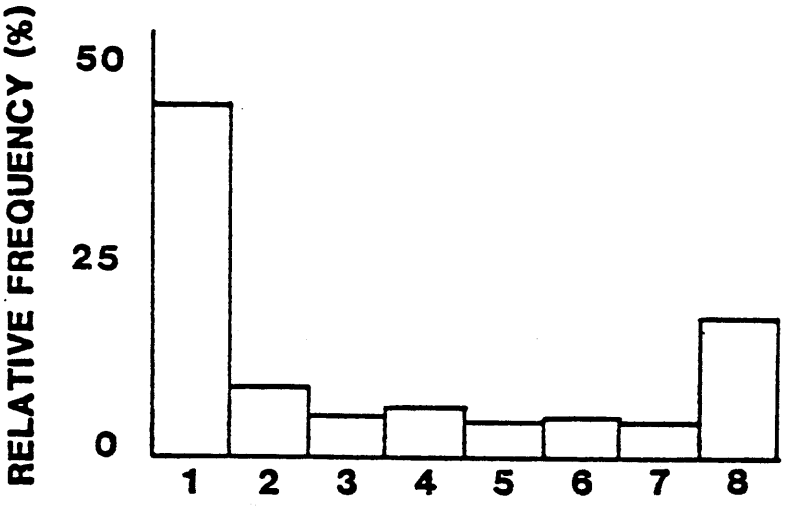
Table 4
Temperature selection of four Colorado River fishes

| Species | Acclimation temperature °C | Number | Range of individual modes | Mean of modes[1] ($\bar{x}$ modes) | Mode | Mean | Standard deviation | Skewness[2] |
|---|---|---|---|---|---|---|---|---|
| Razorback sucker | 8 | 4 | 22 - 27 | 25.0 ± 0.96 | 26 | 24.8 | 3.42 | -0.4 |
| | 14 | 10 | 27 - 31 | 29.0 ± 0.52 | 28 | 28.3 | 2.47 | 0.1 |
| | 20 | 20 | 12 - 28 | 22.7 ± 1.07 | 24 | 22.5 | 2.67 | -0.6 |
| | 26 | 20 | 13 - 29 | 23.1 ± 0.90 | 26 | 23.0 | 2.60 | -1.2 |
| Humpback chub | 14 | 9 | 17 - 26 | 21.0 ± 1.26 | 18 | 20.3 | 3.88 | 0.6 |
| | 20 | 8 | 21 - 31 | 24.4 ± 1.20 | 23 | 23.1 | 3.78 | 0.03 |
| | 26 | 7 | 21 - 27 | 23.5 ± 1.72 | 17 | 21.3 | 4.37 | 1.0 |
| Bonytails | 14 | 6 | 15 - 21 | 17.9 ± 0.92 | 17 | 17.9 | 3.31 | 0.3 |
| | 20 | 8 | 15 - 30 | 22.5 ± 1.94 | 27 | 22.5 | 4.81 | -0.9 |
| | 26 | 8 | 21 - 31 | 25.1 ± 1.71 | 24 | 25.1 | 4.67 | 0.2 |
| Hybrid Squawfish | 20 | 8 | 18 - 28 | 23.8 ± 1.48 | 26 | 22.3 | 4.26 | -0.8 |
| Juveniles | 14 | 18 | 17 - 27 | 21.9 ± 0.74 | 21 | 22.1 | 2.97 | 0.4 |
| Adults | 14 | 4 | 14 - 27 | 21.5 ± 3.07 | 26 | 20.9 | 5.28 | -1.0 |
| Juveniles | 20 | 20 | 24 - 32 | 27.6 ± 0.44 | 28 | 27.4 | 2.46 | -0.3 |
| Adults | 20 | 2 | 20 - 25 | 22.5 ± 2.50 | 20 | 22.1 | 3.68 | 0.6 |
| Juveniles | 26 | 19 | 21 - 31 | 23.7 ± 0.64 | 23 | 24.1 | 3.46 | 0.3 |
| Adults | 26 | 6 | 24 - 27 | 25.7 ± 0.50 | 27 | 24.7 | 3.53 | -0.7 |

1/ ± standard error of mean.

2/ Pearson's skewness coefficient = (mean-mode)/standard deviation. A negative value indicates a longer tail on the low temperature side of the distribution curve.

Figure 4




Humpback chub relative frequency distribution in 8 locations within a horizontal thermal gradient chamber. (Fish were acclimated to 14°C and placed in chamber with a uniform water temperature of 14°C). Data on 10 fish pooled for first hour, one observation/minute.

hour was at one end of the gradient and at the other end during the second hour. Humpback chubs acclimated to 20° C selected higher temperatures (x modes = 24.4° C) than did chubs acclimated to 14° C (x modes = 21° C) (Table 4). Chubs acclimated to 26° C, however, selected temperatures lower (x modes = 23.5° C) than those of 20° C chubs and much lower than would be predicted from data of other researchers (Stauffer et al. 1975, Mathur et al. 1981). Similar results were also seen in spotfin shiner, (Notropis spilopterus), (Stauffer et al. 1975) and in bluegill sunfish (Beitinger 1974). Differences in temperatures selected by humpbacks acclimated to the three temperatures were not statistically significant, however.

Further testing of humpbacks is needed to determine if our lack of relation of acclimation temperature to acute preferenda was the result of a negative energy balance. Energy intake from food must at least equal energy expended in metabolism, or fish seek lower temperature to balance their energy budget. Stuntz and Magnuson (1976) found that insufficient energy stores in bluegills acclimated to high temperatures caused them to select a lower than expected temperature. Another possibility is that photoperiod should have reflected time of year when low and high temperatures were found in the field (Cherry et al. 1975).

It is interesting to note that pooled distributions of humpbacks were skewed in the opposite direction from those of razorback suckers (Table 4, Figure 5) and that the distribution for 26° C humpback chubs was bimodal. The 17° C peak in Figure 5 is the mode by definition, but the mean of the individual modes and the pooled mean (Table 4) line up with the peak on the right (23° C). Perhaps this bimodality is an artifact of the shuttling behavior of fishes described by Reynolds (1978). Reynolds noted that fish tend to "shuttle back and forth within a range of temperatures above and below the preferendum" rather than staying at the preferred temperature.

The electronic shuttleboxes used with razorback suckers provided a direct measure of final preferendum. Estimation of final preferendum from acute preferendum data collected from horizontal gradients, however, must be done indirectly by extrapolating data to the point where acclimation temperature equals preferred temperature (Fry 1947). By use of the graphical method recommended by Richards et al. (1977), preferred temperature (x modes) was plotted against acclimation temperature and a line was drawn connecting the points. The final preferendum for the humpback chubs (24° C) was the point of intersection with the 45 degree line (i.e. the line of acclimation temperature = preferred temperature). Linear regression of the individual modes (Stauffer et al. 1975) gave similar results.

Bonytail chubs acclimated to 14°, 20°, and 26° C were also tested in the horizontal gradient and screened in the same manner as the humpback chubs. They showed a trend of increasing preferred temperature with increasing acclimation temperature which was similar to data of other researchers (Stauffer et al. 1975, Mathur et al. 1981). Fish acclimated to 14° C had a thermal preference of 17.9° C (x mode) whereas 20° C fish preferred 22.5° C and 26° C fish preferred 25.1° C (Table 4). Pooled distributions, however, showed the same pattern as that of the humpback chubs. The pooled mode for 20° C acclimated fish (27° C) was higher than

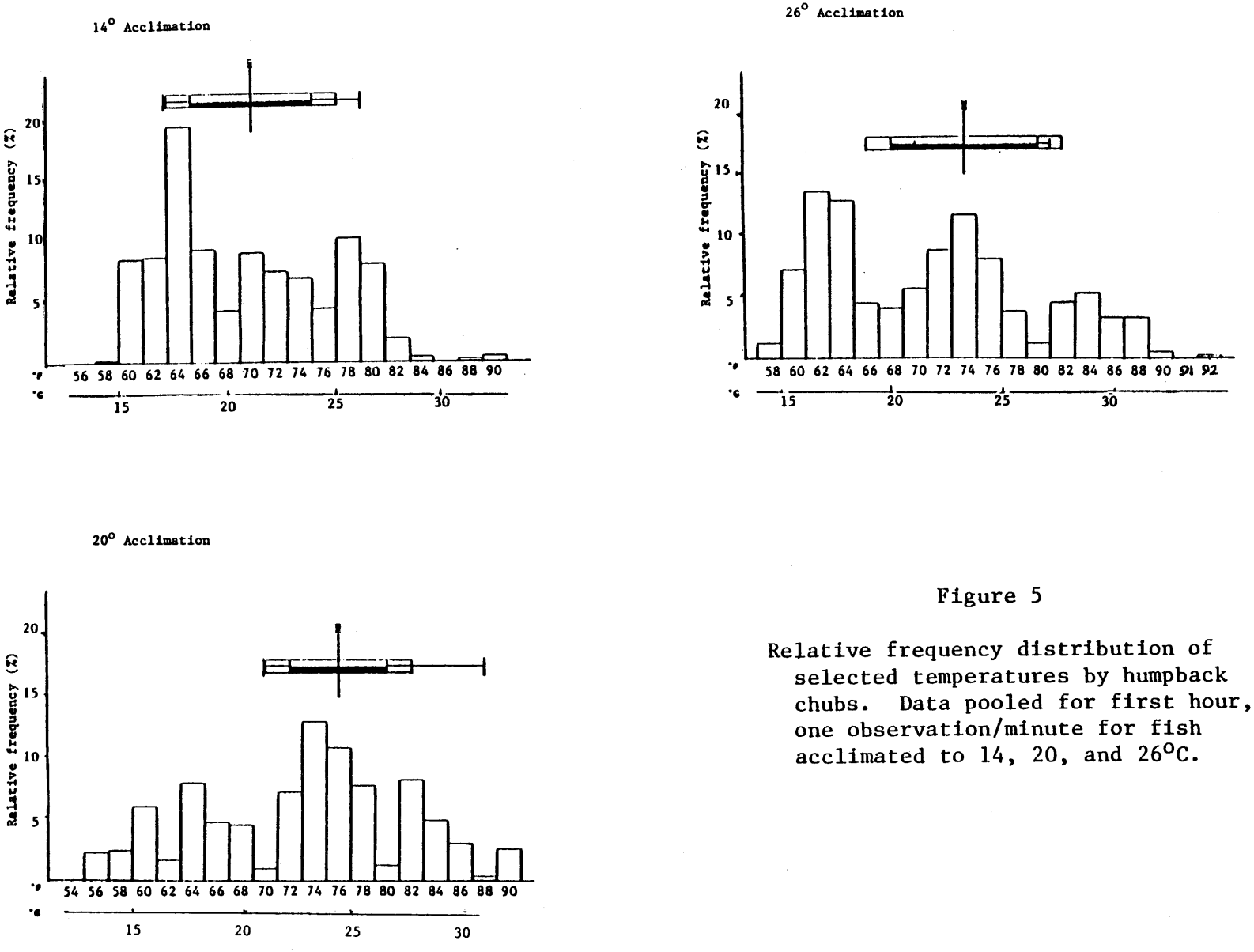



Figure 5

Relative frequency distribution of selected temperatures by humpback chubs. Data pooled for first hour, one observation/minute for fish acclimated to 14, 20, and 26°C.

the pooled mode for the 26° C fish (24° C) (Figure 6). The final preferendum was estimated for the bonytail chubs in same manner as for the humpback chubs. The point of intersection with the 45 degree line was 24.2° C.

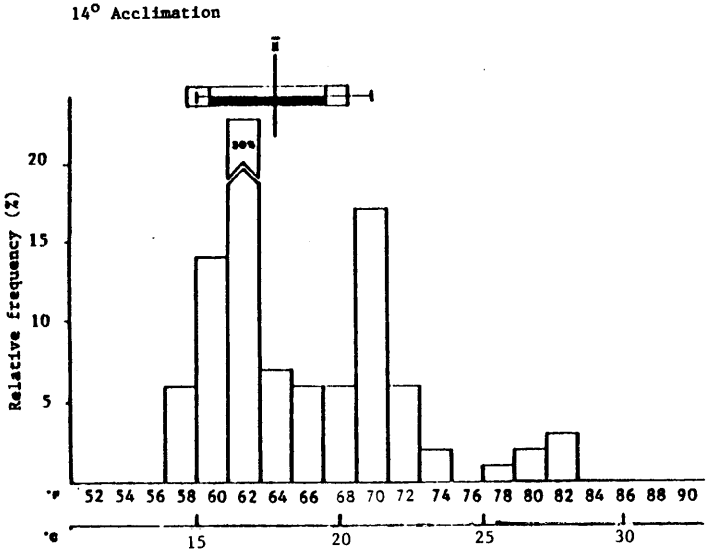
Hybrid chubs (humpback x bonytail) acclimated to 20° C were tested in the horizontal gradient and screened in the same manner as were the humpback and bonytail chubs. The mean of the individual modes (23.8° C) was intermediate to that of the 20° C acclimated humpbacks (24.4° C) and bonytails (22.5° C) (Table 4). The pooled distribution showed a higher mode (26° C vs. 23° C) than that of the humpbacks but was similar to that of the bonytails (27° C) (Figure 7). The distribution was also bimodal as with the 26° C humpback chubs.

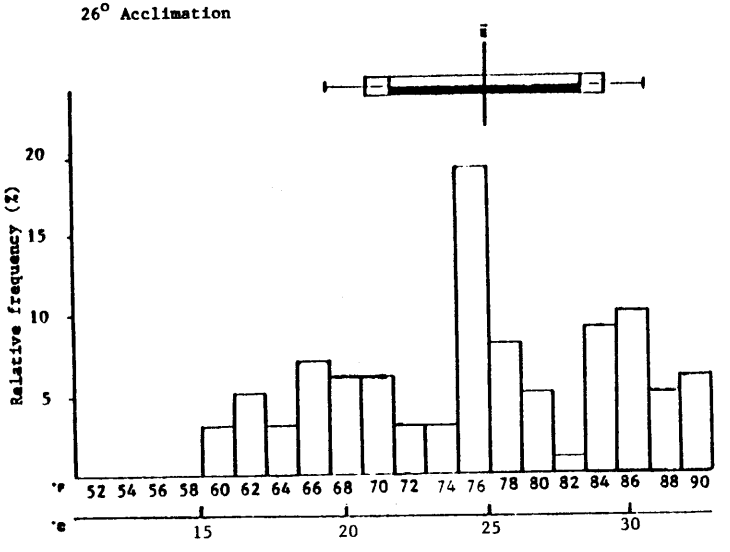
Behavior of juvenile squawfish differed greatly from that of adults during temperature preference testing. The majority of the juveniles appeared to select temperature over position in the gradient trough. Application of criteria for reflection of data similar to that used for humpback and hybrid chubs rejected only 3 of 60 juvenile fish. The majority of the adults either swam randomly or remained at one end of the gradient chamber; data from 18 of 30 adult fish were rejected.

Juveniles acclimated to 14° C were the least precise of the three groups of juveniles tested. Six 14° C-acclimated fish swam to the 30° C region and lost equilibrum within the first few minutes after introduction to the gradient; two subsequently died. The only other indication of a lethal temperature occurred during preliminary testing when one 20° C-acclimated fish lost equilibrium at 35° C.

The pooled mode is often accepted as the statistic that best describes the preferred temperature (Table 4) (Reynolds and Casterlin 1976, Richards et al. 1977, Hesthagen 1979). However, the mean of the individual modes is less sensitive to skewness which can be caused by one or two fish remaining in the same spot (particularly towards one end of the gradient). Use of the mean of the modes as the statistic to describe the preferred temperature also gives each fish equal weight in data computation. When there is little skewness, as in squawfish juveniles (Table 4, Figure 8), all measures of central tendency agree closely. For adult squawfish the pooled mode did not agree with other measures because the data were significantly skewed (-1.0 to 0.6) (Table 4). Means if individual modes for 14°, 20°, and 26° C-acclimated juvenile squawfish were 21.9°, 27.6°, and 23.7° C respectively. For 14°, 20°, and 26° C-acclimated adults, means of individual modes were 21.5°, 22.5°, and 25.7° C (Figure 9).

Acute preferenda of juveniles and adults acclimated to different temperatures was compared by analysis of variance on the individual modes. Acute preferenda of juveniles were significantly different ($P = 0.01$); whereas, those of the adults alone were not (Table 5). Preferenda of juveniles at different acclimation temperatures were further analyzed with Fisher's LSD test (Table 6). Preferenda of each acclimation temperature was significantly different from the others; 20° C-acclimated fish selected the highest temperature (27.6° C), followed by 26° C-acclimated fish (23.7° C) and 14° C-acclimated fish (21.9° C).



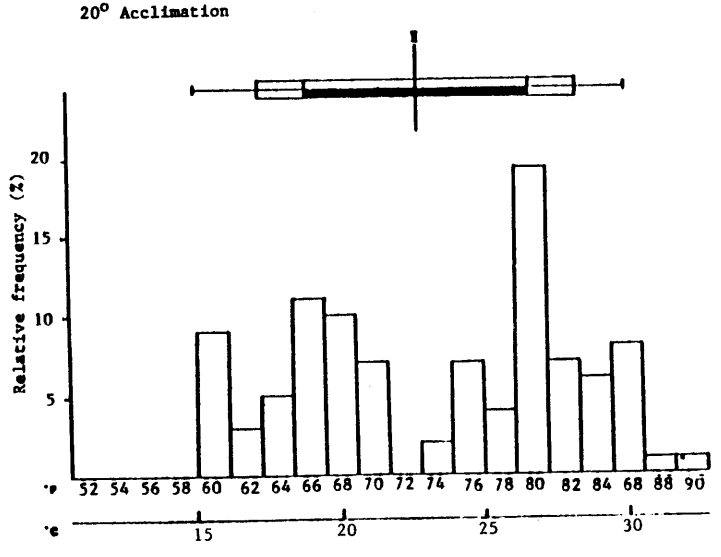
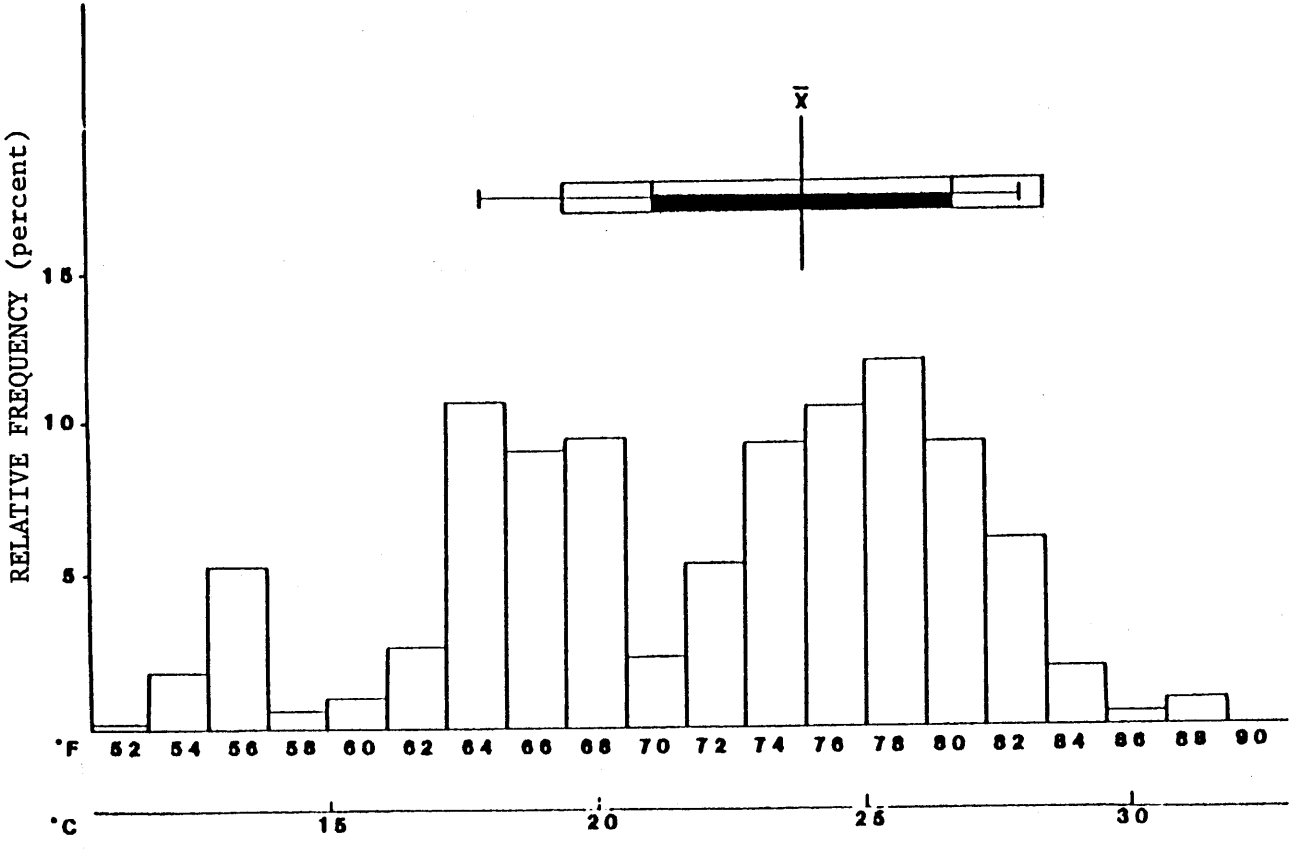




Figure 6

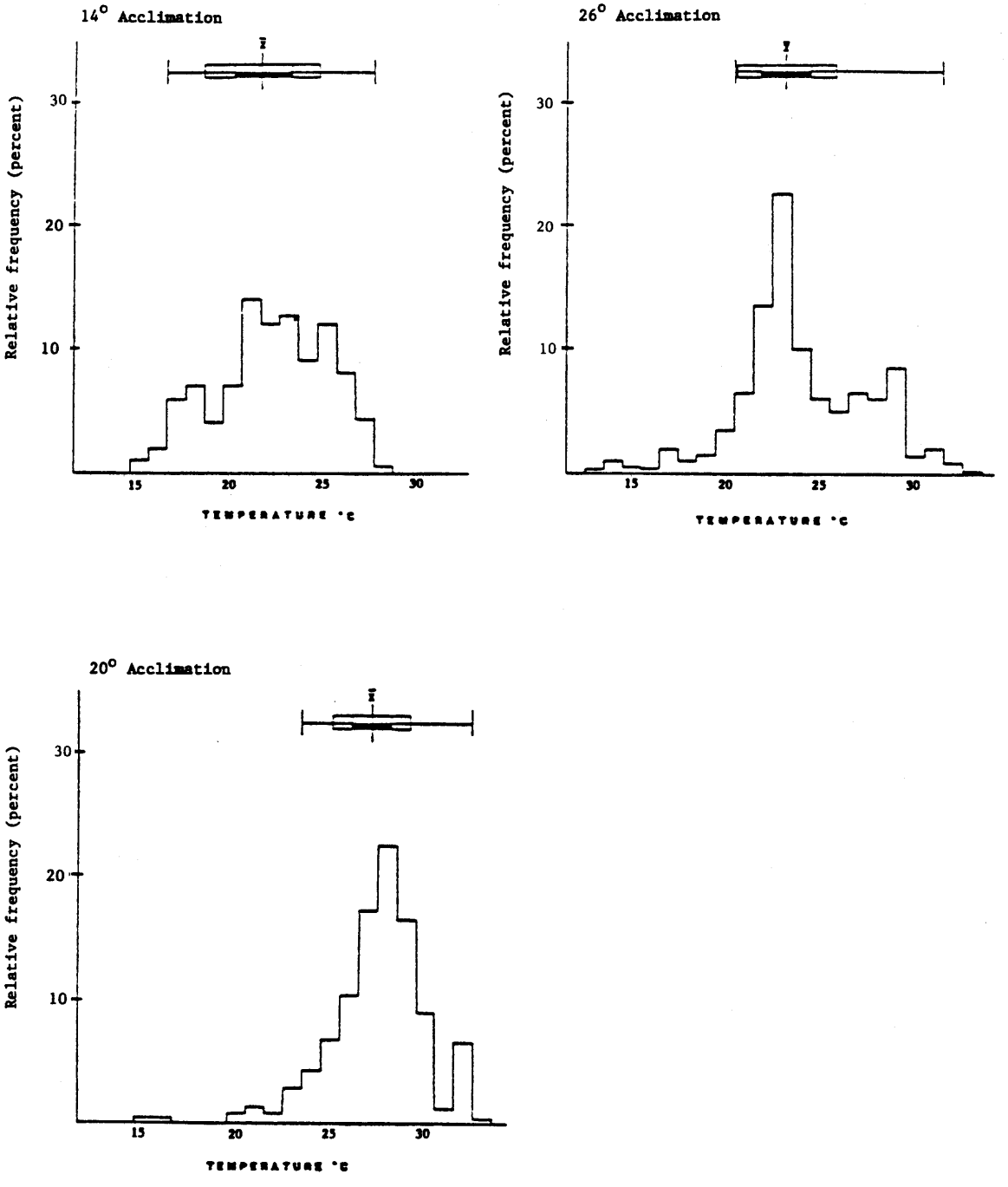
Relative frequency distribution of selected temperatures by bonytail chubs. Data pooled for first hour, one observation/minute for fish acclimated to 14, 20, and 26°C.

Figure 7



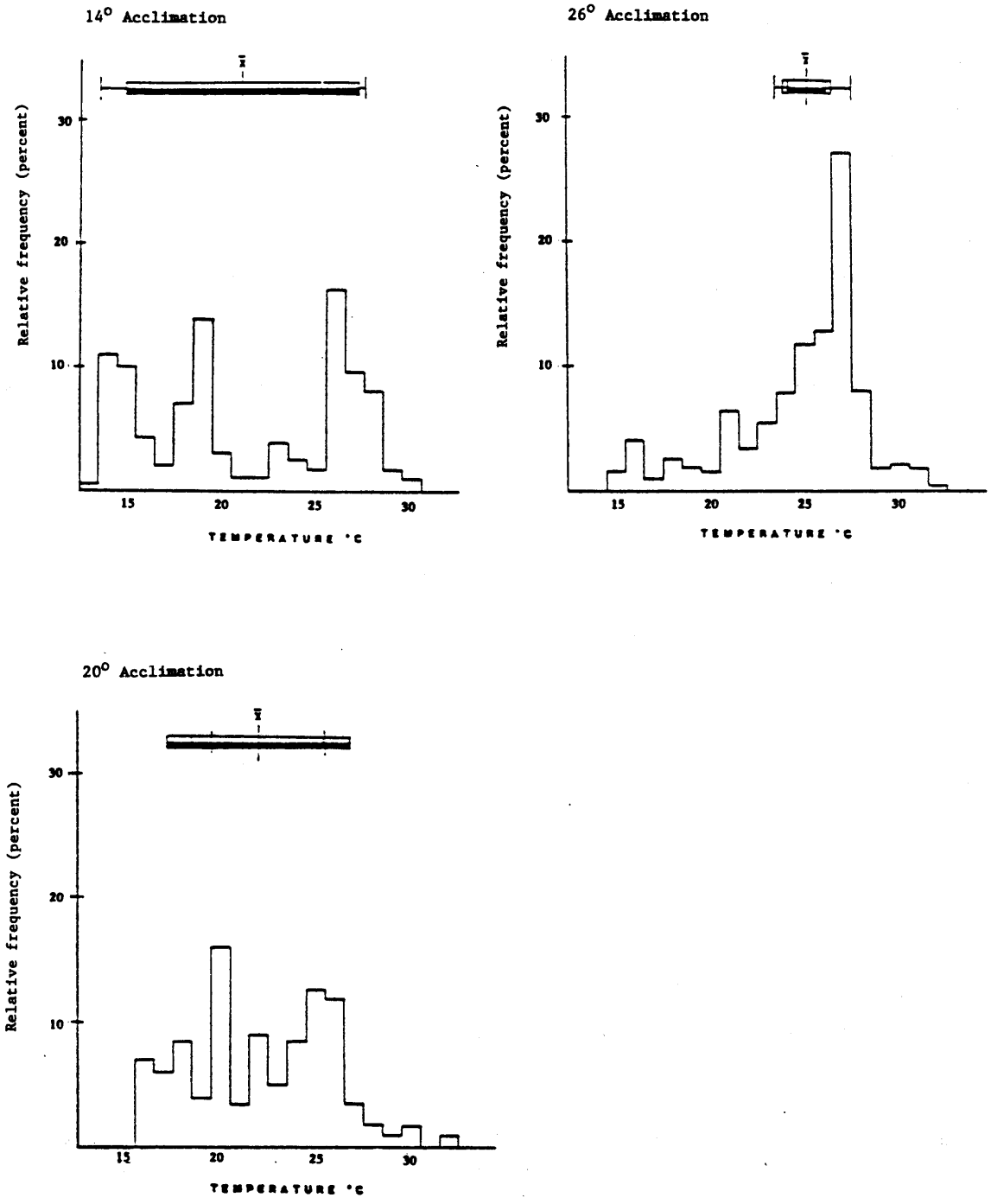

Relative frequency distribution of selected temperatures by hybrid humpback-roundtail chubs acclimated to 20°C. Data pooled for first hour, one observation/minute.

Figure 8




Relative frequency distribution of selected temperatures by juvenile Colorado squawfish. Data pooled for third hour, one observation/minute for fish acclimated to 14, 20, and 26°C. See Figure 3 for explanation of figure.

Figure 9




Relative frequency distribution of selected temperatures for adult Colorado squawfish. Data pooled for third hour one observation/ minute for fish acclimated to 14, 20, and 26°C.

Table 5
Analysis of variance of acute thermal preferenda of Colorado squawfish

| | Degrees of freedom | Sum of squares | Mean square | F |
|---|---|---|---|---|
| Juvenile squawfish | | | | |
| Source of variation | | | | |
| Among temperatures | 2 | 319.8 | 159.9 | 1/ 22.7 |
| Within temperatures | 54 | 379.9 | 7.0 | |
| Total | 56 | 699.7 | | |
| Adult squawfish | | | | |
| Source of variation | | | | |
| Among temperatures | 2 | 45.4 | 22.7 | 1.5 |
| Within temperatures | 9 | 133.3 | 14.8 | |
| Total | 11 | 178.7 | | |
| Juveniles vs. adults | | | | |
| Source of variation | | | | |
| Treatment (between ages) | 1 | 5.5 | 5.5 | 0.6 |
| Block (among temperatures) | 2 | 306.9 | | |
| Error (within temperatures) | 65 | 571.6 | 8.8 | |
| Total | 68 | 884.0 | | |

1/ Significant at the 0.01 probability level.

Table 6
Fisher's (protected) least significant difference of juvenile squawfish at different acclimation temperatures

| Comparison | $\lvert \bar{Y}_1 \ \bar{Y}_2 \rvert$ | Least significant difference (0.05) | Least significant difference (0.01) | Significance |
|---|---|---|---|---|
| 14° vs 20°C | 5.66 | 1.78 | 2.39 | 2/ |
| 14° vs 26°C | 1.85 | 1.8 | 2.42 | 1/ |
| 20° vs 26°C | 3.81 | 1.75 | 2.35 | 2/ |

1/ Significant at the 0.05 probability level.
2/ Significant at the 0.01 probability level.

These results were similar to those found in the preliminary tests of young juveniles. Fish acclimated to 20° C selected 30.3° C, those acclimated to 26° C selected 21.8° C, and those at 14° C selected 21.1° C. In data not reported here but mentioned earlier, growth of juveniles held at 20° C during the testing period was much faster than that of fish held at either 14° or 26° C. In the preliminary tests it appeared that the 26° C-acclimated fish selected a lower temperature because they were on a negative energy budget. Feeding frequency was increased from once or twice daily in the preliminary test to three times daily for all lots of fish in the final test. Differences between the preliminary and final testing of 26° C fish tended to substantiate our impression of a negative energy budget in the preliminary test fish. Mean of individual modes for the first 26° C lot of fish was 21.8° C and in the second 26° C lot was 23.7° C.

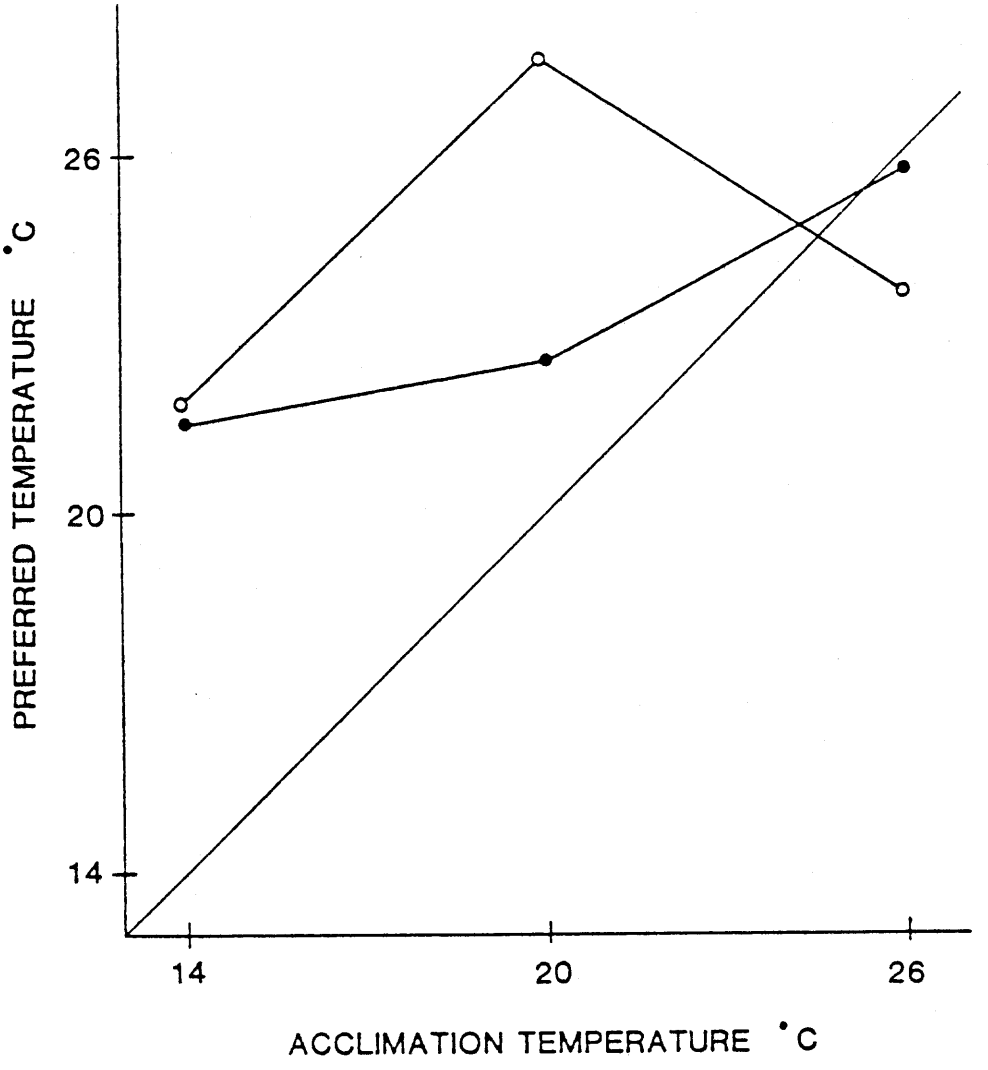
Final preferendum of juvenile squawfish were best estimated from a plot of preferred temperatures against acclimation temperature (Figure 10). The final preferendum, that point at which the preferred temperature equals the acclimation temperature (Fry 1947) for juveniles was estimated as 24.6° C. Linear regression of individual modes vs. acclimation temperature provided a very similar estimate of final preferendum (25.5° C).

Acute preferenda of adult squawfish were not analyzed with Fisher's LSD test because differences were not significant. The acute preferenda increased with increasing acclimation temperature but were not significantly different, probably due to small sample sizes and higher variability within each acclimation temperature. The range of acute preferenda of adults acclimated to different temperatures was 21.5° to 25.7° C. Best estimate of adult final preferendum was 25.4° C (Figure 10). A linear regression of individual modes vs. acclimation temperature provided an estimate of 25.3° C for the adult final thermal preferendum.

Acute preferenda of adult and juvenile squawfish were not significantly different (Table 4) even though age has been found to be an important non-thermal factor influencing temperature preference in other species of fish (Bacon et al 1967, McCauley and Read 1973, Reynolds and Casterlin 1978, and Kwain and McCauley 1978). Young fishes select higher temperatures than do the older conspecifics; and in nature are found in the shallower, warmer water (McCauley and Huggins 1979). Squawfish distributions in nature are consistent with this pattern. Adults have been found in greatest abundance in water with mean summer temperatures of 11.1-21.1° C (Vanicek and Kramer 1969). Juveniles were primarily collected in waters ranging from 12-28° C (Holden 1977). The range of acute preferenda of juveniles (21.9-27° 6° C) agrees well with field data, the range for the adults (21.5-25.7° C) does not. Further testing of adults is necessary to determine if their temperature preference is significantly lower than that of juveniles; estimates of final preferenda suggest that adults and juveniles prefer similar temperatures. Hence, factors other than temperature may affect their distribution in the wild.

Other researchers have found close agreement between temperature preferences in the laboratory and temperatures actually occupied by fish in the field (Neill and Magnuson 1974, Stauffer et al. 1975, Magnson et

Figure 10




Relationship of preferred temperature (mean of individual modes) to acclimation temperature for Colorado squawfish. Final preferendum is the point of intersection with the 45° line (i.e. that point where selected temperature = acclimation temperature). Open circles represent juvenile fish; solid circles adult fish.

al. 1979). This agreement appears to hold for the species we have studied as well. Of the native Colorado fishes tested, acute preferred temperatures have ranged from 18-29° C (x modes) which is in good agreement with the historical summer temperatures of the Colorado River drainage.

Razorback suckers, humpback chubs, and bonytail chubs had almost identical final preferenda (23-24° C vs. 24° C vs. 24.2° C). Final preferendum for hybrid chubs could not be determined, but their acute preferendum of 23.8° C when acclimated to 20° C was very close to the final preferendum of razorbacks, humpbacks, and bonytails. Final preferendum of both juvenile and adult squawfish was only one degree higher from that of the other species. Considering the amount of variation in the estimates, all four species had essentially the same final preferendum.

Stauffer et al. (1975) found that they could predict the distribution of different species of fish in a heated powerplant effluent based on laboratory thermal preference of the fish. Conversely, razorback suckers, humpback chubs, bonytail chubs, and Colorado squawfish based on their laboratory preferences would avoid cold tailwaters of a reservoir. This avoidance probably explains at least in part the disappearance of native species from the Green River below Flaming Gorge Reservoir. For years after construction of the reservoir, native Colorado River fishes have not been found from the dam downstream to the confluence of the warmer Yampa River (McAda and Wydoski 1980, Holden 1978).

## Egg Temperature Tolerance

Two lots of Colorado squawfish eggs received from the Fisheries Experiment Station of the Utah Division of Wildlife Resources, Logan, Utah, did not develop. A third lot developed only at 20° C (test incubation temperatures ranged from 5-35° C) with a 50 percent normal hatch and a 5-day incubation time. A fourth lot was incubated at test temperatures of 5°, 19°, 14°, 20°, and 26° C in the holding tanks, and 16°, 18°, 22°, and 26° C in the gradient trough. Water temperatures in the trough varied and increased as much as 3° C throughout the duration of the experiment. The only group that had a hatch higher than 50 percent was those held at 20° C. They had a 60 percent normal hatch and a 10-day incubation time. No hatching occurred among eggs held at 5°, 10°, or 14° C.

One lot of bonytail chub eggs were received on May 8, 1981, more than 24 hours after fertilization. Eggs were incubated at 5°, 10°, 14°, 20°, 26°, 31°, and 37° C, with four replications per temperature. No eggs hatched at 5°, 10°, 31°, or 37° C. The percent normal hatch at 14° C ranged from 50-70 percent with a 10-day incubation time; at 20° C, 40-100 percent normal hatch with a 6-day incubation time and at 26° C, 70-90 percent normal hatch in two of the replicates with a 3-day incubation time eggs in the other two replicates died before hatching due to fungus infection.

One lot of humpback chub eggs was received on June 4, 1981, approximately 30 hours after fertilization. They were incubated at 5°, 10°, 14°, 20°, and 26° C with four replications per temperature. There was no hatch at 5° C, 30 percent at 10° C (after 19 days); 50 percent hatch at 14° C with a 16-day incubation time; 100 percent hatch into replicates at 20° C with a 4-day incubation time, and 90- 100-percent hatch in two replicates at 26° C with a 3-day incubation time.

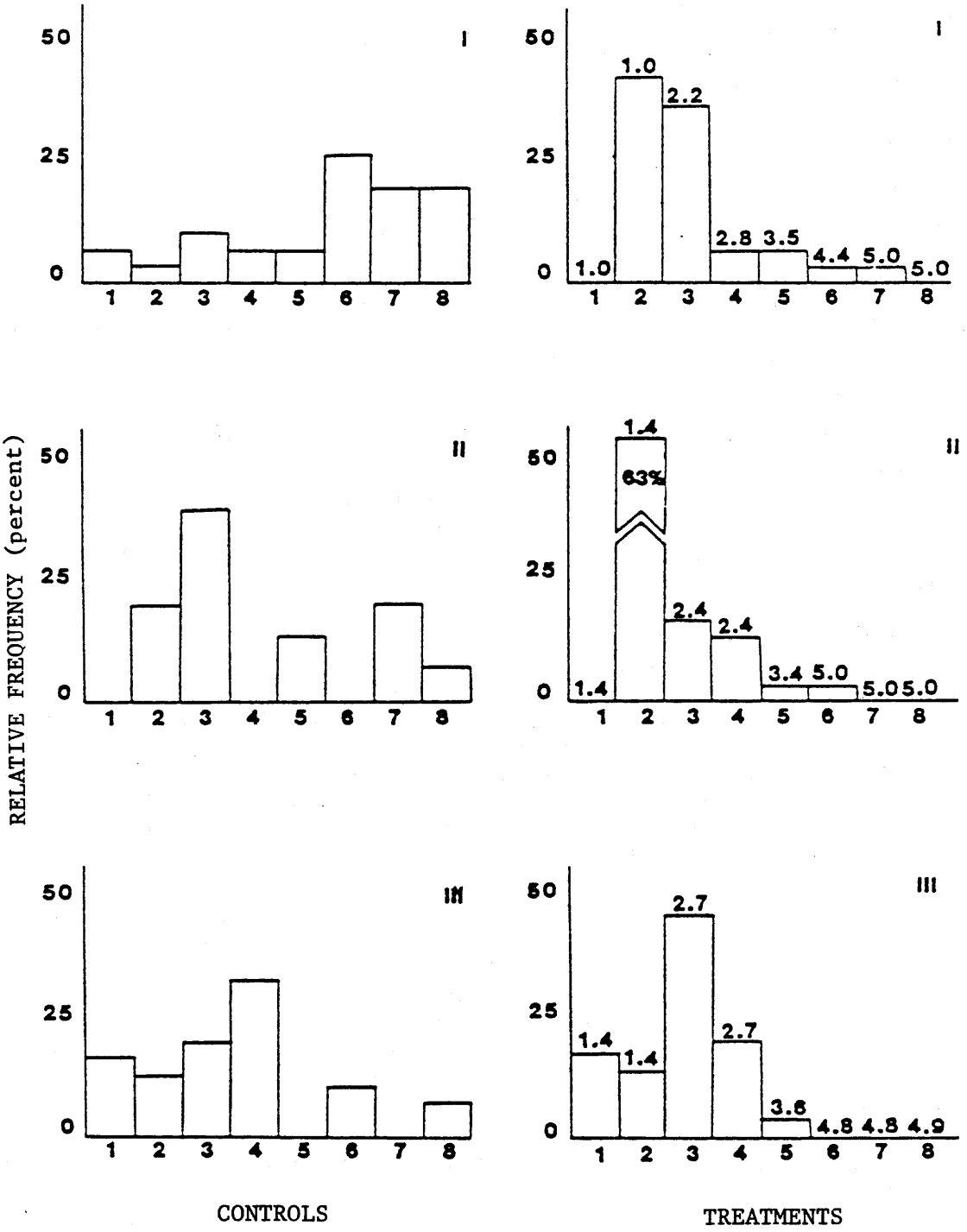
## Total Dissolved Solids Preference

Colorado River fishes tested in the TDS gradient device showed varying degrees of schooling behavior, therefore, no independence could be assumed for their distributions and no analyses were performed. Pooled distributions, however, were made for comparisons between controls and treatments, and between species.

Colorado squawfish were the most mobile species in the gradient of the species tested evidentially because of their tendency to swim in the upper level of the water column and because of their relatively loose schooling behavior. Comparison of the control histograms showed that while the distributions were not uniform, the compartment modes were random between replicates (Figure 11). Conversely, the distributions of the treatmemts appeared to have very consistent modes with a range of 1.0-2.7 mmhos of conductivity. The pooled distributions of the three replicates indicated a fairly uniform control distribution with an unexplainable peak at compartment 3 (Figure 13). The treatments, however, indicated a definite preference for lower TDS (mode = 1.0-1.4 mmhos, Figure 13); 97 percent of the 90 fish tested avoided TDS >3.6 mmhos. Note that because the water was changed with each replicate, no two gradients were identical, and the concentrations of TDS for pooled distributions are given as the range of TDS in that compartment over the three replicates. Note also that the gradients had the same conductivity in more than one compartment (Figure 11). This condition was the result of a "gradient drift," i.e. the gradient started out with a different and discrete increment of TDS concentration in each compartment, but during the 24-hour period of the test some mixing caused by aeration and the fish swimming through the density interface occurred. This shift in gradient may explain why fish were not found in adjacent compartments even though they had equal conductivity (i.e. compartments drifted to same conductivity after the fish had made their final compartment selection).

