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DISTRIBUTION, MOVEMENTS, AND HABITAT USE OF RAZORBACK SUCKER (*XYRAUCHEN TEXANUS*) IN A LOWER COLORADO RIVER RESERVOIR, ARIZONA-NEVADA

Gordon Mueller¹, Paul C. Marsh², Glen Knowles³, and Ty Wolters⁴

ABSTRACT.—Distribution, movements, and habitat use of 10 wild adult razorback suckers (*Xyrauchen texanus*) were examined in Lake Mohave, Arizona-Nevada, from November 1994 through July 1997. Movement rates (0.00–17.35 km d⁻¹) and ranges (\bar{x} = 39 km) were similar to those for riverine populations. All study fish returned to spawning sites used in previous years, but they also visited other spawning areas. Spawning females were significantly ($P = 0.031$) more active than males (480 vs. 87 m d⁻¹) and moved substantial distances between spawning sites during peak reproduction (1–28 February). Fish became most active (m d⁻¹, km month⁻¹) after spawning and moved to areas known to support higher algal production. Fish were typically within 50 m ($P < 0.001$) of shore and at average depths between 3.1 and 16.8 m (range 0.2 to >30.0 m). Adults were detected throughout the available thermal gradient (12°–30°C), but during summer typically had body temperatures between 18° and 22°C. Vertical movements within the water column showed no correlation with depth or time of day, but seasonal shifts suggest fish may regulate body temperature by seeking specific temperatures during reservoir stratification.

Key words: *Xyrauchen texanus*, razorback sucker, reservoir, spawning, habitat, movements, telemetry.

Xyrauchen texanus, the razorback sucker, is the largest catostomid in North America and is endemic to the Colorado River basin. Historically common, this riverine species now is reduced to relic and fragmented populations; 3 of 4 known populations (>100 fish) are in reservoirs (Minckley et al. 1991, Modde et al. 1996, Holden et al. 1997), the largest located in Lake Mohave, Arizona-Nevada. It was listed by the U.S. Fish and Wildlife Service as an endangered species in 1991 (USFWS 1991).

Telemetric research has focused primarily on rivers where adults have been found to use backwater and other lentic type habitats (Tyus 1987, Marsh and Minckley 1989, Modde and Wick 1997). However, riverine monitoring has been hampered by problems associated with working in large, remote systems, a scarcity of wild fish, and a short (2–3 wk) spawning season that occurs on the ascending limb of spring runoff (Tyus 1987, Minckley et al. 1991). Published reports specific to lentic environments are limited to McAda and Wydoski's (1980) description of *X. texanus* use of a gravel pit adjacent to the Colorado River in Colorado and Medel-Ulmer's (1983) abstract describing

X. texanus movement in Senator Wash Reservoir in California. While information is scarce, backwater and floodplain habitat is viewed as critical for species restoration (Valdez and Wick 1981, Wydoski and Wick 1998). The following report presents telemetry data describing *X. texanus* distribution, movements, and habitat use in a Colorado River mainstem reservoir and provides new information on spawner movements and female use of multiple spawning sites.

STUDY AREA

Lake Mohave is a mainstem Colorado River reservoir created with the construction and closure of Davis Dam located 5 km upstream of Laughlin, Nevada. The reservoir borders both Arizona and Nevada and extends 100 km upstream to the tailrace of Hoover Dam. When full (surface elevation 197 m/msl) the reservoir has a surface area of 11,655 ha. The reservoir inundates Black Canyon, located immediately downstream of Hoover Dam, and Pyramid Canyon where Davis Dam was constructed. Between these canyons the reservoir broadens, forming Cottonwood Basin, which

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has a maximum width of 6 km (Fig. 1). Lake Mohave has no tributaries other than the Colorado River, which enters as cold, hypolimnetic releases (Lake Mead) from Hoover Dam. Flows are discernible for the first 20–30 km, at which point the river exits Black Canyon and the reservoir broadens and depth increases. Maximum depth at Davis Dam is 35 m.

