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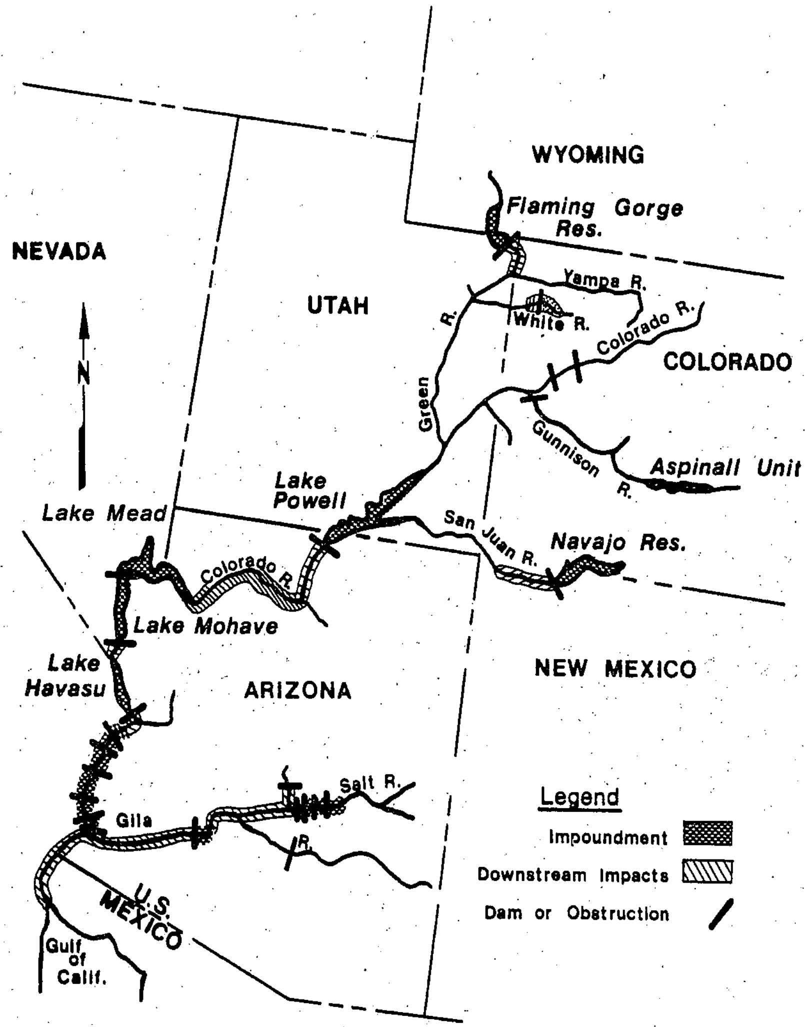
STREAM FLOW NEEDS OF RARE AND ENDANGERED FISHES, YAMPA RIVER, COLORADO



FINAL REPORT
U.S. FISH AND WILDLIFE SERVICE
COLORADO RIVER FISHES PROJECT
1988

07413

STREAM FLOW NEEDS
OF RARE AND ENDANGERED FISHES,
YAMPA RIVER, COLORADO

PRELIMINARY

FINAL REPORT

by

Harold M. Tyus
Catherine A. Karp

April 1, 1988

U.S. Fish and Wildlife Service
Colorado River Fishes Project
1680 W. Hwy. 40, Rm. 1210
Vernal, UT 84078

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INTRODUCTION

The native fish fauna of the Colorado River basin is an unique natural resource that has existed for millennia. Colorado squawfish (Ptychocheilus lucius), humpback chub (Gila cypha), bonytail chub (G. elegans), and razorback sucker (Xyrauchen texanus) are four endemic fishes that were historically common-to-abundant in rivers of the Colorado River basin. All four species were collected in the lower Yampa and upper Green rivers (Dinosaur National Monument (DNM)) prior to closure of Flaming Gorge Dam in 1962 (Vanicek and Kramer 1969). However, these fishes are threatened with extinction throughout the Colorado River basin due to combined effects of habitat loss and alteration, introduction of non-native competitors and predators, and other man-induced impacts. The Colorado squawfish, humpback chub, and bonytail chub are federally listed as endangered species; razorback sucker is protected by the states of Arizona, California, Nevada, Colorado, and Utah, and is a candidate species for federal listing (USFWS 1987a). The decline of these big river fishes is a biological indicator of change and impending loss of an unique and historic ecosystem.

Flow regimens have been substantially altered by dams in all large rivers in the upper Colorado River basin except the Yampa River (Figure 1). As indicated in Figure 2, flows of the Yampa River are not significantly different from historic conditions, and spring runoff from this system maintains the spring/early summer peak in the existing Green River hydrograph (downstream from the Yampa River confluence). Alteration of the natural flow regimen of the Yampa River due to construction of water projects (e.g. Stagecoach and Juniper-Cross Mountain projects on the Yampa River, Cheyenne

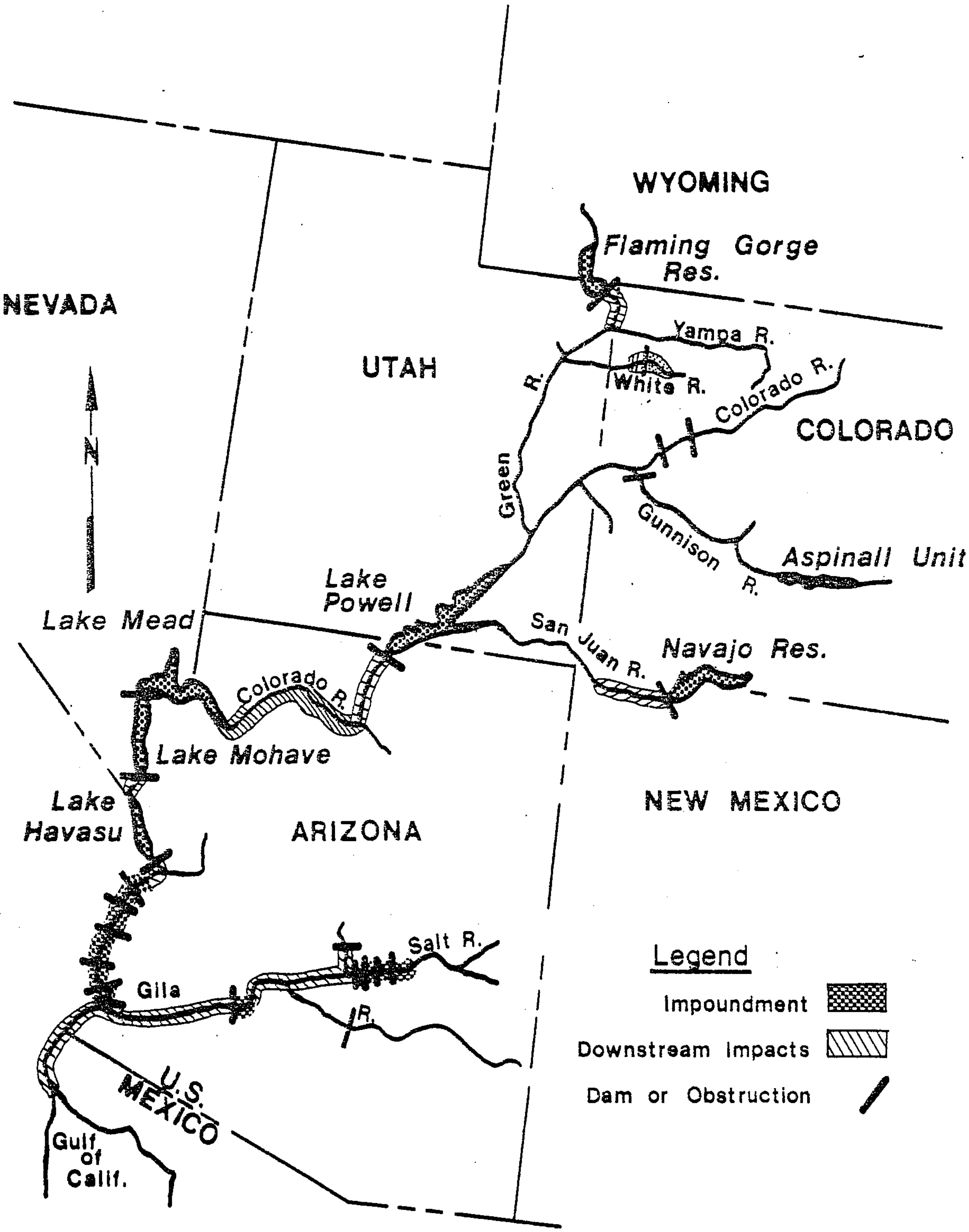
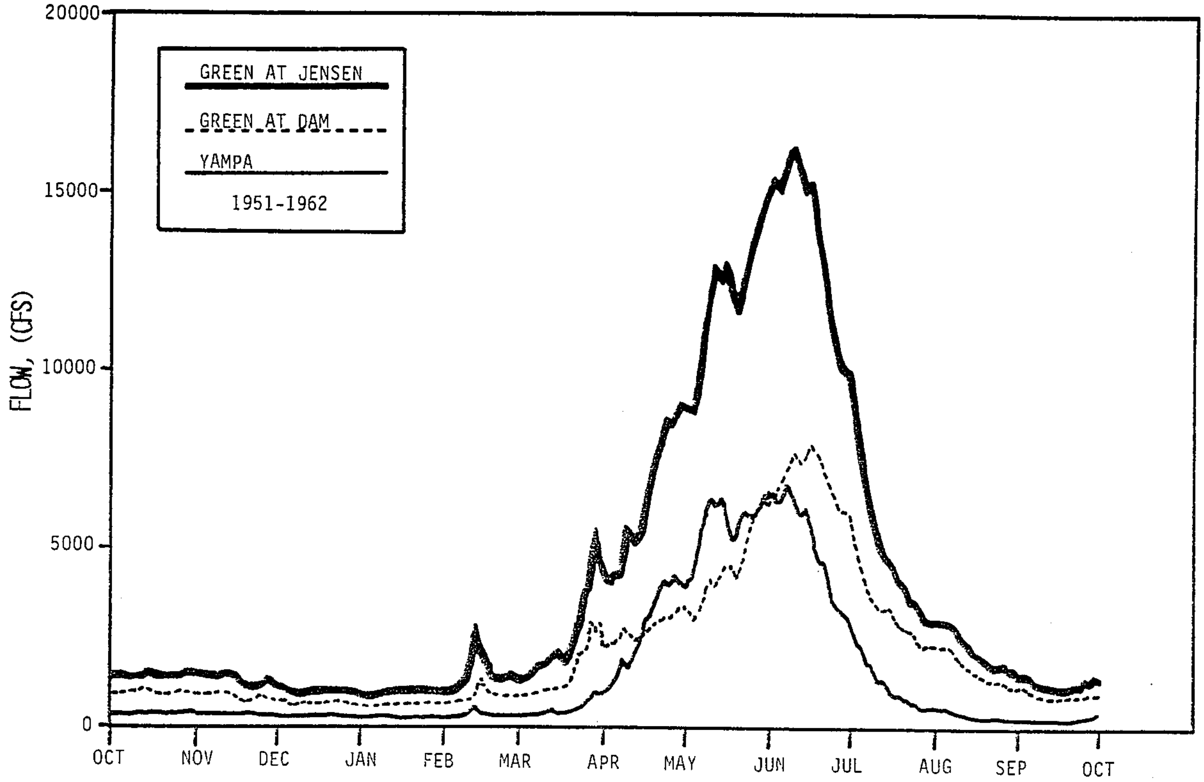


Figure 1. Major water development projects and their impacts in the Colorado River Basin (after Tyus 1984).



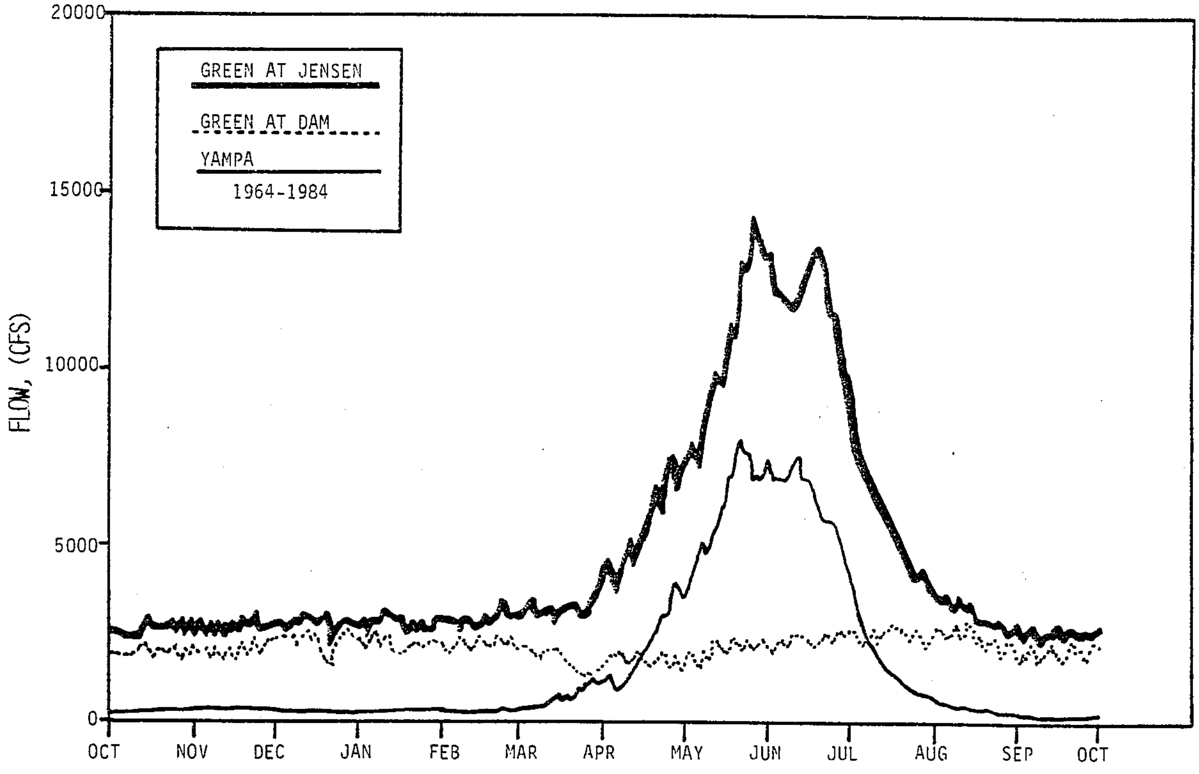


Figure 2. Average annual distribution hydrograph for the Green and Yampa rivers, 1951-1962 and 1964-1984 (Courtesy of Bureau of Reclamation).

