REPRODUCTION AND EARLY LIFE HISTORY OF RAZORBACK SUCKER IN THE GREEN RIVER, UTAH AND COLORADO, 1992–1996

ROBERT T. MUTH[1]

Larval Fish Laboratory, Department of Fishery and Wildlife Biology
Colorado State University, Fort Collins, Colorado 80523, USA

G. BRUCE HAINES

U.S. Fish and Wildlife Service, Colorado River Fish Project
266 West 100 North, Suite 2, Vernal, Utah 84078, USA

STEVEN M. MEISMER[2]

Larval Fish Laboratory, Colorado State University

EDMUND J. WICK

U.S. National Park Service, Division of Water Resources
1201 Oakridge Drive, Suite 250, Fort Collins, Colorado 80525, USA

TOM E. CHART

Utah Division of Wildlife Resources, Moab Field Station
1165 South Highway 191, Suite 4, Moab, Utah 84532, USA

DARREL E. SNYDER AND JAY M. BUNDY

Larval Fish Laboratory, Colorado State University

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[1]Present address: *U.S. Fish and Wildlife Service, Ecological Services, Lincoln Plaza, 145 East 1300 South, Suite 404, Salt Lake City, Utah 84115, USA*

[2]Present address: *Utah Division of Wildlife Resources, Moab Field Station*

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KEYWORDS

Razorback sucker, Green River, reproduction, early life history, larvae, recruitment, floodplain wetlands

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EXECUTIVE SUMMARY

This report integrates results of studies conducted in 1992–1996 on larvae of razorback sucker *Xyrauchen texanus* in reaches of the middle Green River, Utah and Colorado, or lower Green River, Utah. Studies included two Colorado River Recovery Implementation Program projects (numbers 34 and 38) conducted as part of the Flaming Gorge Research Program and research sponsored by the National Park Service. Objectives were to (1) develop effective methods for collecting larval razorback suckers in rivers, (2) document reproduction by razorback suckers, (3) assess the distribution and relative abundance of larval razorback suckers, (4) associate razorback sucker spawning dates with mainstem discharges and temperatures, and (5) estimate growth rates and describe the diet of larval razorback suckers in nursery habitats. Sampling occurred during spring and early summer in reaches near known razorback sucker spawning areas or reported capture locations of individual tuberculate or ripe fish and with quiet-water habitats accessible to fish larvae under varied river discharges. Drift nets were used to collect drifting larvae, and light traps, seines, or dip nets were used to sample larvae in flooded and backwater habitats.

Larval razorback suckers were collected in each year of sampling from the middle (1992–1996) and lower (1993–1996) Green River. These captures represent the first confirmed reproduction by the species in the middle Green River since 1984 and the first ever records of razorback sucker larvae in the lower Green River. A total of 1,735 larvae was caught in the middle Green River and 440 in the lower Green River. Of all individuals collected from the middle Green River, 1,651 were captured by light traps, 69 by seines, 12 by drift nets, and 3 by dip nets. In the lower Green River, 415 specimens were caught by light traps and 25 by seines.

Catches of larval razorback suckers were highly variable among years and reaches. Numbers captured per year ranged from 20 in 1992 to 1,217 in 1994 for the middle Green River and from 5 in 1995 to 222 in 1996 for the lower Green River. In the middle Green River, the Escalante (711 larvae), Jensen (700), and Ouray (318) reaches combined produced over 99% of the total catch. Only six individuals were caught in the Echo Park reach, and none was captured from the Island-Rainbow Park reach. In the lower Green River, 363 larvae were collected from

the middle Stillwater Canyon reach, 76 from the San Rafael River confluence reach, and 1 larva was caught in the Green River Valley reach.

Capture dates of razorback sucker larvae over all years ranged from 16 May to 21 July in the middle Green River and from 7 May to 9 July in the lower Green River. In most years, larvae were first collected 20–30 d after the earliest estimated date of spawning and were usually most abundant in samples collected before mid-June. Earlier first occurrence of larvae in collections from the San Rafael River confluence or middle Stillwater Canyon reaches compared to collections from the middle Green River suggested that razorback suckers reproduced in the lower Green River each year during 1994–1996.

Estimated initiation of spawning by razorback suckers in each year during 1993–1996 was generally associated with the beginning of spring-runoff flows and was probably triggered by a suite of interacting environmental cues that could not be detected by analysis of single water temperature and discharge parameters. Duration of spawning in either the middle or lower Green River varied among years but usually spanned 4–6 weeks each year. Spawning occurred during increasing and highest spring flows and encompassed a wide range of mainstem mean daily discharges (78–696 m^3/s) and instantaneous daily water temperatures (8–21°C).

Most larval razorback suckers (11–18 mm total length, TL) contained food items, and mean percent fullness of digestive tracts increased with fish length (ranged from 35 to 65%). Principal dietary components were chironomid larvae, cladocerans, rotifers, algae, and miscellaneous debris. Estimated mean daily growth of razorback sucker larvae less than 35 d old collected from either river section during 1993–1996 was lowest in 1994 (0.31 and 0.27 mm TL/d for the middle and lower Green River, respectively) and greatest in 1996 (0.35 and 0.33 mm TL/d). Over all years, specimens from the middle Green River grew 6–21% faster than those from the lower Green River. Although food abundance appeared adequate to meet the minimum nutritional requirements for larval survival, the growth potential of razorback sucker larvae is greater than we observed. Poor growth can significantly reduce the survival of fish early life stages if size-dependent processes regulate year-class success. Extremely low survival was suggested by the apparent disappearance of larval razorback suckers from Green River nursery habitats by early or mid-July each year.

Floodplain wetlands inundated and connected to the main channel by spring-runoff discharges appear to be important habitats for all life stages of razorback sucker, and the seasonal timing of reproduction suggests an adaptation for utilizing these habitats. Restoring access to warm, productive floodplain wetlands to serve as growth and conditioning habitats appears crucial for recovery of self-sustaining razorback sucker populations in the Green River, and the natural integrity of large-river ecosystems is dependent on interactions between the main channel and floodplain. Reestablishment of some river-wetland connections by breeching levees along the middle Green River is a promising start, but substantial increases in floodplain inundation will require management of spring-peak releases from Flaming Gorge Dam in wet years when discharge is high to provide the magnitude and duration of flows necessary for overbank flooding.

INTRODUCTION

The razorback sucker *Xyrauchen texanus* is endemic to the Colorado River basin (Miller 1959; Minckley et al. 1986) and was once widely distributed in warm-water reaches of larger rivers from Mexico to Wyoming (Jordan and Evermann 1896; Minckley 1973; Behnke and Benson 1983; Bestgen 1990). Adults of this unique fish are distinguished by a pronounced bony dorsal keel ("razor") arising immediately posterior to the occiput and may attain maximum total length (TL) of about 1 m (commonly 400–700 mm), weigh 5–6 kg (commonly less than 3 kg), and exceed 40 years of age (Minckley 1983; McCarthy and Minckley 1987). Larvae are generally 7–9 mm TL at hatching and 9–11 mm TL at swimup (Minckley and Gustafson 1982; Marsh 1985; Snyder and Muth 1990; R. T. Muth, personal observation). In rivers, larval razorback suckers presumably enter the drift after emerging from spawning substrates (Mueller 1989; Paulin et al. 1989) and are transported downstream into off-channel nursery habitats with quiet, warm, shallow water (e.g., tributary mouths, backwaters, and floodplain wetlands). Transition to the juvenile period (sensu Snyder 1976) occurs at 27–30 mm TL (Snyder and Muth 1990), and, generally, fish greater than 350 mm TL are sexually mature (Minckley 1983; Hamman 1985). Estimates of the total fecundity of wild females ranged up to 144,000 ova/fish (Minckley 1983).

Today, the razorback sucker is one of the most imperiled fishes in the Colorado River basin and is listed as federally endangered under provisions of the 1973 Endangered Species Act, as amended (USFWS 1991). The historic widespread distribution of razorback suckers has been fragmented by dams and water diversions and reduced by over 75%; the species presently exists naturally as only a few disjunct, aging populations or scattered individuals (Minckley et al. 1991). Although there is evidence of reproduction in at least the two largest extant populations, natural survival of fish beyond the larval period appears low or nonexistent, and wild stocks are primarily composed of older fish and continue to decline in abundance (Lanigan and Tyus 1989; Marsh and Minckley 1989). Lack of recruitment sufficient to sustain populations has been mainly attributed to the cumulative effects of habitat loss and modification (including degradation of water quality) caused by water and land development, and predation on eggs, larvae, or early juveniles by nonnative fishes, many of which have well-established and abundant populations in razorback sucker critical habitat (Hawkins and Nesler 1991; Maddux et al. 1993; Lentsch et al. 1996b; Tyus and Saunders 1996; USFWS 1997; Hamilton 1998).

Remaining wild populations of razorback sucker are in serious jeopardy. The largest extant concentration is a remnant population found above Davis Dam in Lake Mohave on the lower main-stem Colorado River, Arizona-Nevada, but no natural recruitment to the population has occurred in recent decades and estimated numbers of adults declined 68% (from 73,500 to 23,300) during 1980–1993 (Marsh 1994). Most riverine razorback suckers are now limited to the upper Colorado River basin and populations are small. The largest riverine population exists in flat-water reaches of the middle Green River, northeastern Utah and northwestern Colorado, between and including the mouths of the Yampa and Duchesne rivers (Tyus 1987). Lanigan and Tyus (1989) used a demographically closed model with capture-recapture data collected from 1980 to 1988 and estimated that the middle Green River population consisted of about 1,000 adults (mean, 948; 95% confidence interval, 758–1,138). Based on a demographically open model and capture-recapture data collected from 1980 to 1992, Modde et al. (1996) estimated the number of adults in the middle Green River population at about 500 fish (mean, 524; 95% confidence interval, 351–696). Modde et al. (1996) characterized the population as "precariously" small but dynamic, with at least some recruitment.

Captures of ripe fish and tracking movements of adults in spring were used to locate razorback sucker spawning areas in the middle Green River. McAda and Wydoski (1980) found a presumptive spawning aggregation of 14 ripe razorback suckers over a cobble bar (stones 20–50 cm in diameter) at the mouth of the Yampa River during a 2-week period in early and mid-May 1975. Those fish were collected from water about 1 m deep with a velocity of about 1 m/s and temperatures ranging from 7 to 16°C (mean, 12°C). Three spawning reaches were reported by Tyus (1987): (1) Island and Echo parks of the Green River in Dinosaur National Monument, including the lower kilometer of the Yampa River; (2) the Jensen area of the Green River from Ashley Creek to Split Mountain Canyon; and (3) the Ouray area of the Green River, including the lower few kilometers of the Duchesne River. The Jensen area contributed 73% of the 60 ripe razorback suckers caught over gravel and coarse sand substrates in those three reaches during spring 1981, 1984, and 1986; water temperatures at capture locations ranged from 10 to

18°C (mean, 15°C). Observations by Tyus (1987) on ripe fish in 1984 were supported by seine collections of sucker larvae (*N* = 33; 10.6–13.6 mm TL) tentatively identified (later confirmed) as razorback sucker from quiet shorelines downstream of suspected spawning areas. Tyus and Karp (1990) located concentrations of ripe razorback suckers (*N* = 191) at two sites during 1987–1989: (1) the mouth of the Yampa River just before it enters the Green River (7% of the total number collected); and (2) the Green River upstream of Jensen, Utah, adjacent to the Escalante Ranch at river kilometers (RK) 486.4–504.0 (93% of the total number collected); note – river kilometers measured upstream of the Green River confluence with the Colorado River. Ripe fish captured at those sites were from runs associated with bars of cobble, gravel, and sand substrates in water averaging 0.63 m deep with a mean velocity of 0.74 m/s. Tyus and Karp (1990) concluded that spawning activities were associated with increasing and highest spring flows (typically May through June) and mean water temperatures of 14.1°C (range, 9–17°C). Although the Escalante site appears to be the primary spawning area for razorback suckers in the middle Green River, Modde and Wick (1997) concluded that spawning probably occurs at secondary sites. Individual razorback suckers in tuberculate or ripe condition have been collected within recent years elsewhere in the Green River drainage, including reaches of the lower Green River in Labyrinth-Stillwater Canyon, often near the mouth of the San Rafael River (e.g., Tyus 1987; Miller and Hubert 1990; Muth 1995; Chart et al. 1997).

Prior to our investigation, direct evidence of reproduction by razorback suckers in the upper Colorado River basin within recent decades or information on the species' natural early life history in riverine environments were limited to those larvae collected by Tyus (1987) and captures of a few early juveniles from backwaters (e.g., Smith 1959; Taba et al. 1965; Gutermuth et al. 1994; Utah Division of Wildlife Resources, unpublished data). However, diagnostic characters for distinguishing larval razorback suckers from larvae of sympatric suckers were only recently developed (Snyder and Muth 1990) and previous sampling for riverine razorback suckers did not target early life stages. This report integrates results of studies conducted during 1992–1996 on razorback sucker larvae in reaches of the middle or lower Green River (Figure 1) to (1) develop effective methods for collecting larval razorback suckers in rivers, (2) document reproduction by razorback suckers, (3) assess the distribution and relative abundance of larval razorback suckers, (4) associate razorback sucker spawning dates with mainstem discharges and temperatures, and (5) estimate growth rates and describe the diet of razorback sucker larvae in existing nursery habitats. Studies included two projects of the Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin (Colorado River Recovery Implementation Program – Wydoski and Hamill 1991) conducted as part of the Flaming Gorge Research Program (FGRP), which was initiated as a Reasonable and Prudent Alternative in the 1992 Final Biological Opinion on operation of Flaming Gorge Dam, and research contracted by the National Park Service through a 3-year (1993–1995) program on endangered fishes in Colorado River basin parks funded by the Natural Resource Preservation Program (Muth and Wick 1997). The two FGRP projects were (1) *Annual assessment of spawning success, larval distribution, and habitat selection of main-stem razorback suckers* in the middle (1992–1996) and lower (1996) Green River (number 34); and (2) *Investigation of potential razorback sucker and Colorado squawfish spawning in the lower Green River*, 1994–1995 (number 38). Project 38 was designated as a Hypothesis-Testing study, and project 34 was part of the Core-Research Effort, which was based on a life-history approach for monitoring the biological responses of target species to recommended flows, and was specifically related to Element 1 (Reproduction) and Element 2 (Age-0 Recruitment). This integrated report serves as the end product for project 34; a separate final report will be prepared for project 38 (Chart et al., August 1997, draft).

METHODS

Study Area and Sampling Sites

The area studied during spring and early summer 1992 through 1996 included up to five reaches of the middle Green River, A–E, and three reaches of the lower Green River, F–H (Figure 1). Reaches were selected based on proximity to previously documented areas of razorback sucker spawning activity (e.g., lower Yampa River in the Echo Park reach and Green River in the Escalante reach) or to reported localized captures of individual tuberculate or ripe fish, and the presence of quiet-water habitats connected to the main channel and accessible to fish larvae under varied Green River discharges during our annual sampling periods. The latter included ephemeral shoreline embayments (e.g., backwaters) and particularly ponded lower sections of flooded tributary streams, side canyons, washes, canals, or channels. These habitats generally persist through at least mid-summer and are primary nursery areas for fish larvae in spring and early summer under the present regulated flow regime of the Green River.

Collections were concentrated in the Escalante, Jensen, and Ouray reaches (C, D, and E) of the middle Green River and in the lower two reaches (G and H) of the lower Green River (Figure 1). Sites within reaches C–E that were intensively sampled on a regular basis throughout the investigation included Cliff Creek (an intermittent tributary stream joining the Green River at RK 487.5, Escalante), Stewart Lake Drain (an outlet canal from Stewart Lake at RK 481.7, Jensen), Sportsmans Drain (an outlet canal from Unitah Sportsmans Club Lake at RK 477.4, Jensen), Greasewood Corral (a side channel at RK 405.6, Ouray), and the inlet canal to the Old Charlie Wash managed wetland (Modde 1997) at RK 405.4, Ouray. Established sampling sites in reaches G and H included washes and backwaters at or just upstream or downstream from the mouth of the San Rafael River (RK 152.1–156.2, reach G), and Millard Canyon (RK 53.9), a wash-backwater-side channel complex at Anderson Bottom-Bonita Bend (RK 49.9–50.7), and Holeman Canyon (RK 45.1) in the middle Stillwater Canyon reach (H). Sampling in reaches A (Echo Park) and B (Island-Rainbow Park) of the middle Green River was mostly opportunistic and occurred at irregular intervals during the investigation. Backwaters and washes in the Green River Valley reach (F) of the lower Green River were sampled in 1996 primarily to assess transport of razorback sucker larvae into the lower Green River from the middle Green River.

Flooded and backwater habitats had low or no water velocity, and typically had predominantly silt and sand or silt and mud substrates and sparse to dense emergent macrophytes near shoreline. These habitats generally averaged less than 1 m deep, were moderately turbid, and often had low-velocity eddies at their interface with the main channel. Water temperatures in these habitats at sunrise and in late afternoon or early evening were routinely recorded only on sampling dates in 1996. Sunrise temperatures ranged from 15 to 23°C (mean, 18°C) in the middle Green River and from 11 to 28°C (mean, 18°C) in the lower Green River. Temperatures in late afternoon or early evening ranged from 17 to 26°C (mean, 21°C) in the middle Green River and from 15 to 33°C (mean, 22°C) in the lower Green River.

Mean daily discharge and instantaneous daily water temperature data in each year of the investigation for the mainstem middle and lower Green River, respectively, were from U.S. Geological Survey gages near Jensen (gage number 09261000) and Green River (09315000), Utah. Mean daily discharges of the middle Green River for the April–July period each year during 1992–1996 averaged 108, 240, 139, 281, and 275 m^3/s, respectively. Annual maximum (peak) mean daily discharges of the middle Green River were 270 m^3/s on 13 May 1992, 566 m^3/s on 28 May 1993, 331 m^3/s on 20 May 1994, 526 m^3/s on 8 June 1995, and 623 m^3/s on 20 May 1996. During 1993–1996, average April–July mean daily discharges of the lower Green River each year were 288, 143, 373, and 320 m^3/s, respectively. Peak mean daily discharges of the lower Green River were 710 m^3/s on 31 May 1993, 331 m^3/s on 22 May 1994, 829 m^3/s on 19 June 1995, and 679 m^3/s on 22 May 1996.

Fish Collections

Sampling was intended to target razorback sucker larvae, and captures of other fishes were secondary to the objectives of the 5-year investigation. However, those secondary captures provided a general description of the assemblages of small fish in habitats and during periods sampled for larval razorback suckers, and roughly illustrated the vulnerability of different species or life stages to the collecting gear and techniques employed. Further, sampling procedures and overall scope of the investigation evolved over time, and rigorous comparisons of fish distribution and abundance among species, years, river reaches, or gear types were not warranted because of unequal effort and variability in environmental conditions.

Middle Green River.—Sampling began in early to mid-May each year, about when main-channel water temperatures first consistently reached or exceeded 14°C, and continued until captures of suspected razorback sucker larvae had declined to only a few fish per collection or ceased (mid- or late June in 1992, 1994, and 1996; early July in 1993; early August in 1995). Collections were made about once per week in 1992 (an exploratory year) and about twice per week in subsequent years. Quiet-water habitats were sampled with seines (1992–1993), light traps (1993–1996), or hand-held dip nets (only two collections in 1993). Drift nets were used in the Echo Park (1993) and Escalante (1992–1993) reaches to collect larvae transported downstream from the two known areas of razorback sucker spawning activity. Seines were 1.2 m deep and 3.0 m long with 1.6 mm mesh, and seine and dip-net collections were made during daylight. Each seine haul or dip-net collection (a composite of one or more samples at a restricted place and time) was considered a single unit of effort. Light traps were floating quatrefoil units (commercially manufactured as the Edlite™ by Southern Concepts, Birmingham, Alabama; modified after the original design of Floyd et al. 1984) with 4-mm wide entry slits. Light traps fished at night are effective for capturing positively phototactic fish larvae and early juveniles (Kelso and Rutherford 1996), and quatrefoil units were successful in collecting razorback sucker larvae from Lake Mohave (Mueller et al. 1993). Numbers of light traps deployed overnight in each habitat per collection date generally increased with surface area of the habitat sampled and ranged from 3 to 12. Light traps were usually set near shoreline (often associated with emergent vegetation, woody debris, or rock outcroppings) in late afternoon or early evening and retrieved before sunrise. Effort was length of time each trap was fished between sunset and sunrise, and catch per unit effort (CPUE) was number of fish per 1 h of sampling. Conical drift nets (4 m long, 0.15 m^2 mouth opening, and 560 μm mesh) were set nearshore just below the water surface in flowing water, typically less than 1 m deep, 0–1 km downstream of the spawning area. Sampling with drift nets usually occurred at dawn or dusk, and three nets were deployed for up to 2 h on each sampling occasion. Effort was length of time each drift net was set, and CPUE was number of fish per 1 h of sampling. Diel sampling with drift nets at 4-h intervals (ca. 1000, 1400, 1800, 2200, 0200, and 0600 hours) was conducted below the Escalante spawning area on 8–9 May, 21–22 May, and 4–5 June in 1992. After 1993, we decided that light trapping was the most effective and logistically efficient method for capturing razorback sucker larvae in the middle Green River, and sampling with drift nets, seines, or dip nets was abandoned. Most fish were preserved in 100% ethanol (1993–1996 samples) or fixed in 10% formalin (1992 samples) immediately after collection for later laboratory processing. Selected sucker larvae captured with light traps in 1993 were reared to juvenile sizes in aquaria and then identified and counted. Some larger fish, particularly from seine collections, were identified, measured, counted, and released in the field.