Construction of Davis Dam in 1954 represented the last mainstem reservoir built on the lower Colorado River. It is believed the reservoir population of *X. texanus* originated from an initially high period of recruitment from individuals trapped upstream during the closure of Davis Dam (Minckley 1983, Marsh 1994).

METHODS

Collections

A trammel net (2 m × 3.7 cm × 50 m) was used to capture wild adult *X. texanus* on 6–7

November 1994 from Lake Mohave at Yuma and Tequila coves. Each fish was measured for total length (mm), weighed (g), anesthetized with tricaine methanesulfate (125 mg L⁻¹), and surgically implanted (after Tyus 1987) with a sonic transmitter. A 30- to 40-mm medio-lateral incision was made slightly anterior and dorsal to the left pelvic fin, and the transmitter was inserted into the abdominal cavity so that it rested on the pelvic girdle. The incision was sutured with 4–5 knots using 3-0 Ethilon black monofilament nylon and an FS-1 cutting needle. We allowed the fish to recover 1–10 min after surgery and then released them at capture sites. Transmitters weighed 6 g, measured 16 × 55 mm, had a 14-month life expectancy, and were individually coded. Transmitters had an average detection range of 1 km and logged the transmitter (fish) temperature ($\pm 0.25^\circ\text{C}$) that was compared with water temperature profile data to determine fish depth.

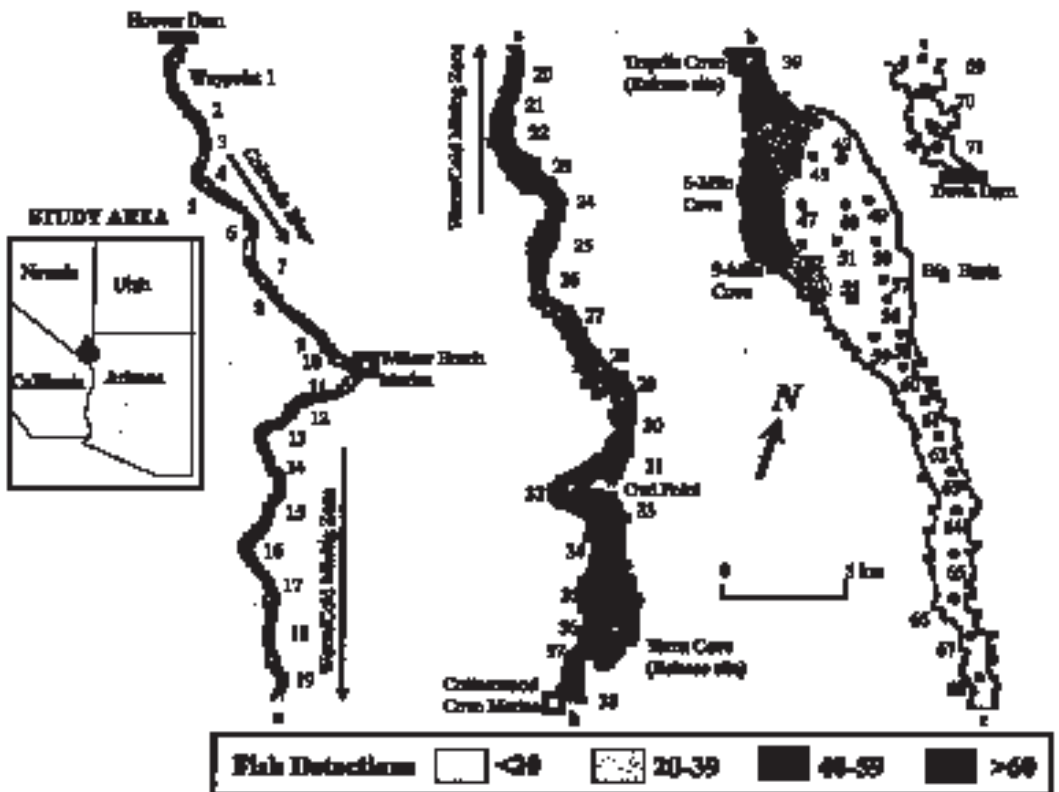


Fig. 1. Segmented map of Lake Mohave, Arizona-Nevada, showing numbered GPS way-point locations and place names mentioned in the text. Shaded areas reflect total number of fish detections per way-point from November 1994 through July 1997.

