IDENTIFICATION OF HABITAT REQUIREMENTS AND LIMITING FACTORS FOR COLORADO SQUAWFISH AND HUMPBACK CHUB

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The results of the research investigations contained in this report represent work of the authors and may or may not have been implemented as Division of wildlife policy by the Director or Wildlife Commission.

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ABSTRACT

Colorado squawfish reproduction appears restricted to reaches of the mainstem Colorado River and lower Yampa River. The primary spawning area in the Yampa for squawfish occurs in the lower 32-kg reach. Limited spawning does occure above this reach. Flow and water temperature variables affect overall success of Colorado squawfish spawning success between rivers and within a given river on an annual basis. Spawning occurs in July through August and coincides with decreasing flows and rising water temperatures at or greater than 20 C. Peak spawning activity occurs in late July at mean water temperatures of 22-25 C. Results from both rivers suggest an optimum range of flows exists providing the best quantity and quality of spawning habitat as well as an optimal number of degree days for egg incubation and larval production. Dispersion of larval Colorado squawfish occurs via downstream drift. No significant diel periodicity was apparent in the drifting larvae. Juvenile squawfish were rarely collected in Yampa Canyon. Under certain circumstances, reproductive success of native fish species in the Yampa River appears enhanced relative to non-native species. Further research recommendations are included.

INTRODUCTION

As a consequence of declines in range and abundance, Colorado squawfish (*Ptychocheilus lucius*) and humpback chub (*Gila cypha*) have been listed as endangered by the federal government and the State of Colorado. Accordingly, recovery plans have been approved for both species. Both plans recognize several factors which appear responsible for the endangered status of these Colorado River endemic species including habitat alterations (e.g., changes in historical flow/temperature regimes); construction of in-channel structures which are possible barriers to Colorado squawfish migrations; introduction of non-native species with concomitant predation and/or competition effects; and, in the case of humpback chub, hybridization with congeners due to a presumed breakdown of reproductive isolating mechanisms.

Since 1977, the Colorado Division of Wildlife (CDOW) has been investigating these species in Colorado via systematic sampling in portions of the mainstem Colorado, Gunnison, White, and Yampa rivers. As a result of this work and other studies (e.g., Vanicek 1967; Holden 1973; Seethaler 1978), considerable information has been gained regarding the overall distribution of both species. Prior to 1981 however, limited information existed relative to the reproductive range of either species, and knowledge of their early life histories was sparse. The first documented captures of larval Colorado squawfish in Colorado were from the mainstem Colorado River west of Grand Junction (Mesa Co.) in 1979, and in the lower reaches of the Yampa River (Dinosaur National Monument, Moffat Co.) in 1980.

This research project was initiated in 1981 as Federal Aid Project SE-3-4. Due to the ongoing investigations of adult squawfish and humpback chubs by the Colorado River Fisheries Project (CRFP, United States Fish and Wildlife Service) and NW Region of CDOW, this study concentrated on the early life history of these species within study areas where the occurrence of both species had been previously documented. The objectives of this project were to (1) delimit the reproductive range of Colorado squawfish in the lower Colorado and Yampa rivers, Colorado, (2) evaluate factors limiting reproduction and recruitment of Colorado squawfish, and (3) develop taxonomic techniques for identifying and discriminating between early life history stages of *Gila* species native to the Upper Colorado River Basin and their hybrids.

During 1979-80, this project and its Principal Investigator, C. M. Haynes, were associated with a similar project administrated by the NW Region of CDOW. In order to provide a complete, up-to-date record of Colorado squawfish early life history, data from those 2 years have been included in this final report. Study Objective 3 will be addressed in a Ph.D. dissertation (R.T. Muth, in preparation) which constitutes the humpback chub portion of this final report.

Numerous other fish species were collected in conjunction with the target species of this study. From length frequency analyses of the samples of these other species, it was possible to construct observed and principle spawning periods for each. This information was not germane to the objectives of this study, but is included as supplementary data in Appendix A. This data may prove useful in investigating the ecological interactions of Colorado squawfish, humpback chubs, and other endangered fish species with these other species.

STUDY AREA

Field activities were conducted in the Colorado, Yampa, and Green rivers (Mesa and Moffat Co.), Colorado (Fig. 1). The Colorado River study included a 32-km reach from Loma to the Colorado-Utah state line. The Yampa River study area included a 95-km reach from the upper end of Cross Mountain Canyon to the Yampa-Green River confluence at Echo Park. Approximately 75 km of the Yampa River study area (from Deerlodge Park to Echo Park) was within Dinosaur National Monument (DNM). An additional site on the Green River at the Colorado-Utah state line in DNM (approximately 9.3 km below the Yampa-Green River confluence) was included in 1984.

METHODS

Field sampling for larvae and early juveniles was conducted during spring through late summer/early fall in 1979-1983, 1980-1984, and 1984 in the Colorado, Yampa, and Green rivers, respectively. During 1981-1983, sampling was conducted at periods which reflected pre-, peak, and post-runoff flow regimes (1979-1980 collections were largely opportunistic; 1984 collections in the Yampa and Green rivers were made only during post-runoff flow). Collections were made during several 4-5-day field trips. Power boats and/or inflatable rafts were used on the Colorado River, while rafts and canoes were used on the Yampa and Green rivers. Cross Mountain Canyon was surveyed entirely on foot since the extremely turbulent nature of the Yampa River within this reach made float trips unsafe.

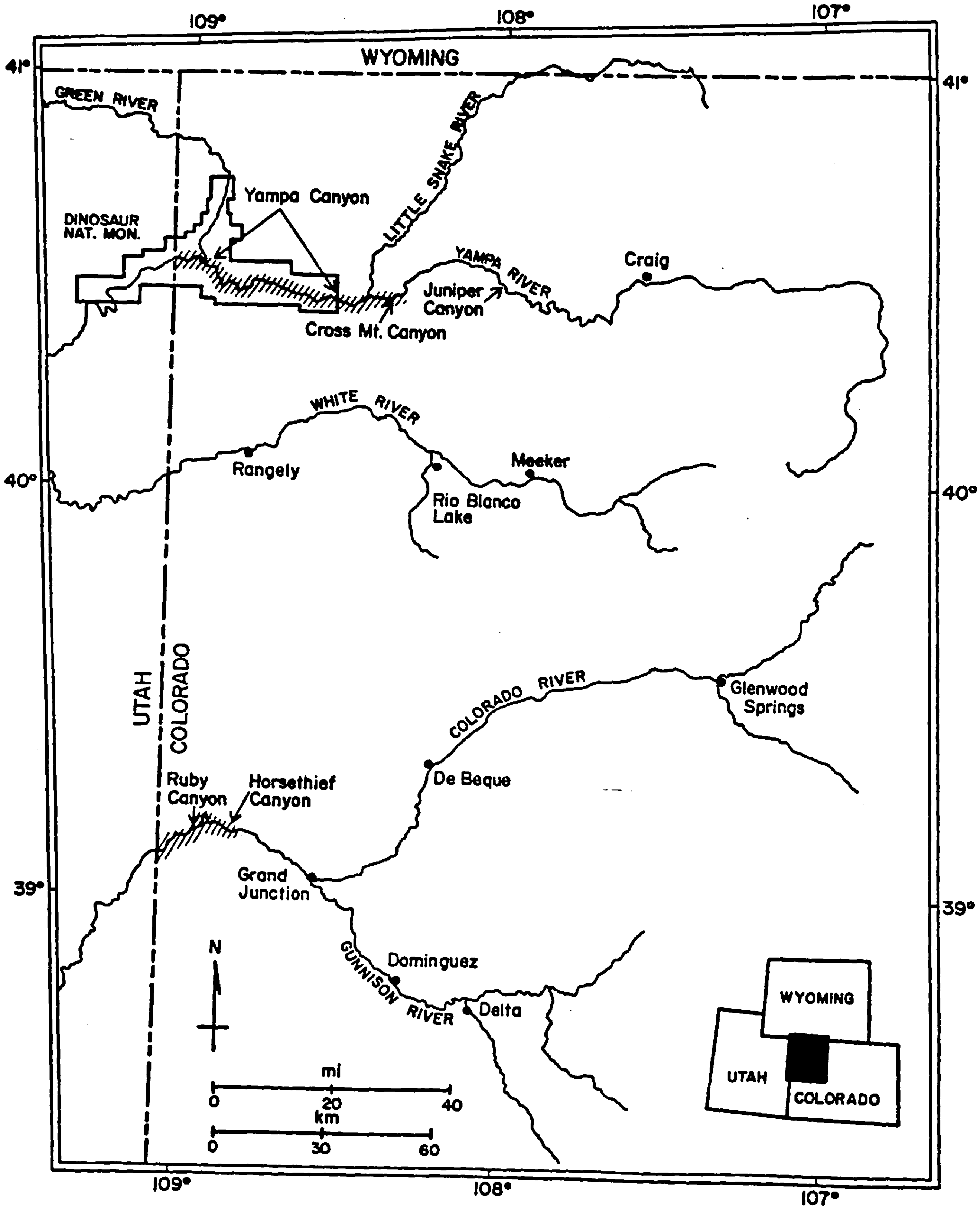
Seine sampling locations within a given study area were, in part, determined using a stratified random design during 1981-1984 and samples were collected in a consistent manner at each individual locality. Three types of sampling sites were designated.

(1) "Intensive" sites were randomly selected prior to each field trip using a random numbers table. This process required the initial random selection of one location within a study area, corresponding to a river kilometer. This site, plus each river kilometer approximately 8 km above and below, was designated as an "intensive" site. At each "intensive" site, all recognizable (and seinable) habitat types were sampled for a distance of 0.8 km above and below the mid-point. Depending upon the location of the initial random site determined, the number of "intensive" sites sampled per field trip were 5-6 and 9-10 for the Colorado and Yampa rivers, respectively.

(2) "Intervening" sites were localities excluded from the random site selection but sampled due to the wide variety of habitat types available.

(3) "Special" sites (e.g., Black Rocks, river km 219.8-218.2, Colorado River) were relatively short, unique river reaches or points included for specific purposes.

Figure 1. Study area (cross-hatched) on the mainstem Colorado River and Yampa River in western Colorado.


109°
108°
107°
41°
WYOMING
41°
GREEN RIVER
LITTLE SNAKE RIVER
Yampa Canyon
DINOSAUR
NAT. MON.
YAMPA RIVER
Craig
Juniper
Canyon
Cross Mt. Canyon
WHITE RIVER
Rangely
Meeker
40°
Rio Blanco
Lake
40°
UTAH
COLORADO
COLORADO RIVER
Glenwood
Springs
De Beque
Ruby
Canyon
Horsethief
Canyon
Grand
Junction
39°
39°
N
GUNNISON RIVER
Dominguez
Delta
mi
0
20
40
km
0
30
60
WYOMING
UTAH
COLORADO
109°
108°
107°

This procedure resulted in a sampling of far more sites per field trip than determined by the random selection process alone. Seine samples were taken with 3.0- x 1.2-m and 1.0- x 1.2-m seines (1.6-mm square mesh). Samples were collected according to a habitat stratification scheme designed to reflect the geomorphic, hydrologic, and ecologic variables of the study area. Habitat variables were described in detail in Haynes and Muth (1982). The width and length of each seine collection were measured with a metric tape and area sampled (m^2) was calculated and recorded. Larger specimens, identifiable to species, were measured to the nearest 0.1 mm (total length, TL), counted, and released. Smaller specimens were preserved in 10% buffered formalin and returned to the Larval Fish Laboratory (Colorado State University, Fort Collins) for processing.

An index of relative young-of-the-year (YOY) abundance (i.e., capture per unit effort, C/f) was developed for seine-collected YOY Colorado squawfish using basic tenets of Ricker (1975), Caughley (1978), Lackey and Hubert (1978), Southwood (1978), and Tanner (1978), i.e., that C/f is related in a constant or predictable way to population size and changes in absolute abundance over space and time will be reflected by changes in C/f. A discussion of the advantages and disadvantages of using C/f methods in open, structurally diverse systems such as the Upper Colorado River Basin was presented in Haynes and Muth (1984). C/f methods were selected in favor of other, more rigorous, abundance models because closure of the system was not possible. C/f values (numbers of YOY per 100 m^2) were derived from seine samples of known area and specific habitat features. An evaluation of YOY Colorado squawfish distribution per specific habitats was made for 1981-1984 for each river and only those habitat types in which YOY had been previously collected were used for C/f calculations (i.e., backwaters, embayments, concavities, pools, isolated pools, and shallow shorelines). In this way, habitats such as riffles, which had never yielded YOY Colorado squawfish, were omitted from the calculations. Further, for any given year and river, samples taken prior to the earliest estimated spawning dates (derived from age estimates of YOY, presented later in Methods) were also excluded. In the Yampa River, only seine samples taken at or below river km 32.0 (the previously suspected upstream limit of Colorado squawfish spawning in the Yampa River) were included in C/f calculations.

During July-August 1982, icythyoplankton drift-nets were deployed in the Black Rocks area, Colorado River, to determine if larval Colorado squawfish disperse via downstream drift and to evaluate gear, sampling design, and methods of gear deployment. These initial trials proved successful and it was decided to extensively utilize drift-nets in the Yampa River (June-August 1983; July-August 1984) and Green River (July-August 1984). Drift-nets were deployed at two Yampa River sites in 1983 (i.e., Harding Hole, river km 32.5; and Box Elder, river km 3.1). The Harding Hole site was selected to evaluate the possibility that Colorado squawfish spawn above river km 32.0. The Box Elder site was chosen to assess larval fish drift patterns near the Yampa River mouth. In 1984 drift collections continued at Box Elder, while the Harding Hole site was dropped in favor of a Green River site approximately 9.3 km below the Yampa-Green River confluence (river km 355.3, Colorado-Utah state line). This site was included to follow progression of drifting fish larvae down the Green River.

