GRAND CANYON MONITORING AND RESEARCH CENTER

THE STATE OF NATURAL AND CULTURAL RESOURCES IN THE COLORADO RIVER ECOSYSTEM

2001

SCORE REPORT

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Purpose –

The mission of the Grand Canyon Monitoring and Research Program (GCMRC) is to provide decision makers with current and objective information needed to maintain the Colorado River Ecosystem (CRE) as a sustainable large river ecosystem given the complexities of multiple resources and conflicting resource values exist. Providing accurate and objective information on the status and trends of these physical, biological, and cultural resources has been envisioned as a critical component of the adaptive approach used in managing the CRE. The purpose of this report, "The State of Natural and Cultural Resources in the Colorado River Ecosystem" (SCORE) is to present quantitative findings and descriptive information about the condition of the CRE for Glen and Grand Canyons. The report includes but is not limited to status data collected in recent years, but where possible includes trend information based on previous research and monitoring activities. Thus we seek to provide information on the status and trends of key CRE resources.

Much of the data being collected by the GCMRC are directed toward documenting resource attributes and components of this ecosystem. Several issues have complicated developing an effective monitoring program to assess the ecological health and functioning of the Colorado River. The issues are, 1) frequency of counts and measurements required to assess all habitats and species contained within this river ecosystem. These efforts can be cost prohibitive, and in many circumstances comparative data for long-term resource trends do not exist owing to either changes in methodologies, discontinuation of measurements, or the lack of an effective index to characterize a resource. 2) Introduced species add to the species richness of an ecosystem and in some cases are highly desirable due to their recreational or aesthetic value (e.g., trout); yet conversely, these same species may compete or prey on native species; consequently, are considered undesirable in parts of the CRE. 3) Typically, endangered species induce much public attention yet are difficult to monitor owing to their spatial or temporal rarity in a system. 4) Lastly, an effective program must provide a consistent set of indices that accurately measure the different resources of interest.

Stakeholders and managers need to accurately articulate their underlying questions and conceptualize a framework they will use to assess the resource to management actions.

Obviously there are numerous parameters that can be measured or estimated; yet selecting a suite of parameters that appropriately reflect specific resource responses is a necessary step. Presently, managers are beginning to establish an ecosystem management framework that prioritizes levels of resources as management targets. This SCORE report is a summary of the status and trends of certain resources, identified as major management goals previously specified in the environmental impact statement Glen Canyon Dam (GCD) operations [(1)], and the GCMRC long-term monitoring and research strategic plan [(2)]. We have reduced the number of parameters to reflect selected resource trends based on GCMRC's perception of their importance to stakeholders and the CRE. From this draft SCORE report GCMRC hopes it will elicit constructive responses and generate requests for greater specificity in data presentation from management and stakeholders. Additional information regarding specific resources can be obtained from reports and publications cited in the text; as well as a bibliographic listing of previous studies available at the GCMRC web site (http://www.gcmrc.gov/).

Water Resources

Reservoir Characteristics - Water year (WY-2001), physical and water quality characteristics of Lake Powell reservoir responded to climatic changes in the Upper Colorado River Basin, evidenced by reduced unregulated inflow equaling 6.96 MAF [(3)]. This represented a 29% decrease from the reservoir's average unregulated inflow (Fig 1). Reservoir elevation varied in response to inflow and descended from a maximum 1121 to 1117 m. The physio-chemical processes occurring in the reservoir regulate the water quality characteristics entering the downstream section of the CRE. Conductivity is a water quality parameter that has demonstrated considerable utility. Previous findings specific to the downstream section of Glen Canyon have correlated higher conductivity with higher nutrient concentration [(4)] and greater water clarity [(5)]. Conductivity in 2001 began to increase after a decade long trend of reduced salinity [(3)], in response to reduced reservoir levels and inflow volume (Fig 2). There is also some evidence to suggest that nutrients (i.e., orthophosphate, nitrate and nitrite) are becoming elevated in the reservoir [(3)]. Additionally, other studies indicate a positive correlation between optical water clarity conditions and conductivity [(5)]. Because of the present physical and chemical conditions in Lake Powell and the positive correlation existing between increased conductivity with nutrients and light availability we would project that environmental conditions would be more conducive for autotrophic production in Glen Canyon. Monitoring data for the past decade specific to limnological changes occurring in the Lake Powell reservoir can be obtained from the GCMRC Integrated Water Quality Program (3).

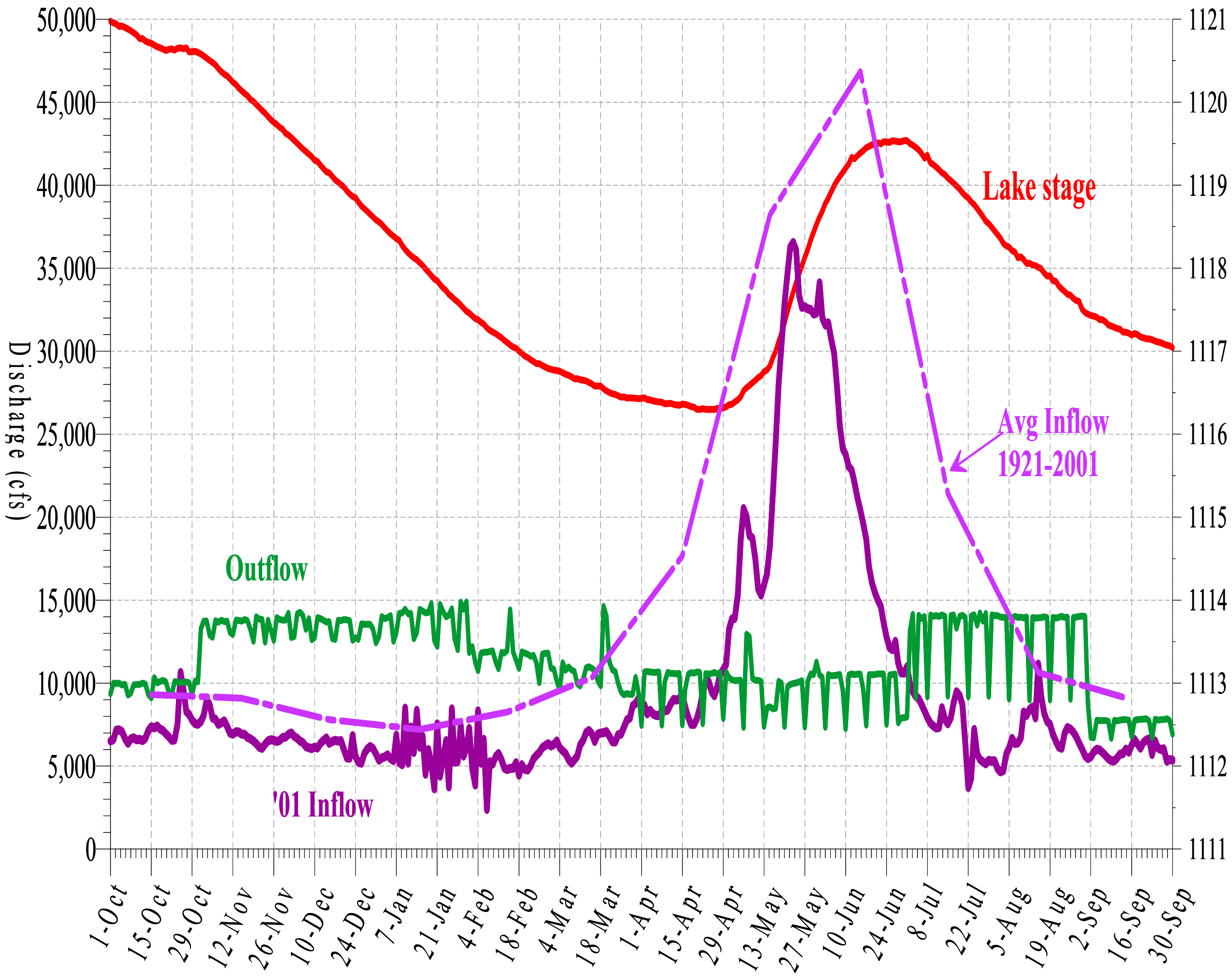


Figure 1, hydrographic time series showing daily averages at Lake Powell Reservoir between 1 October 2000 to 30 September 2001, data series represents surface elevation, unregulated inflow discharge, regulated outflow and mean annual inflow discharge (1921-1963) of the Colorado River.

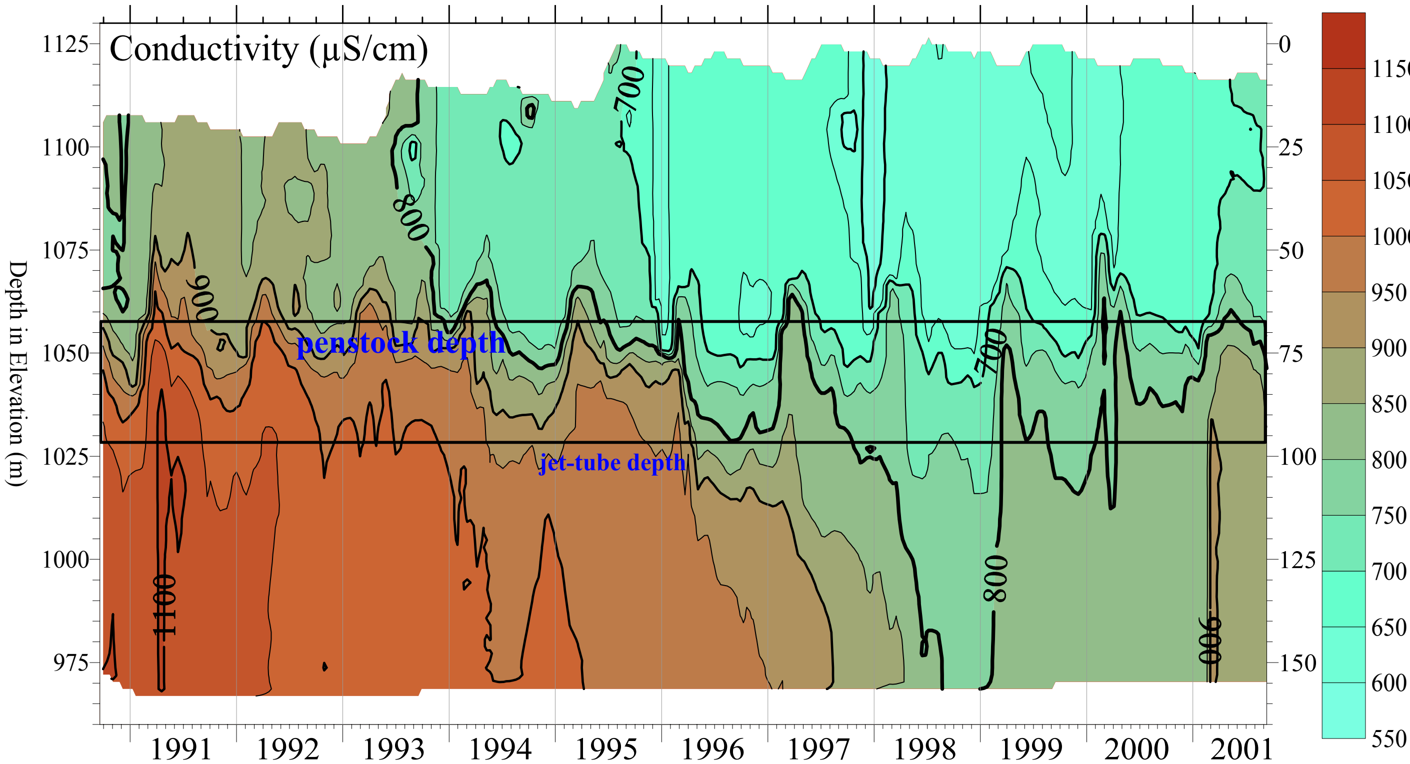


Figure 2, vertical conductivity (µS cm^{-1}) profile measured at the Wahweap forebay station above Glen Canyon Dam. Time series are based on quarterly sampling that extends from September 1990 to September 2001.