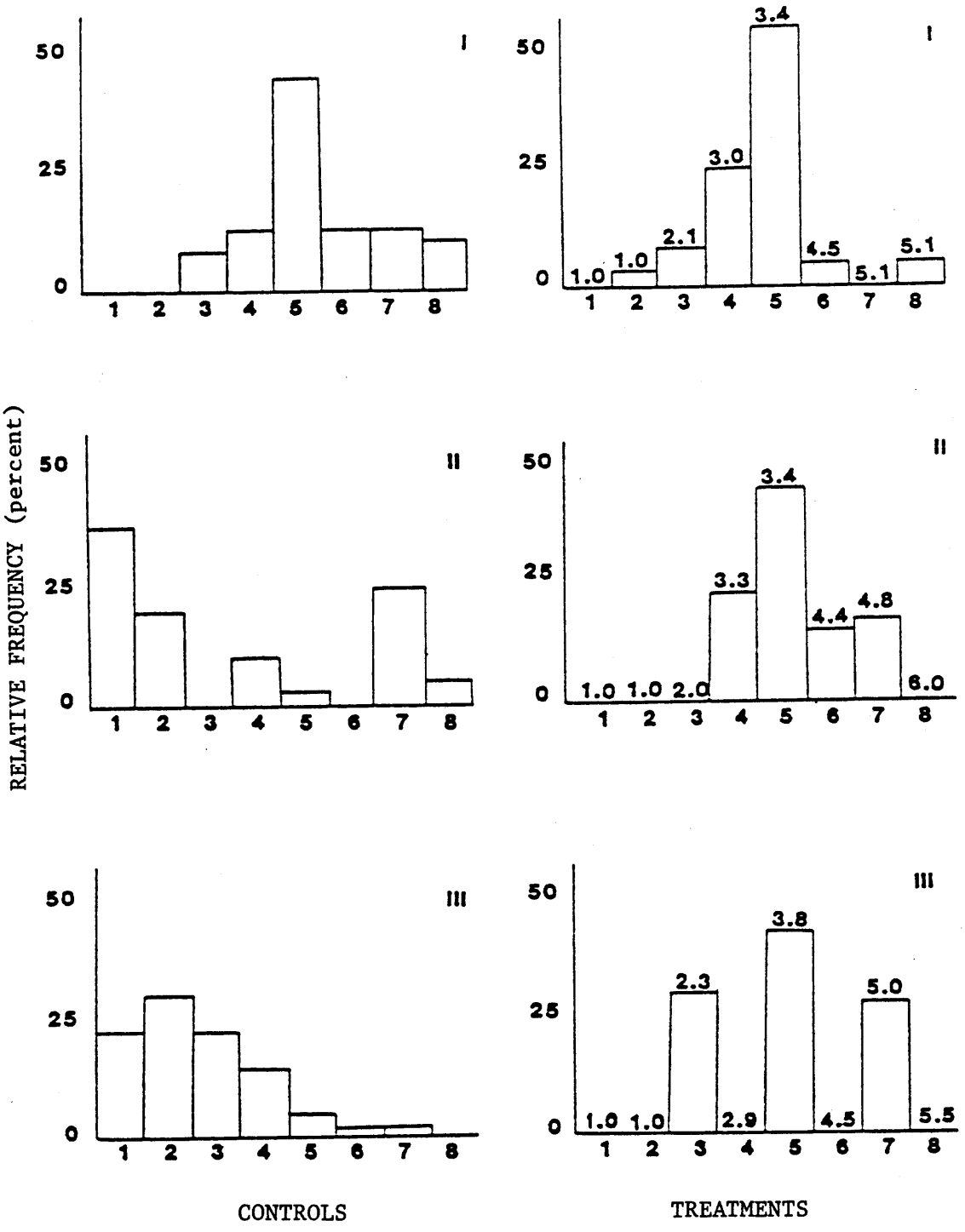
Bonytail chubs were also relatively weak schoolers (intermediate to squawfish and humpbacks) but were more bottom oriented than were the squawfish. Because the bonytails were the smallest of the species tested (2.5-5.0 cm in length), 40 fish/replicate could be used (n = 30/replicate for squawfish, n = 20 or 40/replicate for humpbacks). Comparison of the control histograms (Figure 12) indicated that the distributions were nonuniform, but compartment modes were random between replicates as were those of the squawfish (Figure 11). The treatments, however, had very consistent modes in compartment 5 with a range of 3.4-3.8 mmhos of conductivity and indicated that TDS avoidance levels are above 5.1 mmhos.

Figure 11



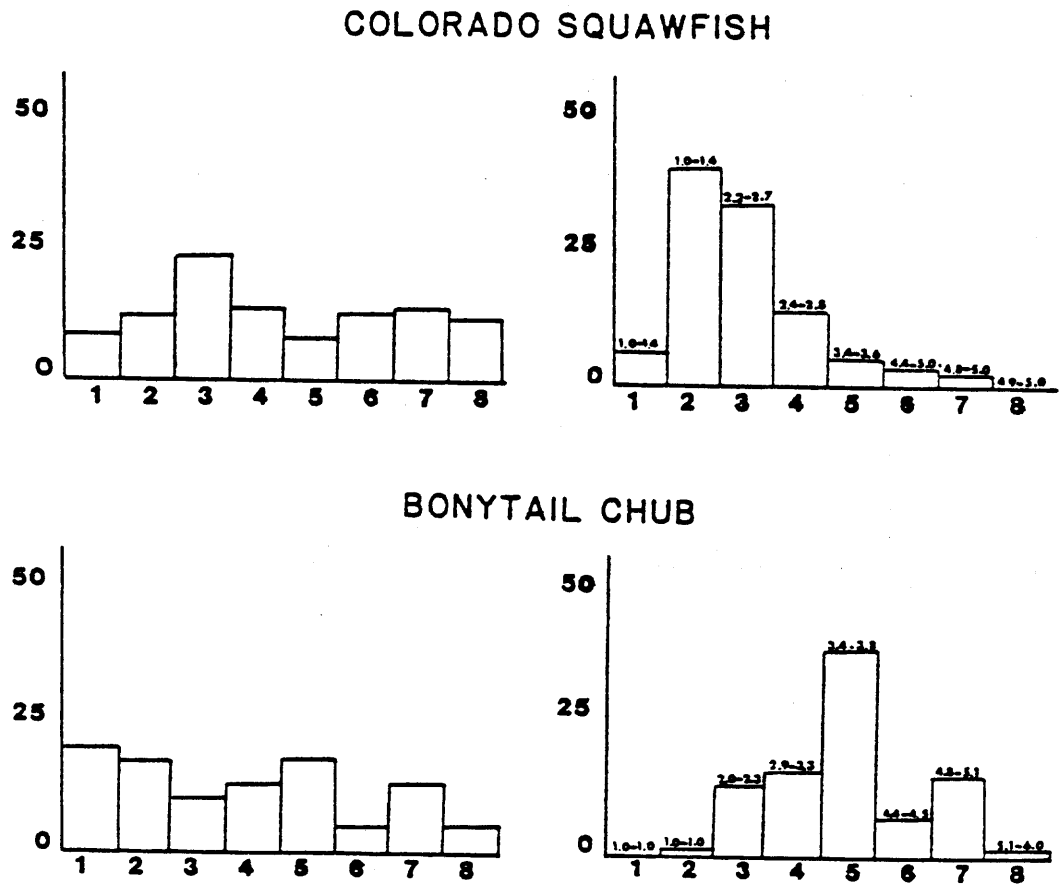

Relative frequency distribution of juvenile Colorado squawfish in 8 compartments of TDS gradient device (Figure 2) with and without gradient established. Numbers I, II, and III are replicates for controls and treatments. Number over vertical bar is conductivity in mmhos. Data on location and conductivity are values 24 hours after start of experiment.

Figure 12




Relative frequency distribution of juvenile bonytail chubs in 8 compartments of TDS gradient device (Figure 2) with and without gradient established. Numbers I, II, and III are replicates for controls and treatments. Number over vertical bar is conductivity in mmhos. Data on location and conductivity are values 24 hours after start of experiment.

Figure 13




Relative frequency distribution in 8 compartments of the TDS gradient device for pooled data from three treatments and three controls for each species. Numbers above vertical bar are the range of conductivity (mmhos) for that compartment over the three treatments (Figures 11 and 12).

Pooled controls histograms indicated a relatively uniform distribution while the pooled treatment histogram had a strong peak in compartment 5 which had a TDS of 3.4-3.8 mmhos of conductivity (Figure 13).

Humpback chubs had the strongest schooling tendency of the fish tested and were bottom oriented like the bonytail chubs. Because of their larger size (8-12 cm), only 20 fish/replicate could be tested in the gradient. An initial two test replicates suggested that distribution of the fish was affected by the schooling tendency of this species so that fish tended to be either abundant or absent in a compartment (Figure 14, Table 1). Fish also appeared to be selecting the highest TDS concentration in the gradient. Hence, concentrations in each compartment except compartment 1 (Logan city water) were doubled so that conductivity up to 9.8 mmhos was present. Distribution of fish in three treatment replicates at these higher concentrations was just as random as for the controls (Figure 15). The mode of treatment 1 was in compartment 5 (6.8 mmhos); treatment 2 was bimodal (compartment 1 = 2.4 mmhos, compartment 7 = 8.5 mmhos); mode of treatment 3 was in compartment 2 (3.0 mmhos). Hence, it did not appear that humpbacks were consistently selecting a particular concentration of TDS within the available range.

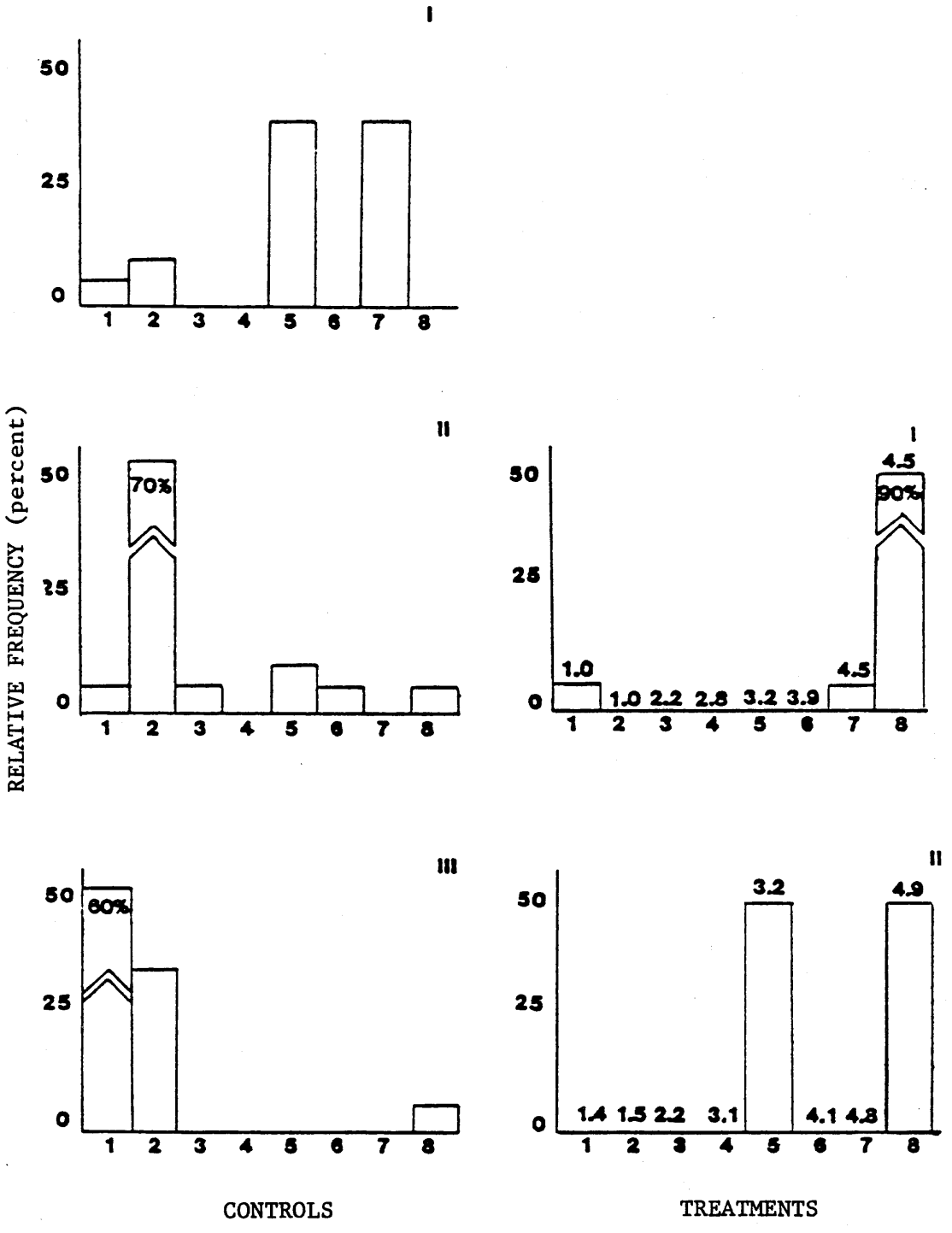
Part of the apparent random distribution of humpback chubs in the TDS gradient was attributed to the small sample size per replicate. A sample of 20 fish 8-12 cm in length was the maximum that could be held in the chamber and maintain dissolved oxygen levels over the 24-hour period. Fish from a later spawning and of suitable length (ca. 4.0 cm) to test 40 individuals/replicate were eventually obtained. Water temperature which could not be controlled in the gradient had decreased, however, from the 16-18° C level used in all previous tests to 12° C. Temperature is a factor that must be considered in TDS preference determinations because low temperature hinders osmoregulation and thus influences tolerance to salinity (Davis and Simco 1976).

Controls and three test replicates were run with the smaller fish, cooler water temperature, and the original TDS concentrations used for the other species (Table 1). Fish in the first control run with the new conditions were rather uniformly distributed over the gradient (Figure 16). Succeeding control runs were less uniform, but distribution was more widespread than when 20 fish/replicate were used. In contrast, fish in test runs were consistently more abundant in compartment 3 where conductivity was either 1.3 or 2.3 mmhos. Conductivity in specific compartments is not constant during replicates because of gradient drift described earlier.

Pooled treatment results from humpbacks of both body sizes tested at 12° and 18° C indicated that most fish selected water with a conductivity of 1.3 to 3.0 mmhos (Figure 17). About 60 percent of the 220 fish tested were found after 24 hours in this conductivity range. No fish selected water with TDS above 9.4 mmhos, and only 5 percent was found in conductivity of 8.5-9.4 mmhos.

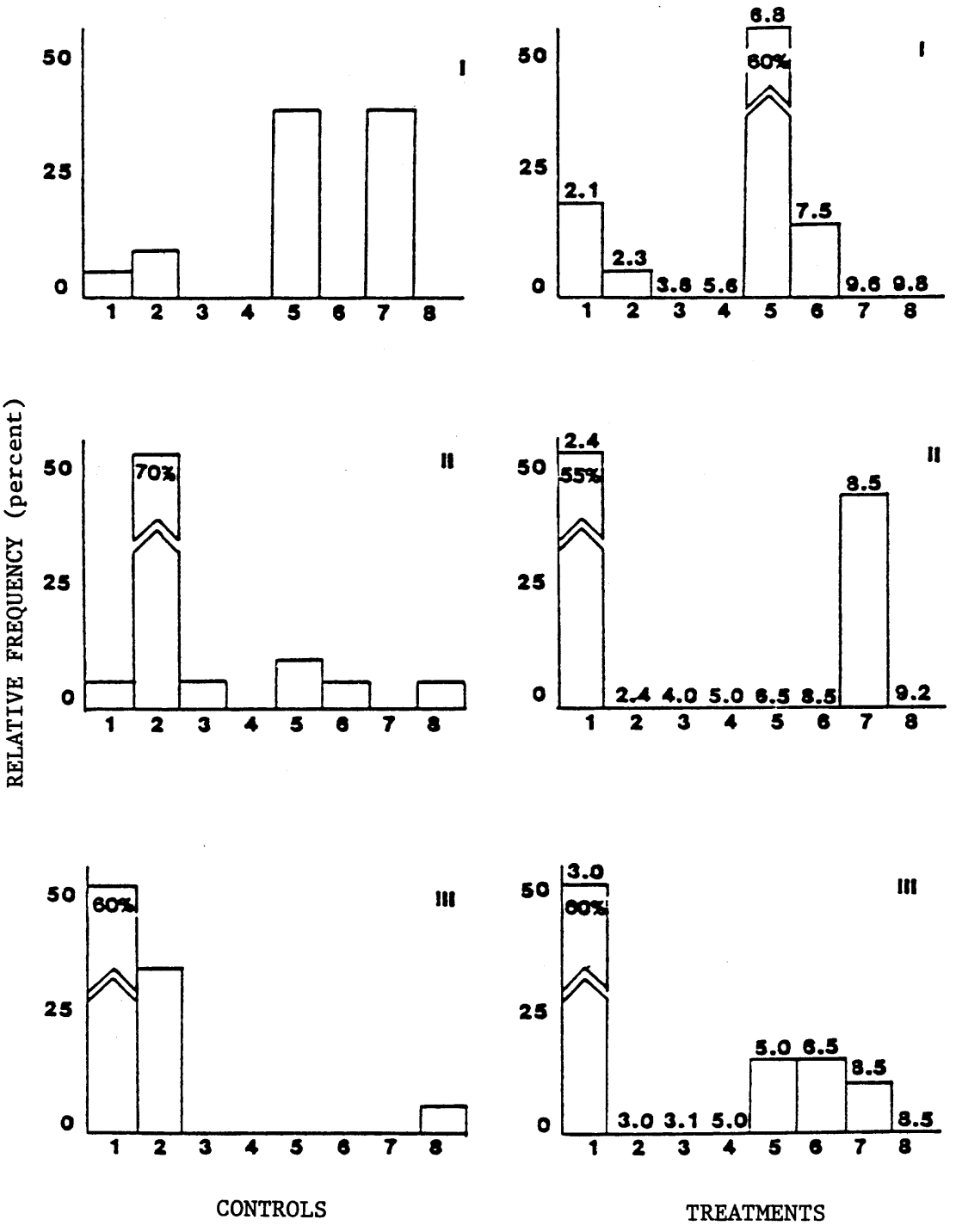
Pooled distribution of Colorado squawfish, bonytail chubs, and small humpback chubs agreed well in overall shape with those of the Gulf of California grunion (Leuresthes sardina) (Reynolds and Thomson 1974),

Figure 14



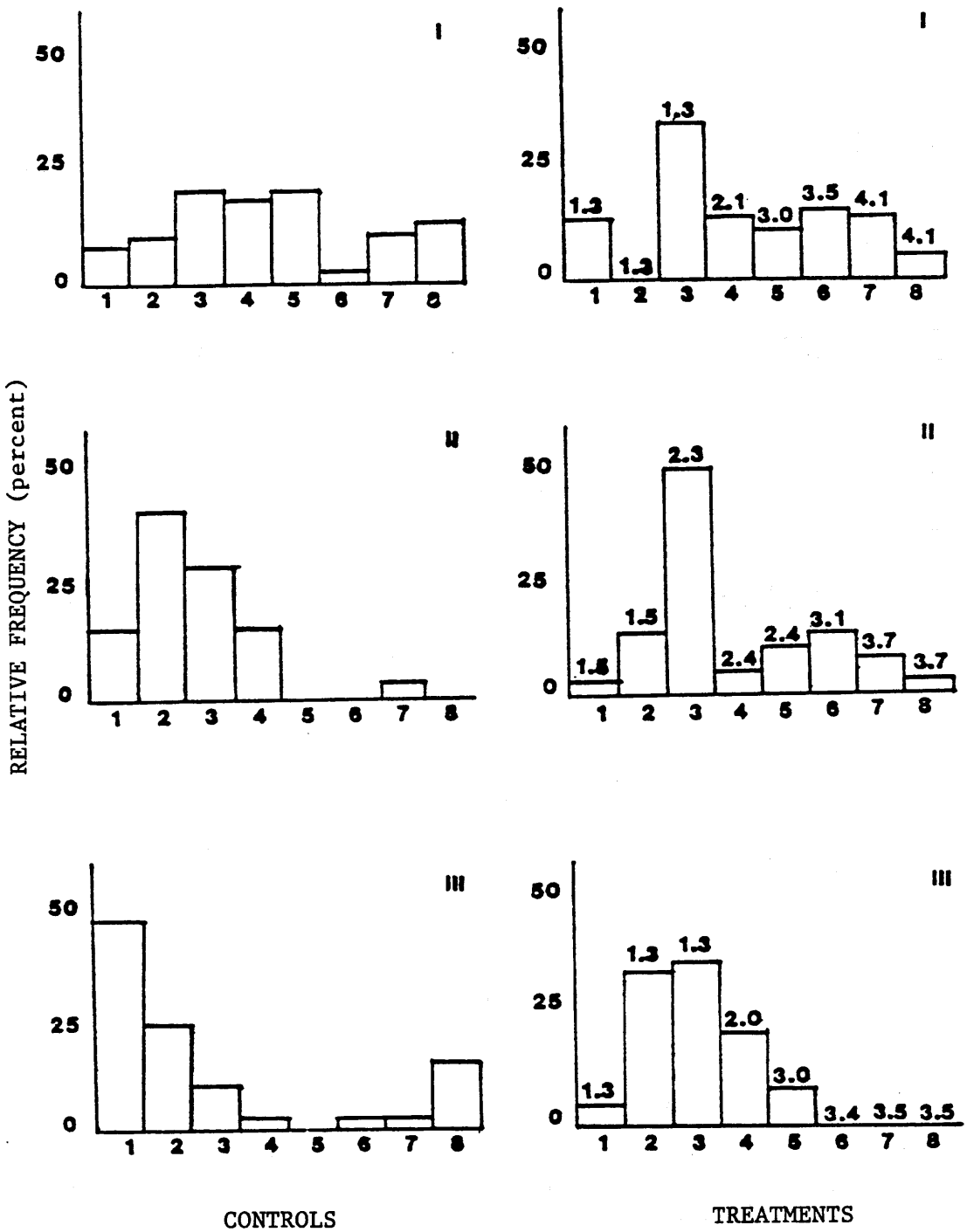

Relative frequency distribution of juvenile humpback chubs in 8 compartments to TDS gradient device (Figure 2) with and without gradient established. Numbers I, II, and III are replicates for controls and treatments. Number over vertical bars is conductivity in mmhos. Data on location and conductivity are values 24 hours after start of experiment. N = 20 8-12-cm fish/replicate.

Figure 15



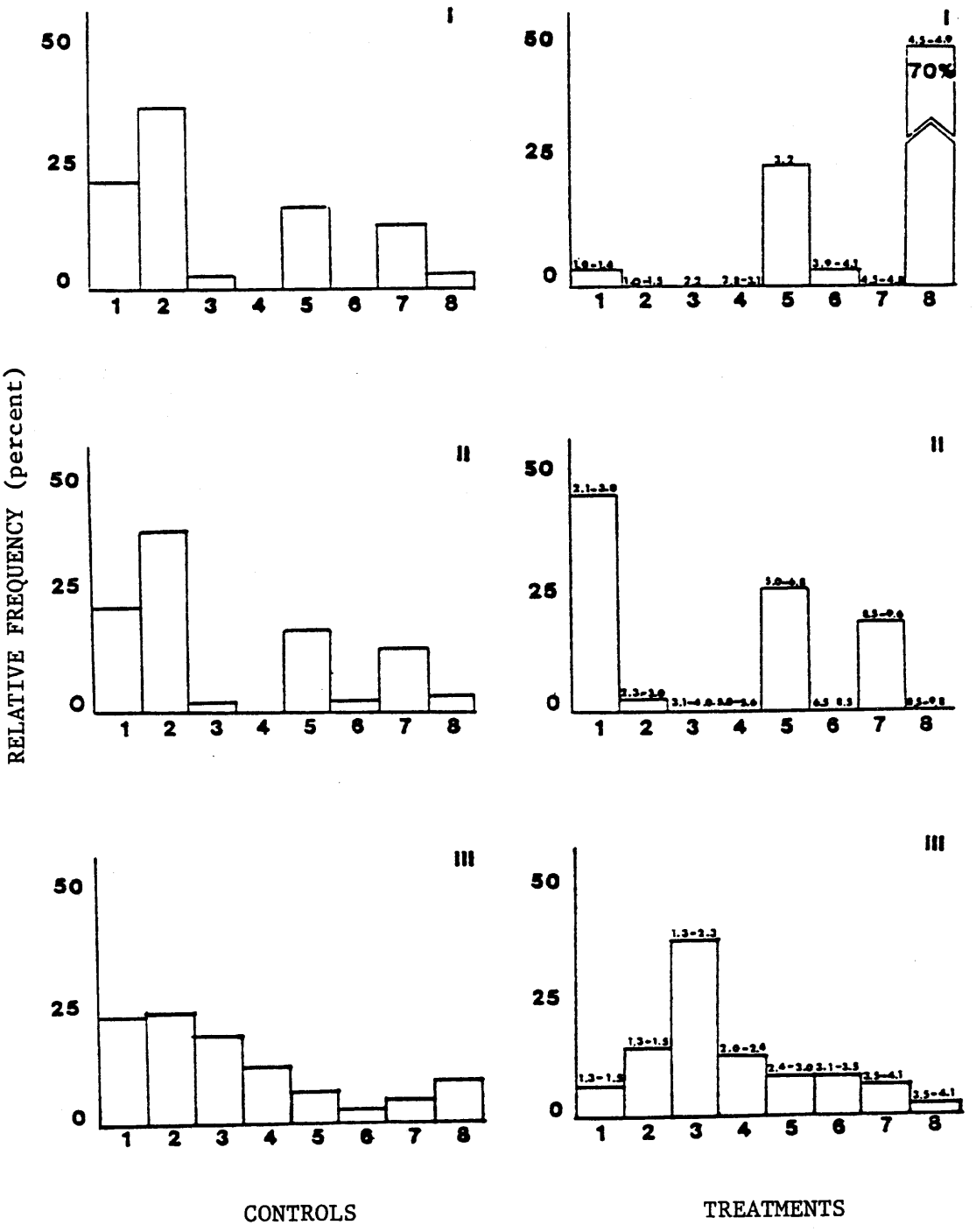

Relative frequency distribution of juvenile humpback chubs in 8 compartments to TDS gradient device (Figure 2) with and without gradient established. Numbers I, II, and III are replicates for controls and treatments. Number over vertical bar is conductivity in mmhos. Data on location and conductivity are values 24 hours after start of experiment. N = 20 8-12-cm fish/replicate. Concentrations were double those of previous test.

Figure 16




Relative frequency distribution of juvenile humpback chubs in 8 compartments to TDS gradient device (Figure 2) with and without gradient established. Numbers I, II, and III are replicates for controls and treatments. Number over vertical bar is conductivity in mmhos. Data on location and conductivity are values 24 hours after start of the experiment. N = 40 4-cm fish/replicate tested at 12°C.

Figure 17




Relative frequency distribution in 8 compartments of the TDS gradient device for pooled date for 8-12 cm humpback chubs tested at 18°C (I, II) and 4-cm chubs tested at 12°C (III). Numbers above vertical bars are the range of conductivity (mmhos) for that compartment for 2 or 3 replicates (Figures 13, 14, and 15).

and the common welk (Buccinum undatum) (Staaland 1969), while distribution of the larger humpback did not. Both Reynolds and Thomson, and Staaland found good agreement with salinity preference in laboratory and salinities occupied in the field. McInerney (1964) also found good agreement between laboratory and field salinity preferences for five species of juvenile Pacific salmon, using a different type of preference chamber. Comparison of our experiments indicated that the Colorado squawfish has the lowest TDS preference (1.0-1.4 mmhos = 0.6-1.1 mg/ml) of the species tested but has a similar TDS avoidance (ca. 5.0 mmhos) to that of the bonytail chub (ca. 5.1 mmhos). TDS preference of the squawfish is similar to TDS levels found in the Green and Upper Colorado Rivers today but the bonytail chub preference (3.4-3.8 mmhos = 4.1-4.7 mg/ml) is much higher. Humpback chub TDS preference (1.3-3.0 mmhos = 1.0-3.5 mg/ml) appears to be intermediate to squawfish and bonytails, however, their TDS avoidance level (>8.5 mmhos) may be much higher. From the results of these experiments, one would predict that of the species tested, the Colorado squawfish would be the most affected by increases in TDS caused from evaporative loss in reservoirs and any salt release from oil shale development. TDS preference of the bonytail and humpback chubs is also low enough that habitat could be lost to them by TDS increases.

## Hematology

No differences were found between sex or with length (15-30 cm) in the blood constituents of 60 (30 male, 30 female) juvenile razorback suckers. Consequently, blood data for sexes were pooled and averaged (Table 7). Hematocrit averaged 33 percent, hemoglobin average 7.5 mg/100 ml, and erythrocytes totaled 1.32 x $10^6/mm^3$. These parameters are correlated and respond rapidy to changes in environmental oxygen levels. Leucocytes totaled 26.9 x $10^3/mm^3$ and were 60.4 percent lymphocytes, 33.7 percent thrombocytes, and 5.4 percent granulocytes. We classified 1.9 percent of the granulocytes as eosinophils based on recommendations of Lester and Daniels (1976). The remainder of the granulocytes were identified as neutrophils. An analysis of the white cell portion of fish blood has been commonly employed to determine the effects of injury or infectious deseases (Pickford et al. 1971). Glucose (blood sugar), a parameter frequently employed to monitor general stress (Hattingh 1977) averaged 52.7 $\pm$ 13.8 mg/100 ml whole blood. Blood chloride averaged 108 mEq/1. Chloride and other blood electrolytes can be indicative of the osmoregulatory state of a fish (Mazeaud et al. 1977).

Hematocrit of juvenile squawfish (n = 31) averaged 38 percent, hemoglobin averaged 7.5 mg/100 ml, and the red blood cells numbered 1.59 x $10^6/mm^3$. White blood cells numbered 77.5 x $10^3/mm^3$ and, as in the razorback sucker, lymphocytes were the most abundant cell (69.8 percent). Thrombocytes and granulocytes made up 25 percent and 3.66 percent of the remaining white blood cells respectively. We could obtain only 50-150 ul of whole blood from the squawfish examined and therefore had an insufficient volume to determine chloride and glucose levels. However, mean chloride (99.1 mEg/1) and glucose (107.1 mg/100 ml) were determined for large squawfish (Table 7). Large squawfish had significantly less total plasma protein levels than small squawfish. Otherwise, the hematological profiles of juveniles and adults were similar.

Table 7
Hematological characteristics of four Colorado River fishes

| Parameter | Razorback suckers (56) | Squawfish Juvenile (30) | Squawfish Adult (19) | Humpback chub (30) | Bonytail chub (31) |
|---|---|---|---|---|---|
| Length (millimeters) | 240.6 | 108.3 | 414 | 92.3 | 98.33 |
| Range | 146-327 | 98-120 | 375-497 | 82-111 | 87-116 |
| Weight (grams) | 151.3 | 8.0 | --- | 5.7 | 8.97 |
| Range | 30-328 | 6.2-11.9 | --- | 3.3-10.2 | 5.7-14.0 |
| Hematocrit (percent) | 33.5 | 38.7 | 38.0 | 30.2 | 34.5 |
| Standard deviation | 4.5 | 7.0 | 7.2 | 7.8 | 5.8 |
| Total protein (g/200 ml) | 4.9 | 10.9 | 1/ 5.57 | 6.1 | 8.8 |
| Standard deviation | 0.7 | 1.7 | 0.8 | 1.3 | 1.1 |
| Red blood cells ($10^6/mm^3$) | 1.32 | 1.59 | 2.085 | 1.92 | 2.22 |
| Standard deviation | 0.27 | 0.41 | 0.49 | 0.33 | 0.48 |
| White blood cells ($10^3/mm^3$) | 27.1 | 72.0 | 90.4 | 52.5 | 91.6 |
| Standard deviation | 8.7 | 27.2 | 25.3 | 13.4 | 21.4 |
| Hemoglobin (g/100 ml) | 7.5 | 7.5 | 9.4 | 7.2 | 7.1 |
| Standard deviation | 1.0 | 1.1 | 1.5 | 0.9 | 1.1 |
| Glucose (mg/100 ml) | 52.7 | 2/ | 107.1 | 2/ | 2/ |
| Standard deviation | 13.8 | | | | |
| Chloride (mEq/1) | 108.0 | 2/ | 99.1 | 2/ | 2/ |
| Standard deviation | 9.2 | | 20.8 | | |
| Lymphocyte (percent) | 60.6 | 69.8 | 62.4 | 33.4 | 63.0 |
| Standard deviation | 16.0 | 11.3 | 9.1 | 10.0 | 8.7 |
| Thrombocytes (percent) | 33.9 | 25.3 | 31.4 | 62.5 | 34.3 |
| Standard deviation | 14.6 | 11.0 | 7.7 | 10.5 | 9.7 |
| Neutrophils (percent) | 3.5 | 0.3 | 1/ 2.0 | 0.8 | 0.6 |
| Standard deviation | 4.4 | 0.5 | 2.5 | 1.1 | 0.9 |
| Eosinophils (percent) | 1.9 | 3.36 | 3.8 | 2.7 | 1.7 |
| Standard deviation | 2.5 | 3.0 | 4.5 | 2.4 | 1.3 |
| Other leucocytes (percent) | 0.0 | 0.9 | 1/ 0.5 | 0.6 | 0.0 |
| Standard deviation | --- | 1.5 | 0.6 | 1.1 | --- |

1/ Juvenile and adults significantly different, *t*-test, P=0.05.
2/ Insufficient sample volume for individual determinations.

Hematocrit of juvenile humpback chub averaged 30 percent, hemoglobin averaged 7.2 g/100 ml, and red blood cells numbered 1.92 x $10^6/mm^3$. Leucocytes numbered 52.5 x $10^3/mm^3$ but, unlike the other two species examined, thrombocytes were the most abundant cell (62.4 percent), followed by lymphocytes (33.4 percent) and granulocytes (3.5 percent). Less than 1 percent of the white blood cells were identified as either hemoblasts or macrophages according to descriptions presented by Grizzle and Rogers (1979) for channel catfish (Ictalurus punctatus).

Hematocrit of juvenile bonytail chubs averaged 34.5 percent, hemoglobin averaged 7.1 g/100 ml, and red blood cells numbered 2.22 x $10^6/mm^3$. Leucocytes numbered 91.6 x $10^3/mm^3$. Like the razorback and juvenile squawfish, lymphocytes of the bonytail were the most abundant (63 percent) white blood cell, followed by the thrombocytes (34.3 percent), and granulocytes (2.5 percent). Total protein levels averaged 8.8 g/100 ml. Overall, the hematology of the bonytail was similar to that of the other juvenile rare species.

Certain similarites were apparent when comparing the hematological profiles of the three Colorado River species (Table 7) with those of three commonly cultured species (Table 8). The white blood cell types found in the Colorado River fish were similar in appearance and occurrence to those of other species. The hematocrit, hemoglobin, and total protein values were in the same order of magnitude among species and similar to the range described as normal for teleost fishes (Stachell 1971). The number of blood cells was the most variable parameter among species.

These hematological data may be useful to fish culturists for assessing the effects of culture and stocking practices on fish health. Recovery plans for the rare fish now or, may in the future, suggest the use of artificial propagation as a means of protecting the species. Clinical tests have been useful to the fish culturist for monitoring fish health and diagnosing disease, diet, and water quality problems (Blaxhall 1972, Wedemeyer and Yasutake 1977). For example, elevated total protein and blood chloride levels may indicate impaired water balance due to osmoregulatory disfunction. Decreased erythrocyte counts, hematocrit and hemoglobin levels may indicate diet-induced anemias. Leukopenia may indicate acute stress. The hematological characteristics presented here may not represent those of fish reared on other diets and at other water temperatures. Therefore, we recommend that a normal hematological profile be established for each hatchery and compared with our values. Because most fish will be reared only the the fingerling stage, our data may be more comparable than if variables such as sex, degree of maturity, and season were involved.

Two methods are commonly used to determine hemoglobin and total protein levels in fish. Colorometric methods using a bench-top meter (e.g., Baush and Lomb Spectronic 70 spectrophotometer) are considered more accurate than refractometric methods using a hand-held meter (e.g., American Optical Brix-Goldberg refractometer for total protein or an American Optical Hb-Meter for hemoglobin) (Wedemeyer and Yasutake 1977). Hand-held meters are portable and most suited for field or hatchery work. A comparison was made between the two methods for determining

Table 8
Baseline hematology of three species of commonly cultured fish[1/]

| Parameter | Goldfish | Channel catfish | Rainbow trout |
|---|---|---|---|
| Hematocrit (percent | 37 | 24 | 24-43 |
| Hemoglobin (g/100 ml) | 3.8 | 6.6 | 5.4-9.3 |
| Total protein (g/100 ml) | 10.6 | 5.4 | 2-6 |
| Glucose (mg/100 ml) | 28.5 | 29 | 41-151 |
| Chloride (mEq/1) | | 114 | 84-132 |
| Erythrocytes ($10^3/mm^3$) | 1.24 | 2.44 | 0.77-20.9 |
| Leucocytes ($10^3/mm^3$) | 21.9 | 164 | 7.8-20.9 |
| Leucocytes differential | | | |
| Lymphocyte (percent) | 77 | 54 | 89-98 |
| Thrombocyte | 8 | 41 | 1-6 |
| Granulocyte (percent) | 11.5 | 3 | 1-9 |
| Other (percent) | 3.5 | 1.0 | 0 |

1/ Data from Watson et al. 1963, Weinreb and Weinreb 1969, Hunn et al. 1968; Smith et al. 1952; Chavin and Young 1970; Wedemeyer and Yasutake 1977.

hemoglobin and total protein levels of the Colorado squawfish and the razorback sucker. Blood was obtained using routine methods, and individual samples were then analyzed using both techniques (Table 9). The refractometric method recorded higher values for both parameters than did the spectrometric method. While the accuracy of the spectrophotometer was probably greater, the precision (as indicated by the magnitude of the standard deviations) of the methods was similar. The hand-held meter would, therefore, be a useful tool for monitoring trends or comparing one group of fish to another.

Wedemeyer and Yasutake (1977) developed a graph useful in determining the sample size needed to be 95 percent certain of determining a 10, 15, 20, or 50 percent difference in blood chemistry between experimental and control groups. The sample size depended on the coefficient of variation for each clinical test (Table 8). Sample sizes needed to detect a 20 percent difference in hemoglobin and total protein for the squawfish would be 15 and 12 individuals, respectively, for the refractometer, and 30 and 19 individuals, respectively, for the spectrophotometer. Sample sizes needed to detect a 20 percent difference in hemoglobin and total protein for the razorback would be 22 and 21, respectively, for the refractometer and 30 and 8, respectively, for the spectrophotometer.

We evaluated transportation stress in 40 (20 male, 20 female) razorback suckers using blood chloride and glucose levels. Blood glucose increased from 54 mg/100 ml at Willow Beach Hatchery to 144 mg/100 ml after hauling to Logan, Utah. A hypochloremic trend was found in the transported fish but the decrease in blood chloride from 108 mEq/l at the hatchery to 99 mEq/l after hauling was not a statistically significant change. No mortalities due to hauling were observed either during the trip or during the 1 week post-hauling period. There was no difference between sexes in chloride or glucose levels before or after hauling. Our finding suggests that salt might be used to advantage during transport. Many studies have shown that the use of salt (0.1-3.0 percent, depending on species) in hauling tanks can be effective in reducing osmoregulatory stress (Hattingh et al. 1975).

## Swimming Ability

Swimming speeds of fish are usually defined as (1) burst speed (darting for a few seconds at 8-12 body lengths/sec), (2) sustained speed (swimming for several minutes at 4-7 body lengths/sec), and (3) cruising speed (swimming for hours at 2-4 body lengths/sec). Great variability exists in swimming data collected in the artificial conditions of a stamina tunnel (Bell 1973, Hettler 1977). We also noted such variability especially at water velocities between the extremes tested at each temperature. For example, one fish in a pair would occasionally tire in a few minutes while the remaining fish swam for 2 hours. We compared the swimming ability of fish tested singly and in pairs and found no difference. We felt, therefore, that the behavior of the fish that we tested probably represented different levels of motivation and ability within each species.

Table 9

Comparison of refractometric and colorometric methods for determining hemoglobin and total protein levels in the Colorado squawfish and razorback sucker[1/]

| Species | Hemoglobin (g/100 ml) | | | | Total protein (g/100 ml) | | | |
|---|---|---|---|---|---|---|---|---|
| | Number | Refracto-meter | Number | Spectro-photometer | Number | Refracto-meter | Number | Spectro-photometer |
| Squawfish | | | | | | | | |
| Mean | 19 | [2/]9.35 | 15 | 7.74 | 18 | 5.57 | 17 | [2/]4.99 |
| Standard deviation | | 1.49 | | 1.95 | | 0.76 | | 0.91 |
| Coefficient variation | | 15.9 | | 25.9 | | 13.6 | | 18.2 |
| Razorback | | | | | | | | |
| Mean | 13 | 5.94 | 13 | 5.28 | 13 | 3.84 | 13 | 3.55 |
| Standard deviation | | 1.15 | | 1.30 | | 0.72 | | 0.38 |
| Coefficient variation | | 19.4 | | 24.6 | | 18.8 | | 10.7 |

1/ A t-test was employed to compare means obtained by the two methods.

2/ Significant at 0.01 probability level.

Several cursory studies were conducted to determine testing protocol. Fish conditioned to the tunnel for 10 minutes at no current and for 5 and 20 minutes at 0.15 m/sec. did not perform differently when tested at 0.45 m/sec. Retesting individual fish four times at 48-hour intervals did not affect performance. Occasionally a fish did not learn to swim in the tunnel in the 5-minute conditioning time, and was not tested further.

Razorbacks could cruise for about 2 hours in water velocities ranging from 0.15-0.3 m/sec. (Table 10). However, fish could only swim for about 1 minute in a water velocity of about 0.6 m/sec. Larger fish performed significantly ($p = 0.05$) better than did smaller fish (Table 11). Water temperature did not significantly affect swimming ability. Most fish tested at 0.15 m/sec. exhibited reotrophic behavior but swam very little since they could maintain position in the tunnel by positioning the pectoral fins against the bottom.

Juvenile squawfish were able to swim for 1 hour or more in velocities of about 0.39 m/sec. Ability rapidly dropped at higher velocities, and no fish could swim for more than a minute at velocities of 0.57 m/sec (Table 12). Juvenile squawfish tested at 20° and 26° C had significantly greater swimming ability than those tested at 14° C (Table 11). Within a length group of 77-142 mm, no significant difference in swimming ability of juvenile squawfish due to length could be detected. However, fish length was an important factor in determining swimming ability of adult squawfish (375-497 mm in length). Adult fish had greater endurance than the juveniles (Table 13). Large squawfish were able to swim for 1 hour or more in velocities of about 0.91 m/sec--about twice the stamina of smaller juveniles. Stamina rapidly decreased as velocity increased, and fish could swim for only a few minutes at 1.09 m/sec. Neither fish length (within the large fish group) nor temperature significantly affected the time to fatigue of large squawfish (Table 11).

Juvenile bonytail chubs had time-to-fatigue levels which were similar to those of other juvenile fish tested. Sustained swimming was observed at 0.45 m/sec at 14° C, 0.56 m/sec at 20° C, and 0.63 m/sec at 26° C. Above these water velocity levels, swimming ability rapidly declined (Table 14). Bonytail performance was significantly affected by water temperature (Table 11). For example, fish could swim for less than 1 minute at 0.57 m/sec at 14° C, but at 20° C, they could swim for over an hour at this velocity. The size range of fish tested (73-120 mm in length) was apparently insufficient to detect size related differences in swimming ability (Table 11).

Humpback chub swimming stamina was similar to that of the squawfish and razorback. Humpbacks could swim for about 2 hours at 0.32 m/sec but only for a few minutes at 0.78 m/sec (Table 15). Their ability was positively and significantly related to temperature. Larger fish (134 mm maximum length) performed significantly ($p < 0.05$) better than did smaller fish (73 mm minimum length).

The results of our studies compare well (considering differences in test conditions) with data collected for similar-sized fish of other species (Table 16). The fish used in our work were reared under culture conditions in low velocity waters since hatching. Lack of conditioning

Table 10
Swimming performance (minutes to fatigue) of razorback suckers (15-30 cm in length) at different water temperatures and velocities
(A test was discontinued when a fish swam for 120 minutes)

| Velocity (m/sec) | 12°C | | | 20°C | | | 26°C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Number | Mean | Standard deviation | Number | Mean | Standard deviation | Number | Mean | Standard deviation |
| 0.15 | 5 | 120 | 0 | 5 | 120 | 0 | - | --- | --- |
| 0.30 | 12 | 82.12 | 56.1 | 10 | 105.37 | 31.1 | 6 | 100.5 | 47.8 |
| 0.375 | 9 | 42.23 | 58.4 | 3 | 80.4 | 68.6 | 5 | 111.0 | 20.1 |
| 0.45 | 10 | 13.92 | 37.3 | 8 | 17.27 | 41.5 | 8 | 30.43 | 55.3 |
| 0.60 | 10 | 1.32 | 0.5 | 10 | 1.75 | 1.25 | 10 | 0.45 | 0.72 |

Table 11
Analysis of variance of the effects of water velocity (main effect), temperature (main effect), and fish length (covariate) on swimming-time-to-fatigue of four Colorado River fishes

| Species | Source of variation | Degrees of freedom | Observed "F" |
|---|---|---|---|
| Razorback sucker | Temperature | 2 | 2.7 ns[1] |
| | Velocity | 4 | [2]38.6 |
| | Length | 1 | [3]4.2 |
| Colorado squawfish | | | |
| Juvenile | Temperature | 2 | [2]19.4 |
| | Velocity | 12 | [2]23.5 |
| | Length | 1 | 3.7 ns[1] |
| Adults | Temperature | 2 | 2.9 ns[1] |
| | Velocity | 3 | [2]71.1 |
| | Length | 1 | 0.1 ns[1] |
| Bonytail chub | Temperature | 2 | [2]7.7 |
| | Velocity | 7 | [2]14.6 |
| | Length | 1 | 2.8 ns[1] |
| Humpback chub | Temperature | 2 | [2]20.6 |
| | Velocity | 17 | [2]9.3 |
| | Length | 1 | [3]5.9 |

1/ ns = not significant at 0.05 probability level.
2/ Significant at 0.01 probability level.
3/ Significant at 0.05 probability level.

Table 12
Swimming performance (minutes to fatigue) of juvenile Colorado squawfish (77-142 mm in length) at different water temperatures and velocities (A test was discontinued if a fish swam for 120 minutes)

| Velocity (m/sec) | 14°C | | | 20°C | | | 26°C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Number | Mean | Standard deviation | Number | Mean | Standard deviation | Number | Mean | Standard deviation |
| 0.21 | 15 | 120 | 0.0 | | | | | | |
| 0.24 | 5 | 120 | 0.0 | | | | | | |
| 0.27 | 5 | 96.23 | 52.3 | | | | | | |
| 0.30 | 5 | 72.8 | 64.6 | | | | | | |
| 0.33 | 5 | 120 | 0 | | | | | | |
| 0.36 | 6 | 80.95 | 60.5 | | | | | | |
| 0.39 | 8 | 61.1 | 63.0 | | | | 10 | 120 | 0 |
| 0.42 | 8 | 16.77 | 41.7 | 6 | 120 | 0 | 8 | 120 | 0 |
| 0.45 | 8 | 1.48 | 1.65 | 9 | 67.58 | 62.2 | 10 | 61.33 | 61.9 |
| 0.48 | 7 | 1.05 | 0.58 | 10 | 37.25 | 57.1 | 9 | 42.88 | 58.1 |
| 0.51 | 6 | 0.98 | 0.72 | 12 | 11.55 | 34.1 | 10 | 25.90 | 49.6 |
| 0.54 | | | | 12 | 1.07 | 0.73 | 10 | 1.2 | 1.28 |
| 0.57 | | | | 12 | 0.98 | 0.63 | 9 | 0.92 | 0.72 |

Table 13
Swimming performance (minutes to fatigue) of large squawfish (375-497 mm in length) at different water temperatures and velocities (A test was discontinued if a fish swam for 120 minutes) Data were analyzed by analysis of variance[1/]

| Velocity (m/sec) | 14°C | | | 20°C | | | 26°C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Number | Mean | Standard deviation | Number | Mean | Standard deviation | Number | Mean | Standard deviation |
| 0.75 | 4 | 120.0 | 0.0 | 2 | 120.0 | 0.0 | 4 | 116.7 | 6.7 |
| 0.91 | 6 | 50.7 | 45.6 | 5 | 120.0 | 0.0 | 4 | 46.3 | 52.0 |
| 1.06 | 5 | 2.5 | 1.0 | 5 | 3.9 | 3.9 | 4 | 1.9 | 1.0 |
| 1.20 | 4 | 0.8 | 0.6 | 3 | 1.6 | 0.5 | 3 | 0.6 | 0.1 |

1/ Analysis of variance of the effects of water velocity (main effect), temperature (main effect), and fish length (covariate) on swimming-time-to-fatigue.

Table 14
Swimming performance (minutes to fatigue) of bonytail chub (72-120 mm in length) at different water temperatures and velocities
(A test was discontinued if a fish swam for 120 minutes)
Data were analyzed by analysis of variance[1/]

| Velocity (m/sec) | 14°C | | | 20°C | | | 26°C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Number | Mean | Standard deviation | Number | Mean | Standard deviation | Number | Mean | Standard deviation |
| 0.33 | 4 | 120.0 | 0.0 | | | | | | |
| 0.36 | | | | | | | | | |
| 0.39 | 10 | 108.1 | 37.6 | 4 | 120.0 | 0.0 | 4 | 120.0 | 0.0 |
| 0.42 | | | | | | | | | |
| 0.45 | 10 | 72.7 | 61.1 | 10 | 74.1 | 59.3 | 3 | 120.0 | 0.0 |
| 0.48 | | | | | | | | | |
| 0.51 | 10 | 25.6 | 49.8 | 10 | 60.9 | 62.3 | 12 | 80.5 | 58.4 |
| 0.54 | | | | | | | | | |
| 0.57 | 10 | 0.8 | 0.5 | 11 | 66.4 | 61.7 | 12 | 51.1 | 60.8 |
| 0.60 | | | | | | | | | |
| 0.63 | | | | 16 | 1.8 | 2.3 | 10 | 61.7 | 61.4 |
| 0.69 | | | | 4 | 2.7 | 0.7 | 12 | 0.6 | 0.3 |
| 0.72 | | | | | | | | | |
| 0.75 | | | | | | | 12 | 0.7 | 0.6 |

1/ Analysis of variance of the effects of water velocity (main effect), temperature (main effect), and fish length (covariate) on swimming-time-to-fatigue.