Survey Design

We conducted weekly surveys by boat using a global positioning system (GPS) and a preestablished survey grid composed of 71 way-points or "listening stations" programed into a GPS navigational system (Fig. 1). Sites were at <1600-m intervals to standardize search effort and ensure systematic coverage of the reservoir. Transmitter signals were detected using a DH-2 hand-held, directional hydrophone, a USR-5W ultrasonic receiver, and headphones. When signals were detected from way-points, we searched out the exact location and further triangulated using the hydrophone and GPS. A digital readout provided time interval measurements between signals that correlated to tag (fish) temperature. Recorded data included fish location (latitude and longitude), body temperature, and estimated distance (<10 m, 10–50 m, 50–100 m, >100 m) from shore. Vertical water temperature profiles were measured using a Hydro-lab™ temperature profiler between May and October 1995.

Surveys were scheduled biweekly for the 14-month transmitter life and were conducted in 2 shifts: 0200–1000 h and 1400–2200 h. Transmitter life greatly exceeded manufacturer estimates, allowing us to collect additional intermittent information between April and August 1996 and from April through July 1997.

Data Analysis

Using digitized shoreline profile maps of Lake Mohave and the geographical information system (GIS) program ARCINFO™, we created movement maps and calculated distances (m) and movement rates (m d^{-1}) between detection locations. Rate measurements and distances from shore were transformed into single classification frequency distributions, and observed data were summarized by classes. Shoreline use was examined by comparing percentiles of available surface habitat to the percentile of fish use within specific zones via a chi square test ($P < 0.001$; Sokal and Rohlf 1981). Comparisons of shoreline habitat utilization, movement rates, and area affinity were divided into spawning (November–April) and nonspawning (May–October) periods as defined by reports for *X. texanus* in Lake Mohave (Minckley 1983, Bozek et al. 1990, Minckley et al. 1991). Active spawning

was determined through observations and the collection of newly emergent larval *X. texanus* by an independent program (Mueller 1995). Movement rates (m d^{-1}) during active spawning (31 January–15 March 1995, 1996) for both sexes were examined for differences in movement patterns and distances using an analysis of variance ($P < 0.05$; Sokal and Rohlf 1981). To compare male and female movement patterns when spawning observations and larval sucker densities were most prevalent, we mapped individual fish movement during peak spawning (1–28 February).

RESULTS

A total of 20 *X. texanus* (10 males and 10 females) were surgically implanted with sonic transmitters. Six females and 4 males were tracked during the entire 14-month study period and were used in this analysis (Table 1; see Mueller et al. 1998). Remaining fish were excluded from analysis because either we lost contact during the study period or transmitters became immobile (shed tag or mortality). An expanded description can be found in Mueller et al. (1998). Study fish averaged 609 mm (555–680 mm) total length and 2.78 kg (1.75–4.21 kg). More than 1000 contacts were recorded representing 580 daily fish sightings, 300 hourly sightings, 800 body temperatures, and 100 vertical water temperature profiles.

Distribution

Fish distribution was distinctly seasonal. Some areas of the reservoir were occupied year-round, while other locations were used specifically for spawning or as summer sanctuaries. Big Basin and Owl Point areas (Fig. 1) were used year-round; Tequila and Yuma coves and the warm/cold mixing zone were used seasonally. Fish were seldom detected in up- or down-reservoir canyon habitats. Detection numbers were highest between way-point (WP) 30 and WP 37. Fish found in Big Basin typically were along the Nevada shoreline between Nine Mile and Six Mile coves (Fig. 2). This area was used by 3 fish during spawning and by 5 during summer. Tequila Cove (WP 39) was visited by all but 1 fish during spawning.