Lower Green River.—Exploratory sampling in 1993 and 1994 was mostly opportunistic and occurred at irregular intervals during mid-June (1993) or mid-May through mid-June (1994). Collections in 1995 and 1996 were made about twice per week during late April through late July. Seines and light traps were used to sample quiet-water habitats throughout the 4 years of collecting. Seines were 1.2 m deep X 1.2 m long with 0.8 mm mesh, 1.2 m deep X 3.0 m long with 1.6 mm mesh, or 1.5 m deep X 4.0 m long with 1.25 mm mesh. Three to 10 light traps with 2- or 4-mm wide entry slits were deployed per habitat and collection date. Most fish collected were preserved in 100% ethanol, but some were fixed in 10% formalin. In 1994, sucker larvae ($N = 41$) from nine light-trap samples were immobilized with aqueous solutions of the anesthetic tricaine (Finquel^{TM}) at 100 mg/L (Snyder 1997); identified, measured, counted, and allowed to recover in the field; and then taken to the laboratory for rearing (Muth and Wick 1997). Juveniles of endangered Colorado squawfish *Ptychocheilus lucius* and some other larger fish collected with seines were identified, measured, counted, and released in the field.

Laboratory Procedures

Fish in each collection were sorted from debris, transferred to fresh 100% ethanol (those originally preserved in 100% ethanol) or 3% phosphate-buffered formalin (those originally fixed in 10% formalin), and identified to species using morphological criteria (e.g., Snyder 1981; Snyder and Muth 1990). The identity of selected native sucker larvae collected in 1993 was verified by mitochondrial DNA analysis (Proebstel 1998). Larvae of native suckers were measured to the nearest mm TL and counted; razorback sucker larvae selected for otolith aging were measured to the nearest 0.1 mm TL. Specimens of other fishes smaller than 41 mm TL were grouped and counted by 5-mm TL intervals, whereas larger fish were grouped as greater than 40 mm TL and counted.

Randomly selected razorback sucker larvae collected each year during 1993–1996 from nursery habitats in the middle or lower Green River and preserved in 100% ethanol were aged by counting daily increments in otoliths from hatching to capture. Preliminary results of a laboratory study to validate patterns of increment deposition in otoliths of captive larval razorback suckers reared under fluctuating water temperatures demonstrated that ages of wild larvae could be accurately estimated (K. Bestgen, Larval Fish Laboratory, personal communication). All specimens collected in 1995 and all remaining in 1993 samples after selected specimens had been removed for mitochondrial DNA analysis were analyzed. Subsampling of individuals was necessary for 1994 and 1996 collections because of the large numbers of specimens available for otolith aging.

The number of fish in each subsample per collection was determined from results of a computer simulation subsampling routine performed on a frequency distribution of ages of razorback sucker larvae in a large sample ($N = 56$) collected on 30 May 1994 from the middle Green River. All larvae in that sample were aged, and individuals were allocated to a categorical frequency distribution of ages that ranged from 8 to 20 d; the median age (13 d) and standard deviation (2.57) were assumed to be representative of other large collections. To determine how many larvae were required in subsamples to achieve that standard deviation, subsamples of 10, 15, 20, or 30 individuals were randomly drawn, with replacement 1,000 times each, from the frequency distribution and the average standard deviation was calculated for each subsample size. Average standard deviations for subsamples with 20 or 30 individuals were 2.52 or 2.79, respectively. Accordingly, for all other 1994 and 1996 samples, subsample sizes were set at 25 individuals for collections with more than 100 razorback sucker larvae and 25% of the total number of razorback sucker larvae in samples with 100 or fewer individuals. Randomization was accomplished by assigning each larva in a sample an unique number from 1 to N and using a random number table to select individuals.

For aging, otoliths were removed from specimens and mounted on numbered glass slides in either immersion oil (left lapillus and sagitta from larvae 13 mm TL or smaller) or thermoplastic cement (left lapillus from larvae 14 mm TL or larger); sagittae in larger larvae were elongated and difficult to age. The maximum diameter of each otolith was measured at 1000X magnification under a compound microscope fitted with a calibrated ocular micrometer. Otoliths mounted in immersion oil were aged without further preparation, whereas otoliths mounted in thermoplastic cement were ground on one side with wet-dry sandpaper and lapping film, and then covered with immersion oil for aging. Daily increments in each otolith were counted three times on separate occasions at 1000X magnification, and capture date, fish length, and otolith diameter were unknown. Counts were averaged for each larva to arrive at an estimated age in days posthatching. Horn (1996) determined that the first increment in otoliths of larval razorback suckers forms at hatching, and increment deposition proceeds at rate of approximately one increment per day.

Spawning dates for razorback suckers in the middle or lower Green River each year during 1993–1996 were estimated by subtracting estimated incubation times of embryos from hatching dates of larvae. The hatching date for an individual larva was established by subtracting its posthatching age from its date of capture. Temperature-dependent incubation times of embryos at ambient Green River temperatures on and closely preceding hatching dates were estimated using data presented by Marsh (1985) and Bozek et al. (1990) for captive embryos.

Mainstem water temperature and discharge parameters selected for association with spawning dates in each river section (middle or lower) and year included (1) mean (range) discharge and temperature during the spawning period; (2) degree days, which was the sum of recorded instantaneous daily water temperatures between 1 January and the earliest date of spawning; (3) days ≥ 10°C or ≥ 14°C, which were the number of days between 1 January and the earliest date of spawning that recorded instantaneous daily water temperatures equaled or exceeded each respective threshold; and (4) days before peak discharge, which was the number of days between the earliest date of spawning and the highest recorded mean daily river discharge. Missing temperature data were estimated by linear interpolation. For this analysis, we assumed that razorback sucker larvae caught in either the middle or lower Green River had been produced locally.

Daily gain in total length (growth) of an individual aged razorback sucker larva between hatching and date of capture was estimated by subtracting an approximate mean TL at hatching of 8.0 mm (Minckley and Gustafson 1982; Marsh 1985; Snyder and Muth 1990) from its total length at capture and dividing by its age. Mean daily growth was calculated for larvae caught in the middle or lower Green River in each year.

Diet was determined for approximately 25% of all razorback sucker larvae 11–18 mm TL collected by light traps. Data were stratified according to fish length (1-mm TL intervals) by year within each river section. The numbers of larvae per TL interval selected for diet analysis from each collection were generally representative of the size composition of razorback suckers in the collection. Each digestive tract (from esophagus to vent) was removed, opened, and qualitatively assessed for percent fullness. Food items were identified, grouped into 11 family, order, or broader-based categories, and a qualitative estimate was made of the percentage contributed by each food category to the total volume of food in each digestive tract (Muth and Snyder 1995). The diet measure calculated for each subset was mean percentage each food category contributed to the total volume of food in each digestive tract (Wallace 1981).

RESULTS

Fish Assemblages

Over all years, 53,750 fish representing six families and 16 species were recorded from 853 light-trap, 142 drift-net, 80 seine, and 2 dip-net collections in the middle Green River, and 59,220 fish representing five families and 15 species were recorded from 650 light-trap and 224 seine collections in the lower Green River (Tables 1 and 2). All fish collected were larvae, early juveniles, or small adults. Three families and 13 species were common to both river sections, and numbers of captured fish were dominated by three native catostomids (bluehead sucker *Catostomus discobolus*, flannelmouth sucker *C. latipinnis*, and razorback sucker) and by nonnative cyprinids (primarily red shiner *Cyprinella lutrensis*, sand shiner *Notropis stramineus*, and fathead minnow *Pimephales promelas*). Native catostomids (including unidentified suckers too damaged or intermediate in diagnostic characters for species identification but assumed to be mostly natives) and nonnative cyprinids, respectively, accounted for 57 and 42% of the total catch for the middle Green River, and 7 and 92% of the total catch for the lower Green River. Of the 30,558 native catostomids captured from the middle Green River, 46% were bluehead suckers, 46% were flannelmouth suckers, 6% were razorback suckers, and 2% were unidentified specimens. In the lower Green River, 9% of the 3,546 native catostomids collected were bluehead suckers, 79% were flannelmouth suckers, 11% were razorback suckers, and 1% were unidentified specimens. About 25% of all nonnative cyprinids caught in either the middle or lower Green River were classified as unidentified, and over 99% of those were likely red shiners, sand shiners, or fathead minnows that were too small (less than 6 mm TL) to distinguish with confidence based on existing morphological criteria.

Other taxa collected inconsistently or in low numbers from both river sections were native chubs *Gila* sp., Colorado squawfish, and speckled dace *Rhinichthys osculus*, and nonnative common carp *Cyprinus carpio*, redside shiner *Richardsonius balteatus*, white sucker *Catostomus commersoni*, and green sunfish *Lepomis cyanellus*. Native mottled sculpins *Cottus bairdi*, and nonnative northern pike *Esox lucius* and brook sticklebacks *Culaea inconstans* (a recent addition to the known fish fauna of the middle Green River drainage, Utah; Modde and Haines 1996) were caught only in the middle Green River, whereas nonnative black bullheads *Ameiurus melas* and channel catfish *Ictalurus punctatus* were unique to collections from the lower Green River.

Of the 16 species caught in the middle Green River, 10 were recorded from drift-net, seine, and light-trap collections; one (mottled sculpin) was represented in seine and light-trap collections; one (northern pike) was only found in seine collections; and four (Colorado squawfish, redside shiner, brook stickleback, and green sunfish) were only captured by light traps. In the lower Green River, 11 of the 15 species collected were represented in seine and light-trap collections, and the other four species (white sucker, black bullhead, channel catfish, and green sunfish) were exclusive to seine collections. Seine and light-trap collections from the lower Green River in each year were composed primarily of nonnative cyprinids, and percentages contributed by those fishes to the total annual catch of each gear ranged from 66 (1994) to 99% (1993) for seines and from 77 (1993) to 98% (1995) for light traps. Most fish collected by drift nets or seines from the middle Green River were either bluehead or flannelmouth suckers. For light-trap collections from the middle Green River, nonnative cyprinids dominated the total catch in 1993 (88%) and 1995 (70%), whereas native catostomids predominated in 1994 (97%) and 1996 (63%). Seines were effective in capturing a wide range of fish sizes (less than 10 to over 200 mm TL), whereas most fish collected by drift nets and light traps were less than

21 mm TL. Drift nets are most effective for capturing small fish larvae passively drifting with water currents, and the maximum size of fish collected with light traps was limited by the 2- or 4-mm wide entry slits.

Razorback Sucker Captures

Larval razorback suckers were captured in each year of sampling in the middle and lower Green River. A total of 1,735 larvae (8–24 mm TL; mean, 12 mm TL) was collected from the middle Green River and 440 (10–20 mm TL; mean, 13 mm TL) from the lower Green River (Tables 1 and 2). Numbers captured per year ranged from 20 in 1992 to 1,217 in 1994 for the middle Green River and from 5 in 1995 to 222 in 1996 for the lower Green River. Of the total number collected from the middle Green River, 1,651 were caught by light traps, 69 by seines, 12 by drift nets, and 3 by dip nets. In the lower Green River, 415 razorback suckers were collected by light traps and 25 by seines.

Sampling was concentrated in the Escalante, Jensen, and Ouray reaches of the middle Green River, and in the San Rafael River confluence reach and particularly the middle Stillwater Canyon reach of the lower Green River. The Escalante, Jensen, and Ouray reaches combined produced over 99% of the total catch of larval razorback suckers in the middle Green River (Table 3). Among those three reaches, 711 razorback suckers were collected from the Jensen reach (668 by light traps and 43 by seines), 700 were collected from the Escalante reach (661 by light traps, 29 by seines, and 10 by drift nets), and 318 were collected from the Ouray reach (all by light traps). Over 90% of all razorback suckers collected from the Escalante reach were caught in Cliff Creek (the remainder were caught upstream near the Escalante spawning area); 83, 11, and 6% of those captured from the Jensen reach were in collections from Stewart Lake Drain, backwaters in the Red Wash Launch area (approximately RK 480–481), or Sportsmans Drain, respectively; and most larval razorback suckers caught in the Ouray reach were from Greasewood Corral (85%) or the inlet to Old Charlie Wash (14%). Only six razorback sucker larvae were caught in the Echo Park reach (four by light traps and two by drift nets), and none was captured from the Island-Rainbow Park reach.

A total of 363 larval razorback suckers was recorded from collections in the middle Stillwater Canyon reach (340 were captured by light traps and 23 by seines), 76 from seine or light-trap collections in the San Rafael River confluence reach (all but two were captured by light traps), and 1 was collected by light traps from the Green River Valley reach (Table 4). Within the middle Stillwater Canyon reach, 80% of the total number of razorback suckers captured were from Millard Canyon and 19% were from the Anderson Bottom-Bonita Bend area. All razorback sucker larvae collected from the San Rafael River confluence reach were caught in nursery habitats at or immediately downstream of the mouth of the San Rafael River.

Mean catch rates (CPUE) of larval razorback suckers for both river sections were often low (rarely exceeding 0.50 fish/unit of effort) and were highly variable among years, reaches, and gear types (Tables 3 and 4). Of the sampling methods employed, we decided that comparisons of CPUE among most years and among the primary reaches sampled were most valid, although problematic, for light-trap collections. Mean CPUE (reaches combined) for the middle Green River among years ranged from 0.02 fish/h of light trapping in 1995 to 1.00 fish/h in 1994 (Table 3); mean CPUE was similar between 1993 (0.12 fish/h) and 1996 (0.16 fish/h). In each year, mean catch per hour of light trapping among the three primary reaches was highest for the Escalante reach, followed in descending order by the Jensen and Ouray reaches. Mean catch rates among years for the lower Green River, reaches combined, ranged from 0.01 fish/h of light trapping in 1995 to 1.36 fish/h in 1993 (Table 4). However, if 1993 results are excluded because of the abbreviated sampling period (17–19 June), the highest annual mean CPUE occurred in 1994 (0.22 fish/h). Mean catch rates were highest for the middle Stillwater Canyon reach, and the highest overall mean CPUE was for that reach in 1996 (1.52 fish/h of light trapping).

Temporal distribution of razorback sucker captures in both river sections varied among years, and dates of capture over all years ranged from 16 May (1994) to 21 July (1995) in the middle Green River and from 7 May to 9 July (1996) in the lower Green River (Figures 2 and 3). In most years, larvae were first caught 20–30 d after the earliest estimated date of spawning (Figures 4 and 5), and numbers collected had usually peaked by early or mid-June. The earliest collection of razorback sucker larvae from the lower Green River each year during 1994–1996 occurred on (1994) or before (1995 and 1996) the earliest capture date in the middle Green River.

This trend was most pronounced in 1996 when 83% of the total number of larval razorback suckers caught in the lower Green River (184 out of 222) were collected 3 to 28 d before the date of first capture in the middle Green River; estimated dates of first reproduction in 1996 were 2 April in the lower Green River and 9 May in the middle Green River.

Spawning Periods

Estimated annual spawning periods for razorback suckers varied temporally among years in both the middle and lower Green River but generally spanned 4–6 weeks each year and were associated with increasing and highest spring flows (Figures 4 and 5). Dates of reproduction in the lower Green River were probably underestimated in 1993 because of restricted sampling and in 1995 because of low captures of larvae, and therefore, those results were excluded from the following comparisons. Over all years, spawning in the middle Green River extended from mid-April (1994) through late June (1995) but generally ranged from early or mid-May through late May or early June. Spawning in 1993, 1995, and 1996 appeared to be concentrated during mid- to late May. In contrast, most spawning in the low-flow year of 1994 was estimated to occur during late April to mid-May. Within the reproductive period across all years, mean daily discharges of the mainstem middle Green River ranged from 78 to 623 m^3/s (mean, 370 m^3/s) and instantaneous daily water temperatures ranged from 8.0 to 19.5°C (mean, 14°C). Spawning in the lower Green River in 1994 occurred from late April through late May at mainstem discharges of 134–331 m^3/s (mean, 233 m^3/s) and water temperatures of 12.5–20.5°C (mean, 17.5°C). Discharges and water temperatures of the lower Green River in 1996 during early April through early June spawning ranged from 145 to 679 m^3/s (mean, 376 m^3/s) and from 10.0 to 21.0°C (mean, 14.5°C), respectively. Most spawning was estimated to occur during early through mid-May in 1994 and mid- through late April in 1996.

Of the selected mainstem water temperature and discharge parameters associated with earliest dates of spawning, excluding 1993 and 1995 for the lower Green River, none appeared to be adequate for predicting when first reproduction would occur (Table 5). Each parameter varied considerably among years within each river section, and trends were inconsistent. Dates of first reproduction in most years generally coincided with a relatively steep and consistent increase in discharge associated with the beginning of spring runoff (Figures 4 and 5). Early reproduction in the middle and lower Green River in 1994 was related to a sharp rise in the increasing spring discharge during late April; maximum mean daily discharge of that flow event was about 70% of the peak runoff discharge in each river section.

Growth of Larvae

Mean and maximum TL of razorback suckers in collections from the middle or lower Green River generally increased as sampling progressed each year, but individuals 11–12 mm TL predominated throughout the season (Figures 2 and 3). Approximately 20% of all razorback suckers captured were larger than 12 mm TL, and the two largest specimens were 20 and 24 mm TL. Estimated mean daily growth (Table 6) of larvae collected from either river section was lowest in 1994 (0.31 and 0.27 mm TL/d for the middle and lower Green River, respectively) and greatest in 1996 (0.35 and 0.33 mm TL/d). In each year, larvae from the middle Green River grew faster than those from the lower Green River, and differences in mean growth rates of larvae between the river sections ranged from 6% in 1996 to 21% in 1995.

Diet of Larvae

The diet of larval razorback suckers 11–18 mm TL in nursery habitats was comparable among years and between river sections. Because no major or consistent annual differences in diet were observed within either river section for fish of similar size, data were combined over all years. For both the middle and lower Green River, the percentage of razorback suckers with food in their digestive tracts out of the total number examined per TL interval and the mean percent fullness of digestive tracts increased as fish length increased (Tables 7 and 8). Digestive tracts of all fish larger than 13 mm TL contained food and averaged more than 50% full. Principal dietary components were early instar chironomid larvae, small cladocerans, rotifers, algae, and organic and inorganic debris, but the relative importance of these food categories varied with fish length. Although chironomids were predominant in guts across all TL intervals, their proportional contribution to the diet generally increased or remained high with increasing fish length.

Conversely, the relative importance of cladocerans, rotifers, and algae tended to decrease as fish length increased. Most digestive tracts contained debris, which accounted for moderate proportions of gut contents (10–30% of food volume) for all TL intervals. Debris consisted of fine, amorphous particles of organic matter, clay particles, and sand grains. Larval razorback suckers from the lower Green River consumed slightly more algae than those from the middle Green River. Ephemeroptera larvae were eaten by fish larger than 14 mm TL, whereas copepods, ostracods, and invertebrate eggs were found in guts of fish smaller than 15 mm TL.

DISCUSSION

Reproduction

We documented annual reproduction by razorback suckers in the Green River through collections of larvae ($N = 2{,}175$) from reaches of the middle or lower river during 1992–1996. These captures represent the first confirmed reproduction by the species in middle Green River since 1984 (Tyus 1987) and the first ever records of larval razorback suckers in the lower Green River. All but 6 of the 1,735 razorback sucker larvae caught in the middle Green River were from reaches including or downstream of the suspected primary spawning area adjacent to the Escalante Ranch. Based on the few larvae ($N = 6$) recorded from collections in the Echo Park reach, reproduction by razorback suckers at the lower Yampa River spawning site during our investigation appeared minimal, but sampling efforts in the two reaches immediately downstream of that spawning site were comparatively low.