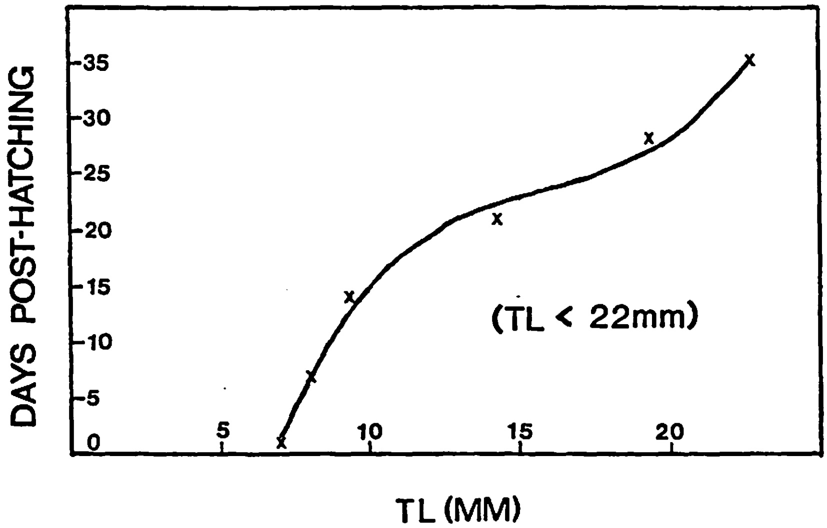
Near-shore drift collections were made using 0.5-m diameter conical plankton nets (Wildlife Supply Company, Saginaw, Michigan) mounted on 0.5- x 0.3-m rectangular steel frames and fitted with 33-cm long (10-cm diameter) removable PVC collection buckets with a threaded cod end. Each net had a 560-micron Nytex nylon mesh length of 4.0 m, and an open mesh to net mouth ratio of 11:1. Filtration efficiency approaches 100% when the open mesh area is more than three times the area of the net mouth (Faber 1968; Tranter and Smith 1968). In the Colorado River, a removable four-point, steel-cable bridle assembly terminating in a spring-loaded carabiner was attached to each net frame. Nets were deployed either by staking the net frames to the river substrate in shallow areas or fastening the bridle carabiner to a polypropylene line fixed to either an instream boulder or a metal post driven into the shore at deeper sites. Mid-channel sets were attempted but discontinued for safety reasons and because of possible boat traffic during collection times. In the Yampa River, drift-nets were deployed off rafts tied to shore during runoff periods when depths and currents made wading difficult. During lower water periods, nets were attached directly to metal posts driven into the river substrate. At all sets, a safety line was attached to each net frame and to a post driven into the shore.

Three drift-nets were deployed along the shoreline at each site just below the water surface. Water volume passing through each net was calculated from velocity readings made with either a Marsh-McBirney (Model 201) or pygmy (Gurley Model 625 F) current meter. Water temperature (C) was measured at each sampling time. In order to evaluate possible diel periodicity in larval fish drift, samples were taken at sunrise, noon, one-half hour after sunset, and at midnight. Sampling duration at each period ranged from 1 to 2 hours depending upon the suspended solids load. The contents of each net were rinsed into 1-gallon plastic jugs, preserved in 10% buffered formalin, and returned to the Larval Fish Laboratory for processing. All specimens were counted, measured to the nearest 0.1 mm (TL), and assigned to a developmental phase according to Snyder (1976). This procedure permitted evaluation of larval fish drift periodicity both within a particular developmental phase (e.g., protolarval) and between phases (e.g., protolarval vs mesolarval). Numerical densities were computed as numbers of larvae per 1,000 m^3. Two-way analysis of variance (2-ANOVA) was used to compare drift densities (response variable) among the four sampling times and between day and night samples (i.e., combined sunrise and noon = day; combined sunset and midnight = night) on individual sampling dates over the entire sampling season. The 0.05 probability level was used to determine significance in F values.

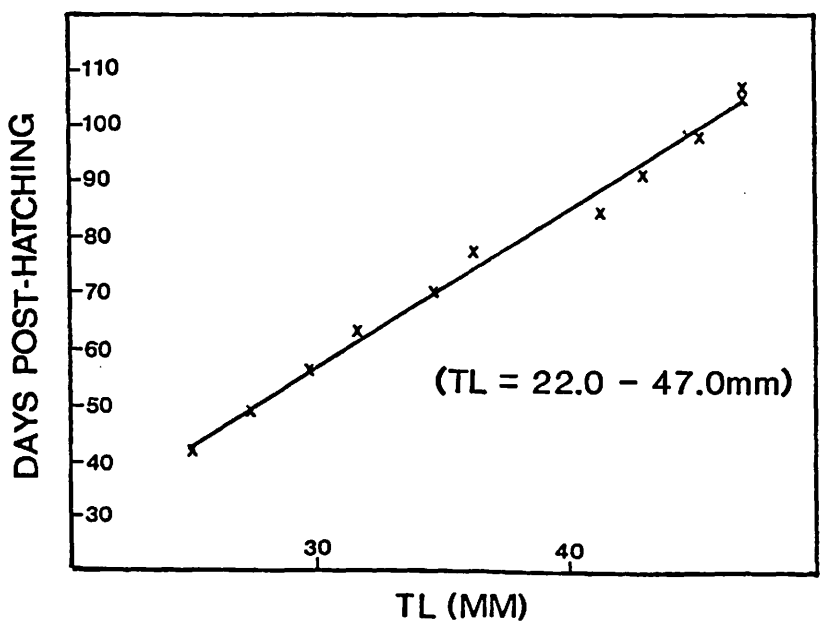
Flow and temperature data were obtained from United States Geological Survey (USGS) readings when available and supplemented with measurements taken during sampling and CRFP thermograph data. All field and laboratory data were recorded to be compatible with data collected by NW Region (CDOW) and CRFP personnel with any differences resulting from specific requirements of early life history studies. Data were generally compatible with the United States Fish and Wildlife Service MANAGE database program. All field data has been filed on dBase II and stored at CDOW, Denver.

To estimate spawning dates using back-calculated age of seine- and drift-net-collected young-of-the-year (YOY) Colorado squawfish, two predictive age equations (Haynes and Muth 1984) were derived using Hamman's (1981) total length at known age data for hatchery cultured and reared Colorado squawfish larvae (Fig. 2).

Figure 2. Relationship of total length (TL, nearest 0.1mm) to age for YOY Colorado squawfish. For TL <22.0 mm, age is best best predicted by a 3rd degree polynomial (A). For TL = 22.0-47.0 mm age is best predicted by a linear regression (B). Note: L=TL.



A. $Age = -76.7105 + 17.4949L - 1.055L^2 + 0.221L^3 \qquad r^2 = 0.99$



B. $Age = -26.6421 + 2.7798L \qquad r^2 = 0.99$

These predictive equations differ from previous equations presented in Haynes et al. (1983, 1984) due to reinterpretation of Hamman's (1981) data and, in general, resulted in a narrowing of previous ranges of estimated spawning dates. The usefulness and accuracy of these equations were discussed in Haynes and Muth (1984).

RESULTS

Colorado River Study Area

General

A total of 1,105 seine and dip net samples were taken in the Colorado River during 1979-1983 (Table 1). Twenty fish species were collected during 1981-1983, mostly within the families Cyprinidae and Catostomidae (Table 2). For those years, non-native species predominated, constituting 90%, 82%, and 60% of the total catch, respectively. Red shiner (Notropis lutrensis), sand shiner (N. stramineus), and fathead minnow (Pimephales promelas) were the most abundant non-native species and accounted for 79% of all specimens collected during 1981-1983. Mosquitofish (Gambusia affinis), which were uncommon in 1981 and 1982 collections, were more abundant in 1983 and accounted for 18% of all fish sampled. Notably, 11 redside shiner (Richardsonius balteatus) were collected between river km 230.4 and 243.4 on 2 May 1981, representing a new distributional record for this species (Haynes et al. 1982). Speckled dace (Rhinichthys osculus), bluehead sucker (Catostomus discobolus), and Gila spp. were the most abundant native species collected, together constituting 16% of the total combined catch for 1981-1983.

Table 1. Total number of samples taken in the Colorado, Yampa, and Green rivers, Colorado, 1979-1984. Numbers are combined seine and dip-net samples. Parentheses denote number of drift-net samples taken.

Year	River		
	Colorado	Yampa	Green
1979	155		
1980	114	215	
1981	295	423	
1982	336(48)	295(13)	
1983	205	245(252)	
1984		148(168)	(155)
Total	1,105(48)	1,326(443)	(155)

Table 2. Seine and dip net catches of fish in the Colorado River, Colorado, 1981-1983. N = number of fish sampled, %T = % of total number of fish sampled; %FO = frequency of occurrence (% of total number of samples containing a particular species; based on 295, 336, and 205 samples for 1981, 1982, and 1983, respectively); asterisk (*) = less than 0.5% of total.

Taxon	1981			1982			1983		
	N	%T	%FO	N	%T	%FO	N	%T	%FO
CYPRINIDAE	48,047	98	96	37,309	91	78	8,311	65	84
Cyprinus carpio	14	*	2	24	*	3	14	*	3
Gila spp.[a]	3,488	7	70	3,674	9	52	1,605	12	36
Notropis lutrensis	24,353	50	77	24,035	58	60	3,834	30	66
N. stramineus	3,409	7	55	3,125	8	34	369	3	34
Pimephales promelas	16,019	33	72	5,308	13	33	888	7	48
Ptychocheilus lucius[a]	1	*	*	14	*	2	3	*	2
Rhinichthys osculus[a]	752	2	38	1,129	3	38	1,598	12	43
Richardsonius balteatus	11	*	2						
CASTOSTOMIDAE	560	1	30	2,666	6	49	1,916	12	31
Catostomus commersoni	6	*	2	32	*	3	5	*	2
C. discobolus[a]	423	1	22	1,648	4	35	1,797	14	27
C. latipinnis[a]	131	*	17	986	2	38	159	1	17
ICTALURIDAE	121	*	9	975	2	12	34	*	6
Ictalurus punctatus	117	*	8	339	1	12	32	*	6
I. melas	4	*	1	636	2	1	2	*	1
CENTRARCHIDAE	150	*	14	141	*	10	322	2	27
Lepomis cyanellus	136	*	11	67	*	7	262	2	25
L. machrochirus	1	*	*				5	*	1
Micropterus salmoides	13	*	4	71	*	4	17	*	4
Pomoxis nigromaculatus				3	*	*	38	*	5

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Taxon	1981			1982			1983		
	N	%T	%FO	N	%T	%FO	N	%T	%FO
POECILIIDAE									
Gambusia affinis	8	*	*				2,291	18	17
CYPRINODONTIDAE									
Fundulus zebrinus	22	*	*	6	*	1	15	*	4
COTTIDAE									
Cottus bairdi[a]	2	*	*						
NATIVES	4,795	10	83	7,451	18	67	5,162	40	66
NON-NATIVES	44,115	90	83	33,646	82	63	7,723	60	77
TOTAL	48,910			41,097			12,885		

[a]Native species

The 10 species and 118 individuals collected in 48 drift-net samples in 1982 were also predominantly cyprinid and catostomid larvae; juvenile and adult forms contributed less than 3% (Table 3). Native species accounted for 91% of all fish caught. Bluehead sucker, speckled dace, and _Gila_ spp. were the predominant native species, constituting 29%, 27%, and 25% of the total catch, respectively. Channel catfish (_Ictalurus punctatus_) was the most commonly sampled non-native species (6% of total catch).

Table 3. Fishes collected during July-August 1982 drift-net sampling in the Black Rocks area (river km 219.8-218.2), Colorado River, Colorado. N=number of fish sampled; %T=% of total number of fish sampled; %FO=frequency of occurrence (% of total number of samples containing a particular species, based on 48 samples).

Taxon	N	%T	%FO
CYPRINIDAE	67	57	34
Cyprinus carpio	1	1	2
Gila robusta[a]	1	1	2
Gila spp.[a]	30	25	21
Pimephales promelas	1	1	2
Ptychocheilus lucius[a]	2	2	4
Rhinichthys osculus[a]	32	27	25
CATOSTOMIDAE	43	36	33
Catostomus discobolus[a]	35	29	29
C. latipinnis[a]	8	7	15
ICTALURIDAE			
Ictalurus punctatus	7	6	10
CENTRARCHIDAE			
Lepomis cyanellus	1	1	2
NATIVES	108	92	48
NON-NATIVES	10	8	15
TOTAL	118		

[a]Native species

Colorado Squawfish

A total of 105 Colorado squawfish YOY were collected by seine and dip net in the Colorado River during 1979-1983 (Table 4). Numbers per year ranged from 77 in 1980 to 1 in 1981. All specimens were collected in low velocity habitats (e.g., shallow shorelines, backwaters, concavities, and isolated pools) between river km 212.2 and 245.7. Specimens were collected as early as 27 July in 1981 and 1982 and as late as 2 November in 1980. C/f ranged from 0.05 in 1981 (one individual) to 0.31 in 1982 (16 individuals). Size (mm TL) at time of capture ranged from 7.8 (27 July 1982) to 38.0 (2 November 1980). Colorado squawfish spawning was estimated to have occurred as early as 3 July in 1981 and as late as 6 September in 1980.

Two age I Colorado squawfish were collected by seine in 1983. One (TL=65.0 mm) was sampled at river km 218.1 on 2 August in a tributary stream embayment, and the second (TL=76.2 mm) was collected at river km 224.6 on 19 September in a mainchannel backwater. Predictive age equations did not permit estimates for individuals of this size.

Two larval Colorado squawfish (TL=9.0 and 9.5 mm) were collected by drift-net on 27 July 1982 (Table 3). These specimens were estimated to be 11.4 and 13.2 days old, respectively, meaning they were spawned on 15 and 17 July.

The relationship between flow/water temperature and estimated Colorado squawfish spawning dates for the months April-September 1979-1983 is presented in Figure 3 and Table 5. In general, estimated spawning dates coincided with decreasing flow and rising water temperature. In 1979, spawning was estimated to have occurred from 16 July to 4 August when maximum flow at the Colorado-Utah state line decreased from approximately 297 to 125 m^3 per second (m^3/sec). Maximum mainchannel water temperature during that period was always greater than 20 C; however, minimum water temperature was occasionally lower. Mainchannel water temperature 22 C occurred by 22 July and lasted well into August. Spawning in 1980 was estimated to have occurred from 16 July to 6 September. Maximum flow during that period ranged from approximately 178 to 115 m^3/sec and maximum mainchannel water temperature was always greater than 22 C. During the very low flow year of 1981, when peak flow reached only 184.5 m^3/sec, only one YOY Colorado squawfish was collected, suggesting a brief spawning period. In 1983, the estimated spawning period was 15 July-11 August. Maximum flow during that period ranged from 218 to 135 m^3 and maximum mainchannel water temperature ranged from 21.0 to 23.5 C. Flow in 1983 was high, with a peak discharge of 1,705 m^3/sec on 27 June. Estimated spawning period for 1983 was 27 July-10 August. Maximum flow during that period ranged from 515 to 334 m^3/sec and maximum mainchannel water temperature ranged from 19.0 to 23.0 C.