Colorado River Hydrology - 2001 was an unusual year with the enactment of emergency criteria at Glen Canyon Dam (GCD), where Western Area Power Authority responded to a series of irregular electrical shortages in California. It was observed that flow releases departed a number of times from the established ramp rates as stipulated in the GCD-EIS [(1)] normal operating criteria. A total of 20, 1-hr periods exceeded the 4,000 cfs/hr ascending rate, with a median up-ramp rate of 4,125 cfs/hr (SE 490), and with a maximum rate of 8,280 cfs/hr. Alternately, a total of 420, 1-hr periods were observed to have exceeded the established descending ramp rate of 1,500 cfs/hr. The median down-ramp rate was 1,560 cfs/hr (SE 116) with a maximum descent of 2,230 cfs/hr. Scheduled daily discharges varied seasonally as indicated in Fig 3. No discharge flows exceeded normal EIS operating criteria (maximum 25,000 cfs, and minimum 5,000 cfs). The hourly maximum, minimum and median flow releases observed for WY-2001 were 21,090 cfs, 6,010 cfs, and 11,610 cfs, respectively. The WY-2001 annual release volume from GCD was 8.23 MAF [3].

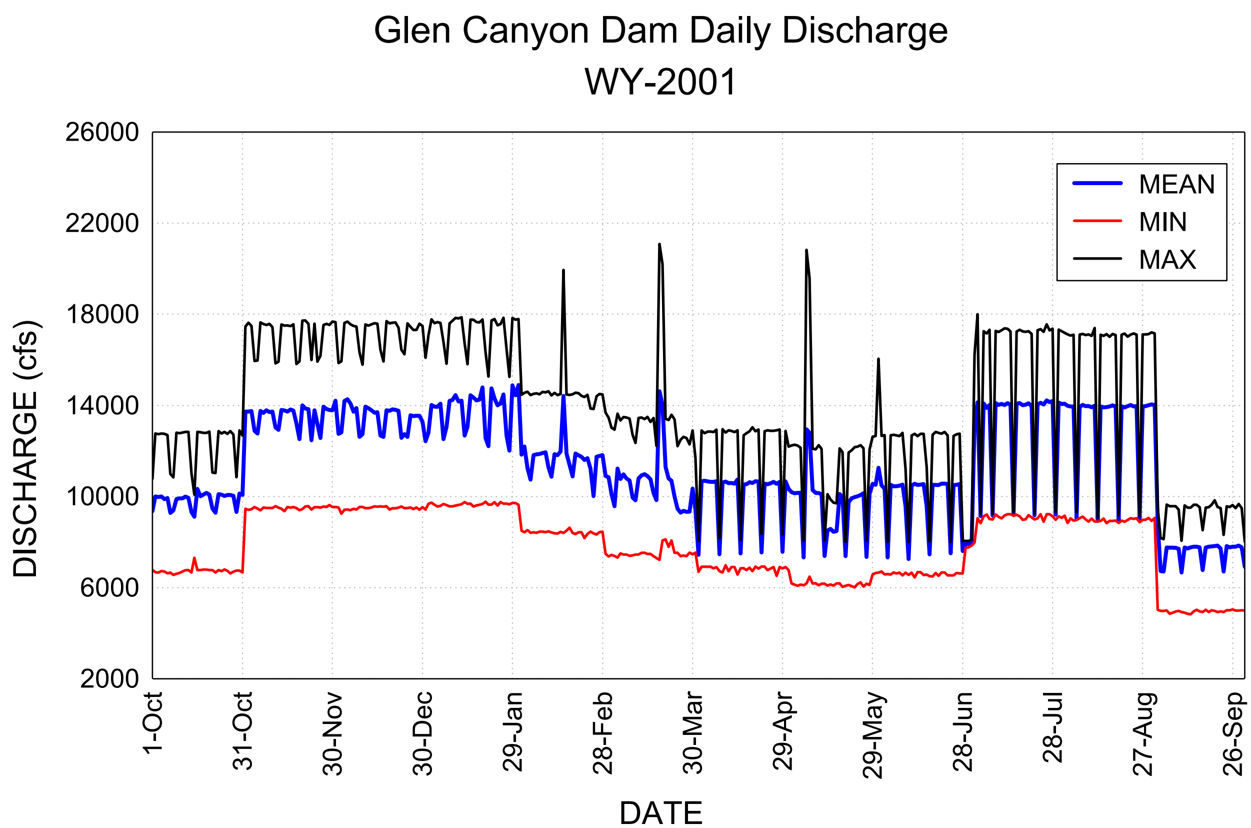


Figure 3, annual hydrograph for the 2001 water-year (October 1, 2000 - September 30, 2001) representing the daily mean, minimum and maximum discharge release from Glen Canyon Dam.

Unregulated Tributary Flows - The relationship of flow frequency, duration and magnitude for the primary tributaries in Grand Canyon are fundamentally significant to the ecological and physical processes occurring in the Colorado River ecosystem [7, 8]. For purposes of spatial reference all sampling locations referred to in this SCORE report are in relationship to the distance from Lees Ferry (0 RM). Values are positive in the downstream direction from Lees Ferry, and negative in the upstream direction toward Glen Canyon Dam.

The frequency and magnitude of tributary discharge determines the extent to which suspended sediment are supplied to the system and available for transport, channel and bar deposition, degree of water clarity conditions for autotrophic production, habitat availability for rearing larval-young fish and spawning adults, and potential piscivory by visual sight-feeders. The cumulative discharge frequency represents the mean daily discharge values drawn from the U.S. Geological Survey streamflow records for two gaged tributaries (Paria River, 1.0 RM; and Little Colorado River (LCR, 61.5 RM)), and reflects the frequency of time when flows are less than or equal to a specific discharge (cfs). For comparative purposes we have graphed the cumulative flow frequency for the period of record for each of the two major gaged tributaries. Mean daily discharge records extend from 1923 to present for the Paria River, and from 1946 to present for the LCR.

Frequency analysis provides a means to compare recent flow events for the last two water years WY-2000 and WY-2001 (i.e., water year (WY) and extends from October 1 to September 30 the following year), relative to the probability distribution for a specific tributary based on the entire period of record. Tributary discharge frequency for the past two years was considerably less than the average distribution for the entire period of record (Fig 4). The cumulative flow frequency for the Paria River in WY-2001 was slightly less than the cumulative average for the period of record. Alternately, the LCR flow frequency in WY-2001 was slightly greater for lower volume flows and less frequent for flows greater than 80 cfs. For WY-2000, we should have observed considerably less sediment supplied to the river system from either tributary source. Additionally, WY-2000 was associated with experimental low summer steady flow (LSSF) [9], which resulted in greater water clarity for phytobenthic production [10], and perhaps a potential for a higher incidence of piscivory for susceptible sized fish.

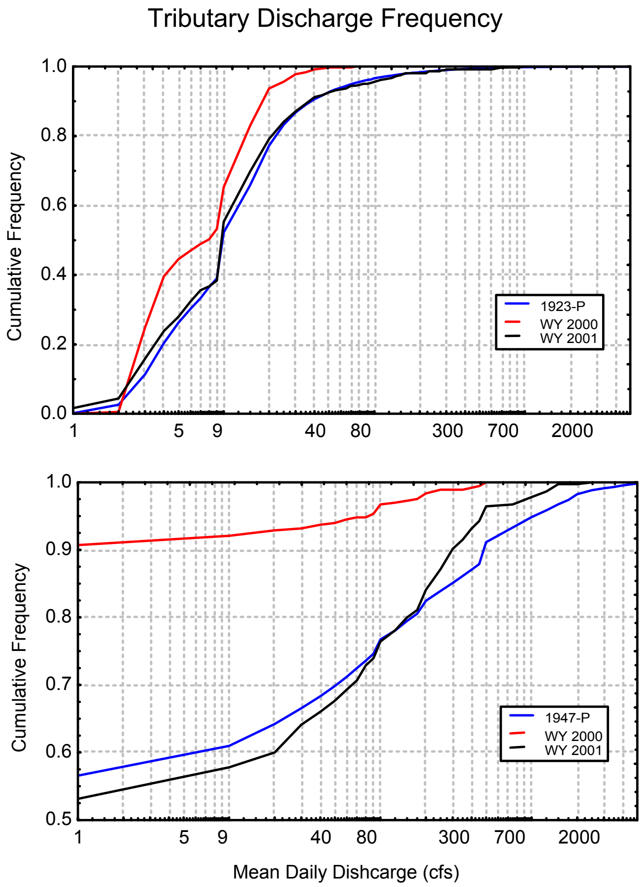


Figure 4, Cumulative frequency analysis of the two primary gaged tributaries, Paria River, 26.5-RKM (USGS 09382000) and the Little Colorado River, 124.5-RKM (USGS 09402000) of the Colorado River, encompassing the period of record and the two most recent water years 2000 & 2001 (October 1 - September 30).

