ASSOCIATIONS AMONG FLOW AND TEMPERATURE REGIMES AND SPAWNING PERIODS AND ABUNDANCE OF YOUNG OF SELECTED FISHES, LOWER YAMPA RIVER, COLORADO, 1980-1984[1]

FINAL REPORT

April 1993

Robert T. Muth
Larval Fish Laboratory, Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, Colorado 80523

and

Thomas P. Nesler
Fish Research Section, Colorado Division of Wildlife, Fort Collins, Colorado 80526

[1]Contribution 58, Colorado State University Larval Fish Laboratory.

EXECUTIVE SUMMARY

Seine and dipnet sampling for small fishes (natives and nonnatives) in low-velocity habitats within five reaches of the lower Yampa River (river km 0.0–94.1) was conducted annually during 1980–1984 by the Colorado Division of Wildlife. Data from each collection were first entered into a MANAGE computer database (during 1985–1986) then transferred to a dBase computer database (during 1998–1990); data included sampling date and location, sampling gear, measured length and width of seine hauls, type and physical characteristics of habitat sampled, and number, size, and life-history period of fish collected.

In this study, we first partitioned the existing database to differentiate between seine-collected age-0 and older fish of each taxon. Two indices of relative abundance, i.e., catch-per-unit-effort (CPUE) and percentage of occurrence (PO), were calculated by river reach and over all reaches (total) per year and by river reach over all years for each age group of eight commonly collected taxa including native *Gila* sp., speckled dace, bluehead sucker, and flannelmouth sucker, and nonnative red shiner, sand shiner, fathead minnow, and redside shiner. Two spawning period parameters, i.e., number of days to initiation of spawning (SPAWN-1) and total number of days in the spawning season (SPAWN-T), were also estimated for each taxon per year. These data were associated with annual spring–summer (April–July) flow and temperature parameters for the lower Yampa River including monthly peak, daily mean, and total discharges and degree-days for five temperature thresholds (12, 14, 16, 18, and 20°C). Preliminary results of this study were previously presented in Nesler (1991).

Annual flow and temperature regimes for April–July varied considerably among the five years studied. Discharge was low in 1981, high in 1983 and especially 1984, and more moderate in 1980 and 1982. Temporal occurrence of annual peak discharge was earliest in 1982 and latest in 1981 and 1983. Rate of decrease in flows following annual peak discharge to near baseline was fastest in 1981, slowest in 1982, and similar among 1980, 1983, and 1984. Annual trends in monthly water-temperature parameters were somewhat predictable given values of corresponding discharge parameters and the shape of yearly hydrographs. Rate of warming per month was fastest in 1981, slowest in 1983, and similar between 1982 and 1984.

Taxon-specific variation in SPAWN-1 and SPAWN-T occurred for both native and nonnative fishes; however, annual spawning periods were mostly consistent among taxa between and within the native and nonnative groups. Variation in total relative abundance of age-0 fish among years differed mostly between the native and nonnative groups. In most years and for most fishes, natives started spawning earlier than nonnatives, and nonnatives ended spawning later than natives. Spawning for both native and nonnative fishes among years started and ended earliest in 1981 and started and ended latest in 1983. Among native fishes in each year, flannelmouth sucker started spawning earliest, and speckled dace ended spawning latest. Among nonnatives in most years, fathead minnow started spawning earliest, and sand shiner ended spawning latest. Highest relative abundance of age-0 fish among native taxa occurred in 1981 for *Gila* sp. and in 1984 for speckled dace, bluehead sucker, and flannelmouth sucker. Lowest relative abundance occurred in 1984 for *Gila* sp., 1982 for speckled dace, and 1981 for bluehead and flannelmouth suckers. Relative abundance of age-0 fish among nonnative species was highest in 1981 and lowest in 1983 or 1984.

Results of this study suggest species- and group-specific (natives versus nonnatives) relationships between timing of spawning and fish abundance and flow and temperature regimes. Earlier initiation of spawning and higher CPUE of age-0 fish for all nonnatives and longer spawning seasons for red shiner, sand shiner, and fathead minnow were generally associated with low peak discharge, low–moderate daily mean and total discharges, and moderate–high numbers of cumulative degree-days. Conversely, later initiation of spawning and lower CPUE for all nonnatives and shorter spawning seasons for red shiner, sand shiner, and fathead minnow were generally associated with high peak discharge, moderate–high daily mean and total discharges, and low–moderate numbers of cumulative degree-days. Spawning periods of native fish species were fairly consistent among years. Associations between flow and temperature and relative abundance of all natives, except *Gila* sp., were opposite of those for nonnatives (associations for *Gila* sp. were similar to those for nonnative fishes). Higher CPUE of age-0 fish for speckled dace, bluehead sucker, and flannelmouth sucker was associated with high discharge and low–moderate numbers of cumulative degree-days, whereas, higher CPUE for *Gila* sp. was generally associated with low–moderate discharge and moderate–high numbers of cumulative degree-days. Conversly, lower CPUE for speckled dace, bluehead sucker, and flannelmouth sucker was associated with low–moderate discharge and moderate–high numbers of cumulative degree-days, whereas, lower CPUE for *Gila* sp. was generally associated with high discharge and low–moderate numbers of cumulative degree-days. Overall trends of fish abundance related to flows observed in our investigation were very similar to those reported by other authors. Management of flow regimes to approximate natural hydrographs and periodically provide above-average magnitudes in spring–summer discharges may benefit native fishes and inhibit certain prolific nonnative fishes.

ACKNOWLEDGMENTS

This study was sponsored by the Colorado Division of Wildlife, Endangered Fishes Investigations SE-3 and the U.S. Fish and Wildlife Service, Division of Federal Aid. J. Bundy, S. Meismer, J. Ruppert, P. Sikoski, D. Snyder, and M. Williams assisted with data analyses. Discussions with K. Bestgen and D. Snyder helped guide data summary and presentation. Some figures were prepared by C. Bjork. C. Carlson, T. Modde, and D. Osmundson provided useful comments on earlier drafts of this report.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Declines in populations of fishes native to the Colorado River System have been attributed to modification or loss of habitat and interactions with nonnative fish species (Behnke and Benson 1983; Stanford and Ward 1986; Hawkins and Nesler 1991; Minckley 1991). Flow and temperature patterns and channel morphology of mainstem and tributary rivers have been greatly altered by water-development projects, and introduced nonnative fishes are now numerically predominant in most fish communities. Successful protection, management, and recovery of natural elements of the Colorado River System require an understanding of relationships among present physical and biological conditions.

Studies conducted by the Colorado Division of Wildlife during 1980–1984 on habitat requirements and limiting factors for rare native fishes of the Upper Colorado River System concentrated on reproduction and early life history of the endangered humpback chub *Gila cypha* and Colorado squawfish *Ptychocheilus lucius* (Haynes et al. 1985). These studies included extensive sampling of small fishes (primarily age-0) in low-velocity nursery habitats of the lower Yampa River. Data on distribution and numeric abundance of native and nonnative fishes were produced from this sampling effort. Our primary objective was to further analyze these data and associate resulting information on annual spawning periods and relative abundance of young of selected fish species with annual spring–summer flow and temperature regimes of the lower Yampa River. We compared our findings with results of other studies conducted in the Upper Colorado River System.

STUDY AREA

The Yampa River, located in northwestern Colorado, is the principal tributary of the Green River and the only large river in the Colorado River Basin not greatly affected by water-development projects (Carlson and Muth 1989; Tyus and Karp 1989). Along its approximately 320-km course, the Yampa River drops in elevation about 2,255 m and enlarges to a sixth-order stream before joining the Green River (Joseph et al. 1977; Behnke et al. 1982). Major aquatic-habitat zones of the Yampa River include a mountainous headwater zone with cold and clear water, an intermediate zone with cool to tepid and occasionally turbid water flowing through cottonwood bottomlands and agricultural valleys, and a lower zone with warm and usually turbid water flowing through deep lime- and sandstone canyons. The present flow regime of the Yampa River appears to approximate historic annual and seasonal patterns and is characterized by variable low-, average-, or high-flow years; high flows in spring and early summer; and low flows during late summer through winter (Haynes and Bennett 1986; Tyus and Karp 1989). Tyus and Karp (1989) summarized U.S. Geological Survey flow records for the Yampa River from 1922 through 1987 and reported that daily discharge averaged about 61 m^3/s annually, 153 m^3/s during spring runoff in April through July, and 14 m^3/s per month for August through March.

Similar to most Colorado River Basin rivers, the fish fauna of the Yampa River is dominated by cyprinids and catostomids. A total of 12 fishes are native to the Yampa River, and at least 20 nonnative fish species have been introduced (Table 1). The upper Yampa River and its tributaries are typical trout waters, and a transition to cool- or warmwater fishes occurs at lower elevations. Of the native fishes, seven are considered in jeopardy or declining and have federal status under the 1973 Endangered Species Act as amended; four are endangered and three are under review (candidates) for federal listing. Most of the nonnative fishes have established reproducing populations.

Fish collections used in our analyses were from the lower 94.1 km (river km) of the Yampa River, between the upper end of Cross Mountain Canyon and the Yampa-Green River confluence (Figure 1). This section of river was divided into five reaches defined mainly by prominent changes in terrain and river morphology (Figures 1, 2). Cross Mountain Canyon (Reach 5) is a high-gradient reach with boulder, cobble, and gravel substrates. Mainchannel habitat is primarily rocky falls, rapids, and runs. Small shoreline pools and eddies occur behind boulders. Reach 4 is a low- to moderate-gradient stretch with cobble, gravel, and sand substrates. Terrain is open and hilly. Mainchannel habitat mostly follows a repetitive run–riffle–pool sequence, and shoreline habitat consists primarily of pools and embayments. From the lower end of Lily Park downstream to Deerlodge Park (Reach 3), the Yampa River broadens and slowly meanders through flat, open terrain and braids around sand and gravel bars. Numerous backwaters and shoreline embayments occur in this reach. Substrates are primarily gravel, sand, and silt. The lower 72.2 km of the Yampa River are contained within Yampa Canyon. In upper Yampa Canyon (Reach 2), the Yampa River is mostly a high-gradient system of rocky runs and rapids, eddies, and riffles. Boulder, cobble, and gravel substrates predominate. Downstream of Harding Hole to the Yampa-Green River confluence (lower Yampa Canyon, Reach 1), channel gradient is mostly low to moderate, and mainchannel habitat consists primarily of deep runs and pools and braided sections interspersed with gravel and cobble bars. In reaches 1 and 2, shoreline habitat is mostly pools, eddies, and embayments. Extent of backwater development is higher in Reach 1 than in Reach 2.

METHODS

Sampling

The main objective of fish sampling conducted in the lower 94.1 km of the Yampa River during 1980–1984 was to document Colorado squawfish reproduction through collection of age-0 fish. Accordingly, annual sampling schedules were based primarily on knowledge of timing and location of Colorado squawfish spawning in the Upper Colorado River System, particularly the Green River sub-system, and were revised as new information was produced. Vanicek and Kramer (1969) collected adult Colorado squawfish in reproductive condition (ripe) from the Green River, Utah, in late June through early August, 1964–1966. They reported that, in all years, ripe Colorado squawfish were first collected about 1 month

Table 1.—Fishes of the Yampa River, Colorado (adapted from Behnke et al. 1982; Tyus et al. 1982).

Taxon	Principal distribution by river sections[a] Upper Section	Middle Section	Lower Section	Relative abundance[b]
NATIVES				
Cyprinidae				
Humpback chub *Gila cypha*[c]			X	rare
Bonytail *G. elegans*[c]			X	incidental[d]
Colorado roundtail chub *G. robusta robusta*[e]		X	X	common
Colorado squawfish *Ptychocheilus lucius*[c]		X	X	rare
Colorado speckled dace *Rhinichthys osculus yarrowi*	X	X	X	common
Catostomidae				
Colorado bluehead sucker *Catostomus discobolus discobolus*	X	X	X	common to abundant
Flannelmouth sucker *C. latipinnis*[e]		X	X	common
Mountain sucker *C. platyrhynchus*	X			rare
Razorback sucker *Xyrauchen texanus*[c]			X	incidental to rare
Salmonidae				
Colorado River cutthroat trout *Oncorhynchus clarki pleuriticus*[e]	X			incidental to rare
Mountain whitefish *Prosopium williamsoni*	X	X		common
Cottidae				
Mottled sculpin *Cottus bairdi punctulatus*	X	X		common
NONNATIVES				
Cyprinidae				
Red shiner *Cyprinella lutrensis*			X	common to abundant
Common carp *Cyprinus carpio*		X	X	common
Utah chub *Gila atraria*			X	incidental
Sand shiner *Notropis stramineus*		X	X	common
Fathead minnow *Pimephales promelas*		X	X	common to abundant
Redside shiner *Richardsonius balteatus*		X		common to abundant
Creek chub *Semotilus atromaculatus*	X			rare
Catostomidae				
White sucker *Catostomus commersoni*		X		common
Ictaluridae				
Black bullhead *Ameiurus melas*		X		incidental to rare
Channel catfish *Ictalurus punctatus*		X	X	common
Esocidae				
Northern pike *Esox lucius*		X	X	rare to common
Salmonidae				
Rainbow trout *Oncorhynchus mykiss*	X			common
Brown trout *Salmo trutta*	X	X	X	incidental to rare
Brook trout *Salvelinus fontinalis*	X			rare to common
Cyprinodontidae				
Plains killifish *Fundulus zebrinus*		X		incidental to rare
Centrarchidae				
Green sunfish *Lepomis cyanellus*		X	X	rare
Bluegill *L. macrochirus*			X	incidental
Smallmouth bass *Micropterus dolomieu*			X	incidental
Largemouth bass *M. salmoides*			X	incidental
Percidae				
Walleye *Stizostedion vitreum*			X	incidental

[a]**Upper section** = headwaters downstream to Hayden, Colorado, **middle section** = Hayden downstream to Cross Mountain Canyon, **lower section** = Cross Mountain Canyon downstream to Yampa-Green River confluence. [b]Relative abundance within river sections of principal distribution: **abundant** = occurring in large numbers and consistently collected, **common** = occurring in moderate numbers and frequently collected, **rare** = occurring in low numbers and having restricted or sporadic distribution, **incidental** = occurring in very low numbers and known only from a few point collections. [c]Federally endangered. [d]Probably extirpated from the Yampa River. [e]Candidate (under review) for federal listing.

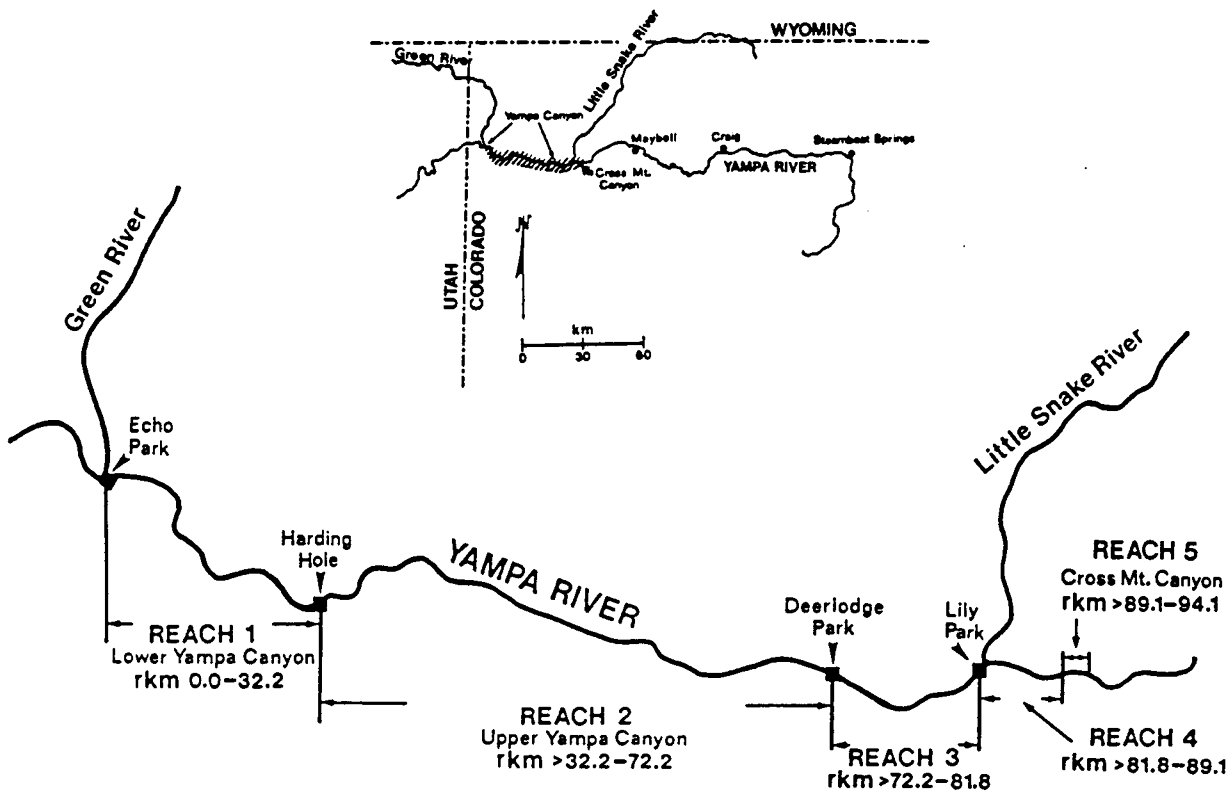

Figure 1.—Yampa River study area, 1980–1984. **rkm** = river kilometer.

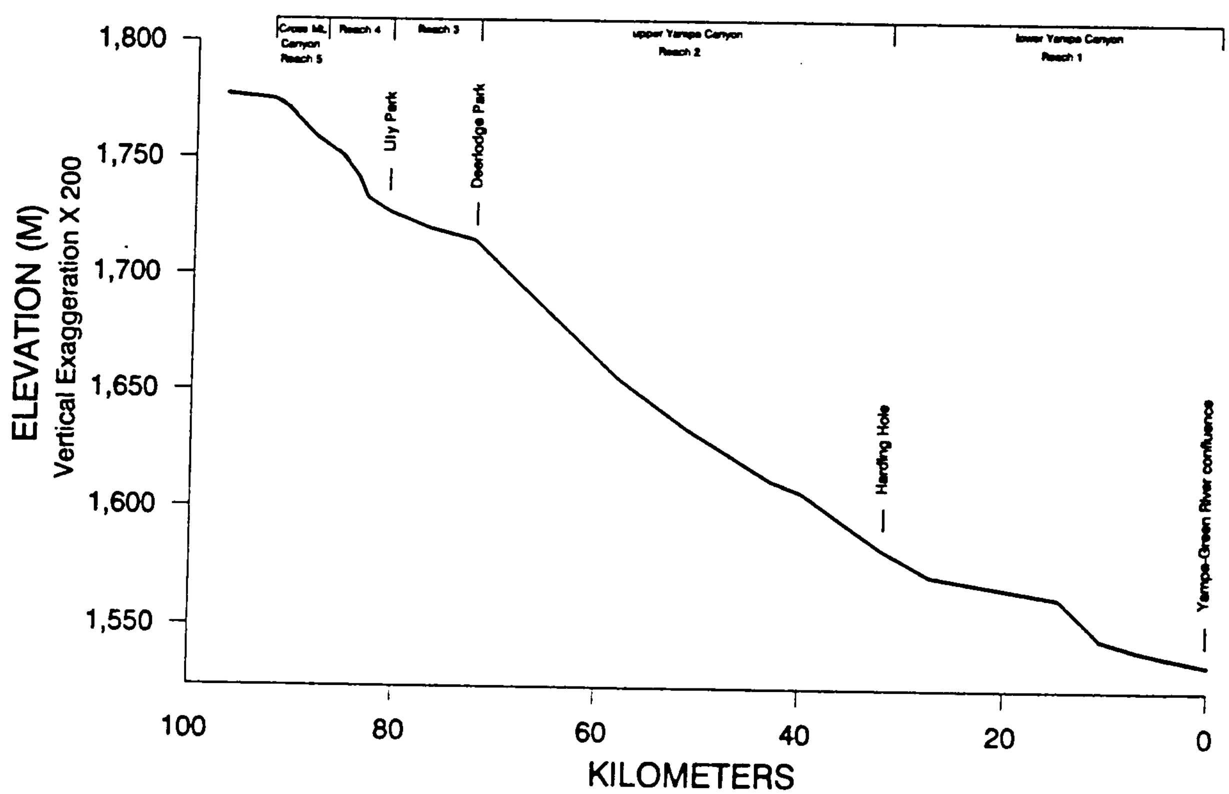

Figure 2.—Gradient profile of the lower Yampa River, Colorado, from just upstream of Cross Mountain Canyon to the Yampa-Green River confluence (redrawn from Wheat 1983).

after the water temperature had reached 18°C and that late larvae (12–20 mm long) were captured 3–4 weeks later. Results of field studies conducted in the Yampa and Green rivers after 1979 generally confirmed Vanicek and Kramer's observations and demonstrated that Colorado squawfish spawn in the lower 50 km of the Yampa River, especially in lower Yampa Canyon, from late June through early August (Tyus et al. 1981; Wick et al. 1983; Haynes et al. 1984). Information on principal spawning seasons of other fishes occurring in the lower Yampa River was also considered when planning sampling efforts.

