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DRAFT FINAL REPORT:

Ecology and Conservation Biology of Humbpack Chub (Gila cypha) in the Little Colorado River

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SECTION 1:

POPULATION ESTIMATES/ POPULATION MOVEMENTS OF *GILA CYPHA*, AN ENDANGERED CYPRINID FISH IN THE GRAND CANYON REGION OF ARIZONA

ABSTRACT

Gila cypha (the humpback chub) is a unique but endangered cyprind fish endemic to the Colorado River system in western North America. Its distribution within the system is patchy; occurrence is restricted primarily to narrow, canyon-bound reaches of these rivers. Greatest abundance is achieved at the confluence of the Colorado and Little Colorado rivers (= LCR) in northern Grand Canyon (Coconino Co., AZ). This study defines the nature and extent of *G. cypha*'s movements within the LCR, and tests the hypothesis that its duration of stay within that river is restricted to the reproductive period.

During 1991/92, adult *G. cypha* were captured and tagged during 19 6--14 day sampling periods in three separate reaches of the LCR. From these data, population estimates were derived for each reach on a monthly basis, by month for the entire LCR, and over the entire study period. Results indicate an upriver migration by some individuals in early spring, followed by a slow, protracted post-reproductive movement downstream. Localized stasis by adults in the LCR, particularly summer through winter, is also strongly supported by the data. Movements by *G. cypha* in the LCR thus appears to be an amalgam of two processes: Upriver movement in spring coupled with localized movements by overwintering adults. The latter suggests a possible alteration in life-history strategy for the species, and is discussed in the context of Glen Canyon Dam, built in 1963 to impound Lake Powell at the northern extent of Grand Canyon.

"The Colorado is probably the most utilized, controlled, and fought over river in the world. It flows through lands of incomparable beauty and includes nearly seven percent of the nation's contiguous land mass, including parts of seven states. From the time of early settlers to the present, the waters of the Colorado River have been the key to development of the arid region" (Crawford and Peterson, 1974:vi).

Waters of the Colorado River basin are not only economically important, but also contain the most distinctive ichthyofauna in North America, with species-level endemism approaching 75% (Minckley, 1991) (93% if undescribed forms and subspecies are included, as in Carlson and Muth, 1989). The parallel importance of economic potential and ichthyofaunal diversity has initiated a classic and ongoing confrontation between development and conservation (see Wydowski and Hamill, 1991).

From the conservation viewpoint, at risk is a unique and endemic ichthyofauna of ancient origin, extending as far back as the Miocene (Miller, 1959, 1961; Minckley et al., 1986). These fishes possess remarkable adaptations to survive in a turbulent environment. Foremost are a suite of morphological and anatomical modifications which may act in concert to minimize the river's impact upon the phenotype of the fish while optimizing the abilities of the fish to negotiate boulder-strewn, high velocity rapids. While alternative hypotheses may explain the evolution of these phenotypes, morphological trends across numerous, unrelated taxa speak for commonality in other than phylogeny, and the selective arena of the river seems reasonable (Minckley, 1991:128). The majority of these fishes are endangered (or candidates for such listing; see Minckley and Douglas, 1991), due to numerous recent habitat modifications by modern humans.

The specialized morphologies of the mainstream Colorado River fish fauna reach their culmination in the phenotype of humpback chub (*Gila cypha*; Fig. 1), the most remarkably specialized minnow in western North America and one of the most bizarre in the world (Miller, 1964; Minckley, 1991; Douglas, 1993; and references therein). It is known only from the Colorado River and its major, swift-flowing tributaries (Holden and Minckley, 1980); it occurs only sporadically and is seldom locally abundant, particularly when compared to other indigenous fishes. *Gila cypha* has been recorded from: (a) the gorge sections of the Green and Yampa rivers in Utah and Colorado (Green River Wilderness Area and Dinosaur National Monument, respectively); (b) the Colorado River in Utah above Lake Powell (Canyonlands National Park); and (c) the Colorado River above its junction with the Green River [between confluences of the Dolores (in eastern Utah) and Gunnison rivers (in western Colorado; Fig. 2a)]. *Gila cypha* was also within other canyon-bound reaches of the Colorado River, as documented from archaeological remains

(Miller, 1955; Miller and Smith, 1984; Sigler and Miller, 1963).

Gila cypha was the last fish to be described from the mainstem Colorado River (Miller, 1946), the type specimen caught in 1932 by angling within Grand Canyon National Park (GCNP) [at Bright Angel Creek, now 141.3 river kilometers (RKM) below Glen Canyon Dam] (Carothers and Brown, 1991:95). The largest population of *G. cypha* is in the Marble Canyon section of GCNP, at the junction of the Little Colorado (LCR) and mainstem Colorado rivers, 99 RKM below Glen Canyon dam (Fig. 2b). While the life history of *G. cypha* is enigmatic (discussed in Douglas, 1993), the Grand Canyon population is least known of all. For example, *G. cypha* inhabiting the Colorado River at the LCR confluence were not even recognized as a reproducing population until 1975 (R. R. Miller, unpubl. field notes, Special Coll., Hayden Library, ASU). Even then their numbers were not considered substantial; the largest population of *G. cypha* at that time was believed to inhabit the Colorado River near Grand Junction (based upon 32 specimens captured in 1974; J. E. Johnson, Bur. Land Manag. Tech. Note 280, 1976, unpubl.).

This study was undertaken to estimate numbers of adult *G. cypha* within the LCR, define the nature and extent of their movements within that river (where reproduction occurs annually), and test the hypothesis that both local movements and residency are restricted to the reproductive period. Habitat use is then discussed in context of Glen Canyon Dam, constructed in 1963 (completed in 1968) to impound Lake Powell at the northern extent of Grand Canyon.

METHODS AND MATERIALS

The study river.---The LCR drains 141,155 km^2 of eastern and northern AZ and western NM, and flows 412 km from headwaters to confluence with the Colorado River (GCNP, Coconino Co., AZ; Figs. 2a, 2b). Unless in flood, the LCR is seasonally dry in much of its upper 390 km, a result of modern land-use practices and water impoundments initiated at the turn of the century (Miller, 1961). However, flow in the lower 21 km is perennial, from numerous groundwater springs which drain 72,520 km^2 of the Black Mesa north and east of Flagstaff, AZ. The largest of these (i.e., Blue Springs, at LCR RKM 21; Fig. 2b) has a discharge of 6.1-6.6 m^3/sec (Johnson and Sanderson, 1968).

The LCR at base flow is saline (conductivity exceeds 5000 umhos/cm^{-1}) and travertine-forming. Carbonate precipitates onto surfaces and in the water column, the latter giving the river a distinct turquoise color. Carbonate deposition (a function of CO_2 degassing and photosynthetic activity of algae and cyanophyceans) produces an intricate and confusing water chemistry (Kubly and

Cole, 1979). Travertine accumulations over geologic time define pools, runs, and rapids, and generate scalloped waterfalls and cascades. Interspersed amongst this structure are broad sandbars and other depositional features more typical of erosive southwestern streams. These shift seasonally (and dramatically) according to duration and extent of flooding. Dominant riparian vegetation is a mixture of native [Catclaw acacia (*Acacia greggii*), Honey mesquite (*Prosopis qlandulosa*), Coyote Willow (*Salix exigua*), Arrowweed (*Tessaria sericea*)], and nonnative species [Tamarisk (*Tamarix chinensis*), Camelthorn (*Alhagi camelorum*)] (Carothers and Brown, 1991; Johnson, 1991). Giant reed (*Phragmites australis*) and cattail (*Typha* spp.) occur patchily. The lower LCR passes through a narrow gorge that progressively widens and deepens as it drops towards Marble Canyon. A series of precipitous travertine falls at RKM 14.9 (Atomizer Falls, Fig. 2b) mark upstream distribution of *G. cypha*.

Base camps.---Three base camps were established in the LCR gorge: Near its confluence (RKM 0.55); at Powell Canyon (RKM 3.1); and at Salt Canyon (RKM 10.8). Biologists worked from each camp. Those at the confluence fished the lower 1.2 km of river, while those at Powell camp fished upriver from 1.3--7.0 km. Salt camp personnel fished from 8.0--14.9 km.

Data collection.---Fishes were captured during 19 6--14 day trips at approximately monthly intervals from July 1991 to December 1992. Hoop nets (0.76 or 1.2 m dia., 2.4 or 3.0 m length, four- or six-hoop, single- or double-throat) were deployed in all available habitat types of sufficient depth (i.e., > 0.4 m). Trammel nets (7.6 to 45.7 m length, 1.8 m depth, 1.3 to 3.8 cm inner and 30 cm outer meshes) were set routinely in the confluence. Fishing effort for a particular trip was recorded as number of net-hours per camp.

All captured fishes were identified, measured (TL to nearest mm) and weighed (nearest g). Native species were examined for tags, markings, secondary sexual characteristics, ripeness, and general health and condition. Those greater than 150 mm TL (= 'adults') were injected with passive integrated transponder (i.e., PIT) tags (see Prentice et al., 1990) and released near points of capture. Nonnative fishes were scanned for presence of PIT tags (a result of consuming tagged native fishes), then sacrificed and either dissected immediately or preserved for later study.

Analytical protocol.---One-way ANOVA (Proc GLM; SAS, 1985) was used to compare total fishing effort and captures of adult *G. cypha* by reach and year. To determine movements during 1992 (which represented a full year of sampling), adult chubs were grouped by reach and season (winter = December, January, February; spring = March, April, May; summer = June, July,

August; and autumn = September, October, November). Numbers of *G. cypha* tagged/recaptured in a given reach during a given trip were condensed into a capture history (i.e., CH) matrix (Burnham et al., 1987; Lebreton et al., 1991). Fifty-seven matrices were derived (three camps over 19 trips).

Closed population estimates.---Population estimates were generated from each CH-matrix under assumption that the three stream reaches contained closed populations. This was appropriate given the brief sampling period at each camp (see Otis et al., 1978), and because only adults were censused. Closure was tested by examining numbers of individuals tagged within one reach then recaptured within a second reach during the same trip. Nine different closed-population estimates were derived from each CH-matrix using an updated (30 Dec. 1991) version of the computer program CAPTURE (G. C. White, D. R. Anderson, K. P. Burnham, and D. L. Otis, Los Alamos Natl. Lab., 1982, unpubl.). Models and assumptions are explained in Otis et al. (1978), Pollock et al. (1990), and Nichols (1992). The single best-fitting population model, as indicated by goodness-of-fit tests and comparisons between competing models, was retained. In this first analysis, population estimates were made relative to one another by dividing each by length of reach (in km). ANCOVA (Proc GLM; SAS, 1985) then contrasted relative population estimates by reach, using fishing effort as a covariate.

In a second analysis, tag/recaptures were evaluated for the entire LCR (rather than by reach). Here, 19 CH-matrices were generated, one for each month of study. Again, the single best-fitting population model was retained. ANOVA was used to test the 19 estimates against those summed by reach for each month. The hypothesis under test is that monthly estimates are not significantly different from those summed by month over reaches.

Finally, a third analysis collapsed all tag/recaptures into a single CH-matrix (i.e., each column of the CH-matrix represented a single month). Here, five best-fitting estimates were retained. However, assumptions of closure may be violated in this analysis by movements of *G. cypha* into/from the mainstem Colorado River over the 19-month study interval, and by recruitment of juvenile chubs into the adult population. Thus, while this analysis is a logical culmination of population estimates (a) by reach, (b) by month summed over reach, and (c) solely by month, results are heuristic rather than practical.

RESULTS

Fishing effort and unadjusted population estimates.---Fishing effort differed significantly among reaches ($F=6.40$; $P < 0.0035$; Proc GLM; SAS, 1985), with effort at Salt Canyon greater than

that at Confluence (Sidak's multiple range test; SAS, 1985). Efforts at Salt and Powell Canyon reaches were statistically similar, however. Population estimates (normalized by river km) also differed significantly among reaches, with greatest overall values at Confluence ($F = 4.19$; $P < 0.01$; SAS, 1985).

Population estimates adjusted for fishing effort.---Differences in normalized population estimates could result from increased effort. To test our estimates with fishing effort fixed, we first evaluated two specifications: (a) that slopes of the between-camp regressions of population estimate vs effort were homogeneous (i.e., regression lines parallel; see Somers and Jackson, 1993), and (b) that interaction between fishing effort and population estimates was nonsignificant. Based upon a priori statistical contrasts, estimated populations in Confluence and Salt Canyon reaches were similar, but each was significantly larger than at Powell Canyon reach, irrespective of fishing effort (Table 1).

Population estimates for each reach and for the entire river.---Three-dimensional plots of adjusted population estimates by reach are presented in Figure 3. Powell Canyon exhibited lower estimates than either Confluence or Salt Canyon, particularly in 1991 (Fig. 3a). In 1992 (Fig. 3b), increased activity at confluence during early March was reflected in elevated estimates at Powell in late March-April, followed by elevated estimates at Salt Canyon April-through-June. Estimates at confluence again increased in April-June. Raw population estimates by reach per sampling period, and estimates normalized by river km, are in Appendix 1. Raw population estimates per sampling period for the entire LCR are presented in Appendix 2. This appendix also contains a second population estimate for the entire river, derived by summing estimates calculated over reaches for each sampling period (as recorded in Appendix 1). An ANOVA comparing these two estimates for the entire LCR (i.e., monthly vs summed by month over reaches) was nonsignificant ($F = 1.15$; $df = 1,36$; $P > 0.7$; Proc GLM, SAS, 1985). Both estimates are plotted in Figure 4. In 1991, highest estimates were recorded for early August (3157 vs 5390), while lowest were for December (745 vs 1285) (Fig. 4). In 1992, highest estimates were for April (5555 vs 5683), while lowest were for August (635 vs 408). A December sampling trip in 1992 was cancelled due to inclement weather. Both techniques indicated elevated population estimates from early March through June of 1992 (Fig. 4). Also, both techniques demonstrated an upswing in estimated population size in autumn of both years. The average estimate summed over reaches was larger (but not significantly so) than that calculated by month (2993 vs 2434; $N = 19$; Sidak's multiple range test; SAS, 1985).

Five best-fitting population estimates were retained from analysis of a CH-matrix for the entire 19 month study (Table 2). The highest criterion (0.61) was Pollock and Otto's estimator

(M_{bh}), which assumes that capture probabilities vary by individual animal and by behavioral response to capture (i.e., behavior and heterogeneity effects; Otis et al., 1978:40--50). The model with the second-highest criterion (i.e., the Null model; M_o) is also the simplest in that it presumes all members of the population are equally at risk of capture on every trapping occasion. Burhnam's estimator (M_b) assumes capture probabilities vary with time and with behavioral effects (such as trap-happiness, trap-shyness). The last two models (Jackknife estimator M_h, and Chao's M_h) accept that capture probabilities vary by individual animal.