Thermal Characteristics – The thermal characteristics for the Colorado River mainstem are influenced by the hypolimnetic releases originating from Glen Canyon Dam. For WY-2001, mean daily temperatures from GCD were stenothermically cold, and annually averaged 9.2°C, and varied little between seasons. Although, little seasonal variation occurred, the warmest releases were during the winter period (maximum, 10.4°C) and coolest in late spring (minimum, 8.5°C). Additionally, longitudinal warming was observed 390 km downstream from GCD at Diamond Creek (225 RM) and attained a maximum daily temperature of 19.6°C (Fig 5).

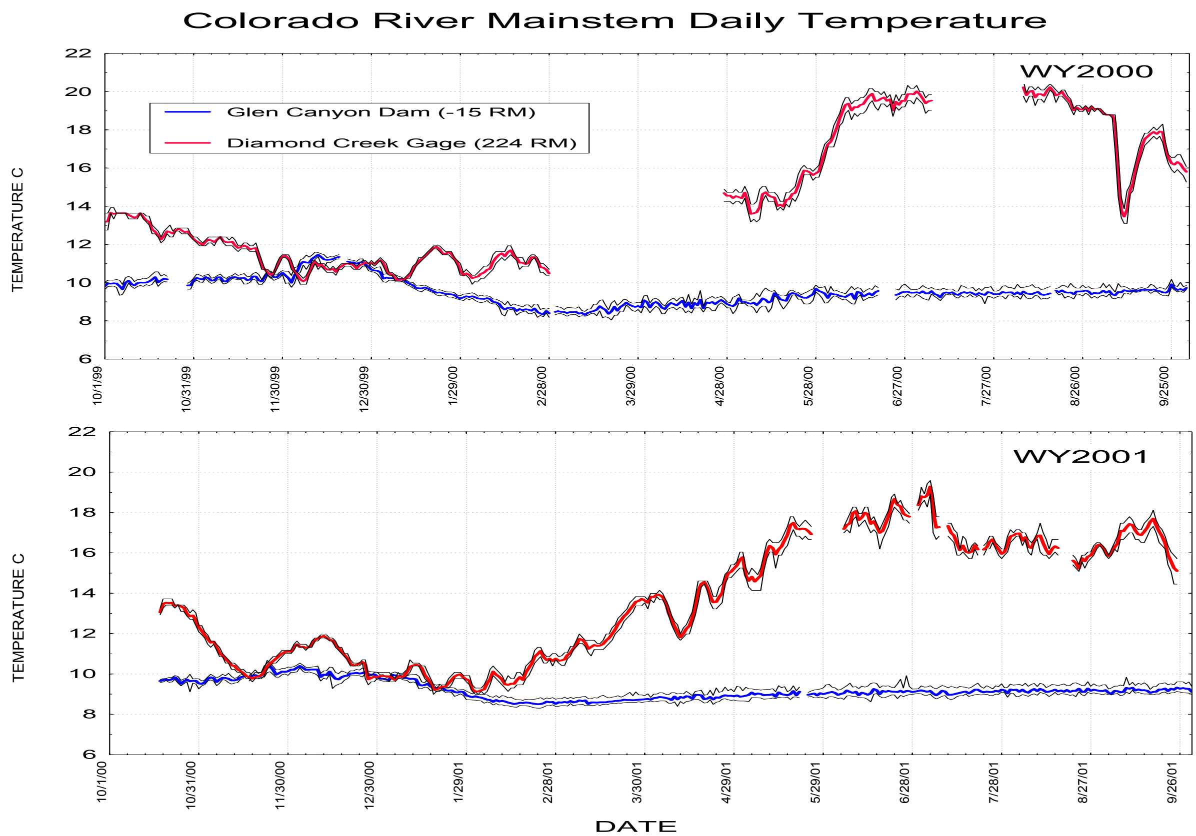


Figure 5, thermal characteristics of the Colorado River, demonstrating seasonal and daily variability (mean, minimum, and maximum) at two sites, Glen Canyon Dam (0-RKM) and Diamond Creek gage (390-RKM). The annual thermograph for the two most recent water years (October 1 - September 30); Fig-6A, WY2000, and Fig-6B, WY2001.

In evaluating summer thermal characteristics for WY-2001 (i.e., extending from June 1 through August 31; 92-days), the mean daily temperature was 9.1°C at GCD, and 16.9°C (SE 0.1) at Diamond Creek, representing a 7. 8°C longitudinal increase (Fig 6A). The maximum water temperatures attained downstream were just at or below levels (16 - 22°C) considered suitable for spawning [(6)] by most native fish. In comparison with the previous year (WY-2000), marked by experimental low summer steady flows (8,000 cfs), mean daily temperatures for the same time period (June 1 - August 31, 2000) were 9.44°C at GCD and 19.46°C at Diamond

Creek (Fig 5B). This longitudinal increase in temperature downstream (10.02°C) over the summer period represented a 2°C difference compared to 2001.

Aquatic Biological Resources

Aquatic foodbase studies – As predicted, the phytobenthic community has responded positively to flow modifications by having increased in biomass. This response is primarily a function of establishing a higher minimum flow level, which has increased the total wetted area and reduced the frequency of atmospheric exposure that often led to desiccation [13, 15]. *Cladophora glomerata*, a green filamentous and branched alga, structurally supports a diverse assemblage of diatoms [11, 12, 13], and provides habitat for aquatic macroinvertebrates [14, 15]. This alga/epiphytic relationship has been recognized as an essential trophic element in this aquatic ecosystem [13, 14, 16]. For this reason, maintaining or increasing this filamentous alga or other aquatic foodbase has been considered an important stakeholder objective.

Although, overall phytobenthic biomass has increased in this system, *C. glomerata* is no longer the dominant autotrophic component, nor has it increased in overall biomass since instituting flow regulations. Instead an alternate phytobenthic assemblage, referred to as miscellaneous algae, macrophytes and bryophytes (MAMB) [13, 17] has become the dominant autotrophic assemblage. Prior to 1996, this same assemblage had not been previously observed in significant quantities. Whether or not the causal response is principally due to flows is unknown. This same autotrophic assemblage is known for being better adapted to lower nutrient conditions than *C. glomerata* [4, 15]. Additionally, *Oscillatoria sp.*, a blue-green alga, is more prevalent in the mid- and lower portions of Grand Canyon and is associated with increased turbidity [8]. Although this algal component has recently increased in this system it is not been known for its trophic importance [15].

A total of six sites are annually monitored (0.5, 1.5, 61.3, 69.1, 128.9, and 205.5 RM), and depending on seasonal conditions, phytobenthic growth in the lower downstream riverine sections of Marble and Grand canyons are strongly variable due to sediment inputs from the major gaged and ungaged tributaries [8]. For this reason, annual trends derived from the monitoring data are displayed only for the early summer period (June-July) because of typical high water clarity conditions for autotrophic production.

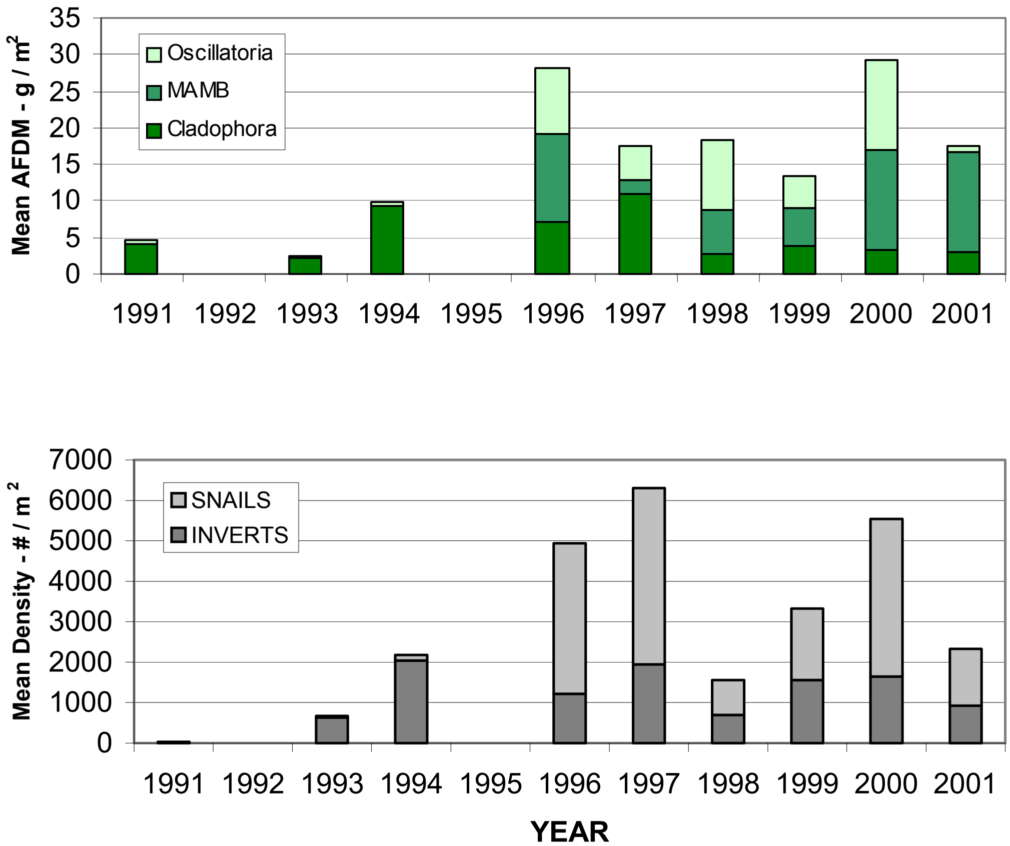
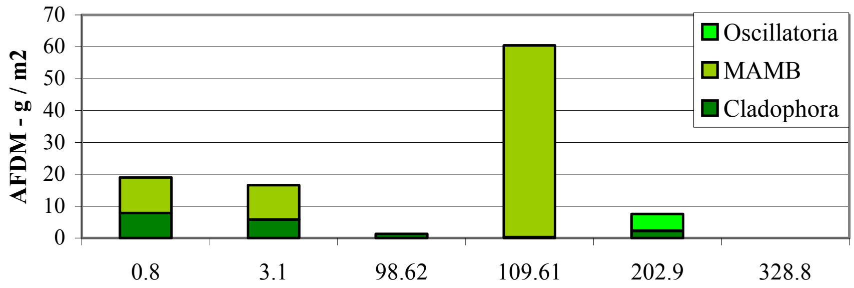


Figure 6, trend in total mean summer (June-July) phytobenthic biomass and densities in the Colorado River; Fig 7A, mean summer autotrophic biomass (g m^{-2}); and Fig 7B, mean summer macroinvertebrate densities (# m^{-2}). Samples were collected during June at six monitoring sites located at 0.5 RM, 1.5 RM, 61.5 RM, 69.1 RM, 128.9 RM, and 205.5 RM.