Water Diversion Project on the Little Snake River) could adversely impact the endangered fish fauna throughout the Green River basin.

Potential conflicts between survival of rare and endangered fishes indigenous in the Yampa River, and development of water projects in that system, prompted multi-agency investigations in the late 1970's. Bureau of Reclamation (BR), Fish and Wildlife Service (FWS), and the National Park Service (NPS) initiated a study in 1980-1981 to obtain information for the formulation of Biological Opinions under Section 7 of the Endangered Species Act, and also to obtain instream flow recommendations for possible water rights acquisition in Dinosaur National Monument. This work resulted in several reports including: Archer and Tyus (1984), and Miller et al. (1982, 1983). Colorado Division of Wildlife (CDOW) and FWS have cooperated in conducting rare and endangered fish studies in the Yampa River since the late 1970's (Archer and Tyus 1984, Haynes and Muth 1984, Miller et al. 1982, Tyus et al. 1987, and Wick et al. 1981, 1983, 1985).

The Biology Subcommittee of the multi-agency upper Colorado River basin Coordinating Committee reviewed existing data and produced a "Rare and Endangered Colorado River Fishes Sensitive Areas" report in 1984 (UCRBCC 1984). This report and other studies confirmed the importance of the Yampa River to the continued survival of rare and endangered fishes in the Green River basin. The requirements of these fishes for large areas of habitat throughout the Colorado River basin emphasizes the need for multi-agency cooperation in management and protection.

Identification of important river reaches and delineation of sensitive areas (UCRBCC 1984) is a critical first-step for protection of rare and endangered fishes. However, such steps alone do not insure long-term recovery of these fishes. Development of alternatives to avoid, minimize, or rectify the impacts of water resource development will become more difficult as future water development adds to the loss and alteration of endangered fish habitat (USFWS 1987a). Solutions to water management conflicts need to be sought in order to avoid confrontations between industry, government, and environmental groups. The need for protection of instream flows, and possible acquisition of water rights is necessary if the endangered fish fauna is to be saved, and possibly recovered under provisions of the Endangered Species Act.

This report evaluates stream flow needs of four rare and endangered Colorado River fishes (Colorado squawfish, humpback chub, bonytail chub, razorback sucker) with respect to the natural flow regimen of the Yampa River. Habitat requirements for each species in the upper Green River basin are first reviewed by life history stage. This is followed by a discussion of factors limiting the distribution and abundance of each species, and lastly, a discussion of stream flow recommendations.

DISTRIBUTION, ABUNDANCE, AND HABITAT USE

General

The distribution and abundance of fishes indigenous to the Yampa River has been documented by various workers (Haynes et al. 1984, Holden and Stalnaker 1975, McAda and Wydowski 1980, Miller et al. 1982, Nesler 1986, 1988, Seethaler 1978, Tyus et al. 1982a, 1987, Wick et al. 1982, 1985, and others).

In 1981, FWS divided the lower 124 miles of the Yampa River (Echo Park to Round Bottom near Craig, Colorado) into eight relatively homogeneous river sections (strata) (Figure 3), using topographic and geologic maps, aerial

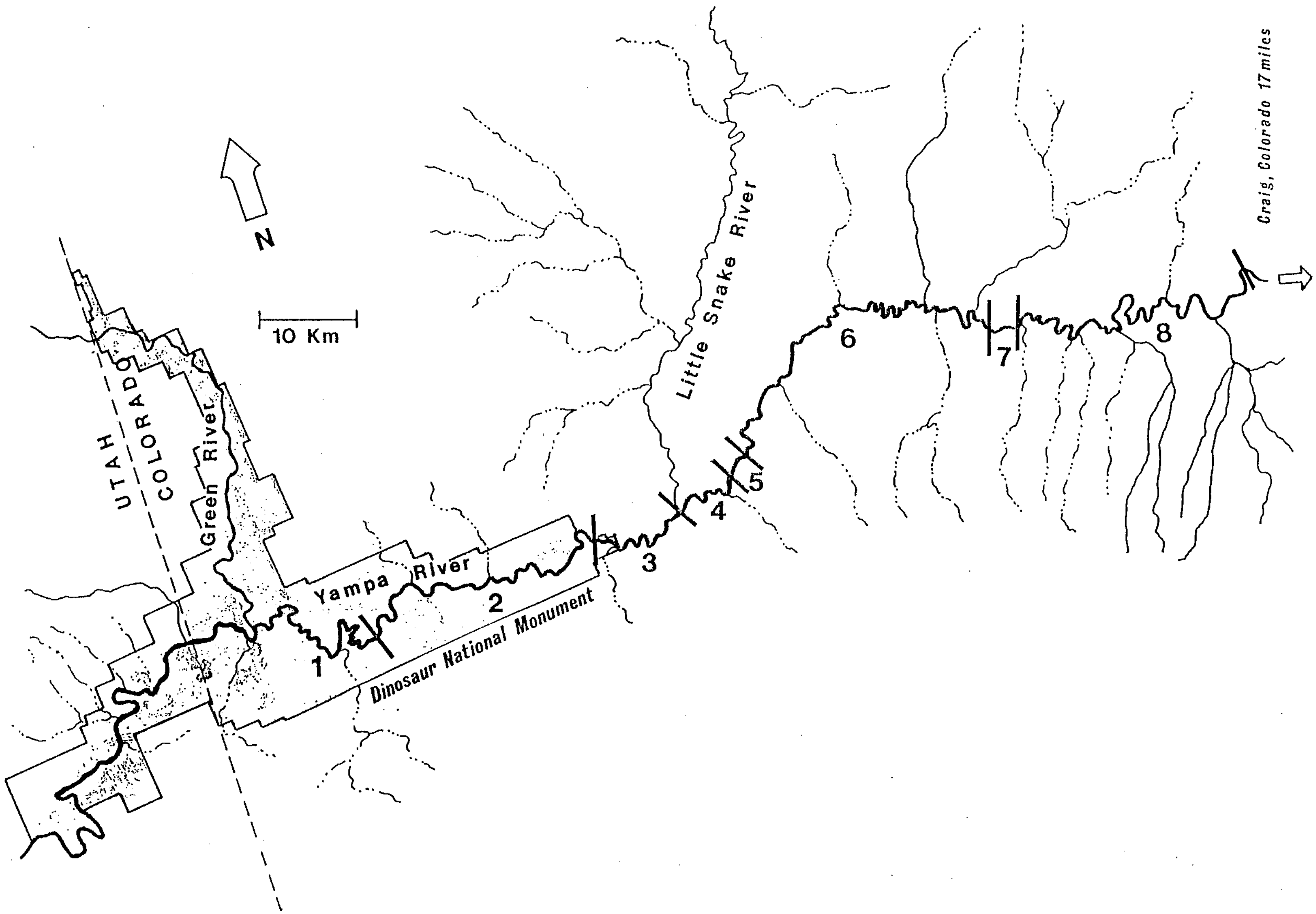


Figure 3. Study area and sampling strata of the Yampa River.

surveys and field reconnaissance, in an effort to identify fish habitat. Detailed descriptions of these strata are provided in Miller et al. (1982). Habitat use data for all fish species (e.g., major habitat type, depth, velocity, and substrate information) was collected by FWS and CDOW in 1981. Migration patterns and habitat use of Colorado squawfish were investigated using radiotracking methods from 1981-1985. Spawning behavior of Colorado squawfish in the Yampa River has been studied 1981-1987 (Tyus et al. 1987, Wick et al. 1983). Studies of general habitat use by humpback chub and winter habitat use by Colorado squawfish were initiated in the Yampa River in 1986. These studies are being continued in 1988 by FWS (Vernal, UT) and the Larval Fish Lab (Colorado State University, Fort Collins, CO).

Colorado squawfish

Adults: Adult Colorado squawfish are distributed in the Yampa River from its mouth upstream to Craig, Colorado. Catch records from standardized sampling programs indicated adults were concentrated in strata 4-8 (Figure 3) during the non-breeding period (Miller et al. 1982, Wick et al. 1985). In 1981, catch of adult Colorado squawfish averaged 0.04 fish per hour below, and 0.3 fish per hour above the confluence of the Little Snake River (Miller et al. 1982).

Adult Colorado squawfish occupied a variety of habitats but were most commonly found in eddies, pools, runs, and shoreline backwaters, over sand and silt substrates (Figure 4). Visual observations in shallow water indicated that adults use sheltered microhabitats behind boulders, flooded vegetation, or other cover. During the summer months, radiotagged fish were most often located in eddies in deeper water, where movements suggested heavy use of

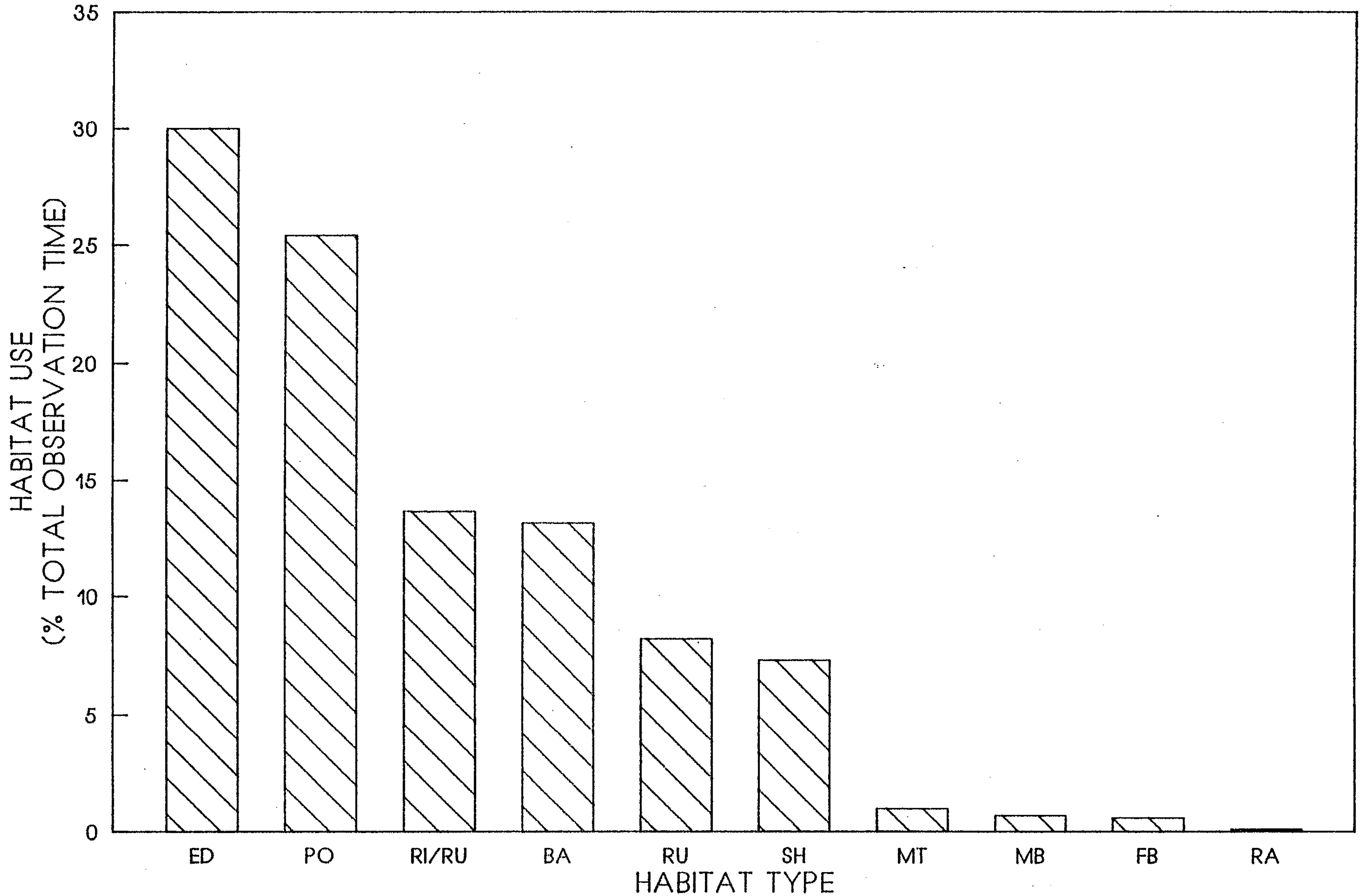


Figure 4. Habitat use by radiotagged Colorado squawfish in the Yampa River, 1981-1985, 1987. ED=eddy, PO=pool, RI/RU=riffle/run<5.5' deep, BA=backwater, RU=run>5.5' deep, SH=shoreline, MT=mouth of tributary, MB=mouth of backwater, FB=flooded bottom, RA=rapid.

eddy-run interfaces. Preliminary data from winter studies suggested that adult Colorado squawfish overwintered in the upper Yampa River, using large backwaters (ephemeral along-shore embayments), runs, and eddies, but were most common in ice covered, low velocity shoreline areas, where large schools of minnows were observed (Wick and Hawkins 1987), and presumably feeding.

Adult Colorado squawfish used backwater habitats in spring and early summer during years of low flow (e.g. 1981), but were common in flooded bottomlands in high flow years (e.g. 1983 and 1984). (NB:: High, average, and low flow designations for type of water year are defined in Butler (1988)). Radiotracking efforts in late spring/early summer in the Yampa River indicated high use of shoreline backwater habitats in the 1981 low flow year (66%, N=6 individual fish). Conversely, during the 1983 high flow year, adults exhibited a high use for flooded bottomlands (40%, N=10; none of the 10 fish contacted during this period were located in backwater habitat). Wick et al. (1983) similarly found that in 1982, adult Colorado squawfish used flooded areas in spring, but moved to backwater habitats as river level dropped. Radiotracking data for adult Colorado squawfish in Green River, 1983 and 1984, generally support these findings (Tyus et al. 1987).