Movement by season within- and among reaches.---To determine extent of movement by *G. cypha* within the LCR, capture and subsequent recapture(s) for 1992 were compiled by reach and season (Table 3). Because these data reflect numbers of individuals tagged within each reach for a given season then subsequently recaptured, percentages for each reach and season total 100%. For *G. cypha* tagged at confluence during winter and subsequently recaptured, 49% (n = 47) were taken upstream in Powell or Salt reaches during winter/spring. Similarly, of those tagged at confluence during spring and subsequently recaptured, 51% (n = 96) were taken upstream during spring/summer. For Powell reach, 18% (n = 7) of recaptures initially tagged there during winter were taken in Salt reach during winter/spring, while 31% (n = 59) of recaptures tagged there in spring were taken at Salt during spring/summer. Overall, 21% of total movements in 1992 (ascertained by mark/recapture) was upstream.

Elevated population estimates at confluence in January/February of 1992 (Fig. 3b), followed by upstream movement, argue strongly for staging. Estimates at the confluence peaked in early March, then gradually decreased through June. A similar peak occurred within Powell Canyon reach in late March, extended into April, then decreased into June. Population size did not peak in Salt Canyon reach until April; estimates remained elevated through June. The last six months of 1992 were similar to that of 1991 (Fig. 3a, 3b), with estimated population sizes dwindling through late summer. However, estimates rose again in Autumn, 1991 but remained low during a similar period in 1992.

Evidence for downstream movement is less convincing (Table 3). Of *G. cypha* tagged in Powell reach during winter and subsequently recaptured, 21% (n = 8) were taken at confluence in the remainder of the year. Similarly, 16% (n = 30), and 15% (n = 15) of recaptures tagged at Powell in spring and summer, respectively, were taken at confluence in the remainder of the year. At Salt, 16% (n = 33) and 7% (n = 12) of recaptures tagged in spring and summer, respectively, were taken in the two lower reaches over the remaining seasons. Overall, 9% of recaptures in 1992 indicated downstream movement.

Table 3 primarily reflects population stasis by reach, particularly summer through winter. At confluence, 17% (n = 33) of individuals tagged in spring were subsequently retaken there summer through winter, while 76% (n = 54) of chub tagged in summer were recaptured in that same reach summer through winter. Similarly, 77% (n = 10) of chub tagged at confluence in autumn were retaken there autumn/winter. At Powell, 23% (n = 45) of individuals tagged in spring were again recaptured there summer through winter, 78% (n = 80) of those tagged during summer were recaptured summer through winter. In addition, 91% (n = 20) of those tagged in autumn were recaptured in that same reach autumn/winter. A similar situation occurred at Salt, where 53% (n = 109) of individuals tagged during spring were recaptured there summer through winter, while 93% (n = 159) tagged during summer were recaptured summer through winter. In autumn, 89% (n = 24) tagged at Salt were recaptured there autumn/winter. Overall, 70% of recorded movements in 1992 was static (i.e., within-reach).

Evidence is minimal for movement of *G. cypha* between reaches during collecting periods (Table 4). In 1991, 13 out of 3272 fish were recaptured during the same trip in a reach upstream from their initial capture, while 23 of 3272 were recaptured downstream from their initial capture reach (i.e., N = 36; 0.01% of total; Table 4). In 1992, only 1 of 4030 fishes was recaptured during the same trip in a reach upstream from their initial capture, while none was recaptured in downstream reaches (i.e., N = 1; 0.0003% of total; Table 4).

DISCUSSION

The Colorado River as habitat.---During historic times, temperature and flow regimes of the Colorado River fluctuated greatly; seasonal flooding transported heavy sediment loads while low waters carried vast amounts of dissolved salts to the Sea of Cortez (Carlson and Muth, 1989). In flood, the Colorado was a wild, swift, turbulent river, the result of extreme flow, a channel constrained for most of its length by steep cliffs, and a 3700 m drop in altitude from headwaters to sea (Fradkin, 1984).

Dams and Impoundments.---Dam construction and chronic dewatering for agriculture and urban development precipitated major changes in the Colorado River ecosystem. Temperature and flow regimes as well as salt and sediment loads of the river are now greatly ameliorated. The 2400 km of riverine habitat suitable for large-river fishes has been reduced to 965 km (Miller, 1982).

Those sections of the Colorado River that were converted into lakes Mead and Mohave (following closure of Hoover and Davis dams in 1935 and 1954, respectively), clearly possessed the river's unique fish fauna, including *G. cypha* (Miller, 1955).

These fishes [except for relictual bonytail chub (*Gila elegans*) and razorback sucker (*Xyrauchen texanus*)] are now extirpated (see also Minckley, 1983). They were also eliminated from the Green River above the mouth of the Yampa River when Flaming Gorge Dam became operational in 1962 (Vanicek et al., 1970; Fig. 2a).

Glen Canyon Dam.---The operation of Glen Canyon Dam precipitated major changes in the Marble/Grand Canyon ecosystem of the Colorado River (Marzolf, 1991:33). Some occurred immediately upon closure of the dam in 1963 (e.g., decreased water temperatures; reduced sediment loads; diminished salinity; alteration of flow regimes). Others developed over a much longer time frame (e.g., geomorphic adjustment of channel; secondary succession of terrestrial vegetation; modification of aquatic species-composition) (Committee, 1991). All have severely impacted the natural ecosystem; some are irreversible.

Indigenous fishes inhabiting Glen, Marble and Grand canyons were impacted following closure of Glen Canyon Dam (Holden and Stalnaker, 1975; Suttkus and Clemmer, 1977; Minckley, 1991). Many (including *G. cypha*: Holden and Stalnaker, 1975; Anonymous, 1980) persisted in Lake Powell, but were unable to reproduce (Holden, 1973:4). Downstream from the dam, the fish community shifted from predominantly warm-water native and introduced fishes to one dominated by either cold-water fishes [i.e., rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*)] or those with broad temperature tolerances. Within GCNP, five of eight indigenous fishes still persist in low to moderate numbers. These are usually restricted to warmer habitats such as tributaries and backwaters. While terrestrial species in GCNP adapted to the post-dam Colorado River ecosystem (Carothers and Brown 1991:147; Johnson, 1991), indigenous fishes generally did not (Kaeding and Zimmerman, 1983:592).

The Little Colorado River as habitat.---Temperataure and flow conditions in the LCR are similar to those of the pre-dam Colorado mainstem, and thus suit habitat requirements of indigenous fishes shaped over evolutionary time. Kaeding and Zimmerman (1983) argued that *G. cypha* persisted within the Canyon, whereas other endemics were eliminated, because a portion of its population spawned within the LCR. They also argued that, given post-dam temperature disparities between LCR and mainstem, significant reproductive success for *G. cypha* must occur within the LCR. Thus, selection should be strong for development of a spawning migration (Kaeding and Zimmerman, 1983). Critical though these observations are to the ecology and conservation of *G. cypha*, they have yet to be substantiated. While data presented herein do not address movements of *G. cypha* from the mainstem into the LCR, they do suggest that staging occurs at the confluence. Our data do demonstrate that adult *G. cypha* actively move up the LCR in spring (primarily to reproduce), and often

remain within the LCR for long periods, possibly the entire year. These observations are based both on monthly population estimates by reach, and on seasonal recaptures of tagged *G. cypha*. Before each of these results are discussed, however, it is important to review population models and their assumptions.

Open vs closed population models.---Modelling of capture history is defined by the idea of population closure. An open population is one in which study organisms enter and leave (via birth, death, immigration, emigration, or ontogeny). A closed population does not change composition during the course of the study (Nichols, 1992). While open populations are the norm in wildlife investigations, closed models approximate the short-duration realities of nature (Skalski and Robson, 1992). In fact, Pollock (1982) recommended as an ideal survey design a sequence of intense trapping sessions each followed by a longer period of cessation of trapping. Data from each session would be analyzed separately using closed models (as done herein). Survival rates derived from the time-duration between trapping sessions could then serve as input for open-population models (M. E. Douglas and P. C. Marsh, in prep.).

Three assumptions are crucial to closed-population studies: Closure is substantiated; organisms do not lose marks during the course of the experiment; and all marks are correctly recorded at each trapping occasion. The most critical is the first. Closure for the duration of a trapping session allows the resulting estimate to represent a "snapshot" of the population at a given point in space and time. In the present study, sampling each month was brief, and movements between reaches were negligible during sampling. Thus, closure both by reach/ month and by month for the entire LCR is indeed supported, and the resulting population estimates are robust.

Past and present population estimates in the LCR.---Population estimates for *G. cypha* in the LCR are presented in Table 5. Our May, 1992 estimate at the confluence was 1,320 adult *G. cypha*. This is a reduction of 27% and 54%, respectively, from estimates of 1,800 and 2,900 individuals in May of 1987 and 1988. An estimate for the entire 14.9 km length of the LCR during May of 1992 was 4,346 (summed estimate for the three reaches = 4,602). This contrasts with the estimate of 25,000 chub in 1989.

The best-fitting population estimate for our entire 19-month study (4,508 individuals) was obtained using Pollock and Otto's estimator (M_{bh}). This model is one of the most realistic and useful for a mark-recapture experiment, in that it allows for individual variance in behavioral response to capture (Otis et al., 1978). Its estimate is larger than two average estimates for the 19-month study [i.e., 2,992 (monthly summed over reaches) and 2,434 (monthly for LCR)]. Although results from a model utilizing

19-months of data should be superior to an average of those data, any such long-term estimate must be viewed skeptically, given the violations of demographic and temporal closure mentioned earlier.

Movements by G. cypha within the LCR.---Our results contrast with those of Kaeding and Zimmerman (1983), who found no consistent relationship between catch rate and river reach within the LCR [where 'river reaches' were 5 km increments, beginning at RKM 2 and ending at Blue Springs (RKM 21; Fig. 2b)]. In our analyses, river reaches were more extensive, and only encompassed those RKM within which *G. cypha* was active (i.e., 0--14.9).

The confluence has often been considered a staging area for *G. cypha* (R. R. Miller, GCNP report, 1975, unpubl.; R. D. Suttkus, G. H. Clemmer, C. Jones, and C. R. Shoop, GCNP report, 1976, unpubl.; C. O. Minckley, unpubl. field notes, 1977). Extent of *G. cypha*'s movement within the LCR was not clarified until September 1977, when three large individuals (278--295 mm TL) were captured 12.8 RKM above the confluence (C. O. Minckley, unpubl. field notes, 1977). From these data, and from AZGF monitoring efforts in spring 1987--1990 (C. O. Minckley, unpubl.), it was believed that *G. cypha* actively moved into the LCR in spring (i.e., April/May) to reproduce, then quickly returned to the mainstem. Greater numbers of *G. cypha* at the confluence during spring of 1992 support an hypothesis of staging prior to upstream movement. Downstream (i.e,, postreproductive) movement also clearly occurred, but spanned a long period and was diffuse. Movements between LCR reaches during a given sampling period were negligible, suggesting temporal closure during periods of sampling. There was no evidence of explosive or extensive reproductive movements.

Our results indicate population stasis within reaches, particularly summer through winter, suggesting that *G. cypha* is more of a resident component of the LCR than previously imagined. These observations support similar data collected by Karp and Tyus (1990) in the Yampa River. There, *G. cypha* remained in or near specific eddies for extended periods, and even returned to the same eddy during the spawning season in different years. It could not be ascertained whether individual chub deposited eggs in the eddies or simply used them for staging, resting, or feeding.

Habitat use.---Data on habitat use by *G. cypha* are primarily anecdotal and observational. Adults characterize whitewater reaches, where they occupy deep, swirling eddies along canyon walls or concentrate in zones of turbulence near boulders and submerged rocks (Minckley 1991:150). Similarly, Kaeding et al. (1990) noted that commonality among *G. cypha* habitats is not great depth, but dynamic flow vectors that result from water moving rapidly among large, angular boulders and shoreline rock

outcrops. Within other areas of the Colorado River, *G. cypha* often associates with large-scale riprap material from riverside railroad and highway construction (Kaeding et al., 1990).

Karp and Tyus (1990) argued that eddy habitat was crucial to breeding requirements of *G. cypha* in the Yampa River. Interfaces between eddies and runs were similarly judged important in the Black Rocks area (below Grand Junction, CO) (R. A. Valdez and B. A. Nilson, Proc. Am. Fish. Soc., Bonneville Chapter, 1982, unpubl.). Adult *G. cypha* are primarily nocturnal (Fig. 5 of Valdez and Clemmer, 1982). During daylight hours in the LCR, they reside in deeper waters along cut banks with overhanging vegetation (primarily reeds), along sheer rock outcrops, or in deeper pools away from shore; they are active during crepuscular hours and in late evening (C. O. Minckley, pers. comm.; M. E. Douglas and P. C. Marsh, pers. obs.).

The greater numbers of *G. cypha* found in the Salt Canyon reach, when compared to Powell Canyon reach, sustain at least two alternative hypotheses. Increased habitat complexity in the Salt Canyon reach, with greater numbers of large travertine dams, eddy/run interfaces, and deep pools, may increase residency of *G. cypha* within this area. Alternatively, those *G. cypha* that move up the LCR may literally 'stack' within the upper reach, due either to a physical barrier at RKM 14.9, or a chemical one produced by high CO_2, or other chemical content.

Glen Canyon Dam and Gila cypha.---There is long-term residency by *G. cypha* within the LCR, particularly summer through winter. In fact, many adults apparently overwinter within the LCR, effectively using it as a warm-water refugium. Two hypotheses are presented to accommodate these data. One suggests residency is a pre-dam component of *G. cypha*'s life history. The other proposes that it is a post-dam alteration. It is unclear which can be rejected; both are untestable in their present form.

Long-term residency by adults may have always been an aspect of *G. cypha*'s life-history. We know, for example, that it spawned within the pre-dam LCR during spring (Kolb and Kolb, 1914:127; Carothers and Brown, 1991:93). However, its duration of stay was unknown. If residency has always been a component of *G. cypha*'s natural history, then our mark/recapture data simply define inherent behavior over evolutionary time.

An alternative hypothesis is that the altered thermal regime of the mainstem has forced *G. cypha* to adjust its life history. It now accommodates lower mainstream temperatures primarily through avoidance (i.e., by increasing residency within the LCR). This hypothesis is anecdotally supported by three facts: First, movements into/from the LCR are primarily accomplished by larger (and presumably older) *G. cypha* (R. A. Valdez, pers. comm.). *Gila*

cypha attains great age (20+ years; Minckley, 1991:150); larger adults may thus represent mainstem-adapted individuals from pre-1968 cohorts (when Lake Powell filled). Secondly, larvae and juvenile *G. cypha* are often transported via flood into the mainstem, but adults less than 200 mm TL are seldom taken there (R. A. Valdez, pers. comm.). Kaeding and Zimmerman (1983:585) similarly noted that individuals larger than 145 mm TL were never taken in the mainstream above the confluence, even though mature fish were present there. Third, hydrologic and thermal profiles of the LCR are consistent with the pre-dam Colorado River, but differ markedly from the post-dam river.

