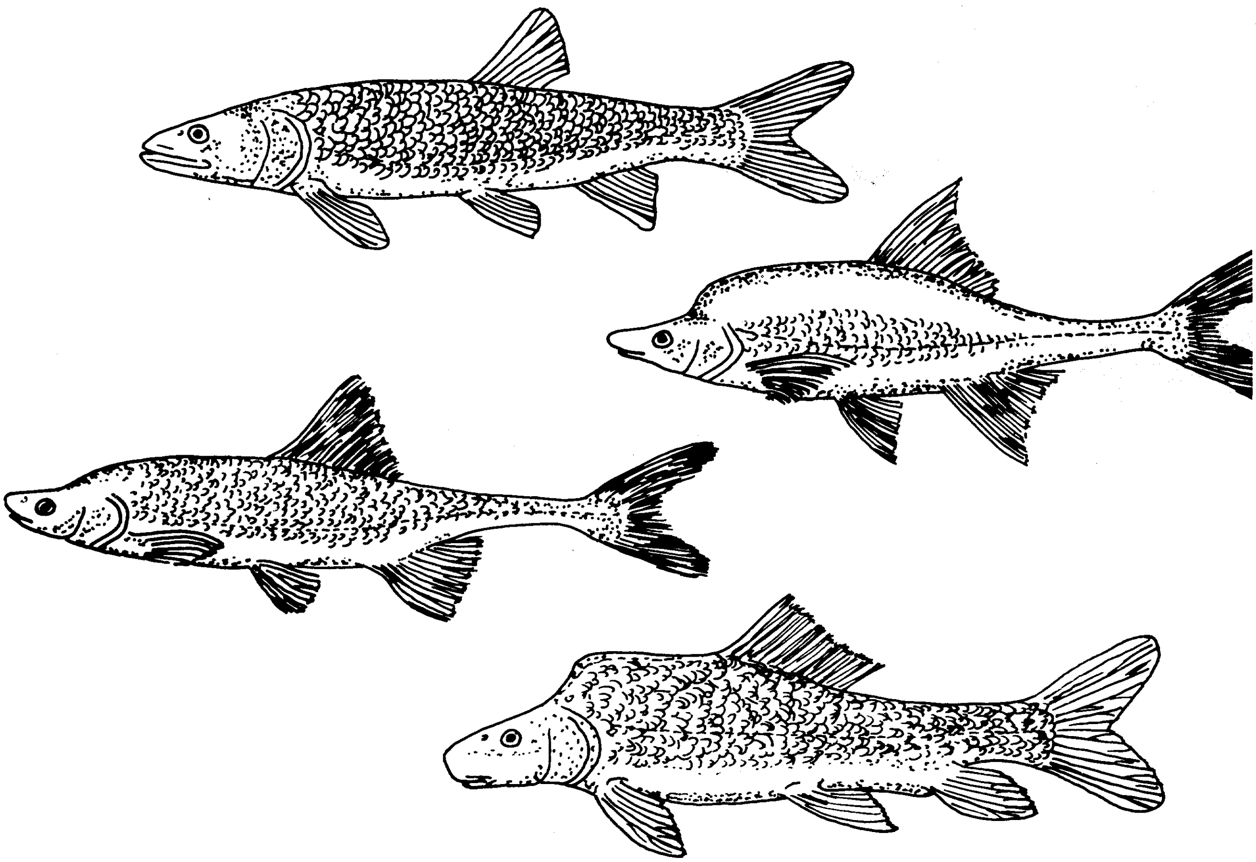
Part 1

Colorado River Fishery Project

FINAL REPORT

SUMMARY



Fish and Wildlife Service
Bureau of Reclamation
Salt Lake City, Utah
April 1982

COLORADO RIVER FISHERY PROJECT

~~PART I~~

Summary Report
Submitted in fulfillment of Contract
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Bureau of Reclamation

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EXECUTIVE SUMMARY

The Colorado River Fishery Report consists of a Summary Report (Part 1) which synthesizes and analyzes Field Investigations (Part 2) and hatchery/laboratory Contracted Studies (Part 3). Those interested in methodology and details of each study should review Parts 2 and 3.

Findings

Colorado squawfish are widespread throughout the Upper Colorado River Basin and do not appear to be concentrated in large numbers in any one location. Numbers of Colorado squawfish appear to be less today than 10 to 20 years ago and may still be declining. Archer (1982) has calculated a 66 percent decline in juvenile and adult Colorado squawfish from 1960 to 1980. The decline in young-of-the-year is even greater with a projected decline of 94 percent between 1960 and 1980. Spawning areas seem to be limited and the life stages of greatest concern are those from spawning through the first year. If adequate spawning and rearing areas cannot be found, protected, and managed, then a species management program with stocking would be required to ensure the continued existence of the Colorado squawfish. Extensive movement of Colorado squawfish was documented with total movement of some individuals over 200 miles. Spawning, migration, and homing behavior was observed and one definite Colorado squawfish spawning site was confirmed in the Yampa River. Movement of Colorado squawfish between mainstem rivers and tributary streams was documented. Blockage of migration routes may be a significant factor in the decline of the species.

Humpback chubs are not wide ranging and are found primarily in four locations (Black Rocks, Westwater Canyon, and Gray Canyon in the Upper Colorado River Basin and the Little Colorado River in the Lower Colorado River Basin). Habitats differ slightly from area to area; however, the chubs appear stable in three of the four locations. Only the Gray Canyon population seems unstable and possibly decreasing at this time. Given the deep and narrow canyon configuration of the Colorado River at Black Rocks and Westwater Canyon, it does not appear that present flow depletions and regulations are limiting factors to the chub in the Upper Colorado River. However, some hybridization with roundtail chub has been documented which may be related to changes in flow and/or temperature. The humpback chubs are very sensitive to temperature and demonstrated a need for temperatures of at least 16-18° C in the spring to successfully spawn and have eggs hatch. Barring significant changes in their habitat humpback chubs should be considered relatively secure at their present population level at Black Rocks and Westwater Canyon in the Upper Basin and in the Little Colorado River in the Lower Basin. The Gray Canyon population, found in the Green River, seems to be decreasing rapidly and will require management programs in the near future if this population is to be maintained.

Few, if any, bonytail chubs still exist in the Upper Basin. A few individual bonytail were found in the Green River in Gray Canyon.

The largest existing population of bonytail chub is found in Lake Mohave in the Lower Basin. The bonytail chub have been artifically propagated in the hatchery where they have produced offspring. At this date it appears doubtful that the bonytail chub will survive without intensive species management.

Razorback suckers, like the bonytail, are rare in the Upper Basin. However, a few razorbacks were observed at spawning time near the Ashley Creek confluence on the Green River, the Walker Wildlife Area, and a gravel pit on the Colorado River near Clifton, Colorado. Reproduction seems to be a major problem and no young razorback have been recorded from the Upper Colorado River in recent years. Almost all fish observed in this study were old individuals. Competition with exotics appears to be a serious problem for the razorback, although only limited data collected during this study and observations recorded in Lower Basin work supports that conclusion. Again, the survival of razorbacks will probably require some intensive species management.

Recommendations

Any program developed to protect the rare Colorado River endemic fishes should focus on three concerns. First, the protection of existing spawning and rearing areas; second, the continued development of habitat improvement areas with associated facilities to ensure propagation and management of the species, in case natural production fails; and third, protection and maintenance of migration routes for Colorado squawfish to ensure access to spawning, feeding, and rearing areas.

A Colorado River endangered fish monitoring program which would evaluate recommended river flow requirements and the use of specific natural and man-made areas by endemic fishes is required. These studies should be reduced in scope to verify flow needs and assess existing reproductive success on known spawning areas. Further, the studies would help arrive at some practical solutions for the propagation of rare fishes which may need intensive management. Potential problems relating to hybridization of chubs may also require monitoring.

Minimum instantaneous flow requirements at selected sites for the Colorado squawfish and humpback chub are presented in the table on the following page. These minimums are based upon computer simulation, physical habitat modeling, and actual flow for 1979-81. The flow of the river at these selected points should not fall below the required level to ensure the present levels of reproductive success. However, it should be noted that the Colorado squawfish populations in many areas are decreasing under present conditions and additional measures will need to be implemented to stabilize or increase the numbers of this endangered species.

Any future water development program in the Colorado River system should be compatible with the known requirements of the endangered Colorado River fishes. The Fish and Wildlife Service is presently developing a conservation plan to provide guidance for future management of the endangered Colorado River fishes. We believe that eventually a management program including habitat improvement, a hatchery, and stocking will be required for some, if not all, of these endangered fishes.

Streamflow and water temperature requirements needed to maintain present production levels for Colorado squawfish[1/] and humpback chub in the Upper Colorado River, data base to 1981

Critical areas	Fish species and life stage	Time period	Flow[2/] (cfs)	Temp.[3/] (C)
Colorado River				
Loma - Utah Line (RM 132-154)	Colorado squawfish spawning and larval stage	6/15-7/31 8/1-8/31	5,000-10,000 3,000-5,000	20-22 20-28
Black Rocks (RM 135-137)	Humpback chub spawning	5/1-6/30	10,000-13,000	16-18
Westwater Canyon (RM 116-124)	Humpback chub spawning	5/1-6/30	10,000-13,000	16-18
Potash - Cataract Canyon (RM 3-47)	Colorado squawfish YOY rearing	7/15-10/15	4,000-9,000	20-28
Green River				
Split Mountain (RM 199-207)	Colorado squawfish spawning	6/15-7/31 8/1-8/31	3,000-4,000 2,000-2,500	20-22 20-22
Jensen - Sand Wash (RM 212-290)	Colorado squawfish YOY rearing	7/15-10/15	2,000-4,000	20-28

1/ Analysis of the last 20 years of information indicates that Colorado squawfish production is declining and present production levels may be inadequate to prevent species from going to extinction.

2/ Flow is given as a minimum range for the period of requirements. For instance, 10,000 cfs at Loma for spawning in mid-June could normally drop to 5,000 by the end of July.

3/ Temperatures are expressed as optimum averages and fluctuations of 1-2° C would be considered normal.

Acknowledgements

Many individuals contributed to the success and completion of the Colorado River Fishery Project Final Reports. First, we would like to recognize the many Colorado River Fishery Project personnel who were instrumental in gathering the data and providing input into this report. FWS field biologists C. W. McAda, R. D. Burdick, R. M. McNatt, K. C. Harper, P. G. Mangan, R. P. Smith and M. A. Zimmerman worked long and arduous hours gathering basic data and analyzing information. C. G. Prewitt assisted the project both as a member of the staff and as a contractor. His assistance in working with physical habitat, modeling, and data interpretation is greatly appreciated. Assistance from FWS fisheries personnel D. L. Skates, B. C. Nilson and F. B. Lilly was also significant. Many temporary Biological Aids worked long and difficult hours assisting in the collection of field data. We appreciated their dedication and commitment.

Appreciation is also expressed to the State of Colorado Division of Wildlife Resources for their cooperative support in gathering and sharing data. Particular thanks goes to Tom Lytle, Nongame Specialist in Grand Junction for his assistance in our work in Colorado. Also, we would like to thank the Utah Division of Wildlife Resources for the use of the Logan Fisheries Experiment Station and for the cooperation and assistance they gave us, particularly Douglas Day, Al Heggen, Donald Andriano and Ronald Goede. We would like to acknowledge J. F. Rinckel, Projects Manager of the Bureau of Reclamation Grand Junction Projects Office, and his staff for their tolerance, cooperation and assistance in carrying out this project.

Our reports could not have been completed without the assistance of the Bureau of Reclamation, Upper Colorado Regional office staff. Particular thanks are expressed to the Reports Branch, the Word Processing staff, and Drafting staff. Vera Kirk of the Reports staff spent many long hours editing and in final preparation of this report. Also, Bureau of Reclamation Biological Studies staff, Reed Harris and Bob Williams, deserve special recognition for their assistance on this project for original project design, assistance in field work, and report editing.

Secretarial and administrative duties for this project were handled quite capably by Cecelia Swainston, Barbara Hayden, and Marge Burfield of the CRFP staff.

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Finally, we would like to acknowledge Bob Shields, Deputy Regional Director of Region 6 of the FWS for his efforts in getting this project initiated, and his continued support of project goals and objectives.

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INTRODUCTION

The activities described in this report were undertaken in June of 1979 in accordance with Memorandum of Understanding (MOU) No. 9-06-40-L-1016 between the U.S. Fish and Wildlife Service (FWS) and the Bureau of Reclamation (BR). Additional funds were provided by the Bureau of Land Management (BLM) during 1980 and 1981 to address special concerns peculiar to their land management responsibilities including the White River. This report is also intended to partially fulfill specifications of MOU No. CO-910-MU9-933 under which those funds were committed.