Table 4. Seine and dip net catches of Colorado squawfish young-of-the-year (YOY) in the Colorado River, Colorado, 1979-1983.

Year	Number of samples collected[a]	Date of YOY collections[b]	Location (river km) of YOY collections[c]	Number of YOY collected	C/f[d]	Size (mm TL) of YOY collected	Estimated Colorado squawfish spawning dates[e]
1979	155(2)	8/24,8/28	217.2-223.6	8		15.0-24.5	7/16-8/04
1980	114(11)	8/13-11/02	212.2-245.7	77		13.0-38.0	7/16-9/06
1981	295(1)	7/27	243.6	1	0.05	18	7/03
1982	336(10)	7/27,8/23	216.1-244.4	16	0.31	7.8-20.1	7/15-8/11
1983	205(2)	8/11,9/09	236.4,237.3	3	0.15	9.0-21.5	7/27-8/10

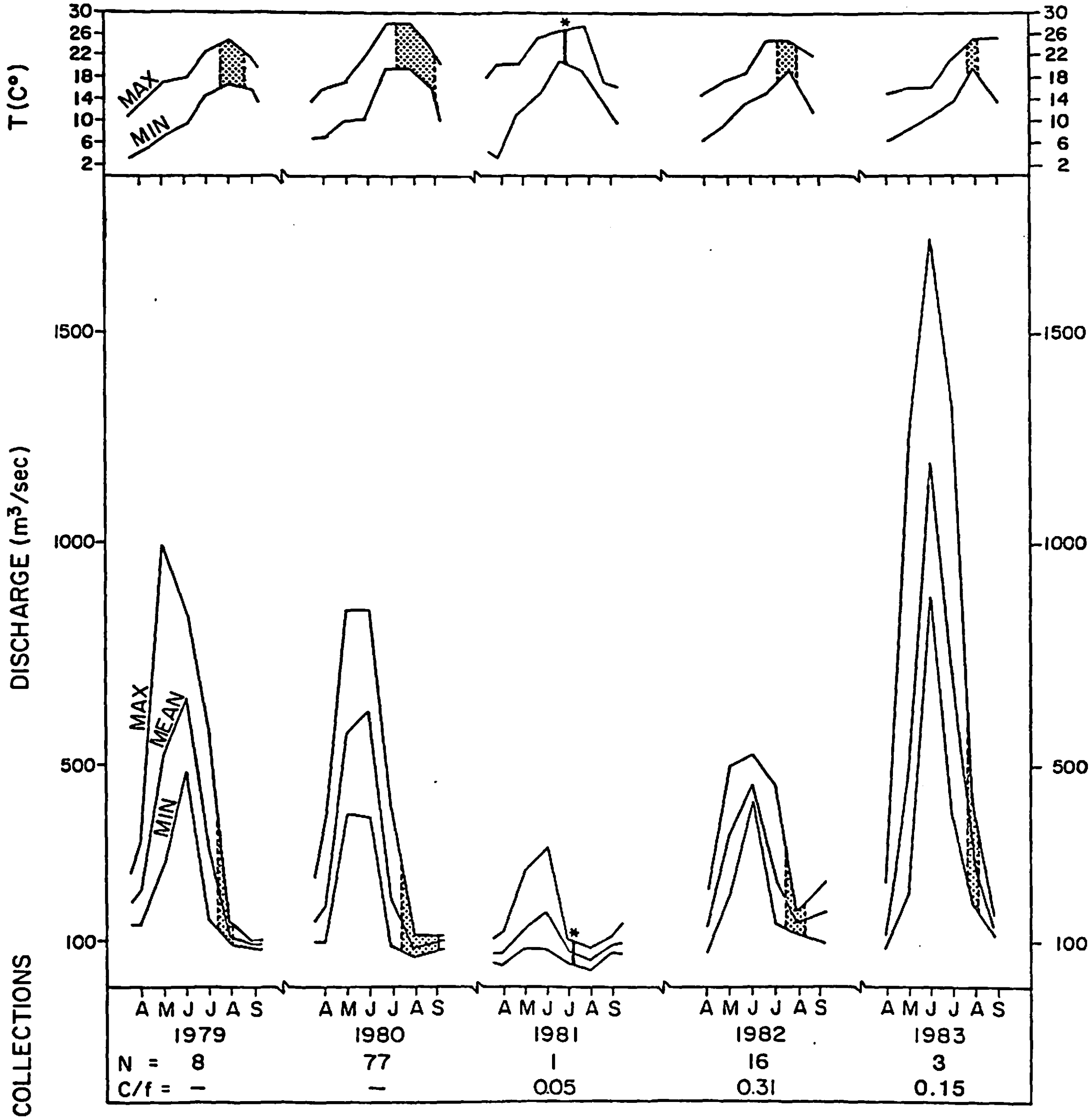
[a]Numbers in parentheses represent the number of samples which contained YOY
[b]Dates of earliest-latest YOY collections
[c]Distance from Colorado-Green River confluence (river km 0)
[d]Numbers of YOY per 100 m^2 of specific habitats sampled
[e]Derived from back-calculated age estimates of YOY

Table 5. Summation of water temperatures (C) related to estimated Colorado squawfish spawning dates, Colorado River (1979-1983) and Yampa River (1980-1984), Colorado. Asterisk (*) means there was insufficent water temperature data.

	Colorado River[a]					Yampa River				
	1979	1980	1981	1982	1983	1980	1981[b]	1982[c]	1983[d]	1984[e]
Dates when maximum mainchannel water temperatures first reached:										
18C	6/29	6/25	4/10	6/27	7/28	*	6/18	6/28	7/07	6/28
20C	7/12	6/26	5/28	7/09	7/19	*	6/20	7/09	7/14	7/05
22C	7/22	6/30	6/20	7/18	8/06	*	6/22	7/15	7/20	7/15
Earliest estimated spawning date[f]	7/16	7/16	7/03	7/15	7/27	7/02	7/06	7/24	7/11	7/04
Maximum mainchannel water temperature at earliest estimated spawning date	21.0	24.5	24.5	21.0	19.5	21.5	25.0	26.0	17.5	19.0
Number of days maximum mainchannel water temperature was:										
≥18C	85	*	117+	84	75	*	102	86	77	85
≥20C	61	88	83+	84	59	*	92	71	65	67
≥22C	26	66	68+	46	37	*	76	59	57	48

[a]USGS Station 09163500 near Colorado-Utah state line
[b]USGS Station 09251000 near Maybell, Colorado
[c]USGS Station 09260050 at Deerlodge Park, Colorado
[d]Field measurements plus USGS Deerlodge Park data
[e]CRFP field thermograph readings
[f]Derived from back-calculated age estimates of YOY

Figure 3. Relationship of estimated Colorado squawfish spawning periods with flows and temperatures in the Colorado River study area, 1979-1983. Stippled areas denote spawning periods. Time period for each year is April-September. N = number of larval squawfish collected. C/f = catch/effort associated with N.


T (C°)
30
26
22
18
14
10
6
2
MAX
MIN
DISCHARGE (m3/sec)
1500
1000
500
100
MAX
MEAN
MIN
COLLECTIONS
A M J J A S
1979
1980
1981
1982
1983
N = 8
77
1
16
3
C/f = –
–
0.05
0.31
0.15

Yampa-Green River Study Area

General

A total of 1,326 seine and dip net samples were taken in the Yampa River during 1980-1984 (Table 1) and 19 fish species were collected (Table 6). Virtually 100% of the fish sampled were cyprinids and catostomids. During 1981-1982, non-native fishes predominated, constituting 51% and 56% of the total catch, respectively. Red shiners, sand shiners and fathead minnows were the dominant non-native species collected. Unidentified *Gila* spp. and speckled dace were the most common native species. In 1983, native fishes constituted 82% of all individuals collected, predominated by *Gila* spp., speckled dace, and bluehead suckers.

A 267-mm (TL) humpback chub was collected by gill net in upper Cross Mountain Canyon (August 1980); representing a range extension for this species.

Thirteen fish species were collected in 420 drift-net samples at the Yampa River sites (1983-1984), while 8 species were collected in 155 drift-net samples at the Green River (state line) site in 1984 (Tables 1, 7, and 8). Almost all fish collected were cyprinids, catostomids and ictalurids. In 1983, 4,495 individuals, mostly larvae (juvenile and adult forms contributed less than 5%), were collected at both Yampa River sites combined (Table 7). Total catch at Harding Hole was almost twice the Box Elder catch. Twelve species were collected at Harding Hole, of which sand shiner, white sucker (*Catostomus commersoni*), and mottled sculpin (*Cottus bairdi*) were exclusive to this site. Ten species were sampled at Box Elder; red shiner was the only species exclusive to this locality. Native species, represented by *Gila* spp., speckled dace and bluehead suckers, were far more abundant than non-natives at both sites and accounted for 83% of the total combined catch. Channel catfish was the predominant non-native species collected at both sites, but were sampled in substantial numbers only at Box Elder (i.e., 514 individuals=34% of total catch).

In 1984, 9 species were collected by drift-net sampling at Box Elder, while 8 species were collected at State Line. A total of 3,607 individuals, predominantly larvae, were sampled at both sites combined. The catch at State Line was less than one-third the Box Elder catch. Redside shiner and sand shiner were exclusive to Box Elder and fathead minnow was exclusive to State Line. Native fishes (same species) were again far more abundant than non-natives and accounted for 65% and 72% of the total catch in the Yampa and Green rivers, respectively. As in 1983, channel catfish was the most commonly collected non-native species.

Table 6. Seine and dip-net catches of fish in the Yampa River, Colorado, 1981-1983. N = number of fish sampled; %T = % of total number of fish sampled; %FO = frequency of occurrence (% of total number of samples containing a particular species; based on 423, 295, and 245 samples for 1981, 1982, and 1983, respectively); asterisk (*) = less than 0.5% of total.

Taxon	1981			1982			1983		
	N	%T	%FO	N	%T	%FO	N	%T	%FO
CYPRINIDAE	18,290	96	85	24,628	92	93	12,913	88	89
Cyprinus carpio	2	*	*	91	*	10	122	1	14
Gila spp.[a]	5,823	30	66	8,388	31	77	6,209	43	74
Notropis lutrensis	7,563	40	40	7,305	27	37	478	3	29
N. stramineus	391	2	20	3,390	13	31	757	5	30
Pimephales promelas	1,024	5	18	3,184	12	26	485	3	24
Ptychocheilus lucius[a]	23	*	3	8[b]	*	2	228	2	7
Rhinichthys osculus[a]	2,843	15	60	1,281	5	59	3,846	26	63
Richardsonius balteatus	620	3	20	980	4	30	786	5	38
Semotilus atromaculatus	1	*	*	1	*	*	2	*	*
CATOSTOMIDAE	715	4	26	2,054	8	43	1,682	12	41
Catostomus commersoni	9	*	7	*	2	13	*	3	
C. discobolus[a]	527	3	21	1,045	4	28	1,386	9	31
C. latipinnis[a]	179	1	15	1,002	4	36	283	2	28
ICTALURIDAE	11	*	1	30	*	4	9	*	3
Ictalurus punctatus	11	*	1	29	*	4	9	*	3
I. melas				1	*	*			

Table 6. Seine and dip-net catches of fish in the Yampa River, Colorado, 1981-1983. N = number of fish sampled; %T = % of total number of fish sampled; %FO = frequency of occurrence (% of total number of samples containing a particular species; based on 423, 295, and 245 samples for 1981, 1982, and 1983, respectively); asterisk (*) = less than 0.5% of total (concluded).

Taxon	1981			1982			1983		
	N	%T	%FO	N	%T	%FO	N	%T	%FO
CENTRARCHIDAE	4	*	*				1	*	*
Lepomis cyanellus	4	*	*						
Pomoxis nigromaculatus							1	*	*
COTTIDAE									
Cottus bairdi[a]	4	*	1	3	*	1	1	*	*
SALMONIDAE									
Prosopium williamsoni[a]	1	*							
CYPRINODONTIDAE									
Fundulus zebrinus	1	*	*						
NATIVES	9,400	49	81	11,727	44	86	11,953	82	76
NON-NATIVES	9,626	51	48	14,988	56	60	2,653	18	58
TOTAL	19,026			26,715			14,606		

[a]Native species
[b]Does not include 12 YOY Colorado squawfish collected by NW Region (CDOW) personnel

Table 7. Fishes collected during June-August 1983 drift net sampling in the Yampa River, Colorado. N = number of fish sampled; %T = % of total number of fish sampled; %FO = frequency of occurrence (% of total number of samples containing a particular species; based on 123 samples at Harding Hole, 129 samples at Box Elder, and 252 total); asterisk (*) = less than 0.5% of total.

Taxon	Harding Hole (km 32.5)			Box Elder (km 3.1)			Total		
	N	%T	%FO	N	%T	%FO	N	%T	%FO
CYPRINIDAE	1,451	49	73	316	21	60	1,767	39	66
Cyprinus carpio	40	1	11	7	*	2	47	1	7
Gila spp.[a]	578	19	61	94	6	37	672	15	49
Notropis lutrensis				1	*	1	1	*	*
N. stramineus	1	*	1				1	*	*
Pimephales promelas	1	*	1	2	*	2	3	*	1
Ptychocheilus lucius[a]	1	*	1	102	7	29	103	2	16
Rhinichthys osculus[a]	829	28	59	108	7	37	937	21	48
Richardsonius balteatus	1	*	1	2	*	2	3	*	1
CATOSTOMIDAE	1,322	44	60	679	45	32	2,001	45	46
Catostomus commersoni	1	*	1				1	*	*
C. discobolus[a]	1,269	42	46	661	43	26	1,930	43	39
C. latipinnis[a]	52	2	23	18	1	9	70	1	17
ICTALURIDAE									
Ictalurus punctatus	211	7	20	514	34	36	725	16	29
COTTIDAE									
Cottus bairdi[a]	2	*	2				2	*	1
NATIVES	2,731	91	75	983	65	70	3,714	83	73
NON-NATIVES	255	9	80	526	35	40	781	17	34
TOTAL	2,986			1,509			4,495		

[a]Native species

Table 8. Fishes collected during July-August 1984 drift net sampling in the Yampa and Green rivers, Colorado. N = number of fish sampled; %T = % of total number of fish sampled; %FO = frequency of occurrence (% of total number of samples containing a particular species; based on 168 samples at Box Elder, 155 samples at State Line, and 323 samples total); asterisk (*) = less than 0.5% of total.