If *G. cypha* has altered its life history to accommodate dam-induced changes in the mainstem Colorado River, then its long-term persistence within the Grand Canyon is tied more intimately to the LCR than previously believed. The evolutionary effects of such a life-history alteration can only be speculated upon.

One potential saving factor (Committee, 1991:4) is that ecosystem components are linked to one another and to flow regimes imposed by the dam. Flows can therefore be manipulated to manage the river and protect the environment in GCNP. This offers the possibility that temperature, sediment load, and volume of discharge from the dam may eventually mimic a natural hydrograph, at least during parts of the year. This could, in turn, enhance long-term survival of *G. cypha* (but may conversely allow upriver movement of introduced fishes from Lake Mead; Minckley, 1991:146). In spite of such optimism, political and economic forces drive the system, even at the expense of cost efficiency (Leopold, 1991). These forces likewise impact indigenous fishes, and transform their conservation from the realm of science to that of politics.

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Appendix 1. Population estimates (= ESTIMATE) for *Gila cypha* in the Little Colorado River by reach and month, with standard deviation of the estimate (= S.D.), and 95% lower and upper confidence intervals (= L.CI; U.CI), and estimates relative to river km (= EST./RKM). TRIP=month/year; C=Confluence; P=Powell; S=Salt.

REACH	TRIP	ESTIMATE	S.D.	L.CI	U.CI	EST./RKM
C	07/91[d]	0	0	0	0	0
P	07/91	643	218	356	1264	113
S	07/91	4007	1521	2001	8315	581
C	08/91[a]	1034	366	552	2071	862
P	08/91[a]	939	123	738	1239	165
S	08/91[a]	3417	620	2430	4901	495
C	08/91[b]	276	56	192	434	230
P	08/91[b]	773	127	576	1084	136
S	08/91[b]	1936	231	1552	2480	281
C	09/91	175	48	109	326	146
P	09/91	205	73	115	426	36
S	09/91	1142	176	862	1583	166
C	10/91	40	14	23	97	33
P	10/91	176	35	124	275	31
S	10/91	4761	2747	1722	13744	690
C	11/91[e]	0	0	0	0	0
P	11/91	381	387	89	2042	67
S	11/91	1621	805	673	4134	235
C	12/91	68	15	48	108	57
P	12/91	339	322	85	5763	59
S	12/91	878	442	371	2283	127
C	01/92	509	506	119	2651	424
P	01/92	774	746	182	3872	136
S	01/92	1201	1199	263	6227	174
C	02/92	778	183	509	1249	648
P	02/92	880	470	368	3531	154
S	02/92	1323	1081	356	5467	192
C	03/92[a]	1944	728	1067	6240	1620
P	03/92[a]	1428	777	585	5720	251
S	03/92[ae]	0	0	0	0	0
C	03/92[b]	1173	440	602	2434	978
P	03/92[b]	2585	773	1491	4642	454
S	03/92[b]	1470	557	745	3067	213
C	04/92	653	118	471	964	544
P	04/92	2152	440	1486	3341	378
S	04/92	2878	508	2068	4091	417
C	05/92	1320	415	4738	944	1100
P	05/92	1050	703	362	6241	184
S	05/92	2232	880	1095	4769	323
C	06/92[c]	670	103	507	931	558

P	06/92[c]	1102	251	730	1741	193
S	06/92[c]	3082	552	2200	4402	447
C	07/92	140	46	82	302	117
P	07/92	487	141	295	932	85
S	07/92	768	220	459	2791	111
C	08/92	48	29	20	261	40
P	08/92	68	25	40	150	12
S	08/92	292	31	240	362	42
C	09/92	124	80	50	417	103
P	09/92[e]	0	0	0	0	0
S	09/92[e]	0	0	0	0	0
C	10/92	397	379	100	1976	331
P	10/92	588	324	236	1658	103
S	10/92	758	49	670	862	110
C	11/92	376	188	167	987	313
P	11/92	545	312	213	1592	96
S	11/92	270	30	221	337	39
C	12/92	0	0	0	0	0
P	12/92	0	0	0	0	0
S	12/92	0	0	0	0	0

[a] = Early month sampling
[b] = Late month sampling
[c] = In flood
[d] = No net set at confluence
[e] = No recaptures

Appendix 2. Population estimates for *Gila cypha* in the Little Colorado River by month (= TRIP), with standard deviation of the estimate (= S.D.), and 95% lower and upper confidence intervals (= L.CI; U.CI). Σ(Estimate) = monthly population estimates summed over the three reaches (data recorded in Appendix 1).

Trip	Estimate	S.D.	L.CI	U.CI	Σ(Estimate)
07/91[d]	2329	291	1842	2994	4650
08/91[a]	3157	381	2516	4021	5390
08/91[b]	2562	224	2172	3055	2985
09/91	1771	300	1296	2492	1522
10/91	2038	518	1276	3368	4977
11/91[d]	1989	489	1264	3235	2002
12/91	745	210	453	1309	1285
01/92[c]	2227	1251	839	6310	2484
02/92[c]	1831	381	1246	2771	2981
03/92[acd]	4380	1359	2459	8004	3372
03/92[bc]	2555	674	1568	4294	5228
04/92[c]	5555	671	4416	7067	5683
05/92[c]	4363	1216	2594	7523	4602
06/92	4384	458	3573	5381	4854
07/92[c]	1265	237	895	1888	1395
08/92[c]	635	184	381	1222	408
09/92[ce]	1950	1381	598	6908	124
10/92[c]	1099	60	990	1224	1743
11/92[c]	1417	408	839	2500	1191
12/92[c]	0	0	0	0	0

[a] = Early month sampling
[b] = Late month sampling
[c] = In flood
[d] = Summation for two of three reaches only
[e] = Summation for one of three reaches only

Table 1. Population estimates (number/ river km) of adult *Gila cypha* (> 150 mm TL) in three reaches of the Little Colorado River (Confluence, Powell, Salt) from July, 1991 through December, 1992. Estimates were adjusted before analysis for length of reach (in km). Log_{10} fishing effort was used as ANCOVA covariate. Diagonal elements represent average least squares population estimates (adjusted for log_{10} fishing effort), and have been converted from log_{10} values. Upper triangular cells represent F-values for pairwise a priori contrasts.

	CONFLUENCE	POWELL	SALT
CONFLUENCE	263	6.2[2]	0.2[3]
POWELL		110[1]	4.3[4]
SALT			222

[1] $F = 4.34$; $p < 0.019$; $df=3,48$
[2] $p < 0.016$
[3] $p > 0.657$
[4] $p < 0.044$

able 2. Population estimates generated under five different models (= MODEL) or adult *Gila cypha* within the Little Colorado River, from July 1991 through ecember 1992. Also provided are goodness-of-fit (= CRITERION), with standard eviation of the estimate (= S.D.), and 95% lower and upper confidence ntervals (= LOWER CI; UPPER CI). Models are defined in text.

MODEL	CRITERION	ESTIMATE	S.D.	LOWER CI	UPPER CI
Pollock & Otto (M_{bh})	0.61	4508	120	4330	4811
Null Model (M_o)	0.49	6793	110	6585	7017
Burnham's (M_{tb})	0.48	8724	920	7242	10901
Jackknife (M_h)	0.42	10444	329	9833	11121
Chao's (M_h)	0.42	8039	210	7648	8472

Table 3. Adult *Gila cypha* tagged in 1992 within one reach (= TAG REACH) of the Little Colorado River during a given season (= TAG SEASON), then recaptured during the same or a subsequent season (= RCP. SEASON) within the same or a subsequent reach (= CONFLUENCE, POWELL, SALT).

TAG REACH	TAG SEASON	RCP.SEASON	CONFLUENCE	POWELL	SALT	TOTAL
Confluence	Winter	Winter	23 (23.6%)	7 (07.3%)	0 (00.0%)	30 (30.9%)
		Spring	11 (11.5%)	18 (18.8%)	22 (22.9%)	51 (53.2%)
		Summer	7 (07.3%)	4 (04.2%)	2 (02.1%)	13 (13.6%)
		Autumn	0 (00.0%)	0 (00.0%)	2 (02.1%)	2 (02.1%)
Confluence	Spring	Spring	56 (29.6%)	41 (21.7%)	20 (10.6%)	117 (61.9%)
		Summer	28 (14.8%)	14 (07.4%)	21 (11.1%)	63 (33.3%)
		Autumn	4 (02.1%)	3 (01.6%)	0 (00.0%)	7 (03.7%)
		Winter	1 (00.5%)	0 (00.0%)	1 (00.5%)	2 (01.0%)
Confluence	Summer	Summer	50 (70.4%)	5 (07.1%)	5 (07.1%)	60 (84.6%)
		Autumn	4 (05.6%)	4 (05.6%)	1 (01.4%)	9 (12.6%)
		Winter	0 (00.0%)	2 (02.8%)	0 (00.0%)	2 (02.8%)
Confluence	Autumn	Autumn	7 (53.5%)	1 (07.7%)	0 (00.0%)	7 (61.2%)
		Winter	3 (23.1%)	1 (07.7%)	1 (07.7%)	5 (38.5%)
Powell	Winter	Winter	2 (05.3%)	8 (21.1%)	1 (02.6%)	11 (29.0%)
		Spring	2 (05.3%)	12 (31.6%)	6 (15.8%)	20 (52.7%)
		Summer	4 (10.5%)	2 (05.3%)	0 (00.0%)	6 (15.8%)
		Autumn	0 (00.0%)	1 (02.6%)	0 (00.0%)	1 (02.6%)

Powell	Spring	Spring	4 (02.1%)	54 (28.0%)	37 (19.2%)	95 (49.3%)
		Summer	23 (11.9%)	37 (19.2%)	22 (11.4%)	82 (42.5%)
		Autumn	2 (01.0%)	6 (03.1%)	4 (02.1%)	12 (06.2%)
		Winter	1 (00.5%)	2 (01.0%)	1 (00.5%)	4 (02.0%)
Powell	Summer	Summer	8 (07.8%)	59 (57.3%)	6 (05.8%)	73 (70.9%)
		Autumn	5 (04.9%)	17 (16.5%)	1 (01.0%)	23 (22.4%)
		Winter	2 (01.9%)	4 (03.9%)	1 (01.0%)	7 (06.8%)
Powell	Autumn	Autumn	1 (04.5%)	16 (72.7%)	1 (04.5%)	17 (77.2%)
		Winter	0 (00.0%)	4 (18.2%)	0 (00.0%)	4 (18.2%)
Salt	Winter	Winter	0 (00.0%)	1 (01.7%)	9 (15.0%)	10 (16.7%)
		Spring	1 (01.7%)	0 (00.0%)	21 (35.0%)	22 (36.7%)
		Summer	0 (00.0%)	0 (00.0%)	21 (35.0%)	21 (35.0%)
		Autumn	0 (00.0%)	1 (01.7%)	6 (10.0%)	7 (11.7%)
Salt	Spring	Spring	2 (01.0%)	1 (00.5%)	64 (31.1%)	67 (32.6%)
		Summer	11 (05.3%)	7 (03.4%)	81 (39.3%)	99 (48.0%)
		Autumn	3 (01.5%)	0 (00.0%)	19 (09.2%)	22 (10.7%)
		Winter	4 (01.9%)	5 (02.4%)	9 (04.4%)	18 (08.7%)
Salt	Summer	Summer	3 (01.8%)	7 (04.1%)	92 (53.8%)	102 (59.7%)
		Autumn	0 (00.0%)	0 (00.0%)	54 (31.6%)	54 (31.6%)
		Winter	1 (00.6%)	1 (00.6%)	13 (07.6%)	15 (08.6%)
Salt	Autumn	Autumn	1 (03.7%)	0 (00.0%)	16 (59.3%)	17 (63.0%)
		Winter	1 (03.7%)	1 (03.7%)	8 (29.6%)	10 (37.0%)

Table 4. Movement (as determined by tag/recapture) of individual *Gila cypha* between three reaches of the Little Colorado River during each of 18 different sampling trips of 1991/92. (Trip = month/year; N = Total Number; C = Confluence; P = Powell; S = Salt; Tot. UP = Total recaptured upstream; Tot. DN = Total recaptured downstream).

Trip	N	C-to-P	C-to-S	P-to-S	S-to-P	S-to-C	P-to-C	Tot.UP	Tot.DN
07/91	500	0	0	0	0	0	0	0	0
08/91[a]	955	2	0	0	9	3	0	2	12
08/91[b]	794	5	0	0	1	1	3	5	5
09/91	376	2	0	2	0	1	3	4	4
10/91	255	1	0	0	0	0	1	1	1
11/91	254	0	0	1	0	0	0	1	0
12/91	138	0	0	0	0	1	0	0	1
TOTAL	3272	10	0	3	10	6	7	13	23
01/92	125	0	0	0	0	0	0	0	0
02/92	299	1	0	0	0	0	0	1	0
03/92[a]	292	0	0	0	0	0	0	0	0
03/92[b]	275	0	0	0	0	0	0	0	0
04/92	933	0	0	0	0	0	0	0	0
05/92	341	0	0	0	0	0	0	0	0
06/92	841	0	0	0	0	0	0	0	0
07/92	258	0	0	0	0	0	0	0	0
08/92	115	0	0	0	0	0	0	0	0
09/92	90	0	0	0	0	0	0	0	0
10/92	278	0	0	0	0	0	0	0	0
11/92	183	0	0	0	0	0	0	0	0
TOTAL	4030	1	0	0	0	0	0	1	0

[a] = Early month sampling
[b] = Late month sampling

able 5. Population estimates for adult Gila cypha in the Little Colorado River, based upon previous and current research (Confl. = confluence area; All = entire LCR).

EAR	MONTH	AREA	METHOD	ESTIMATE	RESEARCHER(S)
1982	May	All	Multiple Census	7-8,000	Kaeding and Zimmerman[1]
1987	May	Confl.	-	5,783	C. O. Minckley[2]
1987	May	Confl.	Multiple Census	1,800	Kubly[3]
1988	May	Confl.	-	7,060	C. O. Minckley[2]
1988	May	Confl.	Multiple Census	2,900	Kubly[3]
1989	May	All	Multiple Census	25,000	Kubly[3]
1992	May	Confl.	Multiple Census	1,320	Douglas and Marsh[4]
1992	May	All	Multiple Census	4,346	Douglas and Marsh[4]
1992	May	All	Multiple Census	4,602	Douglas and Marsh[5]

. R. Kaeding and M. A. Zimmerman, USFWS Final Report, 1982, unpubl. (Special Collections, Hayden Library, Arizona State University, Tempe).
. O. Minckley, AZ/NM Chapter, Amer. Fish. Soc. Proc., 1989, unpubl. (Special Collections, Hayden Library, Arizona State University, Tempe).
. M. Kubly, Bureau of Reclamation Draft Report, 1990, unpubl. (Special Collections, Hayden Library, Arizona State University, Tempe).
ppendix I.
ppendix II.