Earlier first occurrence of razorback sucker larvae in collections from the San Rafael River confluence or middle Stillwater Canyon reaches compared to collections from the middle Green River suggests that at least some reproduction occurred in the lower Green River each year during 1994–1996. Further, the capture of only one larval razorback sucker from the Green River Valley reach in 1996 demonstrated at most a minimal level of transport of larvae into the lower Green River from upstream reaches. This suggests that many of the 439 larval razorback suckers caught in the lowest two reaches had been produced downstream of the Green River Valley reach. Although aggregations of ripe razorback suckers have not yet been found in the lower Green River, our collections of larvae and captures of adults in spring (e.g., Chart et al. 1997) at or immediately downstream of the mouth of the San Rafael River are suggestive of localized spawning. Other possible recent evidence for razorback sucker reproduction in the lower Green River includes the collection of two early juveniles (36.6 and 39.3 mm TL) from a backwater at RK 89.5 on 30 July 1991 (Gutermuth et al. 1994) and the capture of 15 larvae (13–16 mm TL), presumably produced in the Green River, from the Colorado River inflow to Lake Powell on 22 June 1993 (Muth and Wick 1997). However, regardless of the source, the occurrence of razorback sucker larvae in the lower Green River obligates resource agencies to consider management actions for both the middle and lower Green River to enhance survival of early life stages.

Razorback suckers in the Green River system reproduce in spring (April through June) at increasing and highest runoff flows and warming water temperatures, as evidenced by our observations on larvae and those of other investigators on adults (e.g., McAda and Wydoski 1980; Tyus 1987; Tyus and Karp 1989, 1990). In comparison, reproduction by razorback suckers in the lower Colorado River basin generally occurs during January through April (Medel-Ulmer 1983; Minckley 1983; Langhorst and Marsh 1986; Mueller 1989) but may extend from November into May (Bozek et al. 1991). Annual initiation of razorback sucker spawning in the Green River during our investigation was probably triggered by a suite of interacting environmental cues that could not be detected by our analysis of single water temperature and discharge parameters. Modde and Wick (1997) concluded that initial movement of adult razorback suckers to the Escalante spawning site was influenced primarily by increases in river discharge and secondarily by increases in water temperature. Our estimated spawning periods in the middle or lower Green River, respectively, encompassed a wide range of mainstem mean daily discharges (78–623 m^3/s or 134–696 m^3/s) and instantaneous daily water temperatures (8.0–19.5°C or 10.0–21.0°C). The predominance of razorback sucker larvae 11–12 mm TL in our collections throughout the season each year suggests continuous spawning and larval production. Tyus and Karp (1990) associated razorback sucker reproduction in the middle Green River during the low-to-average runoff years of 1987–1989 with discharges of 150–250 m^3/s (estimated from graphs) and water temperatures of 9–17°C. Spawning by razorback suckers in the Yampa River in 1975, 1981, 1988, and 1989 was believed to occur at discharges ranging from 70 to 400 m^3/s (estimated from graphs) and water temperatures averaging 15°C (Tyus and Karp 1989). The observed wide ranges in discharges and water temperatures during spawning suggest that the reproductive strategy of razorback sucker is adapted to a variable and fluctuating environment.

Mean catch rates of razorback sucker larvae, which may be an index of annual larval production, were highly variable among years and reaches. Temporal or spatial variations in catch data were expected because of inherent variability in biological and physical processes. However, we are uncertain if our CPUE estimates were true indicators of population abundance or if they were biased by differences in sampling efficiency. For example, annual CPUE for light-trap collections in the middle Green River was lowest in the wet year of 1995 and highest in the dry year of 1994, but sampling in 1995 was probably comparatively less effective due to greater availability of flooded quiet-water habitats and wide dispersal of larvae. Wick (1997) hypothesized that the low catch rate in 1995 was indicative of poor reproductive success due to increased sedimentation of cobble and gravel substrates at the Escalante spawning bar. He associated increased sedimentation with unnaturally high releases from Flaming Gorge Dam too early in the spring-runoff period. Snyder and Meismer (1997) reported that 13–51% of razorback sucker larvae or early juveniles confined within 0.5 m of light traps in laboratory experiments entered those traps within 1 h. However, they suggested that the usefulness of light traps to approximate the natural density or abundance of fish early life stages should be addressed through additional experiments designed to be more representative of natural conditions. Regardless of observed annual variations in CPUE, whether real or sampling artifact, razorback sucker larvae apparently disappeared from Green River nursery habitats by early or mid-July each year, suggesting extremely low survival. Furthermore, only six early juvenile razorback suckers have been collected from the Green River within recent years (Gutermuth et al. 1994; Utah Division of Wildlife Resources, unpublished data). Thus, recruitment sufficient to sustain wild populations may not be occurring.

Larval Diet, Growth, and Survival

Larval razorback suckers consume most of their yolk and begin exogenous feeding on planktonic or benthic organisms by 10–11 mm TL (Minckley and Gustafson 1982; Marsh and Langhorst 1988; Papoulias and Minckley 1990; Snyder and Muth 1990; USFWS 1997). We found that the diet of razorback sucker larvae 11–18 mm TL caught by light traps in nursery habitats of the Green River consisted mainly of small chironomid larvae, supplemented by zooplankton (mostly small cladocerans and rotifers) and algae (e.g., diatoms), particularly in fish smaller than 14 mm TL. Our description of diet might be confounded because light traps also attract and collect free-swimming invertebrates (Ervin and Haines 1972; Mueller et al. 1993), and we do not know the length of time razorback sucker larvae were in the light traps before retrieval or the evacuation rates of digestive tracts of larval razorback suckers. However, most of the invertebrates captured by the light traps were corixids or larger cladocerans and usually in low numbers. Further, similar to our observations, hatchery-produced razorback sucker larvae recaptured by seines 1 week after stocking in a backwater of the Salt River, Arizona, had consumed primarily larval chironomids (Bestgen 1990). This dietary pattern likely indicates opportunistic feeding because chironomids are among the more common benthic invertebrates in quiet-water soft-sediment riverine habitats of the Colorado River basin (Ward et al. 1986; Grabowski and Hiebert 1989; Muth and Snyder 1995; Wolz and Shiozawa 1995). In contrast, Marsh and Langhorst (1988) reported that larval razorback suckers less than 21 mm TL from a shoreline section of Lake Mohave or an adjacent, isolated backwater without nonnative fishes ate primarily rotifers, cladocerans, or copepods. However, the diet of larvae in the backwater was comparatively more diverse and included larval chironomids and trichopterans. The digestive tracts of 33% of all specimens (41 out of 124) from Lake Mohave and 63% of all specimens (47 out of 75) from the backwater contained food. Similar to the isolated backwater, we found food in the digestive tracts of 67% of 480 larval razorback suckers; 59% of 379 specimens 11–13 mm TL , which averaged 35–45% full, and 100% of all specimens 14–18 mm TL, which averaged 51–65% full.

Poor growth and survival of razorback sucker larvae due to low food abundance has been postulated as contributing to the low or nonexistent recruitment in populations (Minckley 1983;

Marsh and Langhorst 1988; Papoulias and Minckley 1990, 1992; Modde 1997). Papoulias and Minckley (1990) suggested that many wild-caught razorback sucker larvae from Lake Mohave are in the "critical period" (sensu Hjort 1914) of transition from dependence on endogenous to exogenous foods (within about the first 3 weeks after hatching). They concluded that mortality related to low abundance of appropriate foods may contribute to year-class failure of razorback suckers in Lake Mohave. Papoulias and Minckley (1992) found that survival of larval razorback suckers reared at 12–17°C in earthen ponds fertilized at three levels (low, medium, and high) was independent of invertebrate densities (survival ranged from 67.4% in the low-fertilization treatment to 89.8% in the medium-fertilization treatment), but total larval growth was significantly greater at the two higher invertebrate densities. Based on their observations of mean TL at each fertilization level by 7-d intervals, growth rates of larvae during the first 56 d after swimup averaged about 0.17, 0.16, and 0.13 mm TL/d for the high, medium, and low treatments, respectively. By comparison, our estimated mean growth for otolith-aged larval razorback suckers less than 35 d old (posthatching) ranged from 0.27 mm TL/d (1994, lower Green River) to 0.35 mm TL/d (1996, middle Green River). Our estimates of growth on wild-caught fish are likely biased high because many slow-growing individuals had probably already been "removed" from the populations by natural selection (e.g., Miller et al. 1988; Rice et al. 1993; Bestgen et al. 1997). Nonetheless, based on observations of larval diet, composition and abundance of invertebrates in quiet-water soft-sediment riverine habitats, and growth and survival of captive larvae, it appears that food abundance in existing razorback sucker nursery habitats on the Green River is adequate to meet the minimum nutritional requirements for larval survival. However, the growth potential of razorback sucker larvae is greater than we observed. Mean growth rates of larval razorback suckers reared in the laboratory for 28 d after the start of exogenous feeding and fed nauplii of *Artemia* sp. *ad libitum* twice daily were 0.39, 0.58, 0.65, or 0.72 mm TL/d at constant water temperatures of 16.5, 19.5, 22.5, or 25.5°C, respectively (K. R. Bestgen, Larval Fish Laboratory, personal communication). Relatively minor differences in growth rates can be biologically significant if size-dependent processes, such as predation by small, gape-limited predators, are important regulators of larval survival. For example, Bestgen et al. (1997) demonstrated through experiments and recruitment-model simulations that the predatory effects of nonnative adult red shiners on the mortality of larval Colorado squawfish decreased 5–40% as growth rates of larvae increased by 0.1-mm increments from 0.2 to 0.6 mm TL/d. Predation by adult red shiners on larvae of native catostomids in flooded and backwater habitats of the Yampa, Green, or Colorado rivers was documented by Ruppert et al. (1993) and Muth and Wick (1997). Horn (1996) concluded that although nutritional limitations in Lake Mohave may directly contribute to the high mortality of larval razorback suckers, a greater problem is reduced growth, which keeps larvae at a size vulnerable to predation for longer period of time. He further stated that apparently all razorback sucker larvae in Lake Mohave, starving or not, are consumed by nonnative fish predators.

Management Implications

Most collections of wild adult razorback suckers in rivers of the upper Colorado River basin have occurred in unconfined floodplain reaches (Modde et al. 1995; Muth 1995), and the greatest expanse of floodplain habitat in the upper basin is in the Jensen and Ouray reaches of the middle Green River (Irving and Burdick 1995), coincident with the largest extant reproducing population. Floodplain wetlands inundated and connected to the main channel by spring-runoff discharges appear to be important habitats for all life stages of razorback sucker (e.g., Osmundson and Kaeding 1989; Tyus and Karp 1989, 1990, 1991; Modde 1996, 1997; Modde et al. 1996). Floodplain wetlands are typically warmer and more productive than the adjacent river, have abundant vegetative cover, and the natural integrity of large-river ecosystems is dependent on interactions between the main channel and floodplain (Welcomme 1985; Junk et al. 1989; Ward 1989; Stanford 1994; Ward and Stanford 1995; Brookes 1996; Wetzel and Ward 1996; Wydoski and Wick 1998).

The seasonal timing of razorback sucker reproduction suggests an adaptation for utilizing floodplain wetlands. Tyus and Karp (1990) and Modde and Wick (1997) reported that adult razorback suckers in the middle Green River moved into flooded habitats (e.g., wetlands and tributary mouths) shortly before or after spawning. They suggested that this movement was related to temperature preferences and food abundance. Razorback sucker larvae drift downstream after swimup and are transported into nursery habitats. Enhanced growth of larval razorback suckers in warmer, more productive wetlands may increase overall survival by shortening the period of vulnerability to predation by small, gape-limited fishes (Lentsch et al. 1996a). Early juvenile razorback suckers were recently found during late summer or autumn draining of the Old Charlie Wash managed wetland adjacent to the middle Green River (Modde 1996, 1997). Despite the predominance of nonnative fishes (including several known fish predators), 28 razorback sucker juveniles (74–125 mm TL; mean, 94 mm TL) were collected from the wetland in October 1995, and 45 (44–83 mm TL; mean, 66 mm TL) were collected in August 1996. It is unknown whether these fish originated from riverine spawning and drifted into Old Charlie Wash as larvae or were spawned in the wetland. Modde (1997) reported that favorable nursery conditions for young fish existed in Old Charlie Wash during spring and summer each year, 1995 and 1996; e.g., abundant zooplankton (peak mean density of organisms was 54.3/l in 1995 and 42.8/l in 1996), warm water (about 16–28°C; 2–8°C higher than the adjacent river), and abundant vegetative cover. Modde et al. (1996) associated years of high spring discharge and floodplain inundation in the middle Green River (1983, 1984, and 1986) with subsequent suspected recruitment of young adult razorback suckers.

Most floodplain wetlands adjacent to the Green River are now isolated from the main channel by levees, and the historic frequency, magnitude, and duration of seasonal overbank flooding in the Green River have been substantially reduced since closure of Flaming Gorge Dam in 1962 (Lentsch et al. 1996a; Modde 1997; USFWS 1997). Restoring access to these habitats appears crucial for recovery of self-sustaining razorback sucker populations. The Colorado River Recovery Implementation Program recently instituted efforts to reestablish river-wetland connections at selected sites along the middle Green River by breeching levees (Lentsch et al. 1996a). However, substantial increases in the spatial extent of floodplain inundation and duration of river-wetland connectivity will require management of spring-peak releases from Flaming Gorge Dam in wet years when discharge from the Yampa River (and other tributaries) is high to provide the magnitude and duration of flows necessary for overbank flooding (e.g., FLO Engineering, Inc. 1996, 1997; Bell et al. 1998). Wick (1997) recommended that peak releases from Flaming Gorge Dam be closely coordinated with forecasts of spring-runoff for the Yampa River in order to support and build on Yampa River peak flows. Further, the seasonal timing of overbank flooding must be matched with the temporal distribution of razorback sucker larvae in the river (Modde 1997). We estimated that, in most years during 1993–1996, larval razorback suckers in the Green River were first captured 20–30 d after initiation of spawning, which generally coincided with a relatively steep and consistent increase in discharge associated with the beginning of spring runoff, and numbers collected had usually peaked by early or mid-June.

The present existence of razorback sucker populations in the Green River is tenuous, and immediate conservation measures are needed if the species is to persist. Management actions of the Colorado River Recovery Implementation Program to recover the endangered fishes include a combination of restoration of natural habitats, nonnative fish control, augmentation of wild populations, protection of fish in refugia, and monitoring of populations and habitats. We documented annual reproduction by razorback suckers but mortality of larvae was apparently high. Predation on razorback sucker early life stages by nonnative fishes is considered a serious threat to populations (Bestgen 1990; Minckley et al. 1991; USFWS 1997), and concerns exist within the Colorado River Recovery Implementation Program about the effects of degraded water quality (e.g., increased concentrations of selenium) on razorback sucker reproduction and larval survival (Hamilton and Waddell 1994; Hamilton 1998; Hamilton et al. 1998). Restoring access to warm, productive floodplain wetlands to serve as growth and conditioning habitats holds promise for razorback sucker recovery, but much remains to be learned about fish population and community responses to individual and collective management actions.

RECOMMENDATIONS

1. Development of an effective standardized monitoring program for razorback suckers in the Green River is progressing and requires continued flexibility in application and evaluation of sampling methods, data analysis, and overall scope of the program to ensure that population indices are valid indicators of trends and responses to management actions.
2. Light traps set overnight in quiet-water habitats are effective for capturing larval razorback suckers to document reproduction and monitor when larvae are transported downstream from spawning areas. However, studies are needed to directly assess the

efficacy of light-trap CPUE data for approximating the density of larvae in nursery habitats, which would advance the understanding of the causes and biological meaning of capture variability. These studies may include experiments in artificial (e.g., pools or ponds) or natural nursery habitats stocked with known numbers of larvae, or estimates of larval abundance in the wild using capture-recapture methods.

3. Additionally, there is a need to establish relationships among river discharge, spatial extent of flooded habitats for nursery areas, and dispersal patterns of razorback sucker larvae. Present sampling should be expanded to include other river reaches (e.g., Echo and Island-Rainbow parks) and habitats. These efforts would benefit the evaluation of light-trap CPUE and provide information for improving the monitoring program.
4. Efforts to document razorback sucker reproduction in the lower Green River should be expanded and possibly include radio-tracking of adults in spring to locate spawning areas and assess movements and habitat use.
5. Understanding the relationships between biological processes and water temperatures as a function of discharge is important in management of regulated flows to benefit recovery of the endangered fishes. However, much of the temperature data presently recorded by the U.S. Geological Survey or U.S. Fish and Wildlife Service (Channel Monitoring) in rivers of the upper basin are inadequate for accurate analyses of such relationships. A list of priorities for acquisition of temperature data should be developed by researchers and used as the basis of a monitoring program employing continuous-recording thermographs linked to real-time data stations.

REFERENCES

BEHNKE, R. J., AND D. E. BENSON. 1983. Endangered and threatened fishes of the upper Colorado River basin. Colorado State University Extension Service Bulletin 503A.

BELL, A, D. BERK, AND P. WRIGHT. 1998. Green River flooded bottomlands mapping for two water flows in May 1996 and one water flow in June 1997. Technical Memorandum No. 8260-98-07. U.S. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

BESTGEN, K. R. 1990. Status review of the razorback sucker, *Xyrauchen texanus*. Final Report of Colorado State University Larval Fish Laboratory to U. S. Bureau of Reclamation, Salt Lake City, Utah.

BESTGEN, K. R., D. W. BEYERS, G. B. HAINES, AND J. A. RICE. 1997. Recruitment models for Colorado squawfish: tools for evaluating relative importance of natural and managed processes. Final Report of Colorado State University Larval Fish Laboratory to U.S. National Park Service Cooperative Parks Study Unit and U. S. Geological Survey Midcontinent Ecological Science Center, Fort Collins, Colorado.

BOZEK, M. A., L. J. PAULSON, AND G. R. WILDE. 1990. Effects of ambient Lake Mohave temperatures on development, oxygen consumption, and hatching success of the razorback sucker. Environmental Biology of Fishes 27:255–263.

BOZEK, M. A., L. J. PAULSON, G. R. WILDE, AND J. E. DEACON. 1991. Spawning season of the razorback sucker, *Xyrauchen texanus* in Lake Mohave, Arizona and Nevada. Journal of Freshwater Ecology 6:61–73.

BROOKES, A. 1996. River channel change. Pages 221–242 *in* G. Petts and P. Calow, editors. River flows and channel forms. Blackwell Science, Oxford, England.

CHART, T. E., D. P. SVENDSON, AND L. D. LENTSCH. 1997. Investigation of potential razorback sucker (*Xyrauchen texanus*) and Colorado squawfish (*Ptychocheilus lucius*) spawning in the lower Green River, 1994 and 1995. Final Draft Report of Utah Division of Wildlife Resources to Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin, Denver, Colorado.

ERVIN, J. L., AND T. A. HAINES. 1972. Using light to collect and separate zooplankton. Progressive Fish-Culturist 34:171–174.

FLO ENGINEERING, INC. 1996. Green River flooded bottomlands investigation, Ouray Wildlife Refuge and Canyonlands National Park, Utah. Final Report of FLO Engineering, Inc. to Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin, Denver, Colorado.

FLO ENGINEERING, INC. 1997. Green River floodplain habitat restoration investigation – Bureau of Land Management sites and Ouray National Wildlife Refuge sites near Vernal, Utah. Final Report of FLO Engineering, Inc. to Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin, Denver, Colorado.

FLOYD, K. B., R. D. HOYT, AND S. TIMBROOK. 1984. Chronology of appearance and habitat partitioning by stream larval fishes. Transactions of the American Fisheries Society 113:217–223.

GRABOWSKI, S. J., AND S. D. HIEBERT. 1989. Some aspects of trophic interactions in selected backwaters and the main channel of the Green River, Utah, 1987–1988. Final Report of U.S. Bureau of Reclamation Research and Laboratory Services Division, Applied Sciences Branch, Environmental Sciences Section, Denver, Colorado, to U.S. Bureau of Reclamation Upper Colorado Regional Office, Salt Lake City, Utah.

GUTERMUTH, F. B., L. D. LENTSCH, AND K. R. BESTGEN. 1994. Collection of age-0 razorback suckers (*Xyrauchen texanus*) in the lower Green River, Utah. Southwestern Naturalist 39:389–391.