Spawning: Two major spawning migrations have been identified by FWS in the Green River basin by tracking radiotagged Colorado squawfish. One migration was discovered in the Yampa and upper Green River in 1981 (Tyus and McAda 1984), confirmed in 1982 (Wick et al. 1983) and again from 1983-1987 (this report, Tyus et al. 1987). Movement patterns of fish migrating to the Yampa River spawning ground are presented in Figure 5. In May and early June, 1981-1987, Colorado squawfish initiated downstream migrations in the Yampa River

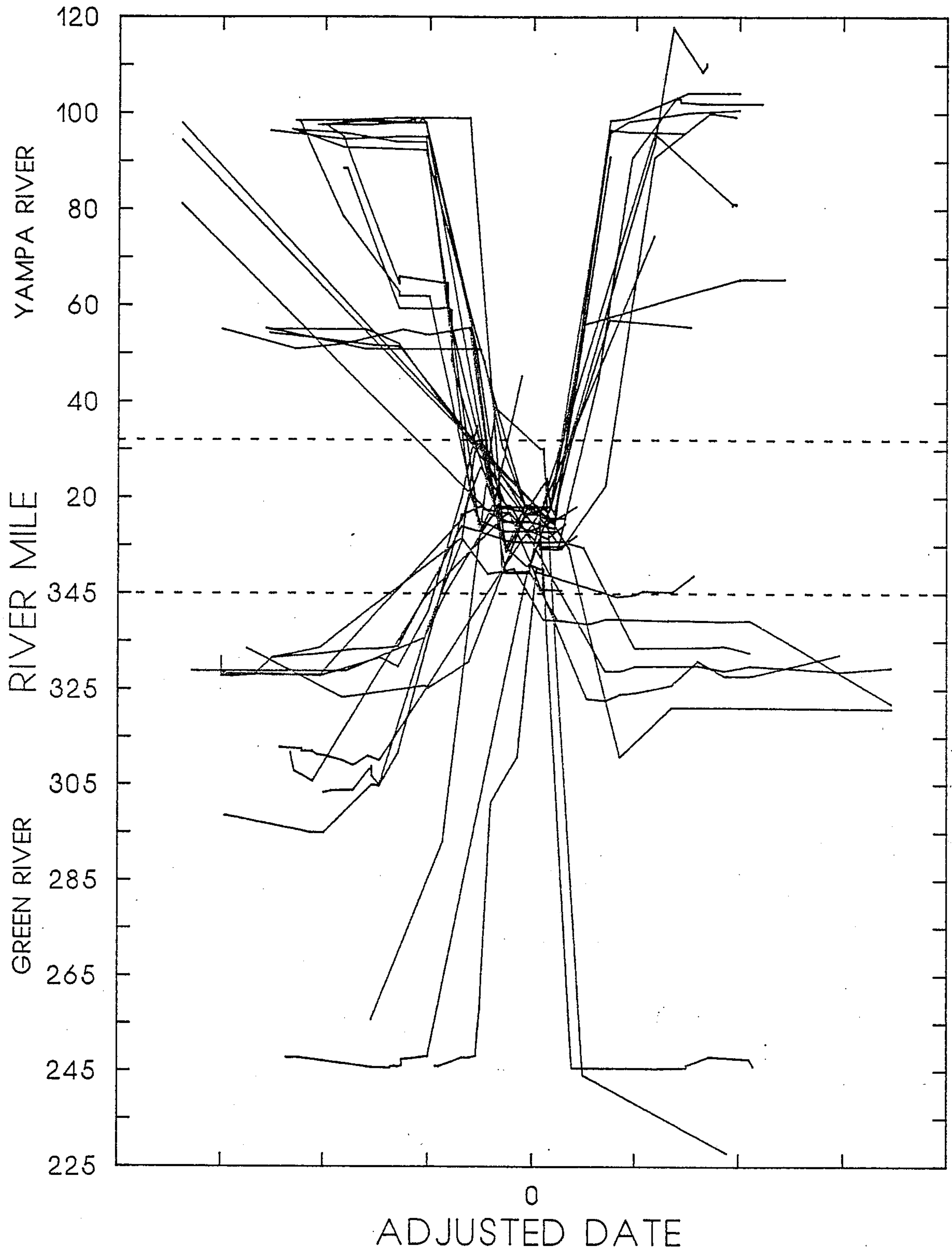


Figure 5. Spawning migrations of radiotagged Colorado squawfish, Yampa River, 1981-1985, 1987. Spawning reaches delineated by (- - - -), 0 = midpoint of calculated optimum spawning period for each year. Adjusted date scale in 28 day increments.

and upstream migrations in the Green, White, and Duchesne rivers to spawn in riffle/pool habitat of the lower 32 miles of the Yampa Canyon. The only other confirmed Colorado squawfish spawning site exists in Gray Canyon of the Green River (Tyus et al. 1987).

A total of 37 Colorado squawfish were radiotracked to the Yampa Canyon spawning ground by FWS (N=31) and CDOW (N=5) from 1981-1987. These included 23 fish from the upper Yampa River, 12 fish from the Green River, and one fish that migrated 233 miles from the White River. Migrants tracked by FWS averaged 78 miles one-way. The distance traveled by the White River fish may have exceeded one year since the fish was tagged at River Mile (RM) 103 White River in 1983, tracked to RM 31 Yampa River in spring 1984, and recaptured at RM 98 White River in 1985. These radiotracking data show that adult Colorado squawfish migrate to the Yampa Canyon (strata 1 and 2, Figure 3) in early summer from many areas throughout the upper Green River basin (including White, Green and Yampa rivers). These data also suggest that all adult fish do not spawn each year. Of four fish radiotracked in consecutive years (1+ years) during the spawning season, two did not migrate each year and remained in the same river reach. Local movements of these non-migrants may be indicative of home range behavior in nonbreeding years.

Adult Colorado squawfish were radiotracked in early spring in the upper Yampa River by FWS in 1981 and 1983 (Tyus and McAda 1984, Tyus 1985), and by CDOW/NPS in 1982 (Wick et al. 1983). These fish initiated spawning migrations from 12 May to 10 June, depending on type water year (Table 1). Flow and water temperature conditions were highly variable within each migration period and between years. However, it appears that spawning migrations were initiated earlier in low water years (e.g. 1981) and later in higher water

Table 1. Initiation of Colorado squawfish spawning migration to Yampa River spawning ground, 1981-1983.

Year	Type Water Year[1]	Discharge[2]	Migration Period[3]	Water Temperature(C)[2]
1981	Low	Mean = 3,643	5/12-6/5	Mean =12.6
		Max. = 5,570		Max. =16.0
		Min. = 1,570		Min. = 9.5
1982	Ave.	Mean = 7,375	6/10-6/20	Mean =12.6
		Max. = 8,310		Max. =15.0
		Min. = 7,040		Min. =10.5
1983	High	Mean = 8,891	6/10-7/10	Mean =13.4
		Max. =11,400		Max. =18.0
		Min. = 5,540		Min. = 8.5

1 Designation of low, average, and high water years after Butler (1988) (i.e., low:<1514cfs, average:1514-2760cfs, high:>2760cfs).
2 USGS records (Maybell Gauge).
3 Period of spawning migration represents the interval between first and last contact with radiotagged fish moving to Yampa River spawning grounds.

years (e.g., 1983) (Table 1). Figure 6 shows the relationships between discharge, water temperature, and migration period for 1981-1983. For each year, Colorado squawfish initiated spawning migrations 8-12 days following a spring peak flow of about 3.5 times the mean annual discharge and a river temperature regimen exceeding 11 C. It is not known whether these conditions are requisite for initiation of spawning movements, but we believe some combination of endogenous and exogenous factors are necessary (including temperature, discharge, photoperiod), and that neither discharge nor temperature alone are adequate for initiation of spawning migrations. Effect of exogenous factors on the control of reproductive cycles of cyprinid fishes is well known (Bye 1984). It is possible that inputs of certain chemical substances due to spring flooding, in combination with increasing water temperatures, acts to initiate spawning migrations in Colorado squawfish.

Homing behavior in Colorado squawfish is indicated by long distance movement patterns and repeated recaptures of the same fish on the Yampa River spawning ground in subsequent years (Tyus 1985, Wick et al. 1983). Of four fish radiotracked to the Yampa River spawning grounds for 1+ years, two migrated to the same location in consecutive years, indicating fidelity to the spawning site. Recaptures of fish on the Yampa River spawning ground also supports the concept of fidelity in Colorado squawfish. A total of five Colorado squawfish in breeding condition have been tagged and recaptured in the Yampa River between RM 11 and RM 18 for intervals of 1+ years (3 fish for two consecutive years, 1 fish after a two year interval, and 1 fish after a three year interval). Adult Colorado squawfish using the Yampa River spawning grounds have not been found to use any other spawning site throughout the Green River system.

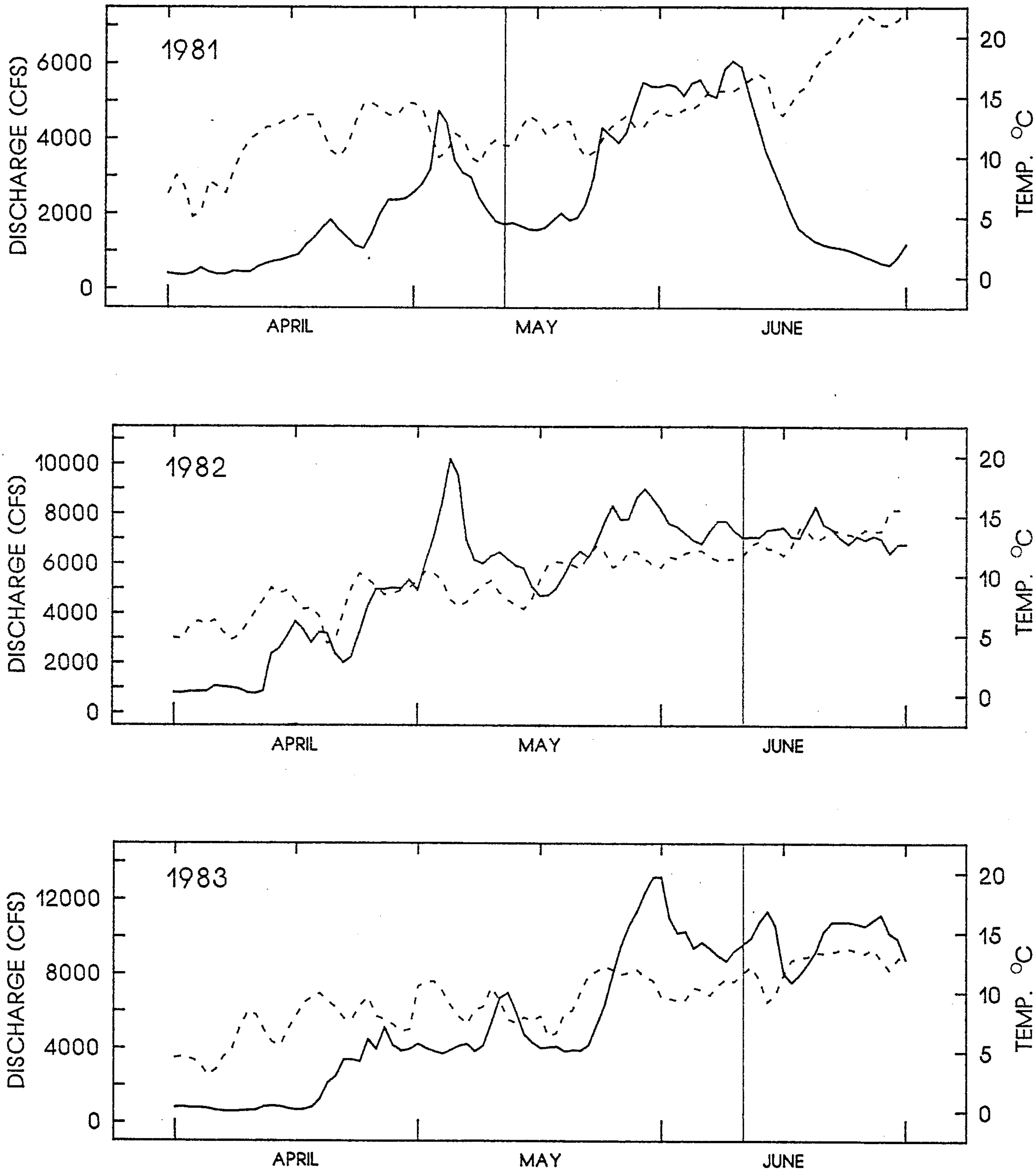


Figure 6. Discharge-temperature relationships and initiation of spawning migration for Colorado squawfish, Yampa River, 1981-1983. Vertical bar indicates initiation of migration.
(USGS records, Maybell gauge)

The Groundwater Seepage Hypothesis, proposed for other species by Harden-Jones (1981), has been advanced as a possible homing mechanism for Colorado squawfish (Tyus 1985). Although no experimental evidence to date confirms or disproves the existence of an olfactory imprinting mechanism for Colorado squawfish, observations at the two confirmed spawning grounds in upper Green River basin indicate that these canyon areas are geohydrologically unique. Colorado squawfish may be orienting to these areas because of freshwater input from spring-fed tributaries and sandstone/limestone seeps (e.g., Florence Creek in Gray Canyon and Warm Springs Creek in Yampa Canyon).

Spawning requirements of Colorado squawfish were evaluated at the Yampa River spawning reach, 1981-1987. Both water temperature and discharge was highly variable during the optimum spawning period (Table 2). Water temperatures ranged from 14.5-27.5C, average minimum and average maximum temperatures for all years were about 19C and 24C, respectively. Mean discharge ranged from 893 cfs in 1981, to 3,825 cfs in 1982. There was no apparent relationship for spawning flows between years, except that spawning always occurred with declining water levels following peak spring floods (Figure 7). Although we did not correlate discharge with spawning period, the mean discharge for 1981-1987 (2,436 cfs) was similar to that reported by Butler (1988) for years 1941-1986 (2,140 cfs). Mean discharge during the optimal spawning period was similar for the four high water years (1983-1986), but there was no agreement between the two low flow years (1981 and 1987). These inconsistencies emphasize the need for long-term studies in order to investigate relationships between physical factors and biological phenomena.

As indicated by Figure 8, there is general agreement between period of migration, collections of ripe fish, and estimated dates of egg deposit, back-

Table 2. Optimum Colorado squawfish spawning period, Yampa River 1981-1987.