FIGURE LEGENDS

Figure 1a: Adult female humpback chub (*Gila cypha*) captured by trammel net at confluence of Little Colorado and mainstream Colorado rivers (Grand Canyon National Park, Coconino Co., AZ).

Figure 1b : Adult male humpback chub (*Gila cypha*) captured by hoop net in Little Colorado River near Salt Trail Camp, 12.8 km above confluence (Navajo Indian Reservation, Coconino Co., AZ).

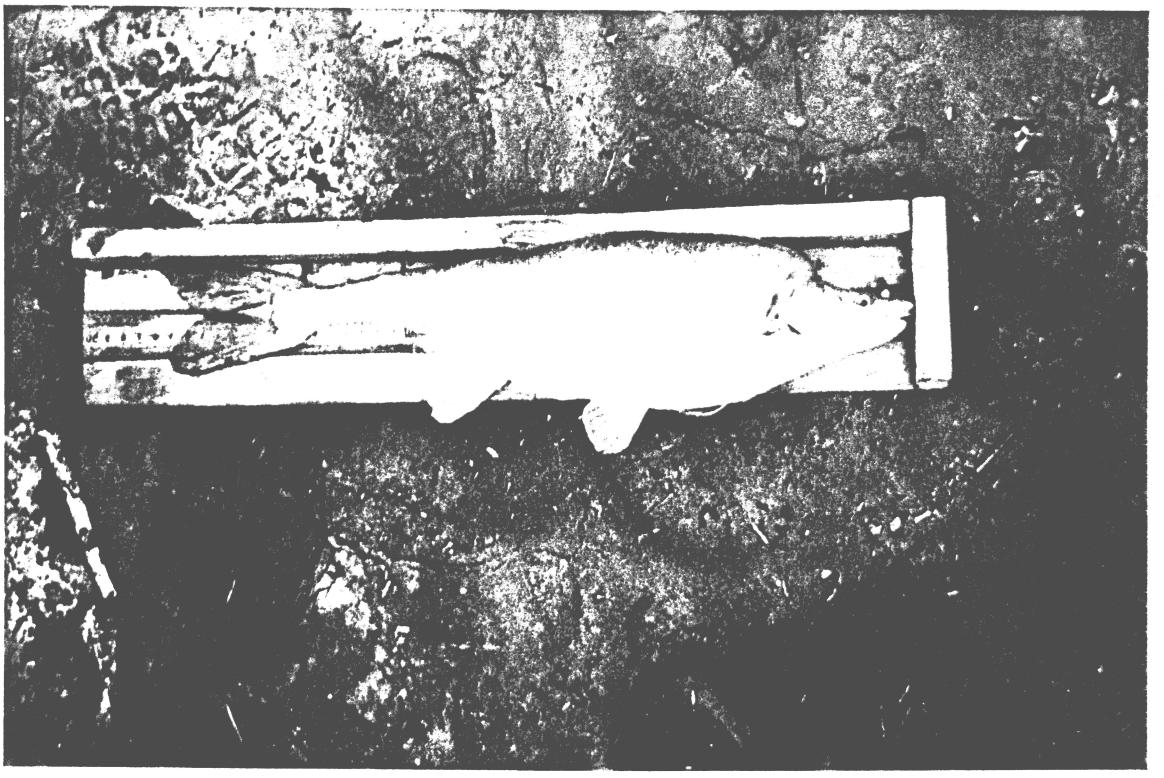
Figure 2a : Map of the Colorado River basin, depicting dams, reservoirs, and component rivers.

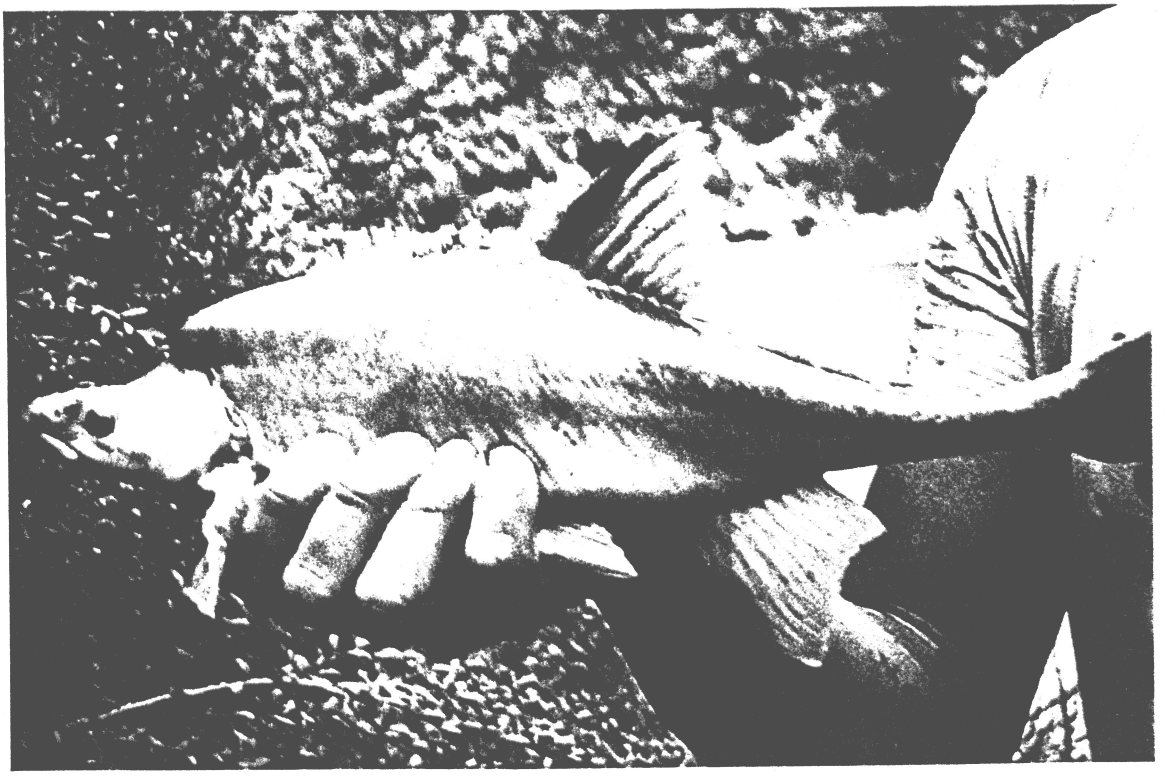
Figure 2b: Map of the lower Little Colorado River, from Blue Springs (21 km above confluence; Navajo Indian Reservation, Coconino Co., AZ) to its confluence with the Colorado River in Marble Canyon (Grand Canyon National Park, Coconino Co., AZ). Confluence is 99 km below Glen Canyon dam.

Figure 3a: Three-dimensional plot of population estimates by reach (where C = Confluence; P = Powell; and S = Salt) during July--December of 1991.

Figure 3b: Three-dimensional plot of population estimates by reach (where C = Confluence; P = Powell; and S = Salt) during January--November of 1992.

Figure 4: Bivariate plot of population estimates for 1991--92 by month (solid line) and by month summed over reach (dashed line).





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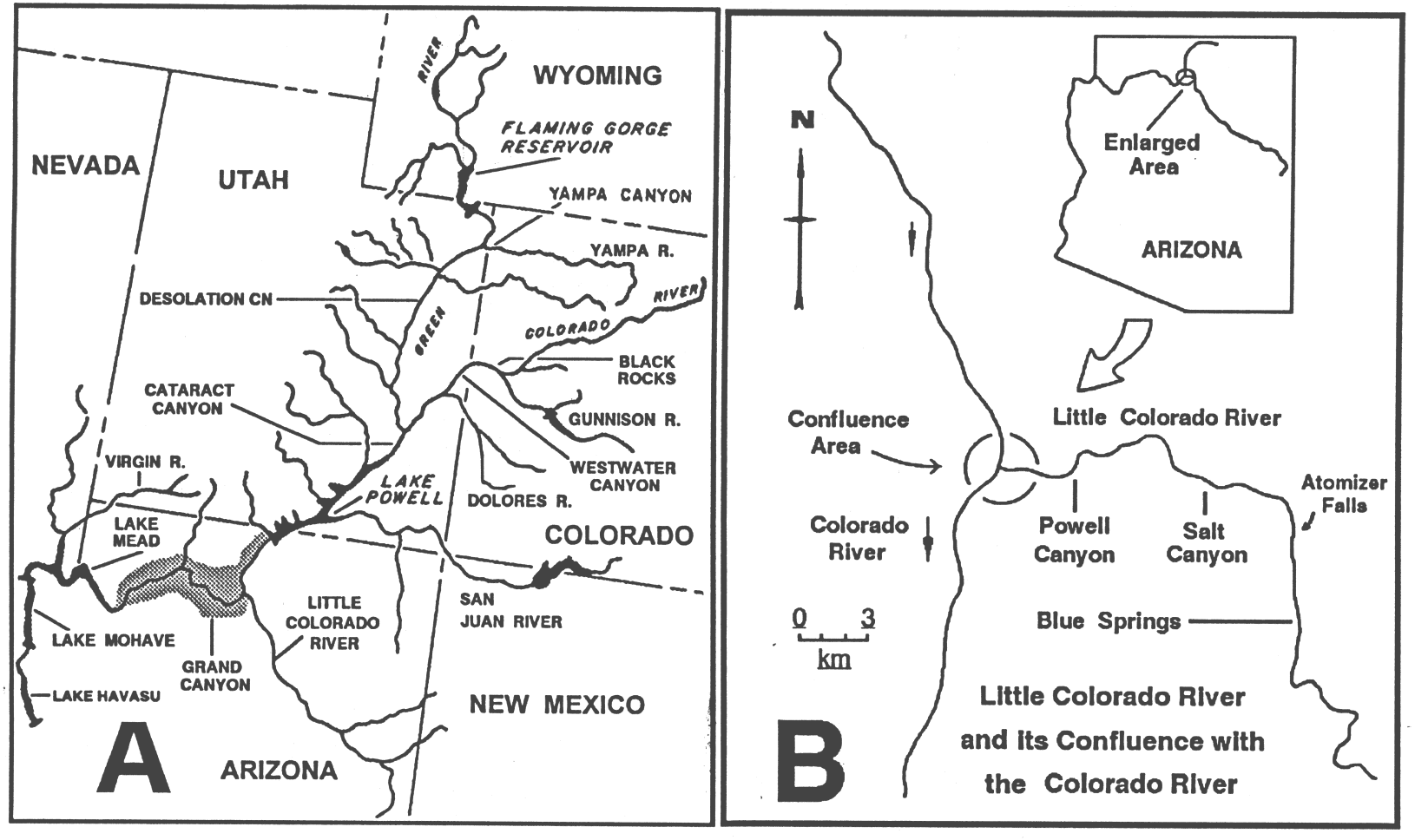

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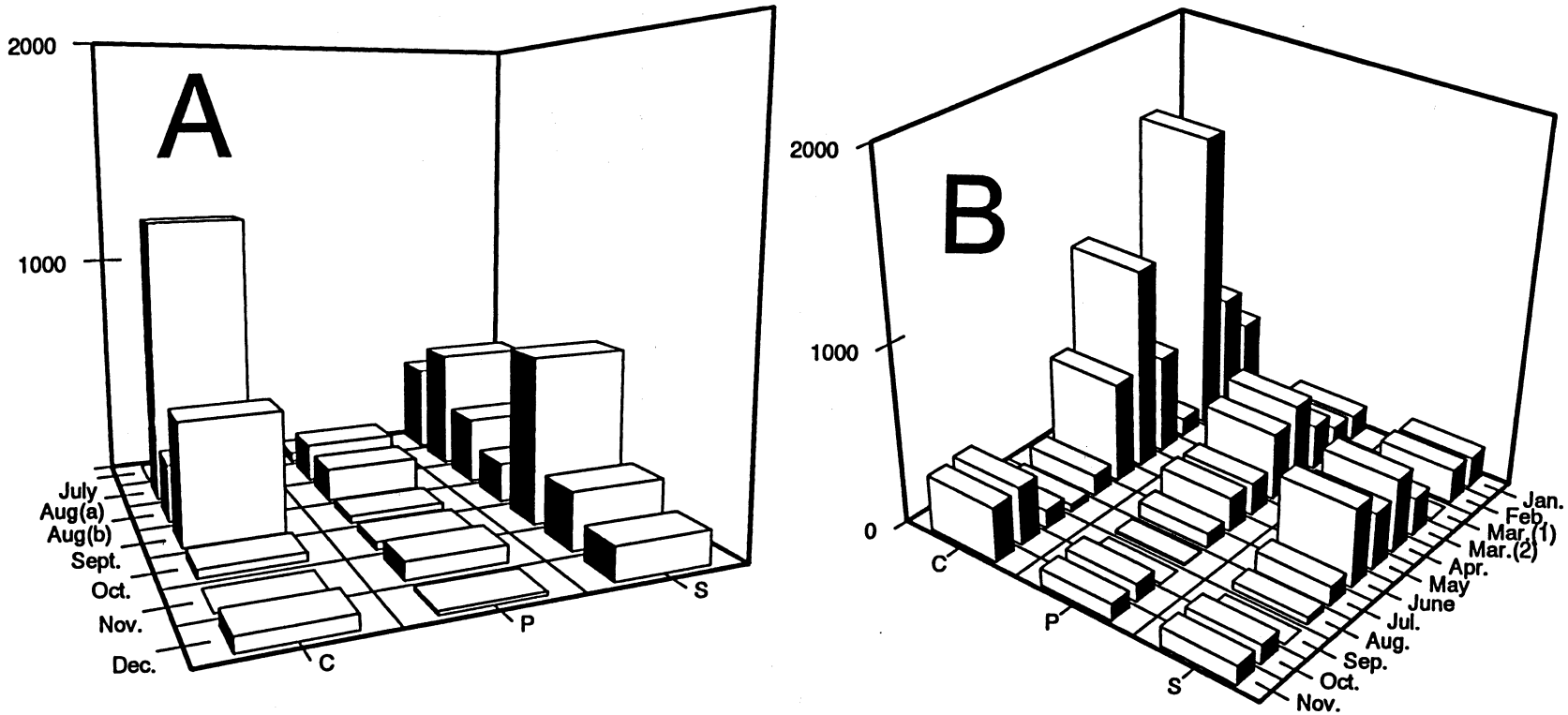