Seines (1.0 or 3.0 × 1.2 m; 0.8-mm-square mesh) were used to collect age-0 or older fish from backwaters or shoreline habitats with negligible water velocity (typically ≤ 0.2 m/s; e.g., pools, embayments, and eddies) throughout each reach. Width and length of each seine haul (each seine haul was considered a separate sample) were measured with a metric tape, and area sampled (m^2) was calculated. Samples were collected according to the "qualitative-representative-sample approach" (Hocutt et al. 1974), i.e., all available habitats in each reach that could be seined were sampled to obtain representative collections of fishes that would yield data on relative abundance. Consequently, number of samples collected and area seined in each reach per year generally reflected amount of seineable habitat. Water temperature (°C) was measured in each habitat type at time of sampling.

Most sampling in 1981–1984 was conducted monthly or bimonthly from early–mid June (shortly after spring flows had peaked) through late September or mid October (Table 2). In 1981 and 1982, samples were also collected in late April (before spring flows had peaked). Collections in 1980 were made in late August and early October. Collections were made primarily during early–mid June through late August in reaches 1 and 2 and in April, late August, mid–late September, or early or late October in reaches 3–5. All samples were fixed in 10% formalin and returned to the Larval Fish Laboratory, Colorado State University, Fort Collins, for processing.

Analyses

Flow and temperature data.—Various environmental factors influence reproduction of fishes (DeVlaming 1972; Lam 1983; Bye 1984; Stacey 1984; Munro 1990). Welcomme (1985) reported that for riverine fishes, timing of spawning is related to water flow and temperature and reproductive success or survival of young are affected by the flow regime. Annual discharge and mainchannel water-temperature data for the lower Yampa River were taken from U.S. Geological Survey monthly records. Stream gages on the Yampa River were located near the town of Maybell (river km 138.9; about 45 km upstream of the study area's upper end) and at Deerlodge Park (river km 72.2; at the upper end of Yampa Canyon). Discharge and temperature data collected at the Maybell gage were available for each year studied, whereas, collection of these data at the Deerlodge Park gage was started in 1982. Discharge of the Yampa River at Deerlodge Park in 1980 and 1981 was approximated by adding monthly values of daily and total discharge taken from Maybell records to corresponding data collected at a stream gage on the Little Snake

Table 2.—Area sampled (m^2) and number of samples per year, sampling period, and river reach for seine collections in backwaters or shoreline habitats with negligible water velocity, lower Yampa River, Colorado.

		River reach[a]											
		5		4		3		2		1		Total	
Year	Sampling period	m^2	Number of samples	m^2	Number of samples	m^2	Number of samples	m^2	Number of samples	m^2	Number of samples	m^2	Number of samples
1980	late August	367	5	476	10	2,121	13	710	14	2,321	31	5,995	73
	early October	33	2	27	1							60	3
	Year	400	7	503	11	2,121	13	710	14	2,321	31	6,055	76
1981	late April	120	12									120	12
	mid June							305	13	295	14	564	27
	late July							510	28	1,310	88	1,820	116
	mid August	100	10	100	7	190	9	788	26	1,430	60	2,608	112
	mid September	42	5	79	4	100	4					221	13
	Year	262	27	179	11	290	13	1,603	67	2,999	162	5,333	280
1982	late April			69	3			27	2	870	20	966	25
	early June							378	13	679	19	1,057	32
	late July							649	27	692	23	1,341	50
	early and late August							1,105	38	4,020	118	5,125	156
	late October	52	9	100	9	265	10					417	28
	Year	52	9	169	12	265	10	2,159	80	6,261	180	8,906	291
1983	early June							215	9	300	12	515	21
	early and late July	30	3	20	3	66	3	239	13	870	21	1,225	43
	early and late August			300	11	600	10	456	23	3,402	122	4,758	166
	late September	30	3	31	3	34	4					95	10
	Year	60	6	351	17	700	17	910	45	4,572	155	6,593	240
1984	mid June			38	4	45	4					83	8
	early and mid July							96	4	4,299	59	4,395	63
	early and late August							100	10	2,208	75	2,308	85
	late September			98	10	90	14					188	24
	Year			136	14	135	18	196	14	6,507	134	6,974	180

[a]**Reach 5** = Cross Mountain Canyon (river km 94.1->89.1), **Reach 4** = lower end of Cross Mountain Canyon to Lily Park (river km 89.1->81.8), **Reach 3** = Lily Park to Deerlodge Park (river km 81.8->72.2), **Reach 2** = Deerlodge Park to Harding Hole (river km 72.2->32.2), **Reach 1** = Harding Hole to Yampa-Green River confluence (river km 32.2–0.0).

River near Lily Park (the Little Snake River joins the Yampa River at Lily Park; river km 81.8). To place the maximum-daily (peak) discharge of the lower Yampa River for each year during 1980–1984 in historical perspective, values of annual peak discharge in 1934–1991 were taken from Maybell records and frequency and cumulative-frequency distributions were prepared. Each peak-discharge value in 1980–1984 was given a percentile rank within the grouped frequency distribution.

Carlson et al. (1979) and Haynes and Muth (1982) reported that in 1976–1977 and 1981, respectively, estimated peak spawning for most of the more common fishes in the lower Yampa River occurred sometime during late May through late August. Discharge of the lower Yampa River typically begins to increase from over-winter, baseline flows in April, peaks in mid May–early June, remains relatively high through July, and is at or near baseline from August through March. Because river flows exert deterministic effects on various physical conditions important in spawning or survival of young fish (e.g., water temperature, velocity, and quality and formation and maintenance of spawning and nursery habitats), we presumed that discharge conditions during spring–summer would affect annual reproductive timing and success of fishes in the lower Yampa River. Three parameters describing the monthly flow regime of the lower Yampa River during April–July in each year studied were selected for our analyses; i.e., peak (maximum-daily), daily mean, and total discharge.

Mainchannel water temperatures of the lower Yampa River typically begin to increase from their over-winter lows in early–mid March, are fairly constant from day-to-day in May–mid June (during spring-runoff discharge), and reach maximum values in early–mid August (after spring-runoff flows have subsided). Degree-days (sensu Arnold 1960; Baskerville and Emin 1969) were used as an index of the annual rate of warming of the lower Yampa River during spring–summer. Degree-days were estimated using mainchannel water-temperature data collected at the Maybell gage in 1981–1984 (1980 data were incomplete). Although this gage is located about 45 km upstream of the study area's upper end, it provided the most continuous data on mainchannel water temperatures (typically, on dates when temperature data were recorded at the Deerlodge Park gage, daily minimum or maximum mainchannel water temperatures were about 1–3°C greater at Deerlodge Park than those recorded near Maybell). For each year, monthly degree-days were estimated as number of days maximum mainchannel water temperature reached or exceeded 12, 14, 16, 18, or 20°C in April–July. These temperature thresholds were selected to represent a range of water temperatures likely affected by variations among years in discharge during spring–summer. It was believed that annual onset and seasonal persistence of each of these temperature thresholds would be especially influenced by magnitude and timing of peak discharges, thus affecting the rate of warming of the lower Yampa River.

Fish data.—In the laboratory, samples were first organized by collection date and location (reach). Fish from each sample were identified to the lowest possible taxon (most were identified to species; native *Gila* were left at genus, although most were probably Colorado roundtail chub). Specimens in each taxon were assigned to a larval phase or the juvenile or adult developmental periods (Snyder 1976), measured (total length, TL) to the nearest millimeter, and enumerated. All data for each sample were entered into a computer database (MANAGE or dBase).

Eight of the more commonly collected fishes were selected for our analyses; four natives (*Gila* sp., speckled dace, bluehead sucker, and flannelmouth sucker) and four nonnatives (red shiner, sand shiner, fathead minnow, and redside shiner). Fish were classified as age-0 (all taxa) or older (nonnatives only) by relating data on date of capture and specimen TL and developmental phase or period with available, taxon-specific information on typical TL at hatching, early growth rates, length at end of first year, and spawning period (see Appendix A).

Initiation and duration of the spawning season for each taxon per year were estimated from length-frequency distributions of age-0 fish organized by sampling dates and using available information on TL at hatching and early growth rates (see Appendix A). Two spawning-period parameters for each taxon were produced from these estimates: (1) total number of days in the spawning season (SPAWN-T) and (2) number of days, beginning April 1, to initiation of spawning (SPAWN-1). April 1 was selected as the starting date because, typically, ice covering the river breaks up and river discharge, water temperature, and extent of low-velocity habitat begin to increase in April; these events were presumed to be biologically relevant to spawning of Yampa River fishes.

Indices of relative abundance of age-0 or older fish for each taxon by river reach and over all reaches (total) per year and by reach over all years were calculated as number of fish collected per area seined (catch-per-unit-effort; CPUE) and percentage of all samples in which a particular taxon occurred (percentage of occurrence; PO). In calculating these indices for age-0 fish, only samples collected on or after estimated initiation of spawning for each taxon per year were included in analyses. According to Ricker (1975) and others, values of CPUE are related in a constant or predictable way to population size, and changes in absolute abundance over space and time will be reflected in CPUE values. Haynes and Muth (1982) discussed strengths and weaknesses of CPUE in estimating abundance of fishes in open, structurally diverse systems like rivers of the Colorado River Basin.

Correlations.—Correlation coefficients (Pearson *r*) were calculated to better assess interdependency among years between monthly discharge parameters and degree-days, among annual relative-abundance indices and spawning-period parameters of fishes, and between annual relative-abundance indices and spawning-period parameters of fishes and monthly discharge parameters and degree-days. Because of the survey-sampling nature of the existing fish database (data were not collected within an experimental framework) and because variables were measured or estimated, therefore subject to error, this descriptive statistical technique was considered most appropriate; our objective was to establish and estimate degree of association between variables (interdependence), not to describe functional relationships between variables (i.e., predict one variable in terms of another). The level of statistical significance for coefficients was set at

$P \leq 0.05$. Degree of association for correlations with non-significant coefficients was subjectively considered strong if r values were within 0.001–0.1 from the lower limit of significance, moderate if r values were within 0.101 from the lower limit of significance to 0.500, and weak if r values were ≤ 0.499.

RESULTS AND DISCUSSION

Flow and Temperature Regimes

Annual flow regimes of the lower Yampa River for April–July varied considerably among the five years studied, encompassing a full range of flow conditions including extremes and averages (Figure 3; Table 3). In increasing order, total discharge (m^3) over these four months near Maybell and at Deerlodge Park, respectively, was about 5.7 and 8.1 $\times 10^8$ in 1981, 1.4 and 2.0 $\times 10^9$ in 1980, 1.5 and 2.1 $\times 10^9$ in 1982, 1.6 and 2.5 $\times 10^9$ in 1983, and 2.4 and 3.3 $\times 10^9$ in 1984. Similarly, annual peak discharge (which, except near Maybell in 1981, occurred in May each year) was low in 1981, high in 1983 and especially 1984, and more moderate in 1980 and 1982. Even though annual peak discharge was higher in 1983 than in 1980 and 1982, values of daily mean and total discharge for April and May were greater in 1980 and 1982 than in 1983; in 1981 and 1984, these values were consistent with the respective lowest and highest annual peak discharges. In 1983, unlike in the other four years, values of daily mean and total discharge for June were substantially greater than those for May; values of these discharge parameters for July were greater in 1983 than in the other four years (even greater than those in 1984). Rate of decrease in flows following annual peak discharge to near baseline was fastest in 1981 and slowest in 1982 (Figure 3).

In historical perspective, extremely low-flow years like 1981 and extremely high-flow years like 1983 or 1984 occurred very infrequently. Values of annual peak discharge during 1980–1984 were some of the smallest and greatest recorded at the Maybell gage in 1934–1991. Peak discharge in 1984 was the highest recorded during the 58-year period. In 1981, peak discharge had a percentile rank of 13 (i.e., only 13% of annual peak-discharge values during 1934–1991 were lower than the value for 1981). Values of peak discharge in 1980, 1982, and 1983 had respective percentile ranks of 79, 57, and 89.

The water-temperature regime of the lower Yampa River during spring and summer in 1981–1984 differed among years (Table 4; Figure 4), and annual trends in monthly water-temperature parameters were somewhat predictable given values of corresponding discharge parameters and the shape of yearly hydrographs. Rate of warming per month (as represented by numbers of degree-days) was fastest in 1981 and slowest in 1983. In 1981, monthly means of maximum daily water temperatures for April–July were about 3–6°C greater than the same values in 1982 and 1983 (compared to 1984 for May–July, monthly means were 2–5°C greater in 1981). Comparing 1981 to each subsequent year of progressively increasing discharge, cumulative numbers of degree-days over the five temperature thresholds for the April–July period were 28–56% lower in 1982, 49–65% lower in 1983, and 28–53% lower in 1984.

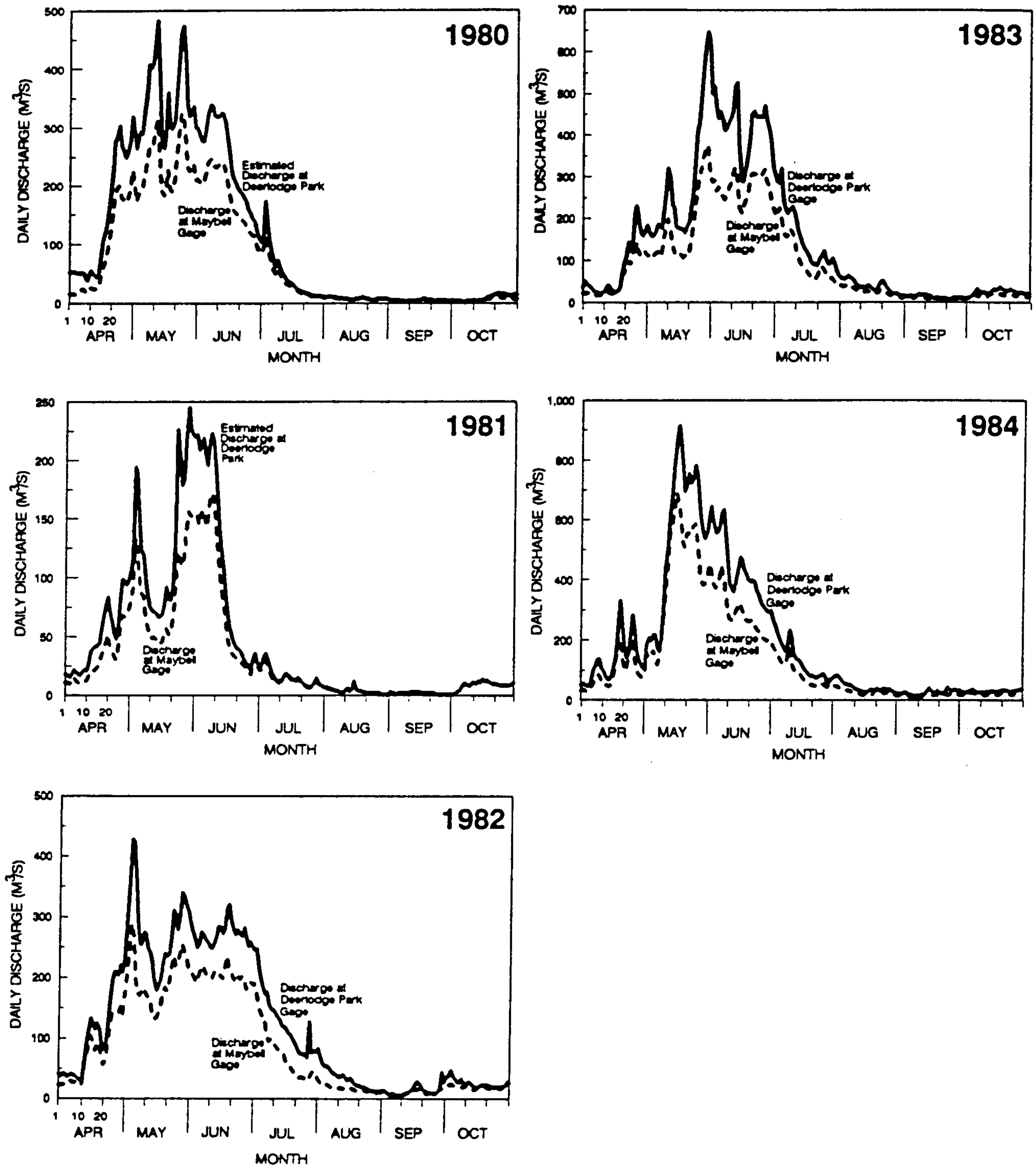

Figure 3.—Annual discharge regimes of the lower Yampa River, Colorado, April–October, 1980–1984 (USGS records).

Table 3.—Discharge parameters for the lower Yampa River near Maybell and at Deerlodge Park, Colorado.

Year	Location	Date of peak discharge	Discharge[a] April Daily (m^3/s) Mean	April Daily Range	April Total (m^3) (x 10^8)	May Daily (m^3/s) Mean	May Daily Range	May Total (m^3) (x 10^8)	June Daily (m^3/s) Mean	June Daily Range	June Total (m^3) (x 10^8)	July Daily (m^3/s) Mean	July Daily Range	July Total (m^3) (x 10^8)
1980	Maybell	27 May	81	14-200	2.09	235	174-325	6.31	181	86-246	4.69	37	9-112	1.00
	Deerlodge Park	15 May	131	39-303	3.40	347	265-482	9.31	243	110-339	6.31	48	10-173	1.28
1981	Maybell	9 June	29	10-68	0.76	86	44-156	2.30	86	18-172	2.23	15	7-30	0.39
	Deerlodge Park	29 May	46	16-98	1.20	130	67-245	3.47	116	22-223	3.01	17	7-36	0.44
1982	Maybell	5 May	70	22-152	1.82	194	133-289	5.21	204	182-235	5.30	82	30-190	2.20
	Deerlodge Park	5 May	97	31-220	2.51	275	179-427	7.36	274	249-320	7.10	134	69-252	3.58
1983	Maybell	30 May	52	17-145	1.34	171	105-374	4.60	279	213-323	7.24	113	42-229	3.02
	Deerlodge Park	31 May	75	23-230	1.94	269	159-648	7.21	436	289-623	11.30	167	76-328	4.47
1984	Maybell	17 May	91	29-211	2.37	396	77-691	10.62	310	199-453	8.04	99	44-204	2.65
	Deerlodge Park	18 May	135	48-331	3.51	519	111-914	13.90	456	297-645	11.84	146	44-297	3.93

[a]Data taken from USGS records.

Table 4.—Water-temperature parameters for the mainchannel of the lower Yampa River near Maybell, Colorado.

Year	Daily maximum water temperature (°C)[a] April Mean	April Range	May Mean	May Range	June Mean	June Range	July Mean	July Range	Degree-days[b] April 12°C	April 14°C	April 16°C	May 12°C	May 14°C	May 16°C	June 12°C	June 14°C	June 16°C	June 18°C	June 20°C	July 16°C	July 18°C	July 20°C
1981	12.6	6.0-17.0	13.8	11.0-16.0	18.6	14.0-24.0	23.9	22.0-26.0	19	16	4	27	17	1	30	30	24	16	12	31	31	31
1982	8.2	6.0-12.0	10.7	8.0-14.0	13.7	12.0-17.0	20.1	16.0-25.0	1	0	0	15	2	0	30	17	3	0	0	31	25	19
1983	8.2	4.0-12.0	10.5	7.0-13.0	12.5	10.0-15.0	19.0	14.0-24.0	1	0	0	11	0	0	22	14	0	0	0	26	24	15
1984			12.0	11.0-14.0	13.3	9.0-17.0	20.9	16.0-24.0				21	4	0	25	19	4	0	0	31	29	20

[a]Data taken from USGS records; records for April in 1984 were not available. [b]Degree-days = number of days per month in each year that maximum mainchannel water temperature reached or exceeded 12, 14, 16, 18, or 20°C (determined from USGS records).