The graphic representation shown in Fig 6, represents the mean quantity of autotrophic biomass and macroinvertebrate densities for the entire CRE during the early summer period [18]. There has been three-fold or greater biomass and densities in the autotrophic and macroinvertebrate community. The phytobenthic data represents standing biomass and densities at or slightly below 8,000 cfs (227 m^3s^{-1}) varial zone (zone of stage fluctuation). These standing crop estimates do not necessarily reflect biomass and densities in the deeper mid-channel section. The frequency of tributary flows varies between years and may in part explain differences in biomass and density values between years. As observed in the winter and early spring period of 1998-1999, flood frequency was higher for LCR and Paria River, which may explain some of the variation in phytobenthic biomass observed between years.

Recent taxonomy based on internal and shell morphology has identified this small aquatic snail as *Potamopyrgus antipodarum*. This species is native to freshwater lakes and streams of New Zealand; however, has recently expanded its distribution world-wide (Europe, Asia, and North America). This snail was originally detected in the mid-1980s in Idaho, and has since dispersed to other states (i..e., Montana, Wyoming, California), most recently Arizona (Colorado River, Lees Ferry tailwater) and possibly Utah (Green River, Flaming Gorge tailwater). There is considerable concern regarding whether this particular invasive snail species may exert a strong influence on the overall phytobenthic community through competitive grazing pressures [(18)]. Although the initial period of encroachment into CRE are presently unknown., attempts are being made to reconstruct arrival time using specimens from voucher collections. Recent GCMRC findings would suggest a potential decrease in densities of other aquatic invertebrates [(10)].

Gastropods (snails) have now become the dominant invertebrate in this system; however they appear to be more commonly found at highest densities in the Glen and Marble canyons. The distributional pattern of snails indicate that they are almost absent in the lower and western Grand canyons (Fig 7). During early summer, the highest snail densities were observed in the Glen and Marble Canyon sections. In WY-2000, during the LSSF the highest snail densities were observed in the Lees Ferry section [(10, 18)], and represented over 95% of the macroinvertebrate composition [(10)]. Overall mean estimates in recent years for the entire CRE show snail densities (numeric count m^{-2}) ranged between 3,700 to 1,000 m^{-2} (Fig 6). It appears that their establishment and population expansion in the CRE followed the 1996-beach habitat building flow (BHBF) [(18)]. Yet, it is unknown whether or not the BHBF and/or the stabilized flow conditions were responsible. However, we do known that these snails have continued to persist in this system since, and appear to favor stable flow and high clarity conditions.



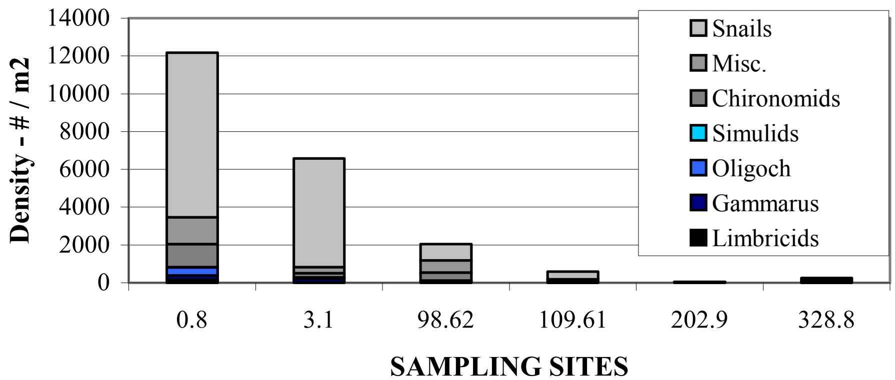


Fig 8, WY2001 longitudinal trend in standing phytobenthic biomass and macroinvertebrate densities distributed throughout the Colorado River. Fig 8A, represents mean summer autotrophic biomass (g / m2); and Fig 8B, mean summer aquatic macroinvertebrate densities (# / m2). Samples were collected during June at six monitoring sites located at 26.3 rkm, 30 rkm, 123.5 rkm, 134.6 rkm, 228 rkm, and 354 rkm.

Trout investigations - Monitoring efforts have emphasized understanding the population size, dynamics and distribution of rainbow (*Onchorynchus mykiss*; RBT) and brown trout (*Salmo trutta*; BNT) in the Colorado River. From a management perspective, RBT represent an aquatic resource of significant importance in the Colorado River for its recreational value upstream in Glen Canyon; however, downstream from Lees Ferry (0-RM) both trout species are of concern due to their potential risk to native fish resources in Grand Canyon. Since management objectives vary spatially we have separated the monitoring efforts to reflect these spatial differences.

Lees Ferry Fishery - The size-class distribution of electrofishing catch indicates that over 35% of fish are equal to or less than 150 mm in length. The desirable management goal of having a high proportion of wild-spawned fish has been attained. Presently, all RBT in Glen Canyon are derived solely from natural spawned stock since stocking of hatchery-reared fish was

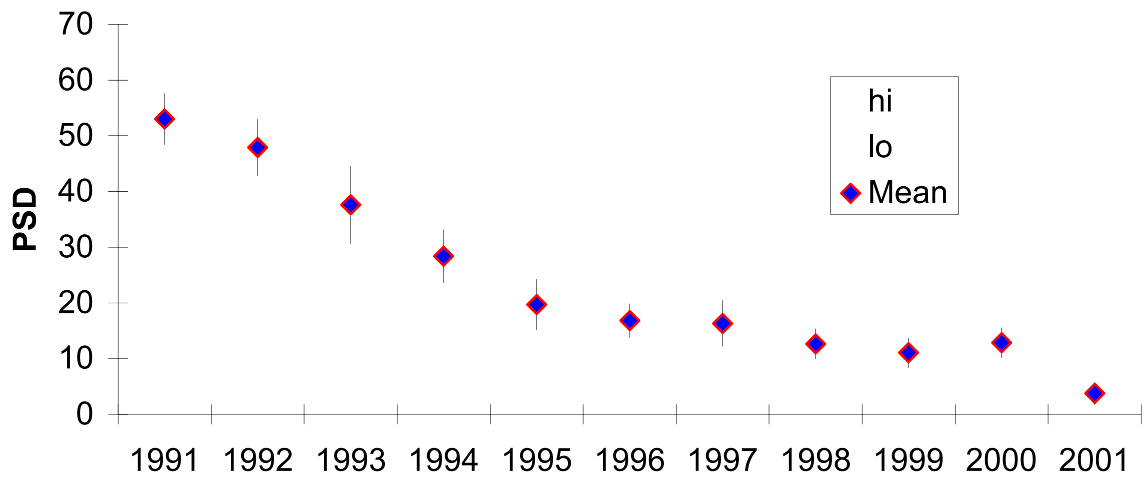


Figure 8, Proportional Stock Density (PSD) is the proportion of fish larger than 406 mm (16 in.) total length (TL) contained within the catchable sized population (>305 mm; 12 in. TL). The annual trend in PSD indicates that the overall proportion of fish >406 mm TL has significantly decreased since 1991.

discontinued in 1999. This signifies a major change in the fishery from the mid-1980's when over 70% of RBT were hatchery reared fish. Estimates of actual population size in Glen Canyon made in 1998 have indicated that the quantity of catchable sized fish greater (>305 mm; 12 in.) have increased significantly from 1990, from 98,000 [19] to over 260,000 [20]. This has represented a 2.6 fold increase over the target population level (100,000).

Graphically represented are the proportional stock density (PSD) estimates for RBT (1990-2001) in Glen Canyon (Fig 8). The PSD is a useful metric to quantify the proportion of large RBT (> 406 mm; 16 in.) contained within the catchable sized population (>305 mm; 12 in) of RBT. The annual trend shown in Figure 8 would indicate that the proportion of fish larger than >406 mm has significantly decreased since 1991. Additionally, the decline in PSD appears to be negatively correlated with RBT abundance (Figure 9). This observation, coupled with the recognition that this is primarily a catch and release fishery for all size classes of fish, suggests

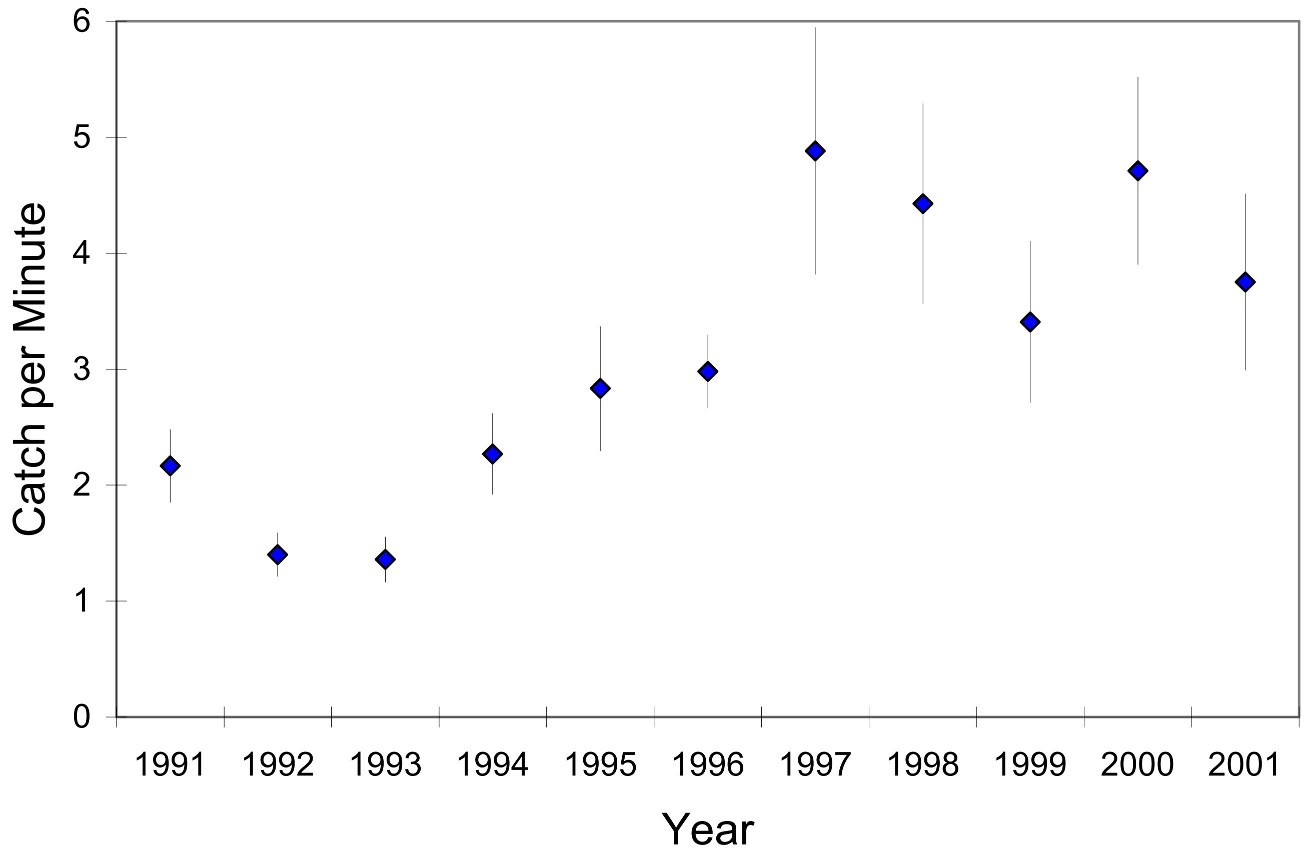


Figure 9, mean catch-per unit effort (CPUE, 95% CI) of rainbow trout caught in Glen Canyon using electrofishing from 1991 to 2000. Mean CPUE is equivalent to the number of fish (RBT) caught per minute, based on nine sampling sites over three sampling periods per year.