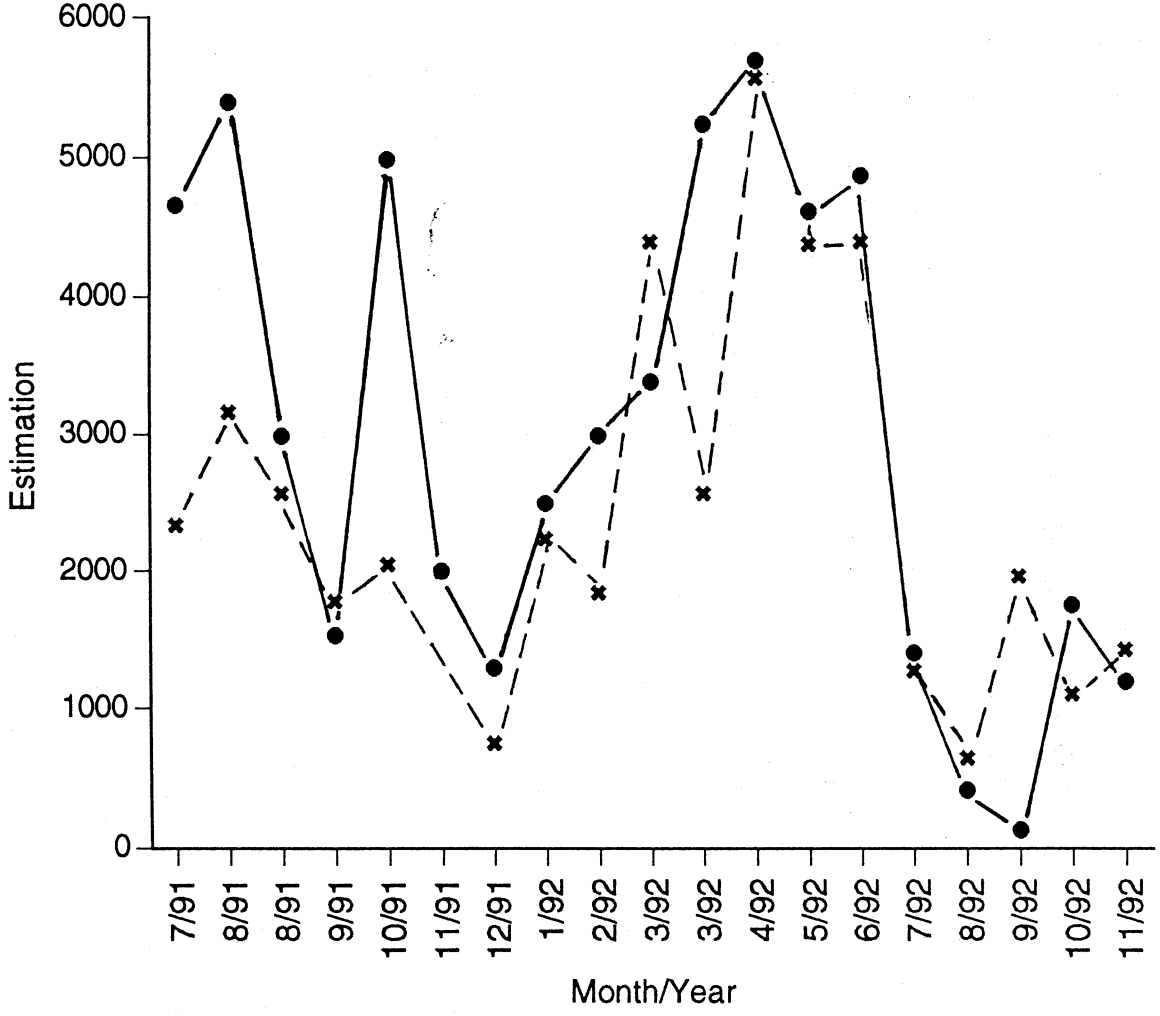
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SECTION 2:

ENDANGERED HUMPBACK CHUB, *GILA CYPHA*, AS PREY OF INDRODUCED FISHES IN THE LITTLE COLORADO RIVER, ARIZONA, WITH NOTES ON FISH STOCKING IN THE GRAND CANYON REGION

ABSTRACT

Endangered humpback chub and other native fishes were minor dietary components (3.2% of 190 stomachs) of five predatory non-native fishes from the Little Colorado River, Arizona. Stomach contents varied among species, were low in diversity, and predominated by detritus, algae (primarily Cladophora), and aquatic insects. Twentyone introduced species occur in Grand Canyon, and more than 25.8 million fish have been stocked there and in reservoirs immediately up- and downstream. Interaction between non-native and native fishes (predation, resource competition, displacement) may consitute a significant impact on the latter.

INTRODUCTION

Interactions between native and introduced species have been implicated in extirpations of indigenous fishes around the globe (reviewed in Courtenay and Stauffer 1984, Welcomme 1988, Pollard 1989, and Rosenfield and Mann 1992). Some mechanisms of direct interaction (e.g., displacement through resource competition) are elusive and difficult to demonstrate convincingly (Douglas et al., 1994), while others such as hybridization or predation may be more easily quantified. Among examples of the last are catastrophic destruction of perhaps hundreds of endemic species in lakes Victoria and Kyoga, Africa, by Nile perch, Lates niloticus (Ogutu-Ohwayo 1985, Barel et al. 1985, Ribbink 1987); elimination of seven local species from Gatun Lake, Panama, by tucanare, Cichla ocellaris (Zaret and Paine 1973); reduction of native salmonids in Lake Ohrid, Yugoslavia, by rainbow trout, Oncorhynchus mykiss (Nijssen and de Groot 1974); and elimination of Galaxias divergens and G. argenteus from New Zealand streams into which brown trout, Salmo trutta, had been introduced (McDowall 1984).

Native fishes of the Colorado River basin of western North America have been impacted similarly. Here an historically depauperate ichthyofauna of 36 species (many polytypic) has been subjected to interactions imposed by a suite of approximately 70 non-native fishes brought intentionally or inadvertently to the region. Coincident with introductions and habitat alteration resulting from development of water resources, the native fauna declined precipitously. Three native kinds are extinct, 22 others are listed as endangered or threatened, and the remainder (with few exceptions) is inarguably imperiled by continuing threats. Predation and competition by introduced fishes has been cited among primary factors resulting in the present faunal status (Dill 1944, Miller 1946, 1961; Moyle et al. 1986, Minckley and Deacon 1968, 1991), but only recently have become a focus of conservation planning in behalf of the native resources. Despite this awareness, management entities have been unwilling with few local exceptions to implement measures to reduce or eliminate predatory and competitive introduced fishes to benefit natives.

In this paper we focus on predation as a mechanism of interaction between endangered native humpback chub, Gila cypha (Cyprinidae), and introduced channel catfish, Ictalurus punctatus (Ictaluridae), in the Little Colorado River, Arizona. Humpback chub is concentrated in that stream (Douglas and Marsh, 1995), and channel catfish is the most abundant co-occurring non-native predator in the system.

The humpback chub is a moderate-sized minnow endemic to larger streams of the Colorado River basin. The species historically was found in canyon-bound reaches of mainstreams and

major tributaries from near Black Canyon, Arizona-Nevada, upstream into Colorado, Utah, and Wyoming. It was generally uncommon, but locally concentrated (Holden and Minckley 1980). A combination of factors including habitat loss and modification, hybridization with congeners, and potential interactions with non-native fishes has resulted in constricted range and local depletion of humpback chub, which persists only in seven reaches among four rivers (USFWS 1990). The largest remaining population is in the Little Colorado River, the major tributary to the Colorado River in Grand Canyon; it also occurs in fewer numbers in the mainstem. Humpback chub has been federally listed as endangered since 1967.

Channel catfish has been introduced worldwide from its native range in central drainages of United States and southern Canada (Glodek 1980, Welcomme 1988). It was first stocked in the lower Colorado River in 1892-93 (Miller and Alcorn 1945), and since planted elsewhere or dispersed to become ubiquitous. Historically valuable as a food fish, it now supports commercial and recreational fisheries of variable importance throughout its range. This opportunistic omnivore also represents, however, a potential threat to indigenous organisms occupying habitats in which the catfish is exotic, and may represent a deterrent to recovery for some imperiled species (Marsh and Brooks 1988). Channel catfish have been present in Grand Canyon for most of this century (USFWS 1980), and was a predominant species prior to closure of Glen Canyon Dam in 1963 (Smith 1959). Recent records indicate rarity to local abundance in the mainstem (Holden and Stalnaker 1975, Arizona Game and Fish Department, and Bio/West, Inc., unpublished); it is common in the Little Colorado River (P. C. Marsh and M. E. Douglas, unpubl.).

Predation by channel catfish on humpback chub is suggested by crescent-shaped wounds interpreted as bite marks (Kaeding and Zimmerman 1983, Karp and Tyus 1990), and documented from stomachs of channel catfish captured in hoop nets (C.O. Minckley, USFWS, pers. comm.); such predation has not been quantified.

A suite of other non-native fishes (APPENDIX A) has been introduced into the Colorado River for food, sport, forage, or by accident. Many have established self-sustaining populations and naturally expanded their ranges, while others are repeatedly stocked to sustain angler harvest (APPENDIX B). These stockings are conducted by the same agencies charged with protection and recovery of imperiled native fishes. Potential predators in addition to channel catfish encountered in or near the Little Colorado River include brown trout, *Salmo trutta*; black bullhead, *Ameiurus melas*, yellow bullhead, *A. natalis*, striped bass, *Morone saxatilis* (all uncommon); and rainbow trout, *Oncorhynchus mykiss* (common). There are no published reports of humpback chub among prey of these species.

We report results of stomach analyses from predatory non-native fishes captured in the Little Colorado River during 1991-1992, and provide an assessment of the potential impact of this predation on endangered humpback chub. We also examine other potential mechanisms of interaction between native and introduced fishes, and record the history of fish non-native stocking in the Grand Canyon region.

STUDY SITE AND METHODS

The Little Colorado River headwaters are in mountainous highlands of east-central Arizona and western New Mexico, from where flow infiltrates underground during most months and does not reach Grand Canyon except during flood conditions. Perennial flow (ca. 6.2 $m^3 s^{-1}$) in the Grand Canyon reach originates in a series of springs beginning at Blue Spring, about 21 km upstream from the Little Colorado-Colorado confluence, augmented downstream by smaller sources. The Little Colorado River at base flow is a saline (conductivity exceeding 5,000 umhos/cm), travertine-forming stream whose water chemistry changes downstream as a result of CO_2 degassing and carbonate degassing (Cole and Kubly 1976); its complex limnology is not well understood. Water clarity scarcely approaches a meter due to suspended carbonates, and is nil during even minor spates as a result of suspended sediments. During our studies, discharge ranged from base flow to approximately 425 $m^3 s^{-1}$, and water temperature was 8 to 25 C.

Native fishes of the Little Colorado River in Grand Canyon include humpback chub, bonytail (Gila elegans, extirpated), roundtail chub (G. robusta, extirpated), Colorado squawfish (Ptychocheilus lucius, extirpated), speckled dace (Rhinichthys osculus), and flannelmouth (Catostomus latipinnis), bluehead (Pantosteus discobolus) and razorback (Xyrauchen texanus) suckers. All species that persist are common, with exception of razorback sucker, which is rare.

Non-native fishes include brown and rainbow trouts, carp (Cyprinus carpio), fathead minnow (Pimephales promelas), channel catfish and black and yellow bullheads, plains killifish (Fundulus zebrinus), green sunfish (Lepomis cyanellus) and striped bass. Other species have been introduced or otherwise recorded in tributaries and/or up- and downstream in Grand Canyon (APPENDIX A; Minckley 1991), but none has yet been found in the Little Colorado River.

We established camps at Salt Canyon (river km 10.6 [RK, measured upstream from the Colorado confluence), Powell Canyon (RK 3.0) and near the Colorado confluence (RK 0.6), which allowed access to the 21-km of perennial flow in the Little Colorado River. A series of precipitous (to 3 m) travertine falls at RK

15 marks the upstream limit of distribution of humpback chub in the Little Colorado River; only carp, speckled dace, fathead minnow, and rainbow trout were found above this point. Sampling above this reach thus was limited to short-term survey-type collections in summer.

Fishes were captured during 19 trips at approximately monthly intervals from July 1991 to December 1992. Hoop nets (0.76 or 1.2 m dia, 2.4 or 3.0 m-length, 4 or 6 hoop, single or double throat) were deployed in all available habitat types of sufficient depth (> about 0.4 m). Trammel nets (7.6 to 45.7 m length, 1.8 m depth, 1.3 to 3.8 mm inner and 30 mm outer meshes) were set routinely in the Little Colorado-Colorado confluence area and occasionally near Powell and Salt canyons (below) in water deeper than about 0.5 m. Angling with baited hooks and artificial lures was performed sporadically throughout the stream.

All fishes were removed from capture devices, identified, counted, measured (TL to nearest mm), and weighed (nearest g). Native species were released near the point of capture after processing. Non-native fishes typically were scanned for presence of PIT tags (which could be present if tagged native fishes were consumed), then sacrificed and either dissected immediately and examined for stomach contents, or preserved in 95% ethanol for later study (the latter primarily of specimens < 100 mm TL). The entire digestive tract was examined and foods determined categorically. Fish prey were examined to determine identity and TL. Material returned to the laboratory was examined microscopically for larval fishes.

Results and Discussion

Predation by Introduced Fishes.--Identifiable humpback chub remains were in six (3.2%) of 190 total digestive tracts among three of five predator species examined (Table 2.1). Other fishes (speckled dace, bluehead and flannelmouth suckers and undetermined remains) were found in stomachs of a dozen predators, and co-occurred with humpback chub in two of those. Measurable humpback chubs in stomachs overall averaged 132 mm TL (n = 11), which did not differ statistically (two sample t-test, Snedecor and Cochran 1967) from mean TL of other ingested fishes (134 mm, n = 8). No larval or small post-larval fishes were found in any predator stomachs. Sample sizes for brown trout and the two bullhead catfishes were too small (3 to 5) to provide definitive results.

One of 44 rainbow trout contained an individual humpback chub (prey length not determined), and one of five black

bullheads also contained an individual chub (49 mm TL). Two other rainbow trout had eaten undetermined fish(es). Speckled dace and undetermined fish(es) were consumed by two of five brown trout, and no fish remains were detected in three yellow bullheads.

Four of 133 channel catfish each contained one to five chubs, which measured 120 to 158 mm TL; remains of other species were in eight stomachs. Channel catfish that consumed humpback chub and other fishes were among the largest individuals captured, and averaged more than twice the length of the overall sample for the species (mean TL 473 vs 233 mm, respectively).