Taxon	Yampa River Box Elder (km 3.1) N	%T	%FO	Green River State Line (km 355.3) N	%T	%FO	Total N	%T	%FO
CYPRINIDAE	214	8	42	164	18	45	378	10	43
Cyprinus carpio	25	1	10	8	1	5	33	1	7
Gila spp.[a]	34	1	12	22	2	9	56	2	11
Notropis stramineus	1	*	1				1	*	*
Pimephales promelas				2	*	1	2	*	1
Ptychocheilus lucius[a]	89	3	22	27	3	12	116	3	17
Rhinichthys osculus[a]	64	2	15	105	12	29	169	5	22
Richardsonius balteatus	1	*	1				1	*	*
CATOSTOMIDAE	1,576	58	34	490	55	62	2,066	57	48
Catostomus discobolus[a]	1,547	57	30	412	46	45	1,959	54	37
C. latipinnis[a]	29	1	13	78	9	30	107	3	21
ICTALURIDAE									
Ictalurus punctatus	921	34	49	242	27	24	1,163	32	38
NATIVES	1,763	65	50	644	72	62	2,407	67	56
NON-NATIVES	948	35	55	252	28	29	1,200	33	43
TOTAL	2,711			896			3,607		

[a]Native species

Colorado Squawfish

Colorado squawfish YOY were present in 71 of 1,438 seine and dip net samples taken in the Yampa River during 1980-1984 (Table 9). A total of 556 specimens were collected during the study, of which 477 were sampled in 1983 and 1984 combined. Specimens were collected in low velocity shoreline areas and ephemeral backwaters, embayments, concavities, and isolated pools between river km 28.8 and 0.2. Colorado squawfish YOY were seined as early as 24 July in 1981 and as late as 25 August in 1982. Size (mm TL) at time of capture ranged from 8.1 (27 July 1984) to 29.0 (8 August 1980). C/f ranged from 0.19 in 1982 (20 individuals) to 6.0 in 1983 (228 individuals). Colorado squawfish spawning was estimated to have occurred as early as 2 July (1980) and as late as 11 August (1983).

In 1983, Colorado squawfish larvae first appeared in drift-net samples on 20 July (Harding Hole) and were collected through 21 August at Box Elder (Table 10). In 1984, Colorado squawfish larvae were sampled from 16 July (both sampling sites) through 8 August at Box Elder (Tables 11 and 12). A total of 192 specimens were collected in the Yampa River during 1983 and 1984 combined and 27 were sampled at State Line in 1984. Size (mm TL) at time of capture ranged from 7.2 to 9.5 (Box Elder, 8 August and 19 July 1984, respectively). Based on age predictions of larvae sampled at Box Elder, estimated Colorado squawfish spawning dates were 11 July-19 August (1983) and 5 July-6 August (1984); using predicted ages of larvae collected at State Line in 1984, estimated spawning dates were 8-27 July. The collection of one larval Colorado squawfish at Harding Hole in 1983 (20-21 July; 7.3 mm TL) established that at least limited spawning occurred above this site.

Colorado squawfish larvae drift densities at Box Elder peaked on 8-9 August in 1983 and 28-29 July in 1984 (Tables 13 and 14). At State Line in 1984, drift densities peaked on 29-30 July (Table 15). Diel variations in drift densities at Box Elder in 1983 and 1984 were not statistically significant ($P \leq 0.05$). Overall mean total abundance ratios (protolarvae + mesolarvae) at Box Elder were 1:2:1:2 and 4:2:1:1 (i.e., sunrise:noon: sunset:midnight) and 1:1 and 3:1 (i.e., day:night) for 1983 and 1984, respectively (Table 16). At State Line in 1984, protolarvae were more abundant in dawn and noon samples with total mean densities of 2.0/ and 0.4/1000m^3 for day and night, respectively. This difference was considered significant ($P \leq 0.05$). Mean total abundance ratio at State Line was 5:5:1:1 (Table 16).

Estimated ages of combined seine- and drift-net-collected Colorado squawfish YOY yielded an overall projected spawning period of 11 July-19 August in 1983 and 4 July-6 August in 1984 (Figs. 4 and 5; Table 17). In 1983, Colorado squawfish spawning apparently peaked between 25 July-10 August with both seine- and drift-net-collected YOY defining the spawning peak. Peak spawning activity in 1984 was estimated to have occurred in mid-July with a second, less intense period during late July through early August. Larvae spawned during 12-20 July were mostly collected in seines, while those spawned after approximately 20 July were almost entirely collected in drift-nets.

Table 9. Seine and dip net catches of Colorado squawfish young-of-the-year (YOY) in the Yampa River, Colorado, 1980-1984.

Year	Number of samples collected[a]	Date of YOY collections[b]	Location (river km) of YOY collections[c]	Number of YOY collected	C/f[d]	Size (mm TL) of YOY collected	Estimated Colorado squawfish spawning dates[e]
1980	215(9)	8/23-25	0.2-13.9	46		14.0-29.0	7/02-8/08
1981	423(11)	7/24-8/15	0.2-28.8	23[f]	0.86	9.0-22.0	7/06-30
1982	295(10)	8/07-25	0.5-19.6	20[g]	0.19	9.9-21.0	7/24-8/08
1983	245(17)	7/22-8/21	1.1-19.8	228	6.02	8.6-16.6	7/24-8/11
1984	148(24)	7/26-8/06	0.2-25.4	249	4.20	8.1-15.1	7/04-22

[a]Numbers in parentheses are number of collections containing YOY
[b]Dates of earliest-latest YOY collections
[c]Distance from Yampa River mouth (river km 0)
[d]Numbers of YOY per 100 m^2 of specific habitats sampled
[e]Derived from back-calculated age estimates of YOY
[f]Includes YOY collected by NW Region (CDOW) personnel
[g]Includes 12 YOY collected by NW Region (CDOW) personnel

Table 10. Drift net catches of Colorado squawfish larvae at Harding Hole (river km 32.5) and Box Elder (river km 3.1), Yampa River, Colorado, 1983.

Date of larval collections	Water temperature (C)[a]	Number of larvae collected	Size (mm TL) of larvae collected	Estimated age (days) of larvae collected[b]	Estimated Colorado squawfish spawning dates[b]
7/20-21	21.5	1[c]	7.3	3	7/19
7/22-23	22.0	5	8.2-9.2	8-12	7/11-7/15
7/23-25	22.0	3	8.8-9.0	11	7/13
8/03-04	23.5	3	7.6-8.0	5-7	7/29-7/31
8/08-09	25.3	63	7.4-9.3	4-13	7/27-8/05
8/09-10	24.5	11	8.1-9.2	6-12	7/29-8/04
8/15-16	24.8	2	8.5,9.2	9,12	8/05-8/08
8/16-17	25.3	11	8.0-9.0	7-11	8/07-8/11
8/20-21	28.8	4	7.3-8.4	3-9	8/13-8/19
TOTAL		103	7.3-9.3	3-13	7/11-8/19

[a]Mean values for four 2-hr periods
[b]Derived from back-calculated age estimates of larvae
[c]Harding Hole collection

Table 11. Drift net catches of Colorado squawfish larvae at Box Elder (river km 3.1), Yampa River, Colorado, 1984.

Date of larval collections	Water temperature (C)[a]	Number of larvae collected	Size (mm TL) of larvae collected	Estimated age (days) of larvae collected[b]	Estimated Colorado squawfish spawning dates[b]
7/17	23.0	3	8.2-9.2	8-12	7/05-09
7/18	24.0	1	8.0	7	7/12
7/19	24.8	5	8.1-9.5	8-13	7/07-12
7/27	23.5	5	7.8-8.4	6-9	7/19-22
7/28	23.8	12	7.8-8.2	6-8	7/21-23
7/29	23.0	26	7.5-8.5	4-9	7/21-26
8/02	24.0	2	8.4-8.5	9	7/25
8/03	22.3	1	8.1	8	7/27
8/04	23.0	2	8.0-8.2	7-8	7/28-29
8/06	22.3	11	7.5-8.5	4-9	7/27-8/03
8/07	22.3	13	7.9-8.8	6-11	7/28-8/02
8/08	22.0	8	7.2-8.9	3-11	7/29-8/06
TOTAL		89	7.2-9.5	3-13	7/05-8/06

[a]Mean value for four 2-hr periods
[b]Derived from back-calculated age estimates of larvae

Table 12. Drift net catches of Colorado squawfish larvae at State Line (river km 355.3), Green River, Colorado, 1984.

Date of larval collections	Water temperature (C)[a]	Number of larvae collected	Size (mm TL) of larvae collected	Estimated age (days) of larvae collected[b]	Estimated Colorado squawfish spawning dates[b]
7/16	19.5	1	8.5	9	7/08
7/17	19.0	1	8.0	7	7/11
7/21	19.5	3	7.5-8.5	4-9	7/13-18
7/22	19.3	5	8.3-8.6	8-10	7/13-15
7/29	19.0	5	7.5-8.5	4-9	7/21-26
7/30	19.3	9	7.7-8.3	6-11	7/20-25
7/31	18.5	2	8.3,9.2	8,12	7/20-24
8/06	17.5	1	8.9	11	7/27
TOTAL		27	7.5-8.9	4-12	7/08-27

[a]Mean value for four 2-hr periods
[b]Derived from back-calculated age estimates of larvae

Table 13. Diel densities of drift-net-collected Colorado squawfish larvae (numbers per 1,000 m^3)[a] in the Yampa River, Colorado, Box Elder site (river km 3.1), 1983. Blank spaces mean no catch. Size ranges for developmental phases are cumulative for the entire sampling season.

Date	Sunrise	Noon	Sunset	Midnight	Day	Night
Protolarvae (7.3-9.2 mm TL)						
7/20-21			0.9			0.5
7/22-23	0.4	1.6			1.0	
7/23-25			0.5			0.3
8/03-04			0.8	0.4		0.6
8/08-09	1.2	13.2	2.9	10.2	7.2	7.0
8/09-10			1.1	1.2		1.1
8/15-16				1.3		0.7
8/16-17			1.5	1.5		1.5
8/20-21	0.4	1.0	0.5		0.7	0.3
MEAN TOTAL	0.2	1.8	0.9	1.6	2.0	2.5
Mesolarvae (8.0-9.3 mm TL)						
7/22-23	0.4				0.2	
7/23-25	0.7				0.4	
8/03-04						
8/08-09	14.6	1.7	5.7	15.8	8.2	10.8
8/09-10	2.8	3.3	1.1	3.5	3.1	2.3
8/15-16						
8/16-17			0.7	0.7		0.7
8/20-21		1.0			0.5	
MEAN TOTAL	2.3	0.8	0.9	2.5	3.1	3.4
Combined larvae						
7/20-21			0.9			0.5
7/22-23	0.8	1.6			1.2	
7/23-25	0.7		0.5		0.4	0.3
8/03-04			0.8	0.4		0.6
8/08-09	15.8	14.3	8.6	26.0	15.4	17.3
8/09-10	2.8	3.3	2.2	4.7	3.1	3.5
8/15-16				1.3		0.7
8/16-17			2.2	2.2		2.2
8/20-21	0.4	2.0	0.5		1.2	0.3
MEAN TOTAL	2.3	2.4	1.7	3.8	4.7	5.6

[a]Mean catch of three nets set for 1-2 hrs at each sampling time; day = combined sunrise and noon samples, and night = combined sunset and midnight samples

Table 14. Diel densities of drift-net-collected Colorado squawfish larvae (numbers per 1,000 m^3)[a] in the Yampa River, Colorado, Box Elder site (river km 3.1), 1984. Blank spaces mean no catch. Size ranges for developmental phases are cumulative for the entire sampling season.

Date	Sunrise	Noon	Sunset	Midnight	Day	Night
Protolarvae (7.2-9.2 mm TL)						
7/15-16	0.0			0.4	0.5	0.2
7/18-19		0.4		0.5	0.2	0.3
7/27-28		1.3	0.9		0.7	0.5
7/28-29	13.9	3.1	3.1	1.1	8.5	2.2
8/02-03			0.8	0.4		0.6
8/03-04		0.4		0.4	0.2	0.2
8/06-07	3.9	4.9		0.4	4.4	0.2
8/07-08	2.8		1.4	0.5	1.4	1.0
MEAN TOTAL	2.7	1.3	0.8	0.5	4.0	1.3
Mesolarvae (8.4-8.9 mm TL)						
7/18-19	1.0			1.0	0.5	0.5
8/07-08		0.5		0.5	0.3	0.3
Combined larvae						
7/15-16	0.9			0.4	0.5	0.2
7/18-19	1.0	0.4		1.5	0.7	0.8
7/27-28		1.3	0.9		0.7	0.5
7/28-29	13.0	3.1	3.1	1.1	9.0	2.1
8/02-03			0.8	0.4		0.6
8/03-04		0.4		0.4	0.2	0.2
8/06-07	3.9	4.9		0.4	4.4	0.2
8/07-08	2.8	0.5	1.4	1.0	1.7	1.2
MEAN TOTAL	2.8	1.3	0.8	0.7	4.1	1.5

[a]Mean catch of three nets set for 1-2 hrs at each sampling time; day = combined sunrise and noon samples, and night = combined sunset and midnight samples

Table 15. Diel densities of drift-net-collected Colorado squawfish larvae (numbers per 1,000 m^3)[a] in the Green River, Colorado, State Line site (river km 355.3), 1984. Blank spaces mean no catch. Size ranges for developmental phases are cumulative for the entire sampling season.