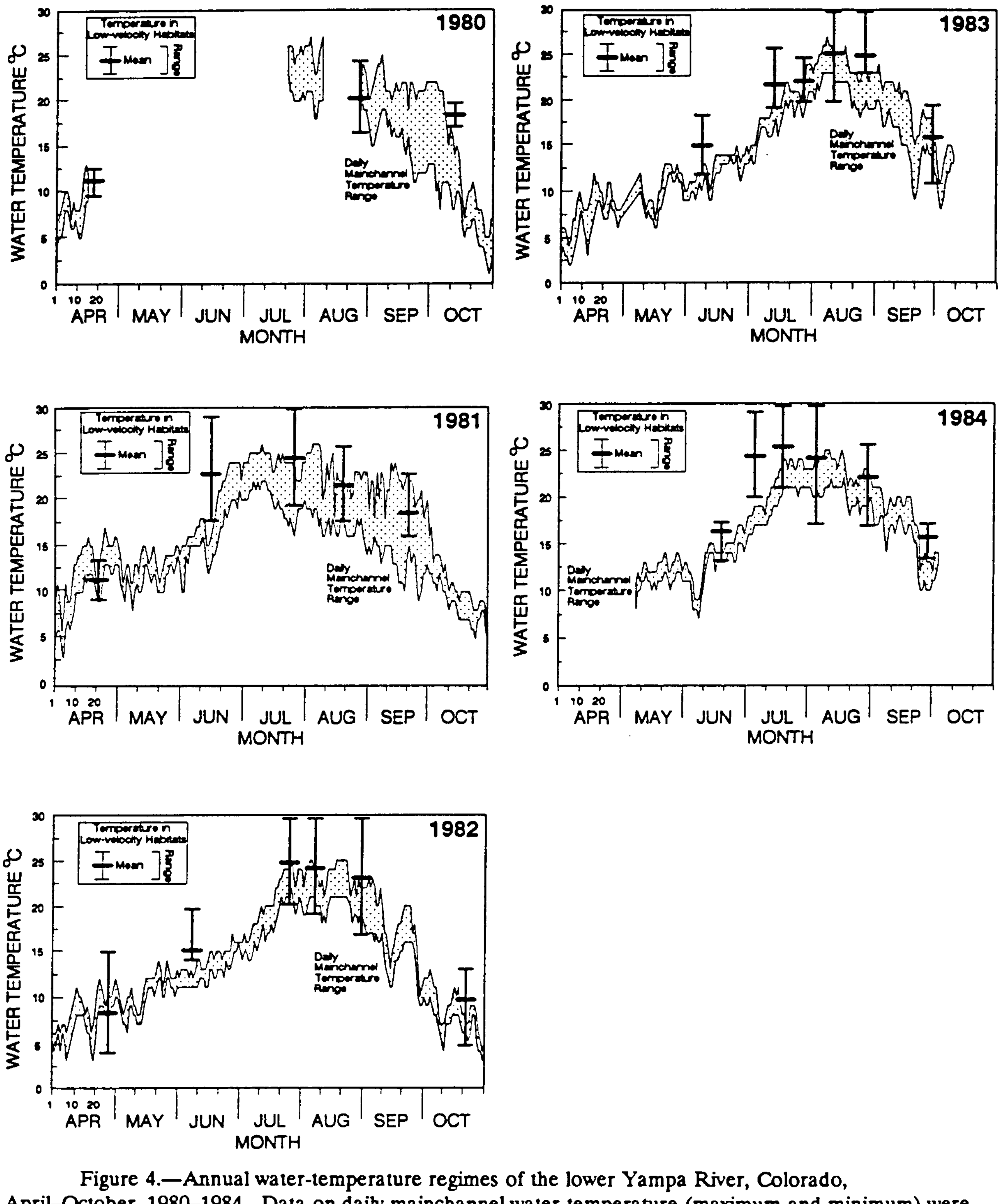

Figure 4.—Annual water-temperature regimes of the lower Yampa River, Colorado, April–October, 1980–1984. Data on daily mainchannel water temperature (maximum and minimum) were taken from USGS records for the Yampa River near Maybell, Colorado. Temperatures in low-velocity habitats were measured when fish samples were collected.

Correlations among years of peak, daily mean, and total discharges in April–July with monthly degree-days were negative, but only a few coefficients were strong or significant (Table 5). The general weak–moderate degree of association for these comparisons was primarily a result of increased rate of warmimg in 1984. Numbers of degree-days per month were similar in 1982 and 1984 even though date of annual peak discharge occurred 12–13 d earlier in 1982 than in 1984, and values of monthly discharge parameters in April–July were greater (especially for May and June) in 1984 than in 1982. However, as noted, flows following annual peak discharge decreased at a faster rate in 1984 than in 1982. Compared to 1982 and 1984, cumulative numbers of degree-days over the five temperature thresholds for the April–July period were 4–26% lower in 1983. Other than noted differences in values of monthly discharge parameters among these three years, date of annual peak discharge in 1983 occurred 13 d later than in 1984 and 25–26 d later than in 1982 and rate of decrease in flows following annual peak discharge was faster in 1984 than in 1983. When assessing effects of discharge on water temperature and rate of warming, characteristics of annual flow regimes other than magnitude of discharge, such as time of peak discharge and rate of decrease in flows following peak discharge, must be considered.

Mean values of water temperatures in low-velocity habitats we sampled were typically greater than or equal to maximum daily water temperatures of the mainchannel on the same dates in each year studied (Figure 4). However, seasonal patterns for water temperatures in these habitats closely tracked those recorded for mainchannel temperatures. Therefore, mainchannel water temperatures appeared to be adequate indicators of trends in thermal conditions of the lower Yampa River.

Fish Data

The eight fishes selected for our analyses were represented by 92,482 age-0 (all taxa) or older (nonnatives only) fish from a total of 1,067 seine samples collected during 1980–1984. Of that total catch, 81,239 fish were classified as age-0 and, of these, about 70% represented native taxa. This high representation by native taxa agrees with conclusions of Tyus and Karp (1989) that, at least in terms of abundance, native fishes dominate the Yampa River fish community. Over the five years studied, within the native group, *Gila* sp. constituted 50% of the total catch, speckled dace 27%, bluehead sucker 18%, and flannelmouth sucker 5%. Within the nonnative group, red shiner constituted 53% of the total catch of age-0 fish and 38% of the total catch of age-1+ fish, sand shiner 11 and 31%, fathead minnow 32 and 11%, and redside shiner 4 and 19%. Annual abundance of fish in each taxon varied considerably for most taxa among years.

Spawning periods.—Taxon-specific variation in estimated number of days to initiation of spawning (SPAWN-1) and total number of days in the spawning period (SPAWN-T) occurred among years for both native and especially nonnative fishes. However, annual spawning periods were mostly consistent among

Table 5.—Correlations (Pearson r) among years between values of monthly river-discharge parameters and numbers of degree-days per month for selected mainchannel water temperatures, lower Yampa River near Maybell, Colorado, 1981–1984. Coefficients in **bold** type followed by an asterisk (*) are statistically significant ($r \geq 0.950$; df = 2; $P \leq 0.05$). Strong correlations ($r = 0.850–0.949$) are indicated by coefficients in bold type not followed by an asterisk.

	Discharge[a]																	
	April			May			June			May and June			July			April-July		
Degree-days[a,b]	Peak	Daily mean	Total	Peak	Daily mean	Total	Peak	Daily mean	Total	Peak	Daily mean	Total	Peak	Daily mean	Total	Peak	Daily mean	Total
April																		
12°C	**-1.000***	**-0.901**	**-0.896**															
14°C	**-1.000***	**-0.901**	**-0.896**															
16°C	**-1.000***	**-0.901**	**-0.896**															
May																		
12°C	-0.419	-0.253	-0.242	-0.254	-0.133	-0.135												
14°C	-0.774	-0.621	-0.612	-0.580	-0.513	-0.515												
16°C	**-0.857**	-0.773	-0.766	-0.694	-0.670	-0.671												
June																		
12°C				-0.663	-0.422	-0.424	**-0.855**	-0.828	-0.826									
14°C				-0.546	-0.457	-0.459	-0.653	-0.828	-0.827									
16°C				-0.640	-0.577	-0.579	-0.710	**-0.872**	**-0.872**									
18°C				-0.694	-0.670	-0.671	-0.718	**-0.874**	**-0.874**									
20°C				-0.694	-0.670	-0.671	-0.718	**-0.874**	**-0.874**									
May and June																		
12°C										-0.448	-0.533	-0.530						
14°C										-0.564	-0.683	-0.682						
16°C										-0.643	-0.756	-0.754						
18°C										-0.694	-0.806	-0.805						
20°C										-0.694	-0.806	-0.805						
July																		
16°C							-0.401	-0.452	-0.451				-0.498	-0.520	-0.521			
18°C							-0.283	-0.510	-0.508				-0.763	-0.770	-0.771			
20°C							-0.694	**-0.855**	**-0.854**				**-0.977***	**-0.980***	**-0.980***			
April-July																		
12°C																-0.619	-0.773	-0.773
14°C																-0.615	-0.790	-0.791
16°C																-0.614	-0.776	-0.776
18°C																-0.555	-0.746	-0.747
20°C																-0.640	-0.807	-0.807

[a]Data taken from USGS records. [b]**Degree-days** = number of days per month that maximum mainchannel water temperature reached or exceeded 12, 14, 16, 18, or 20°C.

taxa between and within the native and nonnative groups (Figure 5). In each year except 1981, native fishes started spawning earlier than nonnative species; in 1981, red shiner and fathead minnow started spawning earlier than all native fishes except flannelmouth sucker. In each year, all nonnatives except redside shiner ended spawning later than native fishes. Spawning for both native and nonnative fishes among years started and ended earliest in 1981 and started and ended latest in 1983. Among native fishes in each year, flannelmouth sucker started spawning earliest, followed closely by *Gila* sp., speckled dace, and bluehead sucker, respectively. Speckled dace ended spawning latest, followed by bluehead sucker, *Gila* sp., and flannelmouth sucker, respectively. For nonnatives, fathead minnow started spawning earliest, followed by red shiner, redside shiner, and sand shiner, respectively in all years except 1981. Sand shiner ended spawning latest, followed by red shiner, fathead minnow, and redside shiner, respectively. In 1981, sand shiner started spawning earlier than redside shiner.

Correlations among years between values of SPAWN-1 and SPAWN-T by taxon were different between the native and nonnative groups (Figure 5). For all nonnative fishes, values of SPAWN-1 were smallest in 1981 and greatest in 1984 and especially 1983, and values of SPAWN-T were smallest in 1983 or 1984 and, except for redside shiner, greatest in 1981. Coefficients for correlations between these spawning-period parameters, for all nonnatives except redside shiner, were negative and significant (positive and moderate for redside shiner). Values of SPAWN-1 and SPAWN-T for each native taxon were similar among years, the greatest difference among years occurring in 1981 with values of SPAWN-1, and correlations were positive for *Gila* sp. and flannelmouth sucker and negative for speckled dace and bluehead sucker; however, correlations were weak for all four fishes.

Relative abundance.—Values of total (over all reaches) relative abundance from the two indices, i.e., catch-per-unit-effort (CPUE) and percentage of occurrence (PO), were positively correlated among years for each age class of all fishes except fathead minnow (Table 6). Correlations were strong or significant for age-0 speckled dace, bluehead sucker, red shiner, and sand shiner and for both age classes of redside shiner.

Variations in total relative abundance of age-0 fish among years and relative abundance among reaches over all years differed mostly between the native and nonnative groups (Tables 7, 8). For all native fishes except *Gila* sp., values of total CPUE and PO were greatest in 1984 (greatest in 1981 for *Gila* sp.), whereas, for all nonnatives except fathead minnow, these values were greatest in 1981 (CPUE and PO for fathead minnow were highest in 1982 and 1984, respectively). Smallest values of total CPUE and PO occurred in 1984 for *Gila* sp., 1982 for speckled dace, 1981 for bluehead and flannelmouth suckers, 1984 for all nonnatives except fathead minnow, and 1983 for fathead minnow. Among reaches, CPUE for native fishes was highest over all years in reaches 1–3 and lowest in reaches 4 or 5. CPUE for red shiner was

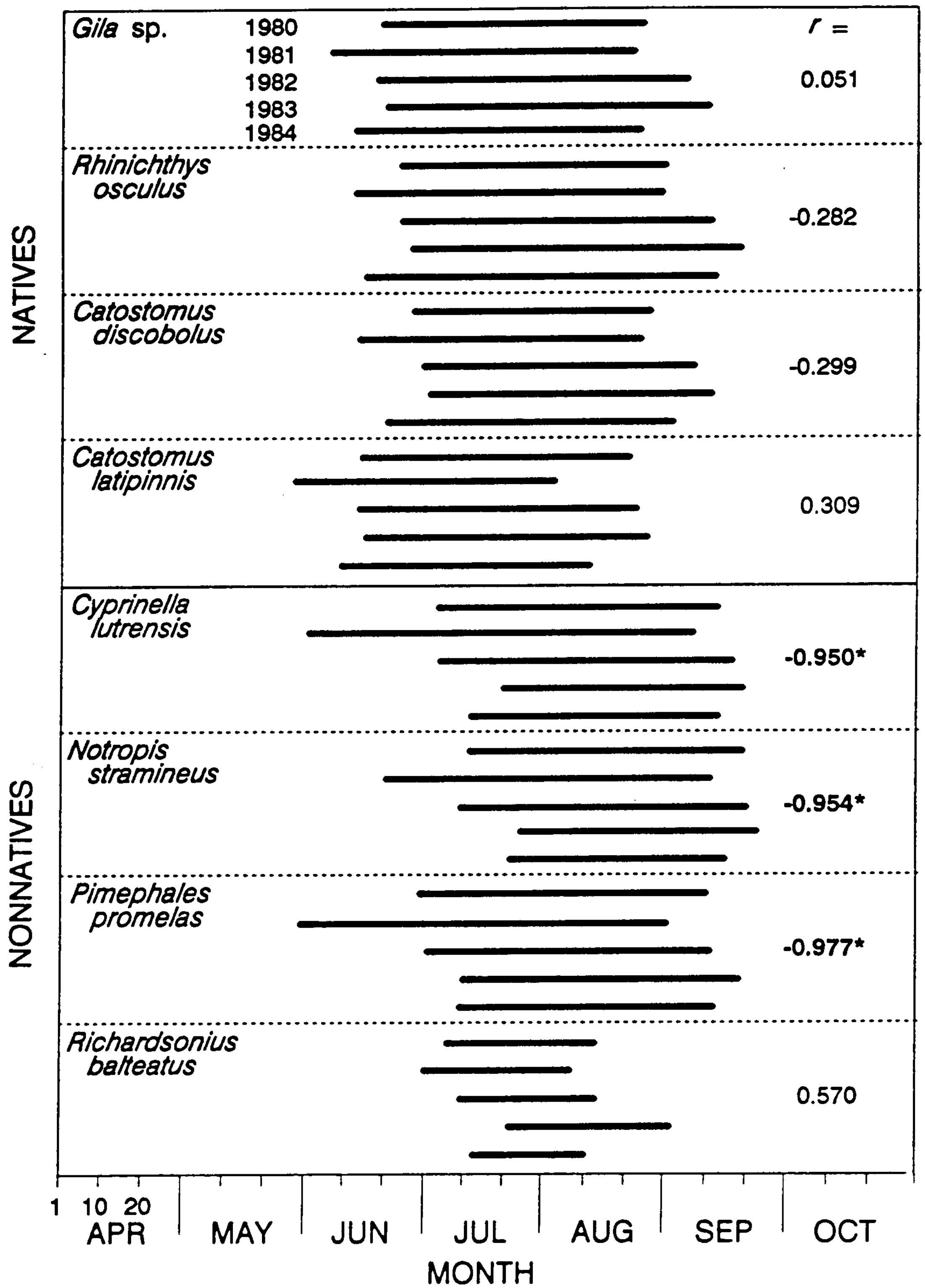

Figure 5.—Estimated annual spawning periods (horizontal bars; determined from collections of age-0 fish) for selected fishes, lower Yampa River, Colorado, 1980–1984, and correlations (Pearson *r*) among years between estimated number of days, beginning April 1, to annual initiation of spawning and estimated total number of days in the annual spawning period for each taxon. Coefficients in bold type followed by an asterisk (*) are statistically significant ($r \geq 0.878$; df = 3; $P \leq 0.05$). *Gila* sp. primarily *G. robusta robusta*.

Table 6.—Correlations (Pearson *r*) among years between total catch-per-unit-effort (number of fish collected per area sampled) and percentage of occurrence (percentage of all samples in which each taxon occurred) of age-0 or older fish for selected fishes, lower Yampa River, Colorado, 1980–1984. Coefficients in **bold** type followed by an asterisk (*) are statistically significant ($r \geq 0.878$; df = 3; $P \leq 0.05$). Strong correlations ($r = 0.778$–0.877) are indicated by coefficients in bold type not followed by an asterisk.

Taxon	Correlation coefficient: Age 0	Correlation coefficient: Age 1+
NATIVES		
Gila sp.	0.235	
Rhinichthys osculus	**0.867**	
Catostomus discobolus	**0.973***	
C. latipinnis	0.593	
NONNATIVES		
Cyprinella lutrensis	**0.857**	0.273
Notropis stramineus	**0.833**	0.010
Pimephales promelas	-0.326	0.377
Richardsonius balteatus	**0.981***	**0.852**

highest in reaches 1 and 3 and lowest in reach 5 (similar to natives). For sand shiner and fathead minnow, CPUE was highest in reaches 3 and 4 and lowest in reach 2. CPUE for redside shiner was highest in reach 4 and lowest in reach 1.

From percent contribution per year of each taxon to the total annual CPUE for age-0 fish (all taxa combined), slightly different patterns emerge, especially for native fishes (Figure 6). Among native fishes, highest percent contribution by taxon occurred in either 1983 or 1984, and lowest percent contribution, except for *Gila* sp., occurred in 1981; for *Gila* sp, lowest percent contribution occurred in 1984. Among nonnative species, highest percent contribution by taxon occurred in either 1980 or 1981, and lowest percent contribution occurred in 1984.

Patterns of total relative abundance among years and relative abundance among reaches over all years for age-1+ fish of nonnative species were somewhat predictable given the patterns exhibited by age-0 fish of these species (Table 8). Total values from both relative-abundance indices for age-1+ fish of each species were smallest in 1984, and, except for redside shiner, CPUE of age-1+ fish for each species was highest in 1982 (for redside shiner, greatest values of CPUE and PO for age-1+ fish occurred in 1983). Over all years, reaches with greatest CPUE values for age-1+ fish were the same as those with highest CPUE for age-0 fish.

Correlations among years between values of total relative abundance for age-0 fish with annual spawning-period parameters by taxon were somewhat similar among most fishes, natives and nonnatives (Table 9). For all fishes, correlation coefficients were positive for CPUE compared with SPAWN-T and, except for flannelmouth sucker, negative for CPUE compared with SPAWN-1. The degree of association was generally stronger for nonnatives than natives. Similarly, for all fishes except flannelmouth sucker and

Table 7.—Relative abundance of age-0 fish, by river reach and over all reaches per year and by reach over all years, for selected native fishes collected with seines from backwaters or shoreline habitats with negligible water velocity, lower Yampa River, Colorado. Relative abundance indices: CPUE = catch-per-unit-effort (number of fish per 1,000 m² sampled), and PO = percentage of occurrence (percentage of all samples, per year and reach, in which fish in either age class for each taxon occurred). Only samples collected on or after estimated initiation of spawning for each taxon per year were included in analyses.