Owl Point (WP 32) was visited by all spawners and by 4 fish during summer and autumn. Following spawning, 7 suckers moved into the area between WP 12 and WP 24

TABLE 1. Individual tracking summaries for sonic telemetry of 10 wild adult *Xyrauchen texanus* in Lake Mohave, Arizona and Nevada, November 1994 to July 1997. Fish are individually identified by tag code; number of observations, average and total distance (m d^{-1}) traveled, days tracked, and range (km) of each fish are presented.

Fish ID	TL (mm)	Weight (kg)	No. of obs.	Distance traveled			s	Total distance traveled (km)	Days tracked	Range (WP ^a)
				Min.	Max.	Avg.				
FEMALES										
88	615	2.70	65	0	6,703	603	1322	250.4	974	32–66
276	654	3.61	71	21	3,502	606	708	352.5	953	24–67
339	665	3.33	62	9	10,108	767	1413	417.4	981	27–99
375	680	3.35	54	4	2,368	417	544	249.7	540	16–64
384	631	2.76	36	0	6,886	614	1133	183.0	466	26–65
465	614	2.94	65	9	6,558	485	851	264.3	969	5–34
\bar{x}	643	3.12	59	7	6,021	582	996	286.2	814	
MALES										
2228	558	2.40	51	3	15,607	788	2280	231.5	540	39–90
366	588	2.29	57	0	1,986	243	509	167.7	974	31–62
348	526	1.75	65	0	17,353	509	2154	181.7	960	32–71
258	595	2.26	57	0	1,635	242	334	120.9	540	29–47
\bar{x}	567	2.18	58	1	9,145	446	1319	175.5	754	

^aWP = way-point

where cold Hoover Dam releases mix with warmer Lake Mohave waters. We observed 9 *X. texanus* (nontagged) near the surface at the mixing zone on 8 June 1997 (9 fish per 1.5 km).

Movements

Fish movements were variable and distinctive by sex and among individuals. Both males ($>17.4 \text{ km d}^{-1}$) and females (10.1 km d^{-1}) traveled substantial distances in short periods of time, while some fish remained sedentary for days. Fish on average moved 527 m d^{-1} ($\bar{x} = 242\text{--}788 \text{ m d}^{-1}$), and while there was no statistical difference between sexes, females tended to be slightly more active ($\bar{x} = 582 \text{ m d}^{-1}$) than males ($\bar{x} = 446 \text{ m d}^{-1}$; Table 1). Hourly movement rates were statistically examined, and although no significant trends were identified, apparently fish might be slightly more active during summer at midmorning hours (0900–1000 h), supporting previous observations (McAda and Wydoski 1980).

Movement rates were examined both for nondirectional (m d^{-1}) and directional (linear km month^{-1}) activities. Monthly averages near the end of, or shortly after, spawning (March, April, May) exceeded 1000 m d^{-1} for 1995, 1996, and 1997 (Table 2). Linear distances traveled (km month^{-1}) peaked following spawning for all 3 yr (March 1995, May 1996, April 1997 [Table 2]). Linear ranges for indi-

viduals ($N = 10$) averaged 39 km (18–72 km) during the course of the study. Females on average ranged 42 km (29–72 km) compared to 35 km (18–51 km) for males.

All study fish returned to spawning sites used in previous years, but they also visited other spawning sites. Spawning (31 January–15 March 1995, 1996) females were significantly (ANOVA/ $F_{1,8} = 6.79$, $P = 0.0314$) more active (460 vs. 87 m d^{-1}) than males. During peak spawning (1–28 February 1995, 1996), the majority of females crossed the reservoir to visit other spawning sites while males typically remained at a single site (Fig. 2).