HAMILTON, S. J. 1998. Selenium effects on endangered fish in the Colorado River basin. Pages 297–313 *in* W. T. Frankenberger and R. A. Engberg, editors. Environmental chemistry of selenium. Marcel Dekker, New York.

HAMILTON, S. J., AND B. WADDELL. 1994. Selenium in eggs and milt of razorback sucker (*Xyrauchen texanus*) in the middle Green River, Utah. Archives of Environmental Contamination and Toxicology 27:195–201.

HAMILTON, S. J., R. T. MUTH, B. WADDELL, AND T. W. MAY. 1998. Selenium and other trace elements in wild larval razorback suckers from the Green River, Utah. Final Report of the U.S. Geological Survey Environmental and Contaminants Research Center to U.S. Bureau of Reclamation Irrigation Drainage Program, Denver, Colorado.

HAMMAN, R. L. 1985. Induced spawning of hatchery-reared razorback sucker. Progressive Fish-Culturist 47:187–189.

HAWKINS, J. A., AND T. P. NESLER. 1991. Nonnative fishes of the upper Colorado River basin: an issue paper. Final Report of Colorado State University Larval Fish Laboratory and Colorado Division of Wildlife to Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin, Denver, Colorado.

HJORT, J. 1914. Fluctuations in the great fisheries of northern Europe viewed in the light of biological research. Rapports et Proces-Verbaux des Reunions, Counseil International pour l'Exploration de la Mer 20.

HORN, M. J. 1996. Nutritional limitation of recruitment in the razorback sucker (*Xyrauchen texanus*). Doctoral dissertation. Arizona State University, Tempe.

IRVING, D. B., AND B. D. BURDICK. 1995. Reconnaissance inventory and prioritization of existing and potential bottomlands in the upper Colorado River basin, 1993–1994. Final Report of U.S. Fish and Wildlife Service to Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin, Denver, Colorado.

JORDAN, D. S., AND B. W. EVERMANN. 1896. The fishes of North and Middle America. Bulletin of the U.S. National Museum 47(1):1–1240.

JUNK, W. J., P. B. BAYLEY, AND R. E. SPARKS. 1989. The flood pulse concept in river floodplain systems. Canadian Special Publication of Fisheries and Aquatic Sciences 106:110–127.

KELSO, W. E., AND D. A. RUTHERFORD. 1996. Collection, preservation, and identification of fish eggs and larvae. Pages 255–302 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

LANGHORST, D. R., AND P. C. MARSH. 1986. Early life history of razorback sucker in Lake Mohave. Final Report of Arizona State University to U.S. Bureau of Reclamation, Tempe, Arizona.

LANIGAN, S. H., AND H. M. TYUS. 1989. Population size and status of the razorback sucker in the Green River basin, Utah and Colorado. North American Journal of Fisheries Management 9:68–73.

LENTSCH, L. D., T. A. CROWL, P. NELSON, AND T. MODDE. 1996a. Levee removal strategic plan. Utah State Division of Wildlife Resources Publication 96-6, Salt Lake City.

LENTSCH, L. D., R. T. MUTH, P. D. THOMPSON, B. G. HOSKINS, AND T. A. CROWL. 1996b. Options for selective control of nonnative fishes in the upper Colorado River basin. Utah State Division of Wildlife Resources Publication 96-14, Salt Lake City.

MADDUX, H. R., L. A. FITZPATRICK, AND W. R. NOONAN. 1993. Colorado River endangered fishes critical habitat biological support document. U.S. Fish and Wildlife Service Utah/Colorado Field Office, Salt Lake City, Utah.

MARSH, P. C. 1985. Effect of incubation temperature on survival of embryos of native Colorado River fishes. Southwestern Naturalist 30:129–140.

MARSH, P. C. 1994. Abundance, movements, and status of adult razorback sucker, *Xyrauchen texanus* in Lake Mohave, Arizona and Nevada. Proceedings of the Desert Fishes Council 25:35.

MARSH, P. C., AND D. R. LANGHORST. 1988. Feeding and fate of wild larval razorback sucker. Environmental Biology of Fishes 21:59–67.

MARSH, P. C., AND W. L. MINCKLEY. 1989. Observations on recruitment and ecology of razorback sucker: lower Colorado River, Arizona-California-Nevada. Great Basin Naturalist 49:71–78.

MCCARTHY, M. S., AND W. L. MINCKLEY. 1987. Age estimation for razorback sucker (Pisces: Catostomidae) from Lake Mohave, Arizona and Nevada. Journal of the Arizona-Nevada Academy of Sciences 21:87–97.

MCADA, C. W., AND R. S. WYDOSKI. 1980. The razorback sucker, *Xyrauchen texanus*, in the upper Colorado River basin, 1974–76. U.S. Fish and Wildlife Service Technical Papers 99.

MEDEL-ULMER, L. 1983. Movement and reproduction of the razorback sucker (*Xyrauchen texanus*) inhabiting Senator Wash Reservoir, Imperial County, California. Proceedings of the Desert Fishes Council 12:106.

MILLER, A. S., AND W. A. HUBERT. 1990. Compendium of existing knowledge for use in making habitat management recommendations for the upper Colorado River basin. Final Report of U.S. Fish and Wildlife Service Wyoming Cooperative Fish and Wildlife Research Unit to Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin, Denver, Colorado.

MILLER, R. R. 1959. Origin and affinities of the freshwater fish fauna of western North America. Pages 187–222 *in* C. Hubbs, editor. Zoogeography. American Association for the Advancement of Science, Publication 51.

MILLER, T. J., L. B. CROWDER, J. A. RICE, AND E. A. MARSCHALL. 1988. Larval size and recruitment in fishes: towards a conceptual framework. Canadian Journal of Fisheries and Aquatic Sciences 45:1657–1670.

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

MINCKLEY, W. L. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbott), in the lower Colorado River basin. Southwestern Naturalist 28:165–187.

MINCKLEY, W. L., AND E. S. GUSTAFSON. 1982. Early development of the razorback sucker, *Xyrauchen texanus* (Abbott). Great Basin Naturalist 42:553–561.

MINCKLEY, W. L., D. A. HENDRICKSON, AND C. E. BOND. 1986. Geography of western North America freshwater fishes: description and relationships to intracontinental tectonism. Pages 519–613 *in* C. H. Hocutt and E. O. Wiley, editors. The zoogeography of North American freshwater fishes. Wiley-Interscience, New York.

MINCKLEY, W. L., P. C. MARSH, J. E. BROOKS, J. E. JOHNSON, AND B. L. JENSEN. 1991. Management toward recovery of the razorback sucker. Pages 303–357 *in* W. L. Minckley and J. E. Deacon, editors. Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.

MODDE, T. 1996. Juvenile razorback sucker (*Xyrauchen texanus*) in a managed wetland adjacent to the Green River. Great Basin Naturalist 56:375–376.

MODDE, T. 1997. Fish use of Old Charley Wash: an assessment of floodplain wetland importance to razorback sucker management and recovery. Final Report of U.S. Fish and Wildlife Service, Vernal, Utah, to Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin, Denver, Colorado.

MODDE, T., A. T. SCHOLZ, J. H. WILLIAMSON, G. B. HAINES, B. D. BURDICK, AND F. K. PFEIFER. 1995. An augmentation plan for razorback sucker in the upper Colorado River basin. American Fisheries Society Symposium 15:102–111.

MODDE, T., K. P. BURNHAM, AND E. J. WICK. 1996. Population status of the razorback sucker in the middle Green River. Conservation Biology 10:110–119.

MODDE, T., AND G. B. HAINES. 1996. Brook stickleback (*Culaea inconstans* [Kirkland 1841]), a new addition to the upper Colorado River basin fish fauna. Great Basin Naturalist 56:281–282.

MODDE, T., AND E. J. WICK. 1997. Investigations of razorback sucker distribution, movements and habitats used during spring in the Green River, Utah. Final Report of U.S. Fish and Wildlife Service, Vernal, Utah, to Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin, Denver, Colorado.

MUELLER, G. 1989. Observations of spawning razorback sucker (*Xyrauchen texanus*) utilizing riverine habitat in the lower Colorado River, Arizona-Nevada. Southwestern Naturalist 34: 147–149.

MUELLER, G., M. HORN, J. KAHL, JR., T. BURKE, AND P. MARSH. 1993. Use of larval light traps to capture razorback sucker (*Xyrauchen texanus*) in Lake Mohave, Arizona-Nevada. Southwestern Naturalist 38:399–402.

MUTH, R. T. 1995. Conceptual framework document for development of a standardized monitoring program for basin-wide evaluation of restoration activities for razorback sucker in the Green and upper Colorado River systems. Final Report of Colorado State University Larval Fish Laboratory to Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin, Denver, Colorado.

MUTH, R. T., AND D. E. SNYDER. 1995. Diets of young Colorado squawfish and other small fish in backwaters of the Green River, Colorado and Utah. Great Basin Naturalist 55:95–104.

MUTH, R. T., AND E. J. WICK. 1997. Field studies on larval razorback sucker in Canyonlands National Park and Glen Canyon National Recreation Area, 1993–1995. Final Report of Colorado State University Larval Fish Laboratory to U.S. National Park Service Rocky Mountain Region, Denver, Colorado.

OSMUNDSON, D. B., AND L. R. KAEDING. 1989. Colorado squawfish and razorback sucker grow-out pond studies as part of conservation measures for the Green Mountain and Ruedi Reservoir water sales. Final Report of U.S. Fish and Wildlife Service Colorado River Fishery Project, Grand Junction, Colorado.

PAPOULIAS, D., AND W. L. MINCKLEY. 1990. Food limited survival of larval razorback sucker, *Xyrauchen texanus*, in the laboratory. Environmental Biology of Fishes 29:73–78.

PAPOULIAS, D., AND W. L. MINCKLEY. 1992. Effects of food availability on survival and growth of larval razorback suckers in ponds. Transactions of the American Fisheries Society 121:340–355.

PAULIN, K. M., C. M. WILLIAMS, AND H. M. TYUS. 1989. Responses of young razorback sucker and Colorado squawfish to water flow and light intensity. Final Report of U.S. Fish and Wildlife Service Colorado River Fishery Project, Vernal, Utah.

PROEBSTEL, D. S. 1998. Analysis of larval collections of razorback suckers based on restriction enzyme digestion of PCR amplified regions of mitochondrial DNA. Final Report of Colorado State University Department of Fishery and Wildlife Biology to U.S. National Park Service Cooperative Parks Study Unit, Fort Collins, Colorado.

RICE, J. A., AND SIX COAUTHORS. 1993. Growth rate variation and larval survival: inferences from an individual-based size-dependent predation model. Canadian Journal of Fisheries and Aquatic Sciences 50:133–141.

RUPPERT, J. B., R. T. MUTH, AND T. P. NESLER. 1993. Predation on fish larvae by adult red shiner, Yampa and Green rivers, Colorado. Southwestern Naturalist 38:397–399.

SMITH, G. R. 1959. Annotated checklist of fishes of Glen Canyon. Pages 195–199 *in* A. M. Woodberry, editor. Ecological studies of the flora and fauna in Glen Canyon. University of Utah Anthropological Papers.

SNYDER, D. E. 1976. Terminologies for intervals of larval fish development. Pages 41–60 *in* J. Boreman, editor. Great Lakes fish egg and larvae identification, proceedings of a workshop. U.S. Fish and Wildlife Service FWS/OBS-76/23.

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 Science Series 3:1–81.

SNYDER, D. E. 1997. Effects of the fish anesthetic tricaine on larval and early juvenile razorback sucker, *Xyrauchen texanus*. Final Report of Colorado State University Larval Fish Laboratory to U.S. National Park Service Cooperative Parks Study Unit, Fort Collins, Colorado.

SNYDER, D. E., AND R. T. MUTH. 1990. Descriptions and identification of razorback, flannelmouth, white, Utah, bluehead, and mountain sucker larvae and early juveniles. Colorado Division of Wildlife, Technical Publication 38, Fort Collins.

SNYDER, D. E., AND S. M. MEISMER. 1997. Effectiveness of light traps for capture and retention of larval and early juvenile *Xyrauchen texanus*, and larval *Ptychocheilus lucius* and *Gila elegans*. Final Report of Colorado State University Larval Fish Laboratory to U.S. National Park Service Cooperative Parks Study Unit, Fort Collins, Colorado.

STANFORD, J. A. 1994. Instream flows to assist the recovery of endangered fishes of the upper Colorado River basin. U.S. Department of the Interior, National Biological Survey Report 24.

TABA, S. S., J. R. MURPHY, AND H. H. FROST. 1965. Notes on the fishes of the Colorado River near Moab, Utah. Proceedings of the Utah Academy of Science, Arts, and Letters 42(II):280–283.

TYUS, H. M. 1987. Distribution, reproduction, and habitat use of the razorback sucker in the Green River, Utah, 1979–1986. Transactions of the American Fisheries Society 116:111–116.

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):1–27.

TYUS, H. M., AND C. A. KARP. 1990. Spawning and movements of razorback sucker, *Xyrauchen texanus*, in the Green River basin of Colorado and Utah. Southwestern Naturalist 35:427–433.

TYUS, H. M., AND C. A. KARP. 1991. Habitat use and streamflow needs of rare and endangered fishes in the Green River, Utah. U.S. Fish and Wildlife Service, Vernal, Utah.

TYUS, H. M., AND J. F. SAUNDERS. 1996. Nonnative fishes in the upper Colorado River basin and a strategic plan for their control. Final Report of University of Colorado Center for Limnology to Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin, Denver, Colorado.

USFWS (U.S. FISH AND WILDLIFE SERVICE). 1991. Endangered and threatened wildlife and plants; the razorback sucker (*Xyrauchen texanus*) determined to be an endangered species, Final Rule. Federal Register 56 (23 October 1991):54957–54967.

USFWS (U.S. FISH AND WILDLIFE SERVICE). 1997. Razorback sucker *Xyrauchen texanus* recovery plan (draft). Denver, Colorado.

WALLACE, R. K., JR. 1981. An assessment of diet-overlap indexes. Transactions of the American Fisheries Society 110:72–76.

WARD, J. V. 1989. Riverine-wetland interactions. Pages 385–400 *in* R. R. Sharitz and J. W. Gibbons, editors. Freshwater wetlands and wildlife. U.S. Department of Energy Symposium Series 61, U.S. Department of Energy Office of Scientific and Technical Information, Oak Ridge, Tennessee.

WARD, J. V., H. J. ZIMMERMAN, AND L. D. CLINE. 1986. Lotic zoobenthos of the Colorado system. Pages 403–422 *in* B. R. Davies and K. F. Walker, editors. The ecology of river systems. Dr. W. Junk, Dordrecht, The Netherlands.

WARD, J. V., AND J. A. STANFORD. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated Rivers: Research and Management 11:105–119.

WELCOMME, R. L. 1985. River fisheries. Food and Agriculture Organization of the United Nations Fisheries Technical Paper 262.

WETZEL, R. G., AND A. K. WARD. 1996. Primary production. Pages 168–183 *in* G. Petts and P. Calow, editors. River biota: diversity and dynamics. Blackwell Science, Oxford, England.

WICK, E. J. 1997. Physical processes and habitat critical to the endangered razorback sucker on the Green River, Utah. Doctoral dissertation. Colorado State University, Fort Collins.

WOLZ, E. R., AND D. K. SHIOZAWA. 1995. Soft sediment benthic macroinvertebrate communities of the Green River at the Ouray National Wildlife Refuge, Uintah County, Utah. Great Basin Naturalist 55:213–224.

WYDOSKI, R. S., AND J. HAMILL. 1991. Evolution of a cooperative recovery program for endangered fishes in the upper Colorado River basin. Pages 123–135 *in* W. L. Minckley and J. E. Deacon, editors. Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.

WYDOSKI, R. S., AND E. D. WICK. 1998. Ecological value of flooded bottomland habitats to endangered fishes in the upper Colorado River basin. Final Draft Report of U.S. Fish and Wildlife Service and U.S. National Park Service to Recovery Implementation Program for the Endangered Fish Species in the Upper Colorado River Basin, Denver, Colorado.

TABLE 1.—Number of fish (mostly larvae or early juveniles), by species and sampling gear per year, collected during sampling for larval razorback suckers *Xyrauchen texanus* in the middle Green River, Utah and Colorado. Parenthetical numbers for *Ptychocheilus lucius* and the native catostomids are mean, range total length (mm).

Taxa	1992 8 May–19 June		1993 11 May–9 July			1994 3 May–21 June	1995 11 May–1 August	1996 20 May–28 June
	Drift net	Seine	Drift net	Seine[a]	Light trap	Light trap	Light trap	Light trap
NATIVE								
Cyprinidae								
Gila sp.	2	7	0	0	1	0	0	0
Ptychocheilus lucius	0	0	0	0	1 (30, 30–30)	0	1 (10, 10–10)	0
Rhinichthys osculus	137	85	15	0	4	0	58	23
Catostomidae								
Catostomus discobolus	1,516 (14, 11–24)	583 (17, 12–42)	69 (14, 12–44)	58 (15, 12–16)	100 (15, 13–17)	6,455 (15, 10–21)	2,088 (15, 11–22)	3,277 (14, 10–20)
C. latipinnis	579 (15, 11–24)	612 (19, 13–38)	140 (15, 14–17)	760 (17, 14–20)	938 (17, 11–22)	5,252 (17, 12–25)	634 (16, 13–30)	5,142 (16, 13–22)
Xyrauchen texanus	3 (11, 10–12)	17 (15, 10–22)	9 (10, 8–13)	55 (13, 11–17)	228 (13, 10–24)	1,217 (12, 10–18)	32 (12, 10–16)	174 (11, 10–16)
Unidentified suckers[b]	7	1	12	79	32	462	13	14
Cottidae								
Cottus bairdi	0	3	0	0	0	0	0	2
NONNATIVE								
Cyprinidae								
Cyprinella lutrensis	5	167	12	65	5,858	0	1,655	281
Cyprinus carpio	1	3	2	0	1,360	0	3	230
Notropis stramineus	3	25	60	12	1,584	0	0	129
Pimephales promelas	0	38	29	1	1,240	0	0	3,678

TABLE 1.—Continued.

Taxa	1992 8 May–19 June Drift net	1992 8 May–19 June Seine	1993 11 May–9 July Drift net	1993 11 May–9 July Seine[a]	1993 11 May–9 July Light trap	1994 3 May–21 June Light trap	1995 11 May–1 August Light trap	1996 20 May–28 June Light trap
Richardsonius balteatus	0	0	0	0	3	0	0	12
Unidentified minnows[c]	7	0	0	221	94	430	4,955	623
Catostomidae								
Catostomus commersoni	2	1	2	1	4	0	3	5
Esocidae								
Esox lucius	0	0	0	1	0	0	0	0
Gasterosteidae								
Culaea inconstans	0	0	0	0	0	0	0	8
Centrarchidae								
Lepomis cyanellus	0	0	0	0	17	0	22	1
Total number of fish	2,262	1,542	350	1,253	11,464	13,816	9,464	13,599
Number of collections	52	30	90	52	203	195	287	168
Hours of sampling; total (collection mean)	51.7 (1.0)		82.5 (0.9)		1,835.1 (9.0)	1,524.1 (7.8)	2,051.9 (7.2)	1,496.0 (8.9)

[a]Includes two dip-net collections.
[b]Native suckers too damaged or intermediate in diagnostic characters for species identification.
[c]Mostly small larvae of *C. lutrensis*, *N. stramineus*, or *P. promelas* less than 6 mm total length.

TABLE 2.—Number of fish (mostly larvae or early juveniles), by species and sampling gear per year, collected during sampling for larval razorback suckers *Xyrauchen texanus* in the lower Green River, Utah. Parenthetical numbers for *Ptychocheilus lucius* and the native catostomids are mean, range total length (mm).