Fisheries investigations in the Upper Basin were further expanded during 1981 through agreements with the National Park Service and special appropriations directly from Congress. This expansion extended investigations into Dinosaur National Monument and the Yampa River above the monument.

Subjects MOU's prescribed a comprehensive investigation of all facets of the life histories of the Colorado squawfish Ptychocheilus lucius, humpback chub Gila cypha and the bonytail chub Gila elegans; species listed as endangered under the National Endangered Species Act (ESA) of 1973, and the razorback sucker Xyrauchen texanus, recognized as rare by most investigators acquainted with the Colorado River's aquatic fauna. The technical reports describing the specific research conducted under this program are contained in Parts 2 and 3 of this three-part report.

BR and FWS undertook this study to acquire needed biological information on the endangered Colorado River fishes so both agencies could meet their requirements under the ESA, including the amendments of 1978. BR entered into the study agreement to acquire data because it is operating and developing water resource projects in the Upper Colorado River Basin which have and will affect and alter the physical and aquatic environment of the Colorado River. FWS entered into this agreement because data were urgently needed on these endangered fishes in order to render Biological Opinions under Section 7 of ESA and to provide BR with impact analyses and recommendations concerning BR operating and proposed projects. The primary objective of this study was to acquire the needed information so both agencies could work together to ensure survival and recovery of the endangered Colorado River fishes in their native ecosystems.

Scope of Study

The MOU between FWS and BR contained a sizeable list of biological studies needed for the four target species. Broad areas of investigation of the four target species included: spawning requirements; young and adult habitat requirements; migratory behavior; interspecific competition; predation and food habits; temperature, salinity, and chemical effects; cultural technologies; disease and parasite diagnostics; and taxonomic classification.

BR's responsibility under the MOU to provide the hydraulic and physicochemical modeling for the Upper Basin was transferred to FWS in 1980 by amendment. This work was then delegated to the FWS Western Energy and Land Use Team's (WELUT) Instream Flow Group (IFG). A second amendment to the MOU provided for investigation of the humpback chub in the vicinity of the Little Colorado River in the Lower Colorado River Basin, which was concluded in March 1982. A third amendment expanded field investigations to the Dolores and Gunnison Rivers during 1981. A final report for the Dolores and Gunnison studies was completed in February 1982 and is contained in Part 2, Field Investigation.

A study of fish fauna under the MOU with BR included the Upper Colorado River from Lake Powell to Debeque, Colorado, and the Green from its confluence with the Colorado River upstream to Split Mountain Gorge (Figure 1), a total of 575 river miles (RM). A major objective was to determine relative abundance and distribution of the target species and to describe the habitats for which they exhibited preferences or were critical to some phase of their life cycle. In order to meet these objectives and limit bias, a sampling program was developed which avoided bias in the treatment of all habitats and permitted statistical analysis of results. Sampling program design and detailed methods of acquiring data are detailed in Part 2 under the various individual reports.

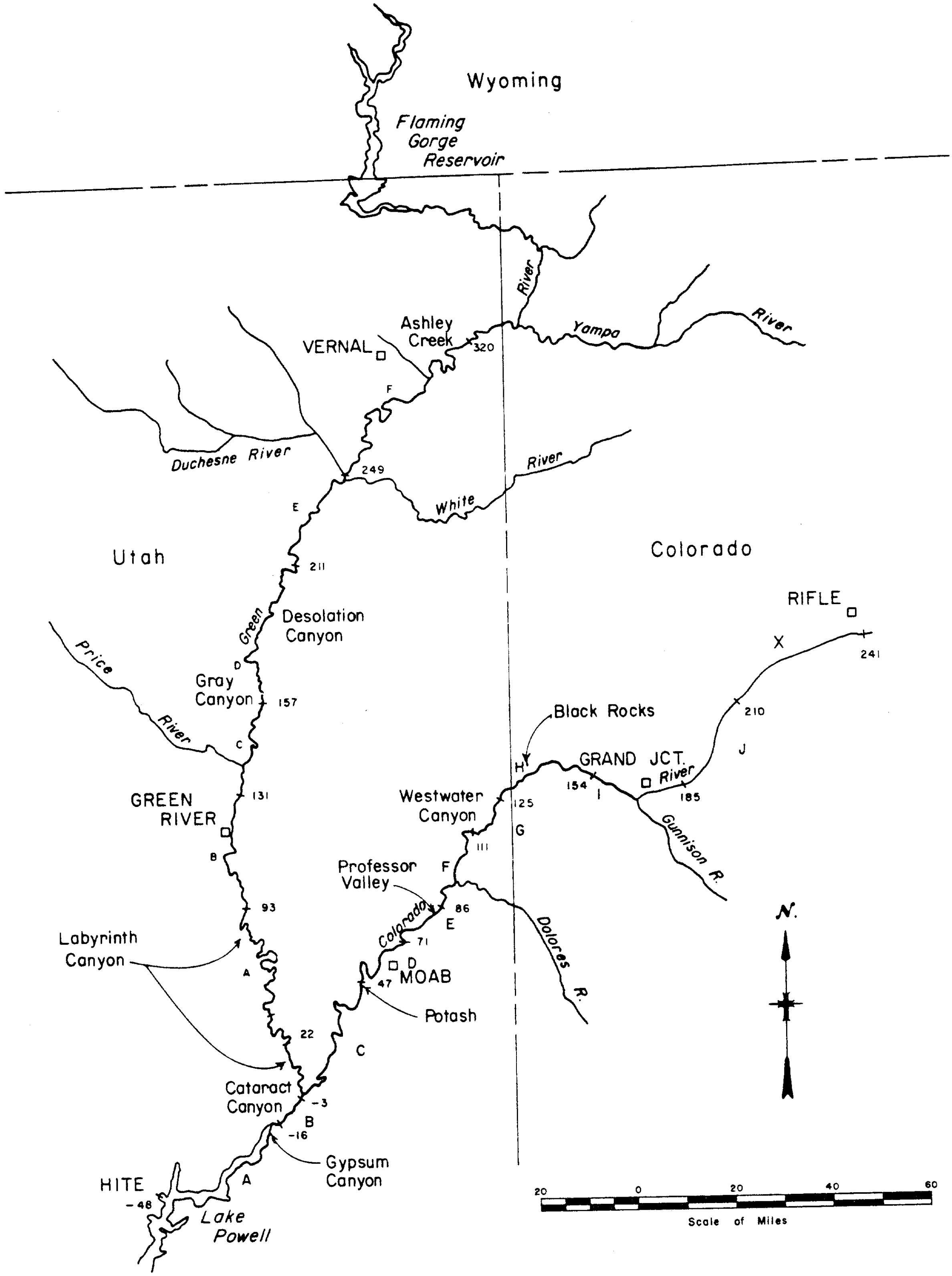
Other field investigations addressed life histories and environmental needs of the target fish. These included a description of spawning, migration, disease, tolerances to natural and artificial chemical compounds, interspecific competition, food supply, taxonomy, and predation by striped bass.

Water turbidity precluded direct observation, therefore, all hypotheses were extrapolated from fish captures and telemetry. One solution was to directly observe the northern squawfish which inhabit streams of much greater clarity in the Columbia River Basin. The Idaho Cooperative Fishery Unit conducted *in situ* behavioral studies of the northern squawfish, one of only two closely related squawfish, as a surrogate to the Colorado squawfish. Another approach was to attach radio transmitters to a number of larger fish and to follow their activities with directional radio receivers.

Program objectives also included laboratory studies of Colorado squawfish including swimming stamina, temperature tolerance and preferences, total dissolved solids (TDS) tolerance and preferences, and bioassay tests for potentially toxic trace elements. These investigations were contracted to the Utah and Idaho Cooperative Fishery Research Units at Logan, Utah, and Moscow, Idaho, respectively.

Included in the overall program was an investigation of the culture of the target species to fulfill the need for laboratory specimens and to advance cultural technologies. These activities were centered at the Willow Beach National Fish Hatchery on the Colorado River near Las Vegas, Nevada, with satellite programs at the Utah State Fisheries Experiment Station at Logan and Dexter National Fish Hatchery near Roswell, New Mexico. These programs included the use of hormones to induce spawning, incubation of eggs, and rearing of fry and older fish.

Figure 1



Colorado River Fishery Project study area, sample strata and associated river miles.

The taxonomy of the three endemic *Gila* species also was investigated. A review of the meristic characteristics of these fish by FWS field staff and several noted taxonomists was undertaken along with cytogenetic karyotyping of the various *Gila* spp. by a scientist at the University of Utah. In addition, tissue from *Gila* spp. was provided to workers at Arizona State University for electrophoretic analysis.

The changes in riverine fish habitat with changes in flow were determined by conducting hydraulic flow simulations based on the FWS program of IFG flow modeling. Three representative sites were modeled on the Colorado River and three were modeled on the Green River. The results or predictions from these modeling efforts were correlated to the critical habitat needs of the endangered fishes to assist in establishing flow needs. In concert with this flow modeling effort, water temperature modeling was also conducted to relate flows and temperature and also temperature needs of the various life stages of the target fish.

HABITAT AND GEOPHYSCIAL CHARACTER, UPPER COLORADO RIVER BASIN

The width, depth, and physical characteristics of streams of the Upper Colorado River Basin vary greatly by geographic area and with flow volume. Some of the deeper areas in the Upper Colorado River were Cataract Canyon with maximum depths of 92 feet, and Black Rocks and Westwater Canyons with maximum depths of about 60 feet. In the Green River a maximum depth of about 60 feet was recorded for Gray Canyon and up to 28-foot depths were recorded for the Lower Green River in Labyrinth Canyon. Average depths for cross sections of the different river strata varied from about 2 feet to over 60 feet.

Various habitats in the Upper Colorado River were quantified at key locations using computer modeling methodology developed by the FWS IFG (Part 3, Report No. 1). Three hydraulic simulation stations were established on the Green River: Mineral Bottom (RM 56), Gray Canyon (RM 141), and Ouray (RM 248); and three stations on the Colorado River at Potash (RM 53), Moab (RM 73), and Black Rocks (RM 136). Analyses were made to evaluate potential habitats available for young squawfish and adult humpback chub at these sites.

Flow changes in the Upper Colorado River were compared by hydrologic time series at the six hydraulic stations. U.S. Geological Survey (USGS) gaging station flow records for 1960-1980 were compared to simulated flows depicting: (1) flow conditions without any development and (2) flow conditions with 1980 development projected from historic conditions. Temparature modeling was also done to determine the effect of flow changes on river temperatures at the key hydraulic stations.

The IFG analysis shows significant peak flow reductions on both the Green and Colorado Rivers. Average monthly peak flows in the Colorado River have been reduced by about 35 percent and the Green River has experienced similiar reductions of 25-40 percent. Instantaneous peaks (daily maximum flows) have changed as indicated by an analysis of the 10 percent exceedance flows for the period before major impoundments and the period after. As shown in Table 1 the peak flow depletions in May, June, and July have all been greater than 20 percent with maximum depletions near 37 percent. Manipulation of flow regimens by reservoir regulation has resulted in higher low flows (fall and winter) and lower peak flows (spring and early summer).

Table 1
Changes in peak flow in the Green and
Colorado Rivers as a result of major impoundments1/

Colorado River		Green River	
Month	Percentage depletion2/	Month	Percentage depletion
May	20.4	May	28.7
June	34.6	June	36.9
July	36.7	July	36.5
August	15.3	August	7.0

1/ Pre-impoundment period - Colorado River 1914-1965, Green River 1947-1962. Post-impoundment period - Colorado River 1969-1981, Green River 1964-1981. A 2- to 4-year reservoir filling period was eliminated from the analysis.

2/ Depletion percentages based on the changes in the 10 percent exceedance flow parameter, i.e., an analysis of those peak flows occurring 10 percent of the time before and after development.

With reduced peak flows, water temperatures are warming more quickly during the spring runoff period in the Colorado River. The opposite occurs in the Jensen area of the Green River with cold water from Flaming Gorge Reservoir depressing temperatures during the summer.

Historic conditions on the Colorado River system no longer exist. Peak flows have been drastically reduced, altering the sediment transport of the river system. Based on an analysis of long-term sediment records collected by the USGS, approximately 1.6 million tons per year of sand and smaller sized sediment accumulates between the Jensen and Ouray gages on the Green River. The majority of this storage may occur within the short reach between the White River confluence and the Ouray gage. At the Green River, Utah, gage the sediment storage is approximately 2 million tons per year. These figures represent imbalance which is normally indicative of moderate aggradation conditions. Thus, materials entering the Green and Colorado Rivers via tributaries during runoff are not efficiently flushed through the system. Sediment entering the rivers is accumulating in sand bars and filling the main river channel. There are now more silt/sand areas, braided channels, and aggradation of the main river channel with a reduction of deep runs, clean gravel/rubble areas, and the frequency and duration of overbank flows. A shallower, wider, and warmer river has resulted which fluctuates less seasonally but substantially more on a daily basis. These changes seem to benefit the introduced (exotic) fishes while having detrimental effects on the endemic endangered species.