Table 15
Swimming performance (minutes to fatigue) of humpback chubs (73-134 mm in length) at different water temperatures and velocities
(A test was discontinued if a fish swam for 120 minutes)

| Velocity (m/sec) | 14°C | | | 20°C | | | 26°C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Number | Mean | Standard deviation | Number | Mean | Standard deviation | Number | Mean | Standard deviation |
| 0.27 | 10 | 116.27 | 11.8 | | | | | | |
| 0.30 | 10 | 117.05 | 9.3 | | | | | | |
| 0.33 | 10 | 95.18 | 47.8 | | | | | | |
| 0.36 | 10 | 96.47 | 49.6 | | | | | | |
| 0.39 | 10 | 74.15 | 59.2 | | | | | | |
| 0.42 | 10 | 44.82 | 52.4 | | | | | | |
| 0.45 | 10 | 28.05 | 48.6 | 10 | 74.38 | 58.9 | 8 | 120 | 0 |
| 0.48 | 10 | 4.68 | 2.8 | - | - | - | 10 | 108.07 | 37.8 |
| 0.51 | 10 | 2.22 | 1.4 | 10 | 85.22 | 56.0 | 10 | 60.65 | 62.6 |
| 0.54 | | | | - | - | - | 10 | 60.62 | 62.6 |
| 0.57 | | | | 10 | 39.8 | 56.5 | - | - | - |
| 0.60 | | | | 10 | 2.03 | 1.3 | 14 | 61.75 | 60.4 |
| 0.63 | | | | 11 | 23.77 | 47.6 | - | - | - |
| 0.66 | | | | - | - | - | 14 | 61.45 | 60.8 |
| 0.69 | | | | 10 | 13.43 | 37.4 | - | - | - |
| 0.72 | | | | 10 | 4.0 | 4.8 | 10 | 2.32 | 3.8 |
| 0.75 | | | | | | | - | - | - |
| 0.78 | | | | | | | 9 | 2.08 | 1.8 |

Table 16
Sustained swimming speeds of various species of fish (28-120 mm in length) compared to swimming speeds of juveniles of three species of rare Colorado River fish

| Species | Sustained speed[1] ft/sec | m/sec | Reference |
|---|---|---|---|
| Colorado River fish[2] | | | |
| Humpback chub | 2.2 | 0.66 | This study |
| Colorado squawfish | 1.6 | 0.51 | This study |
| Razorback sucker | 1.47 | 0.45 | This study |
| Bonytail chub | 1.9 | 0.57 | This study |
| Other species (small fish or fingerlings) | | | |
| Striped bass (12 cm) | 2.75 | 0.83 | Bell 1973 |
| Striped mullet (2.8 cm) | 0.70 | 0.21 | Hettler 1977 |
| Atlantic menhaden (6 cm) | 0.8 | 0.24 | Hettler 1977 |
| Fathead minnow (5 cm) | 0.6 | 0.18 | MacLeod 1967 |
| Largemouth bass fingerlings | 0.75 | 0.23 | MacLeod 1967 |
| Rainbow trout (6 cm) | 1.77 | 0.54 | Fry and Cox 1970 |
| Emerald shiner (6.5 cm) | 1.7 | 0.52 | Jones et al. 1974 |
| Other species (adults) | | | |
| White suckers | 5.2 | 1.58 | Bell 1973 |
| Carp | 4.0 | 1.22 | Bell 1973 |
| Whitefish | 4.4 | 1.34 | Bell 1973 |
| Brown trout | 6.2 | 1.89 | Bell 1973 |
| Coho salmon | 10.8 | 3.29 | Bell 1973 |
| Squawfish | 3.5 | 1.06 | This study |

1/ Sustained speed is that speed which the fish can maintain for a matter of minutes.

2/ Sustained speed at 20°C.

to test velocities may have resulted in reduced time-to-fatigue values compared to wild or exercised fish. Wild fish can swim at a rate of about 30 percent higher than cultured fish (Green 1964, Thomas et al. 1964). Exercised fish usually have greater swimming ability than unexercised fish (Brett et al. 1958, Hammond and Heckman 1966).

A direct relationship between fish length and swimming speed and stamina is fairly well established (Bainbridge 1958). However, small fish usually show greater speed as measured in body lengths per second than larger fish. We also noted the positive relationship between length and stamina in our studies. We expect that adult fish of each species have significantly greater stamina than do juveniles of the same species. Some preliminary data on stamina of adult squawfish support this expectation. The average sustained speed at 14° C of adult squawfish (373-416 mm in length) was 0.76-1.0 m/sec, about twice that of juveniles at 14° C. One might expect the difference to be greater, however, temperature effects have a relatively greater effect on large fish than on juveniles (Brett 1967, Jones et al. 1974).

Temperature influences the swimming ability of most fish (Brett et al. 1958). The typical pattern of influence is that of an adverse effect on either side of the optimum temperature range. Our data generally indicated that 20-26° C was in the range of the optimum temperature for each species. All fish performed more poorly at 14° C than at 20° C or 26° C. We did not examine swimming performance at temperature above 26° C where performance might have been adversely affected.

Brett and Glass (1973) in summarizing swimming literature on the Pacific salmon presented temperature-fish size-response surfaces for critical swimming speed. Uniform isopleths were evident, i.e. temperature effects on the swimming speed of large and small fish were similar. Our data indicate otherwise. The swimming ablility of the juvenile, small (73-142 mm in length) squawfish, bonytail chubs, and humpback chubs was significantly and directly related to water temperature. On the other hand, swimming ability of the older, larger (132-497 mm in length) razorback suckers and squawfish was not significantly affected by water temperature. The difference between the generalizations made from salmonid literature and our data may be due to the oligothermal nature of salmonids and the eurythermal nature of the rare fish of the Colorado. Little information is available on temperature-fish size-effects on swimming speeds of warm water fish. There is some indication (Glova and McInerney 1977) that the relative change in critical swimming speed with temperature is less in large (12 cm) than in small (3 cm) salmon. Brett and Glass (1973) also concluded that optimum temperature produces a more pronounced maximum metabolic rate for small fish than for large. This may be another indication that the swimming ability of small fish may be more responsive to temperature change than that of large fish.

Swimming performance of fish has been investigated in various ways. Some investigators have measured "burst speed" at low water velocity. Others have determined the water velocity at which fatigue occurs using continual incremental increases in water speed. Still others have determined the time required to fatigue at a fixed water velocity. We

employed the latter technique to determine the range of water velocities each species could tolerate up to 2 hours swimming time. We feel that these data are more meaningful to workers who must predict the impact of various alterations in water flow regimes on fish behavior. And, this information can be readily employed in planning and designing man-made alterations to the stream or riverine environment.

The construction of highways requires the installation of culverts at river crossing. Faulty culvert design which allows excessive water flow rates can create barriers to upstream fish migration. The ability of fish to swim through culverts has been investigated by Wales (1950), Metsker (1970) and Blahm (1963). Watts (1974) and MacPhee and Watts (1976) discussed means of incorporating fish swimming speeds into culvert design. A simple way to use the data we have collected is to determine the distance a fish can swim at a certain flow through a proposed culvert using the following formula

$$D = 60VT$$

where D = distance in meters a fish can travel before becoming fatigued, V = velocity of water through the proposed culvert in m/sec, and T = fatigue time at V (T is found in the accompanying data tables for fatigue times of each species tested). For example, if at a water temperatue of 20° C, the flow through a 100-m culvert was to be 1.2 m/sec, then most adult Colorado squawfish of the size tested in our experiments could travel only 96 m before becoming fatigued. Hence, most might not pass through the 100-m-long culvert. However, if the projected water velocity was about 1.0 m/sec then the fish would be able to travel 234 m and easily pass through the 100-m-long culvert,

$$(60)\ (1.0)\ (3.9) = 234\ \text{m}.$$

Hydroelectric plants and other industrial complexes usually remove water from a river at a water intake structure. When water flow rates at these structures are excessive, fish become impinged on intake screens (Barnes 1976). Knowledge of swimming abilities of resident fishes has been employed in estimating the risk in some cases (Hettler 1977, Barnes 1976). Bozeman (1977) summarized that 0.15 m/sec would be the maximum acceptable velocity for protecting small fish. Assuming average approach velocities of 0.3 m/sec at the trashrack of a powerplant, all species tested on our study should be able to avoid being overcome by the current.

Dams constitute a physical barrier which fish cannot overcome without the aid of a fish ladder or fishway. Swimming speeds of fish (in most cases salmonids) have been employed in designing fishways (Collins et al. 1961, Conner at al. 1963, Slatick 1970). Also of concern are effects of periodic releases of water on stream flows below damsites. For example, large quantities of released water may create such excessive in-stream flows that the habitat below the dam would be unsuited for fish. Adults frequently seek higher velocites at obstructions and this behavior could be used to attract adult fish to fishway entrances (Bell 1973). However, attractant velocites should be well under the darting speed but may exceed the cruising speed for species and sizes involved.

When guiding or directing fish with water velocity, smooth transitions and accelerations are required to prevent the fish from hesitating or refusing to enter an area. In summary, data attained in this study on swimming ability of Colorado River fishes are of value in the design of many structures which alter or control river flow rate.

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REPORT NO. 6

# COLORADO RIVER FISHERIES PROJECT

# ACUTE TOXICITY OF SELECTED CHEMICALS: DATA BASE

by

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## INTRODUCTION

The results of investigations contained in this report are in response to needs of the U.S. Fish and Wildlife Service to create and enlarge the data base on endangered fish species of the Upper Colorado River Basin. Rapid accumulation of information was urgently needed for resource management decisions relating to further development of the Colorado River watershed for agriculture and energy production, establishing water quality criteria, and to estimating potential environmental impacts of toxicants. This study addresses the acute toxicity of several toxicants historically found in the watershed to the endangered Colorado River squawfish (Ptychocheilus lucius) and preliminary data on the humpback chub (Gila cypha). Prior to these studies, no toxicology information was available for these species. In addition to the two endangered species of the Colorado River system, an evaluation of the northern squawfish (Ptychocheilus oregonensis) as a surrogate species for the Colorado squawfish was included in these studies. Attempts were also made to compare the endangered species to other common species to obtain a relative indication of their tolerance or susceptibility to toxicants in general.

The specific objectives of this project were to:

1. Determine the statistical $LC_{50}$ and 95 percent confidence limits of selected toxicants for three life stages (postlarval, juvenile, and subadult) of Colorado squawfish at a water temperature of 17° C.

2. Determine the statistical $LC_{50}$ and 95 percent confidence limits of selected toxicants for juvenile squawfish at water temperatures of 12°, 17°, and 22° C.

3. Determine the $LC_{50}$ and 95 percent confidence limits of selected toxicants for juvenile squawfish with three test waters (Palouse River water, University of Idaho well water, and simulated Willow Beach, Arizona, water) at a water temperature of 17° C.

## METHODS

### Toxicants

Thirteen inorganic and eight organic toxicants were selected for evaluation. Selection and prioritization was based on historical presence within the Colorado River watershed and evidence of collateral data on toxicity effects in other fish species. The 21 chemicals tested were as follows:

Arsenic, $As_2O_5$
Cadmium, $CdSO_4$
Chlordane
Chlorine, $Na(ClO)_2$
Chromium, $CrO_3$
Copper, $CuSO_4$
Cyanide, KCn
DDT
Dieldrin
Endrin
Iron, $Fe_2(SO_4)_3$
Lead, $Pb(C_2H_3O_2)_2$
Lindane
Manganese, $MnSO_4$
Mercury, $Hg(C_2H_3O_2)_2$
Nickel, NiSO
Parathion
Selenium, $SeO_2$
Squoxin
Toxaphene
Zinc, $Zn(C_2H_3O_2)_2$

## Fish

An attempt to evaluate the northern squawfish (P. oregonensis) as a surrogate species for the Colorado squawfish was included in these studies. Northern squawfish were seined principally in the St. Joe River, Idaho, its tributaries and backwater areas. Colorado River squawfish utilized in this study were provided by the U.S. Fish and Wildlife Service. The humpback chub (Gila cypha), although not originally proposed as a part of this study, became available in sufficient numbers to enable studies with several of the toxicants. All of the toxicity tests were conducted utilizing post-larval and juvenile life stages of G. cypha.

## Water

Three different waters were originally proposed as candidates for use in the toxicity tests: Palouse River Water, well water (University of Idaho), and simulated Willow Beach water, Arizona. Two formulations of Willow Beach water were used (Table 1). The first of these formulations utilized distilled water as a base and sufficient chemicals were added to duplicate an earlier chemical analysis of Willow Beach water (designated SWB). The large amount of distilled water required and cost of chemicals and labor involved made it necessary to derive a second formulation utilizing University of Idaho well water (designated TSWB) as a base. Chemicals added to the well water permitted a close and adequate approximation of the Willow Beach analysis, which itself varies with time and distance from other site locations on the Colorado River. As with the chemicals, the three waters were arranged in priority: TSWB, University of Idaho well water, and Palouse River water.

## Static Acute Toxicity Tests

Handling of test organisms and procedures for static toxicity tests conformed well with the recommendations by the Committee on Methods for Toxicity Tests with Aquatic Organisms (1975). The one procedure variance this study required was that aeration would be provided in the assays. Oil-free aeration was provided in all tests except for the tests with chlorine.

Table 1
Water analysis

| | Willow Beach National Fish Hatchery (analysis supplied by Fish and Wildlife Service) | Willow Beach National Fish Hatchery (analysis by University of Idaho 8/13/80)[1] | SWB (distilled water based simulated Willow Beach water) | University of Idaho well water | TSWB (University of Idaho well-based simulated Willow Beach water) | Palouse River water |
|---|---|---|---|---|---|---|
| Alkalinity ($CaCO_3$) | 127.000 | 105.19 | 120.89 | 149.92 | 199.81 | 24 |
| Bicarbonate ($HCO_3$) | 155.000 | 86.60 | 161.39 | 158.53 | | 0.42 |
| Biochemical oxygen demand (BOD) | .500 | | | | | |
| Boron | .120 | 0.11 | | 0.02 | 0.03 | 0.02 |
| Calcium (Ca) | 92.180 | 65.00 | 87.00 | 22.00 | 53.00 | 0.21 |
| Carbonate ($CO_3$) | Trace | Nil | Nil | Nil | | Nil |
| Chloride (Cl) | 104.250 | 95.40 | 95.37 | 0.47 | 104.58 | 0.30 |
| Copper (Cu) | Trace | 0.10 | 0.10 | 0.10 | | 0.10 |
| Floride (F) | .450 | | | | | |
| Hardness - $CaCO_3$ | 358.000 | 300.00 | 347.00 | 100.00 | 316.00 | 32 |
| Iron (Fe) dissolved | Trace | | | | | |
| Iron (Fe) total | .070 | 0.10 | Nil | 0.10 | | 0.10 |
| Magnesium (Mg) | 31.180 | 37.50 | 43.00 | 13.40 | 22.00 | 0.01 |
| Manganese (Mn) | Trace | 0.10 | | 0.20 | | 0.05 |
| Nitrates ($NO_3$) | 1.000 | 7.97 | 0.70 | 0.13 | 0.44 | 0.01 |
| ($NO_3$-N) | | 1.80 | | | 0.10 | 0.01 |
| Phosphates ($PO_4$) | .020 | 0.12 | | 0.12 | | .10 |
| ($PO_4$-P) | | 0.04 | 0.01 | 0.04 | | .02 |
| Phosphorus (P) | .010 | | | | | .04 |
| Potassium (K) | 0.260 | 5.00 | | 5.60 | | 0.04 |
| Settleable solids[2] | .100 | | | | | |
| Silica (Si) | Trace | | | | | |
| Sodium (Na) | 117.310 | 120.00 | 138.50 | 19.13 | 160 | 0.12 |
| Specific conductance[3] | 1,040.000 | 950.00 | 1,130 | 233.00 | 1,175.00 | 39.2 |
| Sulfate ($SO_4$) | 317.000 | 314.00 | 275.60 | 1.90 | 350.34 | 2 |
| Suspended solids | 2.000 | | | | | 2 |
| Total dissolved solids (TDS) | 730.000 | | | | | 64 |
| pH | 8.2-8.5 | 7.77 | 8.30 | 7.66 | 8.60 | 7.1 |
| Aluminum (Al) | | | | 1.00 | | |
| Cadmium (Cd) | | | | 0.50 | | |
| Zinc (Zn) | | | | 0.08 | | |
| Lead (Pb) | | | | 0.20 | | |
| Chromium (Cr) | | | | 0.50 | | |

1/ Water received frozen in plastic bags.
2/ Milliliters/liter
3/ Microohms/cm @ 25°C.

Depending on the availability and the size of post-larval and juvenile stages, 10 or 20 fish are normally used for definitive tests. The assays with subadults contained 10 fish per 700-liter tank. The maximum fish load was usually limited to 0.8 g/l load limitation, the maximum average weight of the subadults that could be simultaneously tested in one tank was about 50 grams. As juveniles average less than 5 grams, the difference in weight between juveniles and subadults is at least tenfold. This tenfold difference was sufficient to detect any marked effect that size might have on the tolerance of fish to a chemical.

Range-finding tests were made to determine the approximate toxicant concentrations that should be used in definitive tests with each chemical using juvenile squawfish at 17° C. Generally, groups of five fish are placed for 96 hours in a control aquarium and in experimental aquaria that contained three to five logarithmically spaced toxicant concentrations.

Definitive tests were made with appropriate concentrations developed from range-finding tests to bracket the 96 hour $LC_{50}$ of each toxicant using post-larval, juvenile, and subadult squawfish at 17° C. A control and at least five concentrations of toxicant in a geometric series were used. More bioassays were carried out as necessary, so that a $LC_{50}$ and 95 percent confidence limits could be calculated with reasonable accuracy.

Test chemicals consisted of technical or analytical grade samples of known purity. When purity of test chemicals was known, all calculated concentrations were based on percent active ingredients. Stock solutions were prepared before each test with commercial grade carrier solvents. Solvents concentrations did not exceed 0.5 ml/l in final dilution water. Most tests were conducted in 18.9 one wide-mouth jars containing 16 one of test solution or 2 one jars containing 1.5 one of test solution. Duplicate test chambers were used to accommodate larger fish. At least 10 organisms were exposed to each concentration for all definitive tests.

The tests began upon initial exposure to the toxicant and continued for 96 hours. The number of dead organisms in each test chamber was recorded and removed at 3, 6, 12, 24, 36, 48, 72, and 96 hour observation times.

## Data Analysis

The majority of data collected in this study was analyzed by probit analysis utilizing a SAS[1/] computer program to produce a median lethal concentration ($LC_{50}$). The data set contained 6,894 observations and 11 variables. The raw data which could not be analyzed by probit analysis because two partial kills were not achieved were analyzed by the following formula:

1/ SAS Institute, Inc., SAS Circle, Box 8000, Cary, NC 27511.

$LC_{50} = (AB)^{\frac{1}{2}}$, with limits of A and B

Where:

A = highest toxicant concentration in which none of the test organisms died;

B = lowest concentration in which all of the organisms died.

Stephan (1977) has presented an interesting insight into methods for calculating an $LC_{50}$. Our use of the $(AB)^{\frac{1}{2}}$ formula follows his logic.

## RESULTS

A summary of the 141 toxicity tests completed during this study is presented in Tables 2 and 2-A. An abbreviated user manual for the previously mentioned SAS computer program is available and a computer tape containing all the raw data from this study was made.

## DISCUSSION

We wish to provide the following general opinion on tolerance to toxicants of the three species examined in this study (ranked most to least tolerant):

Humpback chub, Colorado squawfish, northern squawfish.

Also, use of toxicity data for the channel catfish and fathead minnow for management decisions concerning the endangered species of the Colorado River would provide a "margin of safety" in many cases since these species generally appear less tolerant of organic and inorganic toxicants than are humpback chub and Colorado squawfish (see Johnson and Finley, 1980 for organic compounds and Kemp et al. 1973 for inorganic compounds).

The objective of this study was to produce a reference source for scientists and resource managers dealing with the endangered fish species of the Colorado River system that could be used to establish water quality criteria and estimate potential impacts of toxicants. This was deemed necessary in light of anticipated adverse environmental pressures due to expanding development within the Colorado River watershed, such as new pesticide uses, new energy extraction and changing population and land uses. Acute toxicity data have definite limitations; however, they do provide a relative starting point for defining the hazard or safety of a toxicant to aquatic life. $LC_{50}$ values, when accompanied by the expected environmental concentration (EEC), should be viewed as only the beginning in assessing "risk" to the organism in question. Ideally, resource managers would have access to additional measurements concerning toxicant effects on growth, reproduction, pathology, biochemistry, population dynamics, and ecological relationships.

Table 2
Data summary of probit analysis

| Fish | Chemical | Tempera-ture | Lifes | Water | $LC_{50}$ | 95 percent limits Lower | Upper |
|---|---|---|---|---|---|---|---|
| COSQ | CDS04 | 12 | 2 | 1 | 7.617 | -- | -- |
| COSQ | CDS04 | 17 | 2 | 1 | 6.233 | -- | -- |
| COSQ | CDS04 | 17 | 2 | 2 | 7.376 | -- | -- |
| COSQ | CDS04 | 17 | 2 | 3 | 27.809 | 18.982 | -- |
| COSQ | CDS04 | 22 | 2 | 1 | 5.316 | -- | 15.630 |
| COSQ | DDT | 12 | 2 | 2 | 0.986 | 0.609 | -- |
| COSQ | DDT | 12 | 2 | 3 | 0.138 | -- | -- |
| COSQ | DDT | 17 | 2 | 2 | 0.824 | 0.614 | 1.314 |
| COSQ | DDT | 17 | 2 | 3 | 0.341 | -- | -- |
| COSQ | DDT | 17 | 5 | 2 | 1.497 | -- | -- |
| COSQ | DDT | 22 | 2 | 2 | 1.512 | 0.878 | -- |
| COSQ | DDT | 22 | 2 | 3 | 0.130 | -- | -- |
| COSQ | Dieldrin | 12 | 2 | 2 | 0.064 | 0.056 | 0.082 |
| COSQ | Dieldrin | 12 | 1 | 3 | 0.017 | 0.011 | 0.026 |
| COSQ | Dieldrin | 17 | 2 | 2 | 0.060 | 0.054 | 0.075 |
| COSQ | Dieldrin | 17 | 2 | 3 | 0.026 | 0.020 | 0.037 |
| COSQ | Dieldrin | 17 | 5 | 2 | 0.146 | -- | -- |
| COSQ | Dieldrin | 22 | 2 | 3 | 0.017 | 0.009 | 0.028 |
| COSQ | Endrin | 12 | 2 | 2 | 0.010 | 0.010 | 0.011 |
| COSQ | Endrin | 12 | 2 | 3 | 0.009 | 0.008 | 0.010 |
| COSQ | Endrin | 17 | 2 | 2 | 0.007 | 0.003 | 0.018 |
| COSQ | Endrin | 17 | 2 | 3 | 0.004 | -- | 0.011 |
| COSQ | Endrin | 17 | 5 | 2 | 0.017 | 0.011 | 0.050 |
| COSQ | Endrin | 22 | 2 | 2 | 0.008 | 0.003 | 0.014 |
| COSQ | Endrin | 22 | 2 | 3 | 0.005 | 0.004 | 0.006 |
| COSQ | Lindane | 17 | 5 | 2 | 1.005 | 0.453 | 2.559 |
| COSQ | Mercury | 17 | 2 | 2 | 0.127 | -- | -- |
| COSQ | Mercury | 17 | 2 | 3 | 0.312 | 0.111 | 0.640 |
| COSQ | Mercury | 17 | 5 | 2 | 0.011 | 0.006 | 0.015 |
| COSQ | NAOCL | 12 | 2 | 1 | 0.464 | 0.420 | 0.530 |
| COSQ | NAOCL | 12 | 2 | 2 | 0.512 | 0.265 | 0.596 |
| COSQ | NAOCL | 12 | 2 | 3 | 1.322 | 1.106 | 1.943 |
| COSQ | NAOCL | 17 | 2 | 1 | 0.968 | -- | -- |
| COSQ | NAOCL | 17 | 2 | 2 | 0.405 | 0.265 | 0.596 |
| COSQ | NAOCL | 17 | 2 | 3 | 0.819 | 0.387 | -- |
| COSQ | NAOCL | 17 | 5 | 2 | 0.163 | 0.109 | 0.248 |
| COSQ | NAOCL | 22 | 2 | 1 | 0.434 | 0.409 | 0.462 |
| COSQ | NAOCL | 22 | 2 | 2 | 0.366 | 0.349 | 0.383 |
| COSQ | Parath | 12 | 2 | 2 | 4.374 | 4.091 | 4.700 |
| COSQ | Parath | 17 | 5 | 2 | 1.150 | 1.061 | 1.246 |
| COSQ | Parath | 22 | 2 | 1 | 6.559 | 2.821 | -- |
| COSQ | Parath | 22 | 2 | 2 | 4.165 | -- | -- |
| COSQ | SE02 | 17 | 5 | 2 | 26.639 | 19.446 | 42.954 |
| COSQ | SE02 | 12 | 2 | 2 | 45.177 | 41.725 | 49.364 |
| COSQ | SE02 | 12 | 2 | 3 | 48.853 | 46.345 | 51.761 |
| COSQ | SE02 | 17 | 2 | 2 | 46.067 | 39.945 | 54.814 |
| COSQ | SE02 | 17 | 2 | 3 | 38.784 | 35.561 | 42.549 |
| COSQ | SE02 | 22 | 2 | 2 | 45.147 | 42.462 | 48.242 |
| COSQ | SE02 | 22 | 2 | 3 | 34.290 | -- | -- |
| COSQ | Squaxin | 12 | 2 | 1 | 0.384 | 0.339 | 0.586 |
| COSQ | Squaxin | 22 | 2 | 1 | 4.048 | 0.443 | -- |
| COSQ | Toxaphen | 12 | 2 | 2 | 0.128 | 0.073 | 0.365 |
| COSQ | Toxaphen | 22 | 2 | 2 | 0.079 | -- | 1.006 |
| COSQ | Zinc | 12 | 2 | 1 | 4.235 | 3.315 | 6.270 |
| COSQ | Zinc | 17 | 2 | 1 | 8.348 | 4.304 | 115.085 |
| COSQ | Zinc | 22 | 2 | 1 | 4.905 | 3.458 | 16.178 |
| HUMP | DDT | 17 | 2 | 1 | 1.898 | 1.002 | -- |
| HUMP | DDT | 22 | 2 | 1 | 2.471 | 1.243 | -- |
| HUMP | Mercury | 17 | 5 | 3 | 0.070 | -- | -- |
| HUMP | Parat | 17 | 5 | 3 | 1.597 | 1.189 | 2.252 |
| HUMP | SE02 | 12 | 2 | 1 | 34.178 | 32.295 | 36.152 |
| HUMP | SE02 | 17 | 2 | 1 | 24.717 | 22.558 | 26.671 |
| HUMP | SE02 | 17 | 2 | 3 | 35.110 | 24.714 | 53.427 |
| HUMP | SE02 | 22 | 2 | 1 | 27.684 | 20.617 | 35.330 |
| NOSQ | AS205 | 17 | 5 | 3 | 73.074 | 62.437 | 86.218 |
| NOSQ | AS205 | 22 | 2 | 4 | 73.355 | 61.501 | 89.325 |
| NOSQ | CDS04 | 17 | 2 | 4 | 5.518 | 4.591 | 6.812 |
| NOSQ | CDS04 | 17 | 5 | 3 | 5.555 | 2.670 | -- |
| NOSQ | CR03 | 17 | 5 | 3 | 182.215 | 81.054 | -- |
| NOSQ | CUS04 | 12 | 2 | 3 | 0.495 | 0.355 | 1.052 |
| NOSQ | CUS04 | 12 | 2 | 4 | 0.371 | 0.219 | 0.613 |
| NOSQ | CUS04 | 17 | 2 | 3 | 0.411 | -- | -- |
| NOSQ | CUS04 | 17 | 3 | 3 | 0.354 | 0.207 | 0.518 |
| NOSQ | CUS04 | 17 | 5 | 3 | 1.607 | 1.310 | 2.540 |
| NOSQ | CUS04 | 22 | 2 | 3 | 0.331 | 0.316 | 0.346 |
| NOSQ | CUS04 | 22 | 2 | 4 | 0.176 | 0.123 | 0.323 |
| NOSQ | DDT | 12 | 2 | 3 | 0.034 | 0.024 | 0.053 |
| NOSQ | DDT | 17 | 2 | 3 | 0.040 | 0.031 | 0.064 |
| NOSQ | DDT | 17 | 5 | 3 | 0.151 | 0.051 | -- |
| NOSQ | Dieldrin | 12 | 2 | 3 | 0.028 | 0.026 | 0.030 |
| NOSQ | Dieldrin | 17 | 2 | 3 | 0.023 | 0.017 | 0.031 |
| NOSQ | Dieldrin | 17 | 3 | 3 | 0.070 | -- | -- |
| NOSQ | Dieldrin | 17 | 5 | 3 | 0.082 | 0.061 | 0.171 |
| NOSQ | Endrin | 17 | 5 | 3 | 0.016 | 0.010 | 0.056 |
| NOSQ | KCN | 17 | 5 | 3 | 0.241 | -- | -- |
| NOSQ | Lead | 22 | 2 | 4 | 167.524 | 53.497 | -- |
| NOSQ | Mercury | 17 | 2 | 4 | 0.045 | 0.023 | 0.168 |
| NOSQ | Mercury | 17 | 5 | 3 | 0.037 | -- | 0.067 |
| NOSQ | MNS04 | 17 | 2 | 4 | 130.465 | 36.063 | -- |
| NOSQ | MNS04 | 17 | 5 | 3 | 189.482 | 145.410 | 330.001 |
| NOSQ | NAOCL | 12 | 2 | 3 | 0.465 | -- | -- |
| NOSQ | NAOCL | 17 | 2 | 3 | 0.631 | 0.401 | 0.999 |
| NOSQ | NAOCL | 17 | 5 | 3 | 0.304 | 0.293 | 0.315 |
| NOSQ | NIS04 | 17 | 2 | 3 | 40.299 | 30.463 | 53.825 |
| NOSQ | NIS04 | 17 | 2 | 4 | 50.551 | -- | -- |
| NOSQ | NIS04 | 17 | 5 | 3 | 26.233 | 19.684 | 39.417 |
| NOSQ | SE02 | 12 | 2 | 3 | 34.413 | 27.075 | 76.051 |
| NOSQ | SE02 | 17 | 2 | 3 | 44.974 | 32.265 | 104.610 |
| NOSQ | SE02 | 17 | 2 | 4 | 21.515 | 7.348 | -- |
| NOSQ | SE02 | 17 | 3 | 3 | 19.778 | 17.152 | 30.456 |
| NOSQ | SE02 | 17 | 5 | 3 | 28.603 | 21.873 | 50.317 |
| NOSQ | SE02 | 22 | 2 | 3 | 17.550 | -- | -- |
| NOSQ | SE02 | 22 | 2 | 4 | 6.950 | 2.445 | -- |
| NOSQ | Squaxin | 12 | 2 | 1 | 0.013 | 0.012 | 0.014 |
| NOSQ | Squaxin | 17 | 2 | 1 | 0.011 | 0.005 | 0.020 |
| NOSQ | Squaxin | 22 | 2 | 1 | 0.009 | 0.007 | 0.011 |
| NOSQ | Toxaphen | 17 | 2 | 3 | 0.012 | -- | -- |
| NOSQ | Zinc | 17 | 2 | 4 | 5.865 | 2.698 | 26.346 |
| NOSQ | Zinc | 17 | 5 | 3 | 51.510 | 41.513 | 70.558 |
| NOSQ | Zinc | 22 | 2 | 4 | 6.746 | -- | -- |

Table 2-A
Median lethal concentrations ($LC_{50}$) calculated by $(AB)^{\frac{1}{2}}$ formula[1/]

| Fish | Chemical | Temperature | Lifes | Water | $LC_{50}$ | Limits A[2/] | Limits B[3/] |
|---|---|---|---|---|---|---|---|
| COSQ | Dieldrin | 22 | 2 | 2 | 0.03-0.05 | 0.03 | |
| COSQ | NAOCL | 22 | 2 | 3 | -- | 0.70 | |
| COSQ | Parath | 12 | 2 | 1 | 2.32 | 1.80 | 3.00 |
| COSQ | Parath | 17 | 2 | 1 | 1.8-3.0 | 1.80 | |
| COSQ | Parath | 17 | 2 | 3 | 2.24 | 1.0 | 5.00 |
| HUMP | DDT | 12 | 2 | 1 | | > 0.70 | |
| HUMP | DDT | 17 | 5 | 3 | | > 0.50 | |
| HUMP | Dieldrin | 12 | 2 | 1 | | > 0.05 | |
| HUMP | Dieldrin | 17 | 2 | 1 | | > 0.05 | |
| HUMP | Dieldrin | 17 | 5 | 3 | | > 0.02 | |
| HUMP | Dieldrin | 22 | 2 | 1 | | > 0.05 | |
| HUMP | Endrin | 12 | 2 | 1 | | > 0.012 | |
| HUMP | Endrin | 17 | 2 | 1 | | > 0.009 | |
| HUMP | Endrin | 17 | 5 | 3 | | > 0.008 | |
| HUMP | Endrin | 22 | 2 | 1 | | > 0.012 | |
| HUMP | Lindane | 17 | 5 | 3 | | > 0.020 | |
| HUMP | NAOCL | 17 | 5 | 3 | 0.57 | 0.40 | 0.80 |
| NOSQ | AS205 | 17 | 2 | 4 | 54.77 | 30.00 | 100.00 |
| NOSQ | Chlordan | 17 | 2 | 3 | | | <0.10 |
| NOSQ | CRO3 | 17 | 2 | 4 | | | <100.00 |
| NOSQ | DDT | 22 | 2 | 3 | 0.04 | 0.03 | 0.05 |
| NOSQ | Dieldrin | 22 | 2 | 3 | | > 0.03 | |
| NOSQ | Endrin | 17 | 2 | 3 | 0.0003 | 0.0001 | 0.001 |
| NOSQ | FEZSO4 | 17 | 2 | 3 | 54.77 | 30.0 | 100.00 |
| NOSQ | KCN | 17 | 2 | 4 | 0.17 | 0.1 | 0.3 |
| NOSQ | Lead | 17 | 2 | 4 | 173.21 | 100.0 | 300.0 |
| NOSQ | Lead | 17 | 5 | 3 | | 150.0 | |
| NOSQ | Lindane | 17 | 2 | 3 | 0.05 | 0.03 | 0.1 |
| NOSQ | Mercury | 17 | 2 | 3 | | > 0.03 | |
| NOSQ | NAOCL | 22 | 2 | 3 | 0.08 | 0.02 | 0.33 |
| NOSQ | Zinc | 17 | 2 | 3 | | >20.00 | |

1/ $^{1}LC_{50} = (AB)^{\frac{1}{2}}$

2/ A = highest toxicant concentration in which none of the test organisms died.

3/ B = lowest concentration in which all of the organisms died.

The information presented in this report is a starting point and will provide a rationale for management decisions that cannot be postponed until data on sublethal toxicant effects are available. Tables 2 and 2-A are the most valuable part of this document. This summary of results represents many manhours of effort. To emphasize this point, one should review Johnson and Finley (1980). That document contains toxicity data from 1,587 tests collected over a 13-year period by many investigators and technicians. Tables 2 and 2-A contain data from 141 tests.

With respect to the limitations on the use of acute toxicity data, some general inferences can be made. For example, Table 3 contains a sample of comparisons between $LC_{50}$ values from this study and $LC_{50}$ values for organic compounds from published literature (Johnson and Finley, 1980). Also, a graphic representation of sample comparisons of inorganic toxicants is provided in Figure 1 (from Kemp et al. 1973). Obviously, more valid comparisons can be made between the $LC_{50}$ values reported in this study simply due to standardized experimental procedures. When comparing other species from the literature, variations of experimental procedures such as life stage, water chemistry, temperature, etc., result in less valid inferences.

Table 3 indicates that channel catfish are slightly more susceptible to DDT than northern squawfish and dramatically more susceptible than Colorado squawfish. Also, although water hardness had no effect on the $LC_{50}$ values of DDT for rainbow trout, channel catfish and bluegill, either humpback chub are more tolerant to DDT than Colorado squawfish and northern squawfish or water chemistry does, in fact, cause a difference in toxicity. Tolerance of rainbow trout, channel catfish, and bluegill to DDT, dieldrin and endrin is lower than Colorado squawfish and northern squawfish but tolerance to parathion seems to be similar. Examining the five inorganic toxicants presented in Figure 1, there are varied results between different species. This is most noticeable with cadmium and least evident with zinc. However, in four out of the five toxicants, the Colorado squawfish was more tolerant than the northern squawfish.

The $LC_{50}$ values for juvenile rainbow trout at 13° C and fathead minnow and channel catfish at 18° C in medium-soft water for DDT are reported as 0.009, 0.012, and 0.022 mg/L, respectively (Johnson and Finley, 1980). From Tables 2 and 2-A, the $LC_{50}$ value for Colorado squawfish in medium-hard water is higher at 17° C (0.824 mg/L) than all three of these species. Humpback chub at 17 or 22° C has even higher $LC_{50}$ values in soft water. One may then assume that irregardless of water hardness, tolerance to DDT is higher in humpback chub and Colorado squawfish than in rainbow trout, fathead minnow, and channel catfish. These inferences are given only as an example of the many possible.

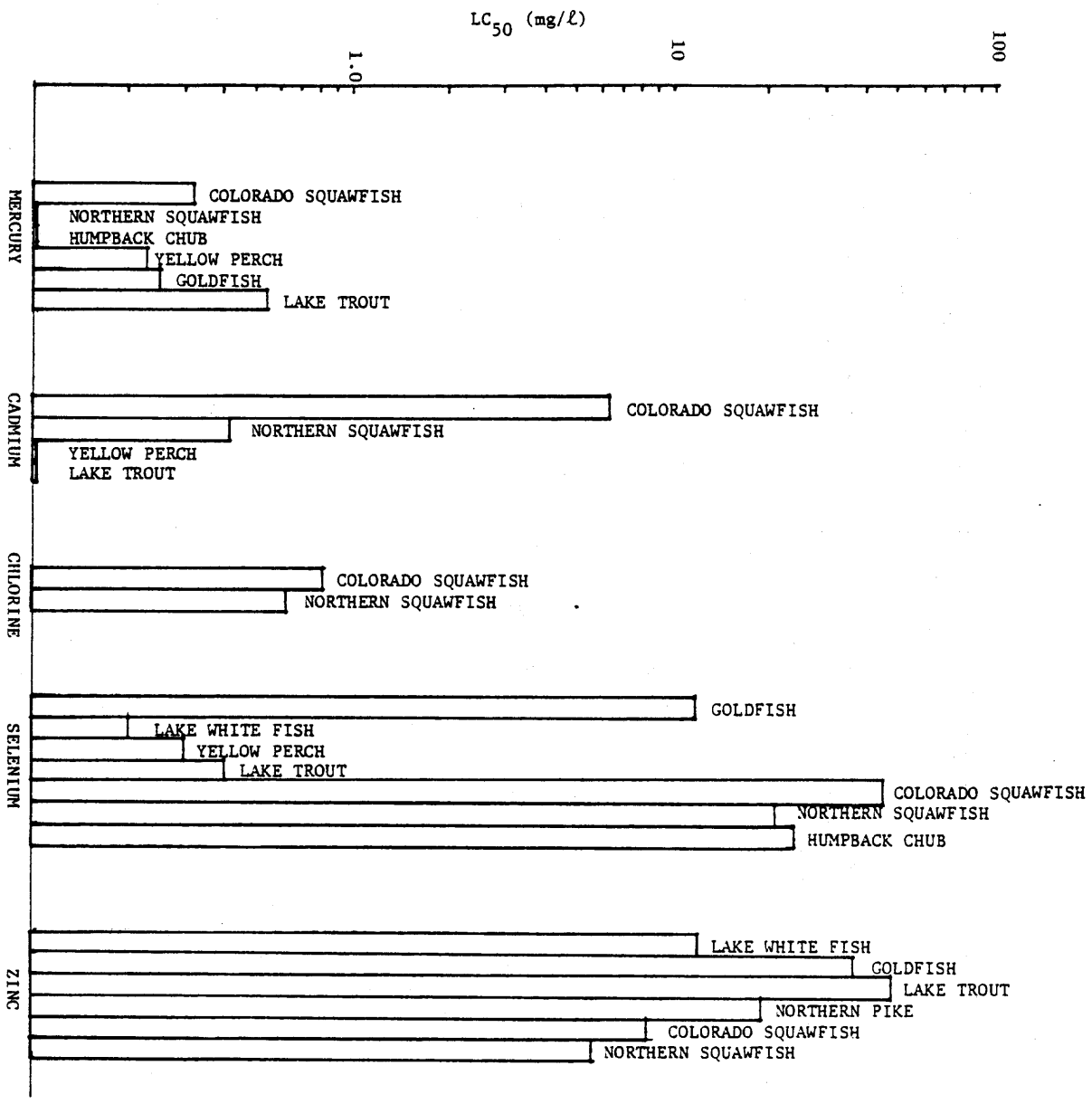
There are many mathematical (regression analysis, etc.) and graphical (three dimensional graphics, etc.) manipulations that would be appropriate for further analyses of the data. Appendix C (the computer tape) is formatted in such a manner that these analyses can be completed with the least amount of effort. Complete interpretations of the data presented here, comparison with other species, and evaluation of "risk" have to be approached on a specific case basis. For example, if a management decision requires assessment of "risk" to Colorado squawfish

Table 3
Examples of comparison of $LC_{50}$ values (organic compounds)

| Fish | Chemical | Temperature | $LC_{50}$ (mg/l) | Comment |
|---|---|---|---|---|
| COSQ | DDT | 12 | 0.986 | Juvenile, UI well water |
| COSQ | DDT | 22 | 1.512 | Juvenile, UI well water |
| NOSQ | DDT | 12 | 0.034 | Juvenile, TSWB |
| NOSQ | DDT | 17 | 0.040 | Juvenile, TSWB |
| RBT | DDT | 13 | .009 | ( No difference between |
| CCF | DDT | 18 | .022 | ( hard and soft water |
| BG | DDT | 18 | .009 | ( |
| HUMP | DDT | 17 | 1.898 | Juvenile, Palouse River water (soft) |
| HUMP | DDT | 22 | 2.471 | Juvenile, Palouse River water (soft) |
| COSQ | Dieldrin | 12 | 0.064 | Juvenile, UI well water |
| COSQ | Dieldrin | 22 | 0.017 | Juvenile, TSWB |
| NOSQ | Dieldrin | 12 | 0.028 | Juvenile, TSWB |
| NOSQ | Dieldrin | 17 | 0.023 | Juvenile, TSWB |
| RBT | Dieldrin | 13 | .001 | ( Toxicity unaffected by water |
| CCF | Dieldrin | 18 | .005 | ( hardness and increased signifi- |
| BG | Dieldrin | 18 | .003 | ( cantly with temperature |
| COSQ | Endrin | 17 | 0.004 | Juvenile, TSWB |
| NOSQ | Endrin | 17 | 0.016 | Post larval, TSWB |
| RBT | Endrin | 13 | .001 | Juvenile, TSWB |
| CCF | Endrin | 24 | .0003 | Juvenile, TSWB |
| BG | Endrin | 18 | .0006 | Juvenile, TSWB |
| COSQ | Parathion | 17 | 1.150 | Post larval, UI well water |
| COSQ | Parathion | 12 | 4.374 | Juvenile, UI well water |
| HUMP | Parathion | 17 | 1.597 | Post larval, TSWB |
| RBT | Parathion, Ethyl | 12 | 1.430 | ( Increased with temperature, |
| RBT | Parathion, Methyl | 12 | 3.700 | ( unaffected by water hardness |
| CCF | Parathion, Ethyl | 18 | 2.650 | ( |
| BG | Parathion, Ethyl | 18 | 0.400 | ( |

RBT - Rainbow trout (Salmo gairdneri)
CCF = Channel catfish (Ictalurus punctatus); from Johnson & Finley 1980.
BG = Bluegill (Lepomis macrochirus)
TSWB = Tap simulated Willow Beach water
UI = University of Idaho

Figure 1




Comparisons of inorganic toxicants (from Kemp et al. 1973)

in a particular habitat area to a particular toxicant for which there is an $LC_{50}$ value in Tables 2 and 2-A, one can compare the EEC directly with the table. The next step is to search the literature for a surrogate species with a comparable $LC_{50}$ value under similar conditions (similar water, life stage, temperature, etc.) and determine if there is information available for the surrogate species on the effects of the toxicant with chronic exposure, bio accumulation, effects on growth, etc. At this point, the decision is made whether there is enough information to make a management decision or whether further evaluation of the specific case is warranted.

## ACKNOWLEDGEMENTS

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## Key to abbreviations

| | |
|---|---|
| **Fish** | |
| Colorado River squawfish (*Ptychocheilus lucius*) | COSQ |
| Humpback chub (*Gila cypha*) | HUMP |
| Northern squawfish (Ptychocheilus oregonensis) | NOSQ |
| **Chemicals** | |
| Arsenic, $As_2O_5$ | AS2O5 |
| Cadmium, $CdSO_4$ | CDSO4 |
| Chlordane | CHLORDAN |
| Chlorine, $Na(ClO)_2$ | NAOCL |
| Chromium, $CrO_3$ | CRO3 |
| Copper, $CuSO_4$ | CUSO4 |
| Cyanide, KCn | KCN |
| DDT | DDT |
| Dieldrin | DIELDRIN |
| Endrin | ENDRIN |
| Iron, $Fe_2(SO_4)_3$ | FE2SO4 |
| Lead, $Pb(C_2H_3O_2)_2$ | LEAD |
| Lindane | LINDANE |
| Manganese, $MnSO_4$ | MNSO4 |
| Mercury, $Hg(C_2H_3O_2)_2$ | MERCURY |
| Nickel, $NiSO_4$ | NISO4 |
| Parathion | PARATH |
| Selenium, $SeO_2$ | SEO2 |
| Squoxin | SQUAXIN |
| Toxaphene | TOXAPHENE |
| Zinc, $Zn(C_2H_3O_2)_2$ | ZINC |
| Chemical concentrations | Milligrams per liter, numerical |
| Temperature | Degrees centigrade, numerical |
| **Life stage** | |
| Post larval | 5 |
| Juvenile | 2 |
| Subadult | 3 |
| **Water** | |
| Palouse River water | 1 |
| University of Idaho well water | 2 |
| Tap water based simulated Willow Beach water | 3 |
| Distilled water based simulated Willow Beach water | 4 |
| Number of fish per container | numerical |
| Load. . . Weight of fish in grams per liter of water, | numerical |
| Observation hour | numerical |
| Response at observation | Percent of total number of fish dead, numerical |

REPORT NO. 7

# MOVEMENTS AND FEEDING OF ADULT STRIPED BASS, COLORADO RIVER INLET, LAKE POWELL, 1980-81

by

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## INTRODUCTION

In the Upper Colorado River drainage three native fishes, Colorado squawfish (Ptychocheilus lucius), humpback chub (Gila cypha), and bonytail (G. elegans) are classified as endangered, and the razorback sucker (Xyrauchen texanus) is rare. The habitat of these fishes has been altered in recent years by manmade water development projects and the fish community has been changed by introduction of exotic species.