Date	Sunrise	Noon	Sunset	Midnight	Day	Night
Protolarvae (7.5-8.9 mm TL)						
7/16-17	0.6		0.6		0.3	0.3
7/20-21	1.0	1.0			1.0	
7/21-22	1.0	1.9			1.5	
7/29-30	1.7	1.3	0.8	0.8	1.5	0.8
7/30-31	0.4	1.3			0.9	
MEAN TOTAL	0.9	1.1	0.3	0.2	2.0	0.4
Mesolarvae (8.9-9.2 mm TL)						
7/30-31	0.4				0.2	
8/05-06				0.4		0.2
MEAN TOTAL	0.2			0.2	0.2	0.2
Combined larvae						
7/16-17	0.6		0.6		0.3	0.3
7/20-21	1.0	1.0			1.0	
7/21-22	1.0	1.9			1.5	
7/29-30	1.7	1.3	0.8	0.8	1.5	0.8
7/30-31	0.8	1.3			1.1	
8/05-06				0.4		0.2
MEAN TOTAL	0.9	0.9	0.2	0.2	1.8	0.4

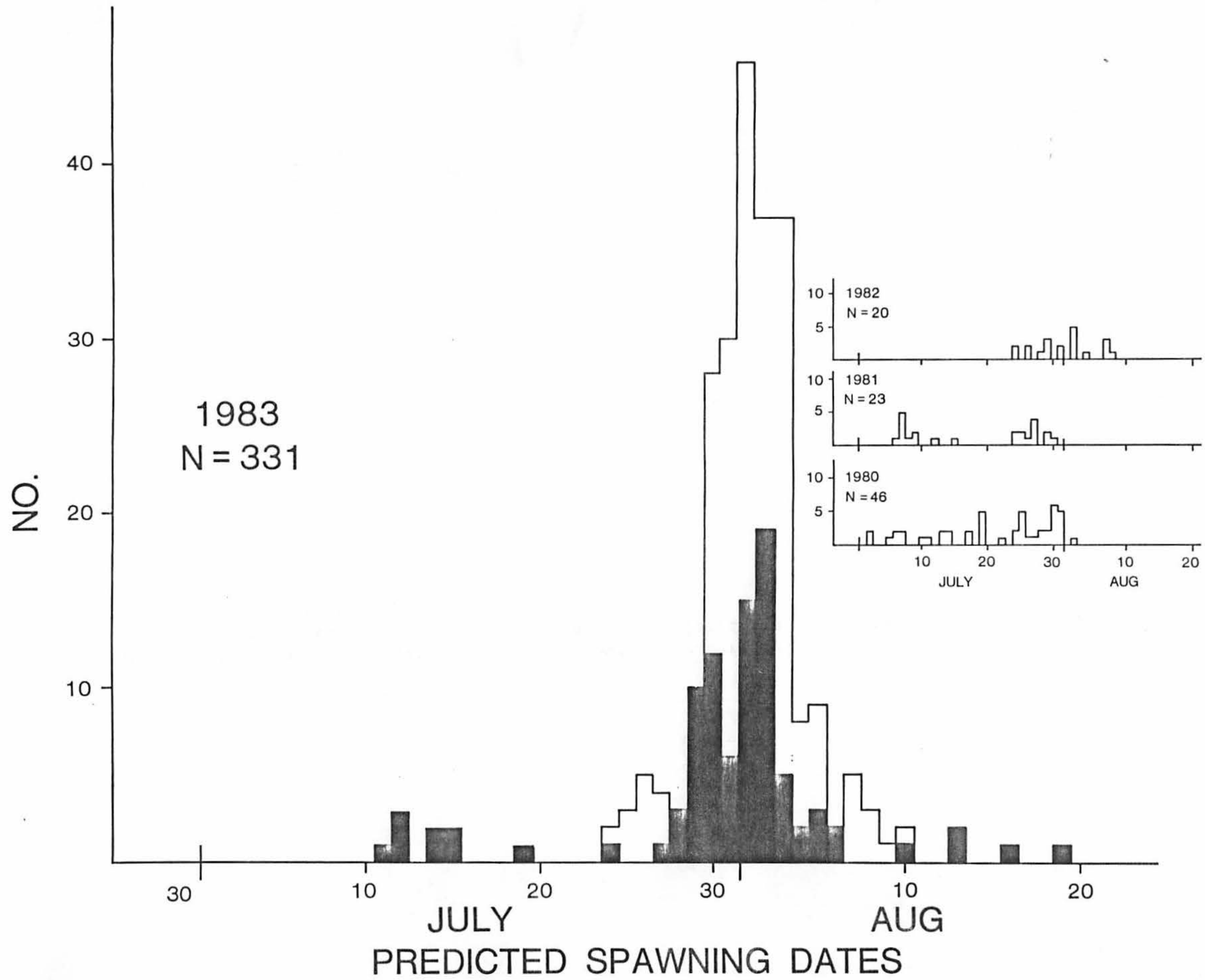
[a]Mean catch of three nets set for 1-2 hrs at each sampling time; day = combined sunrise and noon samples, and night = combined sunset and midnight samples

Table 16. Approximate diel abundance ratios[a] for drift net-collected Colorado squawfish larvae, Yampa and Green rivers, Colorado, 1983-1984.

Year	Site	Developmental phase	Sunrise:Noon:Sunset:Midnight	Day:Night
1983	Box Elder (Yampa)	Peak protolarvae	1:11:2:9	1:1
		Mean total proto.	1: 8:4:7	1:1
		Peak mesolarvae	9: 1:3:9	1:1
		Mean total meso.	3: 1:1:3	1:1
		Peak total	2: 2:1:3	1:1
		Mean Total	1: 1:1:2	1:1
1984	Box Elder (Yampa)	Peak protolarvae	13: 3:3:1	4:1
		Mean total proto.	5: 3:2:1	3:1
		Peak total	13: 3:3:1	4:1
		Mean total	4: 2:1:1	3:1
1984	State Line (Green)	Mean total proto.	5: 6:2:1	5:1
		Peak total	2: 2:1:1	2:1
		Mean total	5: 5:1:1	5:1

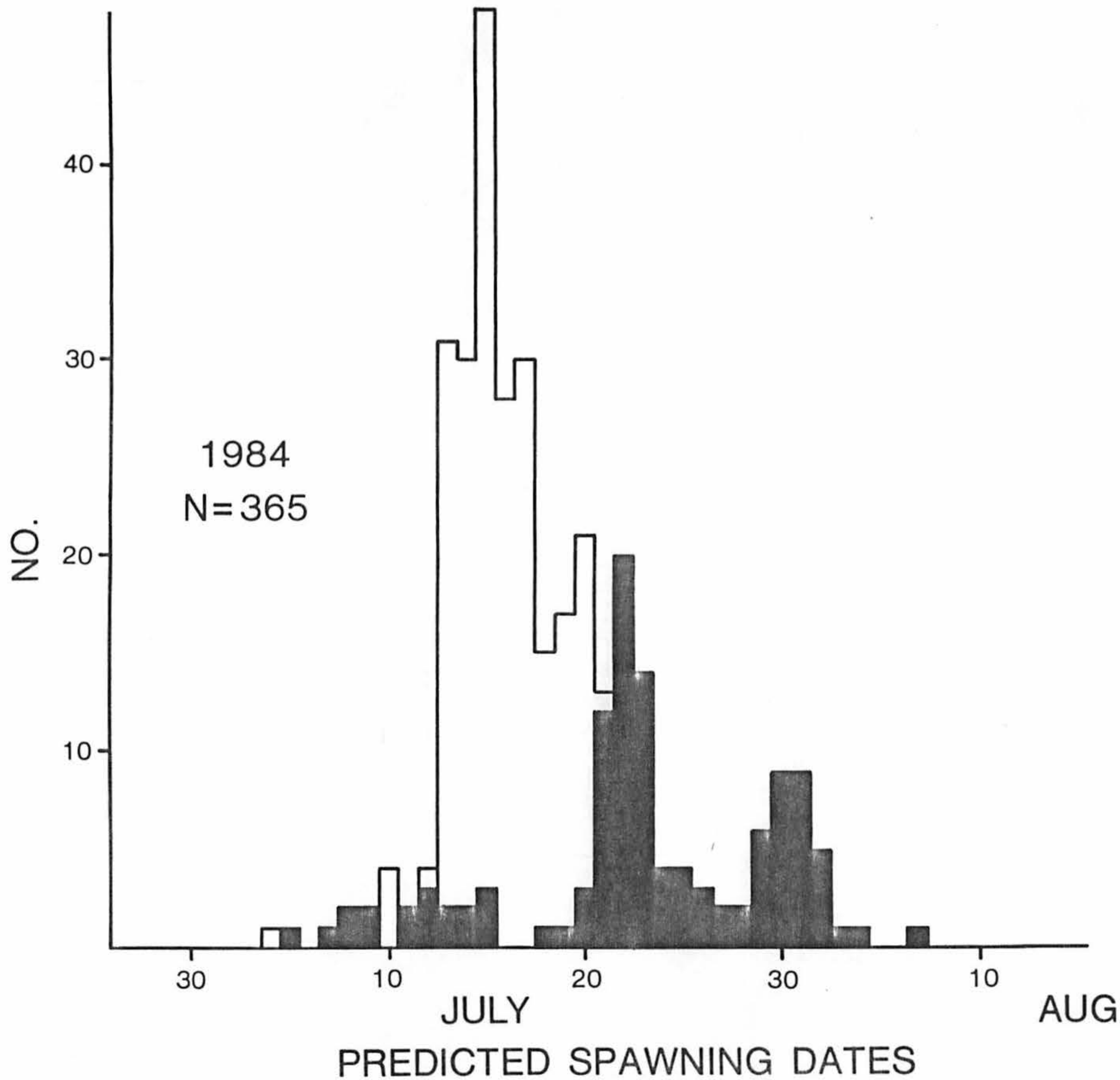
[a]Derived from densities (numbers per 1000 m^3); mean catch of three nets set for 1-2 hrs at each sampling time (day = combined sunrise and noon samples, and night = combined sunset and midnight samples).

Figure 4. Distribution of larval Colorado squawfish numbers collected by seine (open bars) and drift-net (darkened bars) according to predicted spawning dates for 1980-1983 at the Yampa River study area.



NO.
40
30
20
10
1983
N = 331
30
10
20
30
10
20
JULY
AUG
PREDICTED SPAWNING DATES
1982
N = 20
1981
N = 23
1980
N = 46
10
5
10
20
30
10
20
JULY
AUG

Figure 5. Distribution of larval Colorado squawfish numbers collected by seine (open bars) and drift-net (darkened bars) according to predicted spawning dates for 1984 at the Yampa River study area.



40
30
20
10
NO.
1984
N=365
30
10
20
30
10
JULY
AUG
PREDICTED SPAWNING DATES

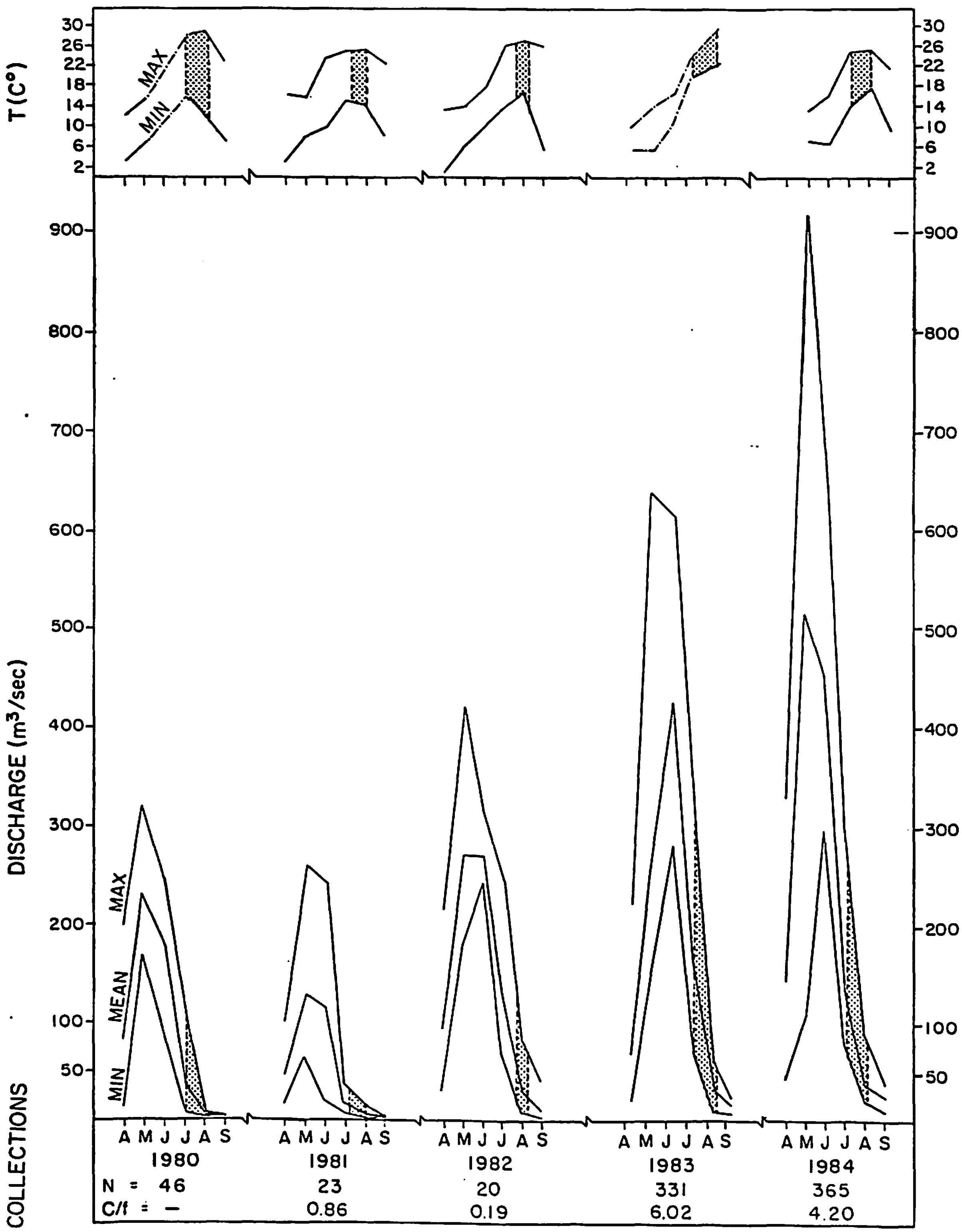
Table 17. Catches (all sampling gear combined) of Colorado squawfish young-of-the-year (YOY) in the Yampa River, Colorado, 1980-1984.