that the decline in RBT PSD is likely being driven by sustained large recruitment and density dependent growth affects. This phenomenon, called conservation of biomass, is typical of fisheries experiencing continued large recruitments and low harvest rates.

In response to modified flows, population densities of RBT initially indicated a positive increase in relative abundance (electrofishing CPUE; Fig 9). However, since 1997 sampling trend has shown that relative abundance (mean CPUE) has stabilized and perhaps is decreasing.

Fig 10, represents both observed and predicted angler catch effort of RBT in the Lees Ferry, Glen Canyon Reach, from 1980 to 2001. These catch efficiency data (CPUE) reflect both empirical data collection efforts, and the recent development of a AGF-RBT Stock Synthesis Model [20] (RSSM) that simulates inter-annual angler catch rates. RSS Model was parameterized using stock assessment parameters, GCD flows, and calibrated to observed angler catch data collected by AGF creel surveys. Although, this data has indicated a sizeable RBT population available to recreational angling, these results suggest that predicted angler catch rate has decreased (Fig 10), and in the near future may reflect qualitatively on angler satisfaction.

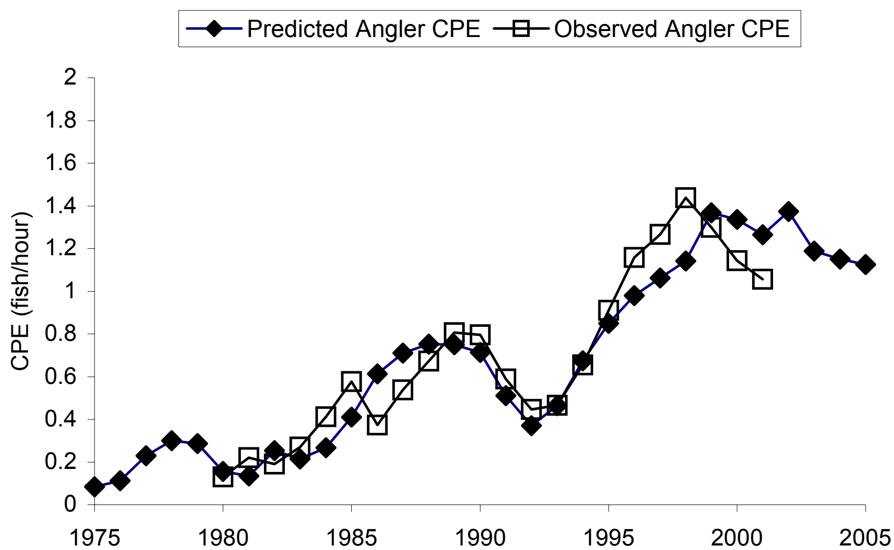


Figure 10, represents both observed and predicted angler catch effort for rainbow trout in the Lees Ferry, Glen Canyon Reach, from 1975 to 2001. These angler catch efficiency estimates (CPUE) reflect both empirical data (AGF creel surveys), and predicted catch efficiency based on the AGF - RBT Stock Synthesis Model used to simulate inter-annual angler catch rates.

Grand Canyon - Recent non-native fish monitoring [21] as of WY-2000 have focused efforts on determining the present RBT and BNT distribution and population size in the Colorado River. Present results have indicated that these two species are widely distributed throughout the entire extent Grand Canyon. Total population estimates for RBT and BNT were 743,000 ($CI_{.95\%}$ ± 250,000 (excluding Glen Canyon)) and 56,000 ($CI_{.95\%}$ ± 35,000), respectively. Population estimates were based on an extrapolation method that relates single pass electrofishing efforts to absolute fish density estimates derived from depletion sampling [21]. Notable, are the differences in the distributional patterns for these two salmonid species. RBT abundance indicates a longitudinal decline as a step-function with distance from Glen Canyon Dam. Highest abundance estimates are in Glen Canyon [20] averaging 11,000 fish km^{-1}, decreasing to 6,000 fish km^{-1} in Marble Canyon, and 2,000-600 fish km^{-1} in the lower reaches of Central and Western Grand canyons. Whereas, BNT has shown the lowest abundance in the upper and lower portions of Grand Canyon, it reaches highest densities in the upper Granite Gorge (76-110 RM). BNT distributional pattern is correlated with the number of tributaries (Clear Creek, Bright Angel Creek, and Shinumo Creek) available for spawning. Although RBT demonstrates a longitudinal decline in abundance, this species still remains one of the most abundant fishes found throughout the CRE.

Predation - Results indicated that the frequency of piscivory was highest for BNT, averaging 8% (n = 154) in comparison to < 0.5% for RBT (n = 241) [25]. Additionally, significant variation in BNT predation occurred in response to seasonal prey availability and spatial proximity to the LCR [25]. Although BNT appear to be the most significant piscivore in this system, cumulative predation by RBT may have as much of an affect owing to this species overall abundance. The recent pattern in salmonid piscivory corresponds with previous field assessments [6, 26] and anecdotal observations [23].

Trout population trends - At present, site-specific estimates of relative abundance (electrofishing arithmetic mean CPUE) are the best trend indicator for RBT and BRT population densities. This index parameter appears to respond in proportion to the actual stock density, as reported above. The trend analysis (1984 to 2001) represents the combined data sets from previous investigations and monitoring efforts [6, 22, 23, 24, 27] using electrofishing as a method to monitor fish in the Colorado River. Although electrofishing methods were used throughout the period of this trend analysis (1984-2001), it should be noted that the electrofishing equipment changed after the mid 1980's (i.e., boat, voltage pulsator unit, and electrical field). Because of this change, CPUE reported from sampling activities during the mid 1980's may not be a directly comparable with index of relative abundance with present sampling efforts. With this caveat in mind, annual population trends (Fig 11) for both RBT and BRT based on CPUE indicate that relative abundance for both species observed at the LCR Inflow (55-65 RM) and Bright Angel Creek (85-94 RM) areas decreased during the early to mid-1990's. Subsequently, population densities for both trout species have increased approximately 400-500% in recent years (1995-P). This response mirrors the response of RBT in the Lees Ferry Reach (-15.5 to 0.0 RM).

The overall trout population response is strongly correlated to flow modifications, as part of the EIS preferred alternative [(1)]. During the mid-1980's in the Bright Angel Creek area electrofishing sampling would indicate that trout composition was composed predominantly of RBT (represented 73% by composition) (assuming no gear selectivity differences between trout species). In comparison, over the last 10-years a compositional shift has occurred where BRT now represent 72% of the all trout found adjacent to the Bright Angel Creek area (based solely on electrofishing). Additionally, although the CPUE data suggests that the Bright Angle Creek reach has switched from being dominated by to being dominated by BNT, species composition in LCR inflow reach has remained relatively constant with the actual proportion of BNT to RBT representing less than 3% of the total (Figure 11; 2nd y-axis).

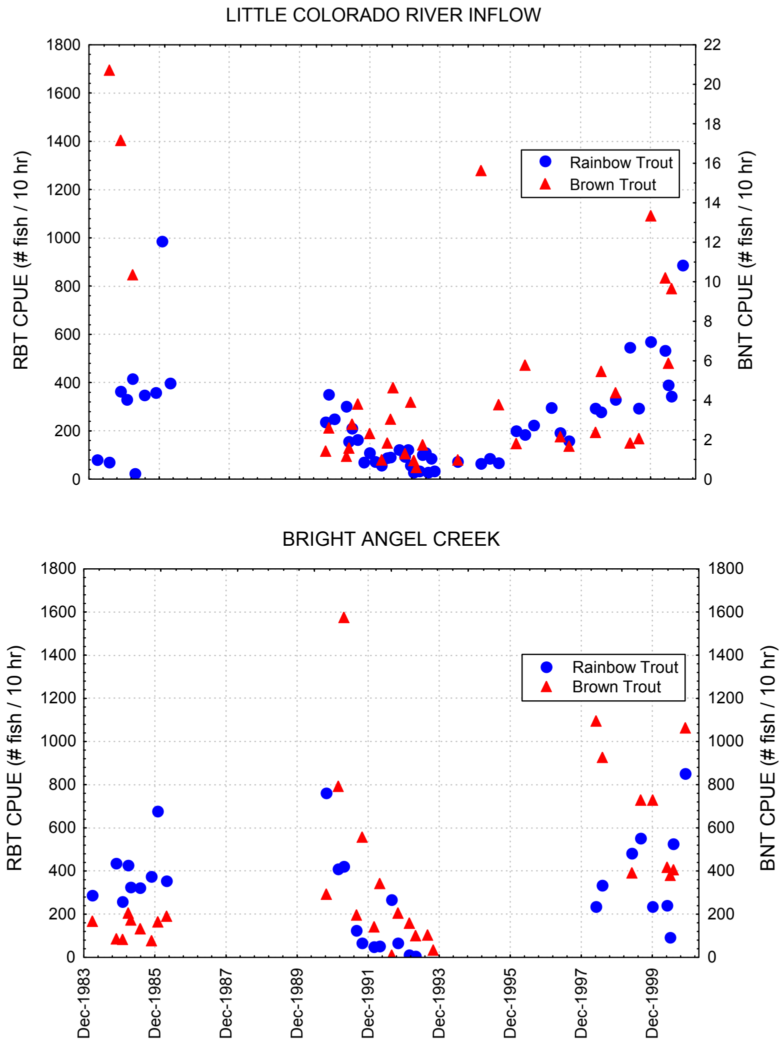


Figure 11, trends in relative abundance for rainbow trout and brown trout (1984-2001) based on electrofishing effort (arithmetic mean CPUE) specific to A) the Little Colorado River inflow (55-75 RM); and B) Bright Angel Creek (85-105 RM).