		River reach[a]											
		5		4		3		2		1		Total	
Year	Taxon	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO
1980	*Gila* sp.[b]	328	86	815	73	346	46	1,556	57	1,080	68	807	64
	Rhinichthys osculus	238	86	439	100	218	69	1,280	79	414	58	437	72
	Catostomus discobolus	38	29	109	27	134	54	251	43	35	35	102	39
	C. latipinnis	75	57	74	45	44	62	52	50	19	39	40	45
1981	*Gila* sp.[b]	401	67	981	82	834	77	806	69	1,224	74	1,043	73
	R. osculus	1,254	73	239	73	572	77	250	48	317	67	334	63
	C. discobolus	28	20	50	45	297	62	59	18	97	25	93	26
	C. latipinnis	7	7	19	45	45	31	11	10	44	20	41	18
1982	*Gila* sp.[b]	0	0	0	0	3,366	50	677	63	946	73	966	64
	R. osculus	0	0	140	100	308	80	266	64	224	53	233	57
	C. discobolus	0	0	0	0	177	50	201	39	149	36	158	34
	C. latipinnis	0	0	0	0	34	50	105	39	162	48	141	42
1983	*Gila* sp.[b]	67	50	1,085	88	729	59	719	56	1,026	75	955	71
	R. osculus	0	0	285	88	426	76	635	48	667	67	602	65
	C. discobolus	67	67	20	24	307	59	110	23	266	34	240	35
	C. latipinnis	83	50	26	35	60	35	35	23	144	36	116	34
1984	*Gila* sp.[b]			306	50	556	50	1,354	79	731	73	740	71
	R. osculus			418	71	333	56	2,219	100	784	85	814	83
	C. discobolus			173	79	552	50	3,333	79	815	87	874	83
	C. latipinnis			112	43	33	44	83	100	150	63	146	63
1980	*Gila* sp.[b]	199	51	637	63	1,166	56	1,022	64	1,001	73		
—	*R. osculus*	371	46	304	85	373	70	930	59	481	67		
1984	*C. discobolus*	33	24	70	37	293	55	791	32	272	44		
	C. latipinnis	41	22	43	35	46	44	57	31	104	40		

[a]**Reach 5** = Cross Mountain Canyon (river km 94.1–>89.1), **Reach 4** = lower end of Cross Mountain Canyon to Lily Park (river km 89.1–>81.8), **Reach 3** = Lily Park to Deerlodge Park (river km 81.8–>72.2), **Reach 2** = Deerlodge Park to Harding Hole (river km 72.2–>32.2), **Reach 1** = Harding Hole to Yampa-Green River confluence (river km 32.2–0.0). [b]Primarily *G. robusta robusta*.

Table 8.—Relative abundance of age-0 or older fish, by river reach and over all reaches per year and by reach over all years, for selected nonnative fishes collected with seines from backwaters or shoreline habitats with negligible water velocity, lower Yampa River, Colorado. Relative abundance indices: CPUE = catch-per-unit-effort (number of fish per 1,000 m^2 sampled), and PO = percentage of occurrence (percentage of all samples, per year and reach, in which fish in either age class for each species occurred). For age-0 fish, only samples collected on or after estimated initiation of spawning for each species per year were included in analyses.

		River reach[a]																				Total			
		5				4				3				2				1							
		Age 0		Age 1+		Age 0		Age 1+		Age 0		Age 1+		Age 0		Age 1+		Age 0		Age 1+		Age 0		Age 1+	
Year	Species	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO	CPUE	PO
1980	*Cyprinella lutrensis*	10	14	28	86	254	100	8	18	62	70	45	38	90	21	39	36	767	42	84	52	348	41	55	45
	Notropis stramineus	175	43	48	86	744	55	20	27	58	54	1	8	63	7	55	14	34	10	9	48	114	23	15	33
	Pimephales promelas	170	14	15	29	2,857	73	18	27	55	31	3	38	20	14	8	14	178	20	9	10	197	28	8	20
	Richardsonius balteatus	130	57	8	29	416	45	4	18	57	31	3	23	38	7	39	14	7	10	59	29	51	16	29	24
1981	*C. lutrensis*	14	13	69	19	151	45	151	64	2,955	77	203	46	221	28	95	28	1,587	46	338	32	1,151	48	239	32
	N. stramineus	134	33	53	15	528	55	140	36	897	77	93	46	96	19	29	10	36	16	73	12	129	25	62	15
	P. promelas	465	40	84	19	4,843	55	173	45	655	62	103	54	81	17	46	10	145	16	11	9	350	23	36	14
	R. balteatus	21	13	118	44	1,289	73	67	45	62	38	62	23	45	17	32	13	13	10	79	17	74	23	66	20
1982	*C. lutrensis*	83	100	38	11	1,540	100	59	17	49	100	449	40	75	6	10	6	1,000	33	356	37	729	34	267	27
	N. stramineus	0	0	58	11	1,140	44	12	33	2,189	100	547	40	52	6	161	9	5	9	324	23	118	13	283	20
	P. promelas	35	22	19	11	16,620	56	77	42	151	80	11	10	16	13	54	13	164	21	88	21	364	23	77	19
	R. balteatus	0	0	39	11	70	56	12	33	30	30	11	10	15	8	53	25	4	7	120	27	9	10	98	26
1983	*C. lutrensis*	16	17	116	50	6	7	48	24	70	35	39	47	25	8	11	9	30	9	55	28	32	11	47	26
	N. stramineus	17	17	33	17	350	71	387	71	273	35	74	35	0	0	71	16	68	9	49	17	100	14	73	22
	P. promelas	50	17	33	33	188	43	225	35	226	59	70	41	17	15	29	7	123	19	19	12	126	21	37	15
	R. balteatus	17	17	67	33	60	14	225	65	14	12	86	65	6	8	163	33	6	5	95	28	10	7	110	34
1984	*C. lutrensis*					20	7	73	29	11	14	67	33	0	0	15	7	19	3	1	1	18	4	4	7
	N. stramineus					10	7	44	14	11	7	170	22	0	0	10	7	2	5	11	5	2	5	14	8
	P. promelas					20	7	44	14	10	7	141	33	146	79	31	21	187	47	6	4	181	44	10	9
	R. balteatus					18	21	37	21	10	7	74	17	0	0	26	21	2	4	2	2	2	6	4	7
1980	*C. lutrensis*	31	35	63	31	394	44	68	29	629	46	161	41	82	15	34	15	681	25	167	27				
—	*N. stramineus*	82	24	48	24	554	47	121	38	686	48	177	30	42	9	65	11	145	10	93	16				
1984	*P. promelas*	180	27	38	20	4,906	44	107	32	219	44	66	37	56	19	34	11	159	25	27	12				
	R. balteatus	42	19	58	35	371	39	71	38	35	21	47	30	21	10	63	22	6	7	69	20				

[a]**Reach 5** = Cross Mountain Canyon (river km 94.1->89.1), **Reach 4** = lower end of Cross Mountain Canyon to Lily Park (river km 89.1->81.8), **Reach 3** = Lily Park to Deerlodge Park (river km 81.8->72.2), **Reach 2** = Deerlodge Park to Harding Hole (river km 72.2->32.2), **Reach 1** = Harding Hole to Yampa-Green River confluence (river km 32.2–0.0).

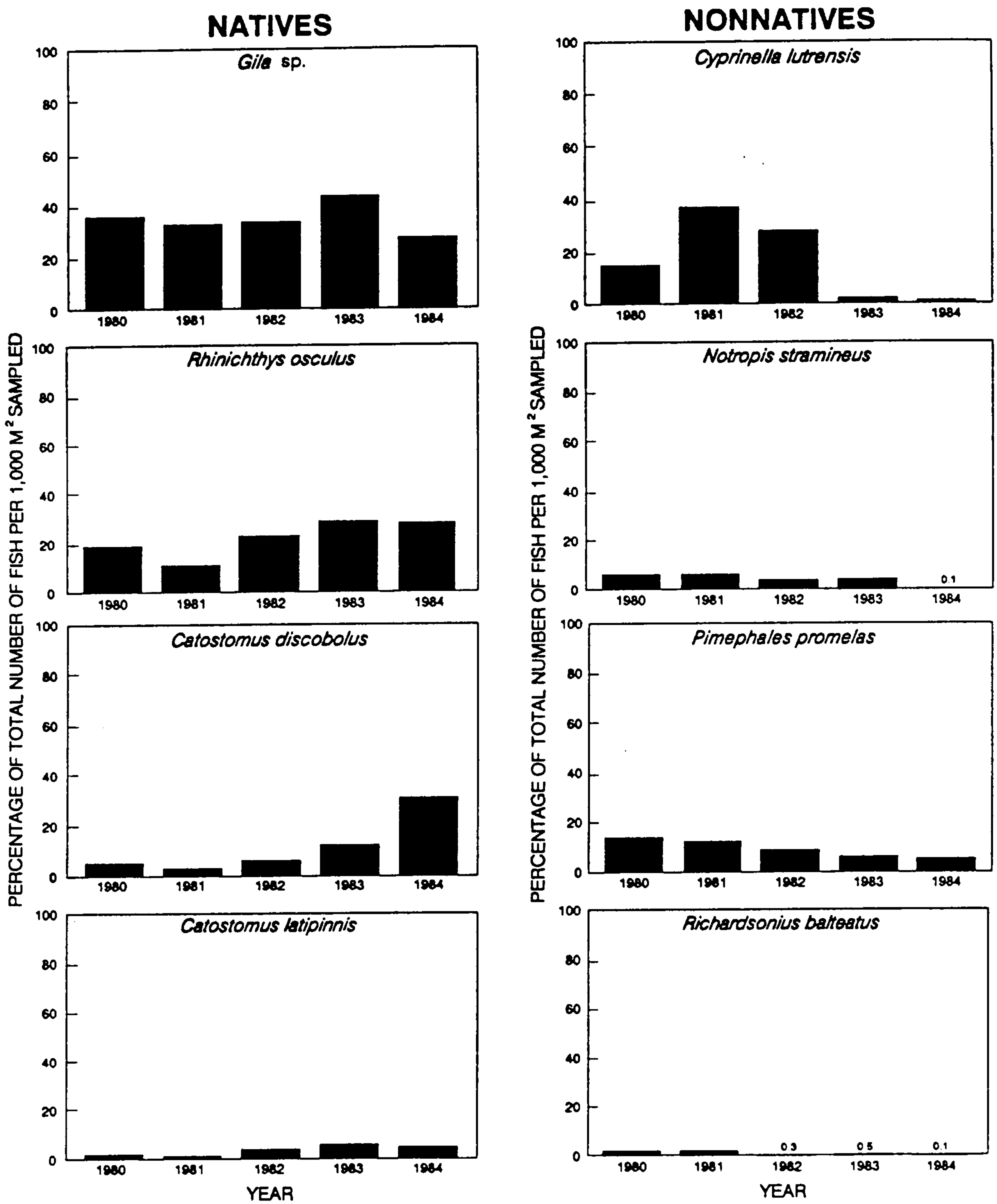

Figure 6.—Percentage contributed by each taxon to the total number of age-0 fish (all eight taxa combined) collected per 1,000 m² sampled per year, lower Yampa River, Colorado. Collections were made with seines in backwaters and shoreline habitats with negligible water velocity. *Gila* sp. primarily *G. robusta robusta*.

Table 9.—Correlations (Pearson *r*) among years between values of total relative abundance of age-0 fish and annual spawning-period parameters for selected fishes, lower Yampa River, Colorado, 1980–1984. Coefficients in **bold type** followed by an asterisk (*) are statistically significant ($r \geq 0.878$; df = 3; $P \leq 0.05$). Strong correlations (r = 0.778–0.877) are indicated by coefficients in bold type not followed by an asterisk.

Taxon and spawning-period parameter[b]	Relative-abundance index[a] CPUE	PO
	NATIVES	
Gila sp.[c]		
SPAWN-1	-0.150	-0.601
SPAWN-T	0.609	0.559
Rhinichthys osculus		
SPAWN-1	-0.103	-0.328
SPAWN-T	0.610	0.268
Catostomus discobolus		
SPAWN-1	-0.160	-0.137
SPAWN-T	0.439	0.225
C. latipinnis		
SPAWN-1	0.294	0.385
SPAWN-T	0.389	-0.418
	NONNATIVES	
Cyprinella lutrensis		
SPAWN-1	**-0.889***	-0.768
SPAWN-T	**0.938***	0.719
Notropis stramineus		
SPAWN-1	-0.474	-0.654
SPAWN-T	0.718	**0.782**
Pimephales promelas		
SPAWN-1	-0.677	0.268
SPAWN-T	0.601	-0.428
Richardsonius balteatus		
SPAWN-1	-0.584	-0.674
SPAWN-T	0.172	0.063

[a]CPUE = catch-per-unit-effort (number of fish collected per area sampled); PO = percentage of occurrence (percentage of all samples in which each taxon occurred). [b]SPAWN-1 = number of days, beginning April 1, to estimated initiation of spawning; SPAWN-T = estimated total number of days in spawning season. Collections were made with seines in backwaters or shoreline habitats with negligible water velocity; spawning-period parameters were determined from collections of age-0 fish. [c]Primarily *G. robusta robusta*.

fathead minnow, coefficients were negative for correlations between PO and SPAWN-1 and positive for correlations between PO and SPAWN-T. Overall, the two spawning-period parameters appeared to be inadequate indicators of relative abundance.

Comparisons of River Flow and Temperature with Fish Spawning Periods and Relative Abundance

Within constraints of a descriptive analysis of survey-sampling data, results of this study suggest species- and group-specific (natives versus nonnatives) relationships between timing of spawning and fish abundance and flow and temperature regimes. Associations among years between annual discharge and temperature parameters of the lower Yampa River in April–May or April–July and annual spawning-period parameters and total CPUE of age-0 fish per taxon were clearer and generally more consistent for nonnative than native fishes.

Associations between flows and abundance of young of various native and nonnative fishes in other, more regulated, rivers of the upper Colorado system in Colorado and Utah, have been examined, i.e., Colorado River (McAda and Kaeding 1989; Osmundson and Kaeding 1989, 1991; Valdez 1990), Gunnison River (Osmundson and Kaeding 1991), and Green River (Haines and Tyus 1990). Most of these studies associated annual peak discharge with abundance of larval or post-larval fish collected from backwaters (post-larvae defined as young-of-the-year juveniles for all fishes or age-1+ fish for smaller cyprinids collected in fall; definition of age-0 fish, larvae and juveniles, was based primarily on TL). Notably, overall trends of fish abundance related to flows observed in the other studies and in our investigation are very similar, despite differences in sampling or analytical procedures among studies and environmental conditions or extent of alterations to natural attributes among rivers.

Nonnatives.—It seems reasonable that conditions allowing for an earlier start of spawning and a longer spawning season would especially enhance the reproductive output of abbreviated interopares (short-lived fractional spawners) like red shiner and fathead minnow (there is evidence to suggest that sand shiner and possibly redside shiner are also fractional spawners). Earlier initiation of spawning and higher CPUE for all nonnatives and longer spawning seasons for red shiner, sand shiner, and fathead minnow were generally associated with low peak discharge, low–moderate daily mean and total discharges, and moderate–high numbers of cumulative degree-days (Figures 7–12). Conversely, later initiation of spawning and lower CPUE for all nonnatives and shorter spawning seasons for red shiner, sand shiner, and fathead minnow were generally associated with high peak discharge, moderate–high daily mean and total discharges, and low–moderate numbers of cumulative degree-days. Associations between length of spawning season for redside shiner and discharge and cumulative degree-days were opposite of those exhibited by the other nonnatives. This difference is probably a result of redside shiner's preference for cooler water.

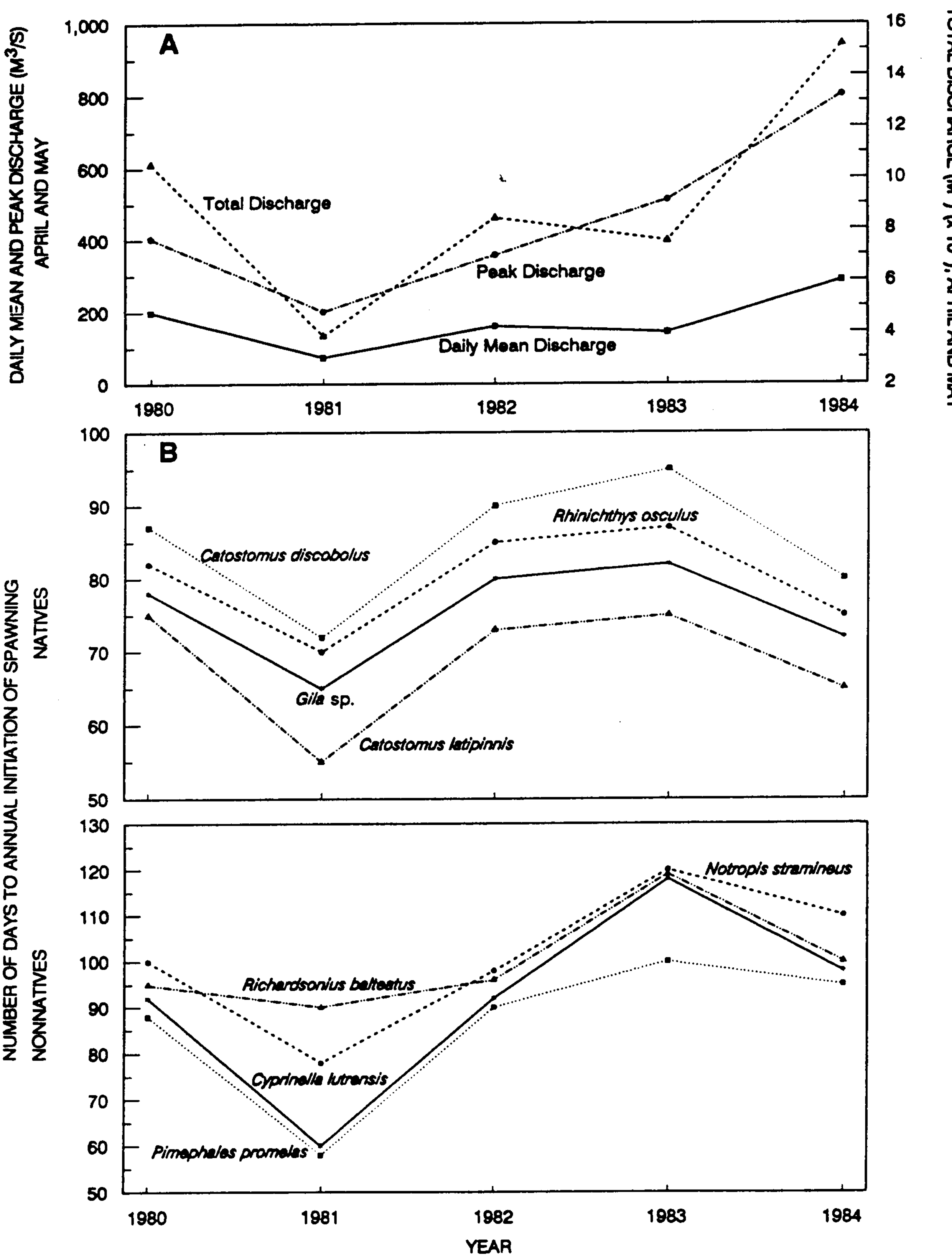

Figure 7.—A) Annual discharge parameters during April and May for the lower Yampa River, Colorado. Data taken from USGS records for the Yampa River near Maybell and at Deerlodge Park, Colorado; annual values of monthly discharge parameters at the two locations were averaged for the lower Yampa River. B) Estimated number of days, beginning April 1, to annual initiation of spawning for selected fishes, lower Yampa River, Colorado. Determined from collections of age-0 fish. *Gila* sp. primarily *G. robusta robusta*.