Some sections of the Upper Colorado River Basin are impacted by daily flow fluctuations as a result of power generation. The Upper Green River is such an area where daily flow fluctuations are evident, especially under reduced flow conditions. The daily fluctuations during the spawning and young-of-the-year (YOY) rearing period are having an impact on both Colorado squawfish and humpback chub survival. The area of impact of daily flow fluctuation is dependent upon the degree of flow change and the base flow level. However, in the Upper Green River this area of impact extends from Flaming Gorge Dam downstream beyond Ouray and possibly as far as Sand Wash.

DISTRIBUTION AND LIFE HISTORY OF MAJOR FISHES

Colorado Squawfish

Distribution and abundance

Colorado squawfish were captured throughout a major portion of the study area. Adult Colorado squawfish had widespread distribution, probably a reflection of their predatory nature and specific requirements for different habitats at different times of the year. Juvenile and YOY squawfish exhibited a less widespread distribution, which was probably attributed to an affinity for more localized habitats.

Investigations over the past 2-1/2 years indicated adult Colorado squawfish inhabited approximately 360 miles of the mainstem Green River, 150 miles of the White River, (Miller et al. 1982a) and 107 miles of the Yampa River (Miller et al. 1982b). Colorado squawfish were collected in 200 miles of the mainstem Colorado above Lake Powell and from the lower 30 miles of the Gunnison River. No squawfish were captured in the Dolores River.

Standardized sampling indicated 41 percent of the adult squawfish collected from the main Colorado were from a 50-mile reach between RM 125 and 175, the section of river between Grand Junction downstream to the head of Westwater Canyon. Black Rocks, a unique 1-mile reach within this section, accounted for 36 percent of all adults captured.

In the Green River and its tributaries, adult Colorado squawfish were more prevalent in those reaches having a moderate gradient and less incised channel, and less abundant in canyon reaches. Reaches between Split Mountain Gorge (RM 320) and the head of Desolation Canyon (RM 212) and from the lower end of Gray Canyon (RM 132) to the confluence of the Green and Colorado Rivers produced 90 percent of the adult Colorado squawfish catch (Table 2). From 1979 to 1981, 30 adult and 7 juvenile Colorado squawfish were tagged in the Green River within 3 miles of the mouth of the White River. This represents 29 percent of all Colorado squawfish tagged from 300 miles of the Green River (Miller et al. 1982b).

Table 2 also demonstrates the occurrence of more large fish at the upstream river locations and smaller YOY fish in the lower section. This information supports the upstream spawning movement theory and downstream YOY drift theory, which are covered in more detail in the section on Migration and Movement.

Table 2
Colorado squawfish captures in the Colorado and Green Rivers, Standardized sampling, 1979-1981

Size Class	Strata[1/] A	B	C	D	E	F	G	H	I	J
Colorado River										
Young-of-the year		11	285	17	15	3	2	3		
Juvenile		3	36	14	6	3	1	2		
Adult			9	3	6	5	1	16	3	4
Green River										
Young-of-the-year	276	106	32	23	160	320				
Juvenile	82	28	28	4	95	43				
Adult	9	13	3	4	17	22				

1/ See Figure 1 for strata location. Each strata represents a homogenous river section systematically sampled. Strata range from A, the lowest sections of the rivers, to F on the Green River and J on the Colorado, the highest sections.

Juvenile squawfish were scarce in most collections, probably due to gear selectivity. General trends in juvenile distribution showed the squawfish more prevalent in the lower 100 miles of the main Colorado River above Lake Powell (Figure 2). Juveniles were more prevalent in the Green River between the White River's confluence and Desolation Canyon, and in Labyrinth Canyon (Figure 3).

Collections of larvae in the lower 20 miles of the Yampa River in 1981 documented the first spawning grounds for Colorado squawfish. Collections of large numbers of larvae in the Green River below Split Mountain and Gray Canyons indicated that these areas too may have spawning grounds (Figure 3). Work in the Yampa and Green Rivers indicated a downstream drift of Colorado squawfish larvae. Larval squawfish apparently drifted downstream away from the swifter, more harsh environments that provide suitable spawning habitat into the more moderate river reaches with a greater prevalence of the needed backwaters and other quiet water niches.

In the Colorado River the picture is not as clear for YOY distribution (Figure 2). Collections of a few larvae below Loma (RM 154) and the presence of apparently good spawning habitat suggests that spawning occurred between Loma and Black Rocks. Most YOY squawfish in the Colorado River were collected between Potash (RM 47) and the head of Cataract Canyon (RM 3). This distribution suggests: (1) poor or no survival from the upstream spawning activity; (2) drift of larvae may have been more extensive, over 100 miles, than anticipated, perhaps because of the absence of good nursery habitat for a considerable distance downstream of Loma; (3) the YOY fish may have come from the Green River, since the Green River empties into this section and may be the source of many of these small Colorado squawfish although YOY would have to swim upstream from the confluence; and (4) spawning may have occurred in the Professor Valley area (RM 78) from which these YOY could have emigrated.

Figure 2

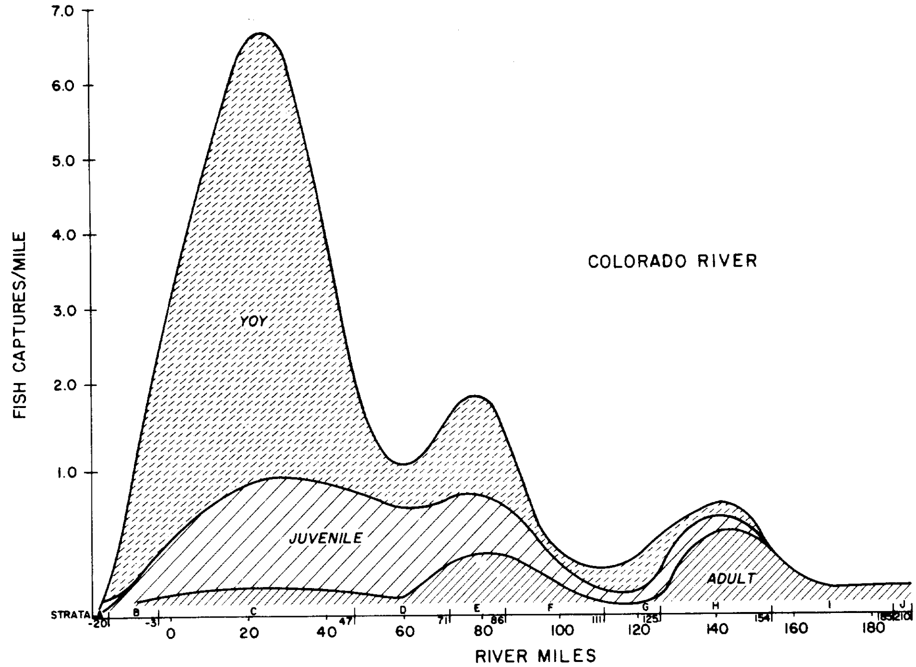
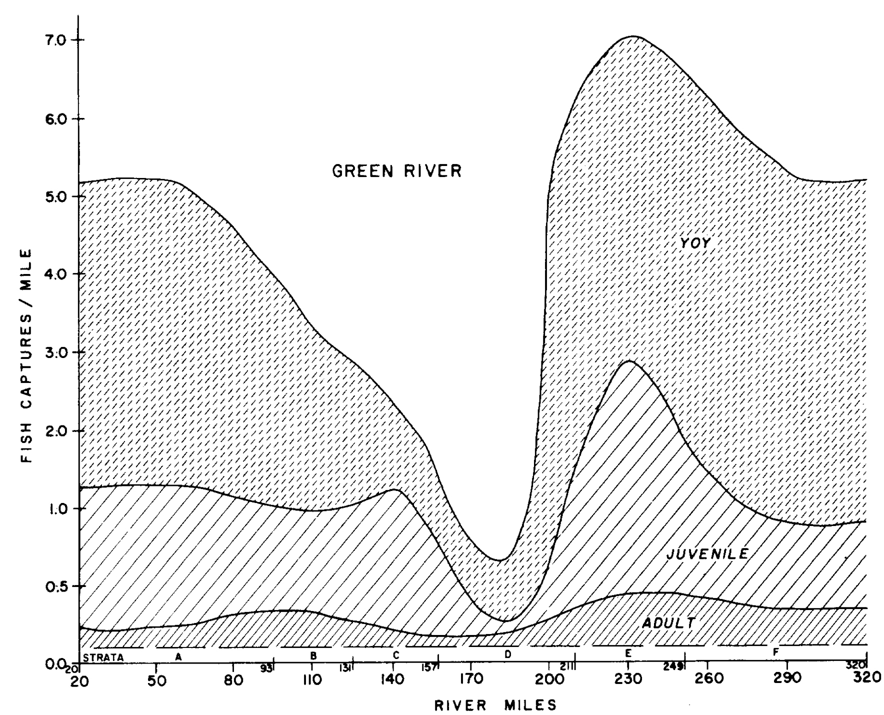


Figure 3



Relative abundance of Colorado squawfish
by size classes, 1979-81.

Migration and movement

Tagging programs in the main Colorado River documented movement patterns of Colorado squawfish. One hundred forty-four wild adult Colorado squawfish were tagged between July 1979 and July 1981, of which, seven were recaptured. No extensive movement was documented for these squawfish and maximum distance between tagging and recapture site was about 20 miles. In February 1980, approximately 1,500 hatchery-reared adult Colorado squawfish, age group V, were released near Moab on the Colorado River. One of 13 recaptured hatchery fish moved approximately 46 miles in a year, with others moving lesser distances.

In the Green River, tagging and radiotracking programs provided additional information on movements and spawning migration. One hundred eighteen fish were tagged between July 1979 and July 1981, of which 14 were recaptured. Extensive movement was noted with one fish moving over 200 miles in slightly over a year and another moving over 100 miles. These two recaptures also exhibited movement from the Green River into the Yampa River. The Yampa and White Rivers studies (Miller et al. 1982a, 1982b) have confirmed major movement patterns into both the White and Yampa Rivers.

Six adult Colorado squawfish were implanted with radio transmitters in the Green River in April and May of 1980. Four of these fish were tracked for over 4 months. Two of them moved extensively, up to 284 miles and 223 miles, while two remained rather stationary. Eight adult Colorado squawfish were radio-tagged in the Green River during April and May of 1981. One fish moved about 217 miles in about 4 months and the others showed lesser movement. Other associated radio tagging studies conducted by FWS in the Yampa and White Rivers also support movement patterns between the Green River and its tributaries.

Tagging studies showed that adult Colorado squawfish exhibit a migratory behavior during spawning season. Upstream and downstream spawning movement of over 100 miles has been documented. Also, in the White and Yampa Rivers, upstream and downstream movement apparently occurs in association with spawning. There is evidence of homing behavior with radio-tagged fish returning to areas where they were originally tagged following extensive migration (Miller et al. 1982b). Upstream spawning movement and subsequent dispersion following a short spawning period was also noted in northern squawfish (Part 3, Report No. 2). Thus, Colorado squawfish spawning behavior appears somewhat similar to northern squawfish.

As the spawning season approached in 1980 and 1981, adult, radio-tagged Colorado squawfish exhibited increased activity and migrated considerable distances. In 1981, seven of these tagged fish traveled to spawning grounds in the Lower Yampa River. This run lasted only a short time. Fish were on the spawning grounds approximately 10 days before dispersing back to the vicinity of their original capture. (Miller et al. 1982)

Movement of Colorado squawfish may also be related to flow, temperature, and/or feeding. Adults were recorded further upstream in the mainstem rivers and in tributaries, such as the Yampa and White, during postrunoff than in prerunoff periods. Downstream movement occurs between postrunoff in the late fall and winter, and runoff the following spring-summer. Downstream movement is probably related to cold water temperatures in the fall, inactivity, and selection of deep pool overwintering areas.

Adults and juveniles appear to exhibit flow-related habitat preferences by leaving main channel habitats during peak runoff and moving into backwaters, tributary streams, side channels, and irrigation-return streams. These lower velocity areas appear to be important during runoff as shelter from high velocities and also as feeding areas.

The large number of adult Colorado squawfish in the upper reaches of both the Colorado and Green Rivers during the spawning and post-spawning periods and the large numbers of YOY in lower river reaches suggest spawning occurs in the upper river canyons and lower tributaries and rearing occurs in mainstem river reaches.