Habitat Use

Xyrauchen texanus exhibited a significant association with inshore ($<50 \text{ m}$ of shore) habitats ($P < 0.001$, chi square test). This affinity was most pronounced during spawning when distance from shore averaged $<30 \text{ m}$. Fish moved offshore during summer (July–November), possibly to avoid warmer water temperatures (Fig. 3).

During warmer months the reservoir presented fish a wide range of thermally stratified habitats. Temperatures up-reservoir were cold ($12^{\circ}\text{--}16^{\circ}\text{C}$), regardless of season or depth, due to hypolimnetic releases from Lake Mead. During summer the reservoir thermally stratifies further downstream presenting temperatures ranging from 30°C (surface) to 15°C

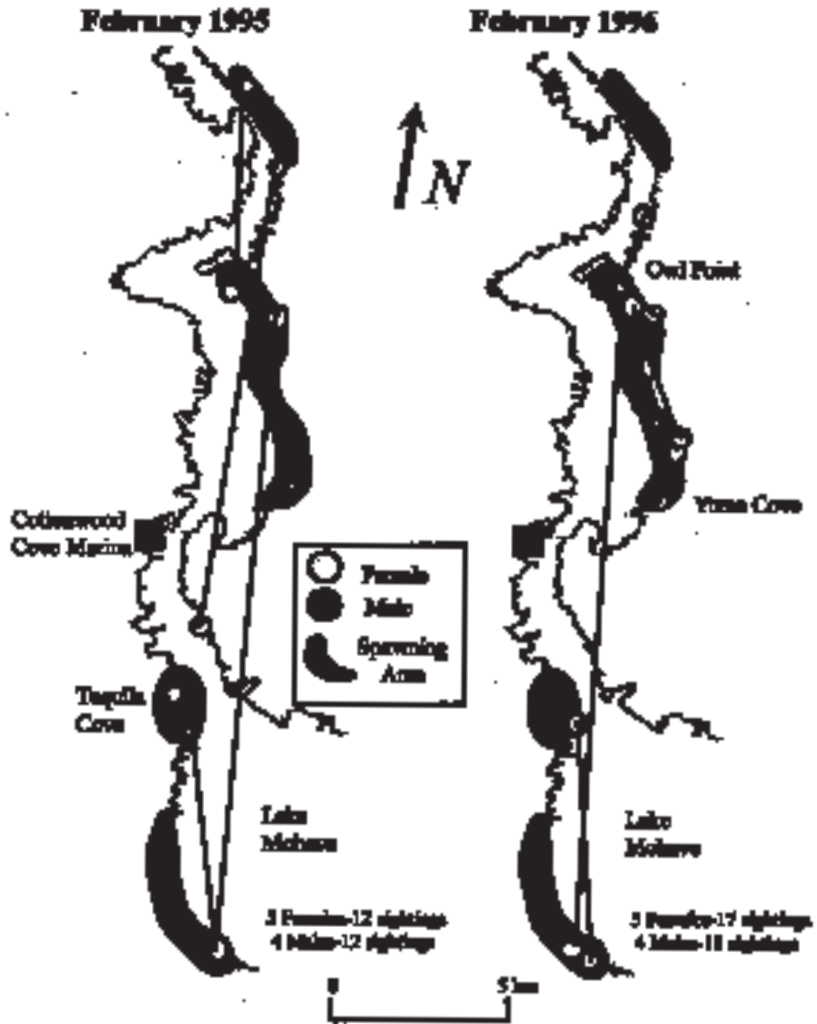


Fig. 2. Location and movements of male and female *Xyrauchen texanus* in association with major spawning areas during peak spawning (1–28 February 1995, 1996) in Lake Mohave, Arizona-Nevada.

(depths >30 m). Fish body temperatures ranged between 12° and 28°C, with summer averages ranging from 18° to 22°C, which was similar to thermal preferences reported by Bulkley and Pimentel (1983). Hourly data indicated fish moved vertically in the water column, but we found no correlations for depth with time of day.