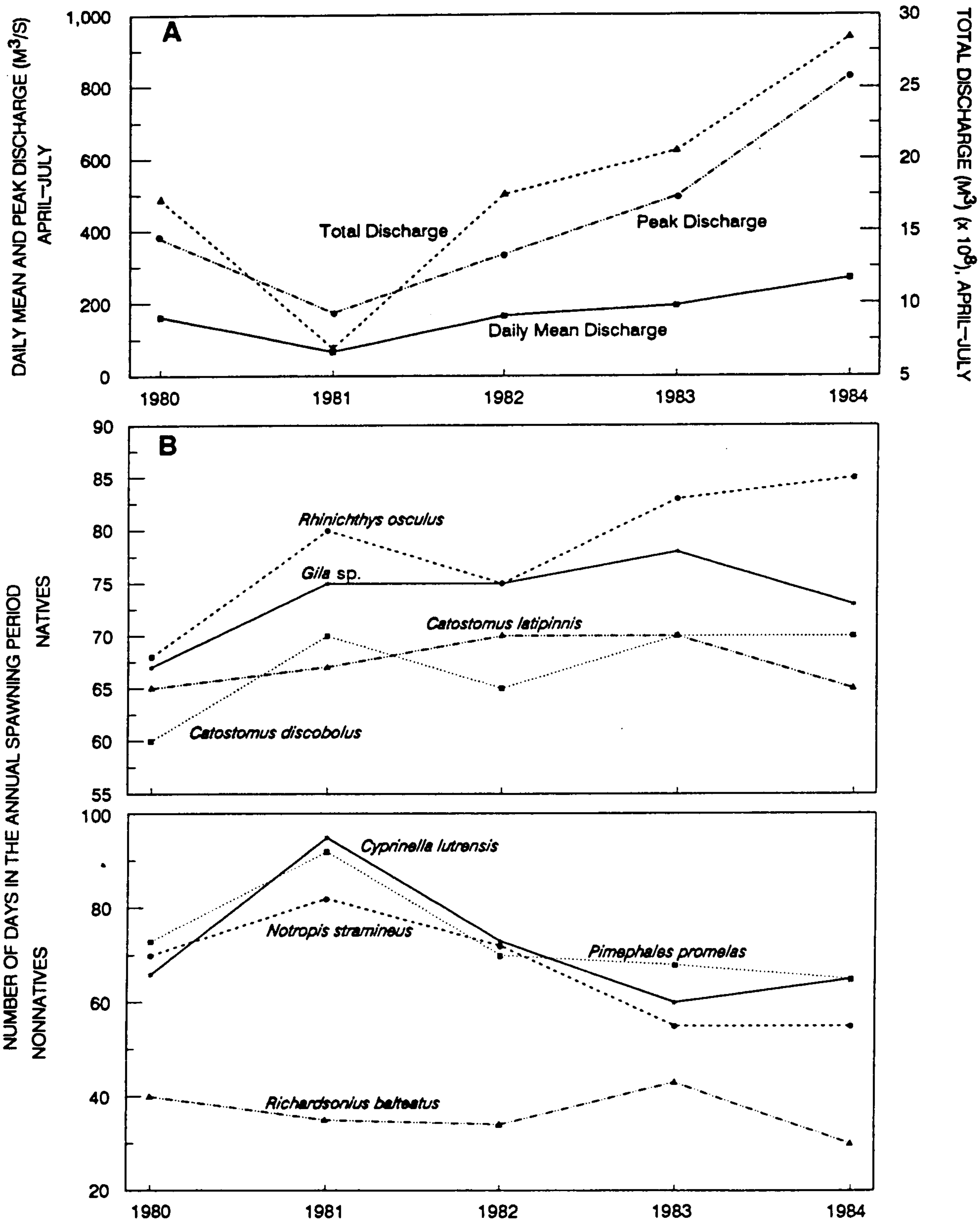

Figure 8.—A) Annual discharge parameters during April-July for the lower Yampa River, Colorado. Data taken from USGS records for the Yampa River near Maybell and at Deerlodge Park, Colorado; annual values of monthly discharge parameters at the two locations were averaged for the lower Yampa River. B) Estimated total number of days in the annual spawning period for selected fishes, lower Yampa River, Colorado. Determined from collections of age-0 fish. *Gila* sp. primarily *G. robusta robusta*.

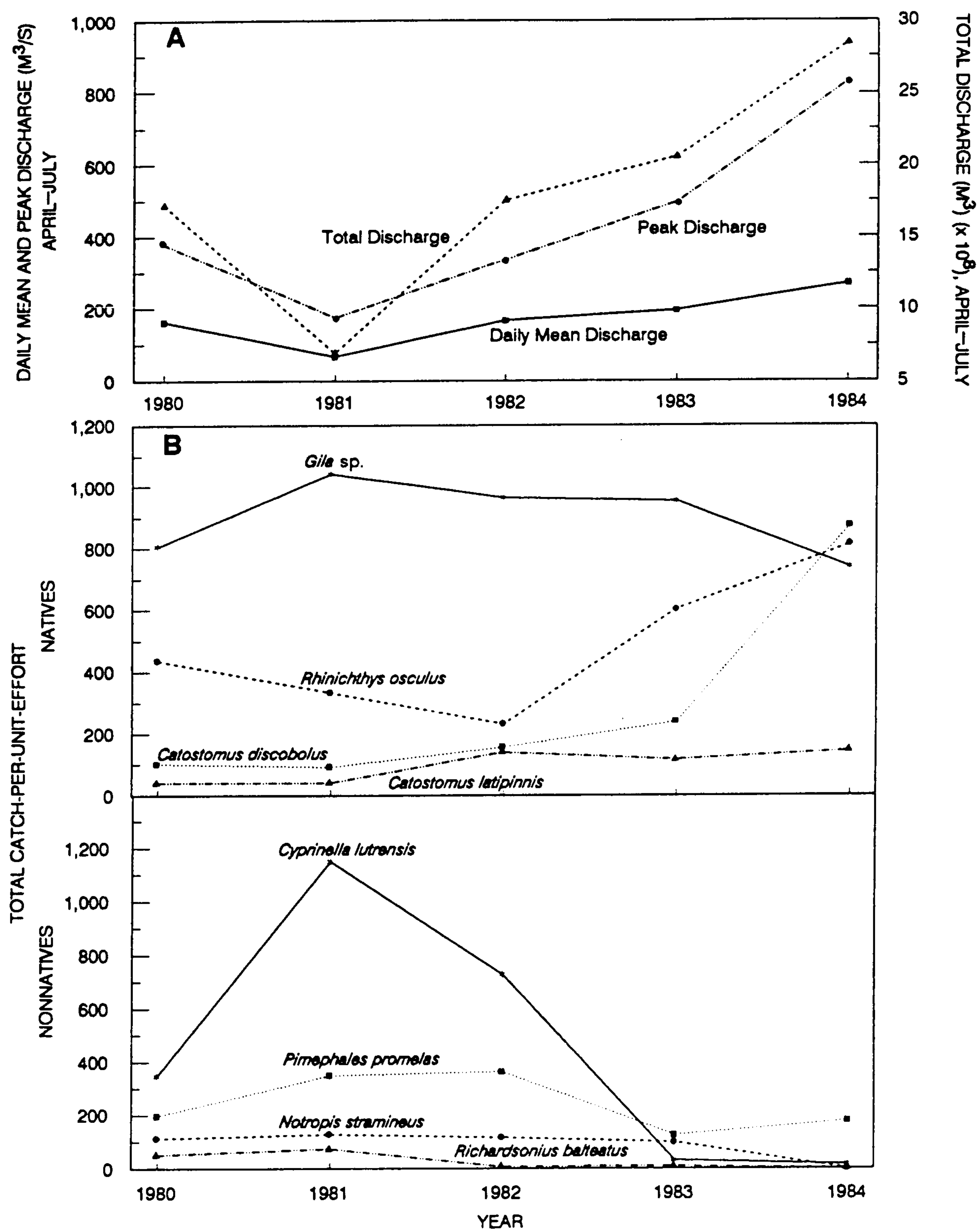

Figure 9.—**A**) Annual discharge parameters during April–July for the lower Yampa River, Colorado. Data taken from USGS records for the Yampa River near Maybell and at Deerlodge Park, Colorado; annual values of monthly discharge parameters at the two locations were averaged for the lower Yampa River. **B**) Total annual catch-per-unit-effort of age-0 fish (number of fish collected per 1,000 m^2 sampled) for selected fishes, lower Yampa River, Colorado. Collections were made with seines in backwaters and shoreline habitats with negligible water velocity. *Gila* sp. primarily *G. robusta robusta*.

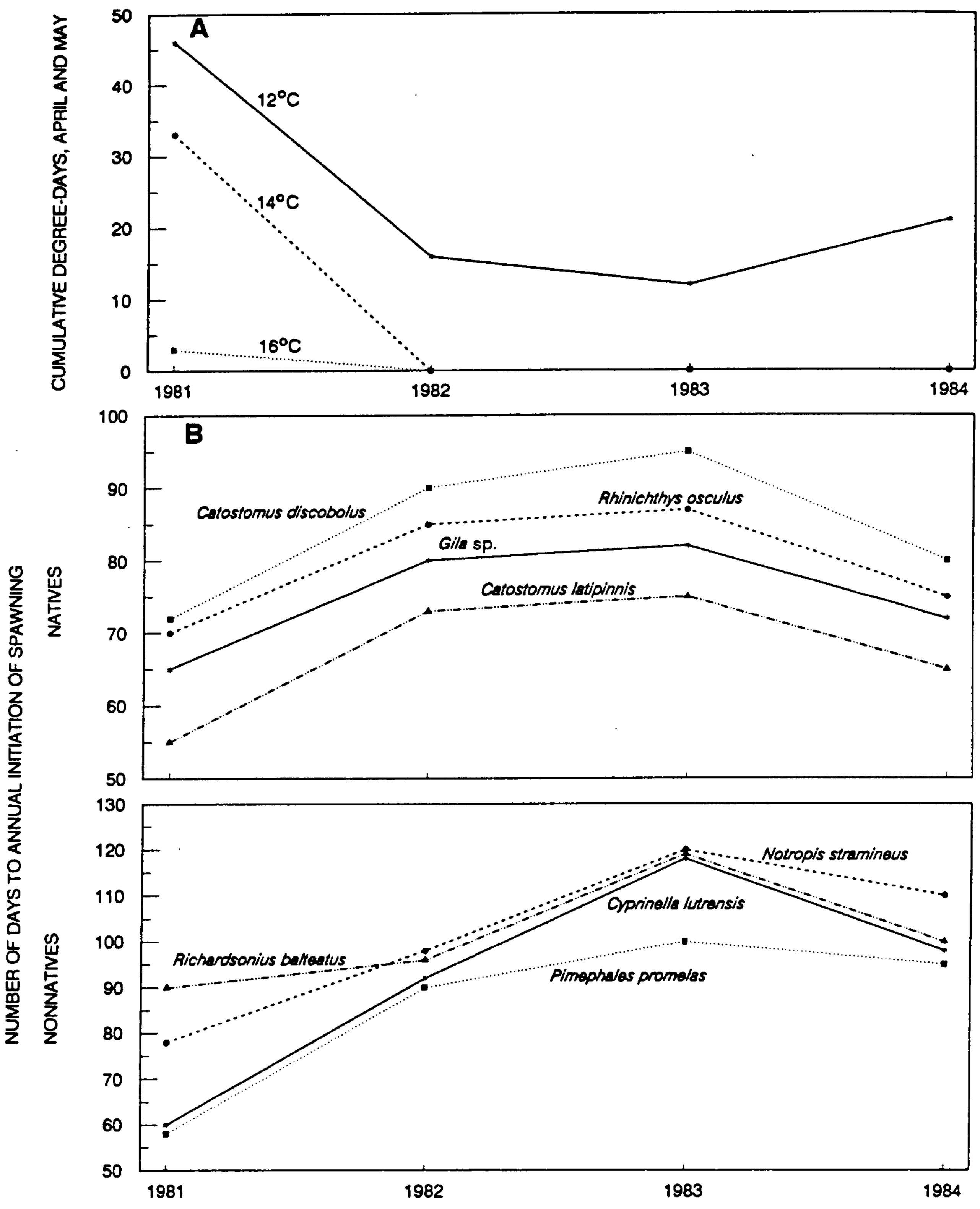

Figure 10.—A) Annual cumulative degree-days for selected mainchannel water temperatures during April and May, lower Yampa River near Maybell, Colorado. Degree-days = number of days that maximum mainchannel water temperatures reached or exceeded 12, 14, or 16°C (data taken from USGS records). B) Estimated number of days, beginning April 1, to annual initiation of spawning for selected fishes, lower Yampa River, Colorado. Determined from collections of age-0 fish. *Gila* sp. primarily *G. robusta robusta*.

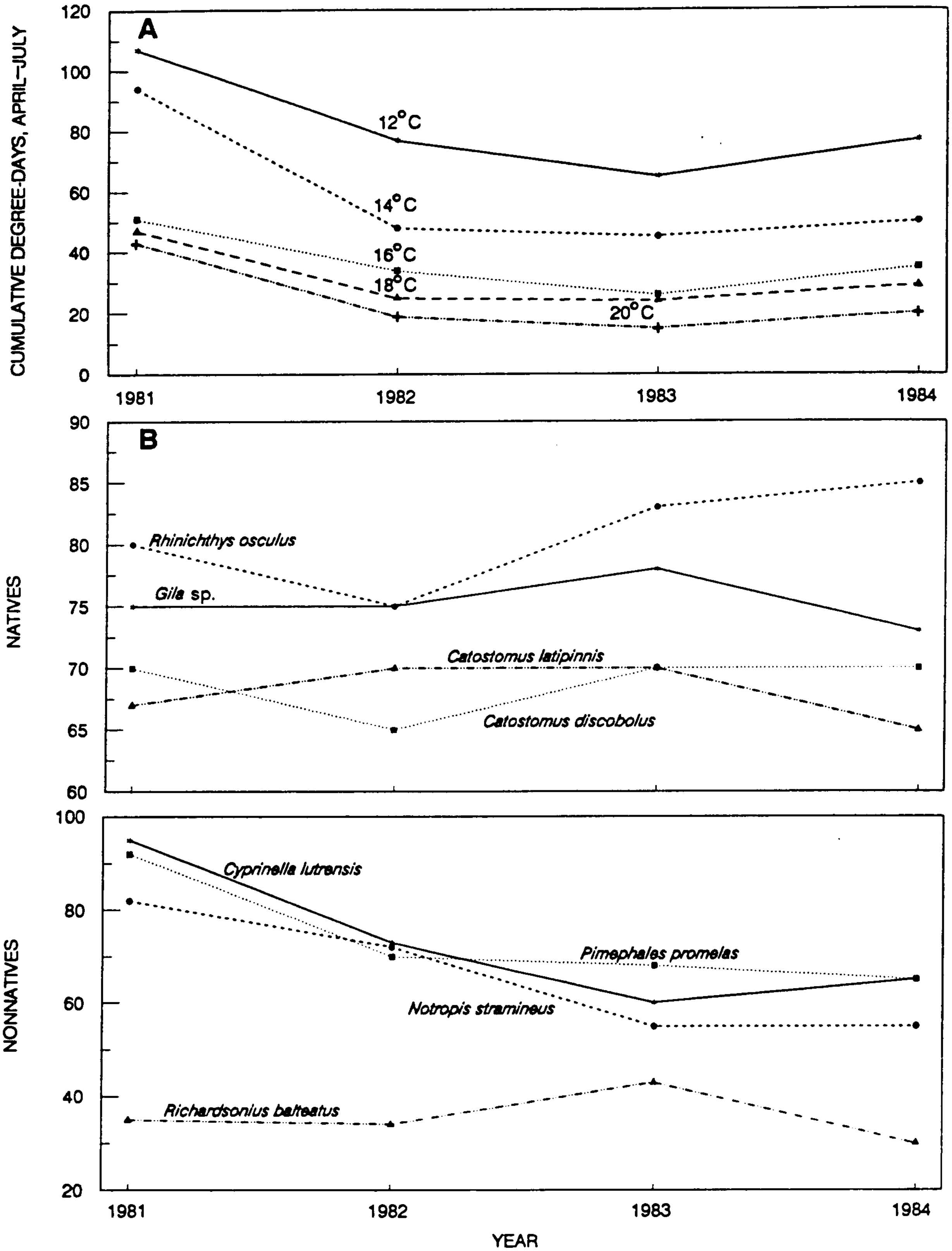

Figure 11.—**A**) Annual cumulative degree-days for selected mainchannel water temperatures during April–July, lower Yampa River near Maybell, Colorado. Degree-days = number of days that maximum mainchannel water temperatures reached or exceeded 12, 14, 16, 18, or 20°C (data taken from USGS records). **B**) Estimated total number of days in the annual spawning period for selected fishes, lower Yampa River, Colorado. Determined from collections of age-0 fish. *Gila* sp. primarily *G. robusta robusta*.

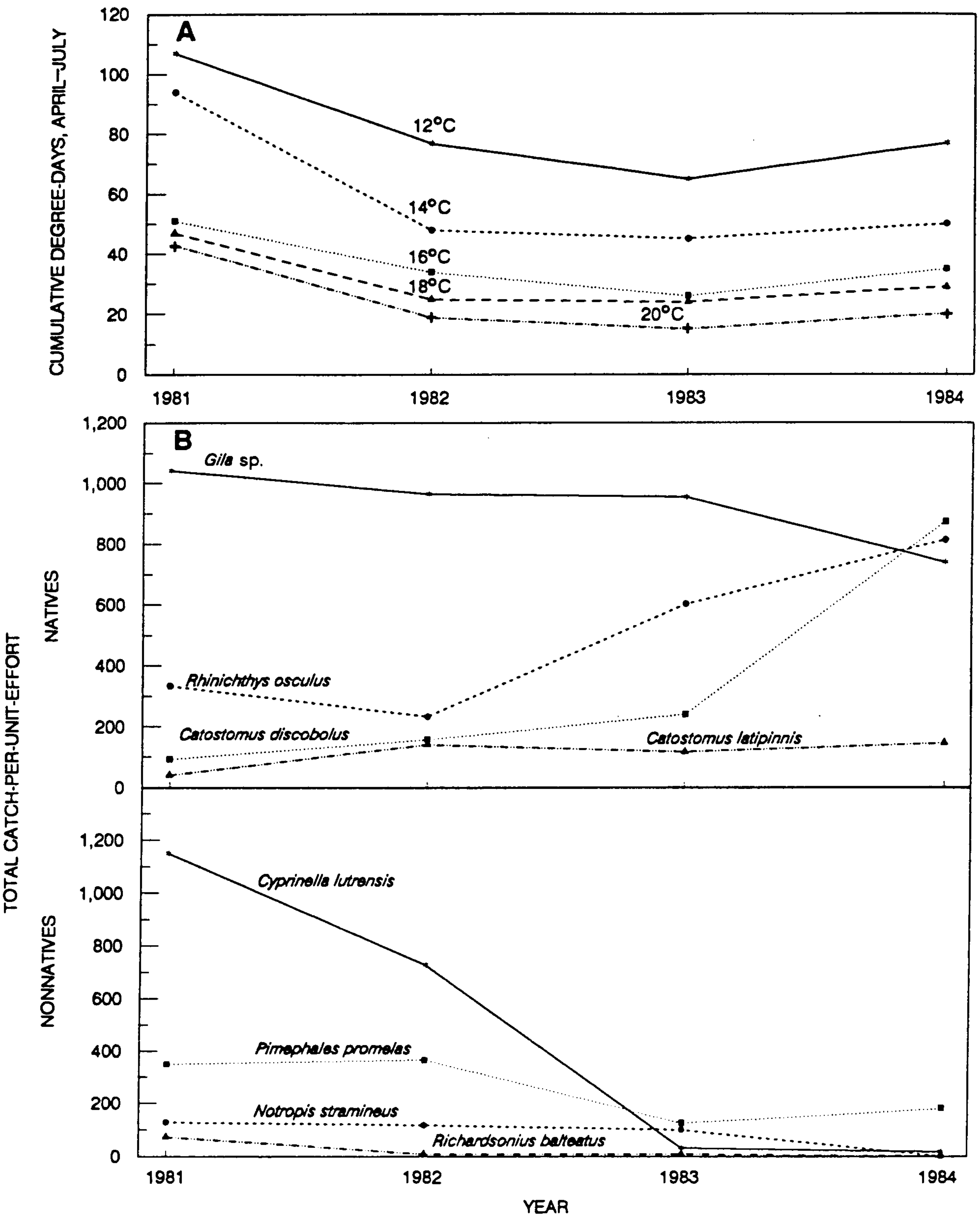

Figure 12.—**A**) Annual cumulative degree-days for selected mainchannel water temperatures during April–July, lower Yampa River near Maybell, Colorado. Degree-days = number of days that maximum mainchannel water temperatures reached or exceeded 12, 14, 16, 18, or 20°C (data taken from USGS records). **B**) Total annual catch-per-unit-effort of age-0 fish (number of fish collected per 1,000 m^2 sampled) for selected fishes, lower Yampa River, Colorado. Collections were made with seines in backwaters and shoreline habitats with negligible water velocity. *Gila* sp. primarily *G. robusta robusta*.

Within each of the comparative trends for nonnative fishes, degree of association between variables among years varied with the species and comparison (Tables 10–13). Values of SPAWN-1 for all nonnatives were mostly weakly–moderately correlated with values of discharge parameters (correlations were generally stronger for comparisons with peak discharge) and moderately–strongly correlated with numbers of degree-days. Comparisons of SPAWN-T for red shiner, sand shiner, and fathead minnow with discharge showed moderate–significant associations (mostly weak for redside shiner). Catch-per-unit-effort for red, sand, and redside shiners was moderately–significantly correlated with discharge (correlations were mostly moderate for fathead minnow). Degree of association between CPUE and degree-days was mostly moderate for red shiner and fathead minnow, weak for sand shiner, and strong–significant for redside shiner. Results from previous studies in the Colorado and Gunnison rivers also showed moderate–significant inverse relationships between magnitude of discharge and abundance of red shiner, sand shiner, and fathead minnow. High flows may flush nonnative cyprinids from preferred lentic-like habitats or slow the rate of warming, resulting in local reductions in their abundance and reproductive success (Valdez 1990).