From collections of larvae and YOY Colorado squawfish in the Green River, we conclude there is a downstream drift of larvae and YOY following hatching. This movement appears to be for approximately 50-110 miles, based upon distribution of YOY Colorado squawfish and known or suspected spawning areas in the Green River. This drift phenomenon also appears to exist in the Colorado River, but distance of movement is not as well known. There is also evidence that juvenile fish move progressively upstream, including lower sections of tributary streams (Miller et al. 1982a).

Observations of YOY and juvenile squawfish in backwaters suggest different movement by the two age groups of fish. YOY moved between shoreline runs and backwaters, apparently preferring the warmer water temperature; they moved into backwaters in late morning and left at night. Juveniles seemed to move out of backwaters in the morning and into backwaters in the evening. Both adults and juveniles were more active in shallow water at dawn and dusk, suggesting twilight feeding activity of a piscivorous nature.

Habitat selection

Observations on water depth and velocity and the predominant substrates were recorded for Colorado squawfish capture sites and for radio-tagged squawfish. As a result, a massive amount of data was generated for different size groups of squawfish and other species. A third body of data was generated under these investigations utilizing the northern squawfish as a surrogate to the Colorado squawfish (Part 3, Report No. 2.)

The life stages that appear to be the most critical for the Colorado squawfish are from spawning through the first year. These phases of Colorado squawfish development are also tied closely to specific habitat requirements. Little is known about Colorado squawfish between 60 and 200 mm TL (total length). Therefore, this stage may also be determined to be critical.

Spawning is a highly vulnerable period for most fishes including the Colorado squawfish. Therefore, a relatively minor environmental change can be devastating to reproductive success. Spawning habitats appear limited and apparently must meet some very rigid requirements.

An additional hazard to eggs and larvae is suffocation. While adult fish may succeed in spawning, the squawfish, like most cyprinids, is a broadcast spawner and neither makes nor guards a nest. Once the eggs are deposited, if they become covered with silt or debris, lack of water exchange will cause their death through lack of oxygen or buildup of metabolites around and within the egg. Also, larvae may be trapped physically. Beamesderfer and Congleton (Part 3, Report No. 2) have shown that large numbers of male northern squawfish seek out gravel substrate that is clean and the right size for egg deposition and hatching. The motion of these males forces eggs deep into the gravel, up to 15 cm, and may keep the gravel silt and sand free. Peak flows and large numbers of male Colorado squawfish no longer occur in the Green and Colorado Rivers and, consequently, the quality and availability of suitable spawning areas may be greatly diminished and may be a limiting factor.

The lower 18 miles of Yampa River contained several areas which appear suitable for Colorado squawfish spawning, but other areas have also been suggested. An identified spawning area at RM 16.5 on the Yampa River provided an interspersion of rapids and deeper pools. This area provided clean cobble in relatively deep water, 3-7 feet, of moderate current, 0-2.8 feet/second, similar to conditions sought out by northern squawfish in the St. Joe River in Idaho for spawning.

The migrations of eight radio-tagged adult Colorado squawfish to this one locale, the capture of many other ripe adults, and the collection of very small larvae downstream are conclusive proof that Colorado squawfish congregated in this localized area to spawn (Miller et al. 1982b). Similar behavior was observed for the northern squawfish where a major portion of that population spawned at a few confined sites (Part 3, Report No. 2). A critical key to preserving the Colorado squawfish is the preservation of spawning sites and the maintenance of conditions conducive to egg survival. Sufficiently high flow on a regular basis to flush the fine sediment out of the cobble areas utilized for spawning is a prerequisite for ensuring egg survival.

Indications are that larvae drift downstream into more moderate reaches which offer sanctuaries in the form of ephemeral backwaters. This drift appears to be up to 110 miles. YOY fish have exhibited such a strong attraction to riverine backwaters that one can only conclude that backwaters are very critical to their survival. There is a danger in comparing off-channel gravel pits or other artifical quiet-water areas with natural riverine backwaters. Most of these man-made gravel pit areas are not beneficial habitats in part because of the extensive exotic, (particularly Centrarchid), populations harbored there. Off-channel gravel pits present an alien environment to the younger squawfish and may have negatively impacted main-channel populations by providing a source of recruitment of exotic species to the river. It is believed that many of the exotics can reproduce in man-made gravel pits and thus provide a chronic source of predation. Natural backwaters preferred by Colorado squawfish are ephemeral in nature and may last only a few months.

From late summer through the fall, YOY squawfish preferred natural backwater areas of zero velocity and less than 1.5 feet in depth over a silt substrate. Where these habitats were prevalent, substantial numbers of YOY squawfish were collected. Where they were lacking, few YOY were found. Similar selective behavior was observed during the early spring prior to runoff. During and after heavy runoff few young Colorado squawfish were captured. It is not known whether their behavior changed drastically in preference for other, less effectively sampled habitats or if these fish experienced high mortalities during runoff.

Juvenile Colorado squawfish (60-200 mm TL) exhibited habitat preferences similar to the YOY fish but appeared to be more mobile and adaptable to conditions away from the sheltered environment provided by backwaters. Collections demonstrated a preference for negligible velocity and silt substrate but the range of conditions where juveniles were caught extended into faster velocities and larger substrates than for YOY. Juvenile Colorado squawfish exhibited a preference for greater depths, averaging between 1.2 and 3.3 feet. Depth preferences were deeper for the Colorado River than the Green River, probably because of a greater availability of deeper waters in the Colorado rather than a difference between populations. We interpret juvenile habitat preference as representing an intermediate phase in the shift from the backwater requirements of YOY to the deeper, main channel eddy and shoreline habitats preferred by the adult squawfish.

Adult Colorado squawfish sought out habitats of moderate depths between 3 and 6 feet, with velocities of less than 1.0 foot per second. During the runoff period they appeared to select areas away from the main channel that provided velocities below those observed during other times of the year. Generally, Colorado squawfish larger than 400 mm preferred habitats adjacent to the main river channel or shoreline areas that offered some depth (not necessarily the greatest depths available in the area) and protection from higher velocities. They were found to sometimes venture into backwaters, side channels, and other off-stream habitats during early evening and morning. Beamesderfer and Congleton (Part 3, Report No. 2) observed northern squawfish in a wide range of conditions but found them to prefer moderate to deep depths, 1.3-9.5 meters (4.3-31.2 feet), and low to moderate velocities (bottom velocity 0.2-1.4 feet/second) during daylight. They suggest that northern squawfish behavior probably changed during darkness because they were captured in nets in areas where they were rarely seen in daylight times. It is possible that these captures probably were a result of a foraging activity during the period of darkness and not an example of a change in preferred habitats for resting periods or times of inactivity.

The depths and velocity selected by Colorado squawfish were analyzed (ANOVA) and a significant difference (PLOI) existed between Colorado squawfish >200 mm in length and squawfish <200 mm. Juvenile (<200 mm) and YOY Colorado squawfish were similar in behavior and habitat selection. They were most often caught in backwaters, but diel movements between the backwaters and the main river were observed. Apparently the backwater provides cover, food, and warmer temperatures during the day and through the evening hours. However, in the early morning hours when the main channel temperatures were equal to or higher than those found in the backwaters, the young fish moved out into the main channel.

We generally concluded that adult Colorado squawfish are demanding in their habitat needs during spawning and in post-runoff. Suitable habitats appear to be quite rare for spawning throughout much of the Upper Basin.

Limiting factors

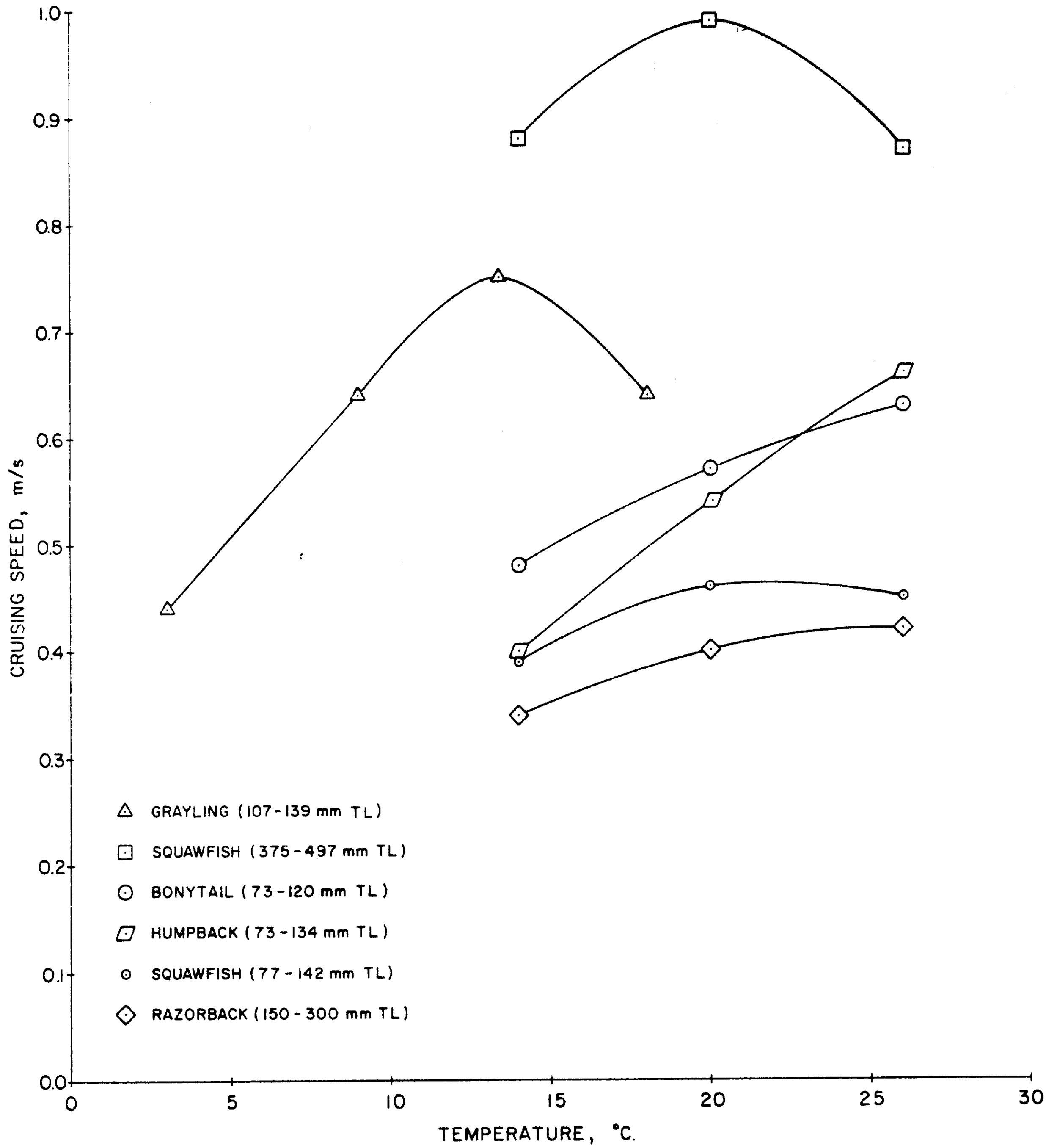
Temperature

Water temperature is a critical factor to adult fish for gonadal development, spawning, and growth. Hamman (Part 3, Report No. 3) showed that gonadal development and spawning of Colorado squawfish were dependent on increasing, and specific, water temperatures. The first signs of maturation were observed in males at or above 15° C in April and seminal fluid appeared in May at 18° C. Females under this temperature regime did not show signs of maturation before early June when the temperature reached 20° C. Spawning followed on June 24, at 20-21° C for three of eight females, while the others were induced to spawn with hormonal injection at 18-24° C. Based on these limited observations (only eight females) males seem to mature earlier than females and need a temperature of around 18° C for 20-30 days for maturation and 20° C for spawning, while females need a temperature of about 20° C for 20-30 days maturation and 20° C for spawning. Spawning, both in the hatchery and in the field, occurred between June 15 and July 15. Temperatures in the river usually are in the low 20s at this time of year and apparently are conducive to spawning. Spawning migrations were documented by our field crews using radiotelemetry. Responding to some triggering mechanism, several fish at different locations initiated long migrations at similar times. Rising water temperatures, descending flows, and photoperiod may be important stimuli to the adult migration.

Adult Colorado squawfish in controlled tests (Part 3, Report No. 5) could not swim as well at either 14° C and 26° C as at 20° C (Figure 4). In preference tests, temperature selected by adults varied from 21.5°-25.7° C depending on acclimation temperature. The estimated final preferred temperature for adults was 25.3° C.

Egg development, hatching success, and larval development are affected by temperature. At 13° C, egg mortality was high in the 1979 Willow Beach NFH tests. At 16° C, hatching was slightly delayed, taking 6.2 days. At 20-22° C, hatching occurred in 5 days and was up to 90 percent successful (Part 3, Report No. 3).