Taxa	1993 17–19 June		1994 13 May–19 June		1995 19 April–20 July		1996 29 April–25 July	
	Seine	Light trap	Seine	Light trap	Seine	Light trap	Seine	Light trap
NATIVE								
Cyprinidae								
Gila sp.	0	0	1	19	0	0	3	47
Ptychocheilus lucius	1 (122, 122–122)	0	36 (57, 45–120)	0	82 (109, 39–240)	11 (10, 8–11)	42 (20, 9–160)	12 (12, 8–33)
Rhinichthys osculus	0	1	0	36	0	6	8	388
Catostomidae								
Catostomus discobolus	0	0	49 (15, 12–16)	113 (14, 12–18)	7 (15, 13–18)	47 (14, 11–23)	17 (15, 12–18)	140 (14, 12–17)
C. latipinnis	1 (18, 18–18)	2 (19, 17–20)	0	211 (15, 11–25)	91 (16, 14–20)	216 (17, 13–31)	529 (16, 12–23)	2,083 (16, 13–22)
Xyrauchen texanus	2 (13, 13–13)	120 (13, 11–16)	15 (13, 11–16)	76 (12, 10–15)	0	5 (12, 11–13)	8 (15, 12–20)	214 (12, 11–18)
Unidentified suckers[a]	1	0	3	0	1	1	4	27
NONNATIVE								
Cyprinidae								
Cyprinella lutrensis	804	273	206	9,118	1,617	1,658	4,037	19,769
Cyprinus carpio	3	7	0	19	1	1	22	0
Notropis stramineus	0	3	0	78	220	126	376	265
Pimephales promelas	2	32	0	708	73	1	332	133
Richardsonius balteatus	0	0	0	0	0	0	1	6
Unidentified minnows[b]	0	82	0	8	61	9,331	65	5,083

TABLE 2.—Continued.

Taxa	1993 17–19 June Seine	1993 17–19 June Light trap	1994 16 May–19 June Seine	1994 16 May–19 June Light trap	1995 19 April–20 July Seine	1995 19 April–20 July Light trap	1996 29 April–25 July Seine	1996 29 April–25 July Light trap
Catostomidae								
Catostomus commersoni	1	0	0	0	0	0	2	0
Ictaluridae								
Ameiurus melas	0	0	0	0	0	0	1	0
Ictalurus punctatus	0	0	0	0	11	0	7	0
Centrarchidae								
Lepomis cyanellus	0	0	0	0	0	0	1	0
Total number of fish	815	520	310	10,386	2,164	11,403	5,455	28,167
Number of collections	2	30	2	41	34	232	186	347
Hours of sampling; total (collection mean)		154.9 (5.2)		352.8 (8.8)		2,082.6 (9.0)		3,206.9 (9.2)

[a]Native suckers too damaged or intermediate in diagnostic characters for species identification.
[b]Mostly small larvae of *C. lutrensis*, *N. stramineus*, or *P. promelas* less than 6 mm total length.

TABLE 3.—Number (N) and mean catch per unit effort (CPUE) of larval razorback suckers collected with drift nets, seines, or light traps from five reaches of the middle Green River, Utah and Colorado, in spring and early summer 1992–1996. Parenthetical numbers are SEs. Catch per unit effort is number of fish per 1 h of drift netting (effort averaged about 1 h per collection) or light trapping (effort averaged about 8 h per collection), or number of fish per seine haul. Effort was based on collections made on and following the date of first capture of sucker larvae in each year (number of collections).

	Reach[a]															Reaches combined
	Echo Park			Island-Rainbow Park			Escalante			Jensen			Ouray			
Year and sampling gear	N	CPUE	Number of collections	N	CPUE	Number of collections	N	CPUE	Number of collections	N	CPUE	Number of collections	N	CPUE	Number of collections	CPUE
1992																
Drift net			0			0	3	0.38 (0.33)	52			0			0	0.38 (0.33)
Seine			0			0	9	0.41 (0.24)	22	8	1.00 (0.42)	8			0	0.57 (0.21)
1993																
Drift net	2	0.11 (0.08)	36			0	7	0.16 (0.08)	43			0			0	0.14 (0.06)
Seine[b]			0			0	20	0.61 (0.25)	34	35	2.33 (0.93)	15			0	1.06 (0.35)
Light trap	4	0.04 (0.03)	15	0	0	10	117	0.15 (0.04)	87	58	0.14 (0.05)	43	49	0.10 (0.04)	50	0.12 (0.02)
1994																
Light trap			0	0	0	16	390	1.63 (0.45)	29	576	1.28 (0.39)	48	251	0.71 (0.20)	61	1.00 (0.17)
1995																
Light trap			0			0	17	0.04 (0.01)	102	4	0.03 (0.01)	28	11	0.02 (0.01)	108	0.02 (0.01)
1996																
Light trap	0	0	12			0	137	0.56 (0.15)	28	30	0.20 (0.07)	17	7	0.01 (0.01)	70	0.16 (0.04)

[a]Echo Park = Green River kilometer (RK) 553.5–555.1, Island-Rainbow Park = RK 526.1–534.2, Escalante = RK 487.5–500.7, Jensen = RK 466.1–485.6, Ouray = 399.8–420.2.

[b]Includes two dip-net collections.

TABLE 4.—Number (N) and mean catch per unit effort (CPUE) of larval razorback suckers collected with seines or light traps from three reaches of the lower Green River, Utah, in spring and early summer 1993–1996. Parenthetical numbers are SEs. Catch per unit effort is number of fish per 1 h of light trapping (effort averaged about 5 h per collection in 1993 and 9 h per collection in 1994–1996), or number of fish per seine haul. Effort was based on collections made on and following the date of first capture of sucker larvae in each year (number of collections).

	Reach[a]									
	Green River Valley			San Rafael River confluence			Lower Labyrinth-upper Stillwater Canyon			Reaches combined
Year and sampling gear	N	CPUE	Number of collections	N	CPUE	Number of collections	N	CPUE	Number of collections	CPUE
1993										
Seine			0			0	2	1.00 (1.00)	2	1.00 (1.00)
Light trap			0			0	120	1.36 (0.56)	30	1.36 (0.56)
1994										
Seine			0			0	15	7.50 (7.50)	2	7.50 (7.50)
Light trap			0	44	0.21 (0.12)	23	32	0.23 (0.08)	17	0.22 (0.07)
1995										
Seine			0	0		15	0		19	
Light trap			0	2	0.01 (0.003)	38	3	0.01 (0.003)	39	0.01 (0.003)
1996										
Seine	0		62	2	0.03 (0.02)	72	6	0.12 (0.06)	52	0.04 (0.02)
Light trap	1	< 0.01	101	28	0.03 (0.01)	94	185	1.52 (0.86)	155	0.06 (0.01)

[a]Green River Valley = Green River kilometer (RK) 176.5–210.4, San Rafael River confluence = RK 151.3–159.4, middle Stillwater Canyon = RK 40.7–55.1.

TABLE 5.—Selected mainstem water temperature and discharge parameters associated with the earliest estimated date of spawning by razorback suckers in the middle Green River, Utah and Colorado, or lower Green River, Utah, in each year during 1993–1996. Spawning dates were estimated from wild-caught otolith-aged larvae. Degree days is the sum of recorded instantaneous daily water temperatures between 1 January and the earliest date of spawning. Days ≥ 10°C or ≥ 14°C are the number of days between 1 January and the earliest date of spawning that recorded instantaneous daily water temperatures equaled or exceeded each respective threshold. Days before peak discharge is the number of days between the earliest date of spawning and the highest recorded mean daily river discharge. Data for the lower Green River in 1993 and 1995 are questionable; see footnotes for explanations.

River section and year	Earliest date of spawning	Water temperature (°C) on earliest spawning date	Degree days	Days ≥ 10°C	Days ≥ 14°C	Days before peak discharge
Middle Green						
1993	5 May	16.0	377	18	3	23
1994	19 April	10.0	570	16	0	31
1995	11 May	11.5	849	36	0	36
1996	9 May	13.0	722	18	0	11
Lower Green						
1993[a]	22 May	19.0	1,090	58	36	9
1994	24 April	16.0	798	47	14	28
1995[b]	6 May	14.0	1,016	61	25	44
1996	2 April	12.0	357	12	0	50

[a]Based on larvae collected during a restricted sampling period, 17–19 June.
[b]Based on only five larvae.

TABLE 6.—Mean (range) total length (TL) and posthatching age at capture and estimated mean (SE) daily growth between hatching and capture of otolith-aged razorback sucker larvae collected with seines or light traps from nursery habitats in the middle Green River, Utah and Colorado, or lower Green River, Utah, 1993–1996.

River section and year	Number of aged larvae	Total length at capture (mm)	Age at capture (d)	Daily growth (mm TL/d)
Middle Green				
1993	68	12.6 (10.5–18.1)	14 (6–30)	0.34 (0.008)
1994	317	11.6 (10.4–15.8)	12 (6–30)	0.31 (0.004)
1995	32	12.1 (10.4–15.6)	12 (8–23)	0.34 (0.011)
1996	66	12.2 (10.7–16.5)	12 (7–23)	0.35 (0.006)
Lower Green				
1993	17	12.3 (11.3–13.5)	14 (10–18)	0.30 (0.012)
1994	44	12.4 (10.6–14.9)	17 (10–24)	0.27 (0.006)
1995	5	12.3 (11.4–13.0)	17 (10–23)	0.28 (0.027)
1996	93	12.7 (10.6–20.3)	15 (6–34)	0.33 (0.004)

TABLE 7.—Diet by 1-mm total length intervals of razorback sucker larvae collected overnight with light traps from nursery habitats in the middle Green River, Utah and Colorado, spring and early summer 1993–1996. Diet measure is mean percentage contributed by each food category to the total volume of food in each digestive tract.

	Total length (mm)						
Food category	11	12[a]	13	14	15	16	18
Insects							
Chironomidae larvae	38	38	44	43	61	61	62
Ephemeroptera larvae					< 1	3	
Zooplankton							
Cladocera	15	12	10	8	7	7	5
Copepoda	1	1	1	2			
Rotifera	12	7	5	5	< 1	2	2
Ostracoda		< 1	< 1				
Hydracarina			1				
Invertebrate eggs		< 1	1	3			
Algae							
Colonial	14	12	11	9	9	8	5
Diatoms or desmids	7	3	1	2	< 1	< 1	2
Organic-inorganic debris	12	27	27	28	23	19	24
Number of fish examined	106	152	36	28	14	15	6
Number of fish with food in digestive tracts (% of fish examined)	55 (52)	88 (58)	26 (72)	28 (100)	14 (100)	15 (100)	6 (100)
Mean % fullness of digestive tracts with food	35	40	45	56	52	54	57

[a]Yolk usually completely assimilated at 12 mm total length (Snyder and Muth 1990).

TABLE 8.—Diet by 1-mm total length intervals of razorback sucker larvae collected overnight with light traps from nursery habitats in the lower Green River, Utah, spring and early summer 1993–1996. Diet measure is mean percentage contributed by each food category to the total volume of food in each digestive tract.

Food category	Total length (mm) 11	12[a]	13	14	15	16	18
Insects							
Chironomidae larvae	32	33	42	51	51	56	58
Ephemeroptera larvae							3
Zooplankton							
Cladocera	10	10	4	5	5	5	< 1
Copepoda		< 1		1			
Rotifera	17	10	3	4	3	6	2
Ostracoda			1	1			
Hydracarina				1			
Invertebrate eggs			1				
Algae							
Colonial	20	18	17	12	12	8	8
Diatoms or desmids	7	5	6	3	4	3	2
Organic-inorganic debris	14	23	26	22	25	22	27
Number of fish examined	22	45	18	15	9	6	8
Number of fish with food in digestive tract (% of all fish examined)	13 (59)	28 (62)	12 (67)	15 (100)	9 (100)	6 (100)	8 (100)
Mean % fullness of digestive tracts with food	37	42	45	51	63	64	65

[a]Yolk usually completely assimilated at 12 mm total length (Snyder and Muth 1990).

FIGURE 1.—Green River study area, 1992–1996. Reaches sampled for larval razorback suckers are indicated by capital letters (A–H). Primary areas of documented razorback sucker spawning activity are located in the lower Yampa River near its confluence with the Green River (Echo Park reach) and in the Green River at river kilometers 486.4–504.0 (Escalante reach).

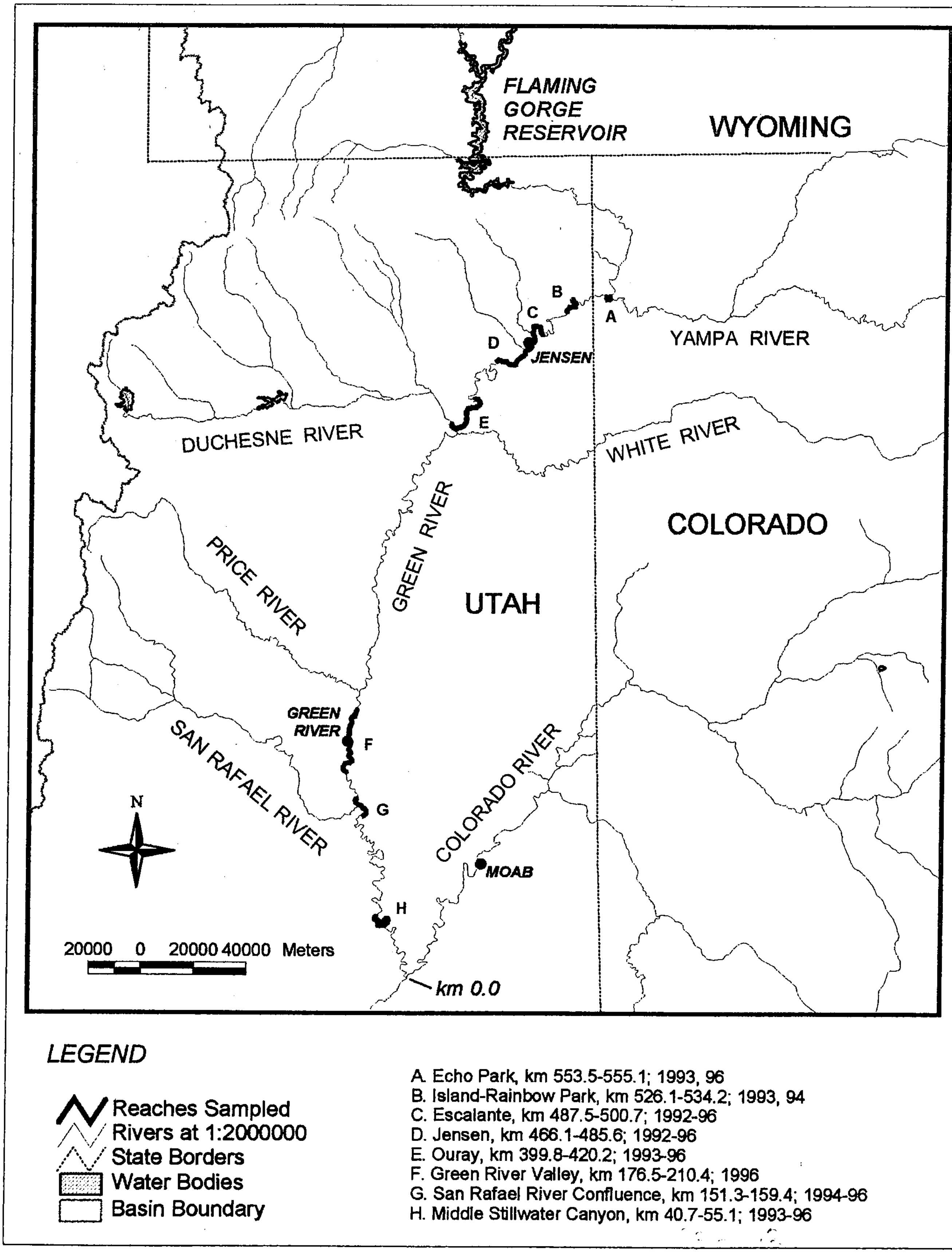
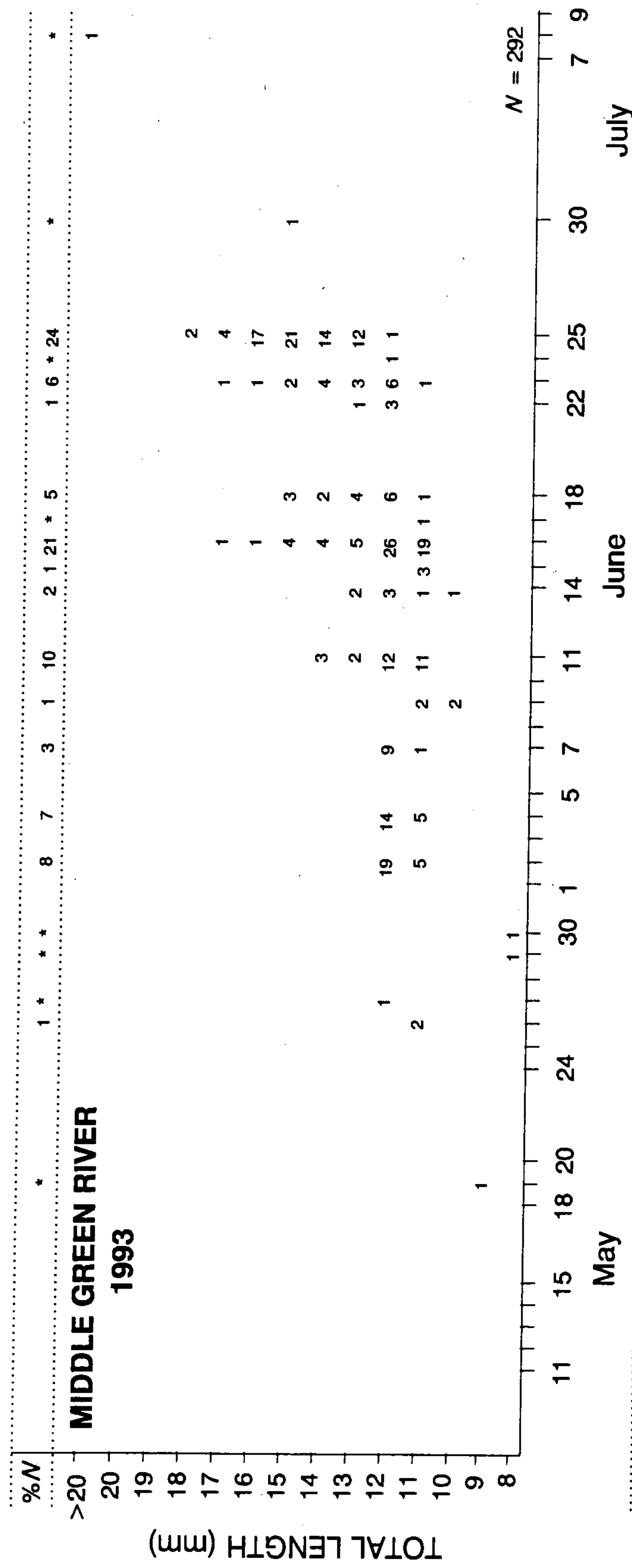
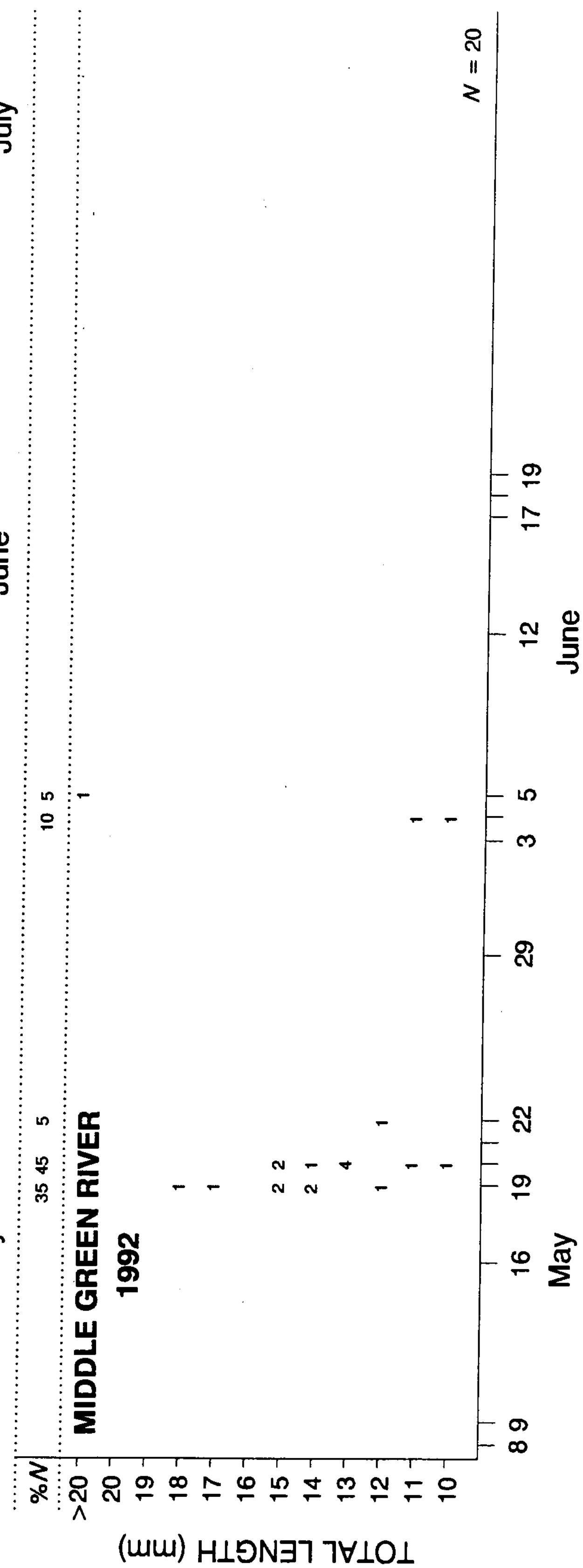
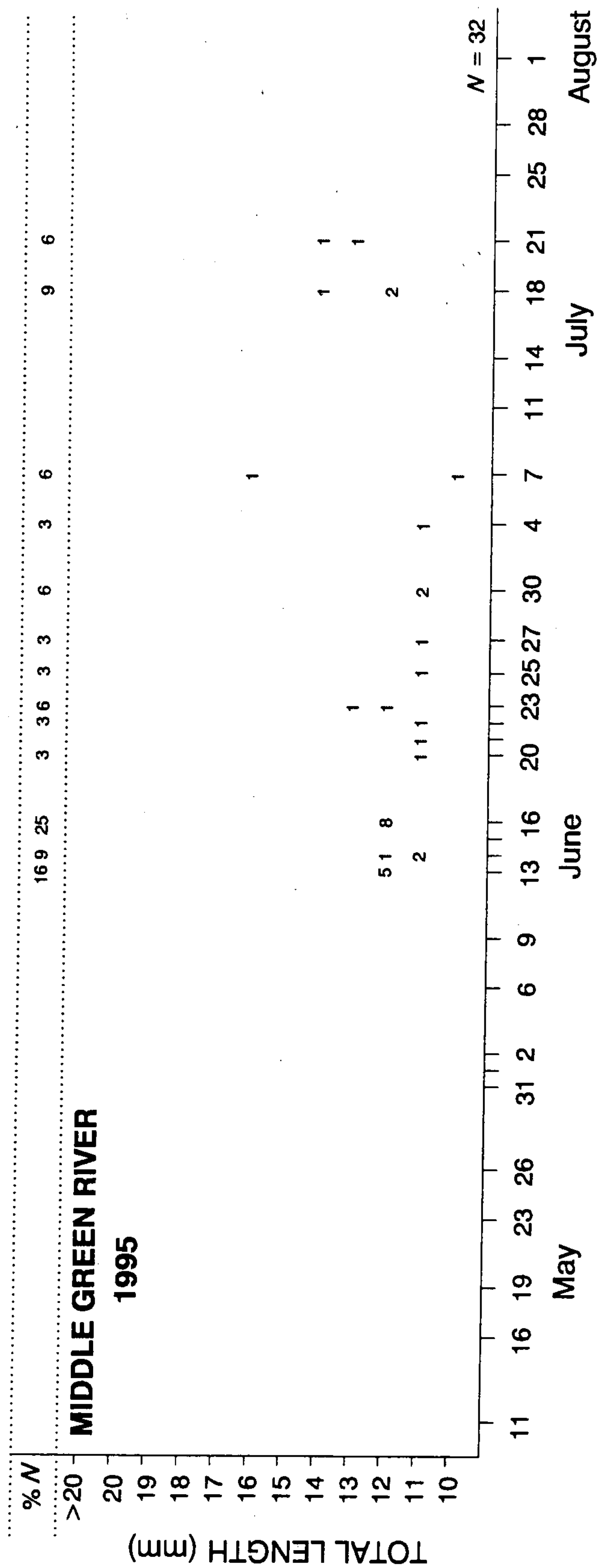
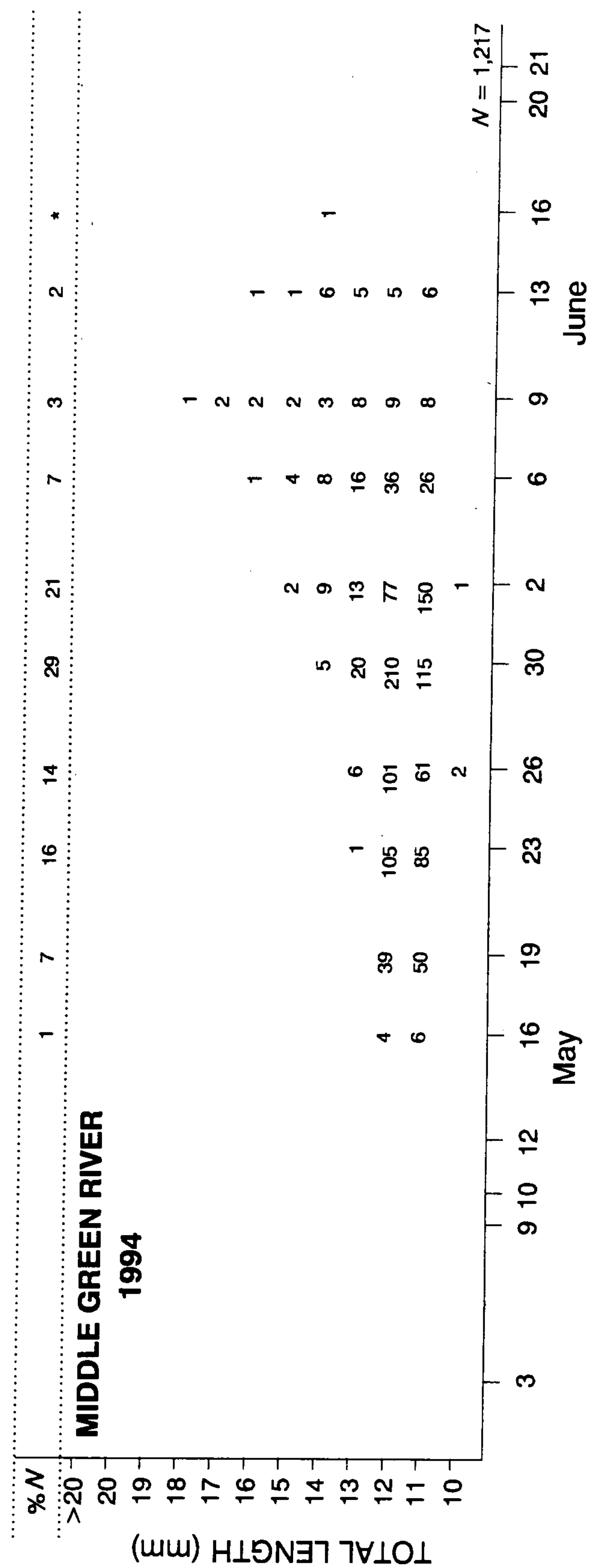