Vertical temperature profiles ($n = 107$) were taken from May through November 1995 to correlate body temperature with depth. Fish ranged to depths >30 m but typically were found near 9 m ($\bar{x} = 9.1$ m; Fig. 3). Average fish depths changed with season, suggesting

fish may regulate body temperature during reservoir stratification (Fig. 3). Fish were found nearer the surface during spring and autumn and deeper during midsummer.

DISCUSSION

Lake Mohave scarcely represents what many would consider pristine *X. texanus* habitat. However, it is noteworthy that 3 of 4 remaining wild populations (>100 individuals) are found in reservoirs (Minckley et al. 1991, Holden et al. 1997, Modde and Wick 1997). Investigators who have conducted research in riverine environments have been challenged

TABLE 2. Monthly tracking summaries for sonic telemetry of 10 wild adult *Xyrauchen texanus* in Lake Mohave, Arizona and Nevada, from November 1994 to July 1997. The average monthly distance traveled is an average of individual monthly movements (total m month⁻¹).

Month	Julian day	Average	s	No. observations
November 1994	34639	1216 ^a	1658	16
December	34669	488	563	25
January 1995	34700	350	431	32
February	34731	345	525	25
March	34759	1100	2703	35
April	34790	309	515	33
May	34820	445	770	24
June	34851	463	593	28
July	34881	679	1256	27
August	34912	686	2030	23
September	34943	157	214	24
October	34973	307	541	24
November	35004	333	380	21
December	35034	521	773	21
January 1996	35065	199	261	17
February	35096	262	390	10
March	35125	247	335	30
April	35156	479	1407	18
May	35186	1730	2179	6
June	35217	475	453	40
July	35247	533	641	33
April 1997	35521	2338	5017	11
May	35551	510	399	14
June	35582	576	806	17
July	35612	477	685	6

^aBoldface numbers, $P < 0.05$.

by fish scarcity, logistics associated with river hydraulics, sampling in remote areas, and poor water visibility (Tyus 1987, Tyus and Karp 1990, Modde and Irving 1998). On the other hand, researchers working in reservoir environments are presented with a broader and less fluctuating range of physical parameters not found in natural river settings. For instance, reservoir water visibility (>10–15 m) allowed direct observations, summer water temperatures presented a stable but wide thermal gradient (12°–30°C), flows ranged from 0 to 2 m sec⁻¹, depths exceeded 40 m, and fish could choose both littoral and pelagic habitats. Reservoir conditions allowed us to observe spawning and document reproduction through the collection of larval *X. texanus* (Mueller 1989, Minckley et al. 1991, Mueller 1995). River studies have not shared in this degree of documentation, and spawning typically has been inferred by transmitter movement and in a few cases by collection of ripe fish (Tyus 1987, Tyus and Karp 1990, Modde and Irving 1998).

It has been widely reported that *X. texanus* migrate to specific spawning areas (Tyus 1987,

Tyus and Karp 1990, Modde and Irving 1998), and while spawning site fidelity has been speculated, it has never been proven (Tyus and Karp 1990, Scholz et al. 1992, and Modde et al. 1996). Recently, Modde and Irving (1998) speculated *X. texanus* may use multiple spawning sites in the Green River; however, this was not documented by observation or collection of gametes or larvae.

Adult *X. texanus* in Lake Mohave typically used broad, shallow shoreline habitats and generally did not occupy deeper canyon habitat typical of the lower or upper reservoir. Fish were seldom found together except during spawning (McAda and Wydoski 1980) and exhibited movement rates and ranges similar to those in riverine habitats (Tyus 1987, Tyus and Karp 1990, Modde and Irving 1998). Individual fish exhibited various degrees of sedentary and roaming behavior similar to other stream fish (Funk 1955).