Year	Type Water Year[1]	Discharge[2]	Optimum Spawning Period[3]	Water Temperature (C)[4]
1981	Low	Mean = 893	6/23-7/13	Range: 18-25.5
		Max. = 1,327		Mean max. = 24.8
		Min. = 437		Mean min. = 19.3
1982	Ave.	Mean = 3,825	7/8-8/1	Range; 16.5-27.5
		Max. = 6,230		Mean max. = 23.3
		Min. = 2,430		Mean min. = 19.5
1983	High	Mean = 3,044	7/15-8/10	Range: 18-27
		Max. = 4,990		Mean max. = 24.3
		Min. = 1,470		Mean min. = 21
1984	High	Mean = 2,535	7/16-8/15	Range: 20-24
		Max. = 4,650		Mean max. = 23.8
		Min. = 1,040		Mean min. = 20.3
1985	High	Mean = 2,261	6/25-7/17	Range: 14.5-25.5
		Max. = 4,800		Mean max. = 22.8
		Min. = 1,010		Mean min. = 17.8
1986	High	Mean = 2,383	7/2-8/2	Range: 18.5-23
		Max. = 4,600		Mean max. = 22.5
		Min. = 933		Mean min. = 19.5
1987	Low	Mean = 2,110	6/9-7/3	Range: 16.5-24.5
		Max. = 4,530		Mean max. = 22.9
		Min. = 847		Mean min. = 17.4

1 Designation of low, average, and high water years after Butler (1988) (i.e., low:<1514cfs, average:1514-2760cfs, high:>2760cfs).

2 USGS Records (1981 sum of Maybell and Little Snake Gauges; 1982-1987 Deerlodge Gauge). Daily discharge data for optimum spawning period were used.

3 Derived from contact with radiotagged adults and collection of ripe fish on spawning ground, and back calculation of larval age.

4 USGS Records (1981-Maybell Gauge, 1982-Deerlodge Gauge) and Hand-Held Thermometers (1983-1987, data collected on spawning ground). Mean minimum and maximum values were calculated from early morning and afternoon temperatures respectively, for optimum spawning period.

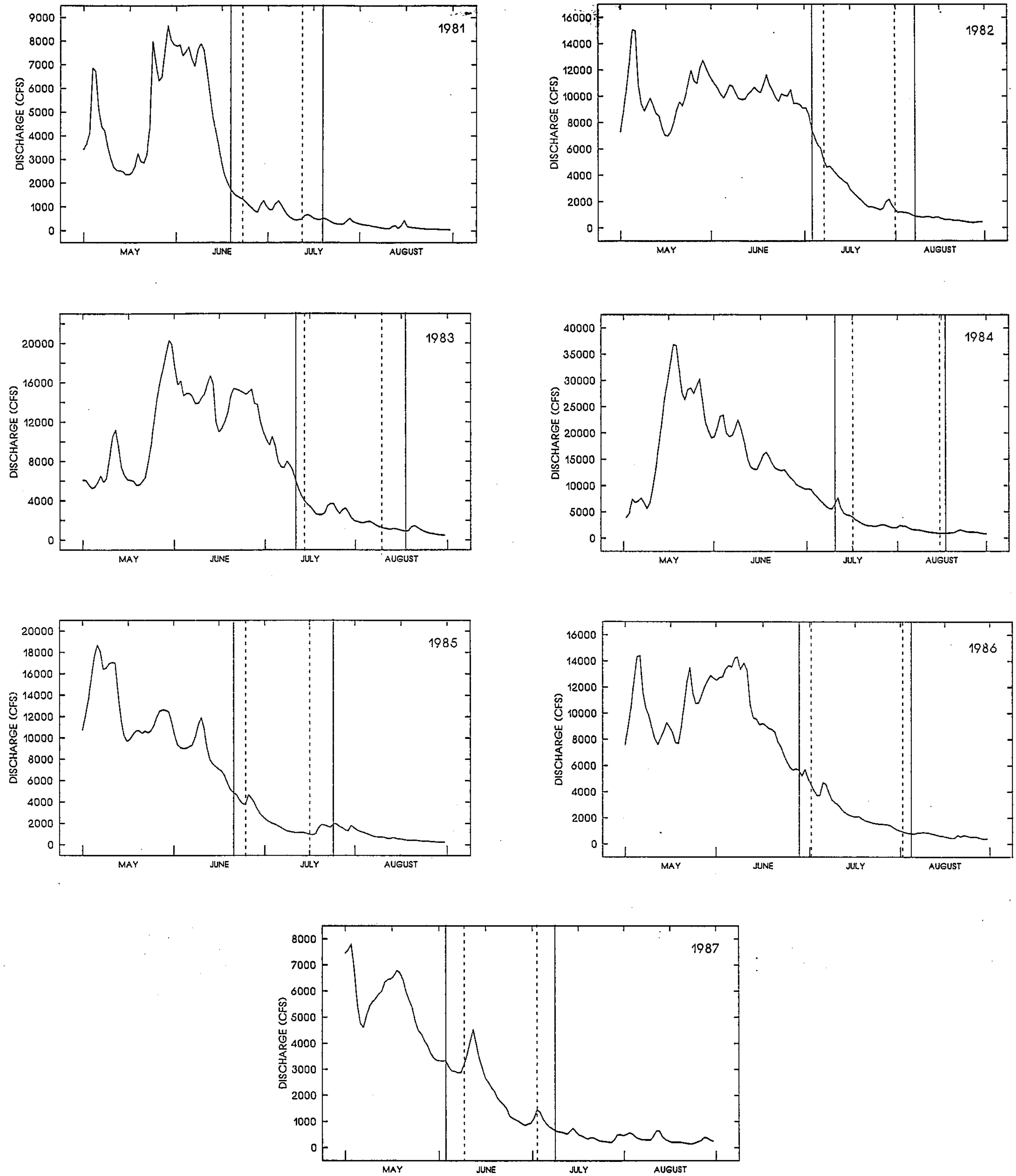


Figure 7. Discharge-spawning period relationship for Colorado squawfish, Yampa River, 1981-1987. Optimum spawning period indicated by dashed lines. Total spawning period indicated by solid lines (USGS records, Deerlodge gauge).

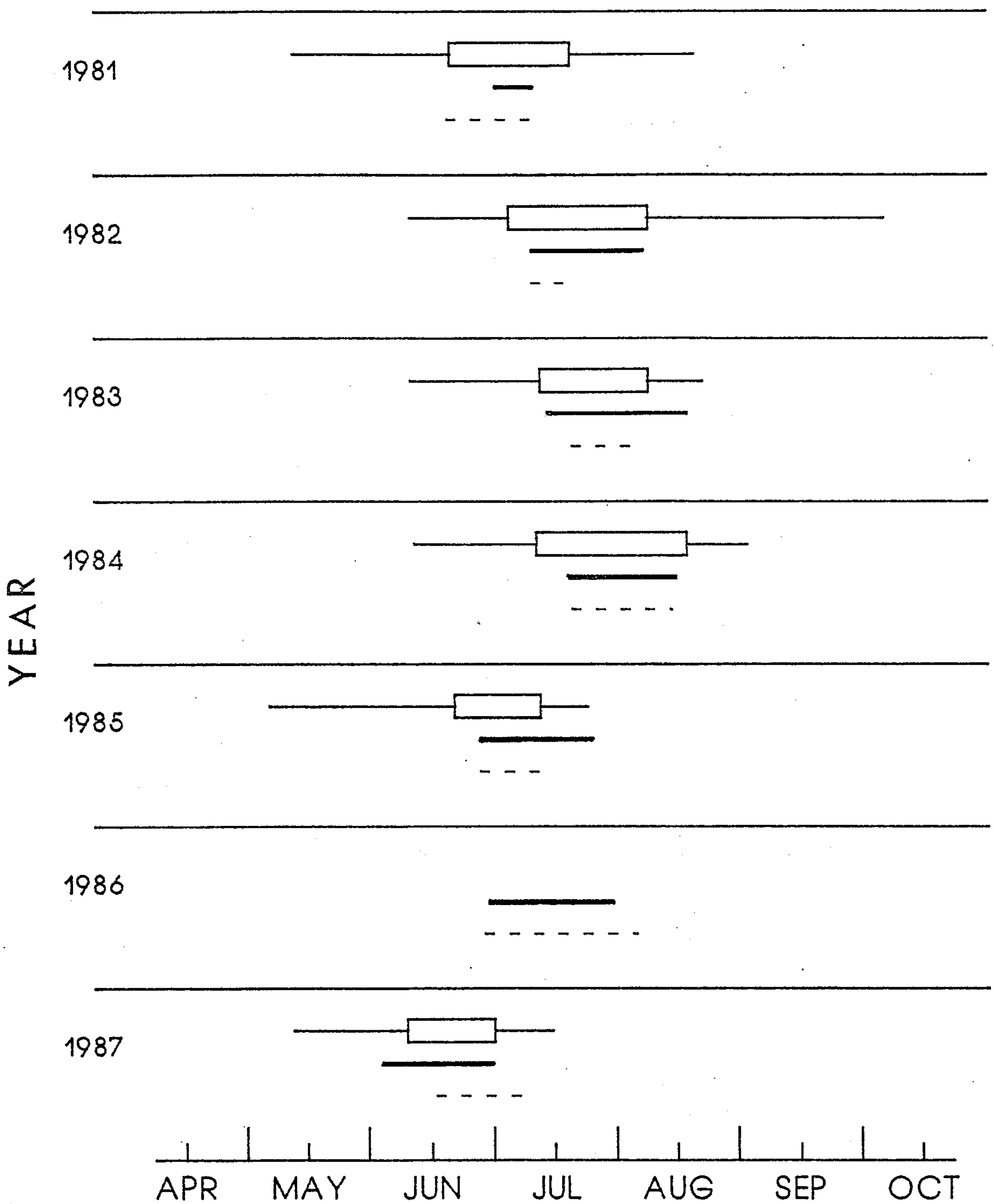


Figure 8. Migrations of radiotagged Colorado squawfish (——), collections of ripe Colorado squawfish (——), and estimated spawning times from backcalculation of larval Colorado squawfish (----) as estimators of optimum spawning periods, Yampa River, 1981-1987. (▭ indicates presence of radiotagged Colorado squawfish on spawning grounds)

calculated from larval size for 1981-1987. The length of optimal spawning period in the Yampa River (Table 2), derived from Figure 8, was similar for each year. Spawning generally occurred earlier in low water years (1981 and, 1987) and later with higher flows (1983 and 1984) (Table 2). Dates used in estimation of "optimal" and "total" spawning periods are provided in Table 3. Total spawning period included any indication of spawning activity (e.g., radiotagged fish, collections of ripe fish, larvae) and was about 4 to 5 weeks in duration. Optimum spawning periods (indicating highest spawning activity as evidenced by simultaneous collections of radiotagged fish, ripe fish, and larvae) were somewhat shorter (Table 3).

Table 3. Calculation of optimal spawning period for Colorado squawfish in Yampa River, 1981-1987.

Year	Back Calculations[1]	Ripe Fish	Radiotagged Fish[2]	Spawning Period Total	Spawning Period Optimum
1981	6/19-7/10	7/1-7/10	6/20-7/20	6/19-7/20	6/23-7/13
1982	7/10-7/18	7/10-8/7	7/4-8/8	7/4-8/8	7/8-8/1
1983	7/20-8/5	7/14-8/18	7/12-8/8	7/12-8/18	7/15-8/10
1984	7/19-8/13	7/18-8/14	7/10-8/17	7/10-8/17	7/16-8/15
1985	6/27-7/13	6/27-7/25	6/21-7/12	6/21-7/25	6/25-7/17
1986	6/29-8/4	7/5-7/30	N/A	6/28-8/5	7/2-8/2
1987	6/16-7/9	6/3-6/30	6/9-6/30	6/3-7/9	6/9-7/3

1 Larvae were separated into two size classes: <22mm and 22-47mm, for back calculation of larval age and estimation of spawning period (equations in Haynes and Muth 1984, Nesler 1986). An estimate of total spawning period was obtained by combining estimated periods for two size classes.
2 Dates (range) represent first and last appearance of radiotagged fish on spawning grounds.

Breeding adults were most often concentrated in river reaches containing deep pools and/or eddies and cobble (rubble) bars. The fish moved from pools and/or eddies to apparently spawn on cobble bars, then returned to the former habitat (behavior similar to that reported for spawning northern squawfish (Beamsderfer and Congleton 1982)). Turbid conditions in the Yampa River precluded direct observation of egg deposition, however, there is substantial evidence that Colorado squawfish and other squawfish species require cleaned cobble surfaces for egg adhesion (Burns 1966, Hamman 1981, Patton and Rodman 1969). Hamman (1981) also noted that hatching occurred on cobble surfaces. Spawning of Colorado squawfish at a time when sediment transport is reduced (Figure 9) tends to support this need.

Colorado squawfish spawning behavior may be divided into two phases:

1. A resting-staging phase in pools or large shoreline eddies where the fish may find suitable resting and feeding habitat between spawning forays or where males may gather around females until they are ready to deposit eggs;

2. A deposition-fertilization phase on cobble bars, where males and females congregate, females deposit eggs and males fertilize them.

Breeding adults occupied pools and/or eddies with an average depth and velocity of about 7.0 ft and 1.0 f/s respectively, and cobble bars with an average depth and velocity of 3.0 ft and 2.0 f/s respectively (Table 4).

FWS data (Tyus et al. 1987) and CDOW-NPS data (Wick et al. 1983) indicate that Colorado squawfish spawning activity in the Yampa River occurs in the lower 32 miles, particularly in a reach extending from Warm Springs Rapid (RM 4.1) upstream to the vicinity of Harding Hole (RM 20). Repeated captures of ripe fish between RM 15 and RM 18.8 suggests that actual deposition and fertilization of eggs may be concentrated in this area. This portion of the Yampa Canyon (stratum 1, Figure 3) differs from other sections in that large, deep pools and eddies are intermingled with runs and cobble bars. The latter habitat is dominated by gravel, cobble, and boulder substrates.