Striped bass were first introduced into Lake Powell on the Colorado River by the Utah Division of Wildlife Resources in 1974. Bass fry were stocked annually from 1974-79 at Wawheap Bay and from 1976-78 at Bullfrog Bay. Inasmuch as striped bass are highly piscivorous, a concern existed as to whether the adult spawners prey on native fishes while on their spawning migration in the river.

Striped bass, an anadromous coastal species, moves upstream in rivers and estuaries to spawn in fresh water during the spring and early summer. Spawning occurs at temperatures of 10° to 25° C, most frequently at 15.6° to 17.8° C (Hardy, 1978). Spawning is usually most concentrated within the first 40-river km above salt water, but distance traveled by spawning fish in individual rivers is highly variable (Hardy, 1978). In the Hudson River, spawning occurs primarily between river km 25-62 (Rathjen and Miller, 1957). In the Roanoke River, North Carolina, major spawning grounds are approximately 209-217 km upriver (Hardy, 1978). Mature striped bass may move upstream as much as 320 km above salt water (Raney, 1954).

An important requirement for successful spawning appears to be a current sufficient to keep the semibuoyant eggs from settling to the bottom where they might become silted over and smother (Bigelow and Schroeder, 1953; Bayless, 1967). Incubation period of the drifting eggs is 48-72 hours at 15.6° to 17.8° C (Talbot, 1966).

Striped bass frequently spawn in turbulent, muddy, silt-laden areas characterized by rapids, boulders, and strong currents (Merriman, 1937; Raney, 1952; Mansueti and Hollis, 1963; Talbot, 1966). They have spawned successfully in the headwaters of at least three reservoirs: Santee-Cooper Reservoir, South Carolina; Kerr Reservoir, Virginia/North Carolina; and Millerton Lake, California (Calhoun, 1966).

The objective of this study was to determine if striped bass prey upon native fish species in the drainage. Specific objectives were to:

1. Sample the Colorado River at the head of Lake Powell and above Cataract Canyon for adult striped bass during their spawning period.

2. Determine the food habits of all migratory striped bass captured.

3. Determine the degree of success of striped bass reproduction in the Colorado River.

## Description of Study Sites

The Colorado River, the largest tributary of Lake Powell, represents a likely site for reproduction by reservoir striped bass populations. Two sampling sites, Spanish Bottom and Gypsum Canyon, were selected to monitor striped bass at the Colorado River inlet (Figure 1).

### Spanish Bottom

Spanish Bottom was selected as a study site because it was above the upper rapid of Cataract Canyon and below the confluence of the Green and Colorado Rivers. The river is narrow and a relatively straight run for 5.6 km from Spanish Bottom to the confluence (Figure 2). A large back eddy is present where the river turns south at the lower end of Spanish Bottom. Small back eddies are present along either bank. Nets were fished in back eddies or along the shore in slower reaches.

Below the confluence the gradient of the river just above the first rapid averages approximately 0.2 m/km. Gradient then increases to approximately 3 m/km (Baars and Molenaar, 1971). Most of the drop in Cataract Canyon occurs in relatively short rapids, in which the rate of fall may exceed 5.7 m/km (30 ft/mi). When Glen Canyon Reservoir (Lake Powell) is completely full at the 1,128 m level, all but 23 rapids in 19.3 km are inundated. Rapid 23, or Big Drop, is the most severe rapid in the canyon, the rate of fall is 7 m/km (38 ft/mi) from river mile 203.5 to the start of the reservoir (Baars and Molenaar, 1971).

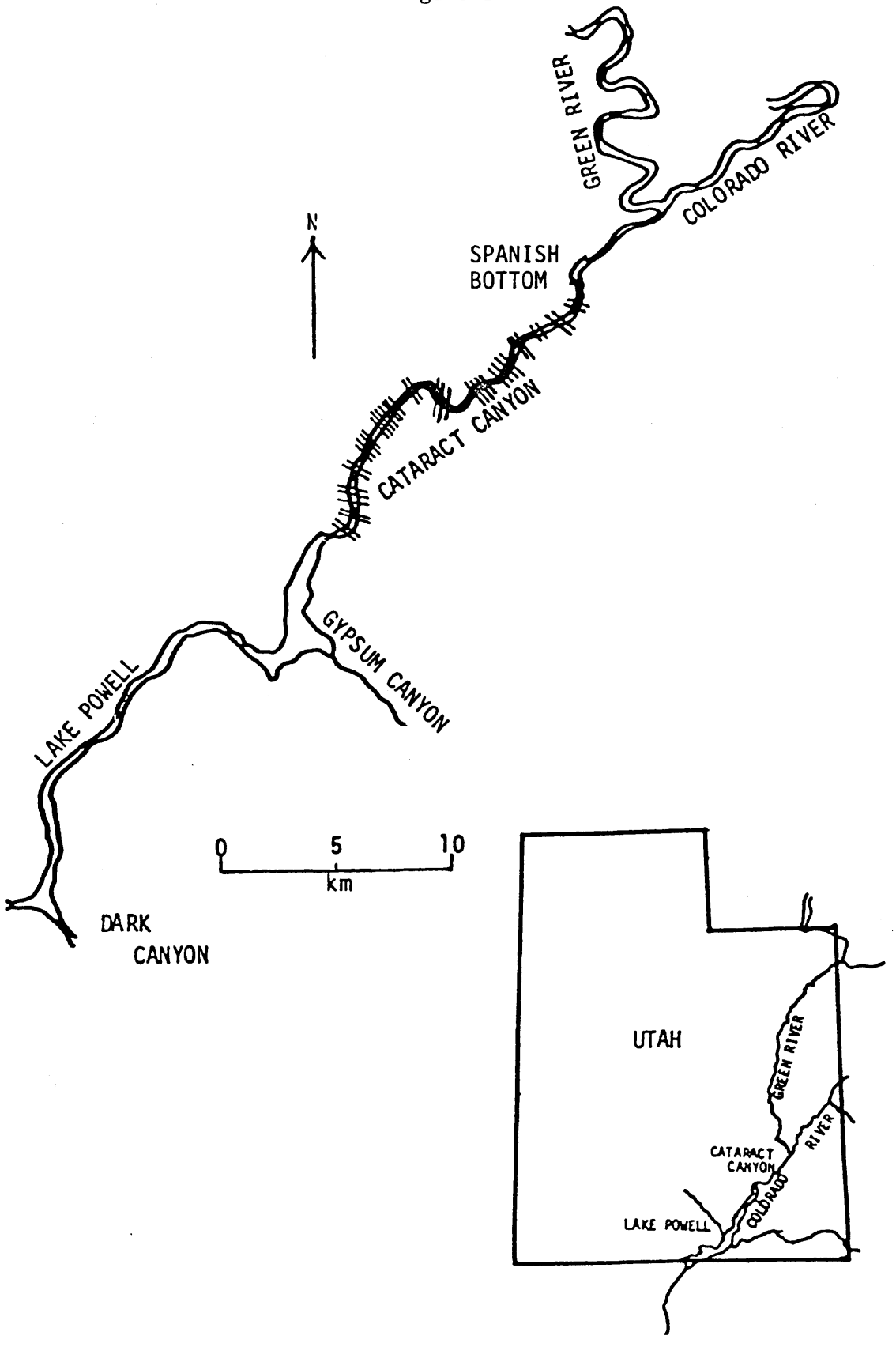
### Gypsum Canyon

Gypsum Canyon was selected as a study site because it was just below the last rapid in Cataract Canyon, had a relatively large expanse of calm water, and provided good locations for gillnet sets.

During 1980, when river flow exceeded 1,416 $m^3$/sec (50,000 cfs), the mixing zone of the river and reservoir extended for several miles below the last rapid. The headwaters where the Colorado River entered Glen Canyon Reservoir resembled a large, swift river at the initial point of entry (river mile 201) with the river constricted between narrow walls. This large river gradually slowed and widened near Gypsum and Palmer Canyons (river mile 196). Large side eddies were common in the mixing zone near Gypsum Canyon during 1980. Water was 9-11 m deep in the main channel, but was more shallow near the recently inundated talus slope shoreline. The reservoir reached maximum elevation (1,128 m) for the first time during 1980.

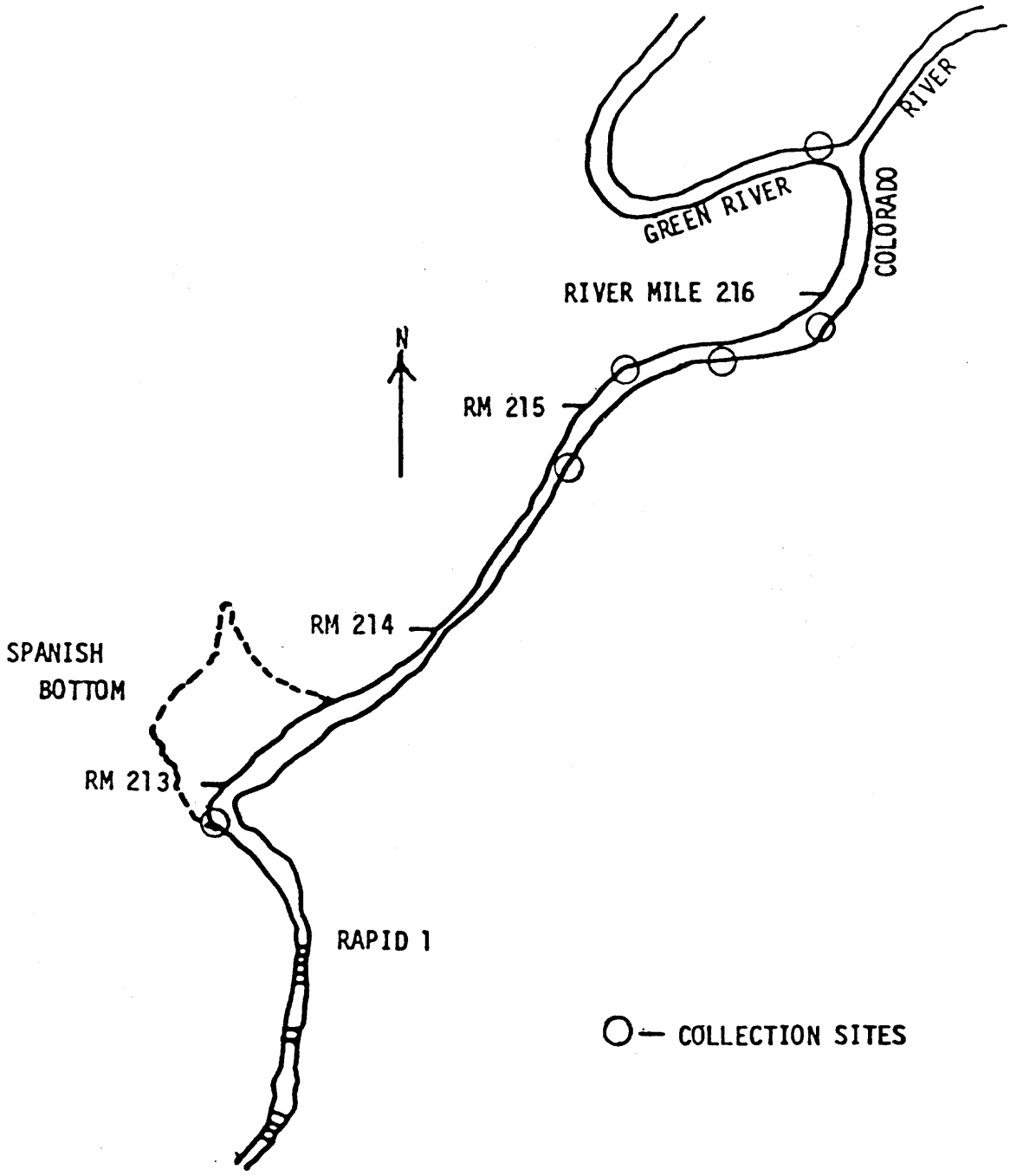
Reservoir level was approximately 1,122 m and river flow averaged less than 311 $m^3$/sec (11,000 cfs) during the 1981 sampling period. As a result of lower reservoir elevation and lower river flow the mixing zone was greatly altered. Mud and silt bars formed during 1980 were exposed in 1981, the channel was narrower and shallower (3-5 m), current velocity was greatly reduced, and there were fewer and smaller side eddies during 1981 than 1980 (Figure 3).

Figure 1



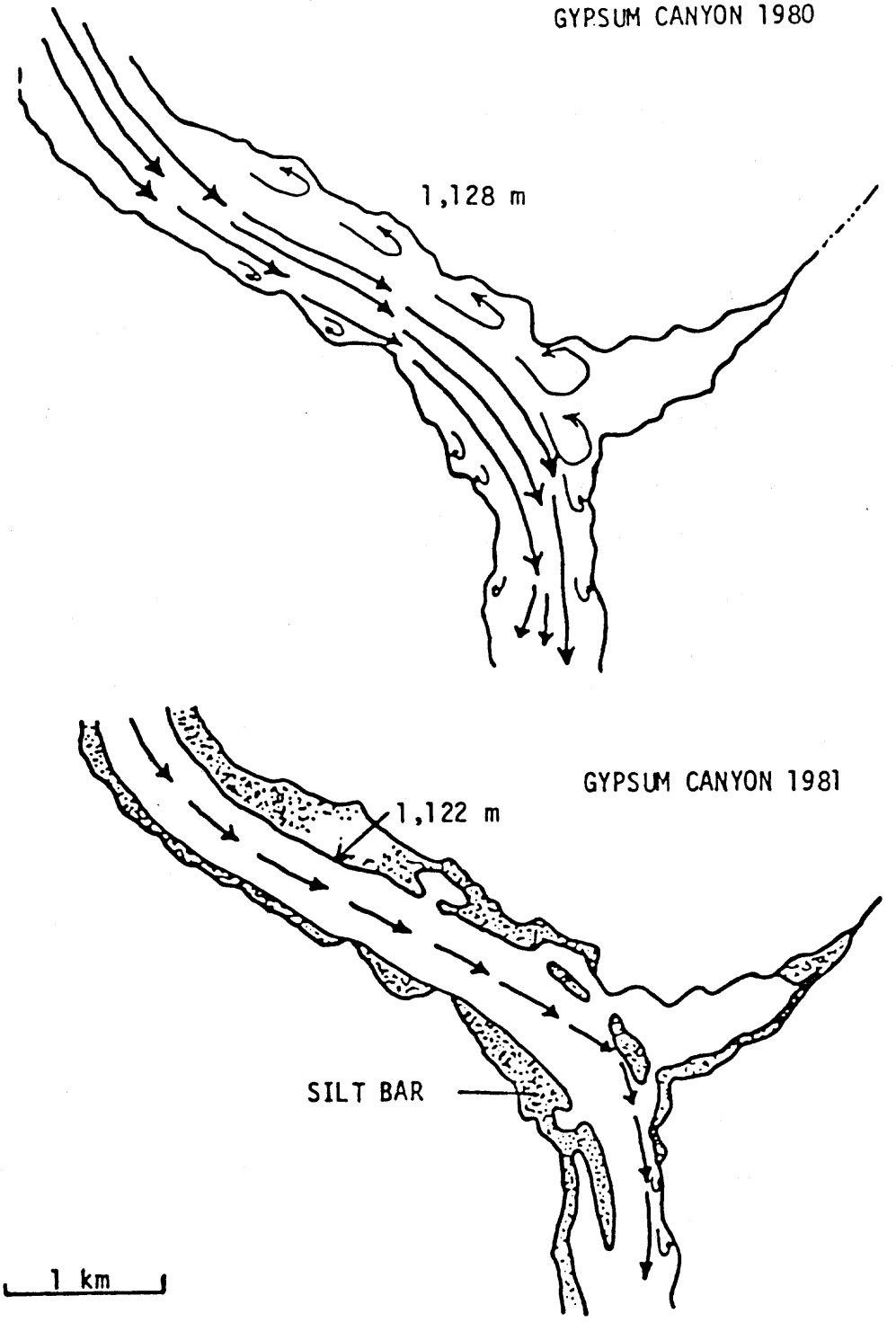

Location of sampling sites on the Colorado River and Lake Powell

Figure 2




Relation of Spanish Bottom to confluence and rapids of Cataract Canyon

Figure 3




Water current patterns at Gypsum Canyon, Lake Powell, 1980 and 1981.

## METHODS

Fish were collected during the period April 26 - June 18, 1980, and May 24 - July 22, 1981, with 31-m long x 3-m deep, 6.4-cm square-mesh multifilament nylon gillnet at the head of Lake Powell near Gypsum Canyon. One end of the net was attached by rope to the shore and the net was fished in water from 1-15 m deep. Nets were checked every 4-5 hours during 1980. Nets were checked every 0.5 to 3 hours during the day in 1981. Overnight net sets were used only occasionally during 1981 because of warm water temperature and possible increased mortality. In addition to the nets fished near Gypsum Canyon, nets were fished near Spanish Bottom (river mile 213) above the Cataract Canyon rapids from May 7-21, 1980, and from May 26 - June 2, 1981, to determine if bass moved upriver through the rapids. Catch per gillnet hour was reported in terms of a 31 m net.

All fish captured were identified, weighed, and measured for total length. Stomachs of most adult striped bass were collected and preserved in 10 percent buffered formalin during 1980. Stomachs were examined in the field during 1981. Gonads were also examined to determine their stage of maturity and preserved when maturity was questionable. In addition, 70 striped bass were marked with Floy tags and released unharmed during 1981 to assist Utah Division of Wildlife Resources in studies of bass distribution in the reservoir.

Striped bass were classified into one of the following stages of maturity, based partly on Scruggs (1957).

### Immature

Immature testes were small and threadlike. Ovaries were small and contained no developing ova. The color varied from pale gray to deep red, and the main blood vessels of the ovary were not dilated.

### Maturing

Maturing testes were very large and the color varied from pale pink to white. Ovaries in maturing females were enlarged, contained developing ova, and varied in color from cream to orangish-yellow. The blood vessels of the ovaries were dilated. Developing ova were small (less than 1-mm diameter) and cream colored. The ratio of ovary weight to body weight averaged 1:45. Scruggs (1957) reported a ratio of 1:40 in South Carolina.

### Mature

Mature testes were very large, white, and they released milt when the fish were gently stripped. Mature ovaries were very large with developed ova and extremely dilated blood vessels. Color ranged from

pale green, with some cream colored ova, to a darker green. As the ovaries approached ripeness ova became clear centered, darker green, and approximately 1 to 1.5 mm in diameter. The ratio of ovary weight to body weight averaged 1:11. Scruggs (1957) reported a ratio of 1:10 in mature South Carolina bass.

### Spent

Spent ovaries were flabby, thick walled, and light purple to dark purple colored. Spent testes were smaller than mature testes, reddish-gray colored, and relatively dry or completely empty when cut. Partially spent testes were difficult to determine. The main blood vessel was frequently loose and milt was less easily extruded from suspected partially spent testes.

Plankton nets (0.5-m diameter mouth, 0.565 mm mesh) were fished daily in the main channel at bottom, mid- and subsurface depths for 3-5 min at each depth. Nets became clogged with debris if towed for a longer period of time. Tows were also made in quiet water and slow back eddies near Gypsum Canyon. Ichthyoplankton samples were preserved in 5-8 percent buffered formalin containing rose bengal dye for later examination for the presence of fish eggs and larvae. Eggs and larvae found in the samples were measured with an ocular micrometer.

A 1.3-cm square mesh fyke net with 15.25 m lead was fished from June 13 - July 12, 1981. The net was set with the lead perpendicular to shore in shallow (0 to 1.5 m) water and checked approximately every 12 hours.

## RESULTS

### Discharge

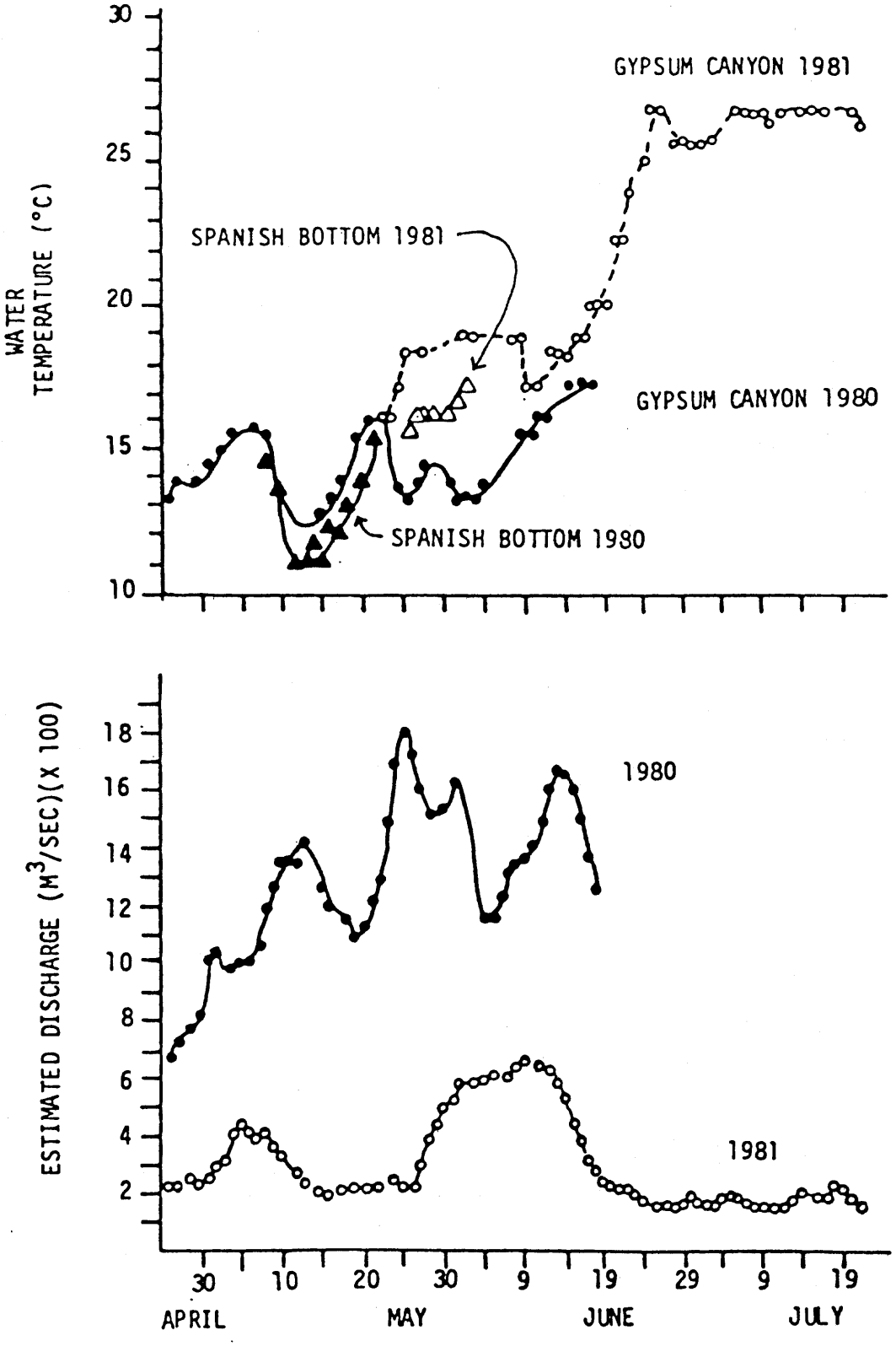
Discharge was calculated by adding Green River discharge measured at Green River, Utah (188 km upstream from the confluence) with Colorado River discharge measured at Cisco, Utah (156 km upstream from the confluence) (USGS, 1980-81). During the 1980 sampling season, (April 26 - June 18), discharge ranged from 681 $m^3$/sec (24,000 cfs) to 1,806 $m^3$/sec (63,790 cfs) and averaged 1,280 $m^3$/sec (45,203 cfs). Discharge during the same period in 1981 ranged from 198 $m^3$/sec (7,000 cfs) to 655 $m^3$/sec (23,120 cfs) and averaged 378 $m^3$/sec (13,352 cfs) (Figure 4). Reduced discharge during 1981 caused several changes in the mixing zone of the river and reservoir as discussed in the Introduction.

### Temperature

#### Spanish Bottom

Shortly after sampling was initiated in 1980, surface water temperature decreased from 14.4° C to 11.1° C, remained cool for several days and then began a slow warming trend (Figure 4). Surface temperature increased from 15° C to 17.2° C during the 1981 sampling period.

Figure 4




Discharge and surface water temperature at sampling sites, 1980 and 1981.

Inasmuch as striped bass spawn in most rivers at temperatures between 15.6° and 17.8° C, temperatures during the 1981 sample period were suitable for spawning, but not during the 1980 period.

### Gypsum Canyon

Surface water temperature at Gypsum Canyon varied from 12.8° to 17.2° C during the 1980 sample period (Figure 4). Water temperature at Gypsum in 1980 was within the range of temperatures normally present during striped bass spawning from May 5-9, May 20-24, and after June 9, 1980. Water temperature at Gypsum was within or above the range suitable for bass spawning throughout the 1981 sampling period.

## Catch

### Spanish Bottom

During the study, 15 species of fish were collected and identified at the two study sites (Table 1). Although gillnets were fished from May 7-21, 1980, and from May 26 - June 2, 1981, near Spanish Bottom, no striped bass were captured above the Cataract Canyon rapids. Although water temperature was lower than ideal for striped bass spawning during the 1980 season, temperature was within the range normally reported for bass spawning during 1981.

Flannelmouth sucker and carp were the most frequently captured species in a total of 871 gillnet hours of sampling above the rapids (Table 2). Brown trout was the second most common species captured in 1981, but was not collected in 1980. Three Colorado squawfish and two razorback suckers collected in 1980 were captured immediately upstream from the confluence, on the Green River side where water was 2-3 m deep in a slower reach. Two Colorado squawfish captured in 1981 were in slow reaches between Spanish Bottom and the confluence at a depth of 2-3 m.

Relatively low catches in gillnets at Spanish Bottom were attributed to a lack of suitable netting areas and drift that clogged nets. It is also likely that the fish population above the rapids was lower than that found below the rapids in the headwater mixing zone.

### Gypsum Canyon

A fyke net was fished in quiet, shallow water of Gypsum Canyon for 38 12-hour sets between June 13 and July 12, 1981. The net was set for 16 daytime periods and for 22 nighttime periods.

Threadfin shad were abundant and made up 57 percent of the total number of fish captured by fyke net (Table 3). Channel catfish was the second most abundant species captured, and carp and black bullhead were common in the net. Two striped bass, including a 340 g 1-year old and a 3,800 g spent adult were captured. Two Colorado squawfish were captured on June 17: 1) 490 mm TL, 907 g, and 2) 485 mm TL, 794 g.

Table 1
Species of fish collected at Gypsum Canyon and Spanish Bottom, 1980-81[1/]

| Common name | Scientific name |
|---|---|
| Threadfin shad | *Dorosoma petenense* |
| Brown trout | *Salmo trutta* |
| Northern pike | *Esox lucius* |
| Carp | *Cyprinus carpio* |
| Red shiner | *Notropis lutrensis* |
| Sand shiner | *Notropis stramineus* |
| Fathead minnow | *Pimephales promelas* |
| Colorado squawfish | *Ptychocheilus lucius* |
| Flannelmouth sucker | *Catostomus latipinnis* |
| Razorback sucker | *Xyrauchen texanus* |
| Black bullhead | *Ictalurus melas* |
| Channel catfish | *Ictalurus punctatus* |
| Striped bass | *Morone saxatilis* |
| Largemouth bass | *Micropterus salmoides* |
| Black crappie | *Pomoxis nigromaculatus* |
| Walleye | *Stizostedion vitreum* |

1/ Nomenclature according to Baily et al., 1970.

Table 2
Total catch of fish in gillnets at Spanish Bottom, 1980-81

| | 1980[1/] | | 1981[2/] | | Total | |
|---|---|---|---|---|---|---|
| Species | Number captured | Catch per effort (x100) | Number captured | Catch per effort (x100) | Number captured | Catch per effort (x100) |
| Flannelmouth sucker | 14 | 3.05 | 8 | 1.94 | 22 | 2.53 |
| Carp | 5 | 1.09 | 6 | 1.46 | 11 | 1.26 |
| Brown trout | 0 | 0 | 7 | 1.70 | 7 | 0.80 |
| Channel catfish | 1 | 0.22 | 4 | 0.97 | 5 | 0.57 |
| Colorado squawfish | 3 | 0.65 | 2 | 0.49 | 5 | 0.57 |
| Razorback sucker | 2 | 0.43 | 0 | 0 | 2 | 0.23 |

1/ Sampling period: May 7-21; total effort 459 net hours.
2/ Sampling period: May 26-June 2; total effort 412 net hours.

Table 3
Catch of fish in fyke net at Gypsum Canyon, 1981

| Species | Day | | Night | | Total | |
|---|---|---|---|---|---|---|
| | Number captured | Catch per 12-hour set | Number captured | Catch per 12-hour set | Number captured | Percent of total |
| Thredfin shad | 145 | 9.1 | 77 | 3.5 | 222 | 57 |
| Channel catfish | 45 | 2.8 | 48 | 2.2 | 93 | 24 |
| Carp | 8 | 0.5 | 36 | 1.6 | 44 | 11 |
| Black bullhead | 5 | 0.3 | 6 | 0.3 | 11 | 3 |
| Largemouth bass | 1 | 0.1 | 3 | 0.1 | 4 | 1 |
| Black crappie | 1 | 0.1 | 3 | 0.1 | 4 | 1 |
| Red shiner | 0 | 0.0 | 4 | 0.2 | 4 | 1 |
| Flannelmouth sucker | 0 | 0.0 | 2 | 0.1 | 2 | 1 |
| Striped bass | 0 | 0.0 | 2 | 0.1 | 2 | 1 |
| Colorado squawfish | 0 | 0.0 | 2 | 0.1 | 2 | 1 |
| Effort (12-hour sets) June 13-July 12 | 16 | | 22 | | 38 | |

Table 4
Total catch of fish in gillnets at Gypsum Canyon, 1980-81

| Species | 1980[1/] | | 1981[2/] | | Total | |
|---|---|---|---|---|---|---|
| | Number captured | Catch per gillnet hour [3/] (x100) | Number captured | Catch per gillnet hour (x100) | Number captured | Catch per gillnet hour (x100) |
| Carp | 166 | 3.59 | 487 | 13.49 | 653 | 7.94 |
| Striped bass | 198 | 4.29 | 228 | 6.32 | 426 | 5.18 |
| Walleye | 90 | 1.95 | 309 | 8.56 | 399 | 4.85 |
| Channel catfish | 108 | 2.34 | 103 | 2.85 | 211 | 2.56 |
| Flannelmouth sucker | 68 | 1.47 | 8 | 0.22 | 76 | 0.92 |
| Colorado squawfish | 45 | 0.97 | 4 | 0.11 | 49 | 0.60 |
| Brown trout | 13 | 0.28 | 18 | 0.50 | 31 | 0.38 |
| Razorback sucker | 6 | 0.13 | 11 | 0.30 | 17 | 0.21 |
| Largemouth bass | 4 | 0.09 | 4 | 0.11 | 8 | 0.10 |
| Black bullhead | 2 | 0.04 | 1 | 0.03 | 3 | 0.04 |
| Northern pike | 0 | 0 | 2 | 0.06 | 2 | 0.02 |
| Black crappie | 0 | 0 | 2 | 0.06 | 2 | 0.02 |

1/ Sampling period: April 16 - June 18; effort 4,620 net hours.
2/ Sampling period: May 24 - July 22; effort 3,609 net hours.
3/ Net was 31 m in length.

Threadfin shad and channel catfish were more abundant in day sets; other species were more common in night sets. Channel catfish may have been attracted to the net by shad which the small catfish frequently consumed.

The fyke net effectively sampled smaller fish not captured by gillnets, particularly threadfin shad. Red shiner, another forage fish, was relatively abundant in Gypsum Canyon but was generally too small to be captured by the fyke net. Other species captured by dip net and seine were sand shiner and fathead minnow.

Carp, striped bass, walleye, and channel catfish were the most frequently captured species during 8,229 hours of sampling with gillnets in 1980 and 1981 (Table 4). Striped bass was the most frequently collected species in 1980; carp and walleye were most abundant in 1981 catches.

Colorado squawfish and flannelmouth sucker, predominantly riverine species, were much more abundant in 1980 samples than in 1981 samples. In addition, northern pike and black crappie, primarily lacustrine species, were collected in 1981, but not in 1980. Approximately 20 percent of the total number of fish captured during 1980 were riverine species (brown trout, Colorado squawfish, flannelmouth sucker, and razorback sucker). During 1981, on the other hand, these species comprised less than 4 percent of the total catch. The species composition appears to reflect the change from a riverine to a more lacustrine habitat near Gypsum Canyon from 1980 to 1981 because of lower river flows and lower reservoir elevation. Warmer water temperature during 1981 may also have been partly responsible for changes in species composition of gillnet catches.

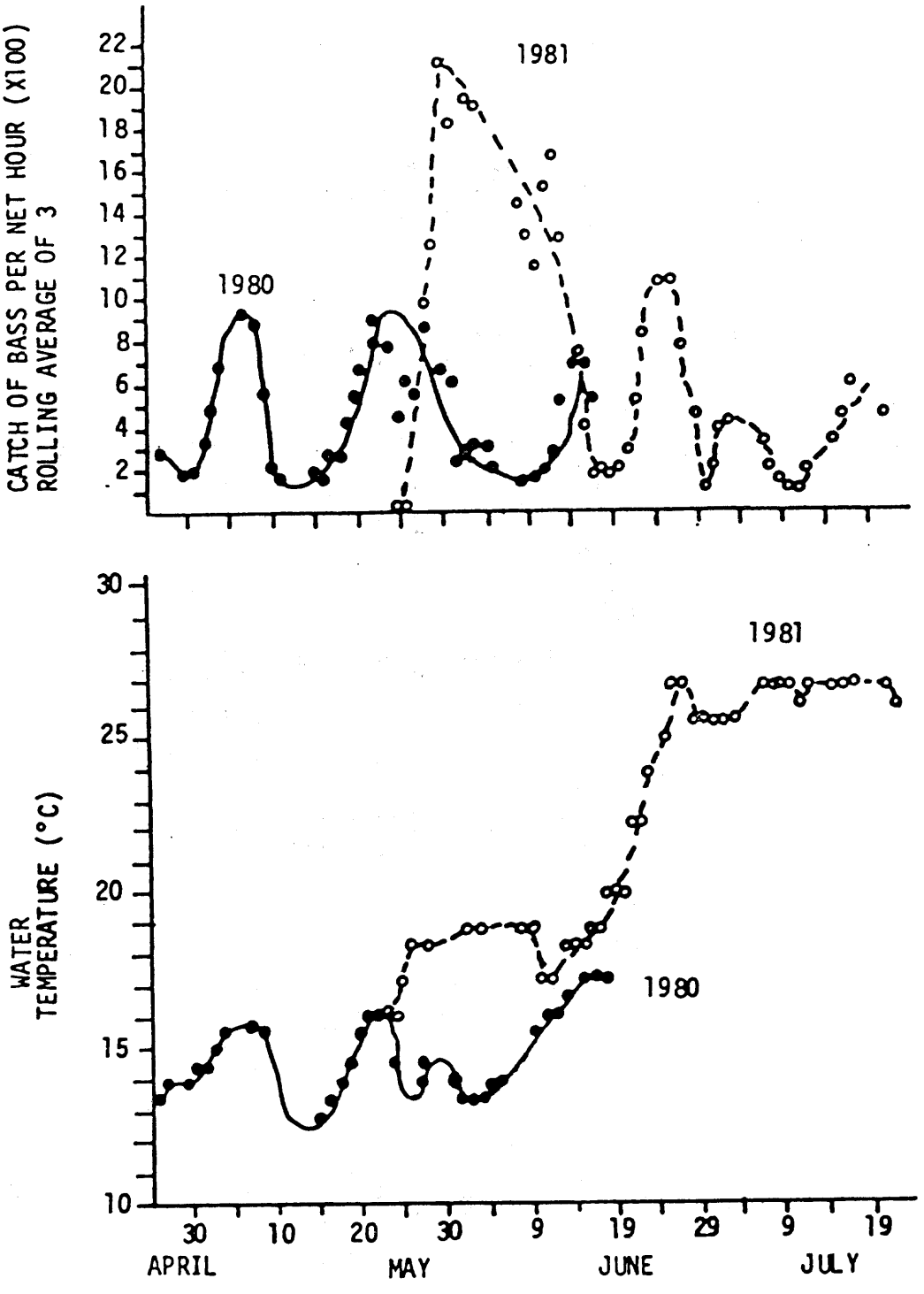
The catch of bass during 1980 showed the same general pattern as surface water temperature, with a peak catch in early May 2-8, a second peak in mid-May 20-24, and a third peak in mid-June 15 (Figure 5). Bass catches during 1981 showed two distinct peaks, one in early June and another in late June. Other workers have also reported 2-4 peaks in spawning activity, possibly correlated with rising temperature and/or falling water (Hardy, 1978).

Peak bass catches during 1981 exceeded 0.2 fish per net-hour. The average catch per effort during 1981 was 1.5 times greater than the average 1980 catch rate. Higher catch per effort of bass during 1981 may represent a larger spawning population present at the headwaters. Assuming equal survival from all stockings, records indicate that the number of potential broodstock (age 4+) fish was 1.7 times higher in 1981 than 1980.

## Sex and Stage of Maturity

In most bass populations, males outnumber females at any given time on the spawning grounds, and male bass normally arrive on the spawning grounds before females during migrations (Raney, 1952). More than twice as many males as females were captured during the 2 study years in the mixing zone (Table 5).

Figure 5




Catch of bass and surface water temperature at Gypsum Canyon, 1980 and 1981.

Table 5

Stage of maturity of adult striped bass captured in 1980-81

| Sex | Stage of maturity | 1980 Number captured | 1980 Percent of total | 1981[1] Number captured | 1981[1] Percent of total | Total Number captured | Total Percent of total |
|---|---|---|---|---|---|---|---|
| Male | Immature | 9 | 4.5 | 3 | 1.5 | 12 | 3.0 |
| | Maturing | 6 | 3.0 | 2 | 1.0 | 8 | 2.0 |
| | Mature | 121[2] | 61.1 | 89 | 43.4 | 210 | 52.1 |
| | Spent | 1 | 0.5 | 51 | 24.9 | 52 | 12.9 |
| | Total | 137 | 69.2 | 145 | 70.7 | 282 | 70.0 |
| Female | Immature | 6 | 3.0 | 8 | 3.9 | 14 | 3.5 |
| | Maturing | 15 | 7.6 | 4 | 2.0 | 19 | 4.7 |
| | Mature | 25 | 12.6 | 8 | 3.9 | 33 | 8.2 |
| | Spent | 15 | 7.6 | 40 | 19.5 | 55 | 13.6 |
| | Total | 61 | 30.8 | 60 | 29.3 | 121 | 30.0 |
| Grand total | | 198 | | 205 | | 403 | |

1/ Does not include 23 released fish with undetermined sex and stage of maturity.

2/ Includes some partially spent fish.

During 1980, sampling began on April 26 when surface water temperature was 13° C. Sexually mature male bass were captured as soon as sampling was initiated in 1980, whereas sexually mature females were not captured until May 20 when water temperature was 16° C. Spent females first appeared in the 1980 catch on June 11 and were captured during the remainder of the sampling period. A single spent male was positively identified on June 16, 1980, and males which appeared to be partially spent were captured after June 1.

Whereas, the early part of the spawning run was sampled during 1980, the later part was sampled in 1981. Evidently, bass had already begun spawning when sampling was initiated in 1981 at water temperature of 16° C. The first bass captured on May 26 was a spent female, and spent fish were captured throughout the remainder of the sampling period. Over 40 percent of bass captured during 1981 were spent, whereas less than 10 percent of those caught in 1980 were spent. Warmer water temperatures and later sampling period during 1981 are probably responsible for the capture of a greater percentage of spent fish.

## Ichthyoplankton

Four striped bass eggs were collected during 374 min of plankton net sampling in 1980. One egg was collected in the main channel of the Colorado River (river mile 198) on June 9 and another on June 17. Two additional eggs were collected in a single sample in the slow moving water of Gypsum Canyon on June 16.

The egg collected on June 17 was evidently not fertilized and floated to the surface of the sample suggesting that it was dead. The other three eggs were alive at time of capture and appeared to be in initial stages of cell division. Measurements of the three presumably fertilized eggs were similar to those of a sample of fertilized striped bass eggs taken in North Carolina (Mansueti, 1958). No eggs or larval fish were collected at Spanish Bottom in 1980.

The plankton net collected 12 eggs, 66 larval shiners (Notropis spp.), and 26 young-of-the-year channel catfish during 324 min of sampling during 1981. Three eggs and two larval shiners were captured at Spanish Bottom; all others were collected at Gypsum Canyon. Eggs were collected on May 28 and 31, 1981, at Spanish Bottom and from June 9 - July 2, 1981, at Gypsum Canyon. Larval fish were collected on May 31 at Spanish Bottom and after June 11 at Gypsum Canyon. No larval striped bass were captured and all eggs captured during 1981 were evidently Notropis stramineus or Notropis lutrensis.

## Striped Bass Spawning Grounds

The ratio of male bass to female bass captured (2.3:1); the capture of male bass before female bass; and the collection of spent fish and striped bass eggs in 1980 suggested that bass spawning grounds were near Gypsum Canyon at the Colorado River inlet to Lake Powell.

The exact location of spawning is unknown. Bass eggs were collected above Gypsum Canyon in 1980 but no bass were captured above Cataract Canyon. Inasmuch as bass frequently spawn in rapids and areas characterized by boulders and swift current, the Cataract Canyon rapids are a likely spawning location. Extent of upstream movement probably varies from year to year depending on river flow and reservoir elevation. During 1980, a high water year, and 1981, a low water year, no bass were captured at Spanish Bottom above the rapids.

## Food Habits

Striped bass evidently feed before and after spawning but rarely when they are involved in spawning. The majority of bass captured in both years in our study had empty stomachs (70 percent) (Table 6). Of the 30 percent of stomachs containing food, 94 percent contained threadfin shad. Red shiners were found in four stomachs, and partially digested unidentified fish remains in two bass stomachs. Approximately 42 percent of stomachs of immature and maturing bass contained food, whereas only 25 percent of stomachs of sexually mature fish contained food. Approximately 33 percent of stomachs of spent fish contained food, of which 94 percent contained shad. Other workers have also found that most striped bass in spawning condition do not feed (Raney, 1952; Morgan and Gerlach, 1950 in Raney, 1952; Trent and Hassler, 1966).

Other explanations for the large percentage of empty stomachs in captured bass include: 1) rapid rate of digestion (Merriman, 1941; Raney, 1952), 2) sporadic feeding, and 3) regurgitation of stomach contents by gillnetted fish. Regurgitation of food by gillnetted fish is a common phenomenon and results in lower estimates of the percentage of fish feeding. The components of the diet are not affected by regurgitation, only the percentage of stomachs containing food. In our study, the similarity of the percentage of stomachs containing food (30 percent) and intestinal tracts containing food (41 percent) suggested that regurgitation was not a major problem because regurgitation does not evacuate the intestine. Rapid digestion rate can alter composition of stomach contents by digestion of soft-bodied organisms first, but was also not considered a problem because most of the food items were fish which should dissolve at a somewhat similar rate.

Incidental to the bass study, walleye and catfish stomachs were collected (Table 7). Approximately 60 percent of walleye and 50 percent of catfish stomachs contained food. Shad was the most common food item; carp and catfish were also consumed. Walleye fed most heavily on threadfin shad, whereas channel catfish had a more varied diet.

Adult striped bass evidently do not often prey on native fishes during the spring and early summer while in the Gypsum Canyon area. Threadfin shad appear to provide the major food source within the reservoir for striped bass. Although endemic species were not found in bass stomachs, adult Colorado squawfish and razorback sucker were captured along with striped bass near Gypsum Canyon. Four small squawfish (67, 72, 106, 106 mm) were captured on July 17-18, 1980, near Imperial Canyon (river mile 200), and during this time five adult striped bass were captured near Gypsum Canyon (Mike Ottenbacher, Utah

Table 6
Stomach contents of adult striped bass at different stages of maturity, Gypsum Canyon, 1980-81

| Sex | Stage of maturity | Number | Number with empty stomach | Number with empty intestine | Number containing: Food | Shad | Red shiner | Unidentified fish remains | Crayfish |
|---|---|---|---|---|---|---|---|---|---|
| Male | Immature | 12 | 7 (58) | 4 (33) | 5 (42) | 4 (33) | 1 (8) | 0 | 0 |
| | Maturing | 7 | 7 (100) | 5 (71) | 0 | 0 | 0 | 0 | 0 |
| | Mature | 147 | 113 (77) | 104 (71) | 34 (23) | 31 (21) | 2 (1) | 1 (1) | 0 |
| | Spent | 50 | 35 (70) | 28 (56) | 15 (30) | 15 (30) | 0 | 0 | 0 |
| | Total | 216 | 162 (75) | 141 (65) | 54 (25) | 50 (23) | 3 (1) | 1 (0.5) | 0 |
| Female | Immature | 14 | 8 (57) | 6 (43) | 6 (43) | 6 (43) | 0 | 0 | 0 |
| | Maturing | 15 | 6 (40) | 7 (47) | 9 (60) | 9 (60) | 0 | 0 | 0 |
| | Mature | 30 | 19 (63) | 13 (43) | 11 (37) | 11 (37) | 0 | 1 (3) | 0 |
| | Spent | 46 | 29 (63) | 22 (48) | 17 (37) | 15 (33) | 1 (2) | 0 | 1 (2) |
| | Total | 105 | 62 (59) | 48 (46) | 43 (41) | 41 (39) | 1 (1) | 1 (1) | 0 |
| Grand total | | 321 | 224 (70) | 189 (50) | 97 (30) | 91 (28) | 4 (1) | 2 (1) | 1 (0.3) |

Table 7
Stomach contents of adult walleye and channel catfish Gypsum Canyon 1980-81 (percent in parenthesis).

| Species | | Range in length (mm) | Number | Number with empty stomach | Number with empty intestine | Number containing: Food | Shad | Carp | Catfish | Crayfish | Insects |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Walleye | 1980 | 384-657 | 46 | 17 (37) | 21 (46) | 29 (63) | 28 (61) | | 2 (4) | | |
| | 1981 | 326-690 | 74 | 32 (43) | 20 (27) | 42 (57) | 41 (55) | 1 (1) | | | |
| Total | | 326-690 | 120 | 49 (41) | 41 (34) | 71 (59) | 69 (58) | 1 (1) | 2 (2) | | |
| Catfish | 1980 | 71-639 | 40 | 20 (50) | 22 (55) | 20 (50) | 13 (33) | 3 (8) | 1 (3) | 5 (13) | 4 (10) |

Fishery Biologist, personal communication, 1980). One juvenile squawfish (251 mm) was gillnetted at Gypsum Canyon on July 22, 1981.

In conclusion, as long as bass congregate for spawning below Cataract Canyon rapids and threadfin shad are abundant, there is evidently little cause for concern about striped bass preying heavily on endemic fishes.

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REPORT NO. 8

# MOVEMENTS OF COLORADO SQUAWFISH IN THE COLORADO RIVER INLET OF LAKE POWELL

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## INTRODUCTION

During investigations of striped bass spawning movements in the spring of 1980, 45 adult-sized Colorado squawfish were captured by gillnets in the Colorado River/Lake Powell mixing zone (Persons and Bulkley, 1980, Appendix A). This relatively large number of adult-sized squawfish raised important questions as to the reason for the uncommon density of these endangered fishes. Were they concentrated for spawning purposes? Had they moved upriver from the reservoir? Or, were they year-round residents of this section of the river-reservoir mixing zone? The objective of this study was to monitor the movements of selected specimens from fish captured in 1981.