FIGURE 4



A comparison of the cruising speeds of four Colorado River fishes with the arctic grayling (MacPhee and Watts, 1975) at various water temperatures. Modified from Bulkley, et al (Part 3, Report No. 5).

Juvenile temperature preference tests showed they preferred temperatures that ranged from 21.9°-27.6° C, with an estimated final temperature preference of 24.6° C, approximately the same as for adults (Part 3, Report No. 5). Extreme high temperatures may be detrimental to squawfish. In the course of temperature studies, several fish were quickly disabled by high temperatures of 30° and 35° C when transferred from acclimation temperatures of 14° and 20° C, respectively.

To complete its life cycle, the Colorado squawfish requires water temperatures of approximately 20-28° C from mid-June to October. A temperature of about 20° C is required for spawning while temperatures near 24° C, the preferred temperature, are needed for optional development and growth of young. These temperature preferences are expressed as averages and variation of ±1-2° C would be considered normal.

Total dissolved solids (TDS)

TDS preference of juvenile Colorado squawfish was determined in the laboratory (Part 3, Report No. 5). The Colorado squawfish preferred TDS concentrations of 600-1,000 mg/L, the lowest available, and completely avoided concentrations greater than 4,400 mg/L. TDS concentrations in the Green and Colorado Rivers seldom exceed 2,000 mg/L, therefore, TDS levels are probably not affecting distribution of Colorado squawfish in the main Green and Colorado Rivers. However, the Dolores River is far above avoidance concentrations in September. Levels >6,000 mg/L near the mouth may be one reason why Colorado squawfish were not found in the Dolores River during this study. Also, irrigation returns and ditches may reach TDS levels that Colorado squawfish avoid, which could explain why Colorado squawfish were not often found in these areas.

Bioassays

Post-larval and YOY Colorado squawfish were exposed to a variety of chemicals in bioassay studies at the University of Idaho (Part 3, Report No. 6). Most of the chemicals that were tested are known to occur in the Upper Colorado River system and have the potential of affecting the Colorado River fishes. Both the humpback chub and Colorado squawfish appear to be relatively tolerant to the chemicals tested. The results of 96-hour static toxicity tests indicated that YOY Colorado squawfish (>60 mm) were more resistant to various metals (Hg, Zn, Cd, Se) than the northern squawfish. LC50 for rainbow trout, fathead minnow, channel catfish, bluegill, and carp (NAS 1973) were lower for these metals than those reported for YOY Colorado squawfish. Also, the Colorado squawfish apparently was more resistant to pesticides (DDT, dieldrin, endrin, parathion, and lindane) than the rainbow trout, channel catfish, and bluegill (comparisons with Johnson and Findley 1980), but slightly less resistant than the humpback chub (for endrin, DDT, dieldrin, and parathion).

Heavy metals were greatly affected by water quality. Mercury and copper could not be tested adequately because they tended to precipitate in hard simulated Colorado River water (>300 mg/L $CaCO_3$). In the Colorado River system where water hardness levels are occasionally quite low, such as in the Yampa River (<50 mg/L $CaCO_3$), metals could be acutely toxic to Colorado squawfish, particularly newly hatched larvae. Standards for this tributary could be drawn in part from this report's toxicity data. Water-born heavy metals do not appear to be affecting the population at this time.

Toxicity of pesticides is little affected by the dissolved solids or hardness and, therefore, has importance throughout the Colorado River system. However, water-born pesticides in the Green and Colorado Rivers are frequently below detectable levels according to some USGS (1979) records.

While the effects of the chemicals tested may not threaten the squawfish directly, most of these chemicals are also carried via the food chain and have been shown to accumulate in fish tissue to levels thousands of times higher than those found in water or sediment. All the heavy metals and pesticides tested here are found to some degree in the tissue of Upper Colorado River fishes but are still at relatively low tissue levels (National Pesticide Monitoring Program data).

Food

An abundance of small fishes, mostly introduced species like the red shiner, provides an ample food supply for the predacious Colorado squawfish. Stomachs of YOY (22-59 mm) Colorado squawfish from the Green River contained about 85 percent fish remains identified as red shiners (Part 3, Report No. 9). Five-year old subadult squawfish also were capable of finding an ample food supply. Of 1,500 subadults stocked in the Colorado River near Moab, Utah, 13 were recaptured in good condition up to a year later. Seven of eight for which data were available increased in length and weight. In fact, one grew 111 mm from 270 to 381 mm TL and gained 420 g from 140 to 580 g in 13 months. From information accumulated under this study, food does not appear to be a limiting factor for Colorado squawfish except, perhaps, the very young larval and post-larval stages that require planktonic and small benthic foods. This could be limiting because of competition from exotics.

Predation and competition

This study found that striped bass in the Lake Powell-Colorado River confluence zone did not prey on Colorado squawfish (Part 3, Report No. 7). Stomach analysis of adult bass did not contain any endangered fish although Colorado squawfish juvenile and adults did occur in the same area of the lower Colorado River. The study also found that striped bass did not migrate above Cataract Canyon during the spring spawning run out of Lake Powell.

There was no documented evidence gathered of Colorado squawfish taking channel catfish as a prey species. This does not put to rest the contention by a few earlier authors that Colorado squawfish suffer mortality when channel catfish are taken because of the spines on the catfish. However, since in our extensive collections we did not document this type of predation, the probability of a significant impact to present Colorado squawfish populations is probably minimal.

Health

Our field sampling over the past 2-1/2 years documented that subadult and adult Colorado squawfish were relatively low in number and did not attain the size they once did. At the present time we do not know why these fish no longer reach the large sizes recorded in literature. However, the majority of subadults and adults sampled were healthy specimens capable of migrating hundreds of miles and of enduring the rigors of spawning. Disease examinations of 11 adults taken by our field crews revealed a variety of bacteria and parasites, particularly among those fish under stress from handling and captivity (Part 3, Report No. 4). Learnaea, an anchor worm easily seen with the naked eye, was very common but does not appear to cause mortality among subadults and adults. In the wild, these diseases may occasionally affect individual fish, especially in manmade gravel pit areas.

The tapeworm, Proteocephalus ptychocheilus, was often found in the stomachs of subadult and adult Colorado squawfish and has been seen in northern squawfish and red shiner in the Columbia River system (Hoffman 1970). The presence of the bass tapeworm, P. amblopl itis reported by Vanicek and Kramer (1969) was not confirmed.

Generally, we believe that diseases and parasites of the Colorado squawfish in the Upper Basin have not been a major factor in the decline of the species. The incidence of infection from pathogens observed, although high for Learnaea, was not out of the ordinary compared to nonendangered fishes also examined as part of the disease survey.

Humpback Chub

Distribution and abundance

The only major populations of humpback chub, Gila cypha, conclusively known to exist in the Upper Basin are located in Black Rocks (RM 135-137) and Westwater Canyons (RM 116-124) on the main Colorado River. Incidental captures were recorded from Cataract Canyon; Gray and Desolation Canyons on the Green River; and in Yampa Canyon on the Yampa River.

During this study we also gathered associated data on a population of humpback chub in the Lower Colorado River Basin. This population existed in the Little Colorado River and in the adjacent Colorado River within Grand Canyon.

This study program demonstrated that humpback chub were prevalent in Black Rocks and Westwater Canyons of the Colorado River. Catch rates yielded 40 and 18 fish per 10 hours of netting as compared to less than 0.1 fish per 10 hours for all other areas. Disproportionate sampling efforts yielded 167 humpback chubs from Black Rocks and 62 from Westwater Canyon. Of 218 adult humpback chubs tagged with Carlin dangler tags in Black Rocks and Westwater Canyons, 16 were recaptured. All but one of these fish were recaptured within less than 0.5 mile of their initial release site. The exception was a fish that moved from Westwater Canyon 14 miles upstream to Black Rocks.

Migration and movement

Tagging and radio tracking programs were conducted in the Black Rocks area of the Colorado River to determine movement patterns of humpback chub. Sixteen of 218 fish marked with Carlin tags in the Upper Colorado River were recaptured from 1 to 434 days after release. All but one of the recaptured fish moved less than 0.5 mile from their release site. Eight fish equipped with radio transmitters also demonstrated little movement upstream or downstream. Generally, we concluded that humpback chub do not make migrational movements in the Upper Colorado River and tend to reside throughout the year within a limited 1/2-1 mile stretch of river. The return of some tagged fish, both Carlin dangler-tagged and radio-tagged, to their original site of capture after release in slightly different microhabitats suggested that they may have a home territory or range within the confined river stretch which they occupy.

Exchange of individual fish between isolated populations was documented. One tagged fish moved from the point of tagging in Westwater Canyon upstream 14.4 miles to the Black Rocks area. This movement was observed over a span of 232 days.

Movement of chubs in the Little Colorado River in the Lower Colorado River Basin was generally greater than in the Upper Colorado River. Fish captured from 1 day to 16 months after tagging moved 0-10.5 miles, with most movement less than 2.5 miles. Additional information supports the hypothesis that small fish, YOY and juvenile, moved downstream out of the Little Colorado River and disperse in very limited numbers in the main Colorado River within Grand Canyon. Movement of fish in the Little Colorado is further analyzed in the report on this work in Part 2 of this report.

In following humpback chub on a daily basis, it was noted that they do exhibit movement to selected depths and microhabitats. Fish were most often observed by radio tracking in midmorning and midafternoon near shore in water 3-5 m (9.8-16.4 feet) deep, and further out toward midchannel at midnight and midday.

Captures of young humpback chub within the Black Rocks area supported the conclusion that in the Upper Colorado River Basin all life stages of the chub occur within the same limited area of river and that the fry did not drift downstream to any significant degree.

Habitat selection

Humpback chub collected from the Upper Colorado River were restrictive in preferred and occupied habitats. Individuals in all life stages were concentrated in canyon areas of great depths and high velocities with bedrock, boulder, and sand substrates. Microhabitat preferred within these canyons indicated the humpback did not spend a lot of time in the swifter, turbulent water but preferred the associated slower pools and eddies with velocities of 0-3.8 feet/second but averaging 0.2-0.3 feet/second.

The highly turbulent, harsh canyon habitat where the humpback occurred harbored fewer fish species than most areas of the rivers. This suggests the humpback lives in a highly specialized environment that excludes other species, particularly exotics. This type of restricted habitat preference is also noted in the Little Colorado River area of the lower basin where high TDS and isolation has limited the number of other species found there.

Juvenile and adult humpback chub seemed to be associated with some of the shallower portions of the deeper river sections. In many of these areas a shelf area existed along the edges of the deeper water which provided a resting and feeding area for the humpback. Also, many pockets, depressions, and crevices occur in the bedrock-boulder substrate which provided isolated microhabitat favored by humpback chub. Although adult humpback were quite capable of navigating the swift, turbulent water, as evidenced from radio tracking efforts, most time was spent in pockets and back eddies adjacent to the deep, swift water.

Reproduction was not directly observed in the wild, but it is suspected that spawning in the Upper Colorado River takes place within the boundaries of the deep, swift water canyon. All age classes of chub were found in the few areas where they occurred, which supported the conclusion that successful reproduction and recruitment was taking place. Pockets of clean rubble-gravel areas are probably utilized for spawning within the immediate canyon area and in upstream associated areas in the Upper Colorado River Basin. In the lower Colorado River in Grand Canyon the Little Colorado River is the only known spawning area being utilized by humpback chub. Young fry have been taken in the Little Colorado River and downstream in the main Colorado River. Spawning is occurring in the first 13 miles of the Little Colorado River.

Limiting factors

Temperature

Temperature was a very critical environmental factor for humpback chub. Areas occupied were not only very unique in depth, velocity, and limited physically, but humpback chub also require specific temperatures for reproduction. According to laboratory and hatchery observations, temperatures of 16-18° C are needed for initiation of humpback chub spawning, and best hatching success and larvae survival occurred at about 20° C. Thus, areas occupied now include the relatively warm Little Colorado River in the Lower Basin and areas of the Upper Colorado River where the needed temperatures still occur. Areas where humpback chub have been extirpated included those areas inundated by dams and those areas impacted by cold water releases below reservoirs, such as Flaming Gorge Canyon in the Green River and much of the Grand Canyon below Glen Canyon Dam.

Ripe male and gravid female humpback chub were observed in the Upper Colorado River at Black Rocks at a water temperature of approximately 12° C during 1980-81. Some of these fish were hand-spawned at the site of capture with the aid of carp pituitary injections on June 2, 1980. Three weeks later most females taken there were spent, indicating spawning had occurred. The temperature had risen to above 18° C by this time. Gravid females were also observed on May 15, 1981, at 16° C and spent females on June 1 at about 16.5° C at Black Rocks (see Part 2 for details). Eggs could be expressed from a female humpback chub taken in the Little Colorado River on April 1, 1981. The water temperature there ranged from 18-20.5° C at that time. Captive Little Colorado humpback chub injected with carp pituitary spawned in a controlled hatchery environment at Willow Beach NFH at a temperature of about 19-20° C on May 5-6, 1981 (Part 3, Report No. 3).