Algae (primarily Cladophora) predominated in rainbow trout (32%), and fish were the most abundant prey item in brown trout (20%) (Table 2.2). Channel catfish consumed a variety of items, predominated by undetermined insects (13%) and algae (10%). Yellow bullheads contained only fish and detritus (20% each), and black bullheads contained only the latter (Table 2.2). Proportion of empty stomachs was similar (52 to 69%) for all species.

Food habits of potential piscivores were unremarkable. The relatively low diversity of food items (10, if fishes are considered collectively) likely reflected a paucity of resources in the Little Colorado River. Foods utilized by individual species were qualitatively consistent with other reports from the Colorado River basin (AZGFD 1987, Marsh 1981, Minckley 1973, 1982, Tyus and Nikirk 1990) and elsewhere (reviewed in part by Calhoun 1966). All studies concluded that channel catfish were opportunistic omnivores, with fishes comprising a small proportion of their diet.

Although representing a constant threat, our data suggest that predatory fishes presently do not exert a major impact to at least juvenile and adult humpback chub in the Little Colorado River. This likely is due to a combination of visual impairment of sight feeders in the frequently turbid waters (trouts), low predator abundance (brown trout and bullhead catfishes), potential occupation of distinct habitats by predator and prey (channel catfish and humpback chub, respectively; but see Karp and Tyus 1990), and availability of alternate foods (especially speckled dace, the most abundant fish in the system). Although channel catfish were common, their piscivory was low and only individuals larger than about 300 mm consumed fishes. Our sampling methods by design were biased for collection of larger (> 150 mm TL) fishes of all species, yet channel catfish of a piscivorous size composed less than a third of the sample. Population densities of non-native fishes in the Little Colorado River may be mediated in part by the natural flooding regime that characterizes the stream, and which has been shown in other places to favor native over non-native species (Minckley and

Meffe 1987).

Temperature Effects and Fate in the Colorado River.--Fates of fishes moving from the relatively warm Little Colorado River into the cold mainstream is unknown. However, coldwater predators (non-native salmonids) concentrated near the tributary mouth might prey opportunistically on young moving into the Colorado River. Thermal shock (up to 15 C during warmer summer months) should impair swimming and predator avoidance capabilities of entrained individuals (Coutant 1973, Coutant et al. 1974), and could be lethal (Brett 1965, Emery 1970). Such impacts would be particularly severe on larvae (Graham 1949), which drift from the Little Colorado into the mainstream (Arizona Game and Fish Dept., unpubl.). Further, perennially depressed temperature in the mainstream would retard growth of warmwater native fishes (Fry 1947), which thus would remain at predator-vulnerable size for an extended time.

Non-native Fishes and Stocking in the Grand Canyon.--Twenty introduced non-native species are known from the Colorado River in Grand Canyon (APPENDIX A). Rainbow, cutthroat, brook, and brown trouts, carp, and channel catfish were present prior to downstream closure of Boulder (Hoover) Dam in 1935 and filling of Lake Mead. Salmonids were stocked directly into Grand Canyon beginning in the 1920s (APPENDIX B). A suite of warm- and coldwater sport (salmonids and centrarchids, plus striped bass) and forage species was stocked to establish recreational fisheries in Lake Mead, and these had access to lower Grand Canyon. Fathead minnow and plains killifish were first found in Grand Canyon between 1935 and 1963. Glen Canyon Dam was completed upstream in 1963, and sport-forage fish introductions to Lake Powell and the tailwaters in Glen Canyon (Lees Ferry reach) began immediately (APPENDIX B). Smallmouth bass was first stocked into Lake Powell in 1982, and a proposal to introduce rainbow smelt (Osmeriae: Osmerus mordax) has recently been entertained. Other, new species undoubtedly will be considered in the future.

Numbers of individuals introduced (nearly 26 million) are staggering, even when spread over a period of years. More than 900,000 salmonids were stocked in Grand Canyon between 1920 and 1978, and 2.6 million have been planted in Glen Canyon since 1964. Nearly 2.5 million fish were stocked in Lake Mead (beginning in 1935) and 19.8 million have been stocked into Lake Powell since 1963. Introductions to all but Grand Canyon continue apace.

CONCLUSION

Native Colorado River fishes that persist in Grand Canyon

are common only in tributaries, and populations in the mainstream are small and/or concentrated near tributary or spring mouths. Their virtual exclusion from the main channel is due to a combination of factors that include interaction with abundant non-natives, and cold temperatures that may exacerbate predation impacts and preclude successful life cycle completion. Established or continually replenished stocks of predatory fishes in the main stream must certainly impose severe constraints on native fishes by predation on young. Conditions in some tributaties like the Little Colorado River remain relatively unaltered by human development, and, although occupied by non-native fishes, these streams apparently retain enough natural characteristics (particularly hydrologic features) to favor natives relative to non-natives. In these places, predation at least on juveniles and adults does not appear excessive, although impacts on earlier life stages are unknown and may certainly affect recruitment.

ACKNOWLEDGMENTS

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TABLE 2.1: Prey fishes in stomachs of piscivorus non-native fishes captured in the Little Colorado River, Arizona, July 1991-December 1992. Some prey were in states of digestion that rendered species identification and/or measurement impractical (indicated by nd).

Piscivore		Prey Fishes in Stomach		
Species	TL (mm)	Species	N	TL (mm)
Rainbow trout	342	undet	---	parts
	395	undet	3	
100,100,100				
	398	humpback chub	1	undet
Brown trout	341	speckled dace	1	77
	566	undet	1	undet
Channel catfish only	281	undet	1	scales
	325	undet	1	75
	366	speckled dace	1	75
		undet	1	58
	412	undet	1	74
	490	humpback chub	1	130
	504	humpback chub	1	158
	555	undet	1	100
	594	humpback chub	3	
120,140,200				
		speckled dace	3	undet
		flannelmouth sucker	1	200
	595	humpback chub	5	
125,125,125, 140,140				
		undet	1	150
	605	bluehead sucker	1	250
Black bullhead	134	humpback chub	1	49

TABLE 2.2: Frequency of occurrence of food items as percentage of total stomachs examined for each of five species of predatory non-native fishes collected in the Little Colorado River, Arizona, July 1991-December 1992.

Food item	Rainbow trout	Brown trout	Channel catfish	Black bullhead	Yellow bullhead
Detritus	0	0	5	20	33
Vegetation	7	0	5	0	0
Algae[a]	32	0	10	0	0
Gammarus	2	0	3	0	0
Corydalidae	2	0	3	0	0
Simuliidae	1	0	0	0	0
Chironomidae	9	0	0	0	0
Undet aquatic insects	0	0	13	0	0
Terrestrial insects	2	4	4	0	0
Humpback chub	2	0	3	20	0
Speckled dace	0	20	2	0	0
Bluehead sucker	0	0	1	0	0
Flannelmouth sucker	0	0	1	0	0
Undet fishes	5	20	5	0	0
Fish eggs	0	20	0	0	0
Number of stomachs	44	5	133	5	3
Percentage empty	52	60	69	60	67
TL mean	369	450	233	147	165
range	273-447	341-566	37-666	93-228	120-206

[a]Primarily *Cladophora*

APPENDIX A. Dates of first introductions to the Colorado River basin of non-native fishes known from Grand Canyon, Arizona. Compiled from USFWS (1980), Minckley (1991), and authorities indicated. Acronyms as follows: AZGFD (Arizona Game and Fish Department), NVDOW (Nevada Department of Wildlife), and UTDRW (Utah Division of Wildlife Resources).

Species	Date(s)	Location	Authority
CLUPEIDAE			
Dorosoma petenense	1953	Lake Mead	LaRivers 1962
SALMONIDAE[a]			
Oncorhynchus clarki	1962	Lake Mohave	NVDOW files
O. kisutch	1966	below Davis Dam	NVDOW files
O. mykiss	1922	Grand Canyon	Williamson and Tyler 1932
Salmo trutta	1924	Grand Canyon	ibid
Salvelinus fontinalis	1920	Grand Canyon	ibid
CYPRINIDAE			
Cyprinus carpio	1890	lower river	Gilbert and Scofield 1898
Cyprinella lutrensis	<1953	lower river	Shapovalov and Dill 1959
Notemigonus crysoleucas	<1953	lower river	ibid
Pimephales promelas	1950s	lower river	Miller and Lowe 1967
Richardsonius balteatus	1950	lower river	Miller 1952
ICTALURIDAE			
Ameiurus melas	1904	lower river	AZGFD 1977
A. natalis	1899	lower river	Beland 1954
Ictalurus punctatus	1892-93	lower river	Miller and Alcorn 1945
FUNDULIDAE			
Fundulus zebrinus	1950	lower river	Miller 1952
POECILIIDAE			
Gambusia affinis	1922	California	Dill 1944

CENTRARCHIDAE			
Lepomis cyanellus	1937-42	lower river	Jonez and Sumner 1954
L. macrochirus	1937	Lake Mead	Wallis 1951
Micropterus salmoides	1890	Utah	Sigler and Miller 1963
	1935	Lake Mead	Jonez and Sumner 1954
PERCIDAE			
Stizostedion vitreum[b]	1951	Utah	Sigler and Miller 1963
PERCICHTHYIDAE			
Morone saxatilis	1959	lower river	St. Amant 1959

[a]Oncorhynchus apache, endemic to headwaters of the Salt and Little Colorado rivers (Colorado River drainage), Arizona, was transplanted by AZGFD in 1963, 1968, and 1978 to North Canyon Creek, a Colorado River tributary in Grand Canyon (Minckley and Brooks 1985). A population persists there, but the species has not otherwise been recorded in Grand Canyon.

[b]Walleye was present in the Colorado River in Utah prior to closure of Glen Canyon Dam in 1963, and later became established in the reservoir (UTDWR, unpublished). An individual was captured in 1971 at Lees Ferry, Arizona (AZGFD, unpublished), but the species has not since been encountered in Grand Canyon.

APPENDIX B. Non-native fish stocking in the Colorado River from Lake Powell, Arizona-Utah, to Hoover (Boulder) dam site, Arizona-Nevada, including the Grand Canyon reach, through 1991. Compiled from Williamson and Tyler 1924, Miller and Alcorn 1953, Jonez and Sumner 1953, AZGFD 1977, Allan and Roden 1978, USFWS 1980, and agency files. Acronyms for stocking agency as follows: AZFC (Arizona Fish Commission), AZGFD (Arizona Game and Fish Department), NPS (National Park Service, Grand Canyon National Park), NVDOW (Nevada Department of Wildlife), UTDWR (Utah Division of Wildlife Resources), USFC (U.S. Fish Commission), USFS (U.S. Forest Service), and USFWS (U.S. Fish and Wildlife Service, including when named Bureau of Sport Fisheries and Wildlife). Stockings were variously of embryos, larvae, juveniles, and adults (not differentiated here). Four localities are indicated, up- to downstream: Powell (Lake Powell), Glen (Glen Canyon dam site downstream to Lees Ferry), Grand Canyon (Lees Ferry downstream to Separation Canyon), and Mead (Separation Canyon downstream to site of Hoover [Boulder] Dam).

Species	Date(s)	Number	Agency	Locality
Dorosoma petenense	1968-69	201500	UTDWR	Powell
	1954-55	11650	NVDOW	Mead
Oncorhynchus kisutch	1969-72	20000	AZGFD	Glen
	1969-73	426151	AZGFD	Mead
			NVDOW	
O. nerka	1963-65	660000	AZGFD	Powell
			UTDWR	
O. mykiss	1963-80	15688501	AZGFD	Powell
			UTDWR	
	1964-91	1924489	AZGFD	Glen
			USFWS	
	1922-63	461800	AZGFD	Grand Canyon
			NPS	
			USFS	
			USFWS	
	1944-91	3336600	AZGFD	Mead

			NVDOW USFWS	
O. clarki	1925-78	>60000	AZGFD	Grand Canyon
	1978-80	60857	AZGFD	Glen
	1972-77	200996	NVDOW	Mead
O. mykiss x O. clarki	1975-77	96176	NVDOW	Mead
Salmo trutta	1924-78	295000	AZGFD NPS	Grand Canyon
	1978-80	78818	NVDOW	Mead
Salvelinus fontinalis	1977-87	606009	AZGFD	Glen
	1920-31	90000	NPS	Grand Canyon
Cyprinus carpio	1881-91	unknown	AZFC USFC	Mead
Micropterus dolomieui	1982-88	272672	UTDWR	Powell
Micropterus salmoides	1963-64	2924000	UTDWR	Powell
	1935-81	794929	AZGFD NVDOW USFWS	Mead
Lepomis macrochirus	1937-42	952770	USFWS	Mead
Pomoxis nigromaculatus	1964-91	51021	AZGFD UTDWR	Powell
Morone saxatilis	1974-79	815318	UTDWR	Powell
	1969-72	60334	AZGFD	Mead

APPENDIX B. Non-native fish stocking in the Colorado River from Lake Powell, Arizona-Utah, to Hoover (Boulder) dam site, Arizona-Nevada, including the Grand Canyon reach, through 1990. Compiled from Williamson and Tyler 1924, Miller and Alcorn 1953, Jonez and Sumner 1953, AZGFD 1977, USFWS 1980, and agency files. Acronyms for stocking agency as follows: AZFC (Arizona Fish Commission), AZGFD (Arizona Game and Fish Department), NPS (National Park Service, Grand Canyon National Park), NVDFG (Nevada Department of Fish and Game), UTDWR (Utah Division of Wildlife Resources), USFC (U.S. Fish Commission), USFS (U.S. Forest Service), and USFWS (U.S. Fish and Wildlife Service, including when named Bureau of Sport Fisheries and Wildlife). Stockings were variously of embryos, larvae, juveniles, and adults (not differentiated here). Four localities are indicated, up- to downstream: Powell (Lake Powell), Glen (Glen Canyon dam site downstream to Lees Ferry), Grand Canyon (Lees Ferry downstream to Separation Canyon), and Mead (Separation Canyon downstream to site of Hoover [Boulder] Dam).