Xyrauchen texanus spawning in reservoirs occurs from January through March, which is earlier and typically 2–3 times longer than riverine spawning (Minckley 1983, Minckley et al. 1991). Highly social, these fish form

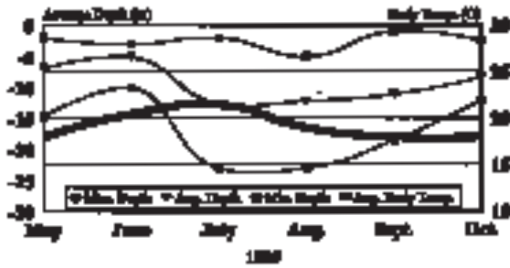


Fig. 3. Monthly comparison of average depth (m) and body temperature ($^{\circ}\text{C}$) of *Xyrauchen texanus* during thermal stratification (May–October) of Lake Mohave, Arizona-Nevada, in 1995.

spawning groups that can number in the hundreds. Males typically dominate (2:1) spawning sites (Minckley 1983). Females normally join males from adjacent deeper waters when ready to release their eggs (Minckley 1983, Mueller 1989), a behavior common with other catostomids (Moyle 1976).

Prolonged spawning combined with excellent observation and field conditions allowed us to more closely examine spawning and post-spawning movements. All study fish returned to spawning sites used the previous year, although they were also tracked to other spawning groups. In some cases the distance between spawning sites exceeded 50 km; 9 of 10 fish were found crossing the reservoir, participating in spawning groups on both the Arizona and Nevada shorelines. Fish movements during peak spawning (1–28 February 1995, 1996) suggested males typically remain on specific spawning sites while females roam substantial distances between spawning sites. We were unable to determine whether females spawned at multiple sites, but reports of females spawning over extended periods combined with the species known fecundity (>100,000 ova; Minckley 1983, Minckley et al. 1991) support the contention that multiple-site spawning occurs. Multiple-spawning-site behavior also helps explain the high genetic diversity of this population (Dowling et al. 1996).

Travel distances and movement rates peaked post-spawning as the majority (70%) of study fish moved immediately up-reservoir to the warm/cold water mixing zone where nutrient-rich hypolimnetic releases from Lake Mead stimulate algal production (Baker and Paulson 1980). Post-spawning movement supports earlier speculations that *X. texanus* historically

moved to more productive habitats following spawning (Valdez and Wick 1981, Tyus and Karp 1990, Modde and Wick 1997). Increased activity (Table 2) in shallower depths (Fig. 3) may indicate planktonic feeding (Marsh 1987). Wydoski and Wick (1998) suggested floodplain habitats and associated feeding activity are critical for fish to regain body condition after spawning.

Homing patterns of spawning and non-spawning populations were typical of those described by Gerking (1958): "Spawning migrations are directed toward a specific location . . . [while] the fish are usually scattered over a wide area during the non-reproductive portion of life." While fish used common areas during spawning, they typically dispersed after spawning, with some fish returning to specific locations in which they had been found the previous summer. The distance between spawning and summer use areas ranged from 20 km (4 fish) to 30 km (6 fish), with no correlations with sex or size. Fish exhibited a great deal of individuality, some being quite active while other were quite sedentary and remained in specific coves for weeks.

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LITERATURE CITED

- BAKER, J.R., AND L.J. PAULSON. 1980. Evaluation of impacts associated with reregulation of water levels in Lake Mohave. Technical Report 4, Lake Mead Limnological Research Center, University of Nevada, Las Vegas.
- 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