A total of 290 Colorado squawfish were collected by FWS at the two confirmed spawning sites in the Yampa and Green rivers during spawning period,

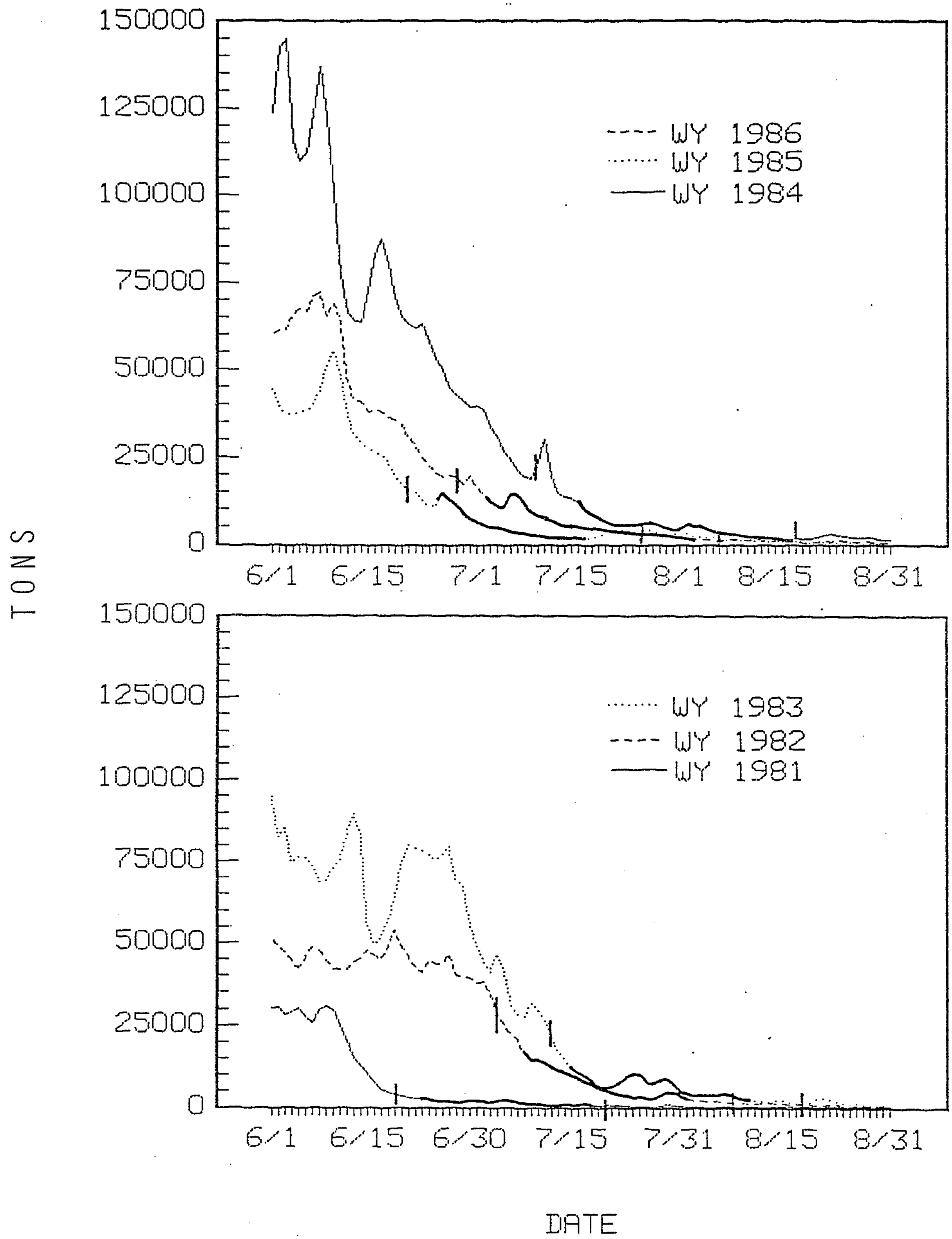


Figure 9. Sediment transport, total and optimal spawning periods, Yampa River, 1981-1986. Colorado squawfish total spawning period indicated by vertical bars. Optimum spawning period is highlighted. (WY=water year)

Table 4. Depth and velocity measurements recorded at locations of radiotagged Colorado squawfish on spawning grounds, Yampa River, 1981, 1983, 1984, 1985, and 1987.

A. **Resting-staging**

Year	Number of Fish	Number of Contacts	Mean Depth (ft)	Mean Velocity (f/s)[1]
1981	7	74	5.90	1.27
1983	7	46	7.75	1.56
1984	5	259	5.56	0.58
1985	3	77	10.82	0.73
1987	4	22	6.46	0.46
Mean			6.71	0.79

B. **Deposition-fertilization**

Year	Number of Fish	Number of Contacts	Mean Depth (ft)	Mean Velocity (f/s)
1981	7	65	3.80	1.95
1983	4	21	3.35	2.60
1984	5	51	2.76	1.75
1985	-	--	--	--
1987	-	--	--	--
Mean			3.35	1.97

1 Mean velocities were calculated from absolute values of velocity data.

1981-1987 (Table 5). Included in this total were 188 "ripe" adults. These fish were classified "ripe" if milt or eggs could be expressed from the vent with light hand pressure on the abdomen. Ripe males (N=178) were always found heavily covered with breeding tubercles and bearing a bronze coloration. A total of 23 additional fish were classified as suspected male because of the presence of these two characteristics. Robust tuberculation in male Colorado squawfish has also been noted by Hamman (1981) and Seethaler (1978). Only 10 ripe or spent female Colorado squawfish were positively identified by expression of eggs. However, 40 additional fish were classified as suspected female because of their large size, and absence of heavy tuberculation and bronze coloration. These data indicate a definite paucity of adult female Colorado squawfish in the Green River system, which may be due to differential mortality (Tyus et al. 1987). High male:female sex ratio in Colorado squawfish has also been noted by Seethaler (1978) (following a re-evaluation of Vanicek's (1967) data) and for other squawfish species (Patten and Rodman 1969).

Larvae and Postlarvae: Following spring runoff, larval Colorado squawfish emerge as sac-fry from cobble bars in the Yampa Canyon and drift downstream (Haynes et al. 1984, Tyus et al. 1982b) to concentrate in shallow backwater habitats of the Green River in Utah (Figure 10) (Tyus et al. 1982b, 1987). Young fish are able to use river transport for dispersal from upstream spawning grounds to these productive downstream nursery habitats (Tyus and McAda 1984, Tyus 1986), habitats created by gradually decreasing summer flows. During this period of emergence and dispersal, yolk is fully absorbed and young fish reach a critical stage when feeding must begin. Postlarval (Young-of-year) Colorado squawfish are rare in the Yampa River and no Age 0 fish

Table 5. Spawning collections of Colorado squawfish, Yampa and Green rivers, 1981-1987.

		Total	Males				Females			
			Ripe		Suspected[1]		Ripe		Suspected[2]	
Year	River	N	N	TL Ave	N	TL Ave	N	TL Ave	N	TL Ave
1981	Yampa	39	20	538	6	528	1	779	2	748
1981	Green	5	1	478	0	--	0	--	0	--
1982	Yampa	1	1	547	0	--	0	--	0	--
1982	Green	11	6	509	0	--	0	--	2	642
1983	Yampa	25	13	596	1	560	3	722	2	662
1983	Green	18	11	569	0	--	0	--	1	625
1984	Yampa	38	20	560	1	510	3	666	11	714
1984	Green	31	14	574	4	544	1	750	7	663
1985	Yampa	13	10	571	0	--	1	723	1	639
1985	Green	37	24	574	5	549	0	--	2	626
1986	Yampa	12	7	535	0	--	1	485	3	702
1986	Green	25	22	541	1	559	0	--	1	781
1987	Yampa	21	13	539	1	510	0	--	4	621
1987	Green	28	16	533	4	520	0	--	4	666
Total	Yampa	140	84	556	9	528	9	683	23	691
	Green	150	94	554	14	540	1	750	17	662
	Both	290	178	555	23	535	10	690	40	679

1 Heavily tuberculated and colored fish, with no expressible sex products.
2 Large fish with little coloration, little or no tuberculation, and large vent.

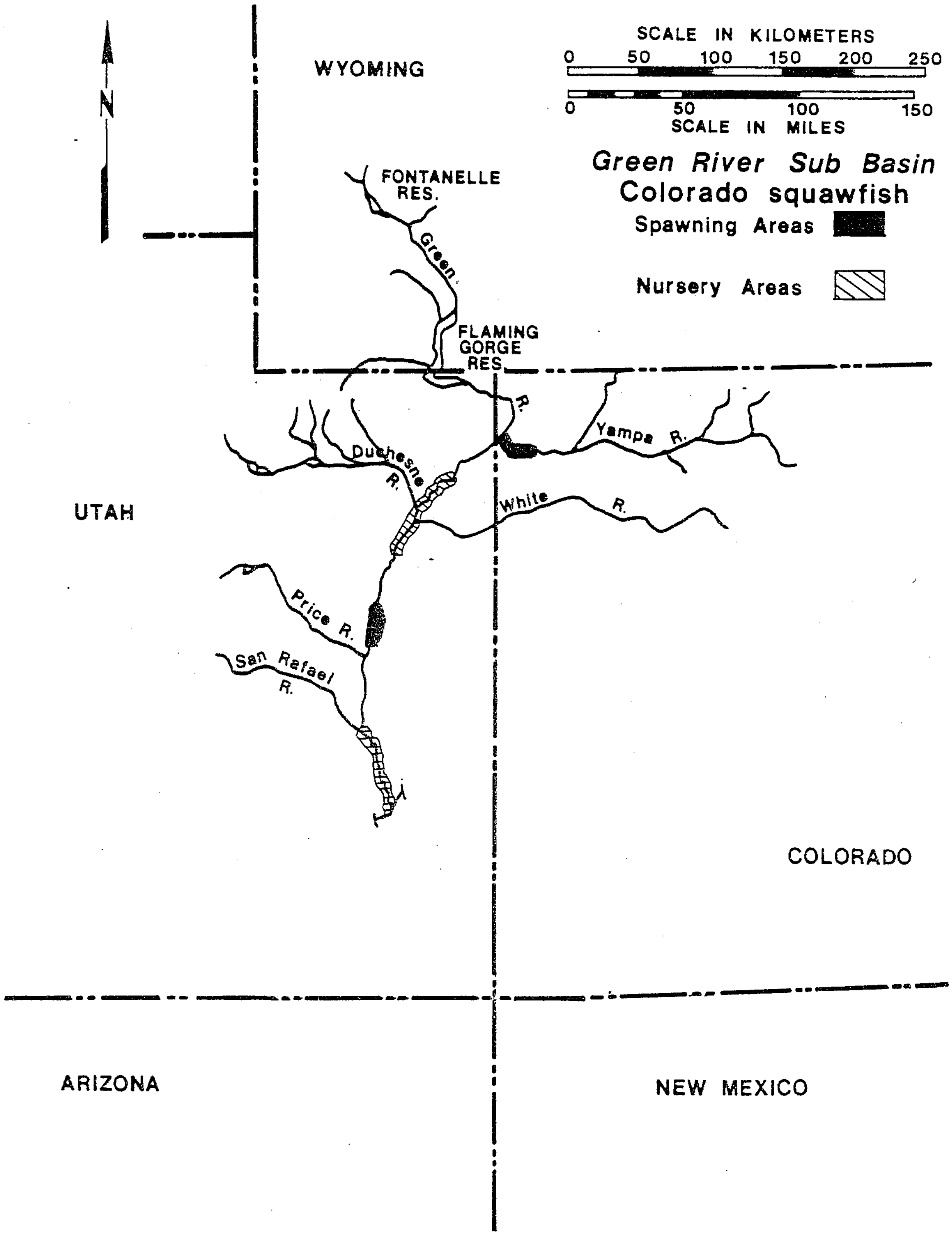


Figure 10. Colorado squawfish spawning and primary nursery habitat in the Green River Basin, Colorado and Utah.

have been collected above the spawning reach (RM 0-32).

Juveniles: Distribution, abundance, and habitat use of juvenile Colorado squawfish in the Yampa River is poorly understood. Juvenile Colorado squawfish (60-400mm TL) are rare in the Yampa River (Miller et al. 1982, this report, Wick et al. 1983, 1985). From 1980-1987, only 1% of all Colorado squawfish greater than 60mm TL collected in the Yampa River by FWS (N=198) were juveniles. These juveniles were captured in the lower Yampa River.

The downstream drift of larvae from Yampa River spawning grounds indicates the necessity for long-distance upstream movement by juveniles in order to repopulate upstream areas (Tyus 1986). Such movement probably occurs in late juvenile or early adult stage, a phenomenon suggested by high concentrations of juvenile Colorado squawfish (average catch rate > 0.18 fish/hour) in the lower section of the mainstream Green River and highest concentrations of adults (average catch rate > 0.6 fish/hour) in upstream sections (Tyus et al. 1987).

Humpback chub:

Adults: A total of 27 humpback chub were captured in the Yampa River (RM 7.5-47) by FWS from 1981-1986. An expanded effort in 1987 from RM 13-37.1 yielded an additional 32 captures, including 6 recaptures. Although taxonomic problems regarding *Gila* species exist in some areas (Holden and Stalnaker 1970, Valdez and Clemmer 1982), adult chubs captured in the Yampa River in 1987 were recognized as either *Gila cypha* (humpback chub) or *G. robusta* (roundtail chub) (no suspected hybrids noted following rigorous morphological inspection). A principal components analysis of 243 adult specimens (200-

300mm standard length) captured in 1987 indicated 27 _G. cypha_ and 216 _G. robusta_ (Douglas et al. 1987). This suggests that morphological variation apparent in some locations in which _Gila_ intergrades occur (reviewed by Valdez and Clemmer, 1982) may be inherent, or induced by recent habitat changes. The Yampa River humpback chub populations are more abundant than previously thought and the separation between syntopic _G. cypha_ and _G. robusta_ in that system mandates further study and protection.

Adult humpback chub were most often collected in eddy habitat (average depth about 5 feet) although there was some use of shoreline runs and riffles. These fish were caught in association with roundtail chub and channel catfish (FWS unpublished data).

Spawning: In 1986, FWS documented spawning of humpback chub in Yampa Canyon with the capture of 2 ripe or spent females and 2 ripe males. This was confirmed in 1987 with the capture of an additional ripe female, 8 ripe males and 11 tuberculated fish (sex not determined). Thus, a total of 24 humpback chub were captured in breeding condition in the Yampa River in 1986 and 1987. Ripe fish were collected in eddy and shoreline run habitat during and immediately following peak spring flows (July 5 to July 15, 1986: RM 18-18.1, and May 18 to June 29, 1987: RM 13-37.1). Humpback chub spawning has also been observed during spring runoff in the Colorado River (Archer et al. 1985, Valdez and Clemmer 1982).