## METHODS

### Collection of Fish

Fish were collected during the period May 24 to July 22, 1981, with 31 meters long x 3 meters deep, 6.4-cm square mesh multifilament nylon gillnets at the head of Lake Powell near Gypsum Canyon (river miles 194-200) (Figure 1). One end of the net was attached by rope to the shore and the net was fished in water from 1 to 15 meters deep. Nets were checked every 0.5 to 3 hours during the day; overnight sets were occasionally used.

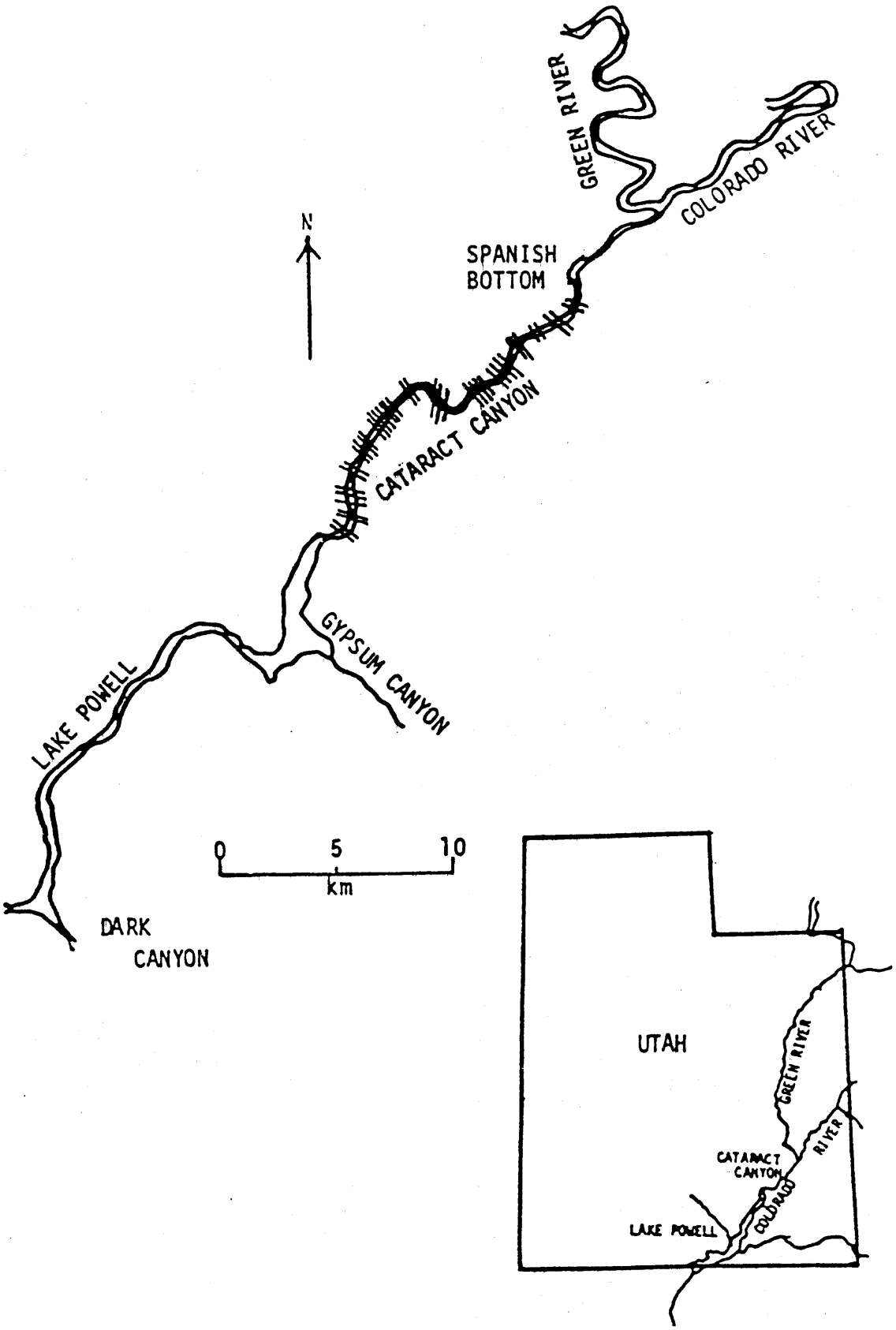
A 1.3-cm square mesh fyke net with 15.25-meters lead was fished from June 13 to July 12, 1981. The net was set with the lead perpendicular to shore in shallow (0-1.5 meters) water and checked approximately every 12 hours.

### Tracking Equipment

Radio transmitters manufactured by AVM Corporation for insertion into the body cavity were used in this study. Transmitters were 3 cm x 1.25 cm x 0.6 cm and weighed 4.5 grams. Frequencies ranged from 40.370 to 40.430 MHz. Receiving equipment manufactured by Smith-Root, Inc. included RF-40 tracking receivers, SR-40 search receivers, omnidirectional and directional antennae. Radio transmission range was approximately 100 meters with the transmitter less than 1 meter deep. Inflowing Colorado River water was extremely conductive and caused limited transmission range.

Interference, or spurious signals, were occasionally received with the SR-40 search receiver near Hite at river mile 169. Microwave transmission from Hite may have been responsible for these signals. They were not confused with actual radio transmitter signals because spurious signals were not received with the tracking receiver (RF-40) which could be tuned to a specific frequency.

Figure 1




Location of sampling sites on the Colorado River and Lake Powell

## Surgical Procedure

Each radio transmitter was dipped in melted beeswax to cover any abrasive surfaces which might irritate the fish. Frequency and pulse rate of the transmitter were checked after dipping and before insertion. The fish to be tagged was placed in a large tub containing 150-250 mg/L of tricain methane sulfonate (MS-222) and watched until opercle movement stopped. The fish was then placed on a measuring board that was washed with MS-222 solution. During surgery the fish's gills were also irrigated with MS-222. Operating instruments were sterilized with isopropyl alcohol after boiling.

A short 3-4 cm incision was made with a number 15 scalpel blade in the side of the fish just anterior to the pelvic fin and ventral to the rib cage. The radio tag was inserted into the body cavity with the antennae loop toward the head of the fish. The incision was then closed with a monofilament nylon 000 suture with a FS-1 cutting needle. Five individual sutures were tied with surgeon's knots and each knot was sealed with "super glue" and inspected for tightness.

After the incision was closed the fish was held in the quiet water of Gypsum Bay until it recovered from the anesthetic. Recovery was rapid (3-4 minutes) and the fish was released immediately into the bay.

## RESULTS

A single squawfish large enough for surgical implant (817 mm, 4,082 grams) was captured by gillnet on June 9 at 10:00 a.m. in a back eddy 3-4 meters deep near river mile 196. The fish was in the net for less than 30 minutes and was in excellent condition both before and after surgery. The fish was released after tag insertion and tracked in Gypsum Canyon where it moved around the bay during the daytime on June 9. On June 10 extensive tracking failed to locate the fish in Gypsum Canyon. Boats tracked upstream to the Cataract Canyon rapids and downstream approximately 5 km without receiving a signal. This search procedure was repeated on the following day (June 11).

On June 12 two boats tracked from Gypsum Canyon to Hite Marina (river mile 168). Four signals were received with the tracking receiver (RF-40) near Rock Canyon (river mile 173) and then the signal was lost. Repeated attempts to relocate the fish failed. Water was approximately 37 meters (120 ft) deep at Rock Canyon; if the fish sounded deep, range of the signal was probably too low to permit detection. Tracking was continued on alternate days through the month of June and into early July without locating the tagged fish.

Several theories have been presented to explain the relatively high capture rate of this endangered species at the Colorado River/Lake Powell mixing zone during the spring of 1980. One theory suggests that the squawfish captured during 1980 were residents of the reservoir and moved upstream to the headwaters, perhaps on a spawning migration. The high condition factor ($K_{TL}$ of many fish captured in 1980 suggested they were

reservoir residents inasmuch as threadfin shad for forage are abundant (Table 1). Mean condition factor for squawfish captured at Gypsum Canyon in 1980 was 1.003 (range = 0.658-2.043) in contrast to a $K_{TL}$ of 0.757 for three fish captured at Spanish Bottom in 1980 and $K_{TL}$ of 0.786 for two fish captured there in 1981. Although sample sizes were small, fish captured in 1980 at Gypsum Canyon tended to be heavier for their length than those captured at Spanish Bottom in 1980 and 1981 (Figure 2).

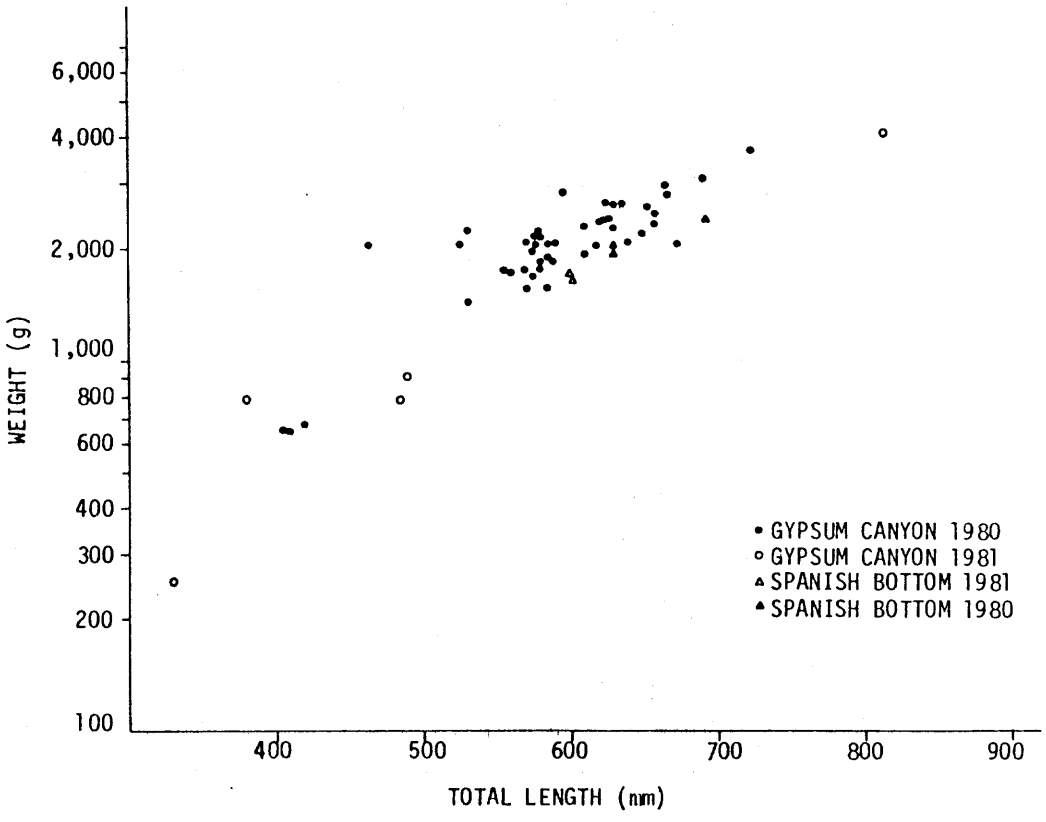
Table 1

Mean condition factors ($K_{TL}$)[1/] of Colorado squawfish captured in 1980 and 1981

| Location | Year | Number | Mean | Standard deviation | Range |
|---|---|---|---|---|---|
| Gypsum Canyon | 1980 | 47 | 1.003 | 0.215 | 0.658 - 2.043 |
| | 1981 | 5 | 0.872 | 0.037 | 0.716 - 1.447 |
| Spanish Bottom | 1980 | 3 | 0.757 | 0.037 | 0.716 - 0.788 |
| | 1981 | 2 | 0.786 | 0.212 | 0.771 - 0.801 |

1/ $K_{TL}$ = weight (grams) x $10^5$/length (mm).

Figure 2




Length-weight relationship of squawfish captured at Gypsum Canyon and Spanish Bottom, 1980 and 1981.

Density currents from the Colorado River inflow extend many kilometers into the reservoir during periods of high spring flow (Johnson and Merritt, 1979). The inflowing water may have stimulated squawfish to move upstream into the mixing zone. Low flows during 1981 might not have provided the necessary stimulus for upstream movement (Figure 3).

During the 1980 season, (April 26 - June 18), discharge ranged from 681 $m^3$/sec (24,060 cfs) to 1,806 $m^3$/sec (63,790 cfs) and averaged 1,280 $m^3$/sec (45,203 cfs). Discharge during the same period in 1981 ranged from 198 $m^3$/sec (7,000 cfs) to 655 $m^3$/sec (23,120 cfs) and averaged 378 $m^3$/sec, (13,352 cfs). Seasonal and temperature differences may also have had an effect on capture of squawfish in the mixing zone during 1980 and 1981. Peak catches during 1980 were in late April and early May (Figure 4) when water temperature ranged from 12-16° C (54-60° F). During 1981, however, sampling was initiated until late May when water temperatures already exceeded 16° C (60° F) (Figure 3).

Another possibility is that squawfish captured during 1980 were residents of the mixing zone which resembled a large, slow moving river. During 1981, habitat conditions (depth and flow) were radically changed from those present in 1980. Mud and silt bars formed during 1980 were exposed in 1981, the channel was narrower and shallower (3-5 meters vs. 9-11 meters), current velocity was greatly reduced, and there were fewer and smaller side eddies during 1981 than 1980 (Figure 5). These changes in the physical habitat may have made the mixing zone less suitable for adultsize squawfish, hence fewer were collected.

It is difficult, if not impossible, to draw conclusions concerning squawfish movement based on tracking a single fish. The tagged fish, a large 4,082-gram adult, evidently moved from the mixing zone over 37 km (23 miles) toward the main body of the reservoir in less than 3 days. The project needs to be repeated in years of normal river flows to determine source of the squawfish and reason for their concentration in the Colorado River inlet area.

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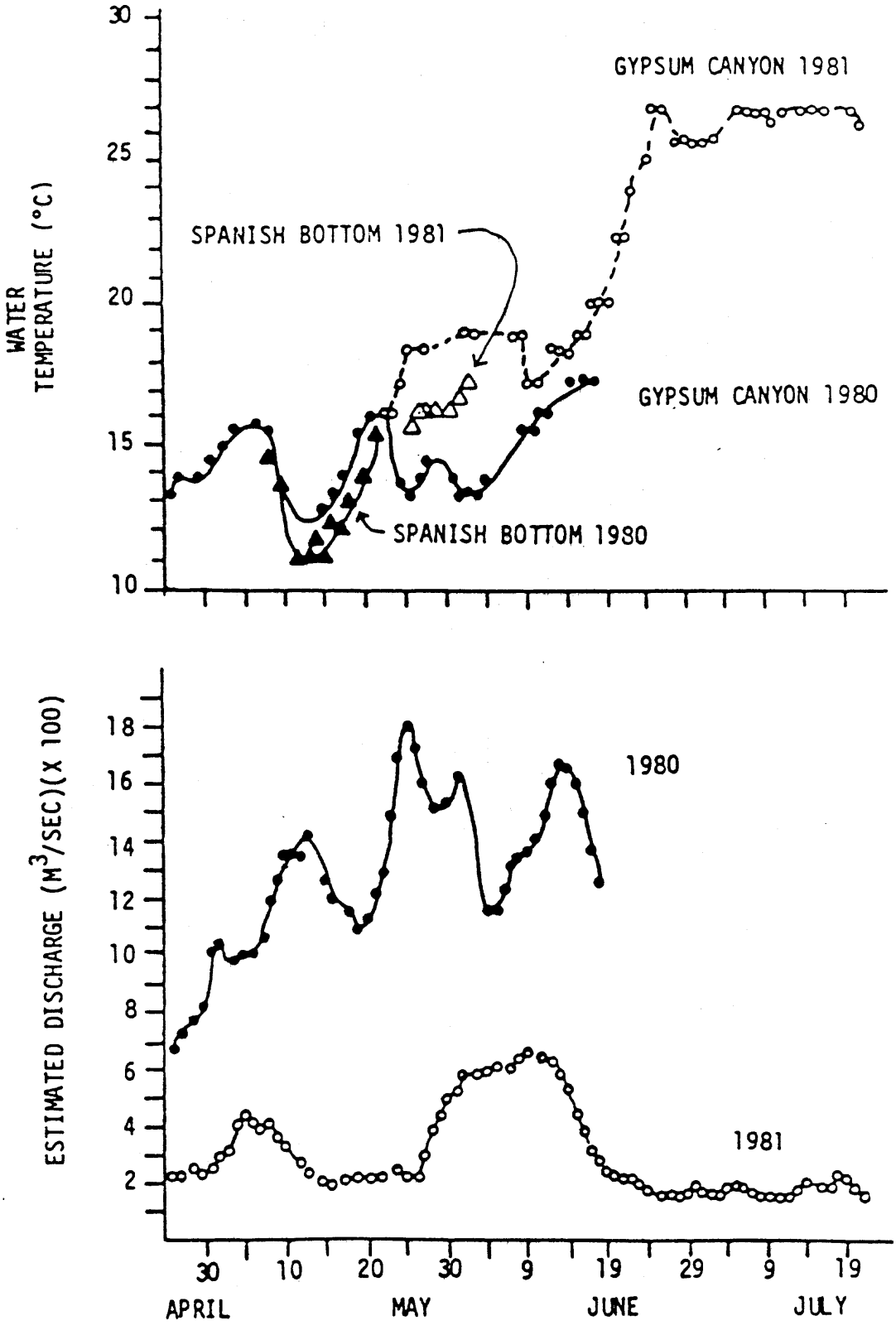
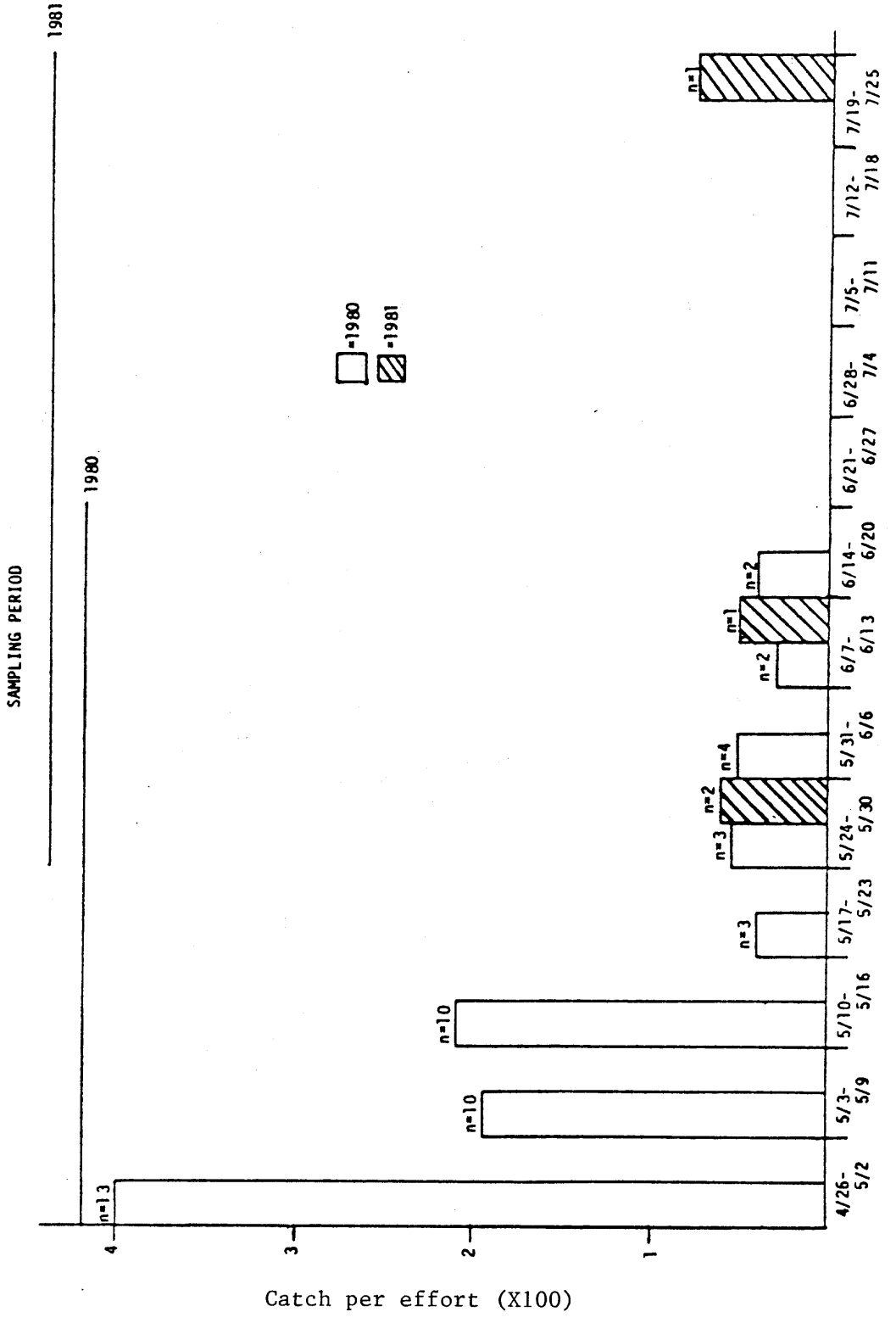
Figure 3



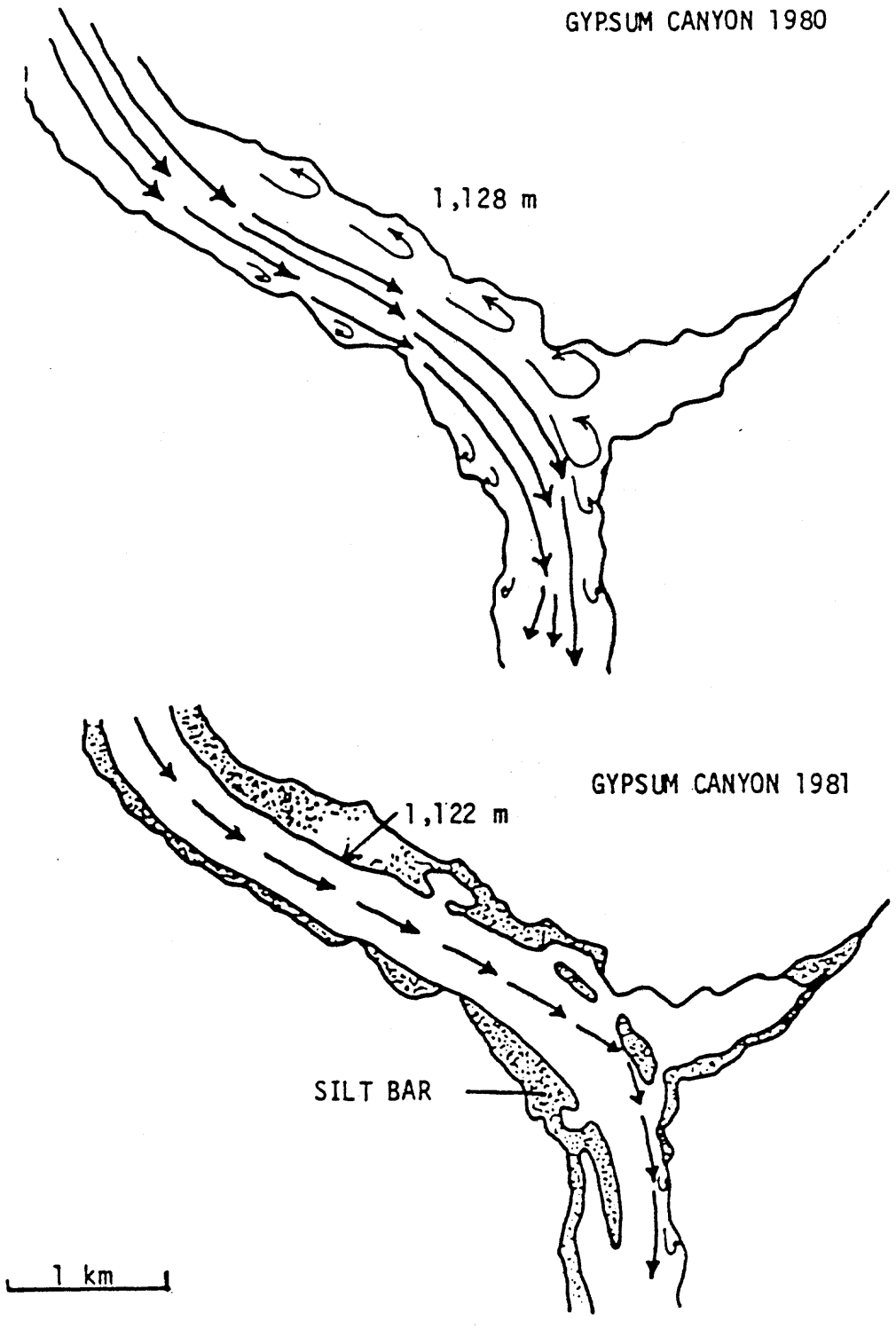

Discharge and surface water temperature at sampling sites, 1980 and 1981

Figure 4




Weekly gillnet capture rate of squawfish at Gypsum Canyon during 1980 and 1981.

Figure 5




Water current patterns at Gypsum Canyon, Lake Powell, 1980 and 1981.

Appendix A

Catch of Colorado squawfish in gillnets, 1980-1981

| Location | Date | Length (mm) | Weight (g) | Temperature (°C) | Depth of set (m) | Tag Number | Comments |
|---|---|---|---|---|---|---|---|
| Gypsum Canyon | 4/26/80 | 660 | 2,495 | 13 | 3-5 | | |
| | 4/27/80 | 667 | 2,948 | 14 | 3-5 | | |
| | 4/27/80 | 532 | 2,211 | 14 | 3-5 | | |
| | 4/30/80 | 677 | 2,041 | 14 | 3-5 | | |
| | 5/1/80 | 626 | 2,381 | 14 | 3-5 | | |
| | 5/1/80 | 590 | 2,070 | 14 | 3-5 | | |
| | 5/1/80 | 579 | 1,673 | 14 | 2-3 | | |
| | 5/1/80 | 586 | 1,843 | 14 | 2-3 | | |
| | 5/1/80 | 555 | 1,729 | 14 | 2-3 | | |
| | 5/2/80 | 580 | 1,814 | 14 | 3-5 | | |
| | 5/2/80 | 571 | 2,070 | 14 | 2-3 | | |
| | 5/2/80 | 580 | 1,758 | 14 | 2-3 | | |
| | 5/2/80 | 610 | 1,928 | 14 | 3-5 | | |
| | 5/3/80 | 672 | 2,722 | 15 | 3-5 | | |
| | 5/3/80 | 560 | 1,729 | 15 | 3-5 | | |
| | 5/3/80 | 636 | 2,637 | 15 | 3-5 | | |
| | 5/4/80 | 569 | 1,758 | 16 | 2-5 | | |
| | 5/4/80 | 586 | 2,041 | 16 | 2-5 | | |
| | 5/4/80 | 419 | 680 | 16 | 2-5 | | |
| | 5/9/80 | 610 | 2,296 | 16 | 2-3 | | |
| | 5/9/80 | 624 | 2,381 | 16 | 2-3 | | |
| | 5/9/80 | 464 | 2,041 | 16 | 2-3 | | |
| | 5/9/80 | 587 | 1,871 | 16 | 2-3 | | |
| | 5/10/80 | 532 | 1,474 | 13 | 2-3 | | |
| | 5/10/80 | 653 | 2,580 | 13 | 2-5 | | |
| | 5/11/80 | 526 | 2,041 | 13 | 2-5 | | |
| | 5/11/80 | 625 | 2,637 | 13 | 2-5 | | |
| | 5/11/80 | 690 | 3,062 | 13 | 2-5 | | |
| | 5/15/80 | 580 | 2,183 | 13 | 2-5 | | |
| | 5/15/80 | 734 | 3,685 | 13 | 2-5 | | |
| | 5/16/80 | 656 | 2,325 | 13 | 2-5 | 0642 | No parasites visible, right eye cloudy. |
| | 5/16/80 | 631 | 2,608 | 13 | 2-5 | | Lernaea on caudal fin. |
| | 5/16/80 | 630 | 2,268 | 13 | 2-5 | | Lernaea on dorsal, anal fins. |
| | 5/17/80 | 573 | 1,559 | 13 | 2-5 | 0628 | Left eye with small pupil. |
| | 5/21/80 | 578 | 2,211 | 16 | 3-5 | 0697 | No parasites visible. |
| | 5/23/80 | 409 | 652 | 16 | 3-5 | 0656 | No parasites visible. |
| | 5/24/80 | 595 | 2,807 | 14 | 3-5 | 0612 | Lernaea on dorsal and anal fins, gular fold; vent swollen and red. |
| | 5/27/80 | 639 | 2,070 | 14 | 3-5 | 0673 | Lernaea on dorsal and anal fins. |
| | 5/27/80 | 618 | 2,041 | 14 | 3-5 | 0640 | Lernaea on pectoral fins. |
| | 5/31/80 | 585 | 1,559 | 14 | 3-6 | 0670 | Lernaea on left pectoral, dorsal, anal fins; body above left pelvic fin, gular fold and plate. |
| | 6/1/80 | 575 | 1,956 | 13 | 3-5 | 0666 | Lernaea on dorsal, caudal fins, gular fold. |
| | 6/1/80 | 650 | 2,183 | 13 | 3-5 | 0681 | No parasites visible, swollen vent. |
| | 6/4/80 | 621 | 2,353 | 14 | 3-6 | 0644 | No parasites visible. |
| | 6/12/80 | 406 | 652 | 16 | 3-6 | 0625 | Lernaea on dorsal fin. |
| | 6/12/80 | 577 | 2,183 | 16 | 3-6 | 0679 | Lernaea on pectoral, anal, dorsal fins, lesions on gular fold, inside mouth. |
| | 6/17/80 | 577 | 2,013 | 17 | 3-6 | 0679 | Recapture from 6/12/80. |
| | 6/17/80 | 577 | 2,013 | 17 | 3-6 | 0679 | Recapture from 6/17/80 and earlier on 6/12/80. |
| | 5/26/81 | 332 | 255 | 18 | 2-3 | 0643 | Lernaea on dorsal, caudal, anal, pectoral, pelvic fins, inside mouth. |
| | 5/29/81 | 380 | 794 | 17 | 2-3 | 0695 | Lernaea on dorsal, caudal, anal, pectoral fins. |
| | 6/9/81 | 817 | 4,082 | 19 | 2-3 | | 40.415 MHz radio tag. Lernaea on dorsal, anal, pectoral, pelvic, head, gular fold. |
| | 6/17/81 | 490 | 907 | 19 | 1-2 | 0696 | Lernaea on dorsal, caudal, pectoral fins. Captured in fyke net. |
| | 6/17/81 | 485 | 794 | 19 | 1-2 | 0676 | Lernaea on ventral fold of left jaw, pelvic, caudal fins. Captured in fyke net. |
| | 7/22/81 | 251 | 114 | 26 | 2-3 | | Dead in net. |
| Spanish Bottom | 5/20/80 | 693 | 2,383 | 14 | 2-3 | 0607 | Two Lernaea on body. |
| | 5/20/80 | 600 | 1,702 | 14 | 2-3 | 0614 | One Lernaea on body. |
| | 5/20/80 | 602 | 1,674 | 14 | 2-3 | | Dead in net, preserved and sent to Fort Morgan Disease Laboratory. |
| | 5/29/81 | 631 | 2,013 | 16 | 2-3 | | No parasites visible. |
| | 6/1/81 | 630 | 1,928 | 17 | 2-3 | | No parasites visible. |

REPORT NO. 9

# FISH STOMACH CONTENT ANALYSIS

by

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## INTRODUCTION

The purpose of this investigation was to examine the stomach contents of young of the year and juvenile endangered and young of the year and adult non-endangered fish species collected by the Colorado River Fisheries Project Team (CRFP) from several strata in the Upper Colorado, Green, and Gunnison Rivers (Figure 1). Food contents were identified and quantified numerically and by weight to determine food item preference by fish species and if food item preferences were significantly different between endangered and non-endangered fish species.

A total of 771 stomachs was examined from three size categories of 11 species of fish. Three endangered fish species were Ptychocheilus lucuis, Gila robusta, and Gila sp. Both Gila robusta and Gila sp. are considered in the endangered category for the purposes of this report, although it is recognized that only G. elegans and G. cypha are classified as endangered by the U.S. Fish and Wildlife Service (FWS). Eight non-endangered species were Rhinichthys osculus, Catostomus latipinnis, Catostomus discobolus, Pimephales promelas, Notropis stramineus, Notropis lutrensis, Ictalurus punctatus, and an unidentified killifish (Table 1).

## METHODS

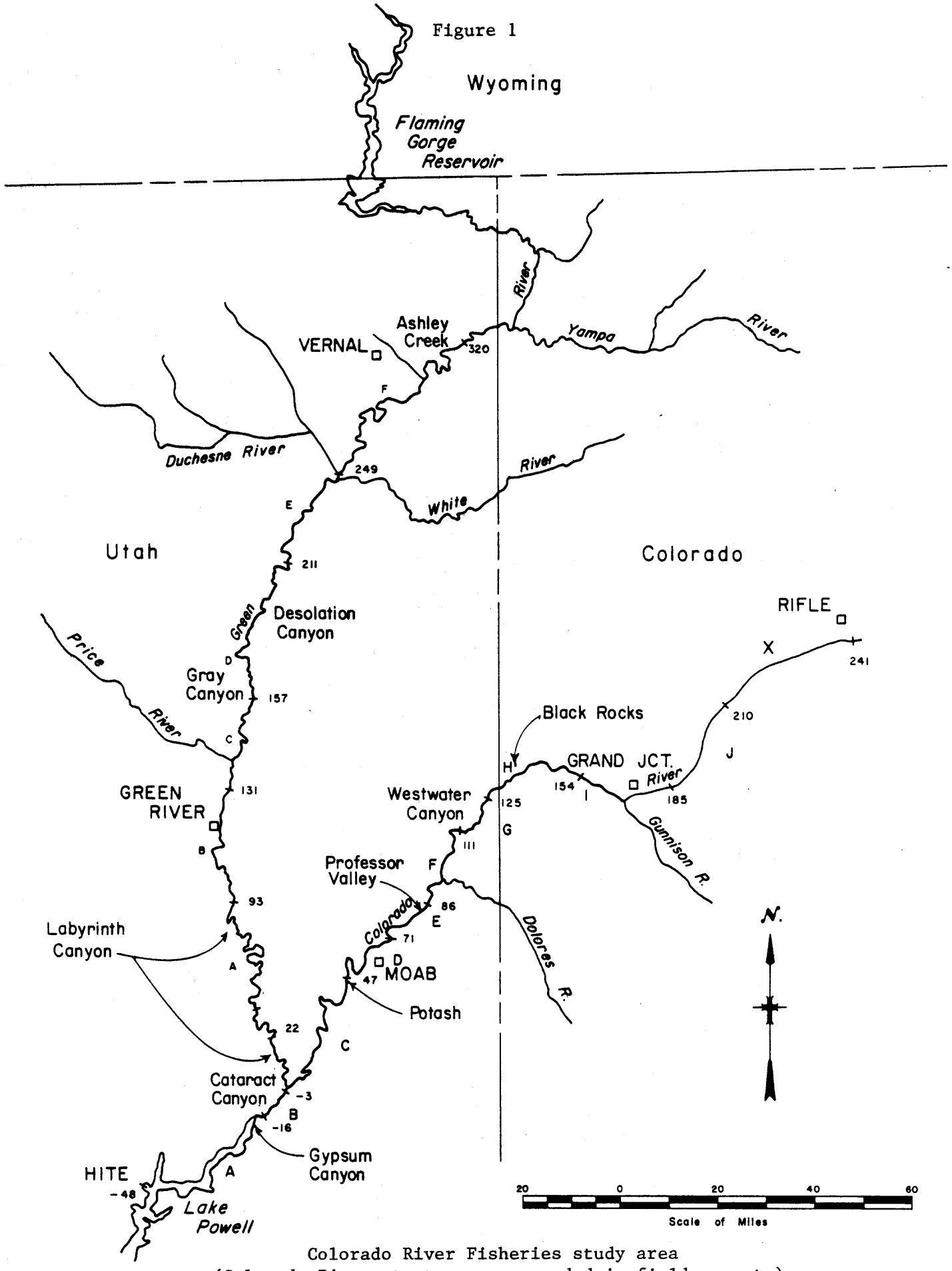
### Fish Stomach Contents

Stomachs were eviscerated by carefully slitting the fish belly (using sharp nosed scissors) at the vent and cutting towards the isthmus. Each stomach (including esophagus and intestine) was carefully removed with forceps and placed into a 3-dram patent-lip vial containing 70 percent ethyl alcohol. Several stomachs were removed in one session so that this step would not add time to and interfere with the process of stomach content removal and food item identification.

We had planned to use the volumetric syringe measuring device (Myers and Peterka 1974) for estimating volumes of individual macro-food items. Because of the very small, fragile, and fragmented condition of most of the food items, it was necessary to modify the biomass technique. The Myers and Peterka method (1974) had been used earlier on Cutthroat trout (Salmo clarki lewisi) stomach contents (Jacobi 1979) where the food items were whole and larger benthic macroinvertibrates.

Before individual food items were removed from each stomach, the following was performed as a check for total stomach content biomass. After carefully removing viscera and other organs from the stomach mass, the stomach was rinsed with water, blotted on a paper towel to remove excess fluid, and then placed into the syringe measuring device. The difference between the initial volume and the displacement volume was roughly equal to the stomach content volume (minimal displacement was attributed to the stomach itself). This value was multiplied by 1.05 (Hynes 1961 and Jacobi 1977) to approximate biomass (weight in mg).

Figure 1




Colorado River Fisheries study area
(Colorado River strata were recorded in field reports)

Table 1
Fish species examined for stomach contents
from the Green, Colorado, and Gunnison Rivers

| Species | Size class | Number of specimens | Strata collection locations |
|---|---|---|---|
| *Ptychocheilus lucius* Girard | YOY[1] | 101 | A,B,C,D,E,F,G[2],K[3] |
| Colorado Squawfish | | | |
| *Gila robusta* Baird & Girard | YOY | 57 | VII,IX,X[4] |
| Roundtail Chub | J[5] | 38 | VI,VII,IX |
| *Gila* Sp. | YOY | 5 | D,F,VI |
| Chubs-Roundtail or Humpback | J | 25 | C,VI,IX |
| *Rhinichthys osculus* Girard | A[6] | 14 | IX |
| Speckled Dace | | | |
| *Catastomus latipinnis* (Baird & Girard) | YOY | 8 | IX,X |
| Flannelmouth Sucker | | | |
| *Catostomus discobolus* (Cope) | YOY | 36 | VI,IX |
| Bluehead Sucker | | | |
| *Pimephales promelas* Rafinesque | YOY | 78 | A,B,C,D,E,F,IV,VI,VII |
| Flathead Minnow | A | 68 | A,B,C,D,E,F,IV,VI,IX |
| *Notropis stramineus* (Cope) | YOY | 2 | |
| Sand Shiner | A | 20 | |
| *Notropis lutrensis* (Baird and Girard) | YOY | 78 | A,B,C,D,E,F,G,V,VI |
| Red Shiner | A | 174 | A,B,C,D,E,F,G,IV,V,VI,IX |
| *Ictalurus punctatus* (Rafinesque) | YOY | 63 | A,B,C,D,E,F |
| Channel Catfish | J | 1 | B |
| Killifish (?) | A | 3 | IV,K |

1/ YOY = young of the year
2/ A through G = Green River
3/ K = Black Rocks area of Colorado River
4/ I to IX = Colorado-Gunnison Rivers
5/ J = juvenile
6/ A = adult

The sum of estimated weights of individual food items should not have exceeded the value obtained by this check method.

Stomach contents were separated, identified, and counted into major taxonomic levels or food item categories using a binocular dissecting scope. Most macroinvertebrates were identified to order, genus, or family while some were unidentifiable because of their mutilated condition (Figure 2).

Food item weights for macroinvertebrates and/or fish from fish species (e.g. Ptychocheilus, Ictalurus, Gila, and Notropis) with relatively short stomachs and unconvoluted intestines were obtained using an average value from the length-weight method (Hynes 1961 and Hynes and Coleman 1968) and the weights for the mayfly (Ephemerella subvari) (Waters and Crawford 1973). The Hynes method assumes that an insect's shape is that of a cylinder, five times as long as wide, and that as it grows linearly its volume increases cubically. This is true for most macroinvertebrates (except Chironomidae-midges and Ceratopogonidae-biting midges which are thinner, approximately 7.5 to 10 times as long as wide) up to a length of 10 mm. The Waters and Crawford weights were obtained from direct weight measurements of mayflies which had been collected for production estimations. For example, the weight of a 4 mm long specimen would be 2.51 mg using an average of these two methods (Figure 3).

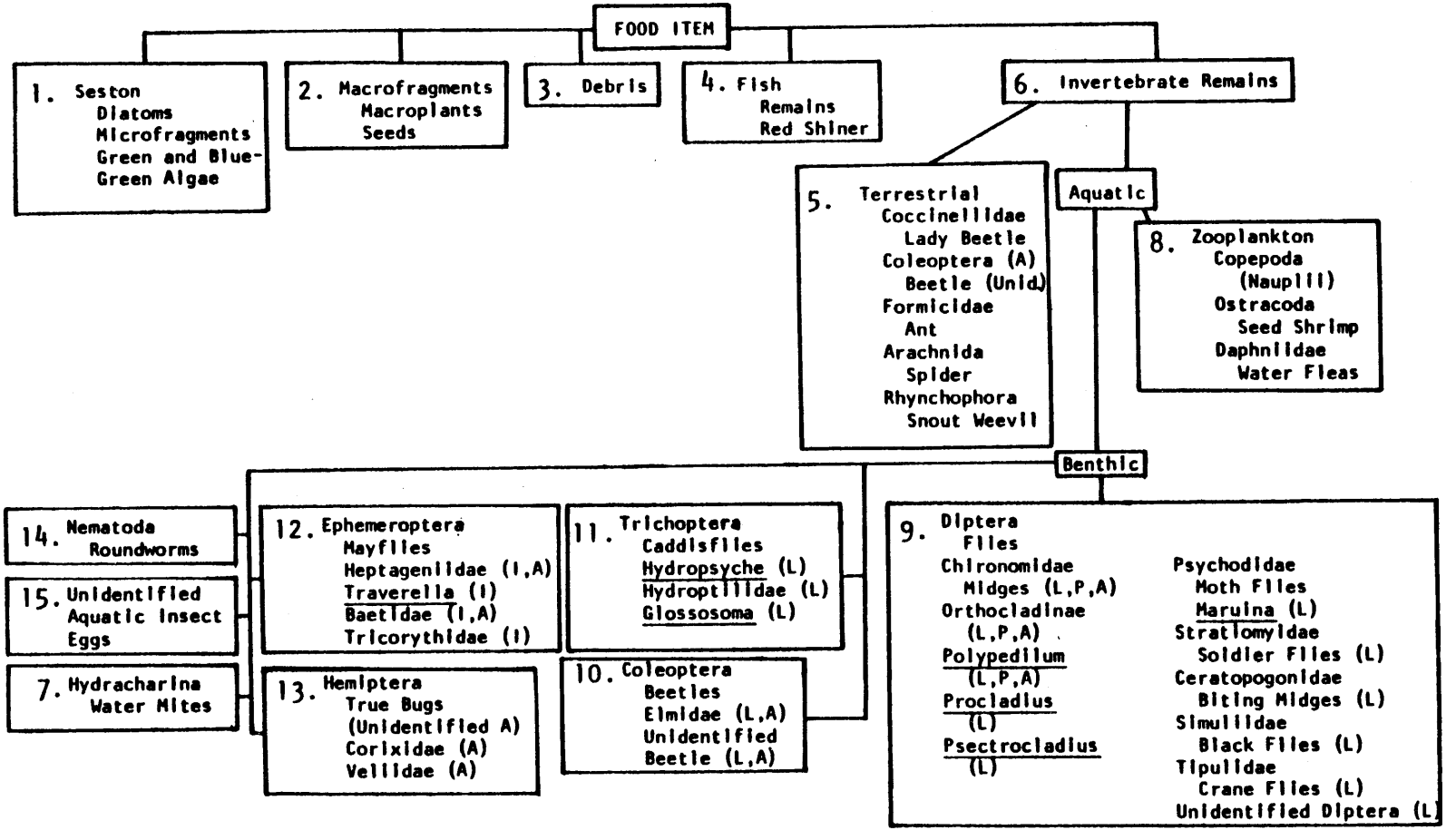
The following subsample method was used to obtain food item numbers and biomass for fish species (e.g. Pimephales and Catostomus) which had long convoluted intestines packed with an amorphic paste of silt, debris, and/or seston. The intestine was unraveled and measured by laying it on a plastic ruler. It was cut in the middle and the inside diameter was measured. A 2 mm long section of gut was removed from one intestine half (adjacent to the cut) and the contents were squeezed out onto a glass slide. One or two drops of water were added to make a paste and then a 22 mm square cover slip was placed over the material so that the paste distribution was uniform. Using a microscope with a 10 X occular micrometer and 10 X objective, seston particles were identified and counted in 5 random fields. The number of seston per gut was equal to the average number from 5 fields X 207 (number of field/cover slip) X gut volume/2. Biomass of diatoms, plant fragments, and green and blue green algae was estimated by the cell volume method (APHA 1976).

## Statistics

Data analysis was carried out by the use of Statistical Analysis System (SAS 1979) and hand calculations where appropriate.

The following variables were recorded for each fish: stratum, location, number (to identify fish from collection) species, age, length, and numbers of items and weights for each of the 53 food items. Initial analyses indicated the necessity of grouping the data where possible so the 53 food items were grouped into 15 categories as indicated in Figure 2. Fish species-age group categories were formed by combining the species and age variables and were used throughout the analysis.

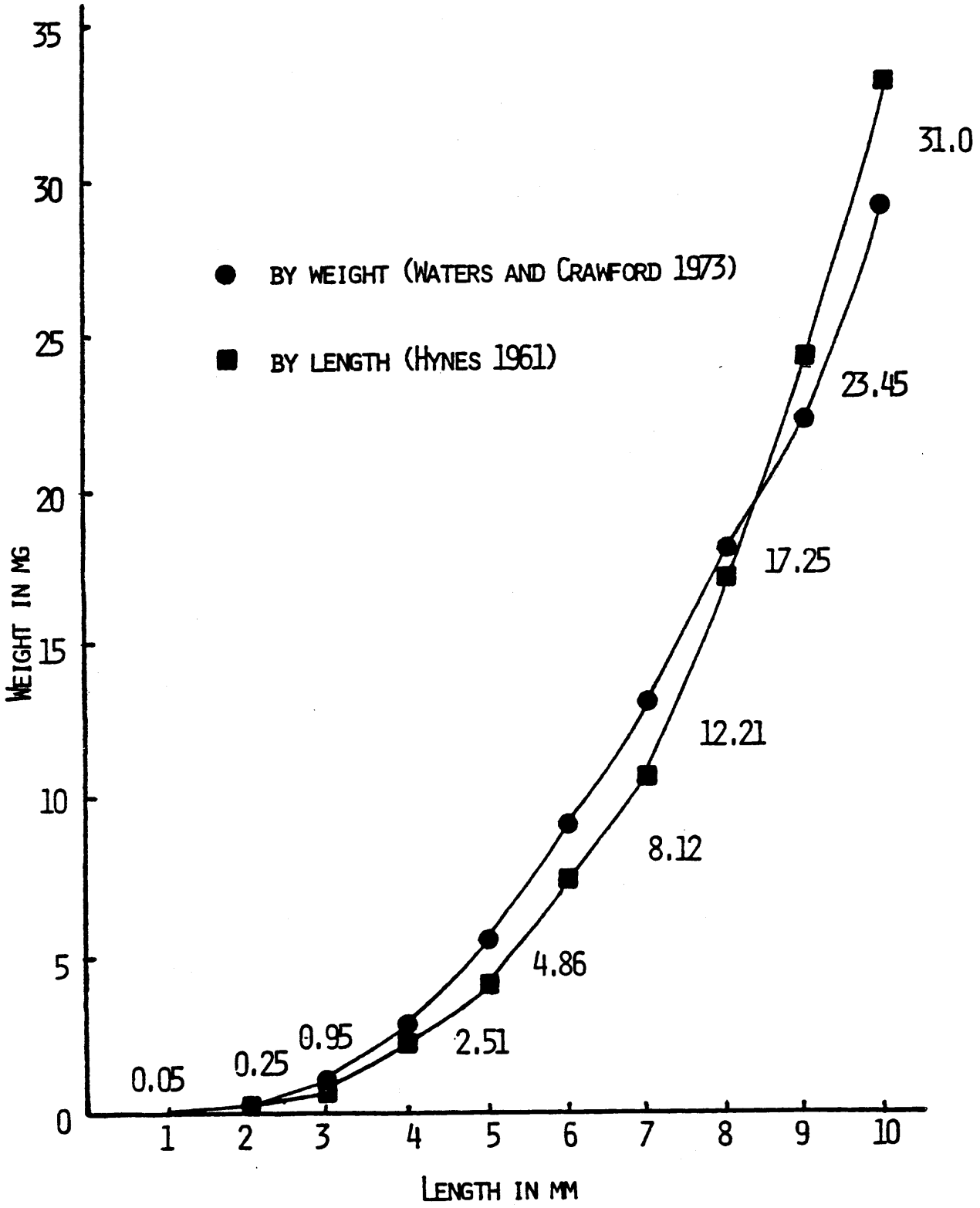
Figure 2




L = Larva
P = Pupa
A = Adult
I = Immature (Nymph)

Food item categories for fish collected in the Green, Colorado, and Gunnison Rivers

Figure 3




Length-weight relationship used for estimating biomass of macroinvertebrate food items

Frequencies of occurrence were obtained by using SAS PROC RECODE and PROC FREQ. Index variables were assigned by PROC RECODE: zero for zero numbers, one for numbers greater than zero. The output for PROC FREQ includes a column percent appropriate for frequency of occurrence when used with recoded variables.