FLAMING
GORGE
RESERVOIR
WYOMING
B
C
A
D
JENSEN
YAMPA RIVER
E
DUCHESNE RIVER
WHITE RIVER
COLORADO
PRICE RIVER
GREEN RIVER
UTAH
GREEN
RIVER
F
SAN RAFAEL RIVER
COLORADO RIVER
G
N
MOAB
H
20000 0 20000 40000 Meters
km 0.0
LEGEND
Reaches Sampled
Rivers at 1:2000000
State Borders
Water Bodies
Basin Boundary
A. Echo Park, km 553.5-555.1; 1993, 96
B. Island-Rainbow Park, km 526.1-534.2; 1993, 94
C. Escalante, km 487.5-500.7; 1992-96
D. Jensen, km 466.1-485.6; 1992-96
E. Ouray, km 399.8-420.2; 1993-96
F. Green River Valley, km 176.5-210.4; 1996
G. San Rafael River Confluence, km 151.3-159.4; 1994-96
H. Middle Stillwater Canyon, km 40.7-55.1; 1993-96

FIGURE 2.—Number of fish per total-length intervals and percent of the total catch (*N*) distributed by sampling dates for larval razorback suckers *Xyrauchen texanus* collected from the middle Green River, Utah and Colorado, spring and early summer 1992–1996. Asterisks indicate percents less than 1.0.


MIDDLE GREEN RIVER
1993
TOTAL LENGTH (mm)
%N
N = 292
May
June
July


MIDDLE GREEN RIVER
1992
TOTAL LENGTH (mm)
%N
N = 20
May
June


MIDDLE GREEN RIVER
1995
TOTAL LENGTH (mm)
%N
May
June
July
August
N = 32


MIDDLE GREEN RIVER
1994
TOTAL LENGTH (mm)
%N
May
June
N = 1,217

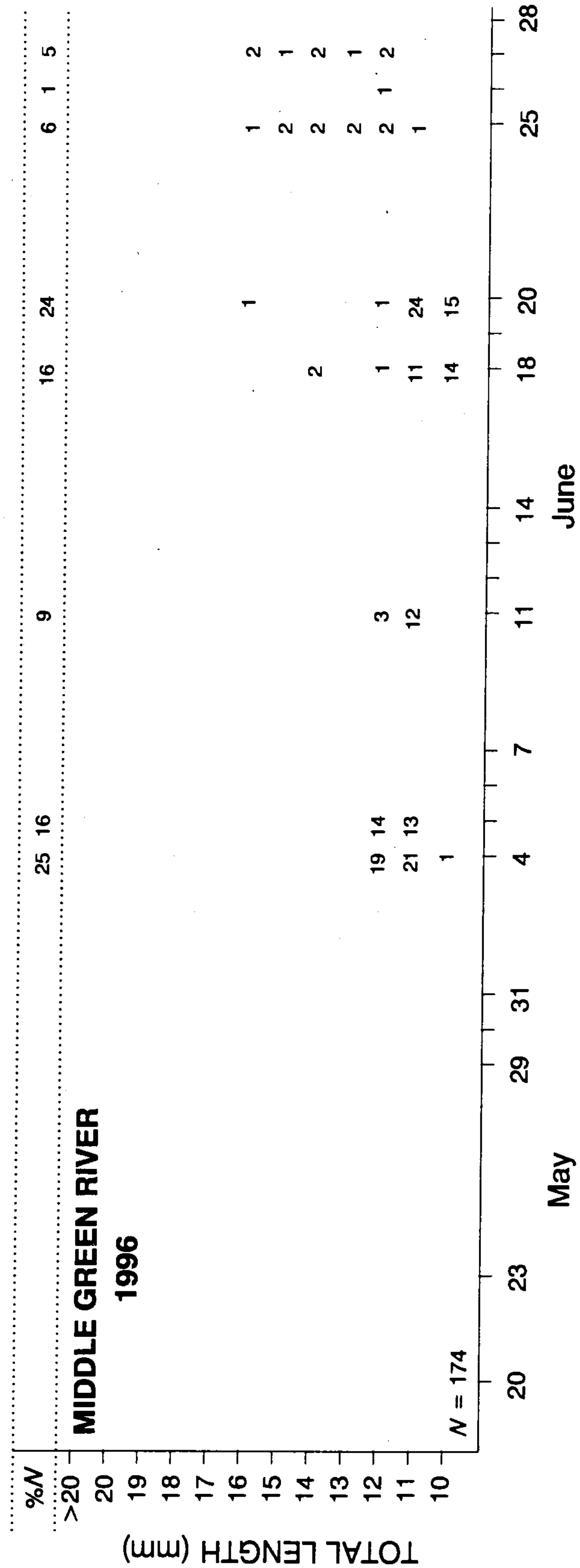
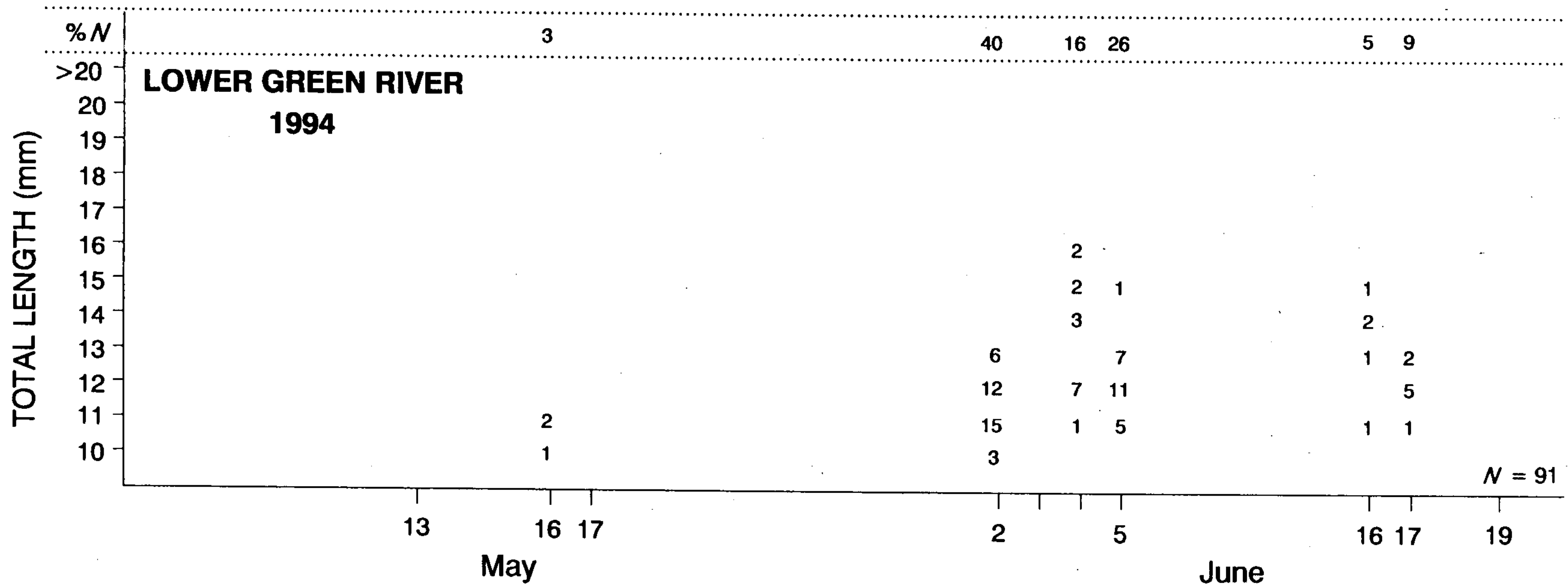
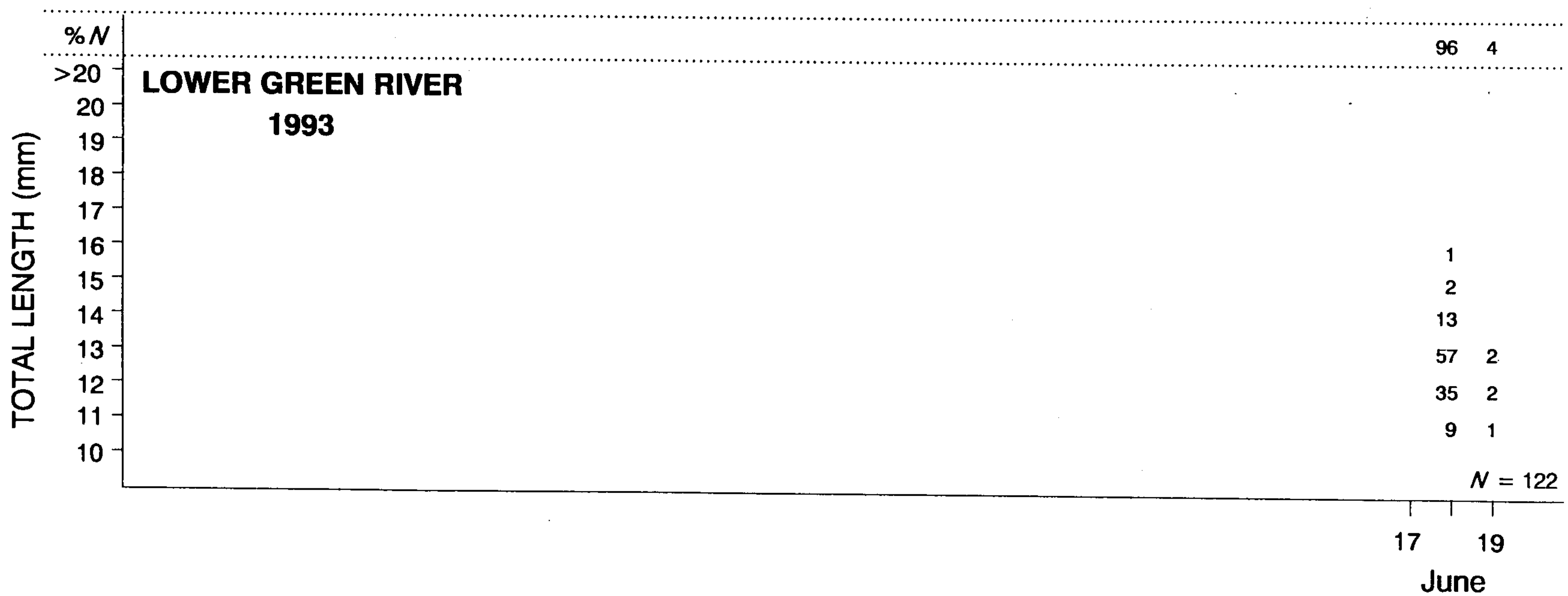
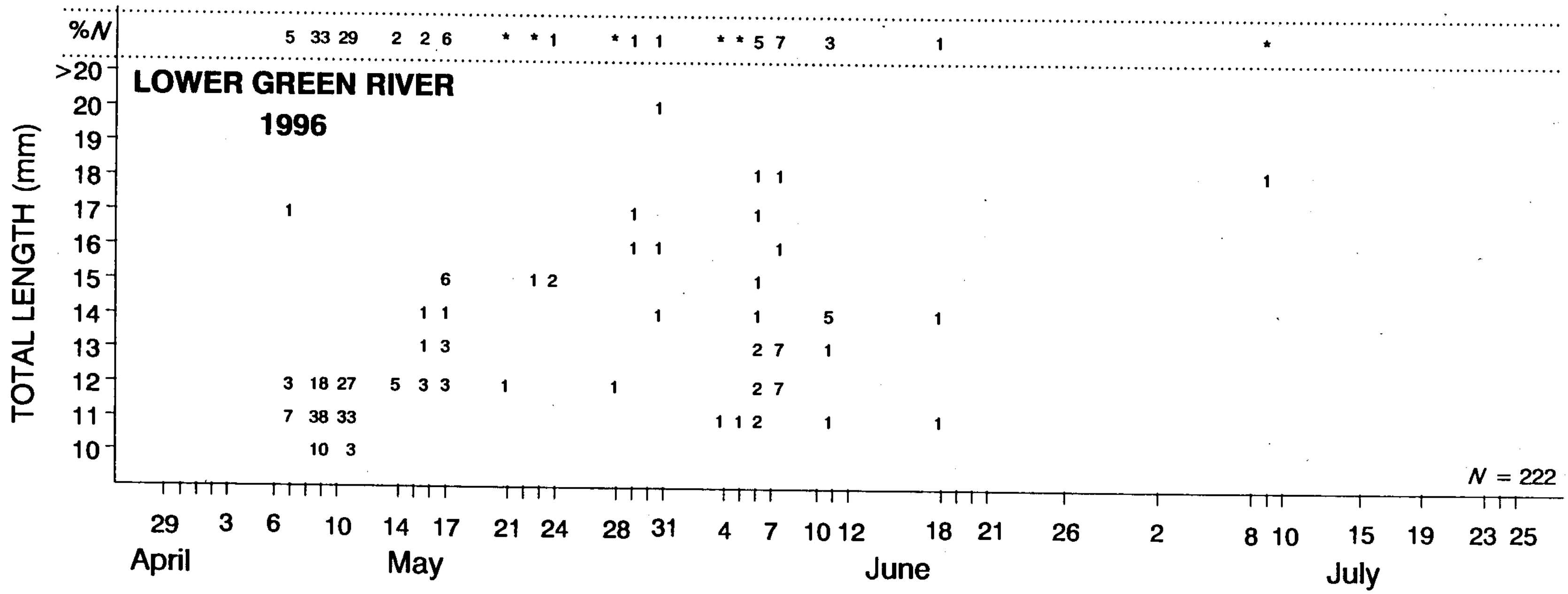

MIDDLE GREEN RIVER
1996
N = 174
TOTAL LENGTH (mm)
%N
May
June

FIGURE 3.—Number of fish per total-length intervals and percent of the total catch (*N*) distributed by sampling dates for larval razorback suckers *Xyrauchen texanus* collected from the lower Green River, Utah, spring and early summer 1993–1996. Asterisks indicate percents less than 1.0.