Juvenile: Larval and postlarval humpback chub have been tentatively identified in Yampa and Cross Mountain Canyon (RM 0-56) collections by the Larval Fish

Laboratory (Colorado State University, and FWS). Problems with identification of young chubs have precluded studies of habitat needs.

Bonytail chub:

Habitat requirements of bonytail chub in the Green River basin are largely unknown. Fish collections in Echo Park (DNM) prior to and following closure of Flaming Gorge Dam indicate that bonytail chub were present in fair numbers at the confluence of Yampa and Green rivers (Vanicek 1967). However, more recent investigations in that area have yielded few individuals. Holden and Stalnaker (1975) reported capture of 36 bonytail chub in lower Yampa and upper Green rivers between 1968-1970. Holden and Crist (1981) collected one bonytail chub in lower Yampa River in 1979 and FWS captured one suspected juvenile in 1987. Reintroduction of bonytail chub into upper Green River (DNM) in 1988 is expected to provide some information on habitat use of this rare species (USFWS 1987a).

Razorback sucker:

Adult and larval razorback sucker have been captured in flat-water sections of upper Green River and lower Yampa River (Holden and Stalnaker 1975, McAda and Wydowski 1980, Tyus et al. 1982b, Tyus 1987). During the nonbreeding season, adult razorback sucker were most common in shoreline runs and near midchannel sand bars (average water depth $< 2m$, average velocity $<$ $0.5m/s$) (Tyus 1987). Collections from 1974-1976 suggested that razorback sucker may overwinter in Echo Park area of DNM (McAda and Wydowski 1980. Captures of ripe fish on cobble/gravel bars and in flooded bottomlands in spring/early summer suggests that this species uses a wide variety of spawning habitats (Tyus 1987). Spawning activity by razorback sucker has been observed in lower Yampa River near its confluence with the Green River (McAda and Wydowski 1980, Tyus 1987). Although records for some years are not complete, razorback sucker spawning was initiated on the ascending limb of the spring hydrograph, and extended into highest peak flows in 1975 (McAda and Wydowski 1980), and in 1981, 1984, 1986, and 1987 (FWS unpublished data, Tyus 1987). Water temperatures were variable during this period, but always exceeded 15C.

Capture of ripe adult and larval fish indicates that reproduction is successful (McAda and Wydowski 1980, Tyus 1987). However, other than the tentative identification of two juvenile fish from Green River in 1977 (Holden 1978), recruitment in razorback sucker has not been documented in the Colorado River basin (McAda and Wydowski 1980, Minckley 1983, Tyus 1987). Habitat requirements of this species in riverine environments are not well known because of the scarcity of extant populations (Lanigan and Tyus 1988) and absence of juvenile/subadult life history stage (Tyus 1987). Apparent decline of this species towards local extinction warrants greater protection.

LIMITING FACTORS

General:

The study of limiting factors is difficult because of complex relationships between the environmental and biological parameters limiting distribution and abundance of organisms. A "limiting factor" is simply one component of a multidimensional system. Thus, single factor studies (e.g., determination of temperature threshold for successful spawn) should not be evaluated in isolation, but from a holistic perspective. We stress the need for system-level cognizance and interpretation when addressing limiting factors.

Studies of factors limiting the distribution and abundance of fishes in the Yampa River are complicated by the variable nature of the environment (including the biota), and logistic problems associated with studying organisms in large turbid rivers. Evaluating limiting factors for rare and endangered fishes is further complicated because there is limited information regarding life cycles and habitat needs.

The following section discusses some factors potentially limiting the distribution and abundance of rare and endangered fishes in the Yampa River. These factors are summarized by species and sensitive river reach in Table 6. We have emphasized habitat needs of Colorado squawfish because this species has been the target of recent studies and more life history information is available, than that for humpback and bonytail chubs, and razorback sucker. However, we do not suggest that protection for one species will adequately protect all, because each species is an unique entity, exhibiting different requirements for survival.

Table 6. Sensitive areas for rare and endangered Colorado River fishes in the Yampa River, with notes on potential limiting factors. (Updated from UCRBCC Biology Subcommittee report (1984).

Life stage or need	Location[1]	Season	Potential limiting factors
		COLORADO SQUAWFISH	
Adults Adult concentration	0-140 51-124	All year August-May	Microhabitat changes with stream discharge, fishing and "natural" mortality, competition with non-native fishes, spring flow depletions, food availability
Migrations	0-140	May-August	Stream blockage, microhabitat conditions, stream temperatures, discharge & photoperiod relationship
Spawning	4-32	June-July July-August	Proper flow conditions for the type water year (low, average, and high), spawning and orientation cues, low number of spawning females, siltation of substrate, temperature-discharge-photoperiod relationship
Larvae Postlarvae	0-31 0-4	July-August August-Dec.	Proper flow regimen, water temperature, food availability, competition/predation, habitat availability
Juvenile	0-140	All year	Competition/predation with non-native fishes, food, stream passage during low flows
		HUMPBACK CHUB	
Adults Adult concentration Spawning Larvae Postlarvae Juvenile	0-56 4-37 18-56 18-56 18-56 0-56	All year All year May-June May-July July-Dec. All year	Effects of flow changes on microhabitats, competition/predation of non-native fishes, food availability, thermal regimen versus photoperiod--discharge relationship, spring spawning flows
		RAZORBACK SUCKER	
Adults Spawning	0-60 0-4	All year April-June	Reproductive failure, competition/predation, food, low population size, spring flows

[1] Location given in miles from confluence with the Green River=0.

Colorado squawfish

An evaluation of factors limiting the distribution and abundance of Colorado squawfish in the Green River system is complex because of the wide range of habitat and flow conditions required by different life history stages. High spring flows in concert with increasing water temperatures are necessary for initiation of spawning migration (Figure 6). Decreasing flows in early/mid-summer are necessary for successful spawn and downstream transport of drifting larvae (Figure 7) (Tyus et al. 1987). Low flows in late summer/fall are directly correlated with availability of nursery habitat (Pucherelli et al. 1988). Historic base flow is necessary for maintenance of winter habitats.

Adults: The potamodromous migrations and homing behavior of this species (Tyus and McAda 1984, Tyus 1985, Wick et al. 1983) from downstream Green River and upstream Yampa River to Yampa Canyon, mandates protection of known migration routes. Blockage of these river sections by dams/water diversions will directly cause local extinction of this species, as evidenced by the loss of the White River population due to blockage to overwintering areas (Martinez 1986). Localized water input at the spawning grounds may provide cues for orientation for spawning Colorado squawfish. Therefore, inputs of groundwater and flows from spring-fed tributaries in these areas should be protected from future water development.

Competition with introduced fishes for food and/or space, predation by non-native forms, and fishing mortality are factors potentially limiting adult survival in the Yampa River. Capture of northern pike and channel catfish in habitats shared by adult Colorado squawfish (FWS unpublished data, Wick et al

1985) suggests that these non-native predators may be competing with and/or preying on Colorado squawfish. Although Pimental et al. (1985) found that Colorado squawfish did not prefer channel catfish as prey, incidence of channel catfish lodged in throats of adult Colorado squawfish (McAda 1983, Pimental et al. 1985, Wick et al. 1985) suggests that these introduced fish may adversely affect survival of Colorado squawfish.

Captures of adult Colorado squawfish with lures and bait in Yampa River (FWS unpublished data, Saile 1986) suggests that large individuals are susceptible to angling pressure. FWS records (Vernal, UT) show that in some years, as much as 10% of the tagged Colorado squawfish are angler-caught. Martinez (1986) has also noted several instances of incidental takes in the White River. Increases in fishing pressure and incidental takes could significantly impact Colorado squawfish abundance.

Reproductive success of Colorado squawfish is dependent upon a number of interdependent factors including number of spawning adults (particularly numbers of ripe females), river discharge, sediment load, temperature, and photoperiod. Loss of successful reproduction in one or more years could result in significant declines of Colorado squawfish, and aid proliferation of non-native competitors.

Because Colorado squawfish eggs are adhesive and attach to substrate surfaces, availability of cleaned cobble and boulder surfaces in spawning areas may be limiting, if spring/early summer scouring action from high sediment loads is curtailed by a reduction in spring peak flows. A gradual decrease in summer flows aids in preventing siltation of cobble bars, and this flushing flow is potentially limiting.

Larvae and postlarvae: Factors potentially limiting the distribution and abundance of young Colorado squawfish in the Yampa River include alteration of natural flow and temperature regimens, and alteration of natural sediment and nutrient loads. These in turn affect availability of nursery habitat in the upper Green River basin. In addition, proliferation of non-native competitors and predators in altered habitats is viewed as limiting.

Mortality of drifting larvae is directly related to flow, river temperature, and backwater habitat availability. Young Colorado squawfish are routinely collected in isolated pools in the Green River system (CDOW and FWS data). These pools are formed when decreasing flows isolate bodies of water from the main channel. Normal fluctuations in river level not only makes this a gradual process but allows the trapped fish an escape route. However, drastic fluctuations in river level, as characteristic of regulated systems, could increase mortality of small fishes by cutting off escape routes and thereby increasing potential for competitive interactions and exposure to terrestrial predation. Herons, raccoons, garter snakes, and other animals have been observed feeding on fishes trapped in isolated pools (Erman and Leidy 1975, FWS unpublished data).

Impact of competition and predation by introduced fishes on growth and survival of young Colorado squawfish has yet to be adequately assessed but common use of backwater habitats by young Colorado squawfish and other small fish species (FWS unpublished data, McAda and Tyus 1984) indicates the potential for significant interspecific interaction. Dietary overlap between young Colorado squawfish (TL<60mm) and other small fishes was noted by Jacobi and Jacobi (1982). Karp et al. (1988) suggested that growth and survival of young Colorado squawfish may be adversely affected by presence of similar-sized non-native fishes in nursery habitats, particularly when increases or decreases in river level reduces backwater availability.

Juveniles: Factors limiting distribution and abundance of juvenile Colorado squawfish are difficult to assess because there is little available information regarding their habitat requirements. Upstream movement of juveniles is necessary to sustain viable populations, and thus, stream blockage is viewed as a limiting factor.

Evidence of predation by non-native fishes in both artificial and natural environments suggests that this factor limits growth and survival of juvenile Colorado squawfish. Hendrickson and Brooks (1987) noted predation by yellow bullhead and largemouth bass on young Colorado squawfish stocked into the Verde River, Arizona. Osmundson (1987) noted predation by largemouth bass, green sunfish, black crappie, and black bullhead on young Colorado squawfish in gravel pits near the Colorado River, Colorado, and indicated predation by channel catfish may have occurred. In addition, Coon (1965) reported channel catfish predation on Colorado squawfish in the Dolores River. Flows aiding proliferation of these non-native predators must be determined and avoided, if possible.

<u>Humpback chub</u>

Distribution, abundance, and habitat requirements of humpback chub in the Yampa River are not well known. Spring peak flows are critical because spawning occurs during this period. Flow reductions and decreased temperatures have been implicated as factors curtailing spawning, and increasing competition in the Colorado River (Kaeding and Zimmerman 1983).

Habitat alteration may also promote hybridization with other species (Valdez and Clemmer 1982).

Competition between humpback chub and channel catfish was indicated by capture of both species with baits in eddy habitats in Yampa River (Tyus and Minckley 1988). Channel catfish comprised about 10% of the catch in the previous study when temperatures were below 20C, but almost 50% when temperatures exceeded 20C, in habitats from which humpback chub were collected (1987). This dramatic increase in numbers of channel catfish at a time of year when river level is dropping, eddy habitat availability is declining, and water temperature is increasing, suggests that this species may have some competitive advantage when resources become limiting. Channel catfish may also prey directly on humpback chub, as speculated by Kaeding and Zimmerman (1983), who attributed bite marks on the latter to channel catfish.

Bonytail chub

The drastic decline of this species in Echo Park (DNM) may be a response to flow and temperature changes resulting from closure of Flaming Gorge Dam. Ongoing negotiations between FWS and BR regarding management of Flaming Gorge for the indigenous rare and endangered fishes may improve the future of bonytail chub in the Green River system.

Razorback sucker

Loss of spring peak flows is an important consideration because spawning occurs on the ascending limb of the runoff period. The absence of young fish throughout the Colorado River basin has been attributed to habitat alteration (e.g., lower water temperatures (Marsh 1985)) and predation by non-native fishes (Minckley 1983, Tyus 1987). Minckley (1983) cited two studies noting egg predation by carp. Marsh and Langhorst (1988) reported significant predation of wild larval razorback sucker by green sunfish, and Brooks et al. (1985) documented significant predation of stocked larval and fingerling-size razorback sucker by channel catfish and flathead catfish.

STREAM FLOW AND HABITAT NEEDS

Stream flow/Sediment Transport: Scientific studies of fluvial dynamics in western streams can be traced to John Wesley Powells' expeditions down the Colorado River in the late 1800's (Powell 1895). More recent recognition of the dependency between upstream and downstream processes led to the concept of dynamic equilibrium (i.e., the dynamic balance between discharge, channel morphometry, and sediment load throughout the system) (Leopold et al. 1964). Implicit to the understanding of dynamic equilibrium is the concept that each stream has a sediment transport capacity with respect to discharge and that streams are continuously eroding to base level. We emphasize the importance of these concepts (i.e., a systems-level perspective) in the study of stream fish habitat because streams (and their watersheds) are longitudinally linked systems (Vannote et al. 1980) and thus, downstream features (e.g., channel morphometry, sediment load, temperature regimen, habitat availability, food variability, biota) are directly influenced by upstream events.

Hydrologic conditions in the Yampa River are not significantly different from historic conditions, and as indicated previously (Figure 1), flows of the Yampa River are necessary for maintenance of spring peaks in the Green River hydrograph. Therefore, relationships between discharge and sediment transport in the Yampa River warrant consideration for protection of downstream areas. Water development in the Yampa River could alter the natural flow/sediment transport-deposition dynamics of the entire upper Green River system.