Humpback egg and larval development and survival were found to be dependent on temperature. Hamman (Part 3, Report No. 3) found that only 12 percent of a group of eggs incubated at a temperature of 12-13° C hatched and only 2 percent survived to become feeding larvae. At 16-17° C hatching success increased to 62 percent. At 19-20° C the percent hatch rose to 79-84 percent. Bulkley, et al. (Part 3, Report No. 3) reported from 90-100 percent hatching success for humpback eggs at 26° C as opposed to a 50 percent hatch at 14° C. However, these eggs were already 30 hours old and had been at a water temperature of 19-20° C prior to testing. Clearly, temperatures less than 16° C were detrimental to humpback egg and larval development and survival.

Juvenile humpback chub, under controlled tests preferred a temperature of 24° C with a range from 21-24.4° C (Part 3, Report No. 5). However, schooling behavior and favoring fixed positions in the test chamber made the data variable and skewed. The preferred temperature calculated for the humpback chub (24° C) was close to that of the juvenile squawfish (25.5° C).

The swimming ability of the humpback chub juveniles was greater than that of the Colorado squawfish juveniles, particularly at 26° C. Figure 4 illustrates that while Colorado squawfish swimming ability was lessened by a 6° C increase in temperature from 20-26° C, the humpback's ability increased. This indicates that the humpback tolerates higher temperatures better than the squawfish. In comparison with juvenile bonytail chub, the two fish are nearly equal in their ability to swim at 26° C, but at 20° and 14° C the bonytail chub seems to be a slightly better swimmer, particularly at 14° C. The razorback sucker, on the other hand, is by far the worst swimmer among the target species (Part 3, Report No. 5).

Temperatures between 16° and 26° C are critical to the spawning, egg and larval development, and growth of the humpback chub. The best temperatures appear to be 16-18° C for spawning, 20-26° C for egg and larval development, and 24-26° C for growth. Temperatures less than 18° C which adversely affect development of egg and larvae while temperatures during the growing season (June-October) below 20° C and above 28° C adversely affect growth and young development.

Total dissolved solids

Although strong schooling behavior interferred with tests to determine TDS preference, YOY and juvenile humpback chub preferred TDS concentration ranged from 1,000-3,500 mg/L (specific conductance 1,300-3,000 umhos). Humpback chub TDS avoidance level was higher than 11,600 mg/L (specific conductance 8,500 umhos) (Part 3, Report No. 5). Specific conductance levels in the Colorado River ranged from 280-1,720 umhos (TDS 380-1,220 mg/L) during there recent studies while TDS concentrations in the Little Colorado River were above 2,500 mg/L (>4,500 umhos) from a USGS analysis in 1979.

The humpback appears to choose high TDS levels in the laboratory compared to present levels found in the Upper Colorado River system. However, their preference level coincides with TDS concentrations found in the Little Colorado River. An avoidance TDS level has not been determined for the humpback but is apparently very high (>11,600 mg/L), at least in short-term (24 hours) tests run in the laboratory (Part 3, Report 5). The avoidance levels determined for the bonytail and squawfish were lower (>6,600 mg/L). Based upon field observation of humpback chub in the Little Colorado River and controlled test results mentioned above, we believe that TDS is not a limiting factor in the distribution of humpback in the Upper Colorado or Green Rivers.

Bioassays

Fewer bioassays were run on humpback chub than on the Colorado squawfish. In the comparisons that were made, the humpback was slightly more resistant to pesticides (DDT, parathion) than the Colorado squawfish and northern squawfish. However, in comparisons of metal tests (Hg, Se), the humpback chub was slightly less resistant than the Colorado squawfish, (Part 3, Report No. 6).

LC50's from NAS (1973) and Johnson and Findley (1980) on several exotic species, including some now found in the Colorado River, were used for comparison with those determined for the humpback chub. The humpback chub appears to be relatively tolerant to the organic and inorganic chemicals tested, compared to rainbow trout, fathead minnow, carp, bluegill, and channel catfish found in the Upper Colorado.

Food

Mayflies (Ephemeroptera) comprised about 77 percent and 33 percent of the main diets of YOY Gila spp. and YOY roundtail chub, respectively. Invertebrate remains comprised 54 percent and 72 percent of the mean diets of YOY and juvenile roundtail chub. In one stratum (D in Colorado River), juvenile roundtail chub only consumed fish. Mayflies and invertebrate parts were found to be the major food items of the red shiner. Competition for food with the red shiner and roundtail may be a problem for YOY and juvenile humpback chub. (Information on stomach analysis is in Part 3, Report No. 9.)

Health

The health and condition of humpback chub in both the Upper Colorado and Green Rivers appears to be good. Fish taken into captivity, however, have been lost to fungus and bacterial infections brought on by injury in handling and stress. Low numbers of Learnaea were often found on chubs in the wild. In the Upper Colorado River 26 percent of 234 humpback chub examined had Learnaea on them. The parasite was not found on young fish, but 17 percent of juveniles and 32 percent of adults were infested with

1-13 copapeds. Although some parasites were observed to occur in significant numbers, the pathogens found in these rivers appear to pose no threat to the general humpback chub populations.

On the other hand, humpback chub from the Little Colorado River had a high incidence of Learnaea (>50 percent) with up to seven parasites per fish. Kaeding and Zimmerman (Part 2) also found sick, stressed adult humpback chub in 1981 following the spawning period. Subsequent examination of samples taken from these fish revealed a systemic bacterial infection. High temperatures, crowding, and less than preferred conditions in the Little Colorado River have resulted in a stressed population of humpback chub which are more susceptible to parasites and diseases.

Bonytail Chub

Distribution and abundance

The apparent morphological variability of endemic *Gila* spp. makes field identification difficult. This problem was aggravated by the fact that taxonomists were not available to examine each live specimen collected in the field; that the adopted taxonomic guide was developed from preserved specimens which, it has turned out, had limited application to live specimens; and that other methods of identification required sacrificing specimens. Due to their status, endemic *Gila* spp. could not be freely sacrificed. A cytogenetic study of the Colorado River Gila complex by Rosenfold (1982, in Press) has confirmed definite chromosome differences between the bonytail and the roundtail and humpback chubs. Thus, the bonytail chub should continue to be considered as a distinctive separate species.

A few senile, very old, specimens of bonytail chub continue to be collected from Lake Mohave in the Lower Colorado River Basin. These Lake Mohave chub represent the only universally recognized pure population of bonytail.

During the duration of this study, no chub thought to closely resemble bonytail were captured from the main Colorado River or its tributaries. In the Green, the taxonomic picture was confused with a relatively typical representative of each chub species being collected along with a number of variants. A concentration of *Gila* spp. located at the lower end of Coal Creek Rapid in Desolation-Gray Canyon included a small number of *G. elegans*. Extensive examination of one sample of 19 specimens from this population confirmed the collection of only one bonytail.

Our studies did not divulge any significant numbers of bonytail chub in the Upper Colorado River Basin.

Migration and movement

Very little information on any life stage of the bonytail chub is available in literature or from this study. Because of the extremely precarious status of the bonytail chub in the wild, this species is considered to be on the edge of extinction.

The chubs captured in the Coal Creek area of the Green River produced one recaptured bonytail at the same site. Because of little information, not much can be said from this one observation concerning migration and movement.

Based on captures in Lake Mohave over the past few years, W. L. Minckley of Arizona State University and others have caught spawning bonytail chub at one location on the reservoir (Part 3, Report No. 3).

Habitat selection

Collections of more specimens will be needed before habitat selection can be determined for the bonytail chub. The positively identified bonytail captured during this study occurred in the deep swift canyon areas in association with both humpback and roundtail chubs. Although a few large adult bonytail chub still occur in Lakes Mohave and Havasu, these areas are not considered typical habitat for this species.

Limiting factors

Temperature

The temperature required for spawning of bonytail chub has been reported to be approximately 18° C (Vanicek and Kramer 1969). Ten bonytail chub were taken in Lake Powell in 1965 in selected water temperatures that ranged from 16.6° C at 70 feet to 25° C at 1 foot of depth. The weighted mean temperature for this group of fish was 22.2° C (Utah DWR 1965). Similarily, YOY bonytail chub tested by Bulkley, et al. (Part 3, Report No. 5) had individual mode temperature preferences that ranged from 15-31° C and a final preferred temperature of 24.2° C.

Survival and development of bonytail eggs and larvae was greatly influenced by varying water temperature (Part 3, Report No. 3). Of 1,300 eggs incubated at 12-13° C, only 4 percent hatched and only 13 feeding larvae survived. About 55 percent of eggs (2,500) incubated at 16-17° C hatched with no more than a 4 percent additional loss prior to the feeding stage. At temperatures from 20-21° C hatching success of about 130,000 axxf was from 88-91 percent and larval survival was from 98-99 percent. In addition, Bulkley, et al. (Part 3, Report No. 5) reported from 70-90 percent hatching success of a few hundred bonytail eggs at 26° C and from 50-70 percent at 14° C. None survived at 10° or 31° C. These eggs were 30 hours old and held at 19-20° C before exposure to test temperatures at Utah State University.

The swimming performance of juvenile bonytail chub improved significantly with temperature (Part 3, Report 5). Overall, bonytail chub swimming performance was slightly better than that of the Colorado squawfish juveniles (Figure 4). While the performances of the Colorado squawfish and razorback sucker were best at 20° C, the bonytail chub performed best at 26° C as did the humpback chub.

Total dissolved solids

The TDS at Lake Mohave in Arizona, where some adults are still found, is about 750 mg/L. Willow Beach NFH, located on the upper end of the lake, has successfully spawned adults and reared young using the lake water.

Bulkley, et al. (Part 3, Report No. 5) found YOY bonytail chub preferred TDS levels from 4,091 to 4,679 mg/L and avoided levels above 6,600 mg/L. Actual concentrations of TDS found in the main rivers seldom exceed 2,000 mg/L. However, the Dolores River often exceeds 6,000 mg/L TDS, which may be the reason this river does not contain bonytail chub.

Food

No bonytail chub stomachs were analyzed in this study. Vanicek and Kramer (1969) found bonytail fed on terrestrial insects and plant material while the closely related roundtail was more optimistic and fed on fish and other aquatic insects as well as terrestrial insects.

Health

Adults in Lake Mohave and in the Green River appear to be in good health. However, as with the humpback chub, handling and captivity sometimes injures and stresses these fish which leads to infection with bacteria and fungus. Disease organisms found on these fish do not appear to be a likely cause for the decline of the wild population.

Razorback Sucker

Distribution and abundance

The razorback sucker was infrequently caught in mainstem Colorado River reaches during systematic sampling. However, substantial numbers were caught in a few limited areas in the spring and early summer during special field investigations.

During the 1979-81 standardized field sampling only five adult razorback suckers in the Green River and ten adults in the main Colorado River were captured. Those razorbacks captured during random sampling efforts for the Colorado River exhibited no discernable trends in population concentrations. Capture locations varied widely with points of capture from Lake Powell to near Rifle, Colorado. In the Green River, collections suggested that the greatest concentrations were in the moderately sandy reach between Split Mountain Gorge and Desolation Canyon in Utah.

Special investigations conducted by FWS and collections by other agencies accounted for 84 adult razorback captures from three localized areas that appeared to be spawning congregations or fish that were staging prior to spawning. These localized areas were in the confluence zone of Ashley Creek on the Green River near Jensen, Utah, the Walter Walker Wildlife Management Area gravel pit on the Colorado River near

Grand Junction, Colorado, and the Clifton Pond gravel pit on the Colorado River near Clifton, Colorado.

Razorback suckers were rare and seemed to be relatively stationary except during the spawning season when they moved to and congregated in a very few specific areas.

In the Lower Colorado River Basin a similar situation exists. A few razorback suckers have been taken from the Colorado River below Parker Dam and some older adults have been taken from Lake Havasu and Lake Mohave (Minckley, 1973). However, reproduction in the lower river is also nonexistent or insignificant. Our investigations did not demonstrate any natural recruitment for these fish within recent times. Unless some significant recovery/management actions are taken, continued survival of razorback suckers in the Upper Colorado River Basin is doubtful.

Migration and movement

McAda and Wydoski (1980) demonstrated that razorbacks can move 20 miles or more over several months and up to 80 miles in a few years.