Natives.—Compared to nonnatives, spawning periods of native fish species were fairly consistent among years. For all native fishes, associations between SPAWN-1 and discharge were positive but mostly weak, whereas, associations between SPAWN-1 and degree-days were negative and moderate–significant (strong–significant for flannelmouth sucker). Correlations between SPAWN-T and discharge were mostly weak, but the nature of associations (positive or negative) varied considerably among months and discharge parameters; overall, correlations were generally negative for *Gila* sp. and flannelmouth sucker and positive for speckled dace and bluehead sucker.

Associations between flow and temperature and relative abundance of all natives except *Gila* sp. were opposite of those for nonnatives. Greater values of CPUE for speckled dace, bluehead sucker, and flannelmouth sucker were associated with high discharge and low–moderate numbers of cumulative degree-days, whereas, higher CPUE for *Gila* sp. was generally associated with low–moderate discharge and moderate–high numbers of cumulative degree-days. Conversely, smaller values of CPUE for speckled dace, bluehead sucker, and flannelmouth sucker were associated with low–moderate discharge and moderate–high numbers of cumulative degree-days, whereas, lower CPUE for *Gila* sp. was generally associated with high discharge and low–moderate numbers of cumulative degree-days. Degree of association for comparisons of CPUE with discharge was mostly moderate–significant for all taxa. Associations between CPUE and degree-days were weak–moderate for *Gila* sp., mostly weak for speckled dace and bluehead sucker, and mostly strong–significant for flannelmouth sucker. Osmundson and Kaeding (1989) reported that as annual magnitudes of spring and summer flows progressively decreased during 1986–1988, abundance of young speckled dace and bluehead sucker similarly decreased; abundance of young *Gila* was highest in 1987. During 1986–1989, correlations between flow and abundance of young fish

Table 10.—Correlations (Pearson *r*) among years between values of monthly river-discharge parameters and annual spawning-period parameters for selected fishes, lower Yampa River, Colorado, 1980–1984. Coefficients in **bold** type followed by an asterisk (*) are statistically significant ($r \geq 0.878$; df = 3; $P \leq 0.05$). Strong correlations ($r = 0.778–0.877$) are indicated by coefficients in bold type not followed by an asterisk.

Taxon and spawning-period parameter[b]	Discharge[a]															
	April			May			June			May and June		July			April–July	
	Peak	Daily mean	Total	Peak	Daily mean	Total	Peak	Daily mean	Total	Daily mean	Total	Peak	Daily mean	Total	Daily mean	Total
NATIVES																
Gila sp.[c]																
SPAWN-1	0.475	0.358	0.348	0.202	0.172	0.174										
SPAWN-T	-0.515	-0.624	-0.627	-0.032	-0.356	-0.357	0.202	0.224	0.223	-0.089	-0.094	0.301	0.491	0.492	-0.045	-0.046
Rhinichthys osculus																
SPAWN-1	0.363	0.246	0.236	0.095	0.052	0.054										
SPAWN-T	-0.135	-0.245	-0.244	0.258	0.184	0.183	0.619	0.503	0.502	-0.358	-0.355	0.347	0.513	0.514	0.346	0.345
Catostomus discobolus																
SPAWN-1	0.488	0.396	0.387	0.233	0.186	0.188										
SPAWN-T	-0.387	-0.481	-0.479	0.250	-0.065	-0.066	0.402	0.275	0.274	0.102	0.098	0.139	0.333	0.334	0.090	0.088
C. latipinnis																
SPAWN-1	0.601	0.501	0.492	0.233	0.268	0.270										
SPAWN-T	-0.427	-0.504	-0.512	-0.319	-0.512	-0.512	-0.100	0.073	0.071	-0.255	-0.258	0.343	0.445	0.447	-0.170	-0.170
NONNATIVES																
Cyprinella lutrensis																
SPAWN-1	0.629	0.618	0.431	0.625	0.470	0.472										
SPAWN-T	**-0.832**	-0.681	-0.675	-0.708	-0.654	-0.656	-0.753	**-0.858**	**-0.858**	**-0.803**	**-0.802**	**-0.878***	-0.757	-0.756	**-0.832**	**-0.832**
Notropis stramineus																
SPAWN-1	0.671	0.652	0.470	0.466	0.569	0.571										
SPAWN-T	-0.691	-0.510	-0.506	**-0.887***	-0.703	-0.704	**-0.973***	**-0.984***	**-0.984***	**-0.895***	**-0.893***	**-0.894***	**-0.861**	**-0.861**	**-0.905***	**-0.904***
Pimephales promelas																
SPAWN-1	**0.785**	**0.787**	0.643	0.715	0.646	0.648										
SPAWN-T	**-0.850**	-0.770	-0.751	**-0.793**	-0.768	-0.770	**-0.782**	**-0.902***	**-0.902***	**-0.890***	**-0.889***	**-0.942***	**-0.856**	**-0.854**	**-0.925***	**-0.926***
Richardsonius balteatus																
SPAWN-1	0.224	0.193	0.030	0.423	0.123	0.125										
SPAWN-T	-0.099	-0.307	-0.283	-0.316	-0.437	-0.434	-0.094	-0.017	-0.019	-0.256	-0.258	0.085	0.009	0.009	-0.226	-0.227

[a]Data taken from USGS records for the Yampa River near Maybell and at Deerlodge Park, Colorado; annual values of monthly discharge parameters at the two locations were averaged for the lower Yampa River. [b]SPAWN-1 = number of days, beginning April 1, to estimated initiation of spawning; SPAWN-T = estimated total number of days in spawning season; spawning-period parameters were determined from collections of age-0 fish. [c]Primarily *G. robusta robusta*.

Table 11.—Correlations (Pearson r) among years between values of monthly river-discharge parameters and total relative abundance of age-0 fish for selected fishes, lower Yampa River, Colorado, 1980–1984. Coefficients in **bold** type followed by an asterisk (*) are statistically significant ($r \geq 0.878$; df = 3; $P \leq 0.05$). Strong correlations (r = 0.778–0.877) are indicated by coefficients in bold type not followed by an asterisk.

Taxon and abundance index[b]	Discharge[a]																
	April			May			June			May and June		July			April–July	
	Peak	Daily mean	Total	Peak	Daily mean	Total	Peak	Daily mean	Total	Daily mean	Total	Peak	Daily mean	Total	Daily mean	Total
								NATIVES								
Gila sp.[c]																
CPUE	**-0.939***	**-0.934***	**-0.935***	**-0.885***	**-0.944***	**-0.945***	-0.635	-0.593	-0.595	**-0.834**	**-0.837**	-0.422	-0.281	-0.279	**-0.797**	**-0.797**
PO	-0.435	-0.535	-0.531	-0.139	-0.145	-0.146	0.268	0.075	0.075	-0.043	-0.046	-0.152	0.008	0.008	-0.088	-0.090
Rhinichthys osculus																
CPUE	0.601	0.463	0.463	**0.973***	0.752	0.752	**0.920***	**0.793**	**0.793**	**0.826**	**0.825**	0.534	0.519	0.519	**0.785**	**0.783**
PO	0.651	0.663	0.667	**0.806**	**0.835**	**0.835**	0.675	0.522	0.523	0.737	0.738	0.229	0.154	0.153	0.670	0.669
Catostomus discobolus																
CPUE	0.589	0.564	0.567	**0.923***	**0.859**	**0.858**	**0.828**	0.727	0.727	**0.854**	**0.854**	0.511	0.535	0.534	**0.819**	**0.818**
PO	0.728	0.724	0.728	**0.930***	**0.943***	**0.943***	**0.785**	0.695	0.696	**0.885***	**0.885***	0.540	0.455	0.454	**0.846**	**0.846**
C. latipinnis																
CPUE	0.401	0.364	0.360	0.657	0.542	0.542	0.670	0.769	0.769	0.694	0.695	**0.838**	**0.901***	**0.901***	0.740	0.741
PO	**0.935***	**0.947***	**0.947***	**0.871**	**0.981***	**0.981***	0.700	0.724	0.724	**0.921***	**0.923***	0.639	0.539	0.537	**0.912***	**0.913***
								NONNATIVES								
Cyprinella lutrensis																
CPUE	**-0.817**	-0.645	-0.641	**-0.860**	-0.748	-0.750	**-0.909***	**-0.927***	**-0.927***	**-0.891***	**-0.890***	**-0.832**	-0.741	-0.740	**-0.894***	**-0.902***
PO	-0.577	-0.422	-0.419	**-0.910***	-0.699	-0.699	**-0.985***	**-0.971***	**-0.971***	**-0.886***	**-0.884***	**-0.862**	**-0.883***	**-0.883***	**-0.893***	**-0.892***
Notropis stramineus																
CPUE	-0.658	-0.625	-0.627	**-0.948***	**-0.897***	**-0.897***	**-0.848**	-0.748	-0.750	**-0.886***	**-0.886***	-0.527	-0.528	-0.527	**-0.850**	**-0.850**
PO	-0.602	-0.538	-0.537	**-0.864**	-0.763	-0.763	**-0.837**	**-0.872**	**-0.873**	**-0.872**	**-0.871**	**-0.833**	**-0.867**	**-0.867**	**-0.891***	**-0.891***
Pimephales promelas																
CPUE	-0.622	-0.409	-0.405	-0.675	-0.518	-0.519	**-0.783**	-0.742	-0.741	-0.668	-0.666	-0.591	-0.499	-0.499	-0.652	-0.651
PO	0.674	0.716	0.721	**0.821**	**0.900***	**0.899***	0.625	0.504	0.506	0.764	0.766	0.262	0.225	0.224	0.710	0.710
Richardsonius balteatus																
CPUE	-0.593	-0.510	-0.505	-0.744	-0.633	-0.633	-0.775	**-0.893***	**-0.893***	**-0.809**	**-0.807**	**-0.961***	**-0.967***	**-0.967***	**-0.857**	**-0.857**
PO	-0.674	-0.556	-0.551	**-0.814**	-0.686	-0.686	**-0.861**	**-0.959***	**-0.959***	**-0.872**	**-0.870**	**-0.988***	**-0.971***	**-0.971***	**-0.912***	**-0.912***

[a]Data taken from USGS records for the Yampa River near Maybell and at Deerlodge Park, Colorado; annual values of monthly discharge parameters at the two locations were averaged for the lower Yampa River. [b]CPUE = catch-per-unit-effort (number of fish collected per area sampled); PO = percentage of occurrence (percentage of all samples in which each taxon occurred); collections were made with seines in backwaters or shoreline habitats with negligible water velocity. [c]Primarily *G. robusta robusta*.

Table 12.—Correlations (Pearson *r*) among years between numbers of degree-days per month for selected mainchannel water temperatures and values of annual spawning-period parameters for selected fishes, lower Yampa River, Colorado, 1980–1984. Coefficients in **bold** type followed by an asterisk (*) are statistically significant ($r \geq 0.950$; df = 2; $P \leq 0.05$). Strong correlations ($r = 0.850$–0.949) are indicated by coefficients in bold type not followed by an asterisk.

Taxon and spawning-period parameter[b]	Degree-days[a]																										
	April			May			June					May and June					July			April–July				
	12°C	14°C	16°C	12°C	14°C	16°C	12°C	14°C	16°C	18°C	20°C	12°C	14°C	16°C	18°C	20°C	16°C	18°C	20°C	12°C	14°C	16°C	18°C	20°C
NATIVES																								
Gila sp.[c]																								
SPAWN-1	-0.833	-0.833	-0.833	**-0.991**	**-0.925**	-0.833																		
SPAWN-T	-0.081	-0.081	-0.081	-0.635	-0.290	-0.081	-0.440	-0.371	-0.232	-0.081	-0.081	-0.630	-0.329	-0.226	-0.081	-0.081	**-0.889**	-0.648	-0.384	-0.365	-0.243	-0.338	-0.260	-0.245
Rhinichthys osculus																								
SPAWN-1	-0.761	-0.761	-0.761	**-0.985**	**-0.873**	-0.761																		
SPAWN-T	-0.115	-0.115	-0.115	0.082	-0.072	-0.115	-0.762	-0.088	-0.128	-0.115	-0.115	-0.248	-0.080	-0.127	-0.115	-0.115	-0.345	-0.238	-0.154	-0.218	-0.093	-0.173	-0.013	-0.137
Catostomus discobolus																								
SPAWN-1	-0.795	-0.795	-0.795	**-0.999**	**-0.903**	-0.795																		
SPAWN-T	0.333	0.333	0.333	0.333	0.326	0.333	-0.549	0.287	0.289	0.333	0.333	0.017	0.307	0.289	0.333	0.333	0.333	0.454	0.219	0.167	0.319	0.215	0.389	0.276
C. latipinnis																								
SPAWN-1	**-0.880**	**-0.880**	**-0.880**	**-0.985**	**-0.995**	**-0.880**																		
SPAWN-T	-0.272	-0.272	-0.272	-0.739	-0.443	-0.272	-0.034	-0.488	-0.372	-0.272	-0.272	-0.541	-0.465	-0.368	-0.272	-0.272	-0.544	-0.824	-0.457	-0.410	-0.400	-0.416	-0.457	-0.375
NONNATIVES																								
Cyprinella lutrensis																								
SPAWN-1	**-0.887**	**-0.887**	**-0.887**	**-0.949**	-0.749	**-0.887**																		
SPAWN-T	**0.938**	**0.938**	**0.938**	0.815	**0.945**	**0.938**	0.804	**0.946**	**0.960**	**0.938**	**0.938**	**0.905**	**0.946**	**0.960**	**0.938**	**0.938**	0.571	0.723	**0.963**	**0.977**	**0.950**	**0.971**	**0.923**	**0.963**
Notropis stramineus																								
SPAWN-1	**-0.867**	**-0.867**	**-0.867**	-0.804	**-0.895**	**-0.867**																		
SPAWN-T	0.800	0.800	0.800	0.607	0.781	0.800	**0.905**	0.784	0.816	0.800	0.800	0.797	0.783	0.815	0.800	0.800	0.550	0.476	0.821	**0.853**	0.795	0.836	0.743	0.821
Pimephales promelas																								
SPAWN-1	**-0.977**	**-0.977**	**-0.977**	-0.841	**-0.988**	**-0.977**																		
SPAWN-T	**0.986**	**0.986**	**0.986**	0.731	**0.862**	**0.986**	0.614	**0.918**	**0.965**	**0.986**	**0.986**	0.769	**0.932**	0.966	**0.986**	**0.986**	0.311	0.656	0.464	**0.930**	**0.958**	**0.939**	**0.938**	**0.963**
Richardsonius balteatus																								
SPAWN-1	-0.599	-0.599	-0.599	-0.812	-0.717	-0.599																		
SPAWN-T	-0.061	-0.061	-0.061	-0.603	-0.267	-0.061	-0.504	-0.351	-0.215	-0.061	-0.061	-0.633	-0.307	-0.208	-0.061	-0.061	**-0.918**	-0.602	-0.371	-0.359	-0.222	-0.326	-0.231	-0.229

[a]Degree-days = number of days per month that maximum mainchannel water temperature reached or exceeded 12, 14, 16, 18, or 20°C (determined from USGS records for the Yampa River near Maybell, Colorado). [b]SPAWN-1 = number of days, beginning April 1, to estimated initiation of spawning; SPAWN-T = estimated total number of days in spawning season; spawning-period parameters were determined from collections of age-0 fish. [c]Primarily *G. robusta robusta*.

Table 13.—Correlations (Pearson *r*) among years between numbers of degree-days per month for selected mainchannel water temperatures and values of total relative abundance of age-0 fish for selected fishes, lower Yampa River, Colorado, 1980–1984. Coefficients in **bold** type followed by an asterisk (*) are statistically significant ($r \geq 0.950$; df = 2; $P \leq 0.05$). Strong correlations (r = 0.850–0.949) are indicated by coefficients in bold type not followed by an asterisk.

Taxon and abundance index[b]	Degree-days[a]																									
	April			May			June					May and June					July			April–July				
	12°C	14°C	16°C	12°C	14°C	16°C	12°C	14°C	16°C	18°C	20°C	12°C	14°C	16°C	18°C	20°C	16°C	18°C	20°C	12°C	14°C	16°C	18°C	20°C
NATIVES																									
Gila sp.[c]																									
CPUE	0.600	0.600	0.600	0.063	0.443	0.600	0.453	0.390	0.511	0.600	0.600	0.227	0.418	0.515	0.600	0.600	-0.149	-0.055	0.412	0.452	0.486	0.457	0.431	0.506
PO	0.549	0.549	0.549	0.501	0.536	0.549	-0.348	0.496	0.506	0.549	0.549	0.271	0.518	0.508	0.549	0.549	-0.211	0.594	0.435	0.376	0.533	0.434	0.593	0.494
Rhinichthys osculus																									
CPUE	-0.410	-0.410	-0.410	-0.083	-0.330	-0.410	-0.783	-0.324	-0.392	-0.410	-0.410	-0.369	-0.328	-0.393	-0.410	-0.410	-0.269	0.075	-0.379	-0.563	-0.359	-0.407	-0.283	-0.398
PO	-0.238	-0.238	-0.238	0.238	-0.093	-0.238	-0.483	-0.060	-0.169	-0.238	-0.238	-0.024	-0.077	-0.171	-0.238	-0.238	-0.119	0.378	-0.104	-0.160	-0.135	-0.146	-0.061	-0.169
Catostomus discobolus																									
CPUE	-0.459	-0.459	-0.459	0.082	-0.296	-0.459	-0.435	-0.246	-0.369	-0.459	-0.459	-0.116	-0.273	-0.373	-0.459	-0.459	-0.187	-0.208	-0.276	-0.322	-0.341	-0.321	-0.279	-0.366
PO	-0.475	-0.475	-0.475	0.086	-0.303	-0.475	-0.379	-0.248	-0.376	-0.475	-0.475	-0.091	0.277	-0.381	-0.475	-0.475	-0.244	-0.204	-0.273	-0.316	-0.517	-0.319	-0.291	-0.372
C. latipinnis																									
CPUE	**-0.963**	**-0.963**	**-0.963**	-0.638	**-0.887**	-0.963	-0.375	-0.843	**-0.909**	**-0.963**	**-0.963**	-0.606	**-0.867**	**-0.912**	**-0.963**	**-0.963**	-0.069	-0.593	-0.828	-0.829	**-0.907**	**-0.852**	**-0.901**	**-0.903**
PO	-0.757	-0.757	-0.757	-0.233	-0.605	-0.757	-0.346	-0.544	-0.661	-0.757	-0.757	-0.305	-0.576	-0.665	-0.757	-0.757	0.187	-0.147	-0.547	-0.571	-0.645	-0.589	-0.610	-0.653
NONNATIVES																									
Cyprinella lutrensis																									
CPUE	0.802	0.802	0.802	0.603	0.781	0.802	**0.901**	0.784	0.816	0.802	0.802	0.793	0.783	0.816	0.802	0.802	0.509	0.563	**0.884**	**0.852**	0.796	0.836	0.744	0.822
PO	0.777	0.777	0.777	0.506	0.730	0.777	**0.859**	0.722	0.774	0.777	0.777	0.707	0.727	0.774	0.777	0.777	0.434	0.370	0.759	0.796	0.750	0.781	0.694	0.776
Notropis stramineus																									
CPUE	0.479	0.479	0.479	-0.050	0.322	0.479	0.471	0.275	0.394	0.479	0.479	0.154	0.300	0.398	0.479	0.479	-0.146	-0.179	0.306	0.352	0.366	0.350	0.302	0.396
PO	**0.872**	**0.872**	**0.872**	0.432	0.757	**0.872**	0.496	0.709	0.803	**0.872**	**0.872**	0.507	0.735	0.807	**0.872**	**0.872**	0.020	0.341	0.715	0.737	0.789	0.750	0.756	0.798
Pimephales promelas																									
CPUE	0.527	0.527	0.527	0.481	0.555	0.527	**0.991**	0.587	0.585	0.527	0.527	0.742	0.571	0.582	0.527	0.527	0.720	0.338	0.642	0.683	0.560	0.647	0.500	0.596
PO	-0.291	-0.291	-0.291	0.296	-0.101	-0.291	-0.212	-0.040	-0.177	-0.291	-0.291	0.126	-0.072	-0.182	-0.291	-0.291	0.414	0.401	-0.062	-0.105	-0.150	-0.111	-0.094	-0.171
Richardsonius balteatus																									
CPUE	**0.994**	**0.994**	**0.994**	0.746	**0.951**	**0.994**	0.548	**0.923**	**0.970**	**0.994**	**0.994**	0.753	**0.939**	**0.971**	**0.994**	**0.994**	0.272	0.684	**0.919**	**0.924**	**0.965**	**0.937**	**0.953**	**0.967**
PO	**0.976**	**0.976**	**0.976**	0.746	**0.943**	**0.976**	0.683	**0.925**	**0.966**	**0.976**	**0.976**	0.807	**0.935**	**0.967**	**0.976**	**0.976**	0.382	0.662	**0.933**	**0.945**	**0.957**	**0.950**	**0.933**	**0.965**

[a]**Degree-days** = number of days per month that maximum mainchannel water temperature reached or exceeded 12, 14, 16, 18, or 20°C (determined from USGS records for the Yampa River near Maybell, Colorado). [b]CPUE = catch-per-unit effort (number of fish collected per area sampled); PO = percentage of occurrence (percentage of all samples in which each taxon occurred); collections were made with seines in backwaters or shoreline habitats with negligible water velocity. [c]Primarily *G. robusta robusta*.

were consistently positive and moderate–significant for speckled dace and bluehead sucker but inconsistent (strength and nature, positive or negative, of association varied among reaches) for flannelmouth sucker and *Gila* sp. (Osmundson and Kaeding 1991). Valdez (1990) noted that associations between year-class strength of *Gila* sp. and flows were similar to those exhibited by red shiner, sand shiner, and fathead minnow.