Mean numbers and weights for all classifications were obtained by SAS PROC MEANS. PROC MEANS output also includes standard deviation, minimum and maximum values, standard error of the mean and sum for each variable.

Analyses of variance were performed using SAS PROC GLM to test for equality of mean weights for the species-age groups for each stratum and for all strata combined and for the strata for each species-age group. Because of the high variability in dispersions, rank analyses were also performed. When significant differences among mean weights were indicated, the Fisher least significant difference (FSD) method was used for multiple comparisons (Koopmans 1981). The significant differences found by analysis of variance and the subsequent FSD results are summarized in Results and listed in Appendix B. The notation [A, B, C] > [D, E, F] is read A, B, and C have significantly higher means than D, E, and F. The notation [A, B, C] > [B, C, D] indicates that A is significantly higher than D, but neither is significantly different from B or C. All tests were made at a 5 percent level of significance.

On the recommendation of the Colorado River Fisheries Project Team, the following size-class groupings were used:

| | YOY (Young of Year) | Juvenile (Sub-adult) |
|---|---|---|
| Ptychocheilus | less than 60 mm | 60 - 300 mm |
| Gila | less than 55 mm | 55 - 260 mm |
| Notropis | less than 30 mm | 30 + adults |
| Pimephales | less than 35 mm | 35 + adults |

Size-class groupings for Rhinichthys, Catostomus, Ictalurus, and Killifish were based on known lengths at maturity.

## RESULTS

### Endangered Species

#### *Ptychocheilus lucius* - Colorado squawfish

Young-of-the-Year (YOY) *Ptychocheilus* were found at Strata A, B, C, D, E, F, G, and K. They ranged in length from 22 to 59 mm with a mean length of 39.8 mm. Fish comprised 85.63 percent of their mean diet (9.952 mg present in 30.70 percent of the fish). At Strata B, F, and G, the major food item was invertebrate remains; at Stratum K, the lone *Ptychocheilus* ate only Diptera. Fish were not consumed at Strata B, G, or K. Empty stomachs were found in 19.8 percent of the *Ptychocheilus*.

*Ptychocheilus* consumed significantly more macrofragments at Stratum A than at other strata. They consumed more invertebrate remains at Stratum B than at other strata. The mean weight of Diptera consumed at Stratum K was greater than that consumed at other strata.

#### *Gila robusta* - Roundtail Chub

YOY *G. robusta* were found at Strata VII, IX, and X. They ranged in length from 25 to 54 mm with a mean length of 39.58 mm. Invertebrate remains comprised 54.16 percent of their mean diet (7.036 mg present in 59.65 percent of the fish). Ephemeroptera comprised 38.37 percent of their diet (4.984 mg present in 28.07 percent of the fish). Empty stomachs were found in 7.02 percent of the YOY *G. robusta*.

YOY *G. robusta* consumed significantly more Diptera at Stratum X than at Stratum IX and more Trichoptera at Stratum VII than at Strata X or IX.

Juvenile *G. robusta* were found at Strata VI, VII, and IX. They ranged in length from 55 to 109 mm with a mean length of 71.61 mm. Invertibrate remains comprised 71.79 percent of their diet (60.58 mg present in 84.21 percent of the fish), but were consumed only at Stratum VI. Fish were the only items consumed at Stratum VI. Ephemeroptera were the only items consumed at Stratum IX.

#### *Gila* sp. - Roundtail or Humpback Chub

YOY *Gila* were found at Strata D, F, and VI. They ranged in length from 31 to 48 mm with a mean length of 37.32 mm. Ephemeroptera comprised 77.46 percent of the mean diet but were consumed only at Stratum VI by one fish. At Strata D and F Diptera comprised 100 percent (one fish) and 57.71 percent of the diets respectively. There were no significant differences among strata for YOY *Gila*.

Juvenile *Gila* were found at Strata C, VI, and IX. They ranged in length from 58 to 120 mm with a mean length of 90.72 mm. Invertebrate remains comprised 66.51 percent of the mean diet (8.158 mg found in 36 percent of the fish). Empty stomachs were found in 44 percent of the Juvenile *Gila*.

Juvenile Gila consumed significantly more terrestrial invertebrates, invertebrate remains, Diptera, and Trichoptera at Stratum VI than at other strata. In the first three food items, significant differences in the raw values are likely due to extreme values in Stratum VI for the food items.

## Non-endangered Species

### Notropis lutrensis - Red Shiner

YOY N. lutrensis were found at Strata A, B, C, D, E, F, G, V, and VI. They ranged in length from 15 to 29 mm with a mean length of 25.31 mm. Ephemeroptera comprised 61.18 percent of the diet. At Stratum A seston and Diptera were the major food items. At Strata B and V invertebrate remains were the major food items. At Strata C and VI invertebrate remains and Diptera were the major food items.

YOY N. lutrensis consumed significantly more terrestrial invertebrates at Stratum B than at the other strata, more invertebrate remains at Stratum V than at other strata, and more Ephemeroptera at Stratum E than at other strata. Ranked values showed that YOY N. lutrensis consumed more Diptera at Strata V and VI than at Strata A, B, C, E, F, and G.

Adult N. lutrensis were found at Strata A, B, C, D, E, F, G, IV, V, VI, and IX. They ranged in length from 30 to 78 mm with a mean length of 45.86 mm. Invertebrate remains comprised 52.54 percent and Ephemeroptera comprised 40.41 percent of the total diet. At Stratum A Trichoptera were the major food items. At Strata B, C, G, IV, V, VI, and IX invertebrate remains were the major food items. At Strata D, E, and F Ephemeroptera were the major food items.

Adult N. lutrensis consumed significantly more seston at Strata A and IV than at other strata, more Diptera at Strata V, F, and VI than at Strata A, B, C, D, E, IV, and IX, more Trichoptera at Stratum A than at other strata, more Ephemeroptera at Stratum E than at other strata, and more eggs at Stratum G than at other strata.

### Notropis stramineus - Sand Shiner

Two YOY N. stramineus were found at Stratum VI. One was 23 mm, the other 27 mm in length. They both ate Diptera.

Adult N. stramineus were found at Strata VI and IX. They ranged in length from 40 to 60 mm with a mean length of 48.15 mm. Invertebrate remains comprised 69.95 percent of their diet. At Stratum IX the major food items were Trichoptera, and the mean was significantly greater than zero (the amount at Stratum VI) with raw and rank $p = .0008$.

### Pimephales promelas - Fathead Minnow

YOY Pimephales were found at Strata A, B, C, D, E, F, IV, VI, and VII. They ranged in length from 17 to 34 mm with a mean length of 29.63 mm. Ephemeroptera made up 71.99 percent of the diet, but were consumed

only at Stratum E. Hemiptera were the major food items at Stratum A; zooplankton at Stratum B; macrofragments at Strata C and VII; Coleoptera at Stratum D; and seston at Strata F, IV, and VI.

YOY Pimephales consumed significantly more seston and Hemiptera at Stratum A than at other strata, and more macrofragments at Strata VII and C than at Strata A, B, D, E, F, IV, and VI.

Adult Pimephales were found at Strata A, B, C, D, E, F, IV, VI, and IX. They ranged in length from 35 to 65 mm with a mean length of 43.62 mm. Seston made up 87.40 percent of their diet and were the major food items at Strata A, D, E, F, IV, VI, and IX. Macrofragments were the major food items at Strata C and D.

Adult Pimephales consumed more seston at Stratum IX than at Strata A, B, C, D, F, IV, and VI, and more Diptera at Stratum A than at other strata.

### Ictalurus punctatus - Channel Catfish

YOY Ictalurus were found at Strata A, B, C, D, E, and F. They ranged in length from 19 to 92 mm with a mean length of 48.27 mm. Their major food items were Diptera (55.85 percent). At Stratum D the major food items were invertebrate remains.

YOY Ictalurus consumed more terrestrial invertebrates, Diptera, Coleoptera, and Hemiptera at Stratum A than at the other strata.

A Juvenile Ictalurus, 114 mm long, was found at Stratum B. It ate Diptera.

### Catostomus discobolus - Bluehead Sucker

YOY C. discobolus were found at Strata VI and IX. They ranged in length from 40 to 81 mm with a mean length of 65.47 mm. Seston made up 99.1 percent of their diet.

### Catostomus latipinnis - Flannelmouth Sucker

YOY C. latipinnis were found at Strata IX and X. They ranged in length from 30 to 95 mm with a mean length of 60 mm. They consumed different items at each stratum. Amounts of seston (Stratum X), debris (Stratum IX), and Diptera (Stratum IX) were significantly different from zero for ranked values $p = .0008$. Debris ($p = .0002$) and Diptera ($p = .0004$) were significantly different from zero for raw values.

### Rhinichthys osculus - Speckled Dace

Adult Rhinichthys were found at Stratum IX. They ranged in length from 40 to 76 mm with a mean length of 53.29 mm. Their major food items were Ephemeroptera.

## Killifish

Two Adult killifish were found at Stratum IV, one at Stratum K. Their lengths were 28, 35, and 45 mm. They ate seston.

## Food Items

### Seston

Seston consisted of primary producers or parts thereof; diatoms and microfragments from vascular plants (<0.1035 mm long) and green and blue-green algae along with very fine inorganic sediments. Occasional larger fragments from vascular plants were present in stomachs of seston feeders but were accounted for in macrofragments.

Diatoms (Navicula and Gomphonema), green algae (Cladophora and Stigeoclonium), and blue-green algae (Oscillatoria) dominated the seston. These are sessile and benthic but can become part of the plankton when washed off the substrate. They grow on the river bottom or are epiphytic (on vascular plant surfaces) and can become an important component of the water column drift community. Items in this food category were probably fed upon in the drifting planktonic phase because very fine particles would remain in suspension more readily than coarser particles such as debris.

Seston was consumed only by non-endangered species. YOY C. discobolus consumed significantly more seston than other fish over all strata. Adult Pimephales consumed significantly more than other fish at Strata A, B, C, and E; YOY Pimephales Stratum VII; YOY C. latipinnis, Stratum X; Adult and YOY Pimephales and C. discobolus, Stratum VI; Adult and YOY Pimephales, Stratum F; and YOY C. discobolus consumed significantly more than all fish except Adult Pimephales at Stratum IX.

### Macrofragments

This category contained larger pieces of plant fragments, $\geq$0.1035 mm in length, and a few seeds. Some macroplant pieces were found in the seston but were considered as coarser items because of the visible cell wall.

Macrofragments were probably from riparian or emergent or submergent habitats. They were components of both the benthic and drift environments because they were consumed by plankton feeders such as P. promelas and benthic feeders such as C. latipinnis and Ictalurus.

Macrofragments were consumed by both endangered and non-endangered species. Adult N. stramineus consumed significantly more macrofragments than other fish over all strata. YOY Pimephales at Stratum VII and Adult Pimephales at Stratum D consumed significantly more than other fish for ranked mean weights. YOY C. discobolus at Stratum IX consumed more on the basis of ranked means than other fish except Adult N. stramineus. At Strata C and F, Adult and YOY Pimephales consumed significantly more than other fish.

## Debris

Debris consisted of a paste of coarse particles of inorganic sediments, macrofragments, unidentifiable invertebrate remains, and some seston. The material in this all-encompassing category was probably consumed in zones of deposition in benthic regions.

Debris was consumed only by YOY C. latipinnis at Stratum IX. P-values were .0001 for both raw and ranked data for total strata and Stratum IX, indicating the mean weight was significantly greater than zero.

## Fish

This food item category consisted of partial remains of fish and whole fish specimens of N. lutrensis (Darrel Snyder, personal communication). YOY food N. lutrensis, less than 12 mm long, were probably found in slack water shallow areas along river banks.

Fish wre consumed only by YOY Ptychocheilus at Strata A, C, D, E, and F and Juvenile G. robusta at Stratum VI. For total strata the mean weight for YOY Ptychocheilus was significantly larger than for G. robusta ($p = .0001$ for raw and ranked data). Mean weights for fish were significantly larger than zero at Strata A, C, D, and E.

## Terrestrials

This category was a minor component of fish diets. Organisms were associated with riparian vegetation and either fell from overhanging vegetation or were blown into the water. Formicidae (ants) and occasional small Arachnida (spiders) were the most numerous representatives.

On the basis of ranked mean weights, Juvenile G. robusta consumed significantly more terrestrial invertebrates than other fish over all strata. At Stratum A, YOY Ictalurus consumed more than other fish.

## Invertebrate remains

This encompassing category included all invertebrate fragments ranging from legs, compound eyes, portions of the exoskeleton (thorax and abdomen), to wings. Invertebrate remains, the dominant food item category, was composed of nine invertebrate subcategories (Figure 2).

Invertebrate remans were found in stomachs of all fish except YOY N. stramineus, Adult killifish, YOY C. discobolus, YOY C. latipinnis, and Juvenile Ictalurus. Stomachs of Juvenile G. robusta contained significantly more invertebrate remains than those of other fish over all strata. Stomachs of Adult N. lutrensis contained significantly more invertebrate remains than other fish at Stratum IV; and significantly more than all other fish except YOY Ptychocheilus and YOY N. lutrensis at Stratum B on the basis of ranked mean weights. At Strata VII, C, and D, stomachs of Juvenile G. robusta, Juvenile Gila, and YOY Ictalurus, respectively, contained more invertebrate remains than those of other fish. On the basis of ranked mean weights, stomachs of

YOY G. robusta and YOY Ptychocheilus contained more invertebrate remains than those of other fish at Stratum X and Stratum A, respectively. Stomachs of Juvenile Gila and Adult N. lutrensis at Stratum VI contained more invertebrate remains than those of other fish; and stomachs of YOY N. lutrensis at Stratum F contained more invertebrate remains than those of all other fish except YOY Gila and YOY Ptychocheilus.

### Hydracharina

This rare food item is a component of the benthic habitat and is associated with vascular plants and algae. Hydracharing (water mites) were consumed by one Juvenile G. robusta at Stratum VII.

### Zooplankton

Zooplankton were represented by three crustaceans. Copepoda (copepods) young or nauplii are planktonic or benthic in habitat. Ostracoda (seed shrimp) are benthic with some movement just above the substrate and Daphniidae (water fleas) are primarily planktonic. Zooplankton were a minor diet item for one endangered fish species, YOY Ptychocheilus, and four non-endangered species, YOY N. lutrensis, YOY Pimephales, YOY C. latipinnis, and YOY Ictalurus. At Stratum X, YOY C. latipinnis consumed significantly more zooplankton than did YOY G. robusta.

### Diptera

Diptera was composed of six families with four genera of Chironomidae as the most frequently occurring food category. All of these are common benthic organisms living on vegetation (algae and vascular plants) or gravel, sand, and rubble substrates. Chironomidae, Psychodidae, Tipulidae, and Stratiomyidae are primarily collector-scrapers of debris and microvegetation; Ceratopogonidae are predators on smaller invertebrates; and Simuliidae are filter feeders.

All fish except Adult Killifish consumed Diptera. The Juvenile Ictalurus consumed significantly more Diptera than other fish over all strata and at Stratum B. YOY Ictalurus consumed significantly more than other fish at Strata A, C, D, and E. At Stratum F, YOY Gila consumed significantly more than all other fish except YOY Ptychocheilus.

### Coleoptera

Beetles were a minor food item composed primarily of Elmidae (Riffle Beetles). These are collectors and gatherers of debris in the benthic habitat.

YOY Ictalurus consumed significantly more Coleoptera than other fish over all strata and at Stratum A.

### Trichoptera

Caddisflies were dominated by Hydropsyche (collector-filterer); Glossosoma and Hydroptilidae (both scrapers) were not as abundant. All of these are benthic in habitat but are an important component of the drift.

On the basis of raw weights, YOY Ictalurus consumed significantly more Trichoptera than all other fish except YOY C. latipinnis, but on the basis of ranked weights, Adult Rhinichthys consumed more than other fish. At Stratum VI, Juvenile Gila consumed significantly more Trichoptera than did other fish and at Strata A and B, YOY Ictalurus consumed significantly more Trichoptera than did other fish.

### Ephemeroptera

Mayflies were an important component of fish diets. All are benthic in habitat, are important in the drift, and are generally collectors in habit. Immatures were consumed as well as emerging sub-imagos (pre-adults), and adults. Adults were probably fed upon while returning to the water to deposit eggs.

Juvenile G. robusta consumed significantly more Ephemeroptera over all strata than did other fish. At Stratum IX, YOY G. robusta consumed significantly more Ephemeroptera than did other fish and at Stratum E, Adult N. lutrensis consumed significantly more than others.

### Hemiptera

True bugs wre represented by Corixidae (boatmen) and Veliidae (broad-shouldered striders). The former are found in the water column and rest on the stream bottom while the latter are surface striders (neuston), both are predators on other invertebrates. They were a minor food item eaten by only three species, Adult N. lutrensis, YOY Pimephales, and YOY Ictalurus.

YOY Ictalurus consumed significantly more Hemiptera over all strata and at Stratum A than did other fish.

### Nematoda

Round worms were found only in G. robusta. Some nematodes are free living on the stream bottom but others are parasitic on a large number of organisms. Those in G. robusta were approximately 2 mm long and were in the interstitial convolutions of the stomach. Further examination is necessary to determine their trophic status.

### Eggs

Eggs may have been from Ephemeroptera which were fed upon in the adult stage of development. Eggs were consumed by YOY N. lutrensis at Stratum G and by Adult N. lutrensis at Strata D, G, and VI.

## SUMMARY

### By Fish

The major food items for endangered fish species were fish, invertebrate remains, Diptera, and Ephemeroptera. Only endangered fish species consumed fish.

YOY and Juvenile Gila sp. and G. robusta were opportunistic feeders on most invertebrate food item categories. A predatory role is evident because particulate matter (fine seston and coarser debris) was not present in stomach contents. Plant macrofragments were also uncommon in stomachs of YOY and Juvenille G. robusta.

Ptychocheilus was a predator on fish as well as on invertebrates. It appears that, given the opportunity, YOY Ptychocheilus will select fish (YOY N. lutrensis) as a major food item over invertebrates. Ptychocheilus and N. lutrensis were present together at seven strata, A, C, D, E, F, B, and G; predation was evident at all except the latter two strata. Since Ptychocheilus consumed 91.78 percent of the total fish consumed, there appears to be no other fish which selected towards this food resource.

As can be seen in Figures 4 through 9, there appears to be diet overlap for all species except perhaps Adult Killfish, YOY C. discobolus, and Adult Pimephales. Adult Killifish ate only seston; YOY C. discobolus consumed significantly more seston than all other fish species as well as some plant macrofragments and Diptera; Adult Pimephales consumed seston, macrofragments, invertebrates, and Diptera.

YOY C. latipinnis appears to be predominantly an invertebrate feeder or at least consumes large sized food items while YOY C. discobolus appears to feed selectively on finer particulates. YOY C. latipinnis was the only fish with stomach contents that contained debris but this may have been the fragmented end product of other macro food items.

YOY and Adult N. lutrensis consumed most major invertebrate food items and some plant macrofragments and seston. Red Shiners may have sought active invertebrates, grazed on attached algae, and fed on drifting seston (plankton) and plant fragments.

Adult N. stramineus was the dominant macrofragment consumer. The number of macrofragments was low but the pieces were larger than those consumed by other fish. Invertebrate remains comprised a significant portion of the stomach contents. Sand Shiners may have selected larger sized plant and invertebrate food items.

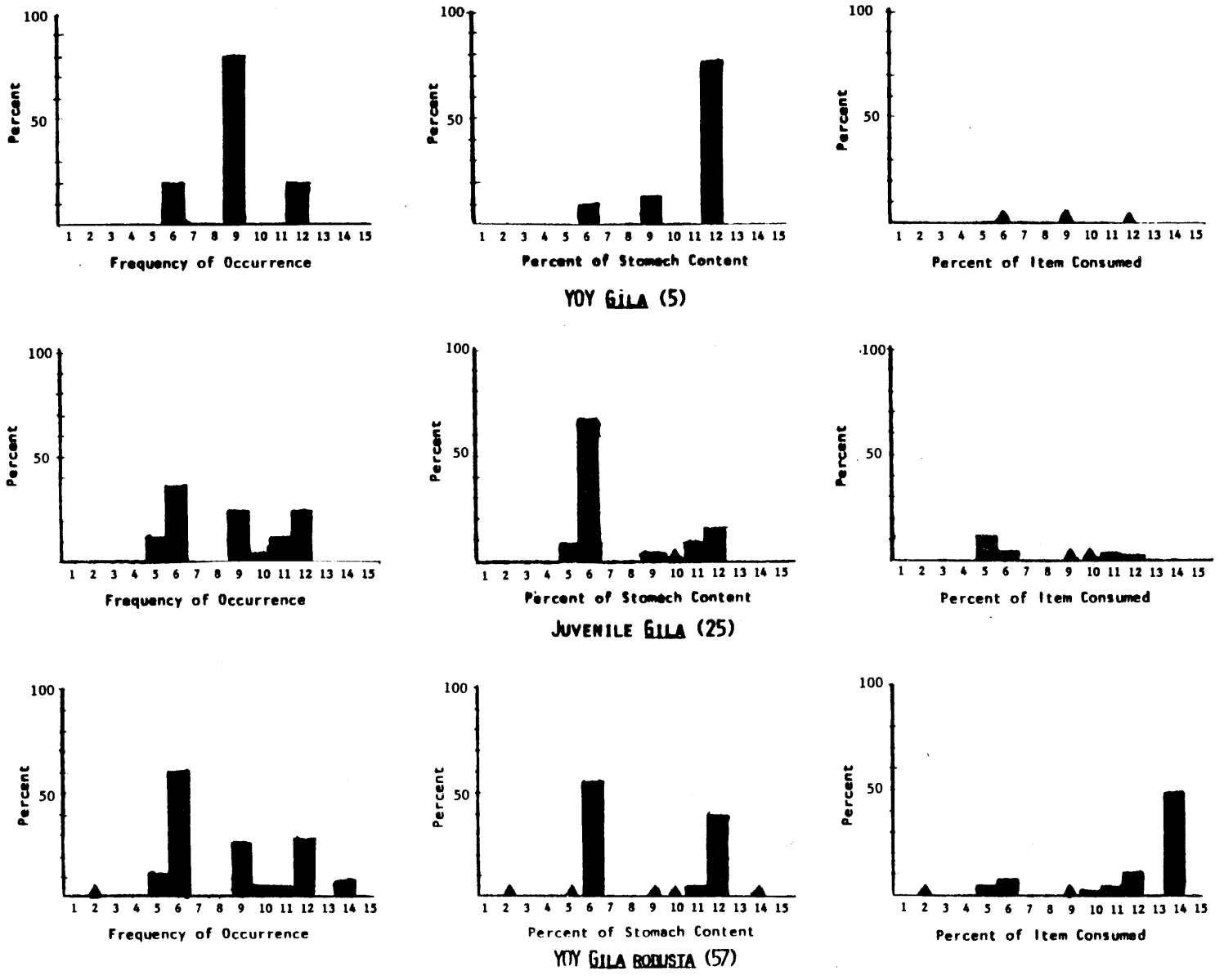
YOY and Adult Pimephales consumed seston, macrofragments, and invertebrates. Though fish in both size groups consumed large numbers of seston, YOY Pimephales consumed more invertebrates.

YOY Ictalurus fed on most major food item categories ranging from small particulates (seston) to larger invertebrates. They consumed significantly more Diptera, Coleoptera, and Hemiptera than other fish.

### By Strata

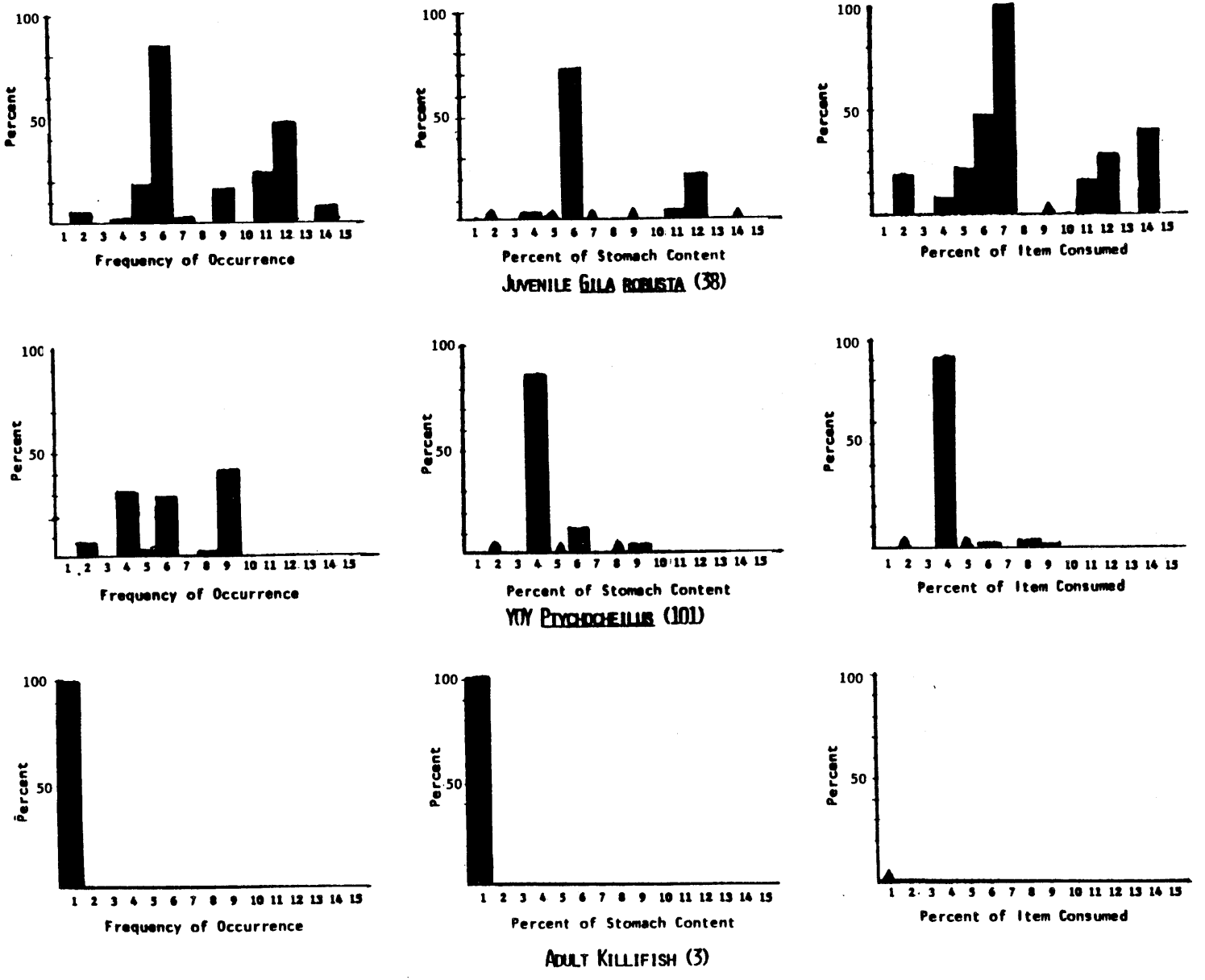
At Strata IV and V no endangered species were collected. The most abundant fish at Stratum IV, YOY Pimephales, consumed seston and plant macrofragments and at Stratum V, Adult N., lutrensis, consumed primarily invertebrates.

Figure 4



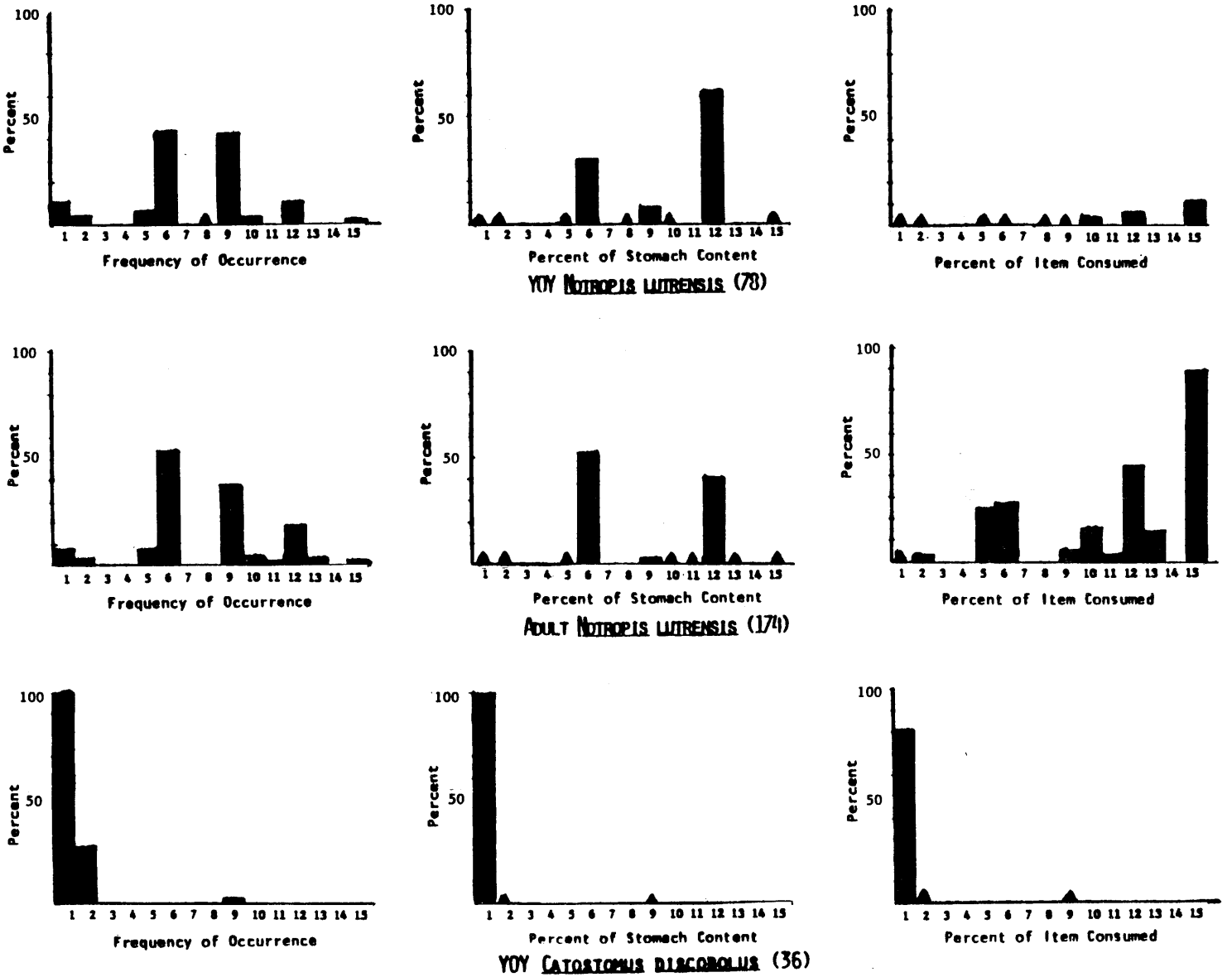

Food item consumption by fish. ▲ = less than 2%. Food items: 1=Seston, 2=Macrofragments, 3=Debris, 4=Fish, 5=Terrestrial, 6=Invertebrate remains, 7=Hydracharina, 8=Zooplankton, 9=Diptera, 10-Coleoptera, 11=Trichoptera, 12=Ephemeroptera, 13=Hemiptera, 14=Nematodes, 15=Eggs.

Figure 5



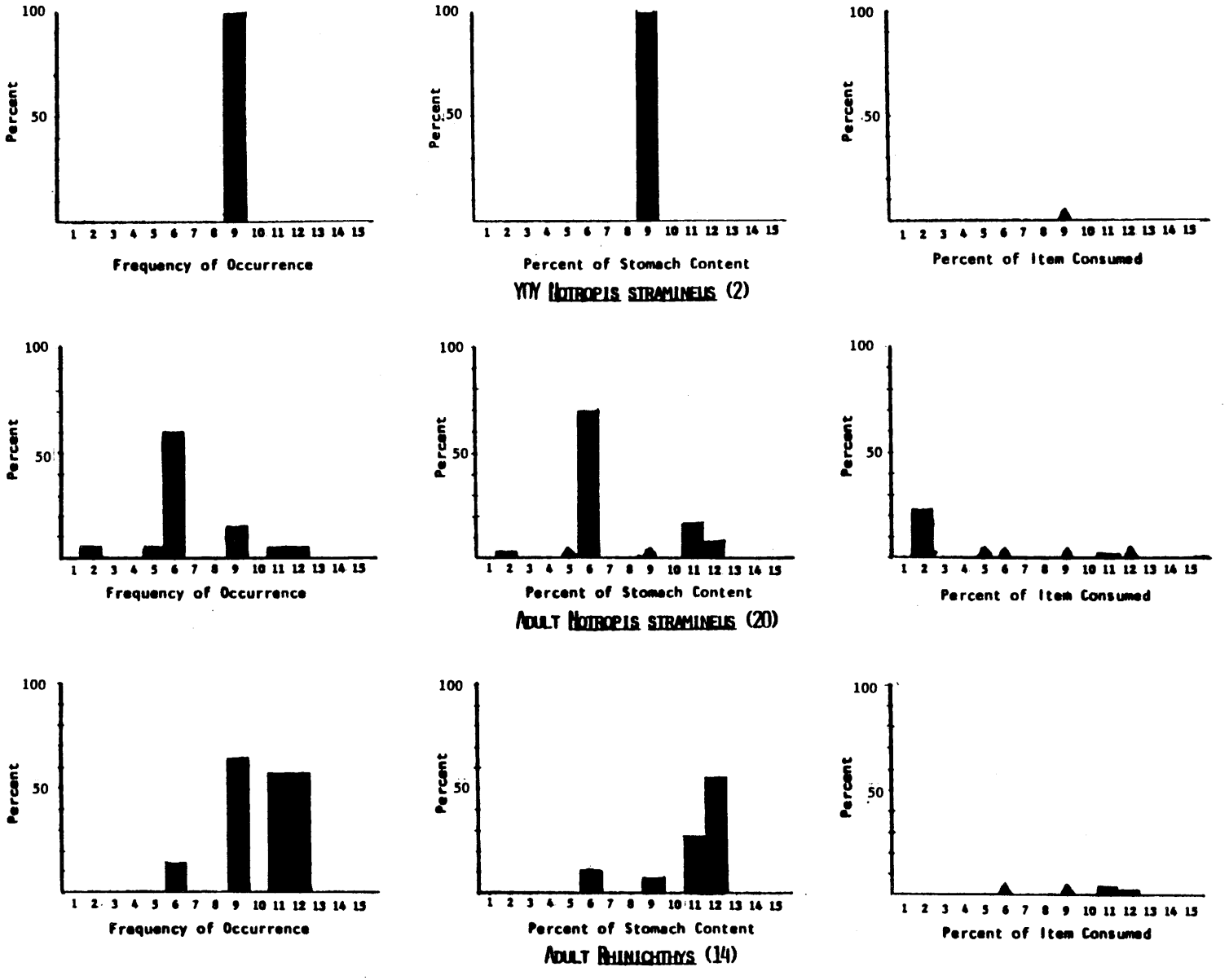

Food item consumption by fish. ▲ = less than 2%. Food items: 1=Seston, 2=Macrofragments, 3=Debris, 4=Fish, 5=Terrestrial, 6=Invertebrate remains, 7=Hydracharina, 8=Zooplankton, 9=Diptera, 10=Coleoptera, 11=Trichoptera, 12=Ephemeroptera, 13=Hemiptera, 14=Nematodes, 15=Eggs.

Figure 6



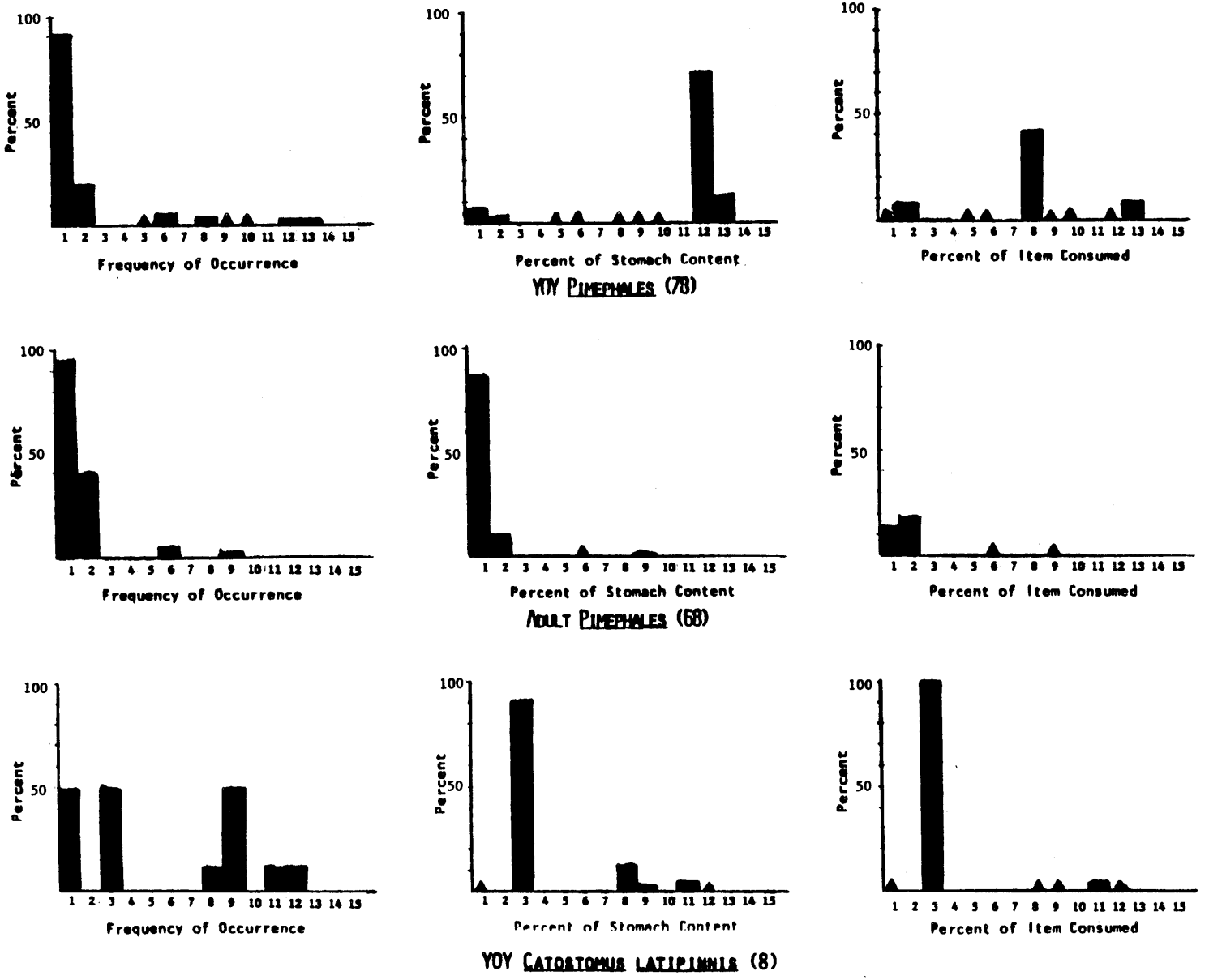

Food item consumption by fish. ▲ = less than 2%. Food items: 1=Seston, 2=Macrofragments, 3=Debris, 4=Fish, 5=Terrestrial, 6=Invertebrate remains, 7=Hydracharina, 8=Zooplankton, 9=Diptera, 10=Coleoptera, 11=Trichoptera, 12=Ephemeroptera, 13=Hemiptera, 14=Nematodes, 15=Eggs.

Figure 7



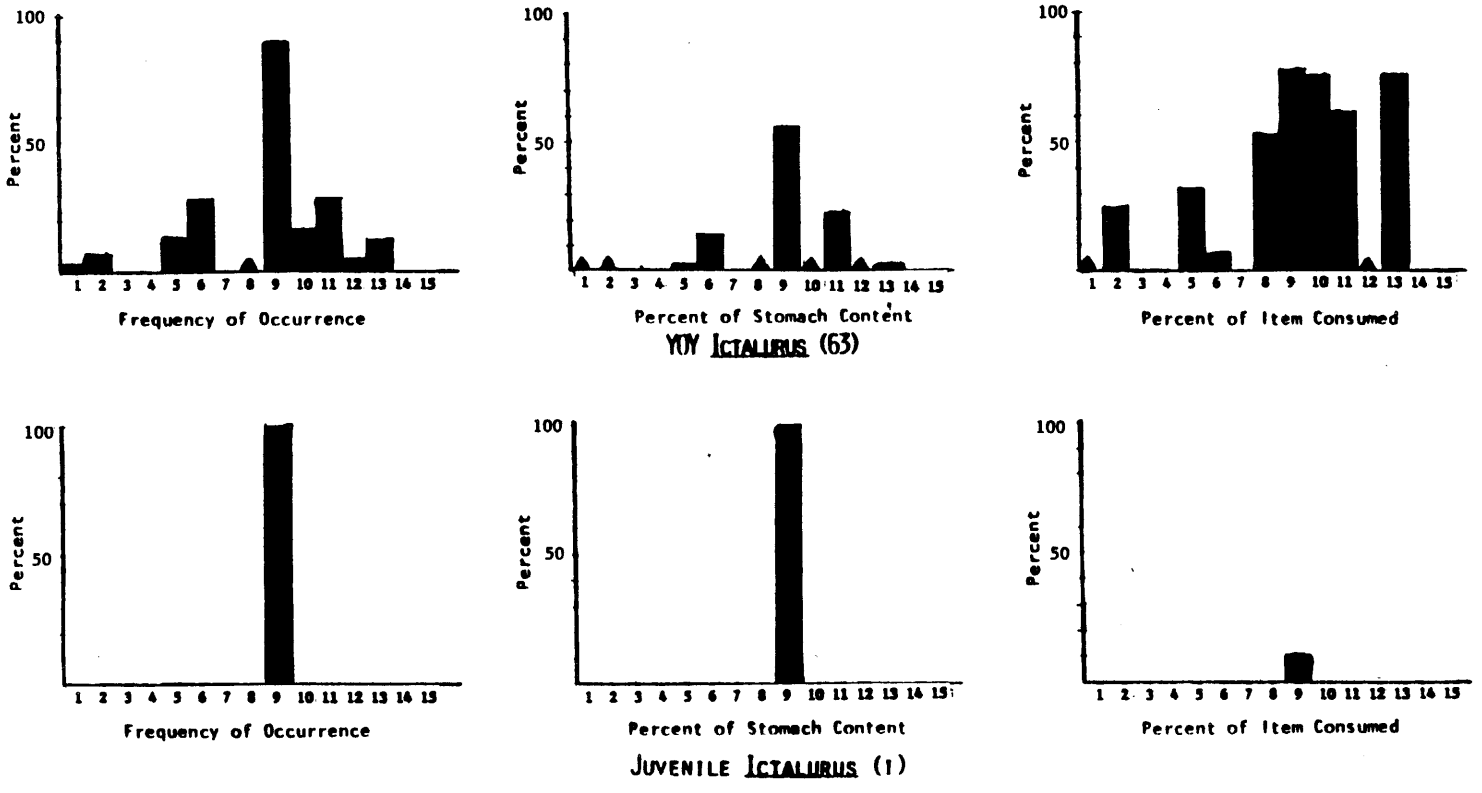

Food item consumption by fish. ▲ = less than 2%. Food items: 1=Seston, 2=Macrofragments, 3=Debris, 4=Fish, 5=Terrestrial, 6=Invertebrate remains, 7=Hydracharina, 8=Zooplankton, 9=Diptera, 10=Coleoptera, 11=Trichoptera, 12=Ephemeroptera, 13=Hemiptera, 14=Nematodes, 15=Eggs.

Figure 8




Food item consumption by fish. ▲ = less than 2%. Food items: 1=Seston, 2=Macrofragments, 3=Debris, 4=Fish, 5=Terrestrial, 6=Invertebrate remains, 7=Hydracharina, 8=Zooplankton, 9=Diptera, 10-Coleoptera, 11=Trichoptera, 12=Ephemeroptera, 13=Hemiptera, 14=Nematodes, 15=Eggs.

Figure 9




Food item consumption by fish. ▲ = less than 2%. Food items: 1=Seston, 2=Macrofragments, 3=Debris, 4=Fish, 5=Terrestrial, 6=Invertebrate remains, 7=Hydracharina, 8=Zooplankton, 9=Diptera, 10-Coleoptera, 11=Trichoptera, 12=Ephemeroptera, 13=Hemiptera, 14=Nematodes, 15=Eggs.

At Stratum VI, Adult N. lutrensis consumed 80.20 percent, 78.62 percent, and 95.02 percent of the invertebrate remains, Diptera, and Ephemeroptera consumed at that strata, respectively. This was not significantly greater than that consumed by Juvenile Gila. One Juvenile G. robusta consumed one fish.

At Stratum VII, only endangered species consumed invertebrate remains, Diptera, and Ephemeroptera. No fish were consumed.

At Stratum IX, YOY G. robusta consumed the largest portions of invertebrates remains (63.60 percent) and Ephemeroptera (38.59 percent). YOY C. latipinnis consumed 64.34 percent of the Diptera consumed at that strata. No fish were consumed.

At Stratum X, the YOY G. robusta and YOY C. latipinnis had different diets. No fish were consumed.

At Stratum A, YOY Ptychocheilus consumed 71.96 percent of the invertebrate remains. YOY Ictalurus consumed 98.71 percent and 100 percent of the Diptera and Ephemeroptera, respectively.

At Stratum B, YOY Ictalurus consumed 57.32 percent of the invertebrate remains, Juvenile Ictalurus consumed 70.80 percent of the Diptera, and Adult N. lutrensis consumed 100 percent of the Ephemeroptera.

At Stratum C, YOY Ictalurus consumed 49.64 percent, 95.63 percent, and 100 percent of the invertebrate remains, Diptera, and Ephemeroptera, respectively.