- razorback sucker. *Environmental Biology of Fishes* 27:255–263.
- BULKLEY, R.V., AND R. PIMENTEL. 1983. Temperature preference and avoidance by adult razorback suckers. *Transactions of the American Fisheries Society* 112: 601–607.
- DOWLING, T.E., W.L. MINCKLEY AND P.C. MARSH. 1996. Mitochondrial DNA diversity within and among populations of razorback sucker (*Xyrauchen texanus*) as determined by restriction endonuclease analysis. *Copeia* 1996:542–550.
- FUNK, J.L. 1955. Movement of stream fishes in Missouri. *Transactions of the American Fisheries Society* 85: 39–57.
- GERKING, S.D. 1958. The restricted movement of fish populations. *Biological Review* 34:221–242.
- HOLDEN, P.B., P.D. ABATE, AND J.B. RUPPERT. 1997. Razorback sucker studies on Lake Mead, Nevada: 1996–1997 annual report. PR-578-1. Bio/West, Inc., Logan, UT.
- MARSH, P.C. 1987. Food of adult razorback sucker in Lake Mohave, Arizona-Nevada. *Transactions of the American Fisheries Society* 116:117–119.
- _____. 1994. Abundance, movements, and status of adult razorback sucker, *Xyrauchen texanus*, in Lake Mohave, Arizona and Nevada. *Proceedings of the Desert Fishes Council* 25(1993):65.
- 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.
- MCADA, C.W., AND R.S. WYDOSKI. 1980. The razorback sucker, *Xyrauchen texanus*, in the upper Colorado River basin, 1974–76. U.S. Fish and Wildlife Service Technical Paper 99:1–15.
- 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 (1980):106 (abstract).
- 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., 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., AND D.B. IRVING. 1998. Use of multiple spawning sites and seasonal movement by razorback suckers in the middle Green River, Utah. *North American Journal of Fisheries Management* 18: 318–326.
- MODDE, T., AND E.J. WICK. 1997. Investigations of razorback sucker distribution, movements, and habitats used during spring in the Green River, Utah. U.S. Fish and Wildlife Service Recovery Program Project Report 49, Vernal, UT.
- MODDE, T., K.P. BURNHAM, AND E.J. WICK. 1996. Population status of the razorback sucker in the middle Green River (U.S.A.). *Conservation Biology* 10: 110–119.
- MOYLE, P.B. 1976. *Inland fishes of California*. University of California Press, Berkeley and Los Angeles.
- MUELLER, G. 1989. Observations of spawning razorback sucker (*Xyrauchen texanus*) utilizing river habitat in the lower Colorado River, Arizona-Nevada. *Southwestern Naturalist* 34:147–149.
- _____. 1995. A program for maintaining the razorback sucker in Lake Mohave. *American Fisheries Society Symposium* 15:127–135.
- MUELLER, G., P.C. MARSH, AND G.W. KNOWLES. 1998. Distribution, migratory behavior, and habitat use of razorback sucker (*Xyrauchen texanus*) in Lake Mohave, Arizona-Nevada. Open-File Report 98-252, U.S. Geological Survey, MESC, Denver, CO. 88 pp.
- SCHOLZ, A.T., R.J. WHITE, S.A. HORTON, AND W.A. KOEHLER. 1992. Measurement of egg and larval thyroxine concentration as an indicator of the critical period for imprinting in razorback sucker (*Xyrauchen texanus* Abbott): implications for endangered stocks in the Colorado River basin. Colorado River Fisheries Project Technical Report 1, U.S. Department of Interior, Bureau of Reclamation, Salt Lake City, UT.
- SOKAL, W.R., AND F.J. ROHLF. 1981. *Biometry*. 2nd edition. W.H. Freeman and Co., New York.
- TYUS, H.M. 1987. Distribution, reproduction, and habitat use of 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. 1990. Spawning and movements of razorback sucker, *Xyrauchen texanus*, in the Green River basin of Colorado and Utah. *Southwestern Naturalist* 35:427–433.
- 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. *Federal Register* 56(205 [23 October 1991]):54957–54967.
- VALDEZ, R.A., AND E.J. WICK. 1981. Natural versus man-made backwaters as native fish habitat. Pages 519–536 in V.D. Adams and V.A. Lamarra, editors, *Aquatic resources management of the Colorado River ecosystem*. Ann Arbor Scientific Publishers, Ann Arbor, MI.
- WYDOSKI, R.S., AND E.D. WICK. 1998. Ecological value of floodplain habitats to razorback suckers in the upper Colorado River basin. Upper Colorado River Basin Recovery Program, U.S. Department of Interior, U.S. Fish and Wildlife Service, Denver, CO.

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