Management Implications

Minckley (1991) hypothesized that introduced nonnative fishes, enhanced by river alterations, are primarily responsible for the demise of native fish species in the Colorado River Basin. He emphasized the need to preserve or restore natural elements of the Colorado River System and argued that, although complete removal of nonnatives is not feasible, maintenance of native species is possible if nonnatives are suppressed through management efforts. Tyus and Karp (1989) concluded that natural flows provided by the Yampa River are critical for maintenance and recovery of rare native fishes in the Green River sub-system. Life histories of native fishes are closely associated with natural flow events, and spring-runoff flows may inhibit nonnative fish species. Osmundson and Kaeding (1991) suggested that flow manipulations might be used to enhance native fishes and facilitate control of nonnative species; high spring flows could be important in suppressing numbers of nonnative fishes, especially those predominanting in low-velocity nursery habitats. McAda and Kaeding (1989) and Valdez (1990) concluded that regulation of peak flows may not be an effective long-term means of negatively affecting the reproductive success of those nonnatives having high reproductive potential or adapted to riverine environments. However, even temporary removal or suppression of nonnative predators or competitors may enhance native fishes (Minckley and Meffe 1987). We suggest that management of flow regimes in regulated rivers to approximate natural hydrographs and periodically provide above-average magnitudes in spring–summer discharges would benefit native fishes and suppress the abundance of certain prolific nonnative fishes.

Inferences drawn from results of this investigation and the other similar studies should be viewed with caution. Ecological intrepretations have been applied to explain interdependent trends between variables illustrated by simple correlation analyses. However, the close interplay among external and internal factors that regulate reproduction and recruitment in fishes is a difficult issue to fully assess outside an experimental framework. Results of this study demonstrate the variability in patterns of a few physical and biological variables in a relatively unaltered river and underline the limitations of short-term trend data in evaluating complex functional (casual) relationships among variables. Water flow and temperature are primary external factors influencing reproduction in riverine fishes but represent only a fraction of the many environmental variables that affect reproductive success and survival of young. Similarly, estimates of annual spawning periods or abundance of age-0 fish provide only superficial insight into recruitment potentials and population dynamics of fishes.

LITERATURE CITED

Arnold, C. Y. 1960. Maximum-minimum temperatures as a basis for computing heat units. Proceedings of the American Society of Horticultural Sciences 76:682–692.

Baskerville, G. L., and P. Emin. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology 50:514–517.

Behnke, R. J., and D. E. Benson. 1983. Endangered and threatened fishes of the Upper Colorado River Basin. Colorado State University Cooperative Extension Services Bulletin 503A, Fort Collins.

Behnke, R. J., C. A. Carlson, D. L. Miller, D. E. Synder, E. J. Wick, and D. L. Zuckerman. 1982. A survey and analysis of existing information on fishes in Northwest Colorado. Volume 6 *in* D. W. Crumpacker, editor. Wildlife conservation and energy development in northest Colorado. Ecological Services Section, Colorado Division of Wildlife, Denver.

Bye, V. J. 1984. The role of environmental factors in the timing of reproductive cycles. Pages 187–205 *in* G. W. Potts and R. J. Wootton, editors. Fish reproduction: strategies and tactics. Academic, London.

Carlson, C. A., and R. T. Muth. 1989. The Colorado River: lifeline of the American Southwest. Pages 220–239 *in* D. P. Dodge, editor. Proceedings of the International Large River Symposium. Canadian Special Publication of Fisheries and Aquatic Sciences 106.

Carlson, C. A., C. G. Prewitt, D. E. Snyder, E. J. Wick, E. L. Ames, and W. D. Fronk. 1979. Fish and macroinvertebrates of the White and Yampa rivers, Colorado. U.S. Bureau of Land Management, Biological Sciences Series 1, Denver.

DeVlaming, V. L. 1972. Environmental control of teleost reproductive cycles: a brief review. Journal of Fish Biology 4:131–140.

Haines, G. B., and H. M. Tyus. 1990. Fish associations and environmental variables in age-0 Colorado squawfish habitats, Green River, Utah. Journal of Freshwater Ecology 5:427–435.

Haynes, C. M., and J. R. Bennett. 1986. The relationship between the preservation of wilderness values and endangered species: a case-study from the Upper Colorado River Basin, U.S.A. Pages 188–196 *in* R. C. Lucas, complier. Proceedings – National Wilderness Research Conference: Current Research. U.S. Forest Service General Technical Report INT-212.

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. 1982. Identification of habitat requirements and limiting factors for Colorado squawfish and humpback chub. Colorado Division of Wildlife, Job Progress Report SE-3-4, Fort Collins.

Haynes, C. M., R. T. Muth, and T. P. Nesler. 1985. Identification of habitat requirements and limiting factors for Colorado squawfish and humpback chub. Colorado Division of Wildlife, Job Final Report SE-3-4, Fort Collins.

Hawkins, J. A., and T. P. Nesler. 1991. Nonnative fishes of the Upper Colorado River Basin: an issue paper. Larval Fish Laboratory, Colorado State University, Final Report, Fort Collins.

Joseph, T. W., J. A. Sinning, R. J. Behnke, and P. B. Holden. 1977. An evaluation of the status, life history, and habitat requirements of endangered and threatened fishes of the Upper Colorado River System. U.S. Fish and Wildlife Service FWS/OBS–77/62.

Lam, T. J. 1983. Environmental influences on gonadal activity in fish. Pages 65–116 *in* W. S. Hoar, D. J. Randall, and E. M. Donaldson, editors. Fish physiology, volume 9, part B. Academic, New York.

McAda, C. W., and L. R. Kaeding. 1989. Relations between maximum-annual river discharge and the relative abundance of age-0 Colorado squawfish and other fishes in the upper Colorado River. U.S. Fish and Wildlife Service, Final Report, Grand Junction, Colorado.

Minckley, W. L. 1991. Native fishes of the Grand Canyon Region: an obituary? Pages 124–178 *in* Colorado River ecology and dam management. National Academic Press, Washington, D.C.

Minckley, W. L., and G. K. Meffe. 1987. Differential selection by flooding in stream-fish communities of the arid American southwest. Pages 93–104 *in* W. J. Matthews and D. C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.

Munro, A. D. 1990. General introduction. Pages 1–12 *in* A. D. Munro, A. P. Scott, and T. J. Lam, editors. Reproductive seasonality in teleosts: environmental influences. CRC Press, Boca Raton, Florida.

Nesler, T. P. 1991. Endangered fishes investigations. Colorado Division of Wildlife, Job Progress Report SE-3, Fort Collins.

Osmundson, D. B., and L. R. Kaeding. 1989. Studies of Colorado squawfish and razorback sucker use of the "15-mile reach" of the upper Colorado River as part of conservation measures for the Green Mountain and Ruedi Reservoir water sales. U.S. Fish and Wildlife Service, Final Report, Grand Junction, Colorado.

Osmundson, D. B., and L. R. Kaeding. 1991. Recommendations for flows in the 15-mile reach during October–June for maintenance and enhancement of endangered fish populations in the upper Colorado River. U.S. Fish and Wildlife Service, Final Report, Grand Junction, Colorado.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fishery Research Board of Canada 191:1–382.

Snyder, D. E. 1976. Terminologies for intervals of larval fish development. U.S. Fish and Wildlife Service FWS/OBS–76/23:41–58.

Stacey, N. E. 1984. Control of the timing of ovulation by exogenous and endogenous factors. Pages 207–222 *in* G. W. Potts and R. J. Wootton, editors. Fish reproduction: strategies and tactics. Academic, London.

Stanford, J. A., and J. V. Ward. 1986. Fishes of the Colorado system. Pages 385–402 *in* B. R. Davies and K. F. Walker, editors. The ecology of river systems. Dr. W. Junk, Dordrecht, The Netherlands.

Tyus, H. M., B. D. Burdick, R. A. Valdez, C. M. Haynes, T. A. Lytle, and C. R. Berry. 1982. Fishes of the Upper Colorado River Basin: distribution, abundance, and status. Pages 12-70 *in* W. H. Miller, H. M. Tyus, and C. A. Carlson, editors. Fishes of the Upper Colorado River System: present and future. Western Division of the American Fisheries Society, Bethesda, Maryland.

Tyus, H. M., and C. A. Karp. 1989. Habitat use and streamflow needs of rare and endangered fishes, Yampa River, Colorado. U.S. Fish and Wildlife Service, Biological Report 89(14).

Tyus, H. M., E. J. Wick, and D. L. Skates. 1981. A spawning migration of Colorado squawfish in the Yampa and Green rivers, Colorado and Utah, 1981. Proceedings of the Desert Fishes Council 13:102–108, Bishop, California.

Valdez, R. A. 1990. The endangered fishes of Cataract Canyon. BIO/WEST, Report 134-3, Logan, Utah.

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.

Welcomme, R. L. 1985. River fisheries. FAO Fisheries Technical Paper 262.

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. Colorado Division of Wildlife, Endangered Wildlife Investigations SE-3-5; National Park Service Water Resources Field Support Laboratory Report 83-7, Fort Collins.

APPENDIX A

NOTES ON GENERAL DISTRIBUTION AND SELECTED LIFE-HISTORY CHARACTERISTICS OF EIGHT FISHES COMMONLY FOUND IN THE LOWER YAMPA RIVER, COLORADO

RED SHINER *Cyprinella lutrensis*

DISTRIBUTION: Indigenous to the Mississippi and Gulf drainages from South Dakota eastward through Illinois and from Louisiana westward into northern Mexico [26]. Introduced into the Colorado River Basin; widespread, common–abundant [34, 48, 53]; first collected in the lower Colorado River system in 1953 [20].

HABITAT: Primarily a riverine species but occurs in impoundments. Found in streams of all sizes but most abundant in moderate- to large-sized creeks and rivers with low gradient and low–moderate water velocities. Inhabit a variety of perennial and ephemeral riverine habitats (including quiet pools, backwaters, and riffles) with a variety of substrate types. Adaptable and tolerant of turbidity, siltation, and fluctuations in flow, temperature, dissolved oxygen, pH, and salinity. Avoid areas that are continuously clear or cool; uncommon or absent in clear, high-gradient streams [2, 3, 11, 15, 18, 28, 34, 36, 38, 44, 48, 53]. Abundance of red shiner was positively correlated with turbidity, pH, conductivity, total alkalinity, total hardness, total dissolved solids, percentage of runs, and human impact and negatively correlated with maximum stream depth and width [23]. Water temperature, velocity, and depth were the most important variables in habitat selection; low-velocity water deeper than 20 cm was consistently selected [28]. Selected median water temperatures ranged from 21.2 to 30.9°C [7]. For fish from the Virgin River, Utah–Nevada–Arizona, preferred water temperature was 27°C. Calculated critical thermal maximum ranged from 30.1 to 38.8°C depending on acclimation temperatures [12].

GENERAL BEHAVIOR: Live in schools in midwater or near the surface. Reported nocturnal movement from deep water into shallow water and to the surface; during daylight, fish found on the bottom or in midwater [32]. Omnivorous, consume primarily aquatic or terrestrial insects, crustaceans, algae, and possibly small fish [2, 4, 8, 11, 17, 19, 24, 29, 34, 36, 44, 48, 58]. Feed primarily by sight [36].

REPRODUCTION

Maturation: Typically mature as yearlings (age I); ≥40 mm total length. Attain a maximum total length of 76–102 mm [2, 4, 8, 14, 19, 24, 36, 37, 44]. Few individuals live beyond age II [36].

Spawning Requirements: Very adaptable in spawning requirements; spawn in both streams and lakes. Spawn over gravel or sand in riffles, over submerged logs, roots, or vegetation, along rocky shorelines in crevices, or in nests of other fishes [10, 15, 34, 36, 39, 44, 50, 58]. Reported spawning season and water-temperature ranges were March through September, 15.5–31.7°C. In Missouri, spawn from late May through early September with peak spawning occurring in June and July [36]. In Iowa, spawn from May through August with peak spawning occurring in May or early June [19]. In Oklahoma and Kansas, spawn from June through August (maybe from May through September) with peak spawning occurring in June and July [8, 11, 14, 50]. In Arizona, spawn from March through June [34]. In Wyoming and eastern Colorado, spawn in June and July [2, 4]. Water temperatures greater than 30°C may inhibit spawning or may be lethal to incubating eggs [14, 15].

Spawning Behavior/Biology: Spawn primarily during morning daylight hours; male establishes spawning territory (see [16, 34] for description of courtship and spawning behavior). Observations made under controlled conditions showed that the red shiner is a fractional (over one clutch per season), crevice spawner. Each female may produce several clutches (5–19) of eggs per season with an average of 585 eggs per clutch; range = 131–1,661 per clutch [15]. Reported number of eggs per gravid female ranged from 1,177 to 5,411 [22].

Eggs and Young: Eggs are demersal, adhesive, and have a maximum diameter of 1.0–1.3 mm. Incubation time is 3–5 d at water temperatures of 21–28°C [15, 50]. Total length at hatching = 4 mm [45]; estimated daily growth of larvae and early juveniles = 0.2–0.3 mm [9] estimated total length at end of first year = ≤40 mm [8].

OTHER OBSERVATIONS: Considered to be a pioneer species, moving into new, disturbed, or marginal habitats where other fishes are rare [19].

Possible reasons for the success of red shiner: (1) small in size (only limited space and resources are necessary to sustain populations); (2) occur in schools; (3) active, move rapidly into accessible waters; (4) short lived, mature rapidly, and produce large numbers of young; and (5) extremely tolerant of adverse conditions [11].

During dry years, red shiner may predominate in streams having high gradients, whereas other fishes decline. In the first year or two of a wet cycle, red shiner may continue to be abundant and occupy nearly all available habitats. If the wet cycle continues, red shiner may decline in abundance until only residual numbers remain [10].

Under laboratory conditions, red shiners were strongly attracted to water previously occupied by conspecifics; olfaction hypothesized as a cue in habitat selection [1].

COLORADO ROUNDTAIL CHUB *Gila robusta robusta*

DISTRIBUTION AND HABITAT: Endemic to the Colorado River Basin. Widespread (especially in upper basin rivers), rare–abundant; in the lower basin, occurs in the Bill Williams, Verde, and Salt River drainages. Found in warm streams and large rivers. Adults have been collected in various habitats, from riffles to pools to backwaters. Typically occupy pools, eddies, or shallow runs with silt–cobble substrate and adjacent to moderate- to high-velocity areas; often found associated with boulders, overhanging cliffs, or vegetation in smaller streams (information summarized by [35]).

REPRODUCTION: Mature at 4–5 years of age. Eggs are broadcast over gravel or cobble substrates in shallow pools or eddies; parents do not guard eggs. Spawn during late May to late July at water temperatures of 16–20°C (typically 18°C or higher). Reported fecundity of manually stripped females ranged from about 39,500 to 41,350 eggs/kg body weight. Water-hardened eggs are 2.7–3.1 mm in diameter, demersal, and adhesive. Young hatch in about 5–6 d at 19–20°C. Total length at hatching = 8–9 mm. Young mostly found in shoreline low-velocity habitats (information summarized by [35]). Estimated daily growth of larvae and early juveniles = 0.2–0.5 mm [35]; total length at end of first year = ≤60 mm [55]; adults typically attain standard lengths of 250–350 mm [23].

SAND SHINER *Notropis stramineus*

DISTRIBUTION: Indigenous to Gulf Slope drainages in Texas northwest of the Mississippi River (excluding Louisiana and Arkansas) into the upper Mississippi Valley (including the Missouri River Basin), lower Red River of North drainage (in Canada), lower Great Lakes east into the upper Ohio River Basin, and south into the Tennessee River drainage [26]. Introduced into the Colorado River Basin. In the Upper Colorado River Basin, common in middle–lower portions of the Yampa and Colorado rivers and rare–incidental in the Green and Dolores rivers [53].

HABITAT: Primarily a riverine species but occurs in impoundments. Prefer medium- to large-sized streams and rivers having permanent flow, seasonally warm temperatures, moderate–high gradient, moderate–high water velocities, and clear–moderately clear water. Typically found in slow-flowing shallow pools with clean sand–gravel substrate or along sand bars. May be uncommon or absent in sluggish, silty, turbid streams [3, 4, 11, 13, 19, 38, 40, 44, 48, 49, 52, 58].

GENERAL BEHAVIOR: Live in schools in midwater or near the bottom. Generalized food habits (omnivorous); feed on or near the bottom. Diet consists primarily of aquatic or terrestrial insects, crustaceans, algae, plant material, and detritus [8, 13, 19, 21, 36, 38, 40, 44].

REPRODUCTION

Maturation: Typically mature as yearlings (age I); ≥40 mm total length. Attain a maximum total length of 80–102 mm [2, 8, 19, 36, 37, 44]. In Kansas, reported maximum life span was 3 years [51]. Generally, there is a sharp decline in abundance of age-II fish after their second spawning [47, 49].

Spawning Requirements: Little is known. Spawn in shallow areas of rivers and impoundments; eggs are probably scattered over clean sand or gravel [2, 8, 33, 38, 40]. In Wisconsin, spawn from late May through mid August [3]. In Iowa, spawn from June through early September [8, 40]. In Kansas, spawn from April through August with peak spawning occurring in late July and August; water temperatures ranged from 21 to 37°C [11, 49]. In Oklahoma, spawn from late spring through summer [33, 38]. In the Yampa River, Colorado, 1976–1977, spawned from June through mid September with peak spawning occurring from mid June through August [9].

Spawning Behavior/Biology: Little is known. Reported fecundity (number of eggs per female) at selected ages was: age I - 250, age II - 1,110, and age III - 1,800 [8, 40]. Average number of mature eggs per female = 650–747 [38].

Eggs and Young: Eggs have a maximum diameter of 0.65–0.9 mm [49]. Total length at hatching = 3–4 mm [45]; estimated daily growth of larvae and early juveniles = 0.2–0.3 mm [9]; estimated total length at end of first year = ≤40 mm [8].

OTHER OBSERVATIONS: Spawning in summer at high water temperatures might be an adaptation to enhance survival of young in Great Plains rivers, where spring flows are characterized by drastic fluctuations [49].

In the Des Moines River, Iowa, poor recruitment might have been related to high population densities and lower amounts of available space (implies self-regulation of population size) [47].

FATHEAD MINNOW *Pimephales promelas*

DISTRIBUTION: Occurs throughout much of North America, from Chihuahua, Mexico, north to the Great Slave Lake drainage, east to New Brunswick, and west to Alberta. Widely introduced throughout the country [26]. Introduced into the Colorado River Basin. Common in most rivers of the Upper Colorado River Basin [53]. Widespread and established in the Lower Colorado River Basin [34, 48].

HABITAT: Found in a wide range of habitats in ponds, lakes, streams, and rivers. Prefer areas with vegetation. Extremely tolerant of waters with high temperature, turbidity, and salinity and low dissolved oxygen; tolerant of a wide pH range. Often one of the last species remaining in small pools of intermittent streams during dry conditions [8, 26, 34, 36, 40, 48, 58].