Other non-native fish species - The distribution of other non-native species are confined predominantly to the middle and lower portion of the CRE (140-225 RM), or certain tributaries and specialized habitat (e.g., backwaters, springs and littoral shoreline) [28, 29]. The overall abundance of this warm-water fishery is considerably less than the non-native trout species. Due to a greater emphasis being placed on native fish sampling; as well as gear type limitations (electrofishing), we are unable to confidently assess relative abundance of these larger (carp and catfish) and smaller bodied fish (fathead minnows, red shiners) persisting in the CRE. In general, these other non-natives species have increased in tributaries. Yet, in recent years there has been a compositional shift with increasing non-natives fish caught in the LCR (Fig 12). The LCR drainage, and the flow frequency and magnitude of hydrological events appear to function as the source of origination and as the primary mechanism for dispersing small-bodied fish into the CR mainstem. Once in the mainstem successful reproduction and recruitment of these non-natives occurs in other tributary confluences; as well as along near shoreline habitat [27, 28]. Warm, stable, and low velocity habitats are conducive for high rapid production of many small-bodied fish as was observed in WY-2000 during the LSSF [30].

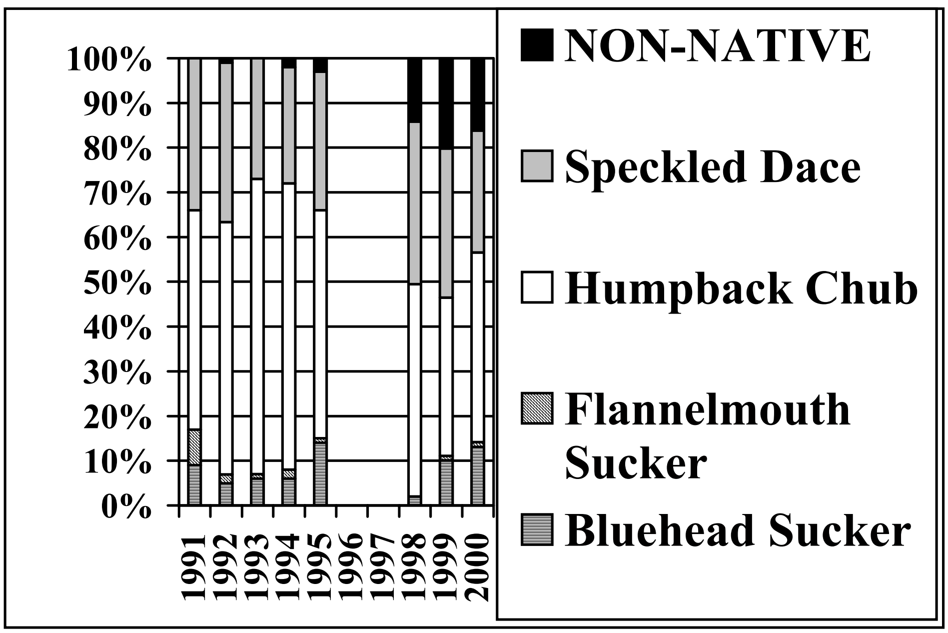


Figure 12, estimated species composition from USFWS sampling in the Little Colorado River using hoopnets, during 1991-1995, and 1998-2000.

Terrestrial Wildlife & Habitat Resources

Beginning in WY-2001, an integrated effort was initiated to census and monitor invertebrates, mammals and herpetofauna concurrent with the avifauna and terrestrial vegetation-monitoring program. The overarching purpose has been to provide ecological information on the terrestrial community. Ground dwelling arthropods can be an effective and an easily monitored group to measure faunal responses to change in habitat quality. Additionally, using an integrated approach assists in relating vegetational structure and trophic links to the distribution and abundance of the vertebrate (i.e., birds, mammals, herpetofauna) and arthropod communities. The data presented here for this first-year terrestrial monitoring effort are based on spatial comparisons made between the up-stream and downstream sections of Grand Canyon (i.e., between RM 0.0 to RM 61.5 and the lower Grand Canyon RM 61.5 to RM 225), and three riparian habitat zones along the CRE (i.e., the hydrologically active zone, HAZ; new high water zone, NHWZ; and old high water zone, OHWZ) [31]. The predominant vegetative composition consisted primarily of Coyote willow (*Salix exigua*), horse-tail (*Equisetum arvense*), brikellia (*Brickellia longifolia*) in the HAZ; tamarisk (*Tamarix ramosissima*), and arrow-weed (*Pluchea sericea*) in the NHWZ; and honey mesquite (*Prosopis glandulosa*), catclaw acacia (*Acacia greggii*), and net-leaf hackberry, (*Celtis laevigata*) in the OHWZ.

Avifauna - Surveys to determine the status of breeding birds detected (visually or auditory) a total of 1787 birds, at 55 monitoring sites [31]. This represented a total of 48 bird species found along the river corridor. Patterns in breeding bird composition and their relative proportion were similar to those found in previous studies [35, 36]. The average number of birds encountered during walking count transects for all zones was 8.5 (SE 0.6). The most common species of birds observed were Lucy's warbler (44.2%, LUWA), house finch (9.2%, HOFI), Bell's vireo (8.1%, BEVI), and blue-gray gnatcatcher (8%, BGGN). The distributional pattern of neotropical migrants and year-long residents occupying riparian zones in the CRE indicated that the highest avifauna richness (# of species) was in the NHWZ, although absolute bird abundance was significantly higher in the OHWZ (Fig 13). Waterfowl surveys were not conducted last year, but were commenced as of this year (WY-2002).

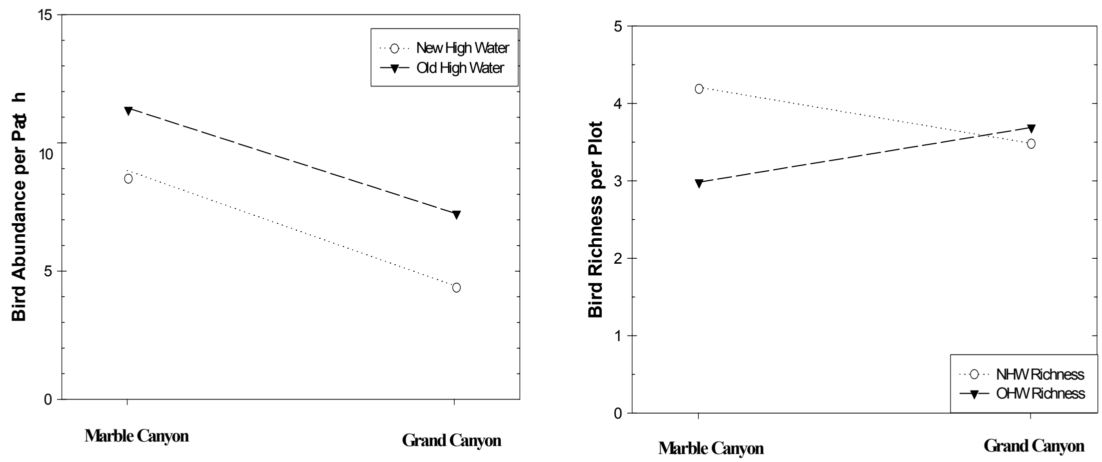


Figure 13, mean avifauna relative abundance and species richness based on walking transects conducted in Marble and Grand Canyons for two hydrological zones (new high water zone, NHWZ; and old high water zone OHWZ).

Mammals - Results for small mammal trapping efforts measuring relative abundance of rodents occupying the three different habitat zones has indicated that nearly one half of all small mammals were captured in the OHWZ; whereas the remainder were equally distributed between the HAZ and NHWZ [31]. Inclusive of all habitat zones, observed trap success (captures/trap set) was very high (27.6%) along the river corridor, indicative of high mammal densities. A total of 20 native mammal species were identified, and represented 77% of the total number of mammals to have previously been documented to occur along the CRE. Differences were observed for mean rodent relative abundance among the three different hydrologic zones with the highest rodent abundance occurring in the OHWZ. Reach comparisons made for Marble Canyon and Grand Canyon indicated that rodent abundance increased in the OHWZ in the mid- and lower western Grand canyons (Fig 14).

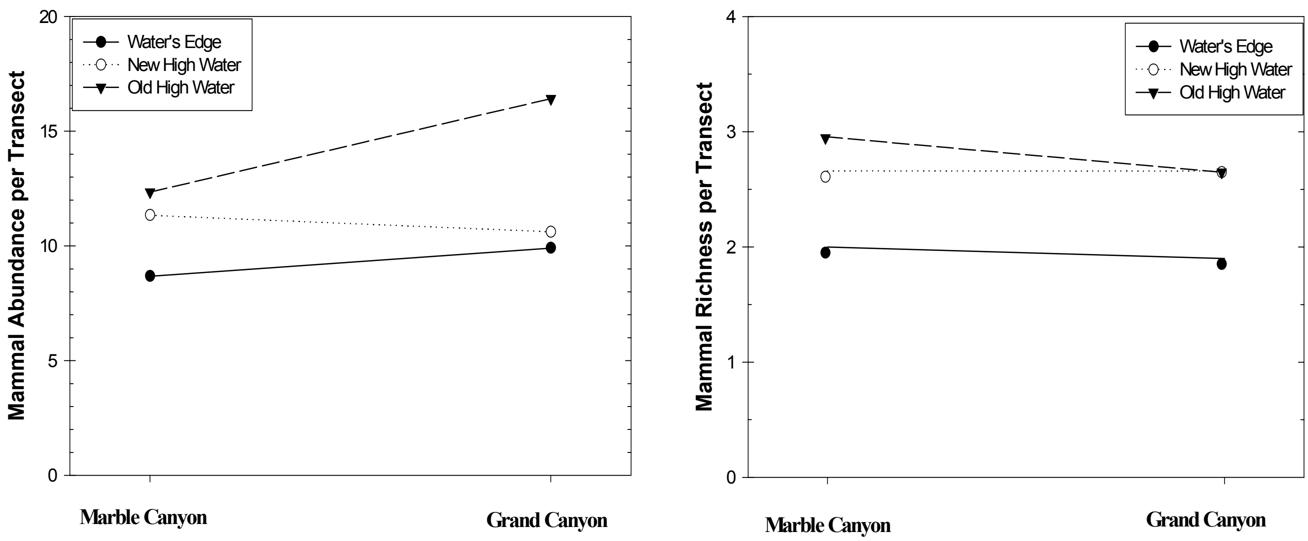
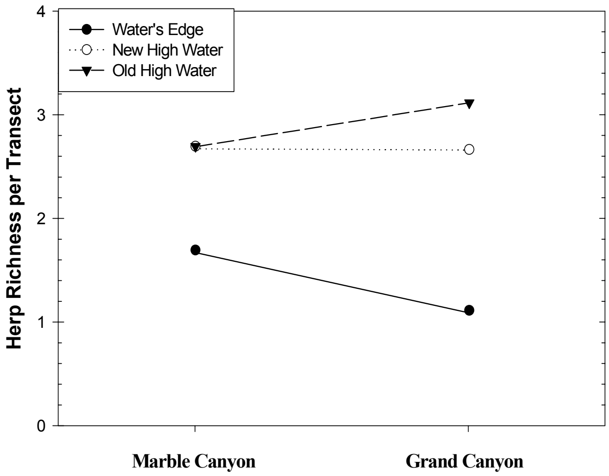