Year	Number of YOY collected	Size (mm TL) of YOY collected	Location (river km) of YOY collections[a]	Estimated Colorado squawfish spawning dates[b]
1980	46	14.0-29.0	0.2-13.9	7/02-8/08
1981	23	9.0-22.0	0.2-28.8	7/06-30
1982	20	9.9-21.0	0.5-19.6	7/24-8/08
1983	331	7.3-16.6	1.1-32.5	7/11-8/19
1984	338[c]	7.2-15.1	0.2-25.4	7/04-8/06

[a]Distance from Yampa River mouth (river km 0)
[b]Derived from back-calculated age estimates of YOY
[c]Does not include 27 larvae collected in drift-nets at State Line (Green River)

As in the Colorado River, Colorado squawfish spawning in the lower Yampa River coincided with times of decreasing flow and rising water temperature (Fig. 6 and Table 5). Spawning in 1980 was estimated to have begun as early as 2 July (Table 17) and ceased on or about 8 August. During that period, maximum flow ranged from 111 to 8.5 m^3/sec and maximum mainchannel water temperature ranged from 21.5 to 25-29 C, respectively. In the low flow year of 1981, the estimated spawning period was from 6 July to 30 July; maximum flow ranged from 30 to 10 m^3/sec, and maximum mainchannel water temperature ranged from 22 to 25 C, respectively. Maximum flow in 1982 was somewhat greater than the previous year and ranged from 74 to 43 m^3/sec during the estimated 24 July-8 August spawning period. Maximum mainchannel water temperature during that period was 26 C. In 1983, the estimated spawning period was 11 July-19 August. Maximum flow during that period ranged from 214 to 29 m^3/sec and maximum mainchannel water temperature ranged from 17.5 to 24.0 C, respectively. Mean water temperature ranged from 22 to 25 C during peak spawning activity in 1983. In 1984, maximum flow on the earliest estimated spawning date (4 July) exceeded 200 m^3/sec and was about 40 m^3/sec when spawning apparently ceased (6 August). Maximum mainchannel water temperature during that period ranged from 19 to 22 C, respectively. During peak spawning (13-23 July), mean water temperature ranged from 22 to 23 C, respectively.

Figure 6. Relationships of estimated Colorado squawfish spawning periods with flows and temperatures in the Yampa River study area, 1980-1984. Stippled areas denote spawning periods. Time period for each year is April-September. N = number of larval squawfish collected. C/f = catch/effort associated with N.


T (C°)
MAX
MIN
30
26
22
18
14
10
6
2
DISCHARGE (m³/sec)
900
800
700
600
500
400
300
200
100
50
MAX
MEAN
MIN
COLLECTIONS
A M J J A S
1980
1981
1982
1983
1984
N = 46
23
20
331
365
C/f = —
0.86
0.19
6.02
4.20

DISCUSSION AND CONCLUSIONS

Based on these results and complementary studies (e.g., Tyus et al. 1981; Wick et al. 1983; Tyus 1984a, 1984b; Tyus and McAda 1984), Colorado squawfish reproduction in Colorado appears restricted to reaches of the mainstem Colorado River (Mesa Co.) and lower Yampa River (Moffat Co.). In the Colorado River, spawning occurs above the Colorado-Utah state line to Clifton (L. Kaeding, CRFP, pers. comm.); however, captures of ripe adults and YOY collections have failed to definitively identify spawning sites and more work is needed. Colorado squawfish spawning in the Yampa River is apparently largely restricted to the lowermost 32 km of Yampa Canyon in DNM (i.e., Harding Hole to Yampa-Green River confluence); the majority of ripe adult fish generally congregate at river km 26-32 (Haynes and Bennett, in press). However, the drift-net collection of one larval Colorado squawfish at Harding Hole in 1983 established that at least limited spawning occurred above this site.

During this study, Colorado squawfish spawning in both rivers was estimated to have begun in early-late July and typically extended to late July through early August. For all years studied in both rivers, spawning coincided with decreasing flow and rapidly rising water temperature; maximum mainchannel water temperature always approximated or exceeded 20 C during spawning. During 1980-1982 (Yampa River), the numbers of Colorado squawfish YOY collected were too low to make realistic evaluations relative to spawning "intensity"; however, estimated spawning dates for 1983 and 1984 revealed that while limited spawning occurred as early as 11 July and 4 July, respectively (mean water temperature=18-20 C, both dates), a peak in spawning activity occurred between 25 July-10 August (1983) and 13-23 July (1984) with mean water temperatures of 22-25 C and 22-23 C, respectively. Hamman (1981) reported an optimum spawning temperature range of 20-22 C under hatchery conditions. The 1983 estimated peak in spawning activity coincided closely with dates when radio-tagged adult fish were active over the spawning areas (H. Tyus, CRFP, pers. comm).

The roles played by water temperature and flow in streams in influencing fish reproduction and larval production/survival are inseparable, with flow exerting a deterministic effect on water temperature. Water temperature has been documented as an important, influencing factor for several aspects of fish ecology including movement and spawning (Nikolsky 1963; De Vlaming 1972). Spawning commences at a particular water temperature and may continue as long as that temperature is maintained. For example, Beamesderfer and Bjornn (1980) observed that peak spawning of northern squawfish (*Ptychocheilus oregonensis*) in Idaho coincided with water temperature of 10-15 C and spawning ceased at 16-18 C. They also observed a reduction in spawning activity following a storm-induced water temperature decline of approximately 5 C. This latter observation suggests that water temperature is an important, regulating factor in *Ptychocheilus* reproduction. Flow exerts a profound influence on fish life cycles and habitats (Nikolsky 1963). For example, flow is important in regulation of the areal extent and preparation/maintenance of spawning and nursery areas, and influences the extent and pattern (spatial and temporal) of larval fish dispersion from spawning areas. Depending on the mode of reproduction (e.g., lithophilic or pelagophilic), several studies have reported variable responses of year-class strength of riverine fishes to variations in discharge (Turner and Chadwick

1972; Stevens 1977; Newcombe 1981, Yermakhanov and Rasulov 1983; Stevens and Miller 1983; Crecco and Savoy 1984). Facultative riverine species frequently exhibited an inverse relationship between year-class strength and flow during spawning and hatching, while a direct relationship was often the case for obligate riverine species.

Overall, for the years of observation, larval Colorado squawfish production (as measured by C/f) appeared to have been greater in the lower Yampa River than in the Colorado River. In the Colorado River, C/f values were quite low each year during 1981-83, making definitive assessment of yearly differences in larval production virtually impossible. However, trends were noted. In 1982 (highest C/f), the flow regime approximated an "average flow" year and the number of 20+ degree C days was 84. The earliest estimated spawning date was 7 July. In contrast, flow in 1981 (lowest C/f) was extremely low, while flow in 1983 was high. For 1981 and 1983, the number of 20+ degree C days were 83+ and 59 and the earliest estimated spawning dates were 3 July and 27 July, respectively. Hypothetically, in 1981, low flow reduced the areal extent and/or quality of suitable spawning and nursery habitats; hence, supressing spawning and/or larval survival. In 1983, prolonged high flow (513 m^3/sec on earliest estimated spawning date) had a negative effect on larval production and/or survival through suppression of the thermal regime. In the Yampa River, C/f values suggested that larval Colorado squawfish production was greatest in 1983 and 1984 (both high flow years). Interestingly, although flow during those 2 years was substantially greater than in 1981 and 1982 (7-20 times greater in 1983), heat accumulation (in terms of summed 20+ degree C days) in 1983 and 1984 were comparable with 1982. Number of 20+ degree C days in 1983 and 1984 were 65 and 67, respectively, compared to 71 in 1982. In 1981, number of 20+ degree C days was 92, but was associated with very low flows. It would seem that relatively high flow in the Yampa River has a positive influence on spawning, possibly via increasing the areal extent and/or quality of suitable spawning sites, provided that rapid heat accumulation occurs with flow reduction and adequate water temperatures for spawning exist for a sufficient time period. Results from both rivers suggest an optimum range of flows exist that provides the best quantity and quality of spawning habitat as well as an optimal number of degree days for egg incubation and production of larvae. A lower range of flows provide an adequate thermal regime but only marginal spawning habitat. A higher range of flows provide suitable spawning habitat but an inadequate thermal regime. The data suggest the Colorado River has demonstrated both extremes, while the Yampa River has demonstrated only the low flow case. It should also be noted that "high" flows on the Yampa River would describe "average" flows on the Colorado River. Tyus (1985) suggested that large, long-lived riverine species like the Colorado squawfish may have developed a life strategy which relies on the production of large numbers of offspring during wet years. The Yampa River results appear to support this hypothesis, but documentation of the relative contribution of larval production to year-class strength during wet and dry years in either river would better substantiate it.

Unquestionably, dispersion of larval Colorado squawfish occurs via downstream transport. There are several possible reasons why stream fish larvae tend to be displaced or transported downstream, either by passive drift or active dispersal. Hoar (1953), Northcote (1962), and Lindsey and

Northcote (1962) suggested that during times of low light intensity (at night or during periods of high turbidity), fish larvae lose their rheotactic orientation (orientation to a current of water) because of reduced visual orientation and are displaced, usually passively, downstream. Pavlov et al. (1968, 1972) and Girsa (1969) observed that rheotactic disorientation is especially evident in the early larval phases, i.e., protolarvae and mesolarvae. They reported that in early larval teleosts, visual orientation is the only rheotropic mechanism operating and as light intensity decreases, there is a concomitant decrease in the critical velocity at which fish larvae can maintain position in a stream. Conversely, as fish larvae develop, tactile orientation mechanisms begin to function and the importance of visual orientation decreases, hence, rheotropism is possible at reduced light intensities. Further, the ability of fish larvae to maintain position in a stream is directly related to body size and musculature/fin development, hence, smaller individuals exhibit a greater tendency to drift than larger, more developed fish. These observations could explain the observed differences in size (TL) of Colorado squawfish YOY collected in drift-nets versus seines. Only protolarvae and early mesolarvae were collected in drift-nets (size range = 7.2-9.3 mm TL), while larger individuals were collected in seine samples (size range = 8.1-29.0 mm TL).

For some fish, downstream transport of their larvae might be related to feeding habits. Muller (1978) and Armstrong and Brown (1983) hypothesized that fish larvae drift either as a means to obtain food (i.e., maintain association with high densities of drifting food organisms) or as a consequence of feeding (i.e., fish larvae emerge from the substrate to feed and are swept downstream). They and Clark and Pearson (1980) also suggested that downstream transport of fish larvae might be associated with strategies for reducing predator pressure. Gale and Mohr (1978) speculated that drifting fish larvae (especially at night) resemble bits of floating debris; as such they probably are not readily detected by sight-feeding predators.

Finally, Frank and Leggett (1982, 1983), working with capelin larvae (Mallotus villosus) and using ideas in Harper et al. (1961) based on work with plant communities, developed the "safe site" concept as rationale for why fish larvae disperse downstream. "Safe sites" were defined as special areas which provided necessary resources and enhanced individual survival; these areas had high food densities and reduced predation/competition pressures. They reported that depending upon the proximity of "safe sites" to spawning areas, two dispersal strategies were possible: (1) if the probability of finding suitable habitat at a distance from the spawning site was high, then fish larvae were transported downstream into these nursery areas: (2) if the probability of finding suitable habitat locally was high, then the magnitude of larval fish drift was reduced and larvae were retained at or near the spawning area. Nikolsky (1963), Priegal (1970), and Gale and Mohr (1978) observed that a larval drift-dispersal strategy is frequently incorporated into the life cycle of riverine fishes as a means of placing young in adequate nursery/feeding areas.

Tyus (pers. comm.) has reported the collection of larval and juvenile Colorado squawfish from Green River (Utah) backwaters below the Yampa confluence, and it is presumed that some of these individuals originated in the lower Yampa River since no confirmed upstream spawning areas in the Green

River above the White River confluence have been documented. Only one Colorado squawfish juvenile has been collected by any means in Yampa Canyon since initiation of the Yampa River studies. Thus, larvae originating in the Yampa River appear to be transported downstream to nursery areas in the Green River. Colorado squawfish larvae deposited in ephemeral, easily isolated, low-velocity shoreline habitats via passive drifting in the Yampa River are most likely subjected to predation, competition, heating, desiccation, and in winter, freezing. It is difficult to envision very many advantages for embryo-like, non-feeding early larvae to be placed in such habitats. Hypothetically, these larvae may be retained in these habitats and become isolated once water levels drop, or they may move back into the mainchannel and actively disperse downstream. The inference here is that it is advantageous for Colorado squawfish larvae to be rapidly transported out of Yampa Canyon to more stable or favorable environmental conditions in Utah's upper Green River (Haynes and Muth, in prep.).

Lack of significant diel periodicity in drift collections of Yampa squawfish larvae may be attributed to the turbid water quality in the river, but it is evident from other studies (Muth and Schmulbach 1984; Pavlov et al. 1977) that these results do not adequately account for several environmental variables that can influence drift behavior in Colorado squawfish larvae. Hopefully, continued drift studies in the lower Yampa Yampa River will provide additional insight into this phenomenon. It should be further verified that the lack of diel periodicity in drifting squawfish larvae is common or characteristic before a reliable methodology for monitoring larval production can be implemented. Evidence from the Soviet Union suggests that cyprinids may exhibit diurnal periodicity in clear rivers but the same species may drift around the clock in rivers of low transparency (Pavolv et al. 1977). If this is the case for Colorado squawfish, it would require alterations in drift monitoring methods depending on the flow year in question.

Results from this study further suggest that in 1983 and 1984 (especially in the Yampa River), spawning and larval production of most non-native species were suppressed, with channel catfish being the exception. Perhaps high flows such as those of 1983-1984 enhance conditions for spawning of native species, while at the same time suppressing spawning success of non-native species.

SUMMARY

Prior to 1979, it was uncertain if Colorado squawfish had ever spawned in Colorado. Since then complementary CDOW and CRFP studies have documented that sections of the Colorado and Yampa rivers, Colorado, are used by the species for spawning and flow and water temperature variables affect overall "success" between rivers and within a given river on an annual basis. It is reasonable to suggest that Colorado squawfish reproduction is generally enhanced by "high" late spring flow accompanied by rapid heat accumulation in the river. These conditions provide high quantity/quality spawning areas and satisfactory incubation and/or growth conditions for squawfish eggs and larvae, and at the same time may serve to suppress non-native fishes' reproductive success. It would appear that 1981 flow in the Colorado River, as well as the 1983 thermal flow regime, was inadequate. Conversely, it would appear that the 1983 and 1984 flow/water temperature regimes in the Yampa River provide a first approximation of "optimal" reproductive conditions for the species.

With regard to this study's objectives, these results do not definitely delimit the reproductive range of Colorado squawfish in either the Yampa or Colorado river. The data do strongly support the conclusion that the lower 32-km reach of the Yampa is the primary reproductive range. Time and manpower limitations during the spawning season prevented extension of sampling efforts in either river. This study only addressed the influence of two factors—flow and water temperature—upon Colorado squawfish reproduction and recruitment. Considering water temperature and flow, the results here provide a preliminary definition of the optimum range of temperature/flow required by Colorado squawfish using the Yampa River for spawning. The data also answer questions regarding recruitment via documented drift dispersal and lack of juvenile squawfish in seine samples in Yampa Canyon. The relationship between temperature/flow and Colorado squawfish reproduction/recruitment as demonstrated by results for the Colorado River are very much less apparent. Recommendations for future research provided in the following section indicate the preliminary status of knowledge concerning the early life history dynamics of Colorado squawfish in these rivers, and suggest areas of refinement.