Several workers have evaluated relationships between discharge, sediment load, and maintenance of spawning habitat for fishes in the Yampa Canyon (reviewed by Butler 1988). The results of those studies suggested that sediment transport equilibria in the spawning reach can be attained under reduced flow regimens. However, attainment of such equilibria would not preclude downstream changes (Butler 1988) ,and the accompanying changes in sediment load and channel morphometry would permanently modify existing fish habitat. Reductions in sediment load resulting from water withdrawal may cause downstream erosion of shoreline areas, and destabilization of riparian communities. For example, sediment depletion due to closure of Flaming Gorge Dam has reduced bank width of the Green River between Flaming Gorge and Ouray, Utah, by 10%, and this stretch has not yet attained its new dynamic equilibrium (Andrews 1986).

Butler (1988) evaluated different scenarios following completion of water development projects in the Yampa River. He found that sediment load in upper Green River system would be robbed of about 626,800 tons of sediment on an annual basis (a 24% sediment reduction), following completion of Juniper Project. Thus, the lower Yampa River (downstream from Little Snake River) would become an aggrading system due to loss of scouring spring flows. Hydrology of Little Snake River also warrants study because 77% of the sediment delivered to the lower Yampa River is derived from the Little Snake River (O'Brien 1984). Further losses are implicated as potential effects of flow and sediment withdrawal in the Yampa River, including a loss of backwater nursery habitat.

The preceding demonstrations of system-wide changes following alteration of natural flow and sediment regimens, emphasizes the futility of recommending flows for an entire system using models developed for discrete stream reaches. The consequent loss and alteration of downstream habitat and indigenous biota would negate benefits from such water development.

Stream Flow/Fish Fauna

Regulation of the natural flow regimen of the Colorado River (Figure 1) and introduction of non-native fishes, has caused a dramatic decline of native fauna, and a concomitant proliferation of introduced forms. This basin-wide phenomenon is most apparent in reservoirs and areas immediately downstream from dams. The Yampa River has yet to be converted into a system of dams, diversions, and regulated flows. Because of this, composition of native fish fauna is similar to historic conditions.

Fishes indigenous to the Yampa River evolved under a regimen of variable flows; a system of floods and drought. Conversely, many of the fishes recently introduced into the Green River system evolved under more mesic conditions. Studies investigating effects of spring and late summer/fall flows on abundance and growth of small fishes in the upper Green River system suggest that the native fauna is well adapted to a regimen of fluctuating annual flows.

Late summer-fall is a critical period for growth and survival of young Colorado squawfish, and flows in the Green River system at this time are historically and predictably low. Pucherelli et al. (1988) found that availability of backwater habitat was negatively correlated with late summer-fall flows ($r=-0.91$, $P<0.05$) (Figure 11). More specifically, area of backwater habitat was maximized at 1687 cfs (average of Jensen, Ouray, and Sand Wash study areas) and number of backwater habitats was maximized at 1381 cfs (average of Jensen, Ouray, and Sand Wash study areas).

Tyus et al. (1987) found that abundance and growth of YOY Colorado squawfish was negatively correlated with late summer-fall flows ($r=-0.73$, $P<0.06$; $r=-0.88$, $P<0.01$, respectively). During late summer/fall, catch and growth were highest in 1979 and 1980 (discharge in August-September ranged from 1600-1900 cfs at Jensen, Utah), and lowest in 1983 and 1984 (discharge in August-September ranged from 3000-4200 cfs) (Tyus et al. 1987). In the latter years, abnormally high discharge from Flaming Gorge Dam in late summer-fall inundated backwater nursery areas and survivorship of YOY Colorado squawfish was low. These relationships suggest that flows optimizing growth and survival of small Colorado squawfish vary with time of year, and that both reproduction and survivorship are maximized in years whose hydrographs approximate historic flow conditions.

In contrast, many workers (e.g., Haynes and Muth 1984, Minckley and Meffe 1987, Nesler 1988) have suggested that abundance of non-native fishes is adversely affected when flow regimens approximate historic conditions. In years of high spring flows, Haynes and Muth (1984) found high numbers of larval Colorado squawfish and low numbers of non-native fishes in drift collections. Using seine catch-effort data from the upper Yampa River for 1980-1984, Nesler (1988) found that total numbers of non-native fishes (red shiner, redside shiner, sand shiner, fathead minnow) were negatively correlated with spring discharge ($P<0.05$). However, correlation of native

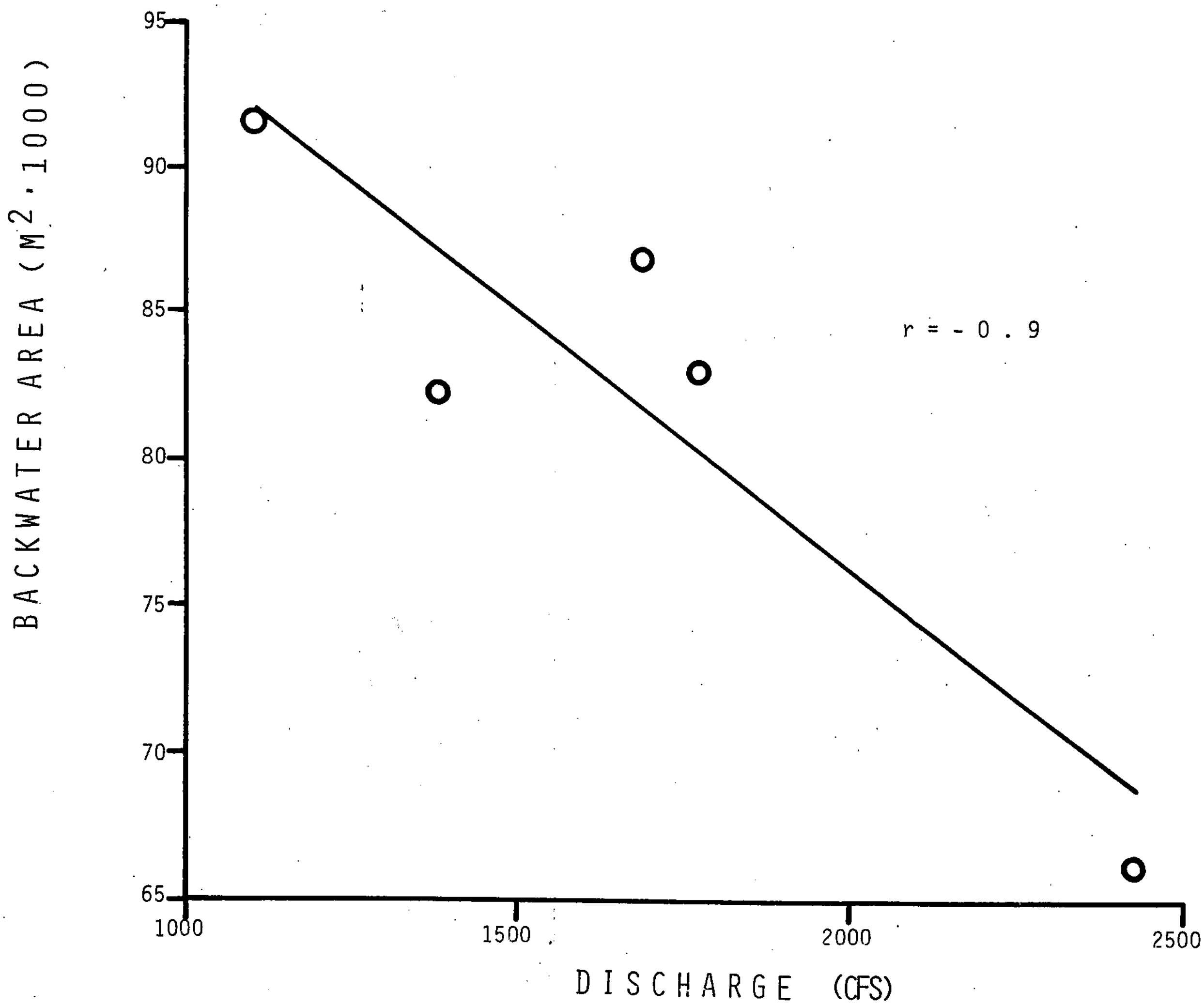


Figure 11. Discharge-backwater habitat availability relationship, upper Green River, 1987 (P<0.05; after Pucherelli et al., 1988).

fish catch (bluehead and flannelmouth suckers, speckled dace, chubs) was positive but not statistically significant (Nesler 1988). The lack of significance in the latter relationship supports the hypothesis that native fishes exhibit greater tolerance to fluctuating flow regimens.

Instream Flow Models

Flow needs of rare and endangered fishes in the Yampa River, and elsewhere, have been evaluated by use of different techniques, including physical habitat simulation models. Application of these models for predicting optimal flows for endangered fishes in large rivers is controversial for several reasons. Poor understanding of limiting factors, stream dynamics, habitat availability and fish habitat needs, has led to improper model application. Early studies were prone to using model outputs without adequate understanding of the biology or distribution of the fishes (e.g., Prewitt et al. 1982). In addition, the PHABSIM model (Bovee 1982) has been used for habitats that violated model assumptions, leading species experts to constrain its applicability (Valdez et al. 1987).

The PHABSIM model has been used to predict flow needs for various endangered fishes. Applications of this model in the Yampa River have incorporated depth, velocity, and substrate parameters as descriptors of "fish habitat", and outputs have not agreed with empirical fish data. FWS funded a major effort to obtain habitat utilization curves for all rare and endangered Colorado River fishes, using a massive data set and a team of species experts (Valdez et al. 1987). These utilization curves were applied to hydrologic stations in the Yampa River by FWS (USFWS 1987b). The results indicated that "physical habitat" for adult Colorado squawfish was maximized during the spawning period at a river discharge that approached 0 cfs. This condition violated the basic assumption that "fish require water", and was not acceptable for stream flow recommendations. Other Yampa River applications of these curves (USFWS 1987b) were made for adult and spawning Colorado squawfish, and humpback chub. Optimum "physical habitat" was maximized near 0, 1200, and 400 cfs, respectively. The lack of supportive biological data and the lack of agreement between these outputs, makes adoption of a single flow difficult. Because of these and other problems, FWS, in 1987, suggested that model outputs be validated with empirical data before being used as guidelines in protecting endangered fish habitat in large river systems.

STREAM FLOW RECOMMENDATIONS

It is beyond the scope of this paper, and current technology, to produce a single flow and sediment recommendation that will unequivocally protect the rare and endangered fishes of the Yampa River. Although FWS and others have committed substantial expenditures of time and manpower in developing and applying incremental stream flow methodologies, flow recommendations produced have not been validated by biological data for Colorado River rare and endangered fishes. We prefer to rely on empirical data and biological judgement to recommend flow regimens that are consistent with life history needs of the fish, because we are constrained by the absence of models incorporating both physical and biological components, and lack of confidence in physical habitat simulation models outputs. The following recommendations[1] are derived from preceding discussions of habitat needs and limiting factors for each rare and endangered species, by time of year.

Colorado squawfish

All year: Minimum flows (for RM 0-140) should not be less than historic minimums for similar hydrologic conditions. For periods not covered by other recommendations, the five-year average should include a frequency of low (80% exceedence), average (50% exceedence), and high (20% exceedence) flows, as reflected by the historic record (1941-present). Temperature and sediment transport regimens should be consistent with historic patterns. In-stream structures that restrict flows and block migrations or local movements are not recommended.

Spring: Migration cues are considered an essential component for successful reproduction in this species. High spring flows approximating 3.5 times the predicted mean annual discharge (March or April prediction) with accompanying temperatures of 11°C or higher during the May and June migration period is recommended. High spring runoff in Yampa and Little Snake rivers is necessary for adequate sediment transport and maintenance of channel geomorphology in downstream areas. Historic peak flows (including instantaneous peak flows) should not be reduced.

Summer: Flows and stream temperatures that occurred during approximate spawning conditions (by type of water year) (Table 2, Figure 7, and accompanying text) are recommended. Flows of tributary streams in Yampa Canyon, including surface and subsurface water sources, need protection from depletions and degradation of water quality. Reductions in flows prior to, during, and following spawning periods, must occur gradually (as defined by an appropriate hydrograph representing conditions in Yampa Canyon, 1981-1987) in order to prevent siltation of spawning substrate, to maintain sediment transport equilibria, to aid downstream drift of larvae, and to create productive nursery areas. Decreases in water surface elevation should follow historic patterns.

Fall: Fluctuations in water surface elevation departing from historic pattern, are not recommended for maintenance of nursery habitats in the lower Yampa and mainstream Green rivers. Habitat for adults would also be obtained by this regimen.

Winter: Extreme daily fluctuations in water surface elevation departing from historic conditions can result in ice scouring of shoreline habitats used by overwintering adults and young. Maintenance of historic winter flow regimens is recommended.

Humpback chub

All year: Minimum flows for lower Yampa River (RM 0-56) should not be lower than 80% exceedence value (1.25 return). The long-term average flow for a 10 year period should include a frequency of low, average, and high flows, consistent with historic conditions. Temperature regimens should also be consistent with historic patterns.

Spring-Summer: Peak spring flows, as reflected by historic conditions, with appropriate temperature regimens, are recommended for successful humpback chub spawning.

Bonytail chub

No recommendations pending further study.

Razorback sucker

All year: No additional recommendations if the other species are protected.

Spring: Early spring runoff conditions that flood bottomlands are associated with spawning. Spring flows approximating historic conditions should be maintained.

1 DISCLAIMER: Flow recommendations are subject to refinement as additional information is obtained.

CONCLUSIONS

The existing flow regimen of the Yampa River is critical for the survival of extant populations of Colorado squawfish, humpback chub, and razorback sucker in the Green River Basin. These natural conditions should be protected unless more definitive stream flow needs can be quantified for all indigenous rare and endangered fishes. Our recommendations were based on empirical field data because outputs from analytical models could not be interpreted. Flow recommendations produced by physical habitat simulation models must be employed only in conjunction with a program that uses empirical data to validate the outputs.

The distribution, abundance and habitat use of the rare and endangered fishes in the upper Colorado River is inextricably associated with the biology of approximately 42 species of non-native fishes introduced into the system. Competition and predation by non-native fishes may significantly reduce stocks of rare and endangered fishes. Habitat use by non-native competitors and predators must be evaluated in conjunction with all flow recommendations for the native fauna.

Work in progress on mainstream Green River by BR and FWS should be evaluated for potential application to the Yampa River. This includes use of aerial photographic mapping of sensitive habitats with different flows, studies of species interactions, and trophic relationships.