At Stratum D, Adult N. lutrensis consumed 75.01 percent of the Ephemeroptera. The YOY Ictalurus consumed 73.90 percent of the invertebrate remains and 51.51 percent of the Diptera. YOY Ptychocheilus consumed fish.

At Stratum E, YOY Ptychocheilus consumed 60.54 percent of the Diptera but the mean weight consumed by YOY Ictalurus was significantly greater than the mean weight consumed by YOY Ptychocheilus. Adult N. lutrensis consumed 48.80 percent of the invertebrate remains and 76.15 percent of the Ephemeroptera.

At Stratum F. YOY Ptychocheilus consumed 54.12 percent of the invertebrate remains; Adult N. lutrensis consumed 45.42 percent of the Diptera and 75.01 percent of the Ephemeroptera.

At Stratum G. YOY N. lutrensis consumed 58.64 percent of the Diptera and 100 percent of the Ephemeroptera, Adult N. lutrensis consumed 55.65 percent of the invertebrate remains.

At Stratum K, the YOY Pimephales and the Adult Killifish had different diets.

## RECOMMENDATIONS

Equal numbers of specimens (at least 30) of all fish from various strata might show more significant differences in food item preference in future food habits studies. Combinations of species from similar strata (i.e., canyonlands, open flat areas) might also show differences. If competition among fish is suspected, food item abundances in both benthic and drift environments should be investigated. Combining YOY Gila with YOY G. robusta and Juvenille Gila with Juvenille G. robusta could provide larger populations of this genus.

## ACKNOWLEDGEMENTS

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## APPENDIX A

Significant differences for consumption by mean weight among strata and Fisher least significant difference (FSD) results

*Ptychocheilus*

Macrofragments: Rank p = .0195 (Stratum A) > others. Invertebrate remains: Raw p = .0001 and Rank p = .0008 (Stratum B) > others. Diptera: Raw p = .0005 and Rank p = .0005 (Stratum K) > (Strata B. E, F) > (Strata F, C, A, D).

YOY *G. robusta*

Diptera: Rank p = .0259 (Strata X, VII) > (Strata VII, IX). Trichoptera: Raw p = .0152 Rank p = .0018 (Stratum VII) > others.

Juvenile *G. robusta*

Invertebrate remains: Rank p = .0063 (Stratum VII) > others. Ephemeroptera: Rank p = .0204 (Stratum IX) > others.

Juvenile *Gila sp.*

Terrestrial: Raw p = .0275 (Stratum VI) > others. Invertebrate remains: Raw p = .0062 (Stratum VI) > others. Diptera: Raw p = .0390 (Strata VI, C) > (Strata C, IX). Trichoptera: Raw p = .019 Rank p = .0047 (Stratum VI) > others.

YOY *Notropis lutrensis*

Seston: Raw p = .0007 Rank p = .0001 (Stratum A) > others. Terrestrial: Raw p = .0288 (Stratum B) > others. Rank p = .0445 (Strata B, G) > (Stratum G, others). Invertebrate remains: Raw p = .0001 (Stratum V) > others. Rank p = .0408 (Strata V, B) > (Strata B, F, C, G, E) > (Strata F, C, G, E, VI) > (Strata C, G, E, VI, D) > (Strata G, E, VI, D, A). Diptera: Rank p = .0040 (Strata V, VI, D) > (Strata D, F, A, G, C) > (Strata G, C, E). Ephemeroptera: Raw p = .0002 Rank p = .0004 (Stratum E) > others.

Adult *Notropis lutrensis*

Seston: Raw p = .0001 Rank p = .0001 (Strata A, IV) > others. Invertebrate remains: Raw p = .0004 (Strata VI, IV, V, B) > (Strata IV, V, B, E, C, G, D) > (Strata V, B, E, C, G, D, F, IX, A). Rank p = .0001 (Strata V, VI, B) > (Strata VI, B, IV) > (Strata IV, C) > (Strata C, D, E, G) > (Strata D, E, G, IX, F) > (Strata F, A). Diptera: Rank p = .0008 (Strata V, F, VI) > (Strata VI, G) > (Strata G, A, D, C, IV) > (Stratum IV, others). Trichoptera: Rank p = .0407 (Strata A, G) > (Strata G, VI) > (Stratum VI, others). Ephemeroptera: Raw p = .0001 (Stratum E) > (Stratum VI) > others. Rank p = .0001 (Stratum E) > (Strata VI, D, IV) > (Strata D, IV, F, B) > (Strata IV, F, B, V, others). Eggs: Raw p = .0171 (Stratum G) > others.

YOY *Pimephales*

Seston: Raw p = .0049 (Stratum A) > (Strata E, IV, F, B, VII, D) > (Strata IV, F, B, VII, D, VI). Macrofragments: Rank p = .0190 (Strata VII, C) (Strata C, F, D, A, B) > (Strata F, D, A, B, IV) > (Strata A, B, IV, VI, E). Hemiptera: Raw p = .0164 Rank p = .0159 (Stratum A) > others.

Adult *Pimephales*

Seston: Rank p = .0001 (Strata IX, E) > (Strata E, VI, IV) > (Strata VI, IV, A, B) > (Strata B, F) > (Strata F, C) > (Strata C, D). Diptera: Raw p = .0370 Rank p = .0031 (Stratum A) > others.

YOY *Ictalurus*
Significant differences showing greater mean weights for Stratum A were found for terrestrial (Raw p = .0386, Rank p = .0004), Diptera (Raw p = .0028), Coleoptera (Raw p = .0097, Rank p = .0001) and Hemiptera (Raw p = .0313, Rank p = .0048). For Diptera, Rank p = .0087, FSD results were (Strata A, D) (Strata D, C) (Strata C. B. E) (Strata B, E, F).

## Seston

### Total strata

Raw p = .0001 (YOY *Catostomus discobolus)* > others. Rank p = .0001 (YOY *Catostomus discobolus*, Adult Killifish) > (Adult Killifish, Adult and YOY *Pimephales*) > (YOY *Catostomus latipinnis*) > (YOY *Notropis lutrensis*, Adult *Notropis lutrensis*) > (Adult *Notropis lutrensis*, YOY *Ictalurus*) > (YOY *Ictalurus*, others).

### By strata

Stratum VI

Rank p = .0001 (Adult *Pimephales*, YOY *Pimephales*, YOY *Catostomus discobolus*) > others.

Stratum VII

Raw p = .0001 and Rank p = .0001 (YOY *Pimephales*) > others.

Stratum IX

Raw p - .0001 and Rank p = .0001 (YOY *Catostomus discobolus*, Adult *Pimephales*) > (Adult *Pimephales*, others).

Stratum X

Raw p = .0001 and Rank p = .0001 (YOY *Catostomus latipinnis*) > (YOY *G. robusta*).

Stratum A

Raw p = .0002 (Adult *Pimephales*) > (Adult *Notropis lutrensis*, YOY *Notropis lutrensis*, YOY *Pimephales*) > (YOY *Notropis lutrensis*, YOY *Pimephales*, others). Rank p = .0001 (Adult *Pimephales*, YOY *Notropis lutrensis*) > (YOY *Notropis lutrensis*, Adult *Notropis lutrensis*, YOY *Pimephales*) > others.

Stratum B

Raw p = .0001 (Adult *Pimephales*) > others. Rank p = .0001 (Adult *Pimephales* (YOY *Pimephales*) > others.

Stratum C

Raw p = .0001 (Adult *Pimephales*) > others. Rank p = .0001 (Adult *Pimephales*, YOY *Pimephales*) others.

Stratum D

Raw p = .0001 (Adult *Pimephales*, YOY *Pimephales*) > (YOY *Pimephales*, others).
Rank p = .0001 (Adult *Pimephales*, YOY *Pimephales*) > others.

Stratum E

Raw p = .0001 and Rank p = .0001 (Adult *Pimephales*) > (YOY *Pimephales*) others.

Stratum F

Raw p = .0217 (Adult *Pimephales*, YOY *Pimephales*) > (YOY *Pimephales*, others).
Rank p = .0001 (Adult *Pimephales*) > (YOY *Pimephales*) > others.

Macrofragments

Total strata

Raw p = .0468 (Adult *Notropis stramineus*) > (Juvenile *G. robusta*, YOY *Ictalurus*, Adult *Pimephales*, YOY *Pimephales*) > others. Rank p = .0001 (Adult *Pimephales*) > (YOY *Catostomus discobolus*, YOY *Pimephales*) > others.

By strata

Stratum VII

Rank p = .0001 (YOY *Pimephales*) > others.

Stratum IX

Rank p = .0271 (YOY *Catostomus discobolus*, Adult *notropis stramineus*) > (Adult *notropis stramineus*, others).

Stratum C

Raw p = .0115 and Rank p = .0001 (Adult *Pimephales*, YOY *Pimephales*) > (YOY *Pimephales*, others).

Stratum D

Rank p = .0001 (Adult *Pimephales*) > others.

Stratum F

Raw p = .0497 and Rank p = .0001 (Adult *Pimephales*, YOY *Pimephales*) > (YOY *Pimephales*, others).

## Terrestrials

### Total strata

Rank p = .0033 (Juvenile *G. robusta*) > (YOY *Ictalurus*, Juvenile *Gila*, YOY *G. robusta*) >(Juvenile *Gila*, YOY *G. robusta*, Adult *Notropis lutrensis*) > (YOY *G. robusta*, Adult *Notropis lutrensis*, YOY *Notropis lutrensis*, Adult *Notropis stramineus*) > (Adult *Notropis lutrensis*, YOY *Notropis lutrensis*, Adult *Notropis stramineus*, YOY *Ptychocheilus*) > (YOY *Notropis lutrensis*, Adult *Notropis stramineus*, YOY *Ptychocheilus*, YOY *Pimephales*) > (Adult *Notropis stramineus*,YOY *Ptychocheilus*, YOY *Pimephales*, others).

### By strata

Stratum A

Raw p = .0007 Rank p = .0001 (YOY *Ictalurus*) > others.

## Invertebrate remains

### Total strata

Raw p = .0001 and Rank p = .0001 (Juvenile *G. robusta*) > others.

### By strata

Stratum IV

Raw p = .0547 and Rank p = .0045 (Adult *Notropis lutrensis*) > others.

Stratum VI

Rank p = .0027 (Juvenile *Gila*, Adult *Notropis lutrensis*) > others.

Stratum VII

Raw p = .0005 and Rank p = .0001 (Juvenile *G. robusta*) > (YOY *G. robusta*, YOY *Pimephales*).

Stratum IX

Rank p = .0001 (Adult *Notropis stramineus*, YOY *G. robusta*, Adult *Notropis lutrensis*) > (Adult *Notropis lutrensis*, YOY *Gila*) > (Juvenile *Gila*, Adult *Rhinichthys*) > (Adult *Rhinichthys*, others).

Stratum X

Rank p = .0485 (YOY *G. robusta*) > (YOY *Catostomus latipinnis*).

Stratum A

Rank p = .0042 (YOY *Ptychocheilus*) > others.

Stratum B

Rank p = .0012 (Adult *Notropis lutrensis*, YOY *Ptychocheilus*, YOY *Notropis lutrensis*) > (YOY *Ptychocheilus*, YOY *Notropis lutrensis*, YOY *Ictalurus*) > (YOY *Notropis lutrensis*, YOY *Ictalurus*, YOY *Pimephales*) > (YOY *Pimephales*, Adult *Pimephales*) > (Adult *Pimephales*, others).

Stratum C

Raw p = .0100 (Juvenile *Gila*) > others. Rank p = .0001 (Juvenile *Gila*, Adult *Notropis lutrensis*, YOY *Notropis lutrensis*) > (YOY *Notropis lutrensis*, YOY *Ictalurus*) > others.

Stratum D

Raw p = .0001 (YOY *Ictalurus*) > (Adult *Notropis lutrensis*) > (YOY *Ptychocheilus*) > others. Rank p = .0286 (YOY *Ictalurus*, Adult *Notropis lutrensis*) > (Adult *Notropis lutrensis*, YOY *Ptychocheilus*, YOY *Notropis lutrensis*) > (YOY *Ptychocheilus*, YOY *Notropis lutrensis*, others).

Stratum F

Rank p = .0189 (YOY *Notropis lutrensis*, YOY *Gila*, YOY *Ptychocheilus*) (YOY *Gila*, YOY *Ptychocheilus*, Adult *Notropis lutrensis*) > others.

## Zooplankton

Significant differences and FSD results show no differences for total strata.

Stratum X

Raw p = .0082 and Rank p = .0082 (YOY *Catostomus latipinnis*) > (YOY *G. robusta*).

## Diptera

### Total strata

Raw p = .0001 (Juvenile *Ictalurus*) > (YOY *Ictalurus*) > others. Rank p = .0001 (Juvenile *Ictalurus*, YOY *Ictalurus*, YOY *Gila*, YOY *Notropis stramineus*, Adult *Rhinichthys*, YOY *Catostomus latipinnis*, YOY *Ptychocheilus*, YOY *Notropis lutrensis*) > (YOY *Notropis stramineus*, Adult *Rhinichthys*, YOY *Catostomus latipinnis*, YOY *Ptychocheilus*, YOY *Notropis lutrensis*, Adult *Notropis lutrensis*, Juvenile *Gila*, YOY *G. robusta*, Juvenile *G. robusta*, Adult *Notropis stramineus*) > (Juvenile *G. robusta*, Adult *Notropis stramineus*, others).

By strata

Stratum VI

Rank p = .0388 (Juvenile *Gila*, YOY *Notropis stramineus*, YOY *Notropis lutrensis*, Adult *Notropis lutrensis*) > (Adult *Notropis lutrensis*, Adult *Notropis stramineus*) > (Adult *Notropis stramineus*, others).

Stratum A

Raw p = .0001 and Rank p = .0001 (YOY *Ictalurus*) > others.

Stratum B

Raw p - .0001 (Juvenile *Ictalurus*) > (YOY *Ictalurus*) > others. Rank p = .0001 (Juvenile *Ictalurus*, YOY *Ptychocheilus*, YOY *Ictalurus*) > others.

Stratum C

Raw p = .0058 (YOY *Ictalurus*, Juvenile *Gila*) > (Juvenile *Gila*, others). Rank p = .0001 (YOY *Ictalurus*) > others.

Stratum D

Raw p = .0001 (YOY *Ictalurus*) > others. Rank p = .0005 (YOY *Ictalurus*, YOY *Gila*, YOY *Notropis lutrensis*) > (YOY *Gila*, YOY *Notropis lutrensis*, Adult *Notropis lutrensis*) > (Adult *Notropis lutrensis*, others).

Stratum E

Rank p = .0001 (YOY *Ictalurus*) > others.

Stratum F

Raw p = .0118 (YOY *Gila*, YOY *Ptychocheilus*) > (YOY *Ptychocheilus*, YOY *Ictalurus*, Adult *Notropis lutrensis*) > (YOY *Ictalurus*, Adult *Notropis lutrensis*, YOY *Notropis lutrensis*) > (YOY *Notropis lutrensis*, others) Rank p = .0004 (YOY *Gila*, YOY *Ictalurus*) > (YOY *Ictalurus*, Adult *Notropis lutrensis*) > (Adult *Notropis lutrensis*, YOY *Ptychocheilus*, YOY *Notropis lutrensis*) > others.

Coleoptera

Total strata

Raw p = .0001 and Rank p = .0001 (YOY *Ictalurus*) > others.

By stratum

Stratum A

Raw p = .0008 and Rank p = .0001 (YOY *Ictalurus*) > others.

## Trichoptera

### Total strata

Raw p = .0001 (YOY *Ictalurus*, YOY *Catostomus latipinnis*) > (YOY *Catostomus latipinnis*, others). Rank p = .0001 (Adult *Rhinichthys*) > (YOY *Ictalurus*, Juvenile *G. robusta*, YOY *Catostomus latipinnis*) > (YOY *Catostomus latipinnis*, others).

### By strata

#### Stratum VI

Raw p = .0001 and Rank p = .0001 (Juvenile *Gila*) > others.

#### Stratum IX

Raw p = .0001 (Adult *Notropis stramineus*, YOY *Catostomus latipinnis*) > others. Rank p = .0001 (Adult *Rhinichthys*, Adult *Notropis stramineus*) > (Adult *Notropis stramineus*,YOY *Catostomus latipinnis*) > (YOY *Catostomus latipinnis*, others).

#### Stratum A

Raw p = .0160 and Rank p = .0001 (YOY *Ictalurus*) > others.

#### Stratum B

Rank p = .0010 (YOY *Ictalurus*) > others.

## Ephemeropters

### Total strata

Raw p = .0001 and Rank p = .0001 (Juvenile *G. robusta*) > (Adult *Notropis lutrensis*, YOY *G. robusta*, Adult *Rhinichthys*, YOY *Gila*) > (YOY *G. robusta*, Adult *Rhinichthys*, YOY *Gila*, Juvenile *Gila*) > (Adult *Rhinichthys*, YOY *Gila*, Juvenile *Gila*, YOY *Notropis lutrensis*) > (YOY *Gila*, Juvenile *Gila*, YOY *Notropis lutrensis*, YOY *Catostomus latipinnis*, Adult *Notropis stramineus*, YOY *Pimephales*, YOY *Ictalurus*) > (Juvenile *Gila*, YOY *Notropis lutrensis*, YOY *Catostomus latipinnis*, Adult *Notropis stramineus*, YOY *Pimephales*, YOY *Ictalurus*, others).

### By strata

#### Stratum VII

Rank p = .0467 (Juvenile *G. robusta*, YOY *G. robusta*) > (YOY *B. robusta*, YOY *Pimephales*).

Stratum IX

Raw p = .0001 (YOY *G. robusta*) > others. Rank p = .0001 (YOY *G. robusta*, Adult *Rhinichthys*) > others.

Stratum E

Raw p = .0001 and Rank p = .0001 (Adult *Notropis lutrensis*, YOY *Notropis lutrensis*) > others.

Hemiptera

Total strata

Raw p = .0004 and Rank p = .0001 (YOY *Ictalurus*) > others.

By strata

Stratum A

Raw p = .0043 (YOY *Ictalurus*) > others. Rank p = .0001 (YOY *Ictalurus*, YOY *Pimephales*) > (YOY *Pimephales*, others).

Nematoda

Total strata

Raw p = .0009 and Rank p = .0001 (Juvenile *G. robusta*, YOY *G. robusta*) > others.

Appendix A-1
Food item values for all strata

| Species | Seston | Macra-fragments | Debris | Fish | Terres-trial | Inverte-brate remains | Hydra-charina | Zoo-plankton | Diptera | Coleop-tera | Trichop-tera | Ephemer-optera | Hemip-tera | Nema-toda | Eggs | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YOY *Gila sp.* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | .20 | | | 80 | | | 20 | | | | 5 |
| Mean number | | | | | | .2 | | | 1.8 | | | .2 | | | | |
| Mean weight (mg) | | | | | | .406 | | | .598 | | | 3.45 | | | | |
| Percent of stomach content | | | | | | 912. | | | 13.43 | | | 77.46 | | | | |
| Percent of item consumed | | | | | | .04 | | | .20 | | | .76 | | | | |
| Juvenile *Gila sp.* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 12 | 36 | | | 24 | 4. | 12 | 24 | | | | 25 |
| Mean number | | | | | .32 | .36 | | | 1.4 | .04 | .92 | .32 | | | | |
| Mean weight (mg) | | | | | .831 | 8.158 | | | .373 | .01 | .992 | 1.901 | | | | |
| Percent of stomach content | | | | | 6.78 | 66.51 | | | 3.04 | .08 | 8.09 | 15.5 | | | | |
| Percent of item consumed | | | | | 12.29 | 4.24 | | | .61 | .73 | 3.27 | 2.09 | | | | |
| YOY *Gila robusta* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 1.75 | | | 10.52 | 59.65 | | | 26.32 | 5.26 | 5.26 | 28.07 | | 7.02 | | 57 |
| Mean number | | .018 | | | .123 | .597 | | | .491 | .053 | .070 | .333 | | .070 | | |
| Mean weight (mg) | | .004 | | | .154 | 7.036 | | | .154 | .019 | .639 | 4.984 | | .001 | | |
| Percent of stomach content | | .03 | | | 1.19 | 54.16 | | | 1.19 | .15 | 4.92 | 38.37 | | .01 | | |
| Percent of item consumed | | 1.54 | | | 5.19 | 8.33 | | | .58 | 3.16 | 4.80 | 12.50 | | 60 | | |
| Juvenile *Gila robusta* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 5.26 | | 2.10 | 18.42 | 84.21 | 2.63 | | 15.79 | | 23.68 | 47.37 | | 7.89 | | 38 |
| Mean number | | .053 | | .021 | .184 | .842 | .026 | | .342 | | .763 | 1.658 | | .395 | | |
| Mean weight (mg) | | .074 | | 2.37 | .997 | 60.58 | .0008 | | .066 | | 3.296 | 17.005 | | .001 | | |
| Percent of stomach content | | .09 | | 2.81 | 1.18 | 71.79 | .00 | | .08 | | 3.91 | 20.15 | | .00 | | |
| Percent of item consumed | | 19.02 | | 8.22 | 22.42 | 47.81 | 100 | | .16 | | 16.49 | 28.44 | | 40 | | |
| YOY *Ptychocheilus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 6.93 | | 30.70 | 2.97 | 28.71 | | 1.98 | 40.59 | | | | | | | 101 |
| Mean number | | .089 | | .416 | .030 | .287 | | .020 | 1.911 | | | | | | | |
| Mean weight (mg) | | .001 | | 9.952 | .018 | 1.266 | | .0006 | .386 | | | | | | | |
| Percent of stomach content | | .00 | | 85.63 | .15 | 10.89 | | .01 | 3.32 | | | | | | | |
| Percent of item consumed | | .07 | | 91.78 | 1.08 | 2.66 | | 3.61 | 2.56 | | | | | | | |
| YOY *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 12.82 | 3.85 | | | 6.41 | 43.59 | | 1.28 | 42.31 | 3.85 | | 10.26 | | | 2.56 | 78 |
| Mean number | 2,142.8 | .218 | | | .077 | .435 | | .013 | 1.590 | .051 | | .141 | | | .372 | |
| Mean weight (mg) | .020 | .0009 | | | .023 | .812 | | .0001 | .184 | .013 | | 1.670 | | | .006 | |
| Percent of stomach content | .74 | .03 | | | .85 | 29.76 | | .004 | 6.74 | .47 | | 61.18 | | | .23 | |
| Percent of item consumed | .93 | .47 | | | 1.06 | 1.32 | | .47 | .94 | 2.96 | | 5.73 | | | 11.35 | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 7.41 | 3.45 | | | 7.47 | 53.45 | | | 37.36 | 4.02 | 2.3 | 18.39 | 3.45 | | 2.3 | 174 |
| Mean number | 2,168.8 | .931 | | | .138 | .535 | | | 2.454 | .098 | .023 | .454 | .040 | | 1.190 | |
| Mean weight (mg) | .019 | .003 | | | .243 | 7.612 | | | .495 | .032 | .151 | 5.855 | .058 | | .021 | |
| Percent of stomach content | .13 | .02 | | | 1.68 | 52.54 | | | 3.42 | .22 | 1.04 | 40.41 | .40 | | .14 | |
| Percent of item consumed | 1.97 | 3.53 | | | 25.02 | 27.51 | | | 5.66 | 16.27 | 3.46 | 44.84 | 15.71 | | 88.65 | |
| YOY *Notropis stramineus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | 2 |
| Mean number | | | | | | | | | 1.0 | | | | | | | |
| Mean weight (mg) | | | | | | | | | .145 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |
| Percent of item consumed | | | | | | | | | .02 | | | | | | | |
| Adult *Notropis stramineus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 5 | | | 5 | 60 | | | 15 | | 5 | 5 | | | | 20 |
| Mean number | | .05 | | | .05 | .6 | | | .2 | | .1 | .05 | | | | |
| Mean weight (mg) | | .175 | | | .048 | 3.561 | | | .048 | | .854 | .406 | | | | |
| Percent of stomach content | | 3.44 | | | .92 | 69.95 | | | .93 | | 16.77 | 7.98 | | | | |
| Percent of item consumed | | 23.68 | | | .57 | 1.48 | | | .06 | | 2.25 | .36 | | | | |
| YOY *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 91.03 | 20.51 | | | 1.28 | 5.13 | | 3.85 | 1.28 | 1.28 | | 2.56 | 2.56 | | | 78 |
| Mean number | 4,088.3 | 95.987 | | | .013 | .051 | | 1.128 | .026 | .013 | | .038 | .051 | | | |
| Mean weight (mg) | .036 | .015 | | | .0004 | .004 | | .009 | .001 | .007 | | .365 | .069 | | | |
| Percent of stomach content | 7.15 | 3.05 | | | .08 | .71 | | 1.79 | .26 | 1.44 | | 71.99 | 13.53 | | | |
| Percent of item consumed | 1.67 | 7.91 | | | .02 | .01 | | 41.88 | .01 | 1.60 | | 1.25 | 8.38 | | | |
| Adult *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 95.59 | 41.18 | | | | 5.88 | | | 2.94 | | | | | | | 68 |
| Mean number | 22,150.6 | 250.6 | | | | .059 | | | .279 | | | | | | | |
| Mean weight (mg) | .346 | .041 | | | | .0005 | | | .008 | | | | | | | |
| Percent of stomach content | 87.40 | 10.36 | | | | .13 | | | 2.12 | | | | | | | |
| Percent of item consumed | 14.03 | 18.86 | | | | .00 | | | .04 | | | | | | | |
| Adult Killifish | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 3 |
| Mean number | 5,543.3 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .078 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Percent of item consumed | .14 | | | | | | | | | | | | | | | |
| YOY *Catostomus discobolus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 27.78 | | | | | | | 2.78 | | | | | | | 36 |
| Mean number | 420,564.7 | 10.361 | | | | | | | 1.111 | | | | | | | |
| Mean weight (mg) | 3.781 | .0008 | | | | | | | .033 | | | | | | | |
| Percent of stomach content | 99.1 | .02 | | | | | | | .87 | | | | | | | |
| Percent of item consumed | 81.14 | .19 | | | | | | | .08 | | | | | | | |
| Adult *Rhinichthys* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 14.29 | | | 64.29 | | 57.14 | 57.14 | | | | 14 |
| Mean number | | | | | | .143 | | | 2.00 | | 1.571 | 1.486 | | | | |
| Mean weight (mg) | | | | | | .874 | | | .554 | | 2.224 | 4.468 | | | | |
| Percent of stomach content | | | | | | 10.76 | | | 6.70 | | 27.39 | 55.01 | | | | |
| Percent of item consumed | | | | | | .25 | | | .51 | | 4.10 | 2.75 | | | | |
| YOY *Catostomus latipinnis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 50. | | 50 | | | | | 12.5 | 50 | | 12.5 | 12.5 | | | | 8 |
| Mean number | 2,361.9 | | .5 | | | | | 12.5 | 76.75 | | 6.25 | 4.5 | | | | |
| Mean weight (mg) | .023 | | 79.93 | | | | | .003 | 2.823 | | 3.563 | 1.131 | | | | |
| Percent of stomach content | .03 | | 91.38 | | | | | 12.5 | 3.23 | | 4.07 | 1.29 | | | | |
| Percent of item consumed | .11 | | 100 | | | | | 1.43 | 1.48 | | 3.75 | .46 | | | | |
| YOY *Ictalurus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 3.17 | 7.94 | | | 14.29 | 28.57 | | 1.59 | 88.89 | 17.46 | 28.57 | 4.76 | 12.7 | | | 63 |
| Mean number | .032 | .143 | | | .540 | .318 | | .460 | 144.540 | 1.952 | 7.813 | .048 | .841 | | | |
| Mean weight (mg) | .0003 | .058 | | | .868 | 4.851 | | .014 | 18.649 | .409 | 7.461 | .311 | .774 | | | |
| Percent of stomach content | .00 | .17 | | | 2.6 | 14.53 | | .04 | 5.85 | 1.22 | 22.34 | .93 | 2.32 | | | |
| Percent of item consumed | .01 | 24.72 | | | 32.36 | 6.35 | | 52.61 | 77.21 | 75.28 | 61.89 | .86 | 75.91 | | | |
| Juvenile *Ictalurus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | 1 |
| Mean number | | | | | | | | | 96 | | | | | | | |
| Mean weight (mg) | | | | | | | | | 150.36 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |
| Percent of item consumed | | | | | | | | | 9.88 | | | | | | | |

Appendix A-2
Food item values by stratum

| Stratum | Seston | Macra-fragments | Debris | Fish | Terres-trial | Inverte-brate remains | Hydra-charina | Zoo-plankton | Diptera | Coleop-tera | Trichop-tera | Ephemer-optera | Hemip-tera | Nema-toda | Eggs | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stratum IV | | | | | | | | | | | | | | | | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 50 | 12.5 | | | | 50. | | | 12.5 | 12.5 | | 12.5 | | | | 8 |
| Mean number | 17,388.6 | 1 | | | | .5 | | | .375 | .125 | | .875 | | | | |
| Mean weight (mg) | .155 | .00006 | | | | 14.339 | | | 2.19 | .119 | | .831 | | | | |
| Percent of stomach content | .88 | .00 | | | | 81.32 | | | 12.42 | .67 | | 4.71 | | | | |
| Percent of item consumed | 53.73 | 46.15 | | | | 100 | | | 100 | 100 | | 100 | | | | |
| Adult Killifish | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 2 |
| Mean number | 3,587.5 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .078 | | | | | | | | | | | | | | | |
| Percent of stomach contents | 100 | | | | | | | | | | | | | | | |
| Percent of item consumed | 6.76 | | | | | | | | | | | | | | | |
| YOY *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 7.14 | | | | | | | | | | | | | | 14 |
| Mean number | 4,040.1 | 1.071 | | | | | | | | | | | | | | |
| Mean weight (mg) | .036 | .00004 | | | | | | | | | | | | | | |
| Percent of stomach content | 99.90 | .10 | | | | | | | | | | | | | | |
| Percent of item consumed | 21.84 | 53.85 | | | | | | | | | | | | | | |
| Adult *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 4 |
| Mean number | 11,466.25 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .102 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Percent of item consumed | 17.68 | | | | | | | | | | | | | | | |
| Stratum V | | | | | | | | | | | | | | | | |
| YOY *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 75 | | | 100 | | | | | | | 4 |
| Mean number | | | | | | .75 | | | 6 | | | | | | | |
| Mean weight (mg) | | | | | | 7.655 | | | .498 | | | | | | | |
| Percent of stomach content | | | | | | 93.90 | | | 6.10 | | | | | | | |
| Percent of item consumed | | | | | | 10.66 | | | 9.01 | | | | | | | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 3.85 | | | | | 80.77 | | | 65.38 | | | 3.85 | 3.85 | | 3.85 | 26 |
| Mean number | .038 | | | | | .808 | | | .385 | | | .038 | .038 | | .077 | |
| Mean weight (mg) | .0002 | | | | | 9.866 | | | .774 | | | .624 | .187 | | .0002 | |
| Percent of stomach content | .00 | | | | | 86.15 | | | 6.76 | | | 5.45 | 1.63 | | .00 | |
| Percent of item consumed | 100 | | | | | 89.34 | | | 90.99 | | | 100 | 100 | | 100 | |
| Stratum VI | | | | | | | | | | | | | | | | |
| Juvenile *Gila robusta* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | 100 | | | | | | | | | | | | 1 |
| Mean number | | | | 1 | | | | | | | | | | | | |
| Mean weight (mg) | | | | 90.06 | | | | | | | | | | | | |
| Percent of stomach content | | | | .100 | | | | | | | | | | | | |
| Percent of item consumed | | | | 100 | | | | | | | | | | | | |
| YOY *Gila sp.* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | | | | 100 | | | | 1 |
| Mean number | | | | | | | | | | | | 1 | | | | |
| Mean weight (mg) | | | | | | | | | | | | 17.25 | | | | |
| Percent of stomach content | | | | | | | | | | | | 100 | | | | |
| Percent of item consumed | | | | | | | | | | | | 3.31 | | | | |
| Juvenile *Gila sp.* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 33.3 | 66.67 | | | 66.67 | | 66.67 | 33.33 | | | | 3 |
| Mean number | | | | | .333 | .667 | | | 6.667 | | 7.333 | .333 | | | | |
| Mean weight (mg) | | | | | 5.41 | 42.087 | | | 1.467 | | 6.65 | .19 | | | | |
| Percent of stomach content | | | | | 9.69 | 75.42 | | | 2.63 | | 11.92 | .34 | | | | |
| Percent of item consumed | | | | | 49.03 | 12.81 | | | 10.94 | | 95.41 | 1.09 | | | | |
| YOY *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 25 | | | 75 | | | | | | | 8 |
| Mean number | | | | | | .25 | | | 3 | | | | | | | |
| Mean weight (mg) | | | | | | .254 | | | .37 | | | | | | | |
| Percent of stomach content | | | | | | 40.11 | | | 59.29 | | | | | | | |
| Percent of item consumed | | | | | | .21 | | | 7.35 | | | | | | | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 5 | 2.50 | | | 12.5 | 67.5 | | | 40 | 2.5 | 2.5 | 30 | | | | 40 |
| Mean number | 79.275 | 3.175 | | | .275 | .675 | | | 3.45 | .025 | .025 | .75 | | | | |
| Mean weight (mg) | .0004 | .0001 | | | .398 | 19.761 | | | .791 | .024 | .024 | 12.384 | | | | |
| Percent of stomach content | .00 | .00 | | | 1.19 | 59.19 | | | 2.37 | .07 | .07 | 37.10 | | | | |
| Percent of item consumed | .09 | .11 | | | 48.09 | 80.20 | | | 78.62 | 100 | 4.59 | 95.02 | | | | |
| YOY *Notropis stramineus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | 2 |
| Mean number | | | | | | | | | 1 | | | | | | | |
| Mean weight (mg) | | | | | | | | | .145 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |
| Percent of item consumed | | | | | | | | | .72 | | | | | | | |
| Adult *Notropis stramineus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 5.56 | | | 5.56 | 55.56 | | | 16.67 | | | 5.56 | | | | 18 |
| Mean number | | .056 | | | .056 | .556 | | | .222 | | | .056 | | | | |
| Mean weight (mg) | | .194 | | | .053 | 3.716 | | | .053 | | | .451 | | | | |
| Percent of stomach content | | 4.35 | | | 1.18 | 83.18 | | | 1.18 | | | 10.10 | | | | |
| Percent of item consumed | | 95.69 | | | 2.88 | 6.79 | | | 2.37 | | | 1.56 | | | | |
| YOY *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 1 |
| Mean number | 385 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .008 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Percent of item consumed | .05 | | | | | | | | | | | | | | | |
| Adult *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | .100 | 28.57 | | | | | | | | | | | | | | 7 |
| Mean number | 117,435 | 39.143 | | | | | | | | | | | | | | |
| Mean weight (mg) | 2.413 | .0219 | | | | | | | | | | | | | | |
| Percent of stomach content | 99.10 | .90 | | | | | | | | | | | | | | |
| Percent of item consumed | 99.49 | 4.20 | | | | | | | | | | | | | | |
| YOY *Catostomus discobolus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 1 |
| Mean number | 3,504 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .063 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Percent of item consumed | .37 | | | | | | | | | | | | | | | |
| Stratum VII | | | | | | | | | | | | | | | | |
| YOY *Gila robusta* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 25 | 66.67 | | | 16.67 | 8.33 | 25 | 33.33 | | 8.33 | | 12 |
| Mean number | | | | | .417 | .667 | | | .333 | .083 | .333 | .500 | | .083 | | |
| Mean weight (mg) | | | | | .396 | 12.155 | | | .127 | .021 | 3.033 | 7.593 | | .0003 | | |
| Percent of stomach content | | | | | 1.70 | 52.11 | | | .54 | .09 | 13.03 | 32.55 | | .00 | | |
| Percent of item consumed | | | | | 11.14 | 5.94 | | | 37.72 | 100 | 22.52 | 14.38 | | 9.57 | | |
| Juvenile *Gila robusta* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 5.88 | | | 20.59 | 94.12 | 2.94 | | 17.65 | | 26.47 | 44.12 | | 8.882 | | 34 |
| Mean number | | .059 | | | .206 | .941 | .029 | | .383 | | .853 | 1.676 | | .441 | | |
| Mean weight (mg) | | .083 | | | 1.115 | 67.99 | .0009 | | .074 | | 3.683 | 15.962 | | .001 | | |
| Percent of stomach content | | .09 | | | 1.25 | 76.47 | .00 | | .08 | | 4.14 | 17.95 | | .00 | | |
| Percent of item consumed | | 79.23 | | | 88.86 | 94.06 | 100 | | 62.28 | | 77.48 | 85.62 | | 90.43 | | |
| YOY *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 60 | | | | | | | | | | | | | | 10 |
| Mean number | 6,376 | 7.9 | | | | | | | | | | | | | | |
| Mean weight (mg) | .016 | .074 | | | | | | | | | | | | | | |
| Percent of stomach content | 18.16 | 81.84 | | | | | | | | | | | | | | |
| Percent of item consumed | 100 | 20.77 | | | | | | | | | | | | | | |

Appendix A-2 (continued)
Food item values by stratum

| Stratum | Seston | Macra-fragments | Debris | Fish | Terres-trial | Inverte-brate remains | Hydra-charina | Zoo-plankton | Diptera | Coleop-tera | Trichop-tera | Ephemer-optera | Hemip-tera | Nema-toda | Eggs | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stratum IX | | | | | | | | | | | | | | | | |
| Juvenile *Gila sp.* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 10 | 25 | | | 15 | 5 | 5 | 25 | | | | 20 |
| Mean number | | | | | .35 | .25 | | | .6 | .05 | .03 | .35 | | | | |
| Mean weight (mg) | | | | | .228 | 3.373 | | | .167 | .013 | .243 | 2.348 | | | | |
| Percent of stomach content | | | | | 3.57 | 52.95 | | | 2.61 | .20 | 3.81 | 36.86 | | | | |
| Percent of item consumed | | | | | 76.92 | 29.19 | | | 9.52 | 25.97 | 5.94 | 12.97 | | | | |
| YOY *Gila robusta* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 4.76 | | | 9.5 | 52.25 | | | 9.5 | 9.5 | | 42.10 | | 14.25 | | 19 |
| Mean number | | .048 | | | .037 | .523 | | | .095 | .095 | | .474 | | .475 | | |
| Mean weight (mg) | | .010 | | | .072 | 7.736 | | | .012 | .039 | | 7.375 | | .003 | | |
| Percent of stomach content | | .07 | | | .47 | 50.74 | | | .08 | .26 | | 48.37 | | .00 | | |
| Percent of item consumed | | 85.78 | | | 23.08 | 63.60 | | | .65 | 74.03 | | 38.59 | | 100 | | |
| Juvenile *Gila robusta* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | | | | 100 | | | | 3 |
| Mean number | | | | | | | | | | | | 2 | | | | |
| Mean weight (mg) | | | | | | | | | | | | 34.5 | | | | |
| Percent of stomach content | | | | | | | | | | | | 100 | | | | |
| Percent of item consumed | | | | | | | | | | | | 28.58 | | | | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 50 | | | | | | | | | | 2 |
| Mean number | | | | | | .5 | | | | | | | | | | |
| Mean weight (mg) | | | | | | .05 | | | | | | | | | | |
| Percent of stomach content | | | | | | 100 | | | | | | | | | | |
| Percent of item consumed | | | | | | .04 | | | | | | | | | | |
| Adult *Notropis stramineus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 100 | | | | | 50 | | | | | 2 |
| Mean number | | | | | | 1 | | | | | 1 | | | | | |
| Mean weight (mg) | | | | | | 2.165 | | | | | 8.535 | | | | | |
| Percent of stomach content | | | | | | 20.24 | | | | | 79.77 | | | | | |
| Percent of item consumed | | | | | | 1.87 | | | | | 20.86 | | | | | |
| Adult *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 1 |
| Mean number | 42,406 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .718 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Percent of item consumed | 6.88 | | | | | | | | | | | | | | | |
| Adult *Rhinichthys* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 14.29 | | | 64.29 | | 57.14 | 57.14 | | | | 14 |
| Mean number | | | | | | .143 | | | 2 | | 1.571 | 1.429 | | | | |
| Mean weight (mg) | | | | | | .874 | | | .554 | | 2.244 | 4.468 | | | | |
| Percent of stomach content | | | | | | 10.74 | | | 6.81 | | 27.57 | 54.49 | | | | |
| Percent of item consumed | | | | | | 5.29 | | | 22.10 | | 38.38 | 17.27 | | | | |
| YOY *Catostomus latipinnis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | 100 | | | | | | 100 | | 25 | 25 | | | | 4 |
| Mean number | | | 1.0 | | | | | | 153.5 | | 12.5 | 9 | | | | |
| Mean weight (mg) | | | 159.86 | | | | | | 5.645 | | 7.125 | 2.263 | | | | |
| Percent of stomach content | | | 91.40 | | | | | | 3.23 | | 4.07 | 1.29 | | | | |
| Percent of item consumed | | | 100 | | | | | | 64.34 | | 34.82 | 2.50 | | | | |
| YOY *Catostomus discobolus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 28.57 | | | | | | | 2.86 | | | | | | | 35 |
| Mean number | 432,480 | 10.657 | | | | | | | 1.143 | | | | | | | |
| Mean weight (mg) | 3.887 | .0009 | | | | | | | .034 | | | | | | | |
| Percent of stomach content | 99.10 | .02 | | | | | | | .87 | | | | | | | |
| Percent of item consumed | 93.12 | 14.22 | | | | | | | 3.39 | | | | | | | |
| Stratum X | | | | | | | | | | | | | | | | |
| YOY *Gila robusta* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 385 | 57.69 | | | 42.31 | | | 15.38 | | | | 26 |
| Mean number | | | | | .038 | .577 | | | .846 | | | .154 | | | | |
| Mean weight (mg) | | | | | .097 | 3.167 | | | .269 | | | 2.033 | | | | |
| Percent of stomach content | | | | | 1.73 | 56.90 | | | 4.83 | | | 36.53 | | | | |
| Percent of item consumed | | | | | 100 | 100 | | | 100 | | | 100 | | | | |
| YOY *Catostomus latipinnis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | 25 | | | | | | | | 4 |
| Mean number | 4,723.75 | | | | | | | 47 | | | | | | | | |
| Mean weight (mg) | .046 | | | | | | | .005 | | | | | | | | |
| Percent of stomach content | 90.24 | | | | | | | 9.76 | | | | | | | | |
| Percent of item consumed | 100 | | | | | | | 100 | | | | | | | | |
| Stratum A | | | | | | | | | | | | | | | | |
| YOY *Ptychocheilus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 21.88 | | 40.63 | 3.13 | 43.75 | | 6.25 | 46.88 | | | | | | | 32 |
| Mean number | | .28125 | | .625 | .0313 | .4375 | | .0625 | 3.0313 | | | | | | | |
| Mean weight (mg) | | .0004 | | 19.91 | .0297 | 1.364 | | .0019 | .1869 | | | | | | | |
| Percent of stomach content | | .00 | | 92.63 | .14 | 6.35 | | .01 | .87 | | | | | | | |
| Percent of item consumed | | .48 | | 100 | 1.71 | 71.96 | | 6.55 | .61 | | | | | | | |
| YOY *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 80 | 10 | | | | 10 | | | 40 | 10 | | | | | | 10 |
| Mean number | 16,596.6 | .5 | | | | .1 | | | .7 | .1 | | | | | | |
| Mean weight (mg) | .1561 | .0004 | | | | .025 | | | .154 | .025 | | | | | | |
| Percent of stomach content | 43.30 | .11 | | | | 6.93 | | | 42.92 | 6.93 | | | | | | |
| Percent of item consumed | 20.91 | .15 | | | | .41 | | | .16 | .96 | | | | | | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 50 | 10 | | | 10 | | | | 30 | 10 | 20 | | | | | 10 |
| Mean number | 23,405.3 | .1 | | | .1 | | | | 7.4 | 1 | .2 | | | | | |
| Mean weight (mg) | .2083 | .0001 | | | .095 | | | | .446 | .25 | 2.44 | | | | | |
| Percent of stomach content | 6.06 | .00 | | | 2.76 | | | | 12.97 | 7.27 | 70.94 | | | | | |
| Percent of item consumed | 27.91 | .04 | | | 1.71 | | | | .46 | 9.62 | 9.76 | | | | | |
| YOY *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 50 | 25 | | | | 12.5 | | | | | | | 25 | | | 8 |
| Mean number | 10,030 | .375 | | | | .125 | | | | | | | .5 | | | |
| Mean weight (mg) | .122 | .0001 | | | | .031 | | | | | | | .67 | | | |
| Percent of stomach content | 14.79 | .02 | | | | 3.8 | | | | | | | 81.40 | | | |
| Percent of item consumed | 13.08 | .03 | | | | .41 | | | | | | | 10.86 | | | |
| Adult *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 83.33 | 33.33 | | | | | | | 33.33 | | | | | | | 6 |
| Mean number | 51,243.3 | 19.67 | | | | | | | 3.167 | | | | | | | |
| Mean weight (mg) | .474 | .002 | | | | | | | .095 | | | | | | | |
| Percent of stomach content | 83. | .35 | | | | | | | 16.65 | | | | | | | |
| Percent of item consumed | 38.16 | .45 | | | | | | | .06 | | | | | | | |
| YOY *Ictalurus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 14.29 | | | 50 | 7.14 | | 7.14 | 85.71 | 71.43 | 50 | 14.29 | 42.86 | | | 14 |
| Mean number | | 42.86 | | | 2.143 | .071 | | 2.071 | 609.0 | 8.714 | 19.214 | .143 | 3.429 | | | |
| Mean weight (mg) | | .1893 | | | 3.834 | 1.179 | | .062 | 68.69 | 1.659 | 16.107 | .526 | 3.144 | | | |
| Percent of stomach content | | .20 | | | 4.02 | 1.24 | | .07 | 72.01 | 1.74 | 16.89 | .55 | 3.3 | | | |
| Percent of item consumed | | 98.86 | | | 96.58 | 27.21 | | 93.45 | 98.71 | 89.41 | 90.23 | 100 | 89.14 | | | |
| Stratum B | | | | | | | | | | | | | | | | |
| YOY *Ptychocheilus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 12.5 | 62.5 | | | 87.5 | | | | | | | 8 |
| Mean number | | | | | .125 | .625 | | | 5 | | | | | | | |
| Mean weight (mg) | | | | | .071 | 7.588 | | | .951 | | | | | | | |
| Percent of stomach content | | | | | .83 | 88.12 | | | 11.05 | | | | | | | |
| Percent of item consumed | | | | | 6.88 | 16.23 | | | 3.58 | | | | | | | |
| YOY *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 20 | 10 | | | 30 | 70 | | | 10 | | | | | | | 10 |
| Mean number | 117.6 | 1.1 | | | .4 | .7 | | | .5 | | | | | | | |
| Mean weight (mg) | .0004 | .0001 | | | .132 | .419 | | | .11 | | | | | | | |
| Percent of stomach content | .06 | .02 | | | 19.94 | 63.36 | | | 16.62 | | | | | | | |
| Percent of item consumed | .40 | .08 | | | 15.99 | 1.12 | | | .52 | | | | | | | |