Species	Date(s)	Number	Agency	Locality
Dorosoma petenense	1954	274	NVDFG	Mead
	1955	11376	NVDFG	Mead
	1968	1500	UTDWR	Powell
	1969	200000	UTDWR	Powell
Oncorhynchus kisutch	1969	36700	AZGFD	Mead
	1970	56116	NVDFG	Mead
	1971	84335	AZGFD	Glen, Mead
	1972	169000	AZGFD	Mead
	1973	100000	AZGFD	Mead
O. nerka[a]	1963	600000	UTDWR	Powell
	1964	35000	UTDWR	Powell
O. mykiss	1922	5000	USFS	Grand Canyon
	1923	20000	NPS	Grand Canyon
	1924	6000	NPS	Grand Canyon
	1925	50000	NPS	Grand Canyon
	1930	100000	NPS	Grand Canyon

		1931	25000	NPS	Grand Canyon	
		1932	25000	NPS	Grand Canyon	
		1940	50000	AZGFD	Grand Canyon	
		1942	30000	AZGFD	Grand Canyon	
		1944	5200	AZGFD	Mead	
		1948	15000	AZGFD	Grand Canyon	
		1950	50400	AZGFD	Grand Canyon	
		1958	51000	AZGFD	Grand Canyon	
		1963	1835000	UTDOW	Powell	
			34400	USFWS	Grand Canyon	
		1964	3691380	UTDOW	Powell	
		1965	4423525	UTDWR	Powell	
			7830	AZGFD	Glen	
			2550	USFWS	Mead	
		1966	2140000	UTDWR	Powell	
			1500	AZGFD	Glen	
			650	USFWS	Glen	
		1967	549844	UTDWR	Powell	
			575	USFWS	Glen	
		1968	201364	UTDWR	Powell	
			8300	AZGFD	Glen	
			2493	USFWS	Glen	
		1969	251238	UTDWR	Powell	
			158219	AZGFD	Glen, Mead	
			41650	NVDFG	Mead	
		1970	24375	AZGFD	Glen	
			154000	NVDFG	Mead	
		1971	848000	UTDWR	Powell	
			54535	AZGFD	Mead	
			13643	NVDFG	Mead	1972
4585	AZGFD	Glen				
			146392-180486	NVDFG	Mead	
		1973	233400	UTDWR	Powell	
			3675	AZGFD	Glen	
			164542-172477	NVDFG	Mead	

	1974	249857-254240	NVDFG	Mead		
	1975	782,536-801-861	NFDFG	Mead		
	1976	50000	UTDWR	Powell		
		100000	AZGFD	Glen		
		650440	NVDGF	Mead		
	1977	18600	UTDWR	Powell		
		95000	AZGFD	Glen		
		112034-144321	NVDFG	Mead		
	1978	50000	AZGFD	Glen		
	1980	13210	UTDWR	Powell		
O. clarki	1925	unknown	AZGFD	Grand Canyon		
	1972	58475	NVDFG	Mead		
	1975	7732	NVDFG	Mead		
	1976	120373	NVDFG	Mead		
	1977	14416-15514	NVDFG	Mead		
	1978	60000	AZGFD	Grand Canyon		
O. mykiss x O. clarki hybrid	1975	28908	NVDFG	Mead		
	1977	67268	NVDFG	Mead		
Salmo trutta	1924	50000	NPS	Grand Canyon		1930
145000 NPS		Grand Canyon				
	1977	unknown	AZGFD	Grand Canyon		
	1978	100000	AZGFD	Grand Canyon		
Salvelinus	1920	5000	NPS	Grand Canyon	fontinalis	1927
60000 NPS		Grand Canyon				
	1931	25000	NPS	Grand Canyon		
	1977	47880	AZGFD	Glen		
Cyprinus carpio	1881-91	unknown	USFC AZFC	Mead		

Micropterui dolomieui[a]	1982	3159	UTDWR	Powell
	1984	30600	UTDWR	Powell
	1985	104115	UTDWR	Powell
	1986	27017	UTDWR	Powell
	1987	34770	UTDWR	Powell
	1988	71031	UTDWR	Powell
Micropterus salmoides	1935	14625	USFWS	Mead
	1937	325000	USFWS	Mead
	1938	21000	USFWS	Mead
	1939	80000-200000	USFWS	Mead
	1940	56000	USFWS	Mead
	1941	32000	USFWS	Mead
	1942	49000	USFWS	Mead
	1963	924000	UTDWR	Powell
	1964	2000000	UTDWR	Powell
	1964	197000	NVDFG	Mead
Lepomis macrochirus	1937	25000	USFWS	Mead
	1940	18000	USFWS	Mead
	1941	320000	USFWS	Mead
	1942	12145	USFWS	Mead
Pomoxis nigromaculatus[1]	1964	9350	UTDWR	Powell
	1965	34700	UTDWR	Powell
Morone saxatilis	1969	10000	NVDFG	Mead
	1970	16300	NVDFG	Mead
	1971	1034	NVDFG	Mead
	1972	1000	AZGFD	Mead
		2000	NVDFG	Mead
	1974	49885	UTDWR	Powell
	1975	94878	UTDWR	Powell
	1976	55062	UTDWR	Powell
	1977	138653	UTDWR	Powell
	1978	254290	UTDWR	Powell
	1979	222550	UTDWR	Powell

[a]Not yet recorded from the Colorado River in Grand Canyon.

SECTION 3:

POPULATION DENSITIES OF *CATOSTOMUS LATIPINNIS* (THE FLANNELMOUTH SUCKER) AND *CATOSTOMUS (PANTOSTEUS) DISCOBOLUS* (THE BLUEHEAD MOUNTAIN SUCKER) IN THE GRAND CANYON REGION OF ARIZONA: LIFE HISTORIES OF MIGRATORY VS NON-MIGRATORY SPECIES

ABSTRACT

INTRODUCTION

THE Colorado River Basin comprises nearly 650,000 km^2 of the most arid terrain in western North America (Fig. 1.1a). As with most major basins dominated by a large river, it is composed of several distinct segments (Minckley et al., 1986): In the upper basin, the Colorado and Green rivers (and tributaries) form a distinct zoogeographic entity for they terminated into closed basins prior to Pliocene. As such, they form a unit. Moving southward, a "contemporary middle segment" (Minckley et al., 1986) is composed of the White, Virgin, and Little Colorado rivers (and parts of the Bill Williams drainage); these flow southwestward to drain this section of the Colorado Plateau. The lowermost section consists of the Colorado and Gila rivers. However, major changes have occurred in these various sections as a result of dam construction and chronic dewatering for agriculture and urban development. For example, the 2400 km of riverine habitat suitable for large-river fishes has been reduced to 965 km (Miller, 1982).

Because of their uniqueness, fishes of the Colorado basin attracted early scientific interest (reviewed in Minckley et al., 1986). Numerous ichthyologists made (or enhanced) reputations based upon descriptions of new species from collections made during numerous military campaigns, government boundary surveys, and expeditions seeking westward transportation routes (Minckley and Douglas, 1991). Minckley et al. (1986:580) divided these fishes into three major categories: Big river endemics (which range throughout the system in larger streams); small-stream, low elevation endemics (which occupy smaller tributaries at low-to-intermediate elevations); and finally, small-stream, high elevation endemics (found at high-to-intermediate elevations and which either straddle drainages or have near relatives in adjacent ones). Both species of concern in this manuscript {i.e, flannelmouth sucker [*Catostomus latipinnis*] and bluehead sucker [*Catostomus (Pantosteus) discobolus*]} are components of Minckley et al.'s "big-river fauna"; each was described from materials collected during the period of western exploration (Fig. 3.1; see below).

The big-river fish fauna of the Colorado is comprised of seven endemics (four cyprinids and three catostomids). Four of these are now listed as endangered, one is a candidate for such listing, one is under review, and one is believed safe (Table 3.1) (USFWS, 1994). The species which comprise the latter two categories [*C. latipinnis* and *C. discobolus*, respectively; Table 3.1] are ecologically enigmatic (see below). The paucity of information on these (and other)

species stems from several factors. One is simply the ruggedness of the terrain drained by the Colorado and its tributaries. Access to these streams is often difficult to achieve; sampling strategies are thus impossible to implement on a consistent basis. In addition, the vast distances that comprise the intermontane west (particularly between towns and cities), strongly influence the logistics of research and have a generally negative impact on sampling. Both aspects (i.e., inaccessability and distance) compound field work and make its design and implementation both difficult and expensive (see also Douglas, 1993).

Native fish work in western North America has focused primarily upon threatened or endangered (i.e., T/E) species. However, the derivation of baseline data for those species not as yet pushed to the brink of extinction is also (or at least should be) a major imperative. For the big-river fish fauna, this would include the two species herein. The present study was thus undertaken with two goals: To estimate within the Little Colorado River (LCR) area of Grand Canyon National Park (GCNP), population sizes for each species by season, by year, and over the entire four-year study period, and to evaluate (and contrast) seasonal and yearly movement patterns for each species.

METHODS AND MATERIALS

Suckers, family Catostomidae, are primarily benthic. The basal stock of this clade is believed to be a deep-bodied fishes of large, low-gradient rivers; the major adaptive events in radiation are associated with teh gradual diversification of the mountain suckers inhabiting medium-to-small tributaries of intermediate gradient. Both forms (larger, more primitive suckers vs slender tributary forms) are found today in North America (Smith and Koehn, 1971; Smith, 1992). The two species of this report fall within each of these clades [i.e., deeper-bodied forms of low-gradient rivers (*C. latipinnis*) vs more slender and highly evolved mountain suckers (*C. discobolus*)]. Life history aspects of each species is documented below.

Flannelmouth sucker (Catostomus latipinnis).--Described originally from the San Pedro River (Arizona) by Baird and Girard (1854). It appears most closely related to species further north and west (Smith and Koehn, 1971). Historically, it was distributed in all moderate-to-large rivers throughout the Colorado River basin (Minckley and Holden, 1980). It is now extirpated below Lake Mead (Fig. 1.1b). Fossil remains of *C. latipinnis* have been found in

Pleistocene beds of the Little Colorado River Basin (Uyeno and Miller, 1963, 1965). Adult size is 300--400 mm TL, with 500+ mm TL maximum (Minckley and Holden, 1980). Maximum size recorded in this study for *C. latipinnis* was 661 mm TL. The life history attributes of this species are sketchy; it typically inhabits pools and deeper runs of rivers and often enters mouths of small tributaries (Minckley and Holden, 1980). Minckley (1991) provides an excellent review of current information on this species, and this, in turn, affords the basis for our synopsis.

In the Yampa River, ripe adults congregate at the upstream end of cobble bars to spawn (depth = 1 m; velocity = 1 m s^{-1}; McAda and Wydowski, 1985). Postreproductive adults apparently remain in flatwater or eddies near margins of strong currents, generally in waters at least 1 m deep. Young often congregate downstream (or on) riffles and along shoreline of flatwater reaches. They frequent tributaries as well.

In Marble and Grand canyons, ripe *C. latipinnis* were caught from March-May at the mouth of the Paria River and other low-gradient streams (Carothers and Minckley, U. S. Bureau of Reclam., Final Rept., 1981). Postreproductive fish remained in these habitats through summer, but returned to the mainstem in winter when temperature differential between tributary and mainstem equilibrated (Suttkus and Clemmer, 1979).
Adult *C. latipinnis* feed upon aquatic invertebrates (primarily dipterans), organic debris, and sand (an apparent by-product of benthic feeding). Those individuals in the mainstream also ingest filamentous alga (*Cladophora glomerata*) which is abundant in Marble and upper Grand canyons (Carothers and Minckley, U. S. Bureau of Reclam., Final Rept., 1981).

There is some controversy with regard to maximum estimated age of *C. latipinnis*. The difficulty centers primarily on the suitability of the biological materials examined. For example, McAda (1977) and McAda and Wydoski (1985) used scales to determine an age of eight or nine years for upper basin *C. latipinnis*. Usher et al. (1980), Minckley (1983), and McCarthy and Minckley (1987) argued that scales were inappropriate media from which to determine maximum age, for these were often regenerated and thus gave false readings. In addition, scale annuli were often unreadable after the first few years of life, adding to inherent unreliability of (and elevated variance in) this medium. Usher et al. (1980) and Carothers and Minckley (U. S. Bureau of Reclam., Final Rept., 1981). used opercular bones to estimate a maximum age of 10 years for *C. latipinnis* in Marble/Grand canyons.

Minckley (1991) suggested that these ages are underestimated and based conclusions on data from Scoppettone (1988) and Minckley (unpubl., cited 1991). In both studies, Green River *C. latipinnis* (n = 30 and five, respectively) were aged using otoliths. In the former, the oldest individual (TL = 530 mm) was 30 years, whereas all five individuals (TL = 530--590 mm) in the latter study were aged > 17 years.

Bluehead sucker [Catostomus (Pantosteus) discobolus].-- Originally described as *Pantosteus delphinus* (Cope, 1872) from the Green River of Wyoming. In a revision, Smith (1966) determined the specific name *discobolus* had precedence over *delphinus*, and furthermore, that the bluehead was most properly classified under the genus *Catostomus*, with the original generic name relegated to a subgenus. However, Minckley (1973) and other western ichthyologists (i.e., Miller, 1976) rejected the synonymization of *Pantosteus* with *Catostomus*. Although the matter is still under debate, the synonymization remains valid until results of additional studies become available.

This species is distributed throughout the upper Colorado River basin; it is replaced by its closest relative, *Catostomus (Pantosteus) clarki* (Smith and Koehn, 1971), which occupies a similar niche in the lower basin (Holden and Minckley, 1980). It is one of a clade of very specialized, mostly herbivorous fishes distributed in relatively high-gradient streams of western North America. Feeding adaptations that make this clade distinct include broad, disc-shaped lips and strong jaws sheathed in cartilage; these allow the fish to adhere firmly to rocks in torrential streams, and while so attached, to scrape algae, diatoms and a variety of sessile invertebrates from rock surfaces. Adult size is 250--300 mm TL, with 400+ mm maximum (Holden and Minckley, 1980). Maximum size recorded in this study for *C. discobolus* was 494 mm TL.

Again, life history of this species is enigmatic; available evidence has been summarized by Minckley (1991) and is synopsized below. Adults remain in deep pools and eddies during diurnal hours, and move nocturnally to shallow riffles or other hard-bottomed habitats to feed. In Marble and Grand canyons, adults spawn in swift water of tributaries, over gravel-sand or gravel-cobble bottoms during April-May.

Estimates of maximum age for *C. discobolus* are as variable as those provided above for *C. latipinnis*; again, variability often stems from the medium from which age estimations are made. Usher et al. (1980) used operculae to derive an age of eight years maximum for *C. discobolus* from

Marble/Grand canyons. However, Scoppetonne (1988) and Minckley (unpubl., cited 1991) used opercular bone and otolith, respectively, to age *C. discobolus* from Green and Yampa rivers, respectively. In the former study, a 400 mm specimen was aged at 20 years, while in the latter, a 470 mm individual was aged at 20+ years.

Many researchers believe two distinct forms of *C. discobolus* occur in the upper Colorado River basin. Miller (1964) noted that *C. discobolus* had evolved a uniquely streamlined body form with small scales and expansive fins; yet, an extreme type was also found in the upper basin which exhibited a very narrow caudal peduncle, much like that found in *Gila elegans*. Similarly, Vanicek (1967) and Holden and Stalnaker (1973) also noted the existence of two morphs: one with a relatively deep, laterally compressed peduncle vs a second with a very narrow peduncle that is rounded in cross-section. The narrow-peduncle form is apparently restricted to the swifter parts of big rivers. However, variation within this species may, in fact, reflect local ecological conditions rather than phylogenetic diversification (Smith, 1966).