LOWER GREEN RIVER
1994
TOTAL LENGTH (mm)
%N
>20
20
19
18
17
16
15
14
13
12
11
10
3
40 16 26
5 9
N = 91
13 16 17
May
2 5
16 17 19
June


LOWER GREEN RIVER
1993
TOTAL LENGTH (mm)
%N
>20
20
19
18
17
16
15
14
13
12
11
10
96 4
N = 122
17 19
June


%N
TOTAL LENGTH (mm)
LOWER GREEN RIVER
1996
April
May
June
July
N = 222

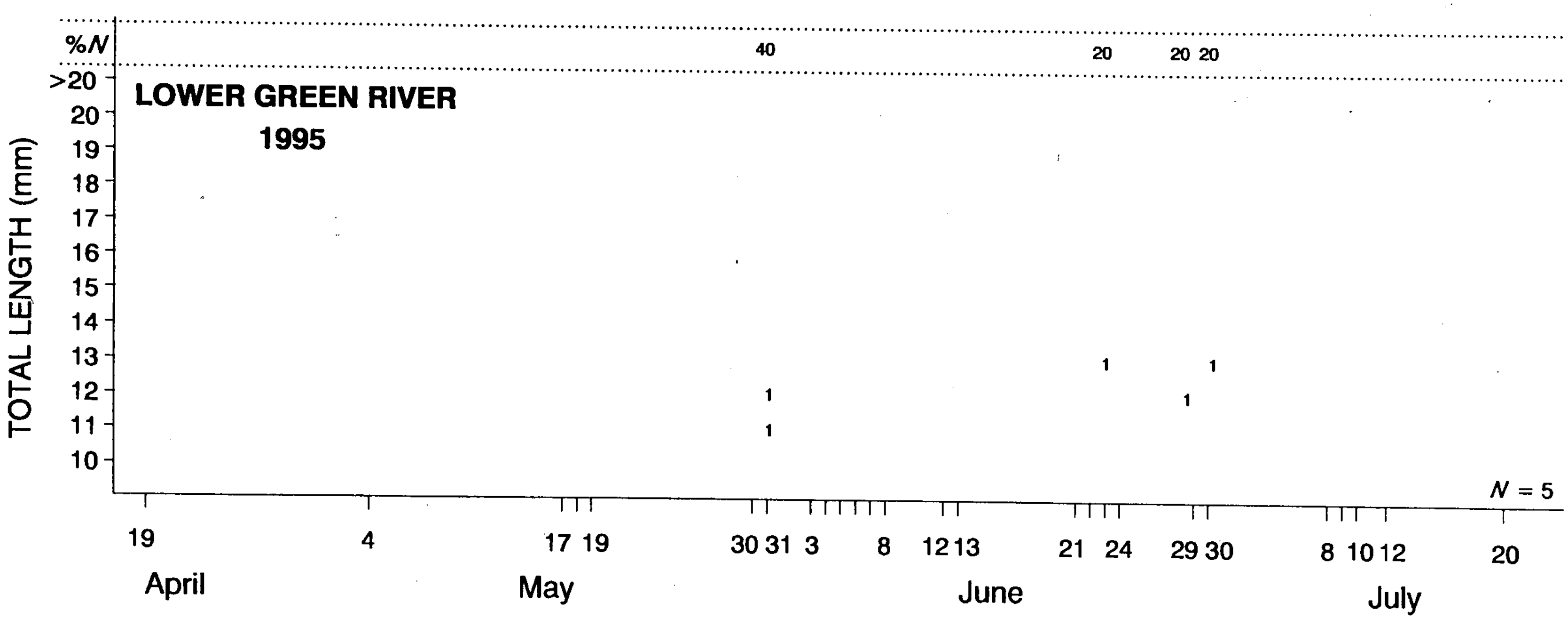
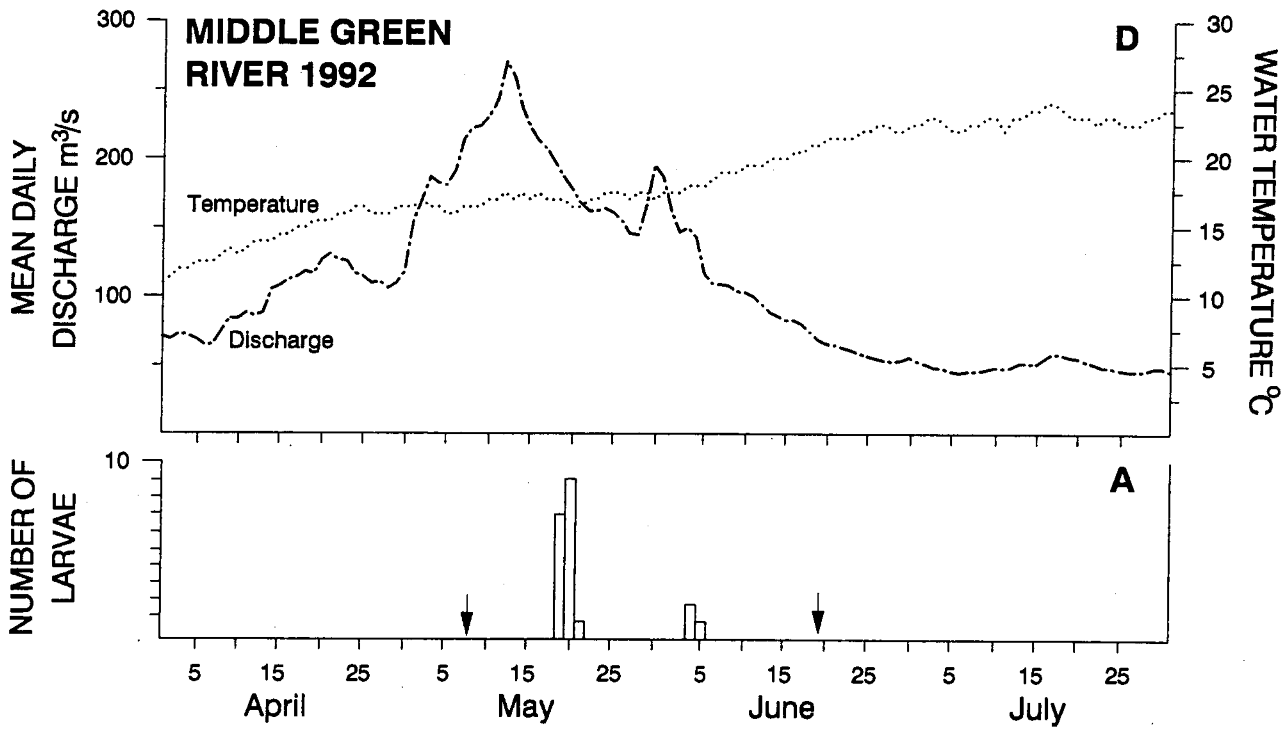
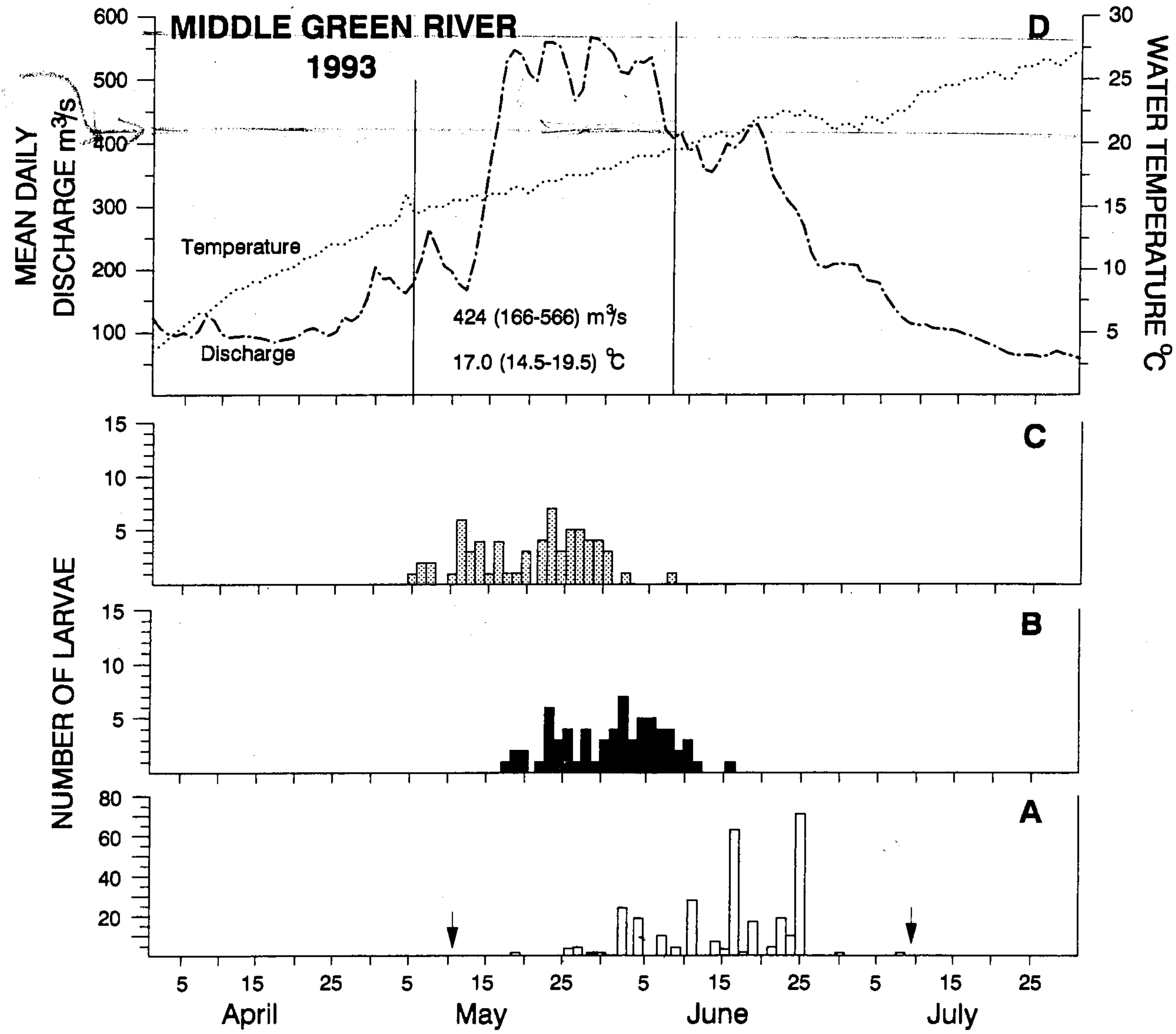

%N
TOTAL LENGTH (mm)
LOWER GREEN RIVER
1995
April
May
June
July
N = 5

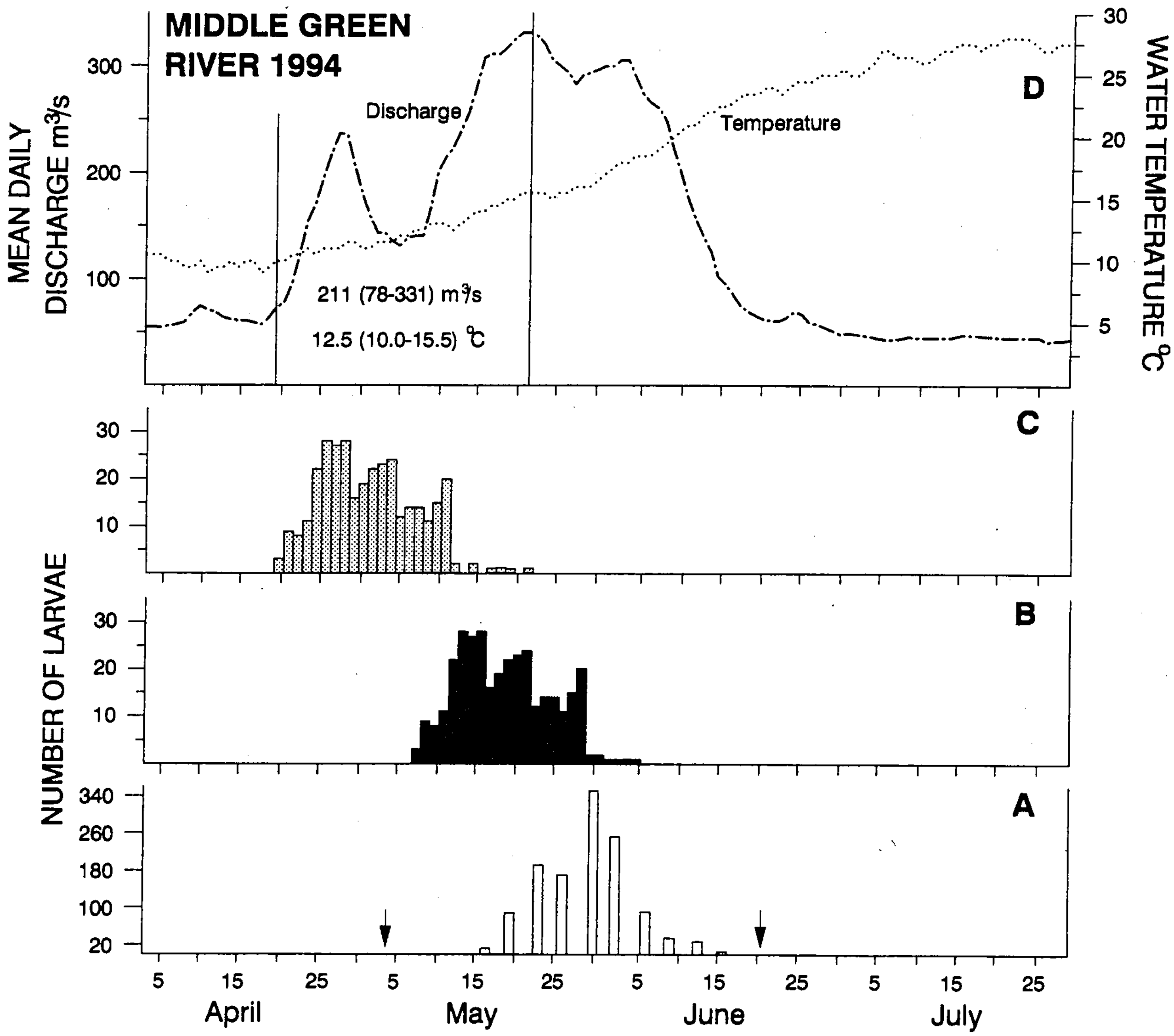
FIGURE 4.—**A**. Number of razorback sucker larvae collected from the middle Green River, Utah and Colorado, 1992–1996, distributed by capture dates. Arrows indicate start and end of sampling. **B**. Number of otolith-aged razorback sucker larvae (from among those caught in nursery habitats each year) distributed by estimated dates of hatching. **C**. Number of otolith-aged razorback sucker larvae distributed by estimated dates of spawning. **D**. Mean daily discharge and instantaneous daily temperature regimes for the mainstem middle Green River in 1992–1996 (April–July) recorded by the U.S. Geological Survey at the gage near Jensen, Utah. Vertical lines delimit the range of estimated razorback sucker spawn dates for each year. Numbers are average (range) mean daily discharge and instantaneous daily water temperature during each estimated spawning period.


MIDDLE GREEN RIVER 1992
D
A
MEAN DAILY DISCHARGE m3/s
WATER TEMPERATURE °C
Temperature
Discharge
NUMBER OF LARVAE
300
200
100
30
25
20
15
10
5
10
5 15 25 5 15 25 5 15 25 5 15 25
April
May
June
July

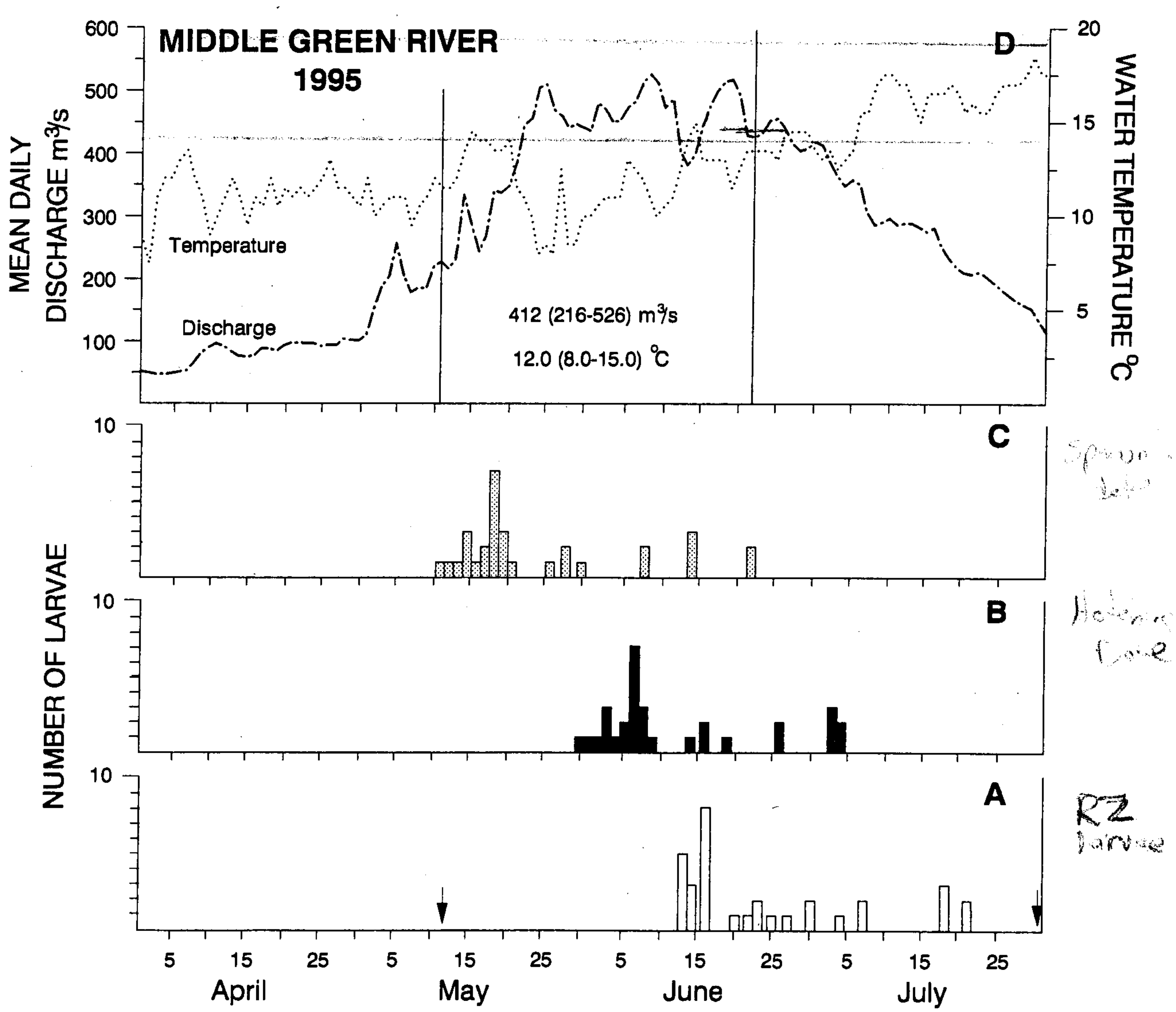
n= 21



E2 larvae n = 292


MIDDLE GREEN RIVER 1994
MEAN DAILY DISCHARGE m³/s
WATER TEMPERATURE °C
Discharge
Temperature
211 (78-331) m³/s
12.5 (10.0-15.5) °C
D
C
B
A
NUMBER OF LARVAE
April
May
June
July

1,217



MIDDLE GREEN RIVER
1995
D
C
B
A
MEAN DAILY DISCHARGE m³/s
WATER TEMPERATURE °C
NUMBER OF LARVAE
Temperature
Discharge
412 (216-526) m³/s
12.0 (8.0-15.0) °C
April
May
June
July
RZ
larvae