Figure 14, mean relative abundance and species richness based on small mammal trapping efforts in Marble and Grand Canyons for three hydrological zones (hydrologically active zone, HZA; new high water zone, NHWZ; and old high water zone OHWZ).

Herpetofauna - During WY-2001, a total of seventeen species of herps were observed, of these the most common taxa were the Western whiptail, *Cnemidophorous tigris*; desert spiny lizard, *Sceloporous magister*; side-blotched lizard, *Uta stansburiana*; tree lizards, *Urosaurus ornatus*; and Woodhouse's toad, *Bufo woodhousei* (31). Differences were observed in herp relative abundance by hydrologic zone, with the greatest abundance occurring in the OHWZ. Additionally, reach comparisons made between Marble Canyon and Grand Canyon showed that the mean herp abundance (#/transect) increased for both OHWZ and NHWZ in the downstream reach (61.5 - 225 RM). Overall, the highest abundance in herps was observed within the OHWZ; although, species composition was found to be distinctly different between the habitat zones (Fig 15).



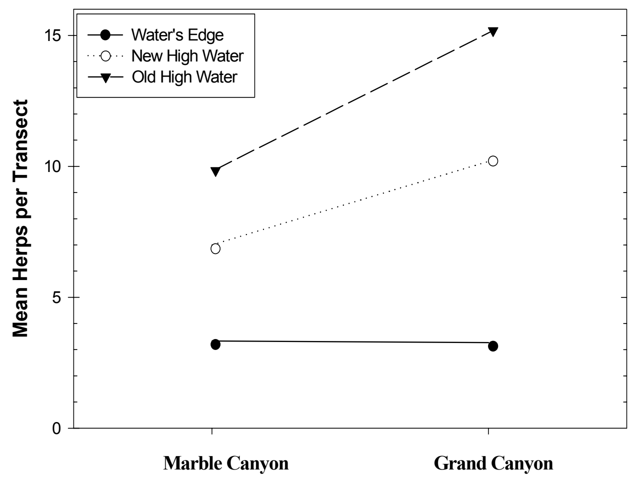


Figure 15, mean abundance and species richness for herpetofauna observed within Marble and Grand Canyons along a linear transect (# / 100 m) for three hydrological zones (hydrologically active zone, HZA; new high water zone, NHWZ; and old high water zone OHWZ).

Terrestrial invertebrates - This program has begun to establish a voucher and reference collection. This will be an ongoing project, and currently over 2200 specimens have been sorted, preserved and partially identified. Preliminary results have indicated that abundance and species richness of terrestrial arthropods are higher for sites below the LCR than found in Marble Canyon (Fig 16) [31]. Yet, comparisons made of average abundance between the three hydrological zones showed no significant differences. The overall pattern in ground dwelling arthropods demonstrated an increase from the wetted shoreline up into the OHWZ.

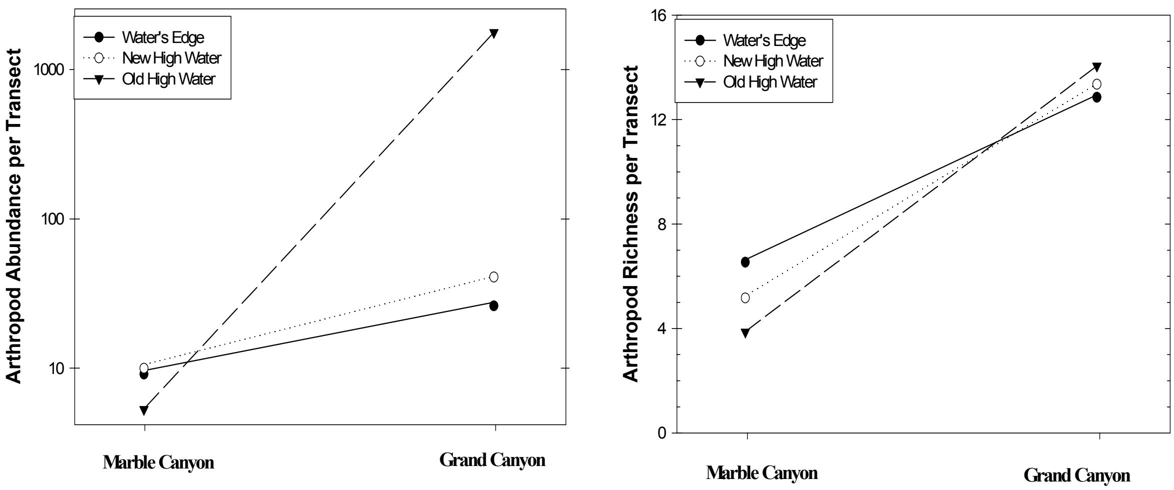


Figure 16, mean arthropod relative abundance and species richness based on sampling efforts in Marble and Grand Canyons for three hydrological zones (hydrologically active zone, HZA; new high water zone, NHWZ; and old high water zone OHWZ).

However there were distinct differences observed in the arthropod composition that resided within each of the hydrologic zones. Several taxa appear specialized to specific habitats with little distributional overlap observed between zones. For the 127 taxa so far identified, 82 were found to reside in only a single habitat zone. Indicating that ground dwelling arthropods were responding to a gradient of soil texture and or soil moisture across zones. There appears to be some compositional relationship between birds and ground-dwelling invertebrates and the vegetation in the monitoring sites, rather than the degree of productivity and biomass associated with the NHWZ.

Terrestrial vegetation – Vegetational transect data from the monitoring sites has indicated that differences existed in total vegetation volume (VV) between OHWZ and NHWZ. The highest VV was observed in the NHWZ and lowest in HAZ [(31)]. The vegetational cover (VC) and plant species richness was strongly influenced by the stage discharge relationship. VC was lowest in the 15,000 cfs zone, highest between 25,000-35,000 cfs and lowest in the upper 45,000 cfs zone. The plant species found in the 15,000 cfs zone were on average facultative wetland species. The highest total VV measured by zone, showed that species richness for woody plant species was highest in the NHWZ for Marble Canyon; yet, in Grand Canyon species richness shifted toward plants favoring the OHWZ (Fig 17).

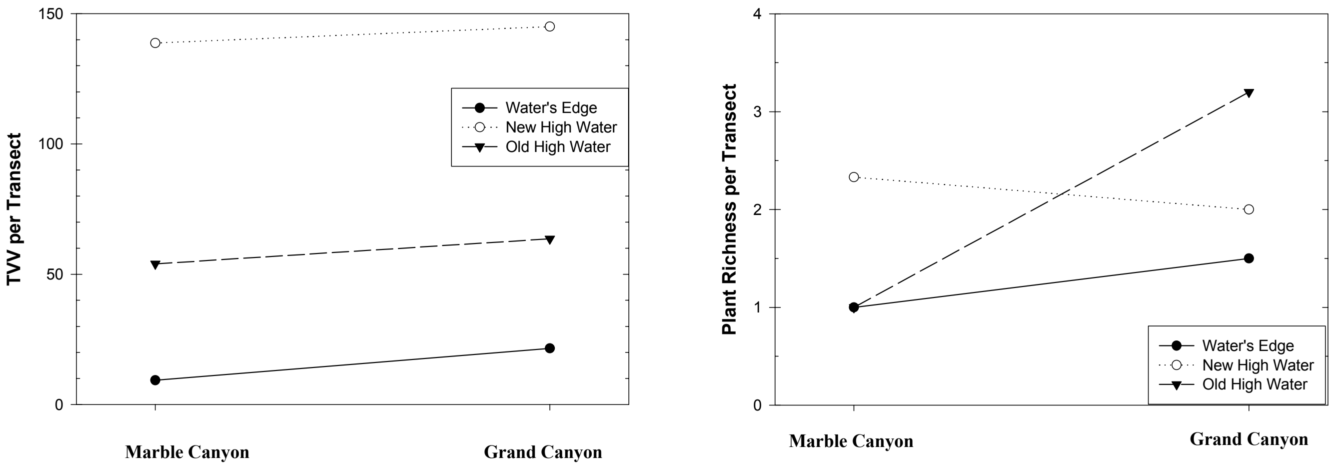


Figure 17, mean total vegetation volume (TVV) and species richness based on linear transects in Marble and Grand Canyons for three hydrological zones (hydrologically active zone, HZA; new high water zone, NHWZ; and old high water zone OHWZ).

Endangered & Special Status Species

Humpback chub - Earlier research and monitoring studies were centered on a descriptive characterization of life history of humpback chub (HBC), *Gila cypha*. Although this information has been valuable it has not allowed until recently, the reconstruction of HBC population dynamics and trends in the Grand Canyon. In the last two years we have restructured and changed the emphasis of the overall monitoring approach and instituted a sampling effort to estimate HBC abundance and recruitment success. We can presently estimate abundance and recruitment only for the LCR population because the numbers of fish captured elsewhere is too small.