Three razorbacks captured and tagged at Ashley Creek were recaptured during a 3-week period. Five of 42 razorbacks captured and tagged in the Walker Wildlife Management Area and Clifton Pond were subsequently recaptured in the same area over periods ranging from 1 day to 1 year.

This study provides a somewhat contradicting picture of razorback migration and movements. In the main Upper Colorado River, almost no razorback movement has been documented from tagging and recapture. Most razorbacks captured in this area were in manmade gravel pits and four out of five were in the same gravel pit area. However, some movements into and out of these gravel pits from the Colorado River were documented.

In the Green River, a razorback was recaptured after 5 years, 125 miles from the tagging site. Also in the Green River, one razorback was radio-tagged near the confluence of the White and Duchesne Rivers and tracked over a 5-month period. This fish moved into the Duchesne River, returned to the Green during runoff, and slowly moved upstream. Total movement was approximately 14 miles over the 5-month period.

Spawning concentrations were observed in the spring both in this study and in previous work. One area of concentration was noted in the Green River during 1981 at the mouth of Ashley Creek. Another area that has been observed in past studies was in the Green River near the mouth of the Yampa River (McAda, 1977). Therefore, some limited movement to these areas of spawning concentration must occur.

The razorback sucker did not appear to make long migrations, but concentrated in restricted areas of the river to spawn. It also moved into backwater gravel pits at high waters, conceivably for the purpose of spawning. As the water level dropped in the gravel pits, razorbacks returned to the main rivers.

Habitat selection

Few razorback suckers were collected in the standardized sampling program, making any extrapolation from the data associated with captures potentially biased. Those few fish that were collected during the systematic sampling generally exhibited a preference for low current (<0.6 feet/second), moderate depth (2.3 feet), and a silt/sand substrate.

Eighty-two percent of the razorback suckers collected from the Colorado River were from gravel pits and backwaters. Those fish inhabiting the Green River did not exhibit this affinity to still waters but were usually associated with deep shorelines (2-8 feet) and main channel areas.

Late spring congregations of this species suggested selection of a specific habitat composite for spawning. Actual spawning was not observed nor byproducts collected; however, it was believed that the congregations of razorbacks in the vicinity of Ashley Creek, the Walter Walker Wildlife Management Area gravel pit, and Clifton Pond gravel pit represented some facet of spawning. These areas lacked the clean, loose rubble and gravel suggested as important by McAda and Wydoski (1980) and Ulmer (1981), although some upwelling of water was detected along one bank of the Walter Walker Management Area gravel pit. Since no recruitment was ever observed during these studies, definitive conclusions relative to spawning habitat cannot be drawn, nor can we conclude whether these sites represented spawning sites.

Limiting factors

Temperature

Spawning of razorback sucker was observed in January 1980 at Dexter NFH at a temperature range of about 10-15° C and eggs were observed on cleaned gravel areas 0.6-10.2 cm (0.25-4.0 inches) in diameter (Part 3, Report No. 3). Douglas (1952) observed spawning razorback in Lake Havasu at 14-18° C. Razorbacks were observed spawning over gravel areas at 15° C in Senator Wash Reservoir, Imperial County, California (Ulmer 1981). Eggs and larvae were subsequently collected from this site.

Hatching success of eggs spawned at Dexter NFH in 1980 was poor, due primarily to the poor condition of the eggs as they came from the female. Eggs were incubated at about 17° C. At these temperatures, on about the sixth day after hatching the larvae began to rise to the surface and start feeding. Toney (1974) found razorback sucker YOY grew about 1 mm/day, reaching 60-70 mm TL 68 days after hatching. Growth of juveniles was highly variable in the hatchery; in their fifth year, 1980, they ranged in size from 150-400 mm TL. The maximum growth rate was about 80 mm per year.

Razorback sucker juveniles (150-300 mm) preferred temperature of 23-24° C, which are similar to temperatures preferred by juvenile Colorado squawfish, humpback chub, and YOY bontail chub (Part 3, Report No. 5).

Swimming ability of the razorback sucker was tested at various temperatures. Overall, the razorback sucker was a poorer swimmer than the Colorado squawfish, humpback chub, and bonytail chub. Temperature was not found to significantly ($P = 0.5$) affect swimming times for the razorback although Figure 4 shows that at 20° C they could swim for approximately 1 hour at a velocity of 0.4 m/sec (1.3 feet/sec), which is higher than velocities recorded at 12° or 26° C. The razorback's unwillingness to swim in face of the current was a factor in making the data highly variable. This caused the differences between temperatures to be insignificant.

McAda and Wydoski (1980) found two probable spawning sites in the Yampa River and one in the Colorado River where average water velocity was 1 m/sec (3.3 feet/sec) and the temperature ranged from 7-16° C. One fish implanted with an ultrasonic transmitter by McAda was observed spending most of its time in slower water (0.42 m/sec), but ventured into faster water for short periods.

Total dissolved solids

All life stages of the razorback seem to do well at TDS levels up to 750 mg/L, that of Willow Beach NFH water. No studies or other records are available by which to approximate preferred or avoidance levels.

Food

No young razorbacks were collected by our field teams and, therefore, no stomach analysis data were available. Other authors (Jonez and Summer 1954; Banks 1964; Vanicek 1967) reported finding algae, plant debris, ephemeroptera, trichoptera, diptera, and chironomid larvae in the stomachs of razorbacks.

Predation

McAda and Wydoski (1980) believed that failure of razorbacks to reproduce successfully may be attributed to predation of eggs and larvae by exotic species such as largemouth bass, channel catfish, and green sunfish. Ulmer (1981) actually found large quantities of razorback eggs in the stomachs of bluegill, channel catfish, and largemeouth bass in Senator Wash Reservoir.

Health

No reproduction of Mohave razorback sucker has been found in many years and the adult population is beset by various disease problems, not the least of which is blindness apparently caused by parasites (*myxosoma*). Upper Colorado River fish also were found to be blind. *Learnaea* was commonly found on razorback adults. This species' preference for slow moving water makes it quite susceptible to invasion by parasites.

Other Native and Exotic Species

Four nonendangered native fish species, the flannelmouth sucker *Catostomus latipinnis*, bluehead sucker *C. discobolus*, roundtail chub *Gila robusta* and speckled dace, *Rhinichthys osculus* were common throughout much of the study area. Flannelmouth suckers were most numerous followed by bluehead suckers. Speckled dace were common to prevalent in nearly all strata. Roundtail chub were prevalent in the Upper Colorado River, particularly in Colorado upstream from the Utah line, but were much less prevalent in the Green River.

Relatively uncommon to rare native species in the study area were the mottled sculpin Cottus bairdi and mountain whitefish Prosopium williamsoni. Both were seldom encountered because their preferred habitats were outside the study area. Many endemic fish were tagged with Floy anchor tags to identify recaptures at sampling stations, Relatively few recaptures signified that recaptures did not significantly influence catch rate values.

Twenty-one non-native fish (exotics) are established in the study area. Most significant were the red shiner, Notropis lutrensis; channel catfish, Ictalurus punctatus; and fathead minnow, Pimmephealeas promelas, which composed a major segment of the fish population.

Other species that were widely distributed but were found in moderate numbers include the carp (Cyprinus carpio), sand shiner (Notropis stramineus), and black bullhead (Ictalurus melas). Largemouth bass (Micropterus salmoides) were widespread in the Upper Colorado River, while smallmouth bass (M. dolomieui) were common in the Green River throughout the Uinta Basin. Eight other exotic species were collected occasionally, but none was regarded as significant or expected to proliferate. Redside shiners (Richardsonius balteatus) were collected in Dinosaur National Monument. In University of Idaho studies, the redside shiner, a native species of the Columbia River system, was found consistently intermixing with schools of YOY northern squawfish. Collections in Dinosaur National Monument indicated that the opposite is true for Colorado squawfish. YOY Colorado squawfish were not collected where redside shiners were present; however, there appeared to be a positive association between YOY Colorado squawfish and red shiners since they were often collected together.

Gravel pits and some other manmade side channels may be adversely impacting the native fish fauna of the Upper Colorado River system. These areas seem to harbor large numbers of adult exotics, particularly the piscavours, which can directly impact the native species by predation and can secondly impact the native species by competition. Razorback suckers have been shown to be impacted by exotics that eat eggs and larvae. Also, these artificial areas provide a chronic source of exotics to the main river to impact native population within their native habitats.

In the deep, swift canyon areas where humpback chub are found, fewer exotics are also found. This may reflect the reason humpback are still secure in these areas and that the habitat is too harsh for exotics.

Field studies of diel movement of fishes show heavy utilization of backwater areas by YOY and juveniles of many species, both native and exotic. This behavior was probably related to temperature, water velocity, and food availability.

Overall, we have concluded that the physical/chemical changes in the Upper Colorado River system associated with man's activity has benefited the introduced exotic fishes by moderation of the harsh historic river environment. The benefit to the exotics has conversely had a detrimental impact on some of the highly specialized endemic species such as the presently listed endangered species.

DISCUSSION

Overview

Over the past 2-1/2 years, this study has compiled a vast amount of new biological information on the endangered Colorado River fishes. We have determined their distribution and identified key critical areas in the Upper Colorado River Basin.

Generally, it appears that the bonytail chub is near extinction in the Upper Basin except for one isolated area near Coal Creek in the Green River. The humpback chub exists as three populations in the Upper Basin; one remnant, poorly defined population in the Coal Creek area of the Green River, and two apparently stable populations in the main Colorado River at Black Rocks and Westwater Canyon near the Utah-Colorado State line. There is an additional population of humpback chub in the Lower Colorado River in and near the Little Colorado River in Grand Canyon. The Colorado squawfish occurs throughout the Upper Basin, but depends on a few key spawning and nursery areas. The only known spawning area is the Lower Yampa River which supports the Upper Green and Yampa River populations. Suspected spawning areas in the Green River drainage include the Lower Yampa down to Split Mountain on the Green River, and Gray Canyon on the Lower Green River. Suspected spawning areas in the Colorado River are in the area from Loma, Colorado, to the Utah State line. Fry rearing areas are downstream from spawning areas and are characterized by shallow depths and backwater habitat.

Life history information has documented the sedentary, isolated existence of the humpback chub populations. Conversely, the Colorado squawfish is a migratory species with a homing behavior and extensive use of tributary streams.

Overall, management of the endangered Colorado River fishes centers on the Colorado squawfish since this species is decreasing in population, but still offers the possibility of management. The humpback chub are believed secure in the isolated habitats where they now reside if habitat conditions in the rivers can be slightly improved or do not deteriorate significantly. The bonytail chub, being extremely low in numbers and now near extinction, needs to be propagated and studied to determine if this species can be maintained in its native habitat.

Requirements

The following flow and temperature requirements are presented for the Colorado squawfish and humpback chub. No requirements are given for bonytail chub since information on needs of this species are incomplete. River flow requirements for the two target species are based upon what is needed for survival of the species at the present reproductive levels recorded over the past 3 years.

Flow and temperature requirements for humpback chub can be expected to maintain this species at present levels if no other environmental factors change significantly. These are not recommendations of the FWS. FWS flow recommendation under Section 7 consultation and the Conservation Plan may be different because of the need to recover the endangered species and/or select management of one species over another.

Because the following flow and temperature requirements for the Colorado squawfish are based extensively on recent flow and limited biological data they may not be adequate to prevent decline of the species and possible extinction. As Archer (1982) has shown, the Colorado squawfish population may still be declining under present reproductive conditions. Thus, other factors than instream flow and temperature may be limiting the species. With this in mind, the following flow and temperature requirements should be viewed as a starting point to establish flow temperature needs at a few key areas and should be used in conjunction with habitat manipulation and species management to halt the decline of this species.

Requirements are limited to the main Green and Colorado Rivers and are specific to representative reaches of the river. Flows provided at upstream stations of the main Green and Colorado Rivers are assumed to remain and provide all or a major portion of the flow needed at downriver locations.

Flow needs for each target fish species were based upon a sequence of evaluations and determinations. The following determination or evaluation was made for each target species: (1) the critical geographic areas of the river system, (2) the critical life stage where the species was experiencing the most urgent problem, (3) flow condition or flow-related condition impacting critical life stage, (4) changes in flows that occurred at the critical areas from predevelopment times to the present, and (5) quantity and timing of flows needed at the critical areas to assure recent level of survival of the target species. The above determinations and criteria for temperature requirements were made based upon findings from the field, laboratory, hatchery, and contracted studies under this project.

Analysis of present, past, and needed flow levels was made using USGS flow records, the Colorado River Simulation System (CRSS) model developed by BR which predicted both virgin and developed flow conditions (see Part 3, Report No. 1 for details of flow partitioning) and the actual 1979, 1980, and 1981 flows (Tables 3 and 4). Weighted Useable Area (WUA) for Colorado squawfish YOY and humpback chub adults were related to flow at key areas to assist in analysis of present, past, and future flow needs of the target species.