Appendix A-2 (continued)
Food item values by stratum

| Stratum | Seston | Macra-fragments | Debris | Fish | Terres-trial | Inverte-brate remains | Hydra-charina | Zoo-plankton | Diptera | Coleop-tera | Trichop-tera | Ephemer-optera | Hemip-tera | Nema-toda | Eggs | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stratum B, continued | | | | | | | | | | | | | | | | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 10 | 10 | | | 10 | 70 | | | | | | 10 | | | | 10 |
| Mean number | 105.4 | 2.4 | | | .4 | .7 | | | | | | .2 | | | | |
| Mean weight (mg) | .0002 | .0001 | | | .536 | 9.469 | | | | | | 2.442 | | | | |
| Percent of stomach content | .00 | .00 | | | 4.31 | 76.07 | | | | | | 19.62 | | | | |
| Percent of item consumed | .20 | .08 | | | 64.93 | 25.32 | | | | | | 100 | | | | |
| YOY *Pimphales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 3.33 | | | | 6.67 | | 13.3 | | | | | | | | 15 |
| Mean number | 2,136.3 | 70.867 | | | | .067 | | 3.4 | | | | | | | | |
| Mean weight (mg) | .020 | .007 | | | | .0009 | | .027 | | | | | | | | |
| Percent of stomach content | 35.39 | 13.53 | | | | 1.57 | | 49.52 | | | | | | | | |
| Percent of item consumed | 30.09 | 8.31 | | | | .00 | | 100 | | | | | | | | |
| Adult *Pimphales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 16.67 | | | | 16.67 | | | | | | | | | | 6 |
| Mean number | 12,462.2 | 241.33 | | | | .167 | | | | | | | | | | |
| Mean weight (mg) | .112 | .025 | | | | .005 | | | | | | | | | | |
| Percent of stomach content | 78.64 | 17.84 | | | | 3.52 | | | | | | | | | | |
| Percent of item consumed | 67.40 | 11.87 | | | | .01 | | | | | | | | | | |
| YOY *Ictalurus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 10.53 | 10.53 | | | 10.53 | 42.11 | | | 84.21 | 5.26 | 36.84 | | 10.53 | | | 19 |
| Mean number | .105 | .105 | | | .211 | .421 | | | 12.158 | .053 | 11.368 | | .263 | | | |
| Mean weight (mg) | .001 | .053 | | | .053 | 11.281 | | | 2.806 | .132 | 12.155 | | .25 | | | |
| Percent of stomach content | .00 | .20 | | | .20 | 12.20 | | | 10.50 | .49 | 45.47 | | .94 | | | |
| Percent of item consumed | 1.91 | 79.67 | | | 12.20 | 57.32 | | | 25.10 | 100 | 100 | | 100 | | | |
| Juvenile *Ictalurus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | 1 |
| Mean number | | | | | | | | | 96 | | | | | | | |
| Mean weight (mg) | | | | | | | | | 150.36 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |
| Percent of item consumed | | | | | | | | | 70.80 | | | | | | | |
| Stratum C | | | | | | | | | | | | | | | | |
| YOY *Ptychocheilus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | 26.32 | | 5.26 | | | 31.88 | | | | | | | 19 |
| Mean number | | | | .263 | | .053 | | | .744 | | | | | | | |
| Mean weight (mg) | | | | 8.092 | | .043 | | | .197 | | | | | | | |
| Percent of stomach content | | | | 47.11 | | .52 | | | 2.37 | | | | | | | |
| Percent of item consumed | | | | 100 | | 1.24 | | | 2.42 | | | | | | | |
| Juvenile *Gila sp.* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 100 | | | 50 | | | | | | | 2 |
| Mean number | | | | | | 1.0 | | | 1.5 | | | | | | | |
| Mean weight (mg) | | | | | | 5.11 | | | .795 | | | | | | | |
| Percent of stomach content | | | | | | 86.54 | | | 13.46 | | | | | | | |
| Percent of item consumed | | | | | | 15.53 | | | 1.03 | | | | | | | |
| YOY *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 66.67 | | | 33.33 | | | | | | | 3 |
| Mean number | | | | | | .667 | | | 1.333 | | | | | | | |
| Mean weight (mg) | | | | | | .14 | | | .143 | | | | | | | |
| Percent of stomach content | | | | | | 49.44 | | | 50.59 | | | | | | | |
| Percent of item consumed | | | | | | .64 | | | .28 | | | | | | | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 11.76 | 58.82 | | | 29.41 | 11.76 | | | | | | 17 |
| Mean number | | | | | .118 | .588 | | | .294 | .176 | | | | | | |
| Mean weight (mg) | | | | | .319 | 1.275 | | | .059 | .044 | | | | | | |
| Percent of stomach content | | | | | 18.79 | 75.11 | | | 3.50 | 2.60 | | | | | | |
| Percent of item consumed | | | | | 100 | 32.94 | | | .65 | 100 | | | | | | |
| YOY *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 33.33 | | | | | | | | | | | | | | 3 |
| Mean number | 944.33 | 588.0 | | | | | | | | | | | | | | |
| Mean weight (mg) | .008 | .025 | | | | | | | | | | | | | | |
| Percent of stomach content | 25.15 | 14.85 | | | | | | | | | | | | | | |
| Percent of item consumed | 5.78 | 7.18 | | | | | | | | | | | | | | |
| Adult *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 88.24 | 52.94 | | | | 5.88 | | | | | | | | | | 17 |
| Mean number | 2,434.41 | 447.06 | | | | .059 | | | | | | | | | | |
| Mean weight (mg) | .023 | .057 | | | | .0001 | | | | | | | | | | |
| Percent of stomach content | 28.60 | 71.23 | | | | .15 | | | | | | | | | | |
| Percent of item consumed | 94.22 | 92.82 | | | | .00 | | | | | | | | | | |
| YOY *Ictalurus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 25 | | | 95 | | 15 | 5 | | | | 20 |
| Mean number | | | | | | .25 | | | 13.25 | | .5 | .05 | | | | |
| Mean weight (mg) | | | | | | 1.633 | | | 7.395 | | .631 | .611 | | | | |
| Percent of stomach content | | | | | | 15.91 | | | 72 | | 6.14 | 5.94 | | | | |
| Percent of item consumed | | | | | | 49.64 | | | 95.63 | | 100 | 100 | | | | |
| Stratum D | | | | | | | | | | | | | | | | |
| YOY *Ptychocheilus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | 36.36 | | 27.27 | | | 9.09 | | | | | | | 11 |
| Mean number | | | | .455 | | .273 | | | .182 | | | | | | | |
| Mean weight (mg) | | | | 8.521 | | .243 | | | .096 | | | | | | | |
| Percent of stomach content | | | | 96.17 | | 2.74 | | | 1.09 | | | | | | | |
| Percent of item consumed | | | | 100 | | 5.84 | | | 14.82 | | | | | | | |
| YOY *Gila sp.* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | 1 |
| Mean number | | | | | | | | | 1.0 | | | | | | | |
| Mean weight (mg) | | | | | | | | | .22 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |
| Percent of item consumed | | | | | | | | | 3.09 | | | | | | | |
| YOY *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 25 | | | 62.5 | 12.5 | | 12.5 | | | | 8 |
| Mean number | | | | | | .25 | | | 1.125 | .25 | | .125 | | | | |
| Mean weight (mg) | | | | | | .044 | | | .173 | .063 | | 1.526 | | | | |
| Percent of stomach content | | | | | | 2.42 | | | 9.56 | 3.46 | | 84.56 | | | | |
| Percent of item consumed | | | | | | .77 | | | 19.42 | 37.95 | | 24.99 | | | | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 16.67 | 50 | | | 33.33 | 8.33 | | 25 | | | 8.33 | 12 |
| Mean number | | | | | .167 | .5 | | | .333 | .083 | | .25 | | | 2.083 | |
| Mean weight (mg) | | | | | 1.082 | .744 | | | .058 | .021 | | 3.053 | | | .037 | |
| Percent of stomach content | | | | | 21.66 | 14.90 | | | 1.17 | .42 | | 61.12 | | | .73 | |
| Percent of item consumed | | | | | 100 | 19.49 | | | 9.77 | 18.98 | | 75.01 | | | 100 | |
| YOY *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 90.91 | 27.27 | | | | | | | 9.09 | 9.09 | | | | | | 11 |
| Mean number | 1,076.36 | 413.27 | | | | | | | .182 | .091 | | | | | | |
| Mean weight (mg) | .010 | .025 | | | | | | | .009 | .052 | | | | | | |
| Percent of stomach content | 10.49 | 26.27 | | | | | | | 9.45 | 53.79 | | | | | | |
| Percent of item consumed | 50.46 | 15.95 | | | | | | | 1.39 | 43.07 | | | | | | |
| Adult *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 66.67 | | | | 22.22 | | | | | | | | | | 9 |
| Mean number | 1,395.11 | 808.67 | | | | .222 | | | | | | | | | | |
| Mean weight (mg) | .012 | .161 | | | | .0002 | | | | | | | | | | |
| Percent of stomach content | 7.02 | 92.87 | | | | .12 | | | | | | | | | | |
| Percent of item consumed | 49.54 | 84.05 | | | | .00 | | | | | | | | | | |
| YOY *Ictalurus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 100 | | | 100 | | | | | | | |
| Mean number | | | | | | 1.0 | | | 9.0 | | | | | | | |
| Mean weight (mg) | | | | | | 33.85 | | | 3.67 | | | | | | | |
| Percent of stomach content | | | | | | 90.22 | | | 9.78 | | | | | | | |
| Percent of item consumed | | | | | | 73.90 | | | 51.51 | | | | | | | |

Appendix A-2 (continued)
Food item values by stratum

| Stratum | Seston | Macra-fragments | Debris | Fish | Terres-trial | Inverte-brate remains | Hydra-charina | Zoo-plankton | Diptera | Coleop-tera | Trichop-tera | Ephemer-optera | Hemip-tera | Nema-toda | Eggs | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stratum E | | | | | | | | | | | | | | | | |
| YOY *Ptychocheilus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | 53.33 | 6.67 | | | | 46.67 | | | | | | | 15 |
| Mean number | | | | .733 | .067 | | | | 2.2 | | | | | | | |
| Mean weight (mg) | | | | 7.971 | .017 | | | | .81 | | | | | | | |
| Percent of stomach content | | | | 90.60 | .19 | | | | 9.21 | | | | | | | |
| Percent of item consumed | | | | 100 | 90.75 | | | | 60.54 | | | | | | | |
| YOY *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 11.11 | | | | 33.33 | | | | | | 55.56 | | | | 9 |
| Mean number | | .111 | | | | .333 | | | | | | .889 | | | | |
| Mean weight (mg) | | .008 | | | | 1.482 | | | | | | 10.853 | | | | |
| Percent of stomach content | | .06 | | | | 12.01 | | | | | | 87.93 | | | | |
| Percent of item consumed | | 87.40 | | | | 31.59 | | | | | | 18.46 | | | | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 9.09 | | | | 36.36 | | | | | | 100 | 18.18 | | | 11 |
| Mean number | | 0.91 | | | | .364 | | | | | | 3.0 | .273 | | | |
| Mean weight (mg) | | .0009 | | | | 1.873 | | | | | | 36.63 | .068 | | | |
| Percent of stomach content | | .00 | | | | 4.86 | | | | | | 94.97 | .18 | | | |
| Percent of item consumed | | 12.02 | | | | 48.80 | | | | | | 76.15 | 100 | | | |
| YOY *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 84.62 | | | | 7.69 | 15.38 | | 7.69 | | | | 15.38 | | | | 13 |
| Mean number | 4,877.46 | | | | .077 | .154 | | 2.846 | | | | .231 | | | | |
| Mean weight (mg) | .052 | | | | .002 | .0015 | | .023 | | | | 2.192 | | | | |
| Percent of stomach content | 2.30 | | | | .10 | .07 | | 1.02 | | | | 96.52 | | | | |
| Percent of item consumed | 60.79 | | | | 9.25 | .05 | | 100 | | | | 5.39 | | | | |
| Adult *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 1 |
| Mean number | 37,748.0 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .436 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Percent of item consumed | 39.21 | | | | | | | | | | | | | | | |
| YOY *Ictalurus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 12.5 | | | | 37.50 | | | 87.5 | | 12.5 | | | | | 8 |
| Mean number | | .125 | | | | .625 | | | 9.125 | | .125 | | | | | |
| Mean weight (mg) | | .00006 | | | | 1.032 | | | .99 | | .119 | | | | | |
| Percent of stomach content | | .00 | | | | 48.21 | | | 46.24 | | 5.55 | | | | | |
| Percent of item consumed | | .58 | | | | 19.56 | | | 39.46 | | 100 | | | | | |
| Stratum F | | | | | | | | | | | | | | | | |
| YOY *Ptychocheilus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | 11.11 | | 33.33 | | | 44.4 | | | | | | | 9 |
| Mean number | | | | .111 | | .333 | | | 1.11 | | | | | | | |
| Mean weight (mg) | | | | .114 | | 1.602 | | | .541 | | | | | | | |
| Percent of stomach content | | | | 5.07 | | 70.97 | | | 23.97 | | | | | | | |
| Percent of item consumed | | | | 100 | | 54.12 | | | 23.18 | | | | | | | |
| YOY *Gila sp.* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 33.33 | | | 100 | | | | | | | 3 |
| Mean number | | | | | | .333 | | | 2.667 | | | | | | | |
| Mean weight (mg) | | | | | | .677 | | | .923 | | | | | | | |
| Percent of stomach content | | | | | | 42.29 | | | 57.71 | | | | | | | |
| Percent of item consumed | | | | | | 7.62 | | | 13.18 | | | | | | | |
| YOY *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 57.14 | | | 50 | 7.14 | | 7.14 | | | | 14 |
| Mean number | | | | | | .571 | | | .714 | .071 | | .071 | | | | |
| Mean weight (mg) | | | | | | .496 | | | .242 | .018 | | .872 | | | | |
| Percent of stomach content | | | | | | 30.45 | | | 14.87 | 1.10 | | 53.58 | | | | |
| Percent of item consumed | | | | | | 26.07 | | | 16.13 | 49.22 | | 24.99 | | | | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 30.77 | | | 53.85 | 3.85 | | 11.54 | 7.69 | | | 26 |
| Mean number | | | | | | 3.08 | | | 1.038 | .039 | | .115 | .077 | | | |
| Mean weight (mg) | | | | | | .126 | | | .367 | .010 | | 1.409 | .133 | | | |
| Percent of stomach content | | | | | | 6.17 | | | 17.96 | .47 | | 68.89 | 6.51 | | | |
| Percent of item consumed | | | | | | 12.30 | | | 45.42 | 50.78 | | 75.01 | 100 | | | |
| YOY *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 33.33 | | | | | | | | | | | | | | 3 |
| Mean number | 2,605.67 | 5,667 | | | | | | | | | | | | | | |
| Mean weight (mg) | .024 | .0003 | | | | | | | | | | | | | | |
| Percent of stomach content | 98.63 | 1.37 | | | | | | | | | | | | | | |
| Percent of item consumed | 6.49 | 1.73 | | | | | | | | | | | | | | |
| Adult *Pimephales* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 47.06 | | | | | | | | | | | | | | 17 |
| Mean number | 7,176.59 | 18.824 | | | | | | | | | | | | | | |
| Mean weight (mg) | .061 | .003 | | | | | | | | | | | | | | |
| Percent of stomach content | 95.46 | 4.54 | | | | | | | | | | | | | | |
| Percent of item consumed | 93.51 | 98.27 | | | | | | | | | | | | | | |
| YOY *Ictalurus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | 1 |
| Mean number | | | | | | | | | 2.0 | | | | | | | |
| Mean weight (mg) | | | | | | | | | .44 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |
| Percent of item consumed | | | | | | | | | 2.09 | | | | | | | |
| Stratum G | | | | | | | | | | | | | | | | |
| YOY *Ptychocheilus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 50 | | | | | | | | | | 6 |
| Mean number | | | | | | .5 | | | | | | | | | | |
| Mean weight (mg) | | | | | | 937 | | | | | | | | | | |
| Percent of stomach content | | | | | | 100 | | | | | | | | | | |
| Percent of item consumed | | | | | | 23.05 | | | | | | | | | | |
| YOY *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 16.67 | 50 | | 8.33 | 41.67 | | | 8.33 | | | 16.67 | 12 |
| Mean number | | | | | .167 | .5 | | .083 | 3.417 | | | .083 | | | 2.417 | |
| Mean weight (mg) | | | | | .042 | .433 | | .0007 | .129 | | | .677 | | | .042 | |
| Percent of stomach content | | | | | 3.15 | 32.74 | | .05 | 9.76 | | | 51.13 | | | 3.17 | |
| Percent of item consumed | | | | | 22.83 | 21.30 | | 100 | 58.64 | | | 100 | | | 13.91 | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 8.33 | | | 16.67 | 41.67 | | | 41.67 | | 8.33 | | 8.33 | | 16.67 | 12 |
| Mean number | | .083 | | | .333 | .417 | | | .833 | | .083 | | .083 | | 15 | |
| Mean weight (mg) | | .046 | | | .142 | 1.131 | | | .091 | | .079 | | .079 | | .260 | |
| Percent of stomach content | | 2.53 | | | 7.75 | 61.88 | | | 4.97 | | 4.33 | | 4.33 | | 14.21 | |
| Percent of item consumed | | 100 | | | 77.17 | 55.65 | | | 41.36 | | 100 | | 100 | | 86.09 | |
| Stratum K | | | | | | | | | | | | | | | | |
| YOY *Ptychocheilus* | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | 1 |
| Mean number | | | | | | | | | 2.0 | | | | | | | |
| Mean weight (mg) | | | | | | | | | 3.56 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |
| Percent of item consumed | | | | | | | | | 100 | | | | | | | |
| Adult Killifish | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 1 |
| Mean number | 9.461 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .08 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Percent of item consumed | 100 | | | | | | | | | | | | | | | |

Appendix A-3
Food item values for fish species

| Fish species | Seston | Macra-fragments | Debris | Fish | Terres-trial | Inverte-brate remains | Hydra-charina | Zoo-plankton | Diptera | Coleop-tera | Trichop-tera | Ephemer-optera | Hemip-tera | Nema-toda | Eggs | Numbe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YOY *Gila sp.* | | | | | | | | | | | | | | | | |
| Stratum D | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | 1 |
| Mean number | | | | | | | | | 1.0 | | | | | | | |
| Mean weight (mg) | | | | | | | | | .22 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |
| Stratum F | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 33.33 | | | 100 | | | | | | | 3 |
| Mean number | | | | | | .333 | | | 2.667 | | | | | | | |
| Mean weight (mg) | | | | | | .677 | | | .923 | | | | | | | |
| Percent of stomach content | | | | | | 42.29 | | | 57.71 | | | | | | | |
| Stratum VI | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | | | | 100 | | | | 1 |
| Mean number | | | | | | | | | | | | 1 | | | | |
| Mean weight (mg) | | | | | | | | | | | | 17.25 | | | | |
| Percent of stomach content | | | | | | | | | | | | 100 | | | | |
| Juvenile *Gila sp.* | | | | | | | | | | | | | | | | |
| Stratum C | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 100 | | | 50 | | | | | | | 2 |
| Mean number | | | | | | 1.0 | | | 1.5 | | | | | | | |
| Mean weight (mg) | | | | | | 5.11 | | | .795 | | | | | | | |
| Percent of stomach content | | | | | | 86.54 | | | 13.46 | | | | | | | |
| Stratum VI | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 33.3 | 66.67 | | | 66.67 | | 66.67 | 33.33 | | | | 3 |
| Mean number | | | | | .333 | .667 | | | 6.667 | | 7.333 | .333 | | | | |
| Mean weight (mg) | | | | | 5.41 | 42.087 | | | 1.467 | | 6.65 | .19 | | | | |
| Percent of stomach content | | | | | 9.69 | 75.42 | | | 2.63 | | 11.92 | .34 | | | | |
| Stratum IX | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 10 | 25 | | | 25 | 5 | 5 | 25 | | | | 20 |
| Mean number | | | | | .35 | .25 | | | .6 | .05 | .05 | .35 | | | | |
| Mean weight (mg) | | | | | .228 | 3.373 | | | .167 | .013 | .243 | 2.348 | | | | |
| Percent of stomach content | | | | | 3.57 | 52.95 | | | 2.61 | .20 | 3.81 | 36.86 | | | | |
| YOY *Gila robusta* | | | | | | | | | | | | | | | | |
| Stratum VII | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 25 | 66.67 | | | 16.67 | 8.33 | 25 | 33.33 | | 8.33 | | 12 |
| Mean number | | | | | .417 | .667 | | | .333 | .083 | .333 | .500 | | .083 | | |
| Mean weight (mg) | | | | | .396 | 12.155 | | | .127 | .021 | 3.033 | 7.593 | | .0003 | | |
| Percent of stomach content | | | | | 1.70 | 52.10 | | | .54 | .09 | 13.03 | 32.55 | | .00 | | |
| Stratum IX | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 4.76 | | | 9.5 | 52.25 | | | 9.5 | 9.5 | | 42.10 | | 14.25 | | 19 |
| Mean number | | .048 | | | .037 | .523 | | | .095 | .095 | | .474 | | .475 | | |
| Mean weight (mg) | | .010 | | | .072 | 7.736 | | | .012 | .039 | | 7.375 | | .003 | | |
| Percent of stomach content | | .07 | | | .47 | 50.74 | | | .08 | .26 | | 48.37 | | .00 | | |
| Stratum X | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 3.85 | 57.69 | | | 42.31 | | | 15.38 | | | | 26 |
| Mean number | | | | | .038 | .577 | | | .846 | | | .154 | | | | |
| Mean weight (mg) | | | | | .097 | 3.167 | | | .269 | | | 2.033 | | | | |
| Percent of stomach content | | | | | 1.73 | 56.90 | | | 4.83 | | | 36.53 | | | | |
| Juvenile *Gila robusta* | | | | | | | | | | | | | | | | |
| Stratum VI | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | 100 | | | | | | | | | | | | 1 |
| Mean number | | | | 1 | | | | | | | | | | | | |
| Mean weight (mg) | | | | 90.06 | | | | | | | | | | | | |
| Percent of stomach content | | | | 100 | | | | | | | | | | | | |
| Stratum VII | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 5.88 | | | 20.59 | 94.12 | 2.94 | | 17.65 | | 26.47 | 44.12 | | 8.882 | | 34 |
| Mean number | | .059 | | | .206 | .941 | .029 | | .383 | | .853 | 1.676 | | .441 | | |
| Mean weight (mg) | | .083 | | | 1.115 | 67.99 | .0009 | | .074 | | 3.683 | 15.962 | | .001 | | |
| Percent of stomach content | | .09 | | | 1.25 | 76.47 | .00 | | .08 | | 4.14 | 17.95 | | .00 | | |
| Stratum IX | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | | | | 100 | | | | 3 |
| Mean number | | | | | | | | | | | | 2 | | | | |
| Mean weight (mg) | | | | | | | | | | | | 34.5 | | | | |
| Percent of stomach content | | | | | | | | | | | | 100 | | | | |
| YOY *Ptychocheilus* | | | | | | | | | | | | | | | | |
| Stratum A | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 21.88 | | 40.63 | 3.13 | 43.75 | | 6.25 | 46.88 | | | | | | | 32 |
| Mean number | | .281 | | .625 | .031 | .438 | | .063 | 3.031 | | | | | | | |
| Mean weight (mg) | | .0004 | | 19.909 | .030 | 1.364 | | .0019 | .187 | | | | | | | |
| Percent of stomach content | | .00 | | 92.63 | .14 | 6.35 | | .01 | .87 | | | | | | | |
| Stratum B | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 12.5 | 62.5 | | | 87.5 | | | | | | | 8 |
| Mean number | | | | | .125 | .625 | | | 5 | | | | | | | |
| Mean weight (mg) | | | | | .071 | 7.588 | | | .951 | | | | | | | |
| Percent of stomach content | | | | | .83 | 88.12 | | | 11.05 | | | | | | | |
| Stratum C | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | 26.32 | | 5.26 | | | 31.58 | | | | | | | 19 |
| Mean number | | | | .263 | | .053 | | | .744 | | | | | | | |
| Mean weight (mg) | | | | 8.092 | | .043 | | | .197 | | | | | | | |
| Percent of stomach content | | | | 97.11 | | .52 | | | 2.37 | | | | | | | |
| Stratum D | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | 36.36 | | 27.27 | | | 9.09 | | | | | | | 11 |
| Mean number | | | | .455 | | .273 | | | .182 | | | | | | | |
| Mean weight (mg) | | | | 8.521 | | .243 | | | .096 | | | | | | | |
| Percent of stomach content | | | | 96.17 | | 2.74 | | | 1.09 | | | | | | | |
| Stratum E | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | 53.33 | | 6.67 | | | 46.67 | | | | | | | 15 |
| Mean number | | | | .733 | | .067 | | | 2.2 | | | | | | | |
| Mean weight (mg) | | | | 7.971 | | .017 | | | .81 | | | | | | | |
| Percent of stomach content | | | | 90.60 | | .19 | | | 9.21 | | | | | | | |
| Stratum F | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | 11.11 | | 33.33 | | | 44.4 | | | | | | | 9 |
| Mean number | | | | .111 | | .333 | | | 1.111 | | | | | | | |
| Mean weight (mg) | | | | .114 | | 1.602 | | | .541 | | | | | | | |
| Percent of stomach content | | | | 5.07 | | 70.97 | | | 23.97 | | | | | | | |
| Stratum G | | | | | | | | | | | | | | | | |
| Frequeny of occurrence | | | | | | 50 | | | | | | | | | | |
| Mean number | | | | | | .5 | | | | | | | | | | |
| Mean weight (mg) | | | | | | .937 | | | | | | | | | | |
| Percent of stomach content | | | | | | 100 | | | | | | | | | | |
| Stratum K | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | |
| Mean number | | | | | | | | | 2.0 | | | | | | | |
| Mean weight (mg) | | | | | | | | | 3.56 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |

Appendix A-3 (continued)
Food item values for fish species

| Fish species | Seston | Macra-fragments | Debris | Fish | Terres-trial | Inverte-brate remains | Hydra-charina | Zoo-plankton | Diptera | Coleop-tera | Trichop-tera | Ephemer-optera | Hemip-tera | Nema-toda | Eggs | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YOY *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Stratum A | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 80 | 10 | | | | 10 | | | 40 | 10 | | | | | | 10 |
| Mean number | 16,596.6 | .5 | | | | .1 | | | .7 | .1 | | | | | | |
| Mean weight (mg) | .156 | .0004 | | | | .025 | | | .154 | .025 | | | | | | |
| Percent of stomach content | 43.30 | .11 | | | | 6.93 | | | 42.72 | 6.93 | | | | | | |
| Stratum B | | | | | | | | | | | | | | | | 10 |
| Frequency of occurrence | 20 | 10 | | | 30 | 70 | | | 10 | | | | | | | |
| Mean number | 117.6 | 1.1 | | | .4 | .7 | | | .5 | | | | | | | |
| Mean weight (mg) | .0004 | .0001 | | | .132 | .419 | | | .11 | | | | | | | |
| Percent of stomach content | .06 | .02 | | | 19.94 | 63.36 | | | 16.62 | | | | | | | |
| Stratum C | | | | | | | | | | | | | | | | 3 |
| Frequency of occurrence | | | | | | 66.67 | | | 33.33 | | | | | | | |
| Mean number | | | | | | .667 | | | 1.333 | | | | | | | |
| Mean weight (mg) | | | | | | .14 | | | .143 | | | | | | | |
| Percent of stomach content | | | | | | 49.41 | | | 50.59 | | | | | | | |
| Stratum D | | | | | | | | | | | | | | | | 8 |
| Frequency of occurrence | | | | | | 25 | | | 62.5 | 12.5 | | 12.5 | | | | |
| Mean number | | | | | | .25 | | | 1.125 | .25 | | .125 | | | | |
| Mean weight (mg) | | | | | | .044 | | | .173 | .063 | | 1.526 | | | | |
| Percent of stomach content | | | | | | 2.42 | | | 9.56 | 3.46 | | 84.56 | | | | |
| Stratum E | | | | | | | | | | | | | | | | 9 |
| Frequency of occurrence | | 11.11 | | | | 33.33 | | | | | | 55.56 | | | | |
| Mean number | | .111 | | | | .333 | | | | | | .889 | | | | |
| Mean weight (mg) | | .008 | | | | 1.482 | | | | | | 10.853 | | | | |
| Percent of stomach content | | .06 | | | | 12.01 | | | | | | 87.93 | | | | |
| Stratum F | | | | | | | | | | | | | | | | 14 |
| Frequency of occurrence | | | | | | 57.14 | | | 50 | 7.14 | | 7.14 | | | | |
| Mean number | | | | | | .571 | | | .714 | .071 | | .071 | | | | |
| Mean weight (mg) | | | | | | .496 | | | .242 | .018 | | .872 | | | | |
| Percent of stomach content | | | | | | 30.45 | | | 14.87 | 1.10 | | 53.58 | | | | |
| Stratum V | | | | | | | | | | | | | | | | 4 |
| Frequency of occurrence | | | | | | 75 | | | 100 | | | | | | | |
| Mean number | | | | | | .75 | | | 6 | | | | | | | |
| Mean weight (mg) | | | | | | 7.655 | | | .498 | | | | | | | |
| Percent of stomach content | | | | | | 93.90 | | | 6.10 | | | | | | | |
| Stratum VI | | | | | | | | | | | | | | | | 8 |
| Frequency of occurrence | | | | | | 25 | | | 75 | | | | | | | |
| Mean number | | | | | | .25 | | | 3 | | | | | | | |
| Mean weight (mg) | | | | | | .254 | | | .37 | | | | | | | |
| Percent of stomach content | | | | | | 40.71 | | | 59.29 | | | | | | | |
| Stratum G | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 16.67 | 50 | | 8.33 | 41.67 | | | 8.33 | | | 16.67 | 12 |
| Mean number | | | | | .167 | .5 | | .083 | 3.417 | | | .083 | | | 1.417 | |
| Mean weight (mg) | | | | | .042 | .433 | | .0007 | .129 | | | .677 | | | .042 | |
| Percent of stomach content | | | | | 3.15 | 32.74 | | .05 | 9.76 | | | 51.13 | | | 3.17 | |
| Adult *Notropis lutrensis* | | | | | | | | | | | | | | | | |
| Stratum A | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 50 | 10 | | | 10 | | | | 30 | 10 | 20 | | | | | 10 |
| Mean number | 23,403.3 | .1 | | | .1 | | | | 7.4 | 1 | .2 | | | | | |
| Mean weight (mg) | .208 | .0001 | | | .095 | | | | .446 | .25 | 2.44 | | | | | |
| Percent of stomach content | 6.06 | .00 | | | 2.76 | | | | 12.97 | 7.27 | 70.94 | | | | | |
| Stratum B | | | | | | | | | | | | | | | | 10 |
| Frequency of occurrence | 10 | 10 | | | 10 | 70 | | | | | | 10. | | | | |
| Mean number | 105.4 | 2.4 | | | .4 | .7 | | | | | | .2 | | | | |
| Mean weight (mg) | .0002 | .0001 | | | .536 | 9.469 | | | | | | 2.442 | | | | |
| Percent of stomach content | .00 | .00 | | | 4.31 | 76.07 | | | | | | 19.62 | | | | |
| Stratum C | | | | | | | | | | | | | | | | 17 |
| Frequency of occurrence | | | | | 11.76 | 58.82 | | | 29.41 | 11.76 | | | | | | |
| Mean number | | | | | .118 | .588 | | | .294 | .176 | | | | | | |
| Mean weight (mg) | | | | | .319 | 1.275 | | | .059 | .044 | | | | | | |
| Percent of stomach content | | | | | 18.79 | 75.11 | | | 3.50 | 2.60 | | | | | | |
| Stratum D | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | 16.67 | 50 | | | 33.3 | 8.33 | | 25 | | | 8.33 | 12 |
| Mean number | | | | | .167 | .5 | | | .333 | .083 | | .25 | | | 2.083 | |
| Mean weight (mg) | | | | | 1.082 | .744 | | | .058 | .021 | | 3.05 | | | .037 | |
| Percent of stomach content | | | | | 21.66 | 14.90 | | | 1.17 | .42 | | 61.12 | | | .73 | |
| Stratum E | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 9.07 | | | | 36.36 | | | | | | 100 | 18.18 | | | 11 |
| Mean number | | .091 | | | | .364 | | | | | | 3.0 | .273 | | | |
| Mean weight (mg) | | .0009 | | | | 1.873 | | | | | | 36.63 | .068 | | | |
| Percent of stomach content | | .00 | | | | 4.86 | | | | | | 94.97 | .18 | | | |
| Stratum F | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 30.77 | | | 53.85 | 3.85 | | 11.54 | 7.69 | | | 26 |
| Mean number | | | | | | .308 | | | 1.038 | .039 | | .115 | .077 | | | |
| Mean weight (mg) | | | | | | .126 | | | .367 | .010 | | 1.409 | .133 | | | |
| Percent of stomach content | | | | | | 6.17 | | | 17.96 | .47 | | 68.89 | 6.51 | | | |
| Stratum G | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 8.33 | | | 16.67 | 41.67 | | | 41.67 | | 8.33 | | 8.33 | | 16.67 | 12 |
| Mean number | | .083 | | | .333 | .417 | | | .833 | | .083 | | .083 | | 15 | |
| Mean weight (mg) | | .046 | | | .142 | 1.131 | | | .091 | | .079 | | .079 | | .260 | |
| Percent of stomach content | | 2.53 | | | 7.75 | 61.88 | | | 4.97 | | 4.33 | | 4.33 | | 14.21 | |
| Stratum IV | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 50 | 12.5 | | | | 50 | | | 12.5 | 12.5 | | 12.5 | | | | 8 |
| Mean number | 17,388.6 | 1 | | | | .5 | | | .375 | .25 | | .875 | | | | |
| Mean weight (mg) | .155 | .00006 | | | | 14.339 | | | 2.19 | .119 | | .831 | | | | |
| Percent of stomach content | .88 | .00 | | | | 81.32 | | | 12.42 | .67 | | 4.71 | | | | |
| Stratum V | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 3.85 | | | | | 80.77 | | | 65.38 | | | 3.85 | 3.85 | | 3.85 | 26 |
| Mean number | .038 | | | | | .808 | | | .385 | | | .038 | .038 | | .077 | |
| Mean weight (mg) | .0002 | | | | | 9.866 | | | .774 | | | .624 | .187 | | .0002 | |
| Percent of stomach content | .00 | | | | | 16.15 | | | 6.76 | | | 5.45 | 1.63 | | .00 | |
| Stratum VI | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 5 | 2.50 | | | 12.5 | 67.5 | | | 40 | 2.5 | 2.5 | 30 | | | | 40 |
| Mean number | 79.275 | 3.175 | | | .275 | .675 | | | 3.45 | .025 | .025 | .75 | | | | |
| Mean weight (mg) | .0004 | .0001 | | | .398 | 19.761 | | | .791 | .024 | .024 | 12.384 | | | | |
| Percent of stomach content | .00 | .00 | | | 1.19 | 59.19 | | | 2.37 | .07 | .07 | 37.10 | | | | |
| Stratum IX | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 50 | | | | | | | | | | 2 |
| Mean number | | | | | | .5 | | | | | | | | | | |
| Mean weight (mg) | | | | | | .05 | | | | | | | | | | |
| Percent of stomach content | | | | | | 100 | | | | | | | | | | |
| YOY *Notropis stramineus* | | | | | | | | | | | | | | | | |
| Stratum VI | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | 2 |
| Mean number | | | | | | | | | 1 | | | | | | | |
| Mean weight (mg) | | | | | | | | | .145 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |

Appendix A-3 (continued)
Food item values for fish species

| Fish species | Seston | Macra-fragments | Debris | Fish | Terres-trial | Inverte-brate remains | Hydra-charina | Zoo-plankton | Diptera | Coleop-tera | Trichop-tera | Ephemer-optera | Hemip-tera | Nema-toda | Eggs | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Adult *Notropis stramineus* | | | | | | | | | | | | | | | | |
| Stratum VI | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | 5.56 | | | 5.56 | 55.56 | | | 16.67 | | | 5.56 | | | | 18 |
| Mean number | | .056 | | | .056 | .556 | | | .222 | | | .056 | | | | |
| Mean weight (mg) | | .194 | | | .053 | 3.716 | | | .053 | | | .451 | | | | |
| Percent of stomach content | | 4.35 | | | 1.18 | 83.18 | | | 1.18 | | | 10.10 | | | | |
| Stratum IX | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | | | | 100 | | | | | 50 | | | | | 2 |
| Mean number | | | | | | 1 | | | | | 1 | | | | | |
| Mean weight (mg) | | | | | | 2.165 | | | | | 8.535 | | | | | |
| Percent of stomach content | | | | | | 20.24 | | | | | 79.77 | | | | | |
| YOY *Pimephales* | | | | | | | | | | | | | | | | |
| Stratum A | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 50 | 25 | | | | 12.5 | | | | | | | 25 | | | 8 |
| Mean number | 10,030 | .375 | | | | .125 | | | | | | | .5 | | | |
| Mean weight (mg) | .122 | .0001 | | | | .031 | | | | | | | .67 | | | |
| Percent of stomach content | 14.79 | .02 | | | | 3.80 | | | | | | | 81.40 | | | |
| Stratum B | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 13.33 | | | | 6.67 | | 13.33 | | | | | | | | 15 |
| Mean number | 2,136.3 | 70.867 | | | | .067 | | 3.4 | | | | | | | | |
| Mean weight (mg) | .020 | .007 | | | | .0009 | | .027 | | | | | | | | |
| Percent of stomach content | 35.39 | 13.53 | | | | 1.57 | | 49.52 | | | | | | | | |
| Stratum C | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 33.33 | | | | | | | | | | | | | | 3 |
| Mean number | 944.33 | 588.0 | | | | | | | | | | | | | | |
| Mean weight (mg) | .008 | .025 | | | | | | | | | | | | | | |
| Percent of stomach content | 25.15 | 74.85 | | | | | | | | | | | | | | |
| Stratum D | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 90.91 | 27.27 | | | | | | | 9.09 | 9.09 | | | | | | 11 |
| Mean number | 1,076.36 | 413.27 | | | | | | | .182 | .091 | | | | | | |
| Mean weight (mg) | .010 | .025 | | | | | | | .009 | .052 | | | | | | |
| Percent of stomach content | 10.49 | 26.27 | | | | | | | 9.45 | 53.79 | | | | | | |
| Stratum E | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 84.62 | | | | 7.69 | 15.38 | | 7.69 | | | | 15.38 | | | | 13 |
| Mean number | 4,877.46 | | | | .077 | .154 | | 2.846 | | | | .231 | | | | |
| Mean weight (mg) | .052 | | | | .002 | .0015 | | .023 | | | | 2.192 | | | | |
| Percent of stomach content | 2.30 | | | | .10 | .07 | | 1.02 | | | | 96.52 | | | | |
| Stratum F | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 33.33 | | | | | | | | | | | | | | 3 |
| Mean number | 2,605.67 | 5.667 | | | | | | | | | | | | | | |
| Mean weight (mg) | .024 | .0003 | | | | | | | | | | | | | | |
| Percent of stomach content | 18.63 | 1.37 | | | | | | | | | | | | | | |
| Stratum IV | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 7.14 | | | | | | | | | | | | | | 14 |
| Mean number | 4,040.1 | 1.071 | | | | | | | | | | | | | | |
| Mean weight (mg) | .036 | .00004 | | | | | | | | | | | | | | |
| Percent of stomach content | 99.90 | .10 | | | | | | | | | | | | | | |
| YOY *Pimephales* | | | | | | | | | | | | | | | | |
| Stratum VI | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 1 |
| Mean number | 385 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .008 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Stratum VII | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 60 | | | | | | | | | | | | | | 10 |
| Mean number | 6,376 | 7.9 | | | | | | | | | | | | | | |
| Mean weight (mg) | .016 | .074 | | | | | | | | | | | | | | |
| Percent of stomach content | 18.16 | 81.84 | | | | | | | | | | | | | | |
| Adult *Pimephales* | | | | | | | | | | | | | | | | |
| Stratum A | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 83.33 | 33.33 | | | | | | | 33.33 | | | | | | | 6 |
| Mean number | 51,243.3 | 19.667 | | | | | | | 3.167 | | | | | | | |
| Mean weight (mg) | .474 | .002 | | | | | | | .095 | | | | | | | |
| Percent of stomach content | 83 | .35 | | | | | | | 16.65 | | | | | | | |
| Stratum B | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 16.67 | | | | 16.67 | | | | | | | | | | 6 |
| Mean number | 124,622 | 241.83 | | | | .167 | | | | | | | | | | |
| Mean weight (mg) | .112 | .025 | | | | .005 | | | | | | | | | | |
| Percent of stomach content | 78.64 | 17.84 | | | | 3.52 | | | | | | | | | | |
| Stratum C | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 88.24 | 52.94 | | | | 5.88 | | | | | | | | | | 17 |
| Mean number | 2,434.4 | 477.06 | | | | .059 | | | | | | | | | | |
| Mean weight (mg) | .023 | .057 | | | | .0001 | | | | | | | | | | |
| Percent of stomach content | 28.60 | 81.25 | | | | .15 | | | | | | | | | | |
| Stratum D | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 66.67 | | | | 22.22 | | | | | | | | | | 9 |
| Mean number | 1,395.11 | 808.67 | | | | .222 | | | | | | | | | | |
| Mean weight (mg) | .012 | .161 | | | | .0002 | | | | | | | | | | |
| Percent of stomach content | 7.02 | 92.87 | | | | .12 | | | | | | | | | | |
| Stratum E | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 1 |
| Mean number | 37,748 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .436 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Stratum F | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 33.33 | | | | | | | | | | | | | | 3 |
| Mean number | 2,605.7 | 5.667 | | | | | | | | | | | | | | |
| Mean weight (mg) | .024 | .0003 | | | | | | | | | | | | | | |
| Percent of stomach content | 98.63 | 1.37 | | | | | | | | | | | | | | |
| Stratum IV | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 4 |
| Mean number | 11,466.25 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .102 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Stratum VI | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | 28.57 | | | | | | | | | | | | | | 7 |
| Mean number | 117,435 | 39.143 | | | | | | | | | | | | | | |
| Mean weight (mg) | 2.413 | .0219 | | | | | | | | | | | | | | |
| Percent of stomach content | 99.10 | .90 | | | | | | | | | | | | | | |
| Stratum IX | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | 1 |
| Mean number | 42,406 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .718 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| YOY *Catostomus latipinnis* | | | | | | | | | | | | | | | | |
| Stratum IX | | | | | | | | | | | | | | | | |
| Frequency of occurrence | | | 100 | | | | | | 100 | | 25 | 25 | | | | 4 |
| Mean number | | | 1.0 | | | | | | 153.5 | | 12.5 | 9 | | | | |
| Mean weight (mg) | | | 159.86 | | | | | | 5.645 | | 7.125 | 2.263 | | | | |
| Percent of stomach content | | | 91.40 | | | | | | 3.23 | | 4.07 | 1.29 | | | | |
| Stratum X | | | | | | | | | | | | | | | | |
| Frequency of occurrence | 100 | | | | | | | 25 | | | | | | | | 4 |
| Mean number | 4,723.75 | | | | | | | 47 | | | | | | | | |
| Mean weight (mg) | .046 | | | | | | | .005 | | | | | | | | |
| Percent of stomach content | 90.24 | | | | | | | 9.76 | | | | | | | | |

Appendix A-3 (continued)
Food item values for fish species

| Fish species | Seston | Macra-fragments | Debris | Fish | Terres-trial | Inverte-brate remains | Hydra-charina | Zoo-plankton | Diptera | Copeop-tera | Trichop-tera | Ephemer-optera | Hemip-tera | Nema-toda | Eggs | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YOY *Catostomus discobolus* | | | | | | | | | | | | | | | | |
| Stratum VI | | | | | | | | | | | | | | | | 1 |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | |
| Mean number | 3,504 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .063 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Stratum IX | | | | | | | | | | | | | | | | 35 |
| Frequency of occurrence | 100 | 28.57 | | | | | | | 2.86 | | | | | | | |
| Mean number | 432,480 | 10.657 | | | | | | | 1.143 | | | | | | | |
| Mean weight (mg) | 3,887 | .0009 | | | | | | | .034 | | | | | | | |
| Percent of stomach content | 99.10 | .02 | | | | | | | .87 | | | | | | | |
| Adult Killifish | | | | | | | | | | | | | | | | |
| Stratum K | | | | | | | | | | | | | | | | 2 |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | |
| Mean number | 3,587.5 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .078 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Stratum K | | | | | | | | | | | | | | | | 1 |
| Frequency of occurrence | 100 | | | | | | | | | | | | | | | |
| Mean number | 9,467 | | | | | | | | | | | | | | | |
| Mean weight (mg) | .080 | | | | | | | | | | | | | | | |
| Percent of stomach content | 100 | | | | | | | | | | | | | | | |
| Adult *Rhinichthys* | | | | | | | | | | | | | | | | |
| Stratum IX | | | | | | | | | | | | | | | | 14 |
| Frequency of occurrence | | | | | | 14.29 | | | 64.29 | | 57.14 | 57.14 | | | | |
| Mean number | | | | | | .143 | | | 2 | | 1.571 | 1.429 | | | | |
| Mean weight (mg) | | | | | | .874 | | | .554 | | 2.244 | 4.468 | | | | |
| Percent of stomach content | | | | | | 10.74 | | | 6.81 | | 27.57 | 54.49 | | | | |
| YOY *Ictalurus* | | | | | | | | | | | | | | | | |
| Stratum A | | | | | | | | | | | | | | | | 14 |
| Frequency of occurrence | | 14.29 | | | 50 | 7.14 | | 7.14 | 85.71 | 71.43 | 50 | 14.29 | 42.86 | | | |
| Mean number | | .429 | | | 2.143 | .071 | | 2.071 | 609 | 8.714 | 19.214 | .143 | 3.429 | | | |
| Mean weight (mg) | | .189 | | | 3.834 | 1.179 | | .062 | 68.688 | 1.659 | 16.107 | .526 | 3.144 | | | |
| Percent of stomach content | | .20 | | | 4.02 | 1.24 | | .07 | 72.01 | 1.74 | 16.89 | .55 | 3.30 | | | |
| Stratum B | | | | | | | | | | | | | | | | 19 |
| Frequency of occurrence | 10.53 | 10.53 | | | 10.53 | 42.11 | | | 84.21 | 5.26 | 36.84 | | 10.53 | | | |
| Mean number | .105 | .105 | | | .211 | .421 | | | 12.158 | .053 | 11.368 | | .263 | | | |
| Mean weight (mg) | .001 | .053 | | | .053 | 11.281 | | | 2.806 | .132 | 12.155 | | .25 | | | |
| Percent of stomach content | .00 | .20 | | | .20 | 42.20 | | | 10.50 | .49 | 45.47 | | .94 | | | |
| Stratum C | | | | | | | | | | | | | | | | 20 |
| Frequency of occurrence | | | | | | 25 | | | 95 | | 15 | 5 | | | | |
| Mean number | | | | | | .25 | | | 13.25 | | .5 | .05 | | | | |
| Mean weight (mg) | | | | | | 1.634 | | | 7.395 | | .631 | .611 | | | | |
| Percent of stomach content | | | | | | 15.91 | | | 72 | | 6.14 | 5.94 | | | | |
| Stratum D | | | | | | | | | | | | | | | | 1 |
| Frequency of occurrence | | | | | | 100 | | | 100 | | | | | | | |
| Mean number | | | | | | 1.0 | | | 9.0 | | | | | | | |
| Mean weight (mg) | | | | | | 33.85 | | | 3.67 | | | | | | | |
| Percent of stomach content | | | | | | 90.22 | | | 9.78 | | | | | | | |
| Stratum E | | | | | | | | | | | | | | | | 8 |
| Frequency of occurrence | | 12.5 | | | | 37.50 | | | 87.5 | | 12.5 | | | | | |
| Mean number | | .125 | | | | .625 | | | 9.125 | | .125 | | | | | |
| Mean weight (mg) | | .00006 | | | | 1.032 | | | .99 | | .119 | | | | | |
| Percent of stomach content | | .00 | | | | 48.21 | | | 46.24 | | 5.55 | | | | | |
| Stratum F | | | | | | | | | | | | | | | | 1 |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | |
| Mean number | | | | | | | | | 2.0 | | | | | | | |
| Mean weight (mg) | | | | | | | | | .44 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |
| Juvenile *Ictalurus* | | | | | | | | | | | | | | | | |
| Stratum B | | | | | | | | | | | | | | | | 1 |
| Frequency of occurrence | | | | | | | | | 100 | | | | | | | |
| Mean number | | | | | | | | | 96 | | | | | | | |
| Mean weight (mg) | | | | | | | | | 150.36 | | | | | | | |
| Percent of stomach content | | | | | | | | | 100 | | | | | | | |