Study area and data collection.--The study was confined to the Little Colorado River (LCR) and its confluence with the mainstem Colorado River (Fig. 1.1b), 99 river km (RKM) below Glen Canyon Dam. The study area resides in both Grand Canyon National Park (GCNP) and territories of the Navajo Nation (Coconino County, AZ). The study area, to include water chemistry, vegetation, and channel topography, are described in Douglas and Marsh (1995).

Briefly, base camps were established in the LCR gorge at 0.55, 3.1 and 10.8 RKM upstream from the confluence. Biologists worked at each camp during 50 six- to 14--day trips at approximately monthly intervals from July 1991 to June 1995 (Appendix 1). To capture fishes, hoop and trammel nets were set routinely (the latter primarily at confluence) (net dimensions provided in Douglas and Marsh, 1995). Fishing effort was recorded at each camp as number of net-hours fished. All captured fishes were identified, measured (TL to nearest mm), weighed (nearest g), and sexed. Native species greater than 150 mm TL (= adults) were injected with passively induced transponder (i.e., PIT) tags (Prentice et al., 1990) and released near points of capture.

Capture matrices.--Adult *C. latipinnis* and *C. discobolus* were analyzed separately. Adults of each species were initially grouped into three categories: Tagged fish, recaptured fish, and those with old tags. The first represents fish PIT-tagged by ASU personnel at time of

capture (i.e., individuals previously not captured). The second represents fish captured by ASU personnel but already PIT-tagged (i.e., recaptured; source of original tag unknown). The third includes those fish tagged previously with either a Carlin or floy-tag and subsequently PIT-tagged by ASU personnel; the old tag was removed and retained. This category also included those few fish that were PIT-tagged twice.

For the purposes of this report, all three groups start their capture history when first handled by ASU personnel. In this sense, those fish PIT-tagged by other research groups or agencies were considered "tagged" by ASU personnel at time of first recapture (i.e., their capture history began from this point). Obviously, fish previously tagged and recaptured by ASU personnel have a prior capture history.

For a given species, all three categories were merged then sorted by PIT-tag number; discrepancies (such as individuals listed as "captured" when in actually they were "recaptured") were then corrected. Individual PIT-tags often occurred multiple times in these data (for *C. latipinnis*, one adult was captured 12 times; for *C. discobolus* the maximum was 12 recaptures for a single individual). Individuals were then condensed into a capture-history (CH) matrix (Burnham et al., 1987), where each individual (i.e., each unique PIT-tag) comprised a single row and each of the 50 sampling periods a column. If an individual was captured (or recaptured) during a given sampling period, that respective column was scored as '1', otherwise '0'. Thus, initial capture and all subsequent recaptures of a given individual are represented in the CH-matrix as a row vector.

The CH-matrix was sorted two different ways for analysis: First, individuals were segregated by season (where winter = December, January, February; spring = March, April, May; summer = June, July, August; and autumn = September, October, and November). In all, 16 seasons were represented (four each over four years). Individuals were also partitioned into 50 mm (TL) size-classes, starting at 150 mm TL.

Population estimates.--Open population estimates were generated for each species by season (n=16), by year (n=4), and over all four years of the study. In each case, estimates were generated for the entire LCR rather than by river reach (as defined in Douglas and Marsh, 1995). The program RECAPCO (Smith, 1981) was used to generate estimates, their standard deviations, and 95% confidence limits. Open estimates were used exclusively because

geographic and demographic closure could not be substantiated for these populations, particularly given the temporal span over which analyses were conducted.

Fishing effort and population estimates were transformed to common logs. ANCOVA was used to test population estimates for differences among and between seasons, and between years, with fishing effort as the covariate. The rationale and prerequisites for ANCOVA are discussed in Douglas and Marsh (1995).

RESULTS

Numbers of *C. latipinnis* and *C. discobolus* captured, recaptured with PIT-tags, and recaptured with old tags are presented in Table 3.2. The outcome from merging, sorting, and condensing these data into CH-matrices are also tabulated. Results from partitioning each CH-matrix by season (n=16) is presented for each species in Table 3.3. Effects of partitioning these matrices by size class (i.e., 50 mm increments beginning at 150 mm TL) are reported in Table 3.4.

Preliminary tests indicated that fishing effort had a significant effect on population estimates for *C. latipinnis*. Season also had a significant effect on these estimates at all levels of fishing effort. However, the population estimate/ fising effort relationship was nonsignificant over seasons (i.e., interactions between these terms were nonsignificant). A standard ANCOVA was then performed; results indicated that population estimates for *C. latipinnis* varied significantly over the 16 seasons [$F=3.70$; $df=15$; $P<0.001$; Proc GLM, Statistical Analysis System (SAS, ver. 6.08), Cary, NC, 1989, unpubl.]. Pairwise linear contrasts of population estimates consolidated by four seasons revealed that two (of six) comparisons were significant: Summer vs autumn ($F=7.69$; $P<0.009$) and autumn vs spring ($F=4.52$; $P<0.04$). Because of the manner in which seasons were partitioned (i.e., winter=December, January, February), and also because of the staggered initiation and completion of the project (i.e., July, 1991--June, 1995), only years 1992, 1993, and 1994 could be tested in pairwise comparisons. There were no significant differences between these years in overall population estimates.

Preliminary tests for *C. discobolus* revealed that neither fishing effort nor season had a significant effect on population estimates. The population estimate/ fishing effort relationship was also nonsignificant over seasons. Pairwise linear contrasts of estimates merged into four

seasons were nonsignificant as well. When pairwise contrasts were done over years, as above, significant differences were found between 1993 vs 1994 ($F=5.04$; $P<0.033$).

A three-dimensional plot of population estimates by season and year is presented for *C. latipinnis* in Figure 1a. A similar plot for *C. discobolus* is in Fig. 1b. Again, the partitioning of months into seasons and the staggered initiation/completion of the project (noted above)

DISCUSSION

Smith and Koehn (1971) argued that the most advanced forms of North American catostomids inhabit the Colorado River on the Colorado Plateau; these forms exhibit parallel evolution. For example, parallel divergence of *C. latipinnis* and *C. discobolus* from *C. insignis* and *C. clarki* in the upper and lower parts of the Colorado River basin involved similar changes in the same characters.

While most introductions were to create sport fisheries in the numerous reservoirs and tailwaters that now compose much of the Colorado River mainstem, smaller nonnative "forage" fishes were also introduced, often accidentally (Douglas et al., 1994). These have likewise been detrimental. For example, adult red shiner (*Cyprinella lutrensis*), sand shiner (*Notropis stramineus*), and redside shiner (*Richardsonius balteatus*) have trophic requirements similar to those of indigenous juvenile cyprinids; their larvae and juveniles also compete spatially and trophically with those of indigenous fishes (T. W. Joseph, J. A. Sinning, R. J. Behnke, and P. B. Holden, Environ. Protection Agency rept., 1977, unpubl.).

The fathead minnow (*Pimephales prolemas*), another small nonnative forage fish, was first recorded within Colorado River drainages of the White Mountains (Arizona) circa 1952 (R. R. Miller, in Smith, 1959:196; see also R. R. Miller and G. R. Smith, 1972, unpubl. field notes, Special Coll., Hayden Library, ASU). This species is now ubiquitous within Grand Canyon. Similarly, the Plains Killifish (*Fundulus zebrinus*), first taken in the upper drainages of the LCR in 1938, has gradually worked its way to the confluence and is now widely dispersed within the canyon (R. R. Miller, GCNP report, 1975, unpubl. field notes, Spec. Coll., Hayden Library, ASU).

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Appendix 1. Number of research trips into the Little Colorado River gorge and their inclusive dates, 1991-1995.

TRIP	DATES: FROM--TO
01	01 July--14 July 1991
02	21 July--03 August 1991
03	11 August--23 August 1991
04	13 September--25 September 1991
05	15 October--24 October 1991
06	07 November--16 November 1991
07	09 December--18 December 1991
08	08 January--15 January 1992
09	11 February--19 February 1992
10	05 March--13 March 1992
11	26 March--03 April 1992
12	20 April--29 April 1992
13	18 May--27 May 1992
14	15 June--24 June 1992
15	14 July--23 July 1992
16	10 August--19 August 1992
17	14 September--23 September 1992
18	12 October--22 October 1992
19	09 November--18 November 1992
20	10 February--17 February 1993
21	02 March--10 March 1993
22	22 March--31 March 1993
23	12 April--21 April 1993
24	10 May--19 May 1993
25	08 June--16 June 1993
26	12 July--21 July 1993
27	10 August--18 August 1993
28	13 September--22 September 1993
29	12 October--21 October 1993
30	08 November--17 November 1993
31	06 December--15 December 1993
32	11 January--20 January 1994
33	10 February--19 February 1994
34	15 March--24 March 1994
35	12 April--21 April 1994
36	10 May--19 May 1994
37	14 June--23 June 1994
38	12 July--21 July 1994
39	09 August--18 August 1994
40	13 September--22 September 1994
41	11 October--20 October 1994
42	01 November--10 November 1994

43	06 December--15 December 1994
44	10 January--19 January 1995
45	07 February--16 February 1995
46	28 February--09 March 1995
47	21 March--30 March 1995
48	11 April--20 April 1995
49	26 May--25 May 1995
50	13 June--27 June 1995

Table 3.1: Conservation status of big-river fishes (sensu Minckley et al., 1986) of the Colorado River basin.

FAMILY	GENUS/SPECIES	COMMON NAME	STATUS
Cyprinidae	*Ptychocheilus lucius*	Colorado Squawfish	Endangered
Cyprinidae	*Gila elegans*	Bonytail Chub	Endangered
Cyprindiae	*Gila cypha*	Humpback Chub	Endangered
Catostomidae	*Xyrauchen texanus*	Razorback Sucker	Endangered
Cyprinidae	*Gila robusta*	Roundtail Chub	Candidate
Catostomidae	*Catostomus latipinnis*	Flannelmouth Sucker	Scrutiny
Catostomidae	*Catostomus discobolus*	Bluehead Sucker	Secure

Table 3.2: Individual *Catostomus latipinnis* and *C. discobolus* grouped into three categories: CAPTURED, RECAPTURED, and OLD TAGS. The first represents fish PIT-tagged by ASU personnel at time of capture. The second represents fish already PIT-tagged when captured (i.e., recaptured; source of original tag unknown). The third includes fish previously tagged with either Carlin or floy-tags and subsequently PIT-tagged by ASU personnel (see text). TOTAL is the three categories summed. CH-MATRIX represents TOTAL collapsed into a capture-history matrix where each unique PIT-tag number is represented but once.

SPECIES	CAPTURED	RECAPTURED	OLD TAG	TOTAL	CH-MATRIX
C. latipinnis	2,179	1,550	10	3,739	2,579
C. discobolus	3,613	484	0	4,097	3,697

Table 3.3: Individual *Catostomus latipinnis* and *C. discobolus* grouped by season (= SEASON) from respective capture-history matrices (where winter = December, January, February; spring = March, April, May; summer = June, July, August; and autumn = September, October, and November, and December). YEAR refers to year-of-capture

NUMBER	SEASON/ YEAR	*C. latipinnis*	*C. discobolus*
01	Summer 1991	236	85
02	Autumn 1991	166	151
03	Winter 1991	65	78
	TOTAL 1991	467	314
04	Spring 1992	75	629
05	Summer 1992	125	261
06	Autumn 1992	171	210
07	Winter 1992	1	07
	TOTAL 1992	372	1107
08	Spring 1993	131	628
09	Summer 1993	250	88
10	Autumn 1993	73	123
11	Winter 1993	139	219
	TOTAL 1993	593	1058
12	Spring 1994	256	620
13	Summer 1994	323	40
14	Autumn 1994	218	70
15	Winter 1994	102	65
	TOTAL 1994	899	795
16	Spring 1995	247	408
17	Summer 1995	1	15
	TOTAL 1995	248	423
	GRAND TOTAL	2,579	3,697

Table 3.4: Individual *Catostomus latipinnis* and *C. discobolus* grouped from respective capture-history matrices by size class (= SIZE CLASS) in 50 mm increments beginning from 150 mm TL.

SIZE CLASS	*C. latipinnis*	*C. discobolus*
150--200	258	1,249
201--250	271	1,689
251--300	251	599
301--350	184	134
351--400	345	26
401--450	417	--
451--500	404	--
501--550	314	--
551--600+	135	--
TOTAL	2,579	3,697

FIGURE LEGENDS

Figure 1a: Three-dimensional plot of population estimates by season and year for *Catostomus latipinnis* in the Little Colorado River, Coconino County, AZ.

Figure 1b: Three-dimensional plot of population estimates by season and year for *Catostomus (Pantosteus) discobolus* in the Little Colorado River, Coconino County, AZ.

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4 December 1995

GLEN CANYON ENVIRONMENTAL STUDIES OFFICE

DEC 07 1995

RECEIVED
FLAGSTAFF, AZ

David M. Wegner
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P.O. Box 22459
Flagstaff, AZ 86002-2459

Dear David:

Find enclosed a draft FINAL REPORT for *Ecology and Conservation Biology of Humpback Chub (Gila cypha) in the Little Colorado River*. This draft is submitted as per obligations for Contract Number 1-FC-40-10490.

Please note that the report is not complete, either in its entirety or within each manuscript. Given this, we would ask that the report be for YOUR examination only and serve as evidence that, indeed, the report is developing on schedule. In this sense, the report consists of four separate manuscripts: The first (*Population estimates/ population movements of Gila cypha, an endangered cyprinid fish in the Grand Canyon region of Arizona*) is currently "in press" [Copeia 1995(4)], while the second (*Endangered humpback chub, Gila cypha, as prey of introduced fishes in the Little Colorado River, Arizona, with notes on fish stocking in the Grand Canyon region*) ~~has been~~ submitted. The third manuscript (*Population densities of Catostomus latipinnis (the flannelmouth sucker) and Catostomus (Pantosteus) discobolus (the bluehead mountain sucker) in the Grand Canyon region of Arizona: Life histories of migratory vs non-migratory species*) is still being developed and will be submitted at the first of the new year. The fourth manuscript (*How many endangered humpback chub (Gila cypha, Cyprinidae) exist within the Grand Canyon region of Arizona? Results of a five-year mark-recapture study*) is still being compiled, and it is anticipated that it will be submitted in spring, 1996.

I thank you in advance for not circulating the report and hope that our progress on it meets with your approval.

Sincerely,

M.E. Douglas

CONFIDENTIAL

Michael E. Douglas, Ph.D.
Co-Principal Investigator

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