This study indicates a number of critical areas in the Upper Colorado River system for Colorado squawfish and humpback chub (Table 5). For Colorado squawfish, the critical life stage is the actual spawning area, including egg survival and YOY rearing areas. For humpback chub, the critical life stage is the actual spawning period. We could not identify the critical life stage of the bonytail chub, but believe it may be more than one stage. The razorback sucker is experiencing recruitment problems due to survival of egg and larvae.

Table 3

Stream flow statistics used in developing the needed flows for the various life stages of the endangered Colorado River fishes

River and gage	Flow statistic	Monthly flows in cfs			
		July		August	
		Pre-impoundment 1/	Post-impoundment 1/	Pre-impoundment	Post-impoundment
Green River at Jensen	Average flow	--	--	--	--
	Median flow, in 200-cfs increments	4,000-4,200	3,600-3,800	1,800-2,000	2,600-2,800
	Most frequent low flow in 200-cfs increments	3,600-3,800	3,200-3,400	1,600-1,800	2,200-2,400
	50 percent average daily exceedance flow	4,300	3,900	2,000	2,700
	75 percent average daily exceedance flow	2,600	2,900	1,400	2,100
Colorado River at Cisco	Average flow	10,569	7,654	4,641	3,492
	Median flow in 200-cfs increments	7,200-7,400	6,000-6,200	3,200-3,400	3,000-3,200
	Most frequent low flow in 200-cfs increments	2,400-2,600	3,400-3,600	2,200-2,400	1,800-2,000
	50 percent average daily exceedance flow	7,300	6,300	3,300	3,000
	75 percent average daily exceedance flow	3,900	3,700	2,100	2,200
Colorado River at State line	Average flow	7,270	6,900	3,440	3,110
	Median flow in 200-cfs increments	3,800-4,000	5,600-5,800	2,400-2,600	2,800-3,000
	Most frequent low flow in 200-cfs increments	2,200-2,400	3,200-3,400	2,200-2,400	2,200-2,400
	50 percent average daily exceedance flow	4,100	5,800	2,600	2,900
	75 percent average daily exceedance flow	2,200	3,500	1,900	2,300

1/ Pre-impoundment period - Colorado River at Cisco 1914-1965, Colorado River at State Line 1951-1965, Green River at Jensen 1947-1962. Post-impoundment period - Colorado River at Cisco 1969-1981, Colorado River at State line 1969-1981, Green River at Jensen 1964-1981. A 2- to 4-year reservoir filling period was eliminated from the analysis.

Table 4
USGS recorded stream flow and selected flow statistics by key months,
Colorado and Green Rivers

River and gaging station	Year(s)	May Min	May Max	May Mean	May 50% average daily exceedance	June Min	June Max	June Mean	June 50% average daily exceedance	July Min	July Max	July Mean	July 50% average daily exceedance	August Min	August Max	August Mean	August 50% average daily exceedance
Green River at Jensen	1979	5,490	19,100	11,200	--	7,720	16,900	10,550	--	2,480	7,960	4,456	--	1,610	3,640	2,238	--
	1980	10,300	18,000	13,390	--	5,670	12,900	9,772	--	1,730	6,680	3,225	--	1,300	2,450	1,942	--
	1981	3,380	9,010	5,332	--	1,850	8,720	5,202	--	1,280	2,790	2,270	--	1,100	2,150	1,823	--
	1947-1962				12,000				9,500				4,300				2,000
	1964-1981				10,000				7,400				3,900				2,700
Colorado River at Cisco	1979	13,600	44,600	24,610	--	19,400	37,300	26,140	--	6,140	21,600	12,280	--	3,770	5,810	4,526	--
	1980	20,400	38,400	26,920	--	15,800	36,400	26,520	--	3,430	16,200	8,283	--	2,650	4,460	3,303	--
	1981	2,900	10,000	4,821	--	2,730	11,800	6,836	--	2,220	4,900	3,184	--	1,340	2,890	2,066	--
	1914-1965				20,000				24,000				7,300				3,300
	1969-1981				14,000				17,000				3,700				3,300
Colorado River at State line	1979	9,900	35,400	18,650	--	17,500	30,100	22,760	--	5,800	20,600	11,580	--	3,580	5,420	4,308	--
	1980	14,000	30,200	20,300	--	13,500	30,200	22,290	--	3,110	14,300	7,143	--	2,380	4,240	3,073	--
	1981	2,910	9,380	4,600	--	2,900	11,200	6,516	--	2,140	3,800	2,954	--	1,580	3,020	2,278	--
	1951-1965				12,000				17,000				4,100				2,600
	1969-1981				12,000				16,000				5,800				2,900

Table 5
Streamflow and water temperature requirements needed to maintain present production level for Colorado squawfish[1/] and humpback chub in the Upper Colorado River, date close to 1981

Critical Areas	Fish species and life stage	Time Period	Flow[2/] (cfs)	Temp.[3/] (C°)
Colorado River				
Loma - Utah Line (RM 132-154)	Colorado squawfish spawning and larval stage	6/15-7/31 8/01-8/31	5,000 - 10,000 3,000 - 5,000	20-22 20-28
Black Rocks (RM 135-137)	Humpback chub spawning	5/01-6/30	10,000 - 13,000	16-18
Westwater Canyon (RM 116-124)	Humpback chub spawning	5/01-6/30	10,000 - 13,000	16-18
Potash - Cataract Canyon (RM 3-47)	Colorado squawfish YOY rearing	7/15-10/15	4,000 - 9,000	20-28
Green River				
Split Mountain (RM 199-207)	Colorado squawfish spawning	6/15-7/31 8/01-8/31	3,000 - 4,000 2,000 - 2,500	20-22 20-22
Jensen - Sand Wash (RM 212-290)	Colorado squawfish YOY rearing	7/15-10/15	2,000 - 4,000	20-28

1/ Analysis of the last 20 years of information indicate that Colorado squawfish production is declining and present production levels may be inadequate to prevent species from going to extinction.

2/ Flow is given as a minimum range for the period of requirement. For instance 10,000 cfs at Loma for spring in mid-June could normally drop to 5,000 by the end of July.

3/ Temperatures are expressed as optimum averages and fluctuation of 1-2° C would be considered normal.

In analyzing the needs and problems of Colorado squawfish, we had to consider large sections of river because we were dealing with a highly mobile species. In contrast, when we evaluated humpback chub needs, we only had to consider small isolated habitats where all life stages were occurring. Razorback suckers also seemed to be somewhat confined and only a few areas are probably important for survival. Not enough information has been acquired on the bonytail chub to determine how broad or narrow the area of consideration should be for this species. The FWS is proceeding with a hatchery propagation program to prevent bonytail chub from becoming extinct. Also, more information on bonytail needs to be obtained from Gray Canyon-Coal Creek area before it is too late.

Basic flow requirements for selected life stages based upon analysis of IFG (Part 3, Report No. 1), field data (Part 2), USGS flow records, and the literature are made for average monthly flows and are presented in Table 5. Minimum instantaneous flows should not drop below the minimum recommended for the designated period of time and the overall monthly average should fall in the range presented. A minimum flow interval is present because under natural conditions the flow tends to decline during the critical period and variation occur within months.

In order to make the flow recommendation for Colorado squawfish spawning, YOY rearing, and humpback chub spawning, we looked at monthly averages, frequency of low flow, and median flows for both pre-impoundment periods and post-impoundment periods. (Table 3). These pre- and post-impoundment periods related to the closure of major CRSP Reservoirs. In conjunction with these statistics we incorporated actual flows for 1979, 1980, and 1981 (Table 4) and also IFG flow modeling statistics. We weighted these values by putting the greater weight on actual 1979-81 flow data and biological field data collected in these years. Next, we incorporated IFG physical habitat modeling data and suitability data. Next, we meshed the above information into actual flow data of pre- and post-impoundment. Using this type of sequence we arrived at our best estimate of required flow needs of the fish. These flow requirements should be received as estimates with a need for additional field data to make adjustments as needed.

Temperature needs are presented because they are flow related. Temperature requirements are presented as average and a 1-2° C variation can be expected under normal conditions. Therefore a requirement of 20°C can be viewed as a need of between 18-22° C because of the natural daily and monthly variation in water temperature.

An evaluation of hybridization also needs to be conducted for humpback chub in Black Rocks and Westwater Canyons. There is a need for maintaining and/or reestablishing spawning separation of roundtail and humpback chub. High flows in the spring may be an isolating mechanism between the two species. Temperature is believed to be a possible factor in separation of the spawning time of roundtail and humpback chub and when the river warms too quickly in the spring, spawning time may coincide. Temperature modeling with flow indicates that, at Black Rocks, flows of 7,000-13,000 cfs in May should be maintained to keep temperatures at about 13-15° C for humpback spawning (Part 3, Report No. 1). However, other information shows spawning at 16-18° C. As stated above, more work needs to be done on the effect of temperature on spawning separation of humpback and roundtail chubs.

Because the Upper Colorado system is aggrading, there is a need for a high flow in critical areas in order to flush sediment from the spawning areas and to maintain and/or improve the integrity of the present river channel. We recommend that the Bureau work closely with the USGS to ascertain what types of flows are needed to maintain key spawning and fry rearing areas. The flows required may be peak flushing flows or could include a higher base flow during critical periods. Flushing flows, whether increased peak or base flows, should be verified by actual field data from the key areas.

Recovery of Target Species

The flow requirements presented in this report and much of the associated data has been directed toward the survival of the species under present-day conditions with only flow as one of many variables. However, the goal in working with these endangered fish should be recovery and subsequent delisting by FWS.

There is now enough information on all the target species, with the exception of the bonytail chub, to initiate active management recovery programs. Our hatchery work has shown that all the target species can be propagated for reintroduction or supplementing present populations. Survival of stocked Colorado squawfish in the Colorado River has been documented and an introduction of humpback chub is now under study.

An evaluation of habitat improvement methods is needed for recovery efforts. Items such as additional ephermeral backwaters, changes in river flow, and water quality improvements need to be evaluated. The information base needed to undertake these types of improvement projects is available from this study.

The recovery plans for the endangered Colorado River fishes call for the prevention of decline of present populations, prevention of adverse modification of existing habitat, maintaining hatchery stocks, and restoration of these fishes to former range. All the information accumulated under this study will aid in achieving these recovery plan goals. Further work will need to be done to actively implement these recovery plan objectives. Such things as monitoring populations, manipulating habitat to evaluate improvement techniques, reintroduction to former range, and various hatchery work will need to be done.

CONTENTS OF PARTS 2 AND 3

Part 2 Field Studies

PART 3 Contracted Studies

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GLOSSARY

Life history terms

Adult	A fish capable of reproduction.
Subadult Juvenile	Fish from 1 year old up to, but not including adults (synonyms; immatures and subadults).
Postlarva	Fish with yolk sac absorbed, and loss of larval and gain of adult appearance.
Larvae Yearling Young-of-the-year	Fish up to 1 year of age. Larvae is the first stage after hatching and in this report refers to a recently hatched fish that is still undergoing metamorphosis and has not yet acquired a complete adult appearance.

Bioassay terms

LC_{50}	Median lethal concentration that kills 50 percent of test fish.
Specific Conductance	Electrical conductivity of water measured in micromhos per centimeter and corrected to 25° C.

Field terms

Braiding	Multiple side channels that appear to be intertwined.
Hydrologic station	Area where physical habitat simulation measurements are made.
RM	River mile from mouth of river.
Stratum	Geomorphologically homogeneous section of river selected for random statistical sampling of fishes (see 1979 Annual Report).
Travertine	Calcium carbonate, $CaCO_3$, deposited from lime rich springs supersaturated with CO_2.

Habitat types

Backwater	A body of water off the main channel with no measureable velocity; often created by a drop in water level which stops the flow through a former side channel or low-lying area.
Eddy	A portion of the stream with a distinct whirlpool effect.
Intermittent Stream	Small, natural, usually ephemeral stream.
Irrigation return flow	Water entering the river from irrigation collector system.
Main channel	Primary river course that carries the major water flow throughout most of the year.
Pool	A portion of the stream that is deep and quiet relative to the main current.
Riffle	A shallow fast flowing area where the water surface is broken into waves by obstructions wholly or partly submerged.
Run	A stretch of relatively deep, fast flow with the surface essentially nonturbulent.
Shoreline	The shallow, low-to-negligible velocity waters next to shore.
Side channel	A secondary channel which carries appreciable flow during high water and provides a low velocity habitat during low flow.

Substrate types

Silt	Fine, gritty material
Sand	Less than 3-mm diameter
Gravel	3 mm to 76 mm
Rubble	76 mm to 305 mm
Boulder	305 mm and larger
Bedrock	Solid, continuous rock layer