It will be necessary to conduct additional research to address questions raised by this study as well as confirm relationships suggested by the data. These steps will be necessary to effectively ascertain if recovery objectives for the Colorado squawfish are (or can be) achieved. This particular research effort was too brief to permit evaluation of other ecological factors which are potentially critical to the population dynamics of Colorado squawfish such as sources of larval squawfish mortality that affect recruitment to the fall population of juveniles in the Green River nursery areas.

FUTURE RESEARCH/MANAGEMENT IMPLICATIONS

The following list of questions suggests future research objectives. The list is largely limited to early life history research and not ranked according to priorities.

1. What is "recovery" for the Colorado squawfish? If recovery is defined in terms of a specified number of self-sustaining subpopulations, what is "self-sustaining"? Is it necessary that the species reproduce every year throughout its range to be self-sustaining, or for recovery to be realized?

2. Can we effectively monitor population dynamics for the species? Can larval production, when measured by relative abundance indices from seine hauls or drift-net sampling be used as a monitoring tool? The results here appear positive, but these methods will require closer scrutiny relative to sources and magnitudes of error. It must be recognized that C/f methodologies do not lend themselves well to application in an open system like the upper Colorado River Basin and results can be misleading.

3. Is there a quantifiable and predictable relationship between flow/ temperature and larval production? Can this relationship be artificially manipulated?

4. Do high spring flows suppress spawning of non-native species while enhancing Colorado squawfish spawning and production? If so, can this knowledge be incorporated into management of a basin-wide water budget for the enhancement of native species?

5. At what life stage do we monitor (census) the species in the upper basin? Can carefully timed drift collections be used as economically efficient monitors of larval production? Are Colorado squawfish larvae truly aperiodic in their drift patterns?

6. Can releases from Flaming Gorge Dam (Green River) be regulated to enhance survival of Colorado squawfish larvae and benefit their dispersion to Green River nursery areas?

7. Are present sampling methods adequate to evaluate recruitment of Yampa River spawned Colorado squawfish larvae to the upper Green River (see Jones and Tyus 1985)? It is conceivable that during high flow years, Yampa River larvae may arrive in higher numbers at upper Green Riveer nursery areas but present sampling techniques would not quantify this, particularly if larvae drift past the particular backwaters being studied.

8. Is artificial propagation and stocking a meaningful tool for enhancing squawfish populations? Although culture of Colorado squawfish is relatively straightforward (Toney 1974 and Hamman 1981), will survival of a sufficient number of stocked young be possible? Would it be appropriate to release larger individuals and limit stocking to historic habitats where spawning has not been documented (e.g., Gunnison, White, and Dolores rivers) and manage for natural recruitment in areas where spawning has been confirmed?

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LITERATURE CITED

Armstrong, M.L., and A.V. Brown. 1983. Diel drift and feeding of channel catfish alevins in the Illinois River, Arkansas. Trans. Amer. Fish. Soc. 112:302-307.

Beamesderfer, R.C., and T.C. Bjornn. 1980. Habitat selection, spawning behavior, and early life history of northern squawfish with inferences to Colorado squawfish. Idaho Coop. Fish. Res. Unit., Univ. Idaho, Moscow. Prog. Rep. to Colo. River Fish. Proj., U.S. Fish and Wildl. Serv., Salt Lake City, Utah. (mimeo).

Caughley, G. 1978. Analysis of vertebrate populations. John Wiley and Sons, Ltd., New York, N.Y. 234 pp.

Clark, A.L., and W.D. Pearson. 1980. Diurnal variations in ichthyoplankton densities at Ohio River Mile 571. Trans. Kentucky Acad. Sci. 41:116-121.

Crecco, V.A., and T.F. Savoy. 1984. Effects of fluctuations in hydrographic conditions on year-class strength of American shad (Alosa sapidissima) in the Connecticut River. Can. J. Fish. Aquat. Sci. 41:1216-1223.

De Vlaming, V. L. 1972. Environmental control of teleost reproductive cycles: A brief review. J. Fish. Biol. 4:131-140.

Faber, D.J. 1968. A net for catching limnetic fry. Trans. Amer. Fish. Soc. 97:61-63.

Frank, K., and W. Leggett. 1982. Coastal water mass replacement: its effect on zooplankton dynamics and the predator-prey complex associated with larval capelin (Mallotus villosus). Can. J. Fish. and Aquat. Sci. 39:991-1003.

Frank, K., and W. Leggett. 1983. Multispecies larval fish associations: accident or adaptation? Can. J. Fish. and Aquat. Sci. 40:754-762.

Gale, W.F., and H.W. Mohr. 1978. Larval fish drift in a large river with a comparison of sampling methods. Trans. Amer. Fish. Soc. 107:46-55.

Girsa, I. 1969. Reaction to light in some freshwater fishes in the course of early development and in altered physiological states. J. Ichthyol. 9:126-135.

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

Harper, J., J. Clatworthy, I. McNaughton, and G. Sagar. 1961. The evolution and ecology of closely related species living in the same area. Evolution 15:209-227.

Haynes, C.M., and J.R. Bennett. In press. The relationship between the preservation of wilderness values and endangered species: a case study from the Upper Colorado River Basin, U.S.A. Proc. Nat. Wilder. Res. Conf., Colo. State Univ., Fort Collins, 23-26 July.

Haynes, C.M., and R. T. Muth. 1982. Identification of habitat requirements and limiting factors for Colorado squawfish and humpback chubs. Job Prog. Rep., Fed. Aid Proj. SE-3-4, Work Plan 1, Job 1. 43pp.

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.

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. Southwest. Nat. 29(1):21-33.

Haynes, C.M., R.T. Muth, and G.T. Skiba. 1983. Identification of habitat requirements and limiting factors for Colorado squawfish and humpback chubs. Prog. Rep., Fed. Aid Proj. SE-3, Work Plan 1, Job 1. 19pp.

Hoar, W.S. 1953. Control and timing of fish migration. Biological Review 28:437-452.

Holden, P.B. 1973. Distribution, abundance, and life history of the fishes of the Upper Colorado River Basin. Ph.D. diss. Utah State Univ., Logan. 59pp.

Jones, R.L., and H.M. Tyus. 1985. Recruitment of Colorado squawfish in the Green River Basin, Colorado and Utah, 1979-1984. Colo. River Fish. Proj., Vernal, Utah. Prepared for Endangered Species Office, U.S. Fish and Wildl. Serv., Denver, Colo., April 5. 24pp. (mimeo).

Lackey, R.T., and W.A. Hubert. 1978. Analysis of exploited fish populations Rep. VPI-SG-76-04, Sea Grant, Va. Poly. Inst., and State Univ., Blacksburg, Virginia. 97pp.

Lindsey, C., and T. Northcote. 1963. Life history of redside shiner, Richardsonius balteatus, with particular reference to movements in and out of Sixteenmile Lake streams. J. Fish. Res. Bd. Can. 20:1001-1029.

Muller, K. 1978. Locomotor activity of fish and environmental oscillations. Pp 1-19 in J.E. Thorpe (ed.) Rhythmic activity of fishes. Academic Press, New York, N.Y.

Muth, R.T., C.M. Haynes, and C.A. Carlson. 1985. Culture of roundtail chub, Gila robusta (Cyprinidae) through the larval period. Southwest. Nat. 30(1):152-154.

Muth, R.T., and J.C. Schmulbach. 1984. Downstream transport of fish larvae in a shallow prairie river. Trans. Amer. Fish. Soc. 113:224-230.

Newcombe, C. 1981. A procedure to estimate changes in fish populations caused by stream discharge. Trans. Amer. Fish. Soc. 110:382-390.

Nikolsky, G.V. 1963. The ecology of fishes. Academic Press, New York, N.Y. 352 pp.

Northcote, R.G. 1962. Migratory behavior of juvenile rainbow trout, Salmo gairdneri, in outlet and inlet streams of Loon Lake, British Columbia. J. Fish. Res. Bd. Can. 19:201-270.

Pavlov, D.S., A.M. Pakhorukov, G.N. Kuragina, V.K. Nezdoliy, N.P. Nekrasova, D.A. Brodskiy, and A.L. Ersler. 1977. Some features of the downstream migrations of juvenile fishes in the Volga and Kuban Rivers. J. Ichthyol. 792-363-374.

Pavlov, D., Yu. Sbikin, and A. Mochek. 1968. The effect of illumination in running water on the speed of fishes in relation to features of the orientation. J. Ichthyol. 8:250-255.

Pavlov, D., Yu. Sbikin, A. Vashchinnikov, and A. Mochek. 1972. The effect of light intensity and water temperature on the current velocities critical to fish. J. Ichthyol. 12:703-711.

Priegel, G. 1970. Reproduction and early life history of the walleye in the Lake Winnebago region. Wisc. Dept. Nat. Res. Tech. Bull. 45. 105pp.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Bd. Can. 191:382.

Seethaler, K. 1978. Life history and ecology of the Colorado squawfish (Ptychocheilus lucius) in the Upper Colorado River Basin. M.S. Thesis, Utah State Univ., Logan. 156pp.

Snyder, D.E. 1976. Terminologies for intervals of larval fish development. U.S. Fish and Wildl. Serv. Biol. Serv. Program, FWS/OBS-76/23:41-58

Stevens, D.E. 1977. Striped bass (Morone saxatilis) year class strength in relation to river flow in the Sacramento-San Joaquin Estuary, California. Trans. Amer. Fish. Soc. 106(1):34-42.

Stevens, D.E., and L.W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin River system. N. Amer. J. Fish. Manage. 3:425-437.

Southwood, T.R.E. 1978. Ecological methods with particular reference to the study of insect populations. Chapman and Hall Publ., New York, N.Y. 524pp.

Tanner, J.T. 1978. Guide to the study of animal populations. Univ. Tenn. Press. Knoxville, Tenn. 186pp.

Toney, D.P. 1974. Observations on the propagation and rearing of two endangered fish species in a hatchery environment. Proc. Wst. Assoc. State Game and Fish Comm. 54:252-259.

Tranter, D.J., and P.E. Smith. 1968. Filtration performance. Pp 27-56 in D.J. Tranter (ed.) Zooplankton sampling. UNESCO Press, Paris, France.

Turner, J.L., and H.K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, Morone saxatilis, in relation to the river flow in the Sacramento-San Joaquin Estuary. Trans. Amer. Fish. Soc. 101(3):442-452.

Tyus, H.M. 1984a. Loss of stream passage as a factor in the decline of the endangered Colorado squawfish. Pp 138-144 in Issues and technology in the management of impacted western wildlife: Proc. of a national symposium. Thorne Ecol. Inst. Tech. Publ. No. 14. Boulder, Colo.

Tyus, H.M. 1984b. Life strategies in the evolution of the Colorado squawfish (Ptychocheilus lucius). Paper presented at Utah's Water-Biolog. Symp., Sept. 21. Utah State Univ., Logan, Utah.

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

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. Southwest. Nat. 29:289-299.

Tyus, H.M., C.W. McAda, and B.D. Burdick. 1981. Radiotelemetry of Colorado squawfish and razorback sucker, Green River system of Utah, 1980. Trans. Bonneville Chap. Amer. Fish. Soc. 19-24.

Vanicek, C.D. 1967. Ecological studies of native Green River fishes below Flaming Gorge Dam, 1964-66. M.S. Thesis, Utah State Univ. Logan, Utah. 125pp.

Wick, E.J., D.L. Stoneburner, and J.A. Hawkins. 1983. Observations on the ecology of Colorado squawfish, Ptychocheilus lucius, in the Yampa River, Colorado, 1982. Nat. Park. Serv., Water Res. Field Support Lab Rep. 87-7, Colo. Div. Wildl. Endang. Wildl. Invest. SE-3-5. 55pp.

Yermakhanov, Z., and A.Kh. Rasulov. 1983. Analysis of spawning population and characteristics of the "Aral asp", Aspius aspius iblioides (Cyprinidae), from the lower reaches of the Syr Darya' River. J. Ichthyol. 23(6):39-47.

PUBLICATIONS, POPULAR ARTICLES, AND PAPERS

PRESENTED AS A RESULT OF THIS PROJECT

Haynes, C.M. 1980. Endangered humpback chub range extension documented. Endang. Species Tech. Bull. 5(10):35.

Haynes, C.M., and J.R. Bennett. 1985. The relationship between the preservation of wilderness values and endangered species: A case study from the Upper Colorado River Basin, U.S.A. Proc. Nat. Wildl. Res. Conf., Colo. State Univ., Ft. Collins, 23-26 July.

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. Southwest. Nat. 29(1):21-33.

Haynes, C.M., and R.T. Muth. 1981. Lordosis in Gila, Yampa River, Colorado. Paper presented at 13th Ann. Symp. Desert Fish. Counc., 19-20 Nov., Death Valley, Calif. (In press).

Haynes, C.M., R.T. Muth, and L.C. Wycoff. 1982. Range extension for the redside shiner, Richardsonius balteatus (Richardson) in the Upper Colorado River. Southwest. Nat. 27(2):223.

Haynes, C.M., and R.T. Muth. 1983. Reproduction of Colorado squawfish, Ptychocheilus lucius, in the Yampa River, Colorado (1980-83). Paper presented at 15th Ann. Symp. Desert Fish. Counc., Death Valley, Calif., 17-19 Nov. (Abstract).

Haynes, C.M., and R.T. Muth. 1983. Overview of early life history research of Upper Colorado Rivr fishes, Utah and Colorado. 7th Ann. Larval Fish. Conf., Amer. Fish. Soc., Colo. State Univ., Ft. Collins, 16-19 Jan.

Haynes, C.M., and R.T. Muth. 1985. Early-life history of the Colorado squawfish (Ptychocheilus lucius Girard) in the Upper Colorado River Basin, Colorado. 20th Ann. Meet., Colo-Wyo Chap., Amer. Fish. Soc., Laramie, Wy., 20-21 March. (Abstract).

Haynes, C.M., and R.T. Muth. 1985. The early life history of Colorado squawfish (Ptychocheilus lucius) in the upper Green-Yampa River system, Colorado and Utah. Paper presented at 1985 Meet. West. Assoc. Fish and Wildl. Agencies and West. Div. Amer. Fish. Soc., Snowmass, Colo., 14-19 July.