GENERAL BEHAVIOR: Live in schools in midwater or near the bottom. Diet consists mostly of organic detritus, algae, and other plant material but also consume aquatic insects and zooplankton. Appear to be intolerant of competition with other fishes [29, 34, 36, 40, 48, 58].

REPRODUCTION

Maturation: Growth is rapid. Some individuals may mature and spawn during their first summer or fall of life, but most do not spawn until their second summer (age I); ≥40 mm total length. Short lived; life span is typically 2 years. Attain a maximum total length of about 75–89 mm; commonly 50–75 mm [8, 34, 36, 40, 41].

Spawning Requirements: Prolonged spawning season. Spawn from May well into summer or early fall. Apparently, spawning begins when water temperatures reach about 16–18°C; reported range up to 19°C [13, 36, 40, 41, 44, 48, 58]. In the Yampa River, 1976–1977, spawned from early May through early September with peak spawning occurring from late May through mid August [9]. Some uncertainty as to whether temperature, photoperiod, or both initiates spawning [3].

Spawning Behavior/Biology: General spawning habits are well known. Eggs are spawned on the undersurface of submerged or floating objects (may create suitable spawning sites under rocks in the absence of such objects). Male guards and tends the "nest" and may spawn with several females, producing a large nest possibly containing several thousand eggs; maybe up to 12,000 eggs in a single nest [8, 16, 27, 34, 36, 40, 48, 58]. Fecundity and spawning frequency was studied under controlled conditions, and it was determined that the species is a fractional spawner [16]. In that study, 16–26 clutches of eggs were produced by each spawning pair. Number of eggs spawned per female ranged from 6,803 to 10,164 (mean 8,604). Nine to 1,136 eggs were spawned per clutch (mean ranged from 391 to 480). Intervals between spawning of each clutch ranged from 2 to 16 d. Spawning typically began before dawn and ended by mid morning. No postspawning mortality was noted; however, in another study [27], about 85% of the adults died after spawning.

Eggs and Young: Eggs are demersal, adhesive, and have a maximum diameter of 1.15–1.3 mm (maybe up to 1.6 mm). Incubation time is 4–6 d at water temperatures of 23–30°C; 5 d at 25°C [8, 27, 40, 48]. Total length at hatching = 4 mm [45]; estimated daily growth of larvae and early juveniles = 0.2–0.3 mm [9]; total length at end of first year = ≤50 mm [8].

SPECKLED DACE *Rhinichthys osculus*

DISTRIBUTION: Native to all major western river drainages from the Columbia River to the Colorado River and south to Sonora, Mexico. Also in coastal drainages and in interior waters [26]. The Colorado speckled dace *R. o. yarrowi* is common in most rivers of the Upper Colorado River Basin, except for the mainstem Colorado River; similar situation for the lower basin [34, 53].

HABITAT: Occupy a variety of habitats, from permanent or intermittent streams and rivers to large and small lakes to outflows of springs. In streams and rivers, most often found in shallow runs and riffles with rocky substrate; in lakes, frequent shallow water, swimming near the bottom or in crevices between rocks. Rarely collected from water over 50–75 cm deep [2, 24, 25, 26, 34, 40, 41, 42, 43, 48, 53, 58]. For fish from the Virgin River, preferred temperature was 15.8°C (extremes ranging from 9.5 to 16°C). Calculated critical thermal maximum was about 30.5–36.8°C depending on acclimation temperature [12].

GENERAL BEHAVIOR: Omnivorous, consume aquatic and terrestrial insects, crustaceans, algae, and detritus. Feed either on the bottom or in midwater [2, 17, 21, 24, 26, 34, 41, 42, 43, 58].

REPRODUCTION

Maturation: Most females mature at age II; ≥50 mm total length. Short life span; few individuals live beyond 3 years of age. Attain a maximum total length of up to 127 mm; commonly 51–102 mm [2, 8, 24, 41, 42].

Spawning Requirements: Spawn in spring and early–mid summer [8, 41, 42, 48]. In the Yampa River, 1976–1977, spawned from mid May through mid August with peak spawning occurring from late May through late July [9].

Spawning Behavior/Biology: Reproductive habits are poorly described (many accounts are based on observations of other *Rhinichthys* sp.). Have been observed spawning in riffle areas. Some type of "nest" may be "constructed" (spawning site cleaned free of silt) by males; males may be territorial. Spawning may involve single pairs. Fecundity may range from 174 to 514 eggs per female [2, 8, 29, 34].

Eggs and Young: Eggs are demersal, adhesive, and have a maximum diameter of about 1.0 mm. Incubation time is 6 d at water temperatures of 18–19°C [2, 42, 48]. Total length at hatching = 5–6 mm [45]; estimated daily growth of larvae and early juveniles = 0.2–0.4 mm [9]; estimated total length at end of first year = ≤50 mm [8].

REDSIDE SHINER *Richardsonius balteatus*

DISTRIBUTION: Occurs naturally mostly west of the Rocky Mountains from the Nass River, British Columbia, south through Washington, Oregon, and the Columbia River drainage. Also in the Harney Basin, Oregon, and Bonneville Basin, Idaho, Wyoming, Utah, and Nevada. Native east of the continental divide only in British Columbia and Alberta in the Peace River system [26]. Introduced into the Colorado River Basin. In the Upper Colorado River Basin, rare–incidental to common–abundant in the Yampa River and upper portion of the Green, Duchesne, and Dirty Devil rivers [53]. Established in upper portions of the Lower Colorado River Basin [34].

HABITAT: Occupy a variety of habitats under various environmental conditions. Found in creeks, rivers with low–moderate water velocities, ponds, lakes, canals, sloughs, and warm springs. In streams, may occur in slow–swift, clear–turbid water and over rubble, gravel, sand, clay, or mud substrates. Frequently found associated with vegetation. Prefer cool water, typically with summer water temperatures ranging from 16 to 19°C (maximum range from 13 to 21°C). Calculated upper lethal water temperature was 25°C when fish were acclimated at 8.9–11.1°C [6, 40, 41, 42, 43, 53, 58, 59].

GENERAL BEHAVIOR: Live in schools, tend to stay near vegetated areas. In lakes, exhibit daily and seasonal movement patterns. In streams, move inshore in spring and remain there until mid–late summer; subsequently, move to deeper, cooler water. Omnivorous, consume primarily aquatic or terrestrial insects, snails, crustaceans, and fish eggs and larvae. Cannibalistic on own eggs and larvae; may be one of the most important factors limiting survival of their eggs and larvae [2, 6, 8, 25, 34, 40, 41, 42, 43, 58, 59].

REPRODUCTION

Maturation: Mature at age II or III; ≥60 mm total length. Attain a maximum total length of 178 mm (typically less than 125 mm). Relatively short lived; maximum life span is 5 years [6, 8, 40, 41, 43, 59].

Spawning Requirements: In streams, spawn in areas less than 15 cm deep (maybe riffles or upwellings) with gravel or rocky substrates; in lakes, spawn along shoreline. Spawning area often associated with submerged vegetation. Spawning begins when water temperatures reach 10–14°C. Reported spawning season range was from May through August; typically June and July [2, 6, 8, 25, 34, 40, 41, 42, 43, 58, 59]. In the Yampa River, 1976–1977, spawned from late May through August with peak spawning occurring from early June through mid August [9].

Spawning Behavior/Biology: During spawning, fish gather in groups of about 30–50 individuals; actual spawning takes place is smaller groups of about six individuals [5, 25, 40, 56]. No territoriality or courting behavior has been noted. Spawn during daylight and darkness. Eggs are broadcasted over the substrate or over vegetation in lots of 10–20 each per female (eggs are expelled at irregular intervals). Spawning may continue for 3–7 d; individuals may spawn several times in a season. Reported fecundity ranged from 829 to 3,602 eggs per female. Apparently, high mortality in adult fish occurs after spawning [6, 8, 34, 40, 42, 43, 59].

Eggs and Young: Eggs are demersal, adhesive, and have a maximum diameter of 1.9–2.2 mm. Incubation time is 3–7 d at water temperatures of 20–21°C [2, 6, 8, 25, 34, 40, 41, 42, 43, 56]. Total length at hatching = about 6 mm [45]; estimated daily growth of larvae and early juveniles = 0.2–0.3 mm [9]; total length at end of first year = ≤50 mm [8].

BLUEHEAD SUCKER *Catostomus discobolus*

DISTRIBUTION AND HABITAT: Native to the Colorado River Basin; replaced by *C. clarki* below the Grand Canyon, Arizona. Also occurs in the Bear and Weber River drainages in Idaho, Wyoming, and Utah [26]. The Colorado bluehead sucker *C. d. discobolus* is common in most rivers of the Upper Colorado River Basin [53]. Found in a wide variety of habitats, ranging from cold, clear streams to warm, turbid streams. Prefer deep riffles or shallow runs over rocky substrates [26, 53].

REPRODUCTION: Eggs are broadcast over rocky substrates; parents do not guard young. Spawn from May to September, usually in June and July, at water temperatures of 15–18°C. Reported estimated fecundity ranged from about 4,000 to 16,000 eggs per female [30]. Water-hardened eggs are 3.3–3.5 mm in diameter, demersal, and initially adhesive. Estimated daily growth of larvae and early juveniles = 0.2–0.4 mm [30]; total length at hatching = 8–11 mm. Larvae drift. Young occupy shoreline low-velocity habitats [46]. Total length at end of first year = ≤60 mm [54]; adults attain a total length of up to 400 mm (commonly 250–350 mm) [23].

FLANNELMOUTH SUCKER *Catostomus latipinnis*

DISTRIBUTION AND HABITAT: Endemic to the Colorado River Basin [26]. Common to abundant in most rivers of the upper basin [53]. In the lower basin, occurs in the mainstem Colorado River above the lower end of Lake Mohave and in the Little Colorado River drainage; extirpated from the Gila River drainage [46, 57]. Found in moderate- to large-sized rivers, typically in pools, deeper runs, and eddies and along shorelines [26, 53].

REPRODUCTION: Mature at 4–6 years of age [31]. Eggs are broadcast over gravel–rubble bars or riffles, or coarse gravel under <1.2 m of water; parents do not guard eggs. Spawn from April to August, mostly May to early July, at water temperatures of 6 to at least 13°C. Reported fecundity ranged from 4,000 to 40,000 eggs per fish in females 450–500 mm long. Water-hardened eggs are 3.8–3.9 mm in diameter, demersal, and initially adhesive. Total length at hatching = 8–11 mm. Larvae drift. Young occupy shoreline low-velocity habitats [31, 46]. Estimated daily growth of larvae and early juveniles = 0.2–0.4 mm [9]; total length at end of first year = ≤60 mm [31]; adults attain a total length of up to 600 mm (commonly 300–400 mm) [23].

REFERENCES

1. Asbury, K., W. J. Matthews, and L. G. Hill. 1981. Attraction of *Notropis lutrensis* (Cyprinidae) to water conditioned by the presence of conspecifics. Southwestern Naturalist 25:525–528.

2. Baxter, G. T., and J. R. Simon. 1970. Wyoming fishes. Wyoming Game and Fish Department, Bulletin 4, Cheyenne.

3. Becker, G. C. 1985. Fishes of Wisconsin. The University of Wisconsin Press, Madison.

4. Beckman, W. C. 1952. Guide to the fishes of Colorado. University of Colorado Museum Leaflet 11, Boulder.

5. Breder, C. M., Jr., and D. E. Rosen. 1964. Modes of reproduction in fishes. The Natural History Press, New York.

6. Brown, C. J. D. 1971. Fishes of Montana. Montana State University, Bozeman.

7. Calhoun, S. W., E. G. Zimmerman, and T. L. Beitinger. 1982. Stream regulation alters acute temperature preferenda of red shiner, *Notropis lutrensis*. Canadian Journal of Fisheries and Aquatic Sciences 39:360–363.

8. Carlander, K. D. 1969. Handbook of freshwater fishery biology, volume 1. Iowa State University Press, Ames.

9. Carlson, C. A., C. G. Prewitt, D. E. Snyder, E. J. Wick, E. L. Ames, and W. D. Fronk. 1979. Fish and macroinvertebrates of the White and Yampa rivers, Colorado. U.S. Bureau of Land Management, Biological Sciences Series 1, Denver.

10. Cross, F. B. 1967. Handbook of fishes of Kansas. University of Kansas Miscellaneous Publications 45.

11. Cross, F. B., and J. T. Collins. 1975. Fishes in Kansas. The University of Kansas Museum of Natural History and State Biological Survey Public Education Series 3.

12. Deacon, J. E., P. B. Schumann, and E. L. Stuenkel. 1987. Thermal tolerances and preferences of fishes of the Virgin River System (Utah, Arizona, Nevada). Great Basin Naturalist 47:538–546.

13. Eddy, S., and J. C. Underhill. 1974. Northern fishes. University of Minnesota Press, Saint Paul.

14. Farringer, R. T., and A. A. Echelle. 1979. Reproductive cycle of the red shiner *Notropis lutrensis*, in central Texas and south central Oklahoma. Transactions of the American Fisheries Society 108:271–276.

15. Gale, W. F. 1986. Indeterminate fecundity and spawning behavior of captive red shiner—fractional, crevice spawners. Transactions of the American Fisheries Society 115:429–437.

16. Gale, W. F., and G. L. Buynak. 1982. Fecundity and spawning frequency of the fathead minnow—a fractional spawner. Transactions of the American Fisheries Society 111:35–40.

17. Greger, P. D., and J. E. Deacon. 1988. Food partitioning among fishes of the Virgin River, Copeia 1988:314–323.

18. Haines, G. B., and H. M. Tyus. 1990. Fish associations and environmental variables in age-0 Colorado squawfish habitats, Green River, Utah. Journal of Freshwater Ecology 5:427–435.

19. Harlan, J. R., E. B. Speaker, and J. Mayhew. 1987. Iowa fish and fishing. Iowa Department of Natural Resources, Des Moines.

20. Hubbs, C. L. 1954. Establishment of a forage fish, the red shiner (*Notropis lutrensis*), in the lower Colorado River system. California Fish and Game 40:287–294.

21. Jacobi, G. Z., and M. D. Jacobi. 1982. Fish stomach content analysis. Pages 285–324 *in* Colorado River Fishery Project Final Report, Part 3, Contracted Studies. U.S. Fish and Wildlife Service and Bureau of Reclamation, Salt Lake City, Utah.

22. Jennings, M. R., and M. K. Saiki. 1990. Establishment of red shiner, *Notropis lutrensis*, in the San Joaquin Valley, California. California Fish and Game 76:46–57.

23. Joseph, T. W., J. A. Sinning, R. J. Behnke, and P. B. Holden. 1977. An evaluation of the status, life history, and habitat requirements of endangered and threatened fishes of the Upper Colorado River System. U.S. Fish and Wildlife Service FWS/OBS–77/62.

24. Koster, W. J. 1957. Guide to the fishes of New Mexico. University of New Mexico Press, Albuquerque.

25. La Rivers, I. 1962. Fishes and fisheries of Nevada. Nevada State Fish and Game Commission, State Printing Office, Carson City.

26. Lee, D. S., C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer, Jr. 1980. Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, North Carolina Biological Survey Publication 1980–12, Raleigh.

27. Markus, H. C. 1934. Life history of the blackhead minnow (*Pimephales promelas*). Copeia 1934:116–122.

28. Matthews, W. J., and L. G. Hill. 1979. Influence of physico-chemical factors on habitat selection by red shiners, *Notropis lutrensis*. Copeia 1979:70–81.

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

30. McAda, C. W., and R. S. Wydoski. 1983. Maturity and fecundity of the bluehead sucker, *Catostomus discobolus* (Catostomidae), in the Upper Colorado River Basin, 1975–76. Southwestern Naturalist 28:120–123.

31. McAda, C. W., and R. S. Wydoski. 1985. Growth and reproduction of the flannelmouth sucker, *Catostomus latipinnis*, in the Upper Colorado River Basin, 1975–1976. Great Basin Naturalist 45:281–286.

32. Mendelson, J. 1972. Trophic relationships among species of *Notropis* (Pisces: Cyprinidae) in a small Wisconsin stream. Ph.D. dissertation. University of Wisconsin, Madison.

33. Miller, R. T., and H. W. Robison. 1973. The fishes of Oklahoma. Oklahoma State University Museum of Natural and Cultural History Series 1.

34. Minckley, W. L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix.

35. Muth, R. T. 1990. Ontogeny and taxonomy of humpback chub, bonytail, and roundtail chub larvae and early juveniles. Ph.D. dissertation. Colorado State University, Fort Collins.

36. Pflieger, W. L. 1975. The fishes of Missouri. Missouri Department of Conservation, Jefferson City.

37. Phillips, G. L., W. D. Schmid, and J. C. Underhill. 1982. Fishes of the Minnesota region. University of Minnesota, Saint Paul.

38. Robison, H. W., and T. M. Buchanan. 1988. Fishes of Arkansas. The University of Arkansas Press, Fayetteville.

39. Sakensa, V. P. 1962. The post-hatching stages of the red shiner, *Notropis lutrensis*. Copeia 1962:539–544.

40. Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184.

41. Sigler, W. F., and R. R. Miller. 1963. Fishes of Utah. Utah State Department of Fish and Game, Salt Lake City.

42. Sigler, W. F., and J. W. Sigler. 1987. Fishes of the Great Basin, a natural history. University of Nevada Press, Reno.

43. Simpson, J. C., and R. L. Wallace. 1978. Fishes of Idaho. University Press of Idaho, Moscow.

44. Smith, P. W. 1979. The fishes of Illinois. University of Illinois Press, Urbana.

45. Snyder, D. E. 1981. Contributions to a guide to the cypriniform fish larvae of the Upper Colorado River System in Colorado. U.S. Bureau of Land Management, Biological Sciences Series 3, Denver.

46. Snyder, D. E., and R. T. Muth. 1990. Description and identification of razorback, flannelmouth, white, Utah, bluehead, and mountain sucker larvae and early juveniles. Colorado Division of Wildlife, Technical Publication 38.

47. Starett, W. C. 1951. Some factors affecting the abundance of minnows in the Des Moines River, Iowa. Ecology 32:13–27.

48. Sublette, J. E., M. D. Hatch, and M. Sublette. 1990. The fishes of New Mexico. University of New Mexico Press, Albuquerque.

49. Summerfelt, R. C., and C. O. Minckley. 1969. Aspects of the life history of the sand shiner, *Notropis stramineus* (Cope), from the Smoky Hill River, Kansas. Transactions of the American Fisheries 98:444–453.

50. Taber, C. A. 1969. The distribution and identification of larval fishes in the Buncombe Creek Arm of Lake Texoma with observations on spawning habits and relative abundance. Ph.D. dissertation. University of Oklahoma, Norman.

51. Tanyolac, J. 1973. Morphometric variation and life history of the cyprinid fish, *Notropis stramineus* (Cope). Occasional Papers of the Museum of Natural History University of Kansas 12:1–28.

52. Trautman, M. B. 1981. The fishes of Ohio. Ohio State University Press, Columbus.

53. Tyus, H. M., B. D. Burdick, R. A. Valdez, C. M. Haynes, T. A. Lytle, and C. R. Berry. 1982. Fishes of the Upper Colorado River Basin: distribution, abundance, and status. Pages 12–70 *in* W. H. Miller, H. M. Tyus, and C. A. Carlson, editors. Fishes of the Upper Colorado River System: present and future. Western Division of the American Fisheries Society, Bethesda, Maryland.

54. Vanicek, C. D. 1963. Ecological studies of native Green River fishes below Flaming Gorge Dam, 1964–1966. Ph.D. dissertation. Utah State University, Logan.

55. 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.

56. Weisel, G. F., and H. W. Newman. 1951. Breeding habits, development and early life history of *Richardsonius balteatus*, a northwestern minnow. Copeia 1951:187–194.

57. Williams, J. E., D. B. Bowman, J. E. Brooks, A. A. Echelle, R. J. Edwards, D. A. Hendrickson, and J. J. Landye. 1981. Endangered aquatic ecosystems in North American deserts with a list of vanishing fishes of the region. Journal of the Arizona-Nevada Academy of Sciences 20:1–62.

58. Woodling, J. 1981. Colorado's little fish, a guide to the minnows and other lesser known fishes in the state of Colorado. Colorado Division of Wildlife, Denver.

59. Wydoski, R. S., and R. R. Whitney. 1979. Inland fishes of Washington. University of Washington Press, Seattle.