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LITERATURE CITED

Andrews, E. D., 1986. Downstream Effects of Flaming Gorge Reservoir on the Green River, Colorado and Utah. Geological Society of America Bulletin, 97:1012-1023.

Archer, D.L., and H.M. Tyus. 1984. Colorado squawfish spawning study, Yampa River. U.S. Fish and Wildlife Service, Salt Lake City, UT

Archer, D.L., L.R. Kaeding, B.D. Burdick, and C.W. McAda. 1985. A study of endangered fishes of the upper Colorado River. Final Report- Cooperative Agreement No. 14-16-0006-82-959. U.S. Department of the Interior, Fish and Wildlife Service, Grand Junction, CO.

Beamsderfer, R.C. and J.L. Congleton. 1982. Spawning behavior, habitat selection and early life history of northern squawfish with inferences to Colorado squawfish. Pages 471-427 in U.S. Fish and Wildlife Service, and Bureau of Reclamation, 1982 Final Report, Colorado River Fishery Project Part 3, Salt Lake City, UT

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. U.S. Department of the Interior, U.S. Fish and Wildlife Service, FWS/OBS-82/26, Washington, D.C.

Brooks, J. E., P. C. Marsh and W. L. Minckley. 1985. Reintroduction and monitoring of razorback sucker in the lower Colorado River basin. Proceedings Western Division, Amer. Fish. Soc. 65:203.

Burns, J.W. 1966. Sacramento squawfish. In. Calhoun, A. (ed.). Inland Fisheries Management, State of California, Department of Fish and Game.

Butler, M. 1988. Minimum mean streamflow hydrographs and total sediment transport in the Yampa River Canyon. U. S. Fish and Wildlife Service, Region 6, Denver, CO.

Bye, V. J. 1984. The role of environmental factors in the timing of reproductive cycles, pages 187-206. In Potts, G. W. and R. J. Wootton (eds.). Fish Reproduction: strategies and tactics. Academic Press, Inc, London.

Coon, K. L., Sr. 1965. Some biological observations on the channel catfish, *Ictalurus punctatus* (Rafinesque), in a polluted western river. Master's thesis, Utah State University, Logan, Utah, USA.

Douglas, M.E., W.L. Minckley, and H.M. Tyus. 1987. Qualitative characters in field identification of Colorado River Chubs (Cyprinidae, Genus *Gila*). Arizona State University, Tempe. (Unpublished manuscript)

Erman, D.C. and G.R. Leidy. 1965. Downstream movements of rainbow trout fry in a tributary of Sagehen Creek, under permanent and intermittent flow. Trans. Amer. Fish. Soc. 3:467-473.

Hamman, R. L., 1981. Spawning and culture of Colorado squawfish in raceways. Prog. Fish-Cult. 43(4):173-177.

Harden-Jones, R.F. 1981. Fish migration: Strategy and tactics. Pages 139-165 in D.J. Aidley, editor. Animal Migrations. Seminar Series 13. Society for Experimental Biology, Cambridge University Press, New York, New York. USA.

Haynes, C.M., T.A. Lytle, E.J. Wick and R.T. Muth. 1984. Larval Colorado squawfish (Ptychocheilus lucius Girard) in the Upper Colorado River Basin, Colorado, 1979-1981. Southwestern Naturalist 29:21-33.

Haynes, C.M. and R.T. Muth. 1984. Identification of Habitat Requirements and limiting factors for Colorado squawfish and humpback chubs. Job. Prog. Rep., Fed. Aid Proj. SE-3, Work Plan 2, Job 1. 21pp.

Hendrickson, D.A. and J.E. Brooks. 1987. Colorado River squawfish reintroduction studies. Proc. D.F.C. 1986, Vol. 18:207-208.

Holden, P.B. 1978. A study of the habitat use and movement of the rare fishes in the Green River, Utah. Trans. Bonneville Chapter, Amer. Fish. Soc. Vol. 1978::64-90.

Holden, P. B. and C. B. Stalnaker, 1970. Systematic studies of the cyprinid genus Gila, in the Upper Colorado River Basin. Copeia, No. 3:109-120.

Holden, P.B., and C.B. Stalnaker. 1975. Distribution of Fishes in the Dolores and Yampa River systems of the Upper Colorado Basin. Southwestern Naturalist 19:403-412.

Jacobi, G., and M. Jacobi. 1982. Fish stomach content analysis. Pp. in Part 3, Colorado River Fishery Project Final Report Contracted Studies. U.S. Fish and Wildlife Service and Bureau of Reclamation, Salt Lake City, UT.

Karp, C.A., H.M. Tyus, and G. Dean. 1988. Behavioral responses of young Colorado squawfish to other similar-sized species. Unpublished manuscript.

Kaeding, L.R. and M.A. Zimmerman. 1983. Life history of the humpback chub in the Little Colorado and Colorado rivers of the Grand Canyon. Trans. Amer. Fish. Soc. 112:577-594.

Lanigan, S. H. and H. M. Tyus, 1988. Population size and status of razorback sucker in the Green River basin of Utah, based on capture-recapture data from 1980-1987. Unpublished manuscript. Submitted to N. A. Jour. Fish Mgt.

Leopold, L. B., M. G. Wolman, and J. P. Miller, 1964. Fluvial processes in Geomorphology. Freeman, Co., San Francisco, CA.

Marsh, P. C., 1985. Effect of incubation temperature on survival of embryos of native Colorado River fishes. Southwestern Naturalist 30(1):129-140.

Marsh, P.C. and D. R. Langhorst, 1988. Feeding and fale of wild larval razorback sucker. Env. Biol. Fishes 21:59-67.

Martinez, P.J. 1986. White River Taylor Draw Project. Pre- and Postimpoundment Fish Community Investigations. Final Report. Col. Div. of Wildlife. 121pp.

McAda, C.W. 1983. Colorado squawfish, Ptychocheilus lucius (Cyprinidae), with a channel catfish, Ictalurus punctatus (ictaluridae), lodged in its throat. Southwest Nat. 28(1):119-120.

McAda, C. W. and H. M. Tyus, 1984. Resource overlap of Age-0 Colorado squawfish with other fish species in the Green River, 1980. Proceedings of the Boneville Chapter, American Fisheries Society 1984:44-54.

McAda, C.W. and R.S. Wydoski. 1980. The razorback sucker, Xyrauchen texanus in the Upper Colorado River Basin, 1974-76. U.S. Fish and Wildlife Service Technical Paper 99, Washington, DC

Miller, W.H., D.L. Archer, H.M. Tyus, and R.M. McNatt. 1982. Yampa River fishes study. U.S. Fish and Wildlife Service, Final Report FWS-NPS Cooperative Agreement 14-16-0006-81-931 (1A), Salt Lake City, UT

Miller, W.H., H.M. Tyus and C.W. McAda 1983. Movement, migration, and habitat preferences of radiotelemetered Colorado squawfish, U.S. Fish and Wildlife Service, Salt Lake City, UT

Minckley, W.L. 1983. Status of the razorback sucker, Xyrauchen texanus (Abbott), in the lower Colorado River Basin. Southwestern Nat. 28(2):165-187.

Minckley, W.L., and G.K. Meffe. 1987. Differential selection by flooding in stream fish communities of the arid american southwest. Pg. 93-104 In. W.J.Matthews and D.C. Heins, (eds.). Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press

Nesler, T.P. 1986. Aquatic non-game research 1985-1986. Squawfish, humpback studies, Colorado Division of Wildlife, Fort Collins.

Nesler, T.P., 1988. Unpublished manuscript. Colo. Div. Wildlife, Fort Collins, CO.

O'Brien, J. S., 1984. 1983 Yampa River cobble reach morphology investigation. Civil Engineering Dept. Colo. St. Univ., Fort Collins, CO.

Osmundson, D. B., 1987. Growth and survival of Colorado squawfish (Ptychocheilus lucius) stocked in riverside ponds, with reference to Largemouth Bass (Micropterus salmoides) predation. M. S. Thesis, Utah St. Univ., Logan, UT.

Patten, B. G. and D. T. Rodman, 1969. Reproductive behavior of northern squawfish, Ptychocheilus oregonensis). Trans. Amer. Fish Soc. 98:108-111.

Pimentel, R. V. Bulkley, and H. M. Tyus, 1985. Choking of Colorado squwfish, Ptychocheilus lucius (Cyprinidae), on channel catfish, Ictalurus punctatus (Ictaluridae), as a cause of mortality. Southwestern Naturalist 30:154-158.

Powell, J. W., 1895. Canyons of the Colorado. Published by Flood and Vincent. Republished by Dover Publications, N.Y. 1961. as The Exploration of the Colorado River and its Canyons.

Prewitt, C. G., B. A. Caldwell, and W. Miller, 1982. Completion report, Yampa-White physical habitat study. In Colorado River Fishery Project Final Report Yampa River. Fish and Wildlife Service, Salt Lake City, Utah 1-24.

Pucherelli, M. J., R. C. Clark, and J. N. Halls, 1988. Green River backwater habitat mapping study, 1987. U. S. Bur. of Rec., Engineering and Research Center, Denver, CO.

Saile, B. 1986. Squawfish not so rare in Yampa. Denver Post. 21, August.

Seethaler, K. 1978.. Life history and ecology of the Colorado squawfish (Ptychocheilus lucius) in the Upper Colorado River Basin. M.S. Thesis, Utah State University, Logan.

Tyus, H.M. 1984. Loss of stream passage as a factor in the decline of the endangered Colorado squawfish. Pages 138-144 in Issues and technology in the management of impacted Western Wildlife. Proceedings of a National Symposium. Thorne Ecological Institute Technical Publication 14. Boulder, CO.

Tyus, H.M. 1985. Homing behavior noted for Colorado squawfish. Copeia (1):213-215.

Tyus, H.M. 1986. Life strategies in the evolution of the Colorado squawfish (Ptychocheilus lucius). Great Basin Naturalist 46:656-661.

Tyus, H.M. 1987. Distribution, Reproduction, and Habitat Use of the Razorback Sucker in the Green River, Utah, 1979-1986. Trans. Amer. Fish. Soc. 116:111-116.

Tyus, H.M. and C.W. McAda. 1984. Migration, movements, and habitat preferences of Colorado squawfish, Ptychocheilus lucius, in the Green, White and Yampa rivers, Colorado and Utah. Southwestern Naturalist 29:289-299.

Tyus, H. M. and W. L. Minckley, 1988. Migrating Mormon crickets, Anabrus simplex (Orthopters: Tettigoniidae), as food for stream fishes. Great Basin Naturalist Vol. 48, No. 1:25-30.

Tyus, H.M., B.D. Burdick, R.A. Valdez, C.M. Haynes, T.A. Lytle and C.R. Berry. 1982a. Fishes of the Upper Colorado River Basin: Distribution, abundance and status. Pages 12-30 in Miller, W.H., H.M. Tyus and C.A. Carlson,(eds.) Fishes of the Upper Colorado River System: Present and future. American Fisheries Society, Bethesda, MD

Tyus, H.M., C.W. McAda, and B.D. Burdick. 1982b. Green River Fish Investigations. U.S. Fish and Wildlife Service and Bureau of Reclamation, Final Report Part 2, Colorado River Fishery Project, Salt Lake City, UT

Tyus, H.M., R.L. Jones, and L. M. Trinca. 1987. Green River Rare and Endangered Fish Studies, 1982-1985. Final Report. Colorado River Fishes Monitoring Project, U. S. Fish and Wildlife Service, Vernal, UT

UCRBCC, 1984. Rare and endangered Colorado River fishes sensitive areas. Biolological Subcommittee report to the Upper Colorado River Basin Coordinating Committee. Denver, CO. 23pp.

USFWS, 1987a. Recovery implementation program for endangered fish species in the Upper Colorado River Basin. U. S. Fish and Wildlife Service, Region 6, Denver, CO.

USFWS, 1987b. Yampa River Historic Site Habitat Analysis using the instream Flow Incremental Mehtodology. Upper Colorado River Basin Instream Flow Team, Grand Junction, CO.

Valdez, R.A., P.B. Holden, T.B. Hardy, and R.J. Ryel. 1987. Habitat suitability index curves for endangered fishes of the Upper Colorado River Basin. Final Report. HSI Curve Development Project. U.S. Fish and Wildlife Service, Denver, CO.

Valdez, R.A. and G.H. Clemmer. 1982. Life history and prospects for recovery of the humpback chub and bonytail chub, p. 109-119. In W.W. Miller, H.M. Tyus and C.A. Carlson (eds.). Fishes of the Upper Colorado River system: Present and Future. American Fisheries Society, Bethesda, MD

Vanicek, C. D., 1967. Ecological studies of native Green River fishes below Flaming Gorge Dam, 1964-1966. Ph.D. Thesis USU, Logan.

Vanicek,C.D. and R.H. Kramer. 1969. Life history of the Colorado squawfish, Ptychocheilus lucius, and the Colorado chub, Gila robusta, in the Green River in Dinosaur National Monument 1964-1966. Transactions of the American Fisheries Society 98:193-208.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37:130-137.

Wick, E.J. and J.A. Hawkins. 1987. Colorado squawfish winter habitat study, Yampa River, Colorado. Final Report. Larval Fish Laboratory, Colorado State University, Fort Collins, CO.

Wick, E.J. T.A. Lytle, and C.M. Haynes. 1981 Colorado squawfish and humpback chub population and habitat monitoring, 1979-1980. Progress Report SE-3-3. Endangered Wildlife Investigations. Colorado Division of Wildlife. Denver, Colorado.

Wick, E.J., C.W. McAda, and R.V. Bulkley. 1982. Life history and prospects for recovery of the razorback sucker. Pages 120-126 in W.H. Miller, H.M. Tyus, and C.A. Carlson, (eds.). Fishes of the Upper Colorado River system: Present and Future. Western Division, American Fisheries Society, Bethesda, MD

Wick, E.J., D.L. Stoneburner and J.A. Hawkins. 1983. Observations on the Ecology of the Colorado squawfish (Ptychocheilus lucius) in the Yampa River. Report Number 83-7, Colorado Water Resources Field Support Laboratory. U.S. National Park Service, Fort Collins, CO

Wick, E.J., J.A. Hawkins, and C.A. Carlson. 1985. Colorado squawfish and humpback chub population and habitat monitoring, 1983 and 1984 Colorado Division of Wildlife, Denver.