Muth, R.T., and C.M. Haynes. 1984. Plexiglass light-trap for collecting small fishes in low-velocity riverine habitats. Prog. Fish-Cult. 46(1):59-62.

Muth, .T., C.M. Haynes, and C.A. Carlson. 1985. Culture of roundtail chub, Gila robusta (Cyprinidae), through the larval period. Southwest. Nat. 30(1):152-154.

Muth, R.T., C.M. Haynes, and C.A. Carlson. 1985. Reproduction and early life-history of the Colorado squawfish, Ptychocheilus lucius, in the Green-Yampa River system, Utah and Colorado: A synthesis of current knowledge. Paper presented at 9th Ann. Larval Fish Conf., Amer. Fish. Soc., Univ. Texas Marine Sci. Inst., Port Aransas, 24-28 Feb. (Abstract).

Muth, R.T., C.M. Haynes, and C.A. Carlson. 1985. Taxonomic identification of larval and early-juvenile Gila native to the upper Colorado River basin. Paper presented at 1985 Meet. West. Assoc. Fish and Wildl. Agencies and West., Div., Amer. Fish. Soc., 14-19 July, Snowmass, Colo.

Muth, R.T., C.M. Haynes, and D.L. Miller. 1983. Ichthyoplankton distributional studies: Diverse sampling strategies in different environments. Paper presented at 7th Ann. Larval Fish Conf., Amer. Fish. Soc., Colo. State Univ., Ft. Collins, 16-19 Jan. (Abstract).

Muth, R.T., and S.P. Platania. 1985. Comparative morphology of the interneural bones of metalarval and early-juvenile razorback sucker (Xyrauchen texanus), bluehead sucker (Catostomus discobolus), and flannelmouth sucker (C. latipinnis) from the upper Colorado River basin. Paper presented at 1985 Meet., West. Assoc. Fish and Wildl. Agencies and West. Div. Amer. Fish. Soc., 14-19 July, Snowmass, Colo.

Tyus, H.M., B.D. Burdick, R.A. Valdez, C.M. Haynes, T.A. Lytle, and C.R. Berry. 1981. Fishes of the upper Colorado River basin: Distribution, abundance, and status. Pp 12-70 in W.H. Miller et al. (eds.) Fishes of the upper Colorado River system: Present and future. Amer. Fish. Soc. Publ. 131pp.

POPULAR ARTICLES;

Haynes, C.M. 1980. Saving Colorado's big-river fish. Colo. Outdoors 29(1):26-29.

Haynes, C.M. 1982. The humpback chub. What good is it? Colo. Outdoors 31(6):30-33.

Haynes, C.M. 1983. The Yampa (a photo essay). Colo. Outdoors 32(4):1-3.

APPENDIX A

Spawning periods of the most commonly collected species, Colorado and Yampa rivers, Colorado, 1981-1983; based on length-frequency analysis of YOY. E, M, L refer generally to early, middle, or late periods during a given month, respectively. Dashed line represents observed spawning season, sold line represents principal spawning period.

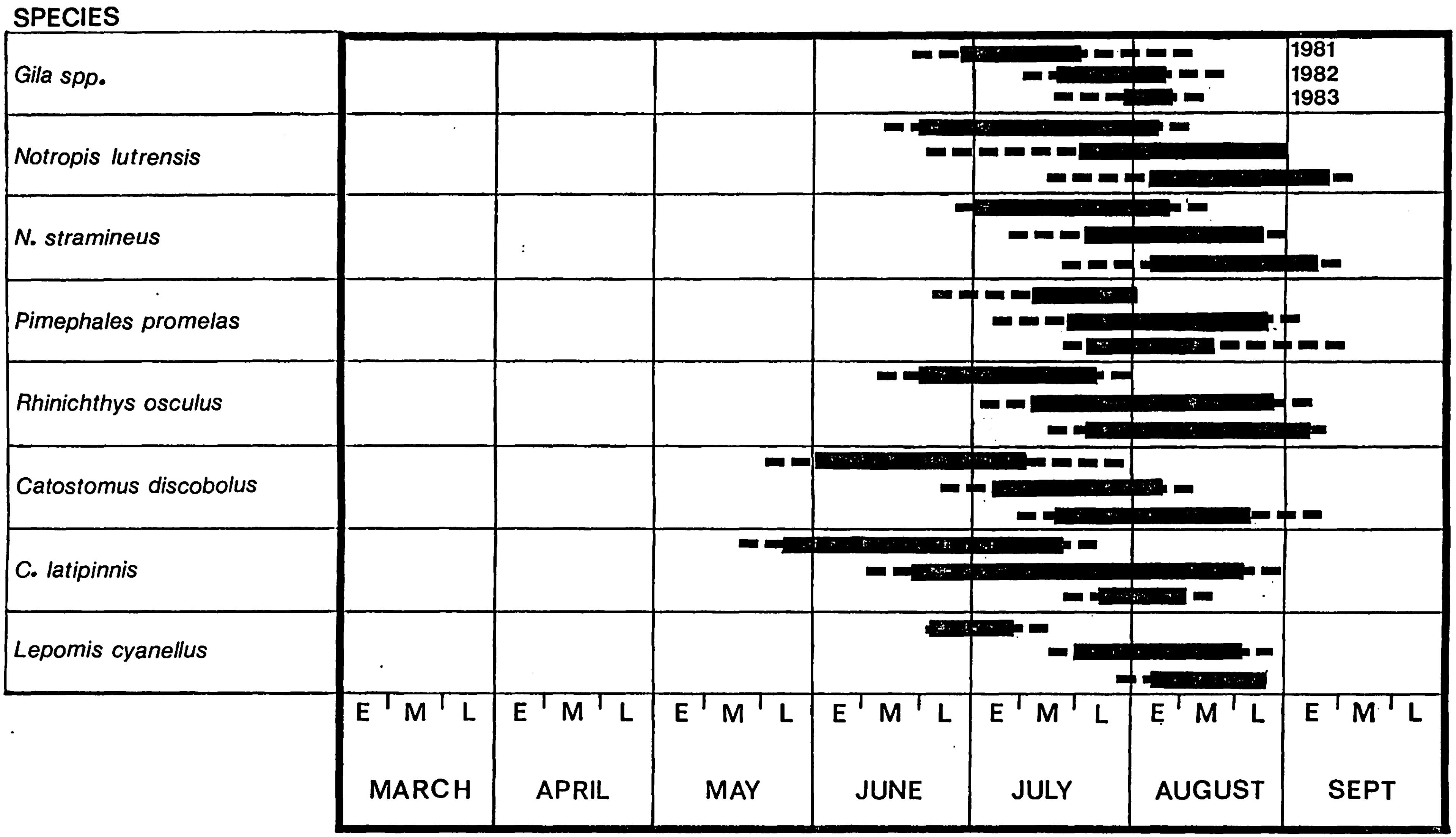

Figure A. Spawning periods of selected species, Colorado River study area, 1981-1983.

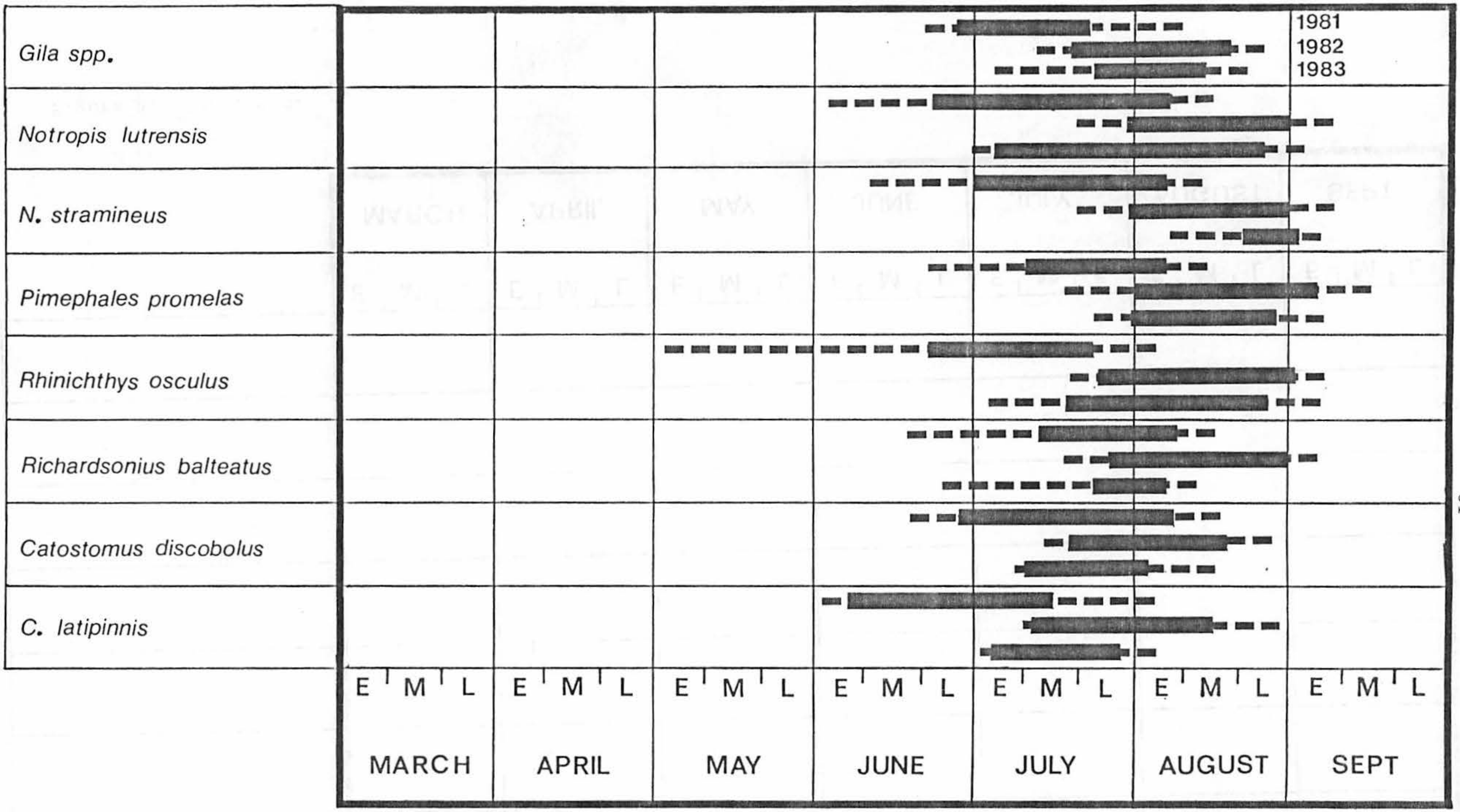

Figure B. Spawning periods of selected species, Yampa River study area, 1981-1983.

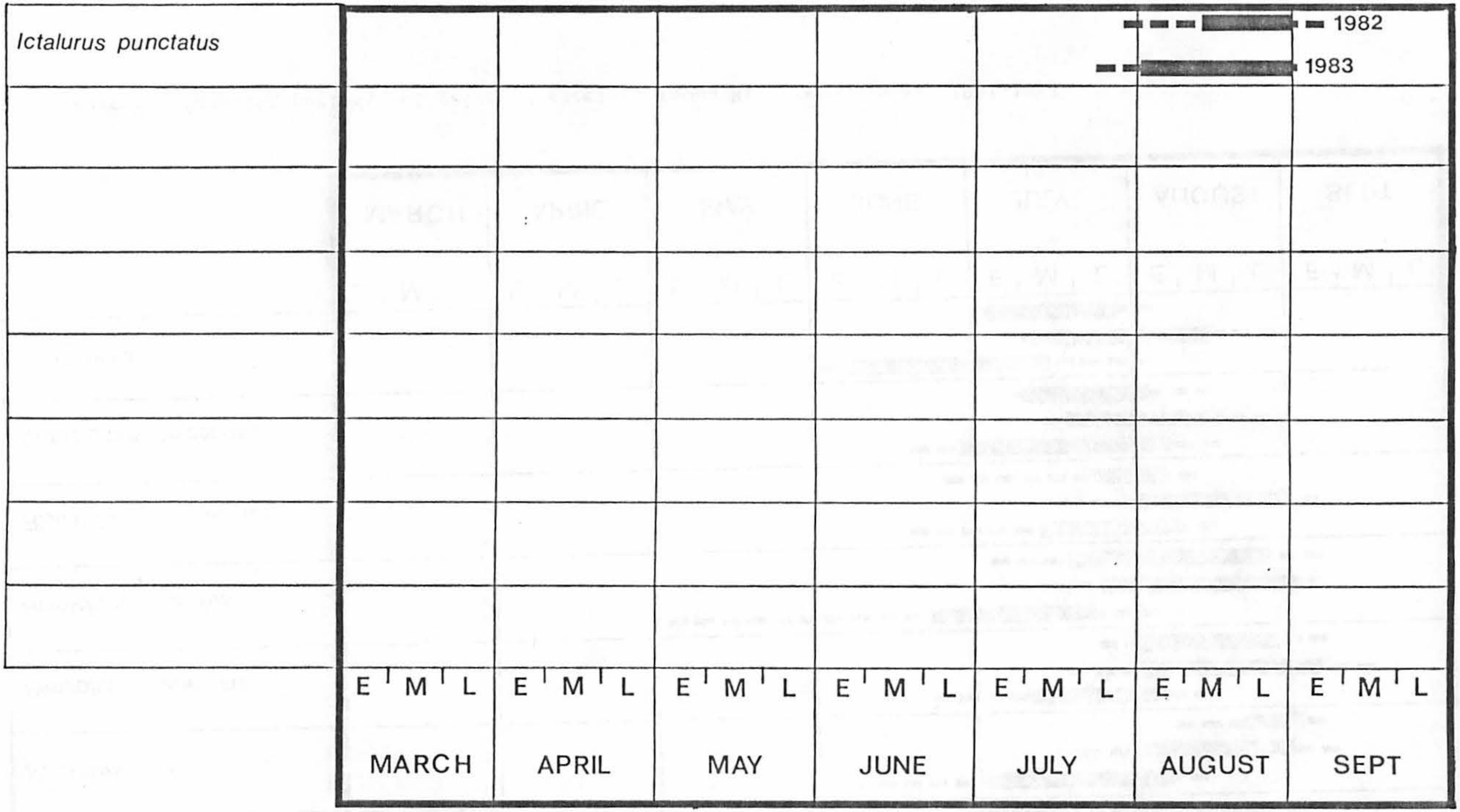

Figure B. Continued.