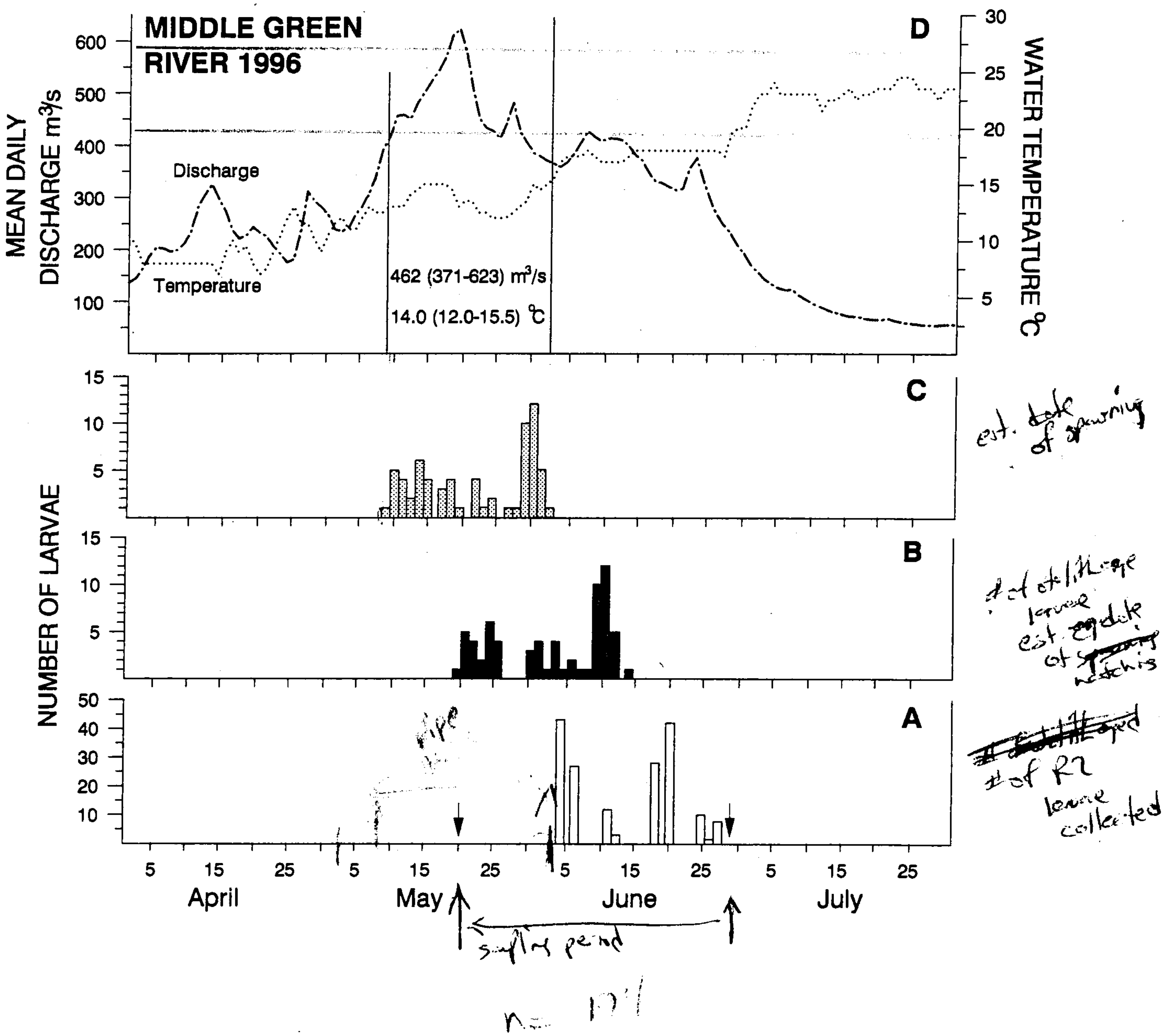
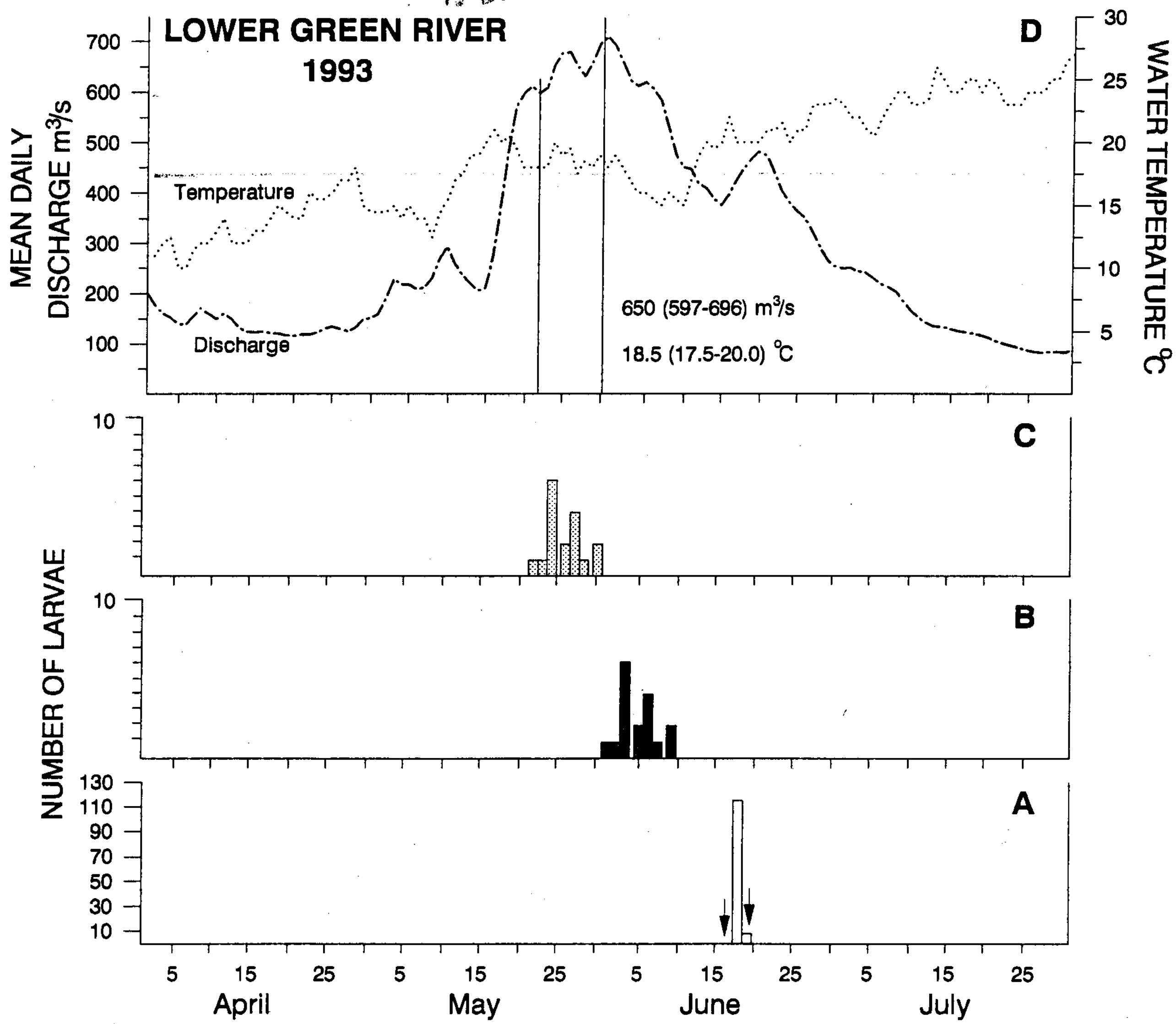
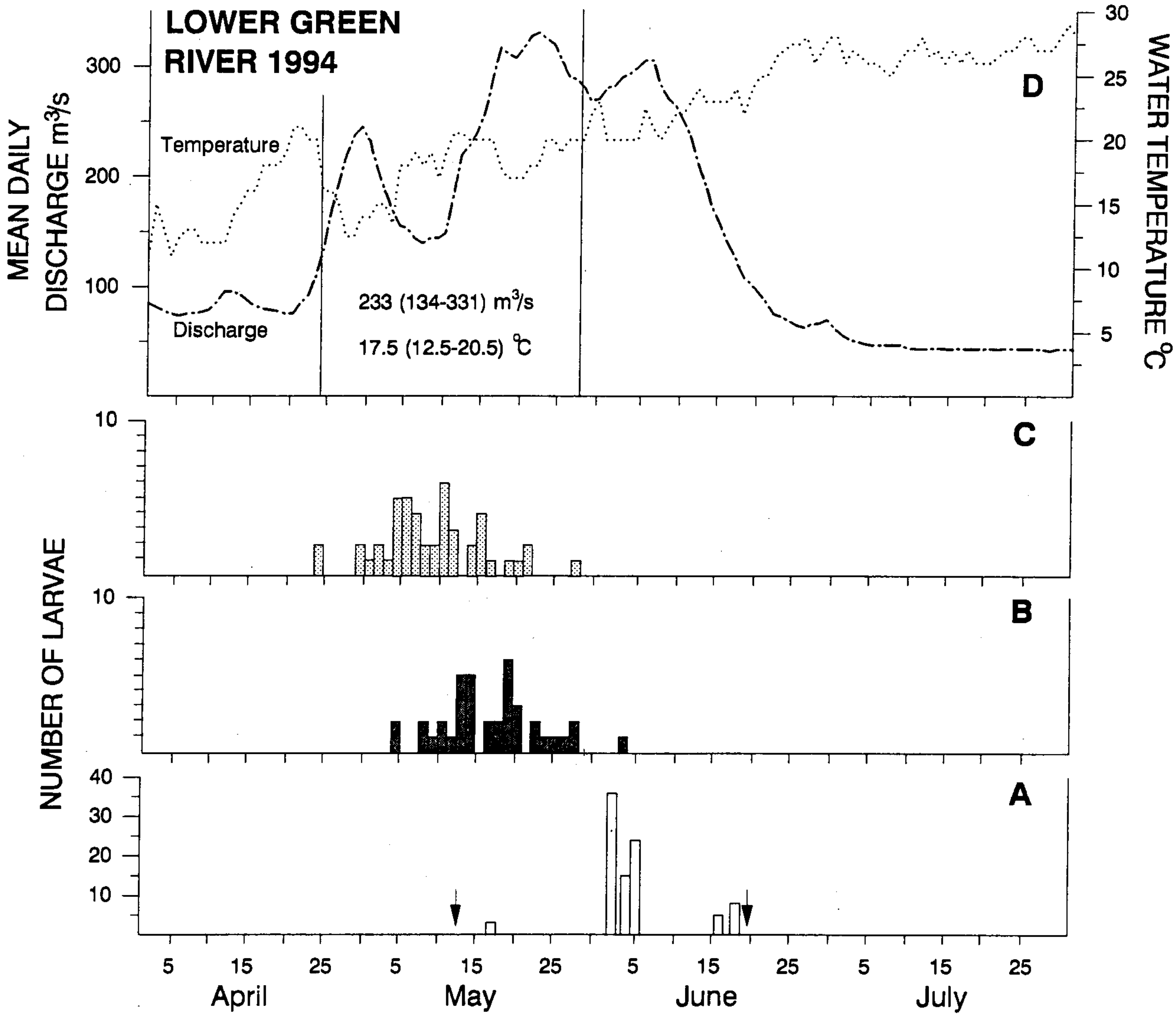

MIDDLE GREEN RIVER 1996
D
C
B
A
MEAN DAILY DISCHARGE m³/s
WATER TEMPERATURE °C
Discharge
Temperature
462 (371-623) m³/s
14.0 (12.0-15.5) °C
NUMBER OF LARVAE
April
May
June
July

FIGURE 5.—**A**. Number of razorback sucker larvae collected from the lower Green River, Utah, 1993–1996, distributed by capture dates. Arrows indicate start and end of sampling. **B**. Number of otolith-aged razorback sucker larvae (from among those caught each year) distributed by estimated dates of hatching. **C**. Number of otolith-aged razorback sucker larvae distributed by estimated dates of spawning. **D**. Mean daily discharge and instantaneous daily temperature regimes for the mainstem lower Green River in 1993–1996 (April–July) recorded by the U.S. Geological Survey at the gage near the town of Green River, Utah. Vertical lines delimit the range of estimated razorback sucker spawn dates for each year. Numbers are average (range) mean daily discharge and instantaneous daily water temperature during each estimated spawning period.

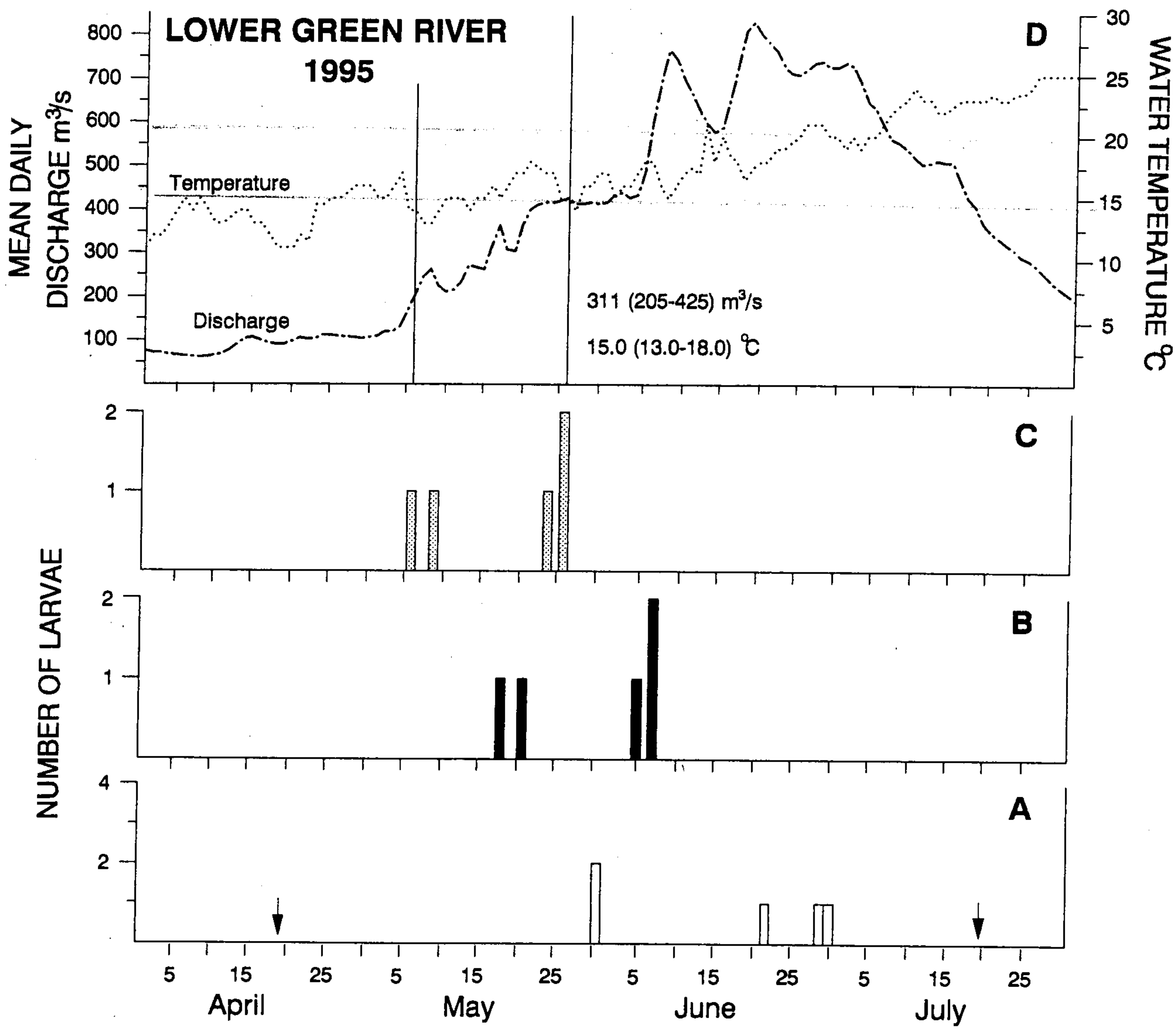
At what Q [illegible] flood?
20,500 cfs predike ≈ 580 m³/s
15,000 cfs [illegible] dikes [illegible] removed 425 m³/s



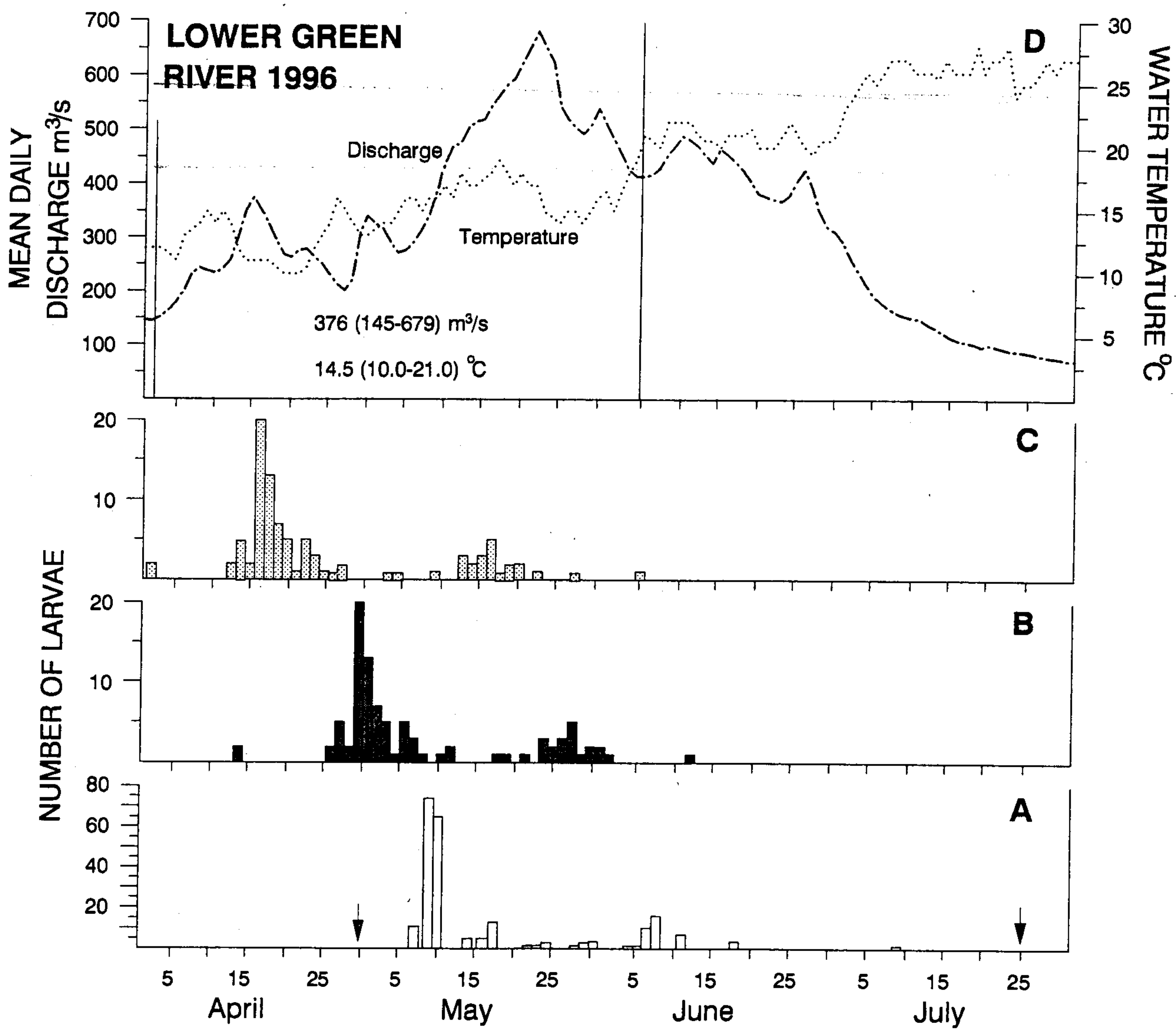
n: 122 [illegible]


LOWER GREEN RIVER 1994
MEAN DAILY DISCHARGE m³/s
300
200
100
Temperature
Discharge
233 (134-331) m³/s
17.5 (12.5-20.5) °C
D
WATER TEMPERATURE °C
30
25
20
15
10
5
NUMBER OF LARVAE
10
C
10
B
40
30
20
10
A
5
15
25
5
15
25
5
15
25
5
15
25
April
May
June
July

n: 91 12


LOWER GREEN RIVER
1995
D
MEAN DAILY DISCHARGE m³/s
WATER TEMPERATURE °C
Temperature
Discharge
311 (205-425) m³/s
15.0 (13.0-18.0) °C
C
B
A
NUMBER OF LARVAE
April
May
June
July

n= 5 e2


LOWER GREEN RIVER 1996
D
C
B
A
MEAN DAILY DISCHARGE m³/s
WATER TEMPERATURE °C
NUMBER OF LARVAE
Discharge
Temperature
376 (145-679) m³/s
14.5 (10.0-21.0) °C
April
May
June
July