The transient nature of HBC residence within the LCR poses significant sampling design problems in attaining unbiased estimates of abundance. Typically the portion of the adult population residing in the CR mainstem exhibits seasonal immigration into the LCR (early-Spring) to spawn. Following the spawning period, these spent adults disperse back to the CR mainstem by late June-July. The remaining and apparently small proportion of the total adult population continues to reside in the LCR as yearlong residents. The reproductive contribution and spatial fidelity of these two adult sub-components remains largely unknown. Lastly, young of year fish and juveniles from the previous reproductive year are occasionally dispersed into the CR mainstem by monsoonal flooding or density dependent factors.

Cornerstone to GCMRC's recent shift to monitoring abundance and recruitment of HBC are the utilization of techniques collectively termed mark-recapture methods. Many of the models developed from these methods rely on the concept of geographic closure during and between sampling periods. To account for the fish movement issues described above, a serial sampling design using the two-event Chapman-Petersen abundance estimator [(66)] was incorporated into the GCMRC native-fish monitoring program beginning in 2000. This design includes a total of two sampling periods within the LCR (Spring and Fall) and one within the LCR inflow reach of the CR (Summer). Because the movement and distributional pattern of adult HBC in the LCR population are variable among years, this design also allows for a combination of estimators to be used strategically depending on how HBC movement patterns are manifested during any particular year. The spring sampling period was chosen to avoid violating assumptions of closure due to immigration. Sampling began in the LCR (May & June), followed by sampling in the CR-mainstem (August & September) and then repeated once again in the LCR (October & November). The sampling area was confined spatially and included the CR mainstem (55.6 to 68.3 RM), and the LCR, which extended from the confluence upstream to 14.2 km.

During the fall 2000, a total of 1,590 ($CI_{95\%}$ ± 992-2,552) individuals >135 mm TL [65] were estimated within the LCR. Because this estimate was conducted during the fall, the majority of these fish are sub-adults. During 2001, attempts were made to increase the precision of the estimator and reduce the sampling bias attributed to minimal mixing and immigration timing of adult fish. Preliminary estimates from 2001 suggest that approximately 2,090 ($CI_{95\%}$ ± 1,611-2,569) individuals >150 mm TL were present in the LCR during Spring (USFWS IN REVIEW), 1,044 ($CI_{95\%}$ ± 446-1,644) individuals >200 mm TL were present in the CR mainstem (55.6 to 68.3 RM) during Summer (SWCA IN REVIEW), and 1,106 ($CI_{95\%}$ ± 934-1,179) individual >150 mm TL were present in the LCR during Fall. Preliminary examination of the Spring 2001 data further indicate that the estimated abundance of HBC > 150 mm TL in Spring 2001 may be biased low by an unknown amount because a substantial number of adult fish may have already spawned and exited the LCR before the initiation of sampling. With these preliminary estimates in hand and considering what is known about typical timing of adult movement (Valdez and Ryel 1995), the best abundance estimate for fish >150mm for the entire LCR population is the sum of the Summer CR abundance estimate and the Fall LCR abundance estimate. Under this assumption, the total abundance is approximately 2,150 ($CI_{95\%}$ ± 1,511-2,885) >150 mm TL. It is of interest to note that this preliminary estimate is nearly identical to the abundance of HBC >150 mm TL found in the LCR during Spring 2001. The reader should explicitly note that the 2001 estimates are preliminary and subject to change as 2001 analyses are subjected to peer review and subsequent revision.

A stock assessment model referred to as HBC Super-Tag has been in the process of development to evaluate population dynamics in HBC [42]. The stock assessment method uses statistical and mathematical calculations in estimating past and current population abundance and production. This model uses a combination of estimated parameters (average recruitment, recruitment anomalies, and adult mortality) and other specified parameters (growth, vulnerability schedule, von Bertalanffy growth equation) [43, 44]. It is hoped that in the future this stock assessment approach will allow one to construct quantitative predictions about fish population in response to alternative management choices.

The modeling suggests that recruitment among brood years for the 1st year age-class (70-140 mm) have significantly decreased (Fig 18). Combining independent data sets from previous annual sampling efforts (1987-2000) [37, 38, 39] in the LCR indicate that catch rates (# fish/hour) for age-1 and unmarked age-2 fish have substantially declined corresponding to the 1992-1998 brood years. These independent analyses provide further evidence that the declining trend for HBC recruitment is real and suggest that recruitment following the 1991 brood year is lower than previous brood years contained in the period of record.

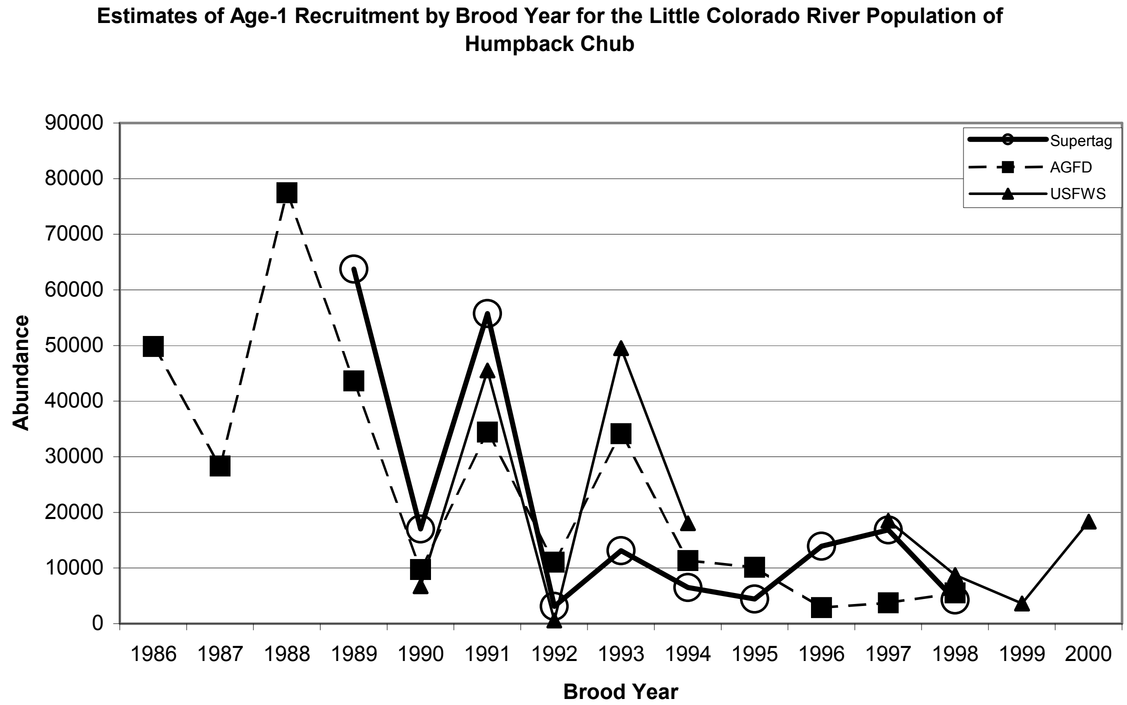


Figure 18, graphical representation of recruitment trends for the Little Colorado River population of humpback chub, reflecting the abundance of age-class 1 for a particular brood year. The trend analysis represents inter-annual variation in CPUE data from independent sampling efforts performed by both the Arizona Game and Fish Department and the US Fish and Wildlife Service as compared to estimated trends from the Super-Tag model.

Furthermore, given that the model accurately estimated both recruitment and mortality rate, the modeled results would indicate that HBC abundance (>150 mm) has declined substantially between 1993-2000 (Fig 19) [37, 38, 39, 40]. Although the actual causal mechanism for the recruitment decline is unknown, there are a number of hypotheses that could be responsible for the inter-annual trend. These include: 1) predation and competition occurring either in the CR and/or the LCR, 2) tributary hydrology, 3) GCD operations (research & interim flows 1990-01), and 4) parasitism (Asian tapeworm) [34]. Although at first glance one might tend to conclude that predation by non-native salmonids are the single causal factor responsible for the recruitment decline due to the extraordinary increase in their abundance beginning in the mid 1990’s, recognize that the increase in trout abundance in the CRE appears to follow rather than precede the observed decline in HBC recruitment (See Fig 11 & 18). However, it is likely that any of the above mentioned factors might act as a dominant controlling mechanism within any particular year. Therefore, it is critical that alternative hypotheses be evaluated (e.g. predation or parasitism within the LCR).

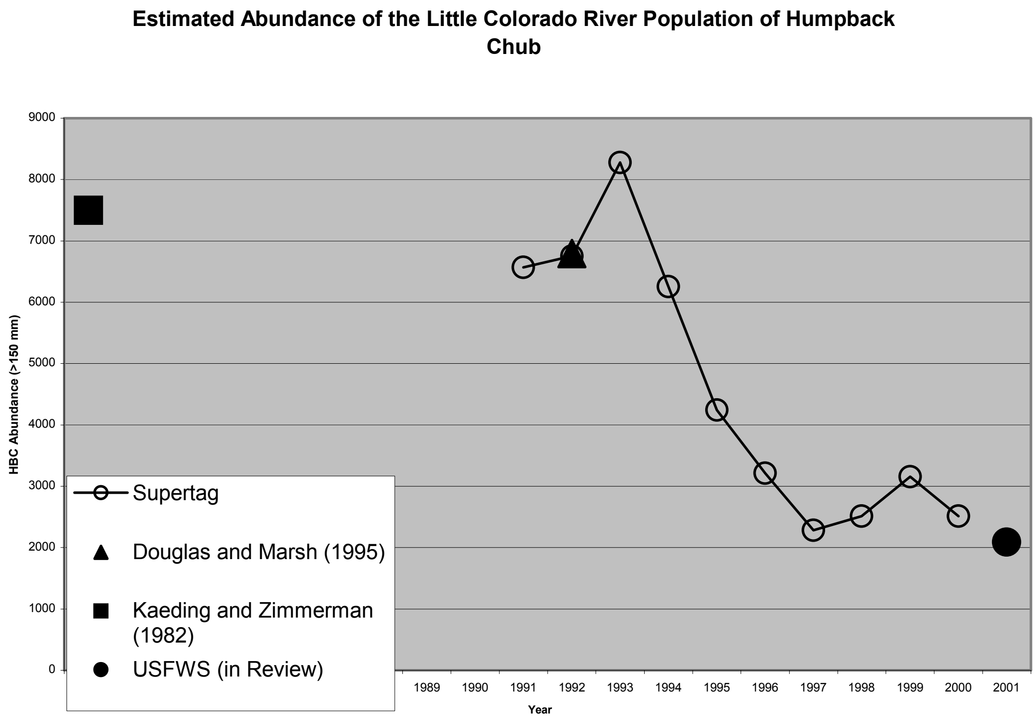


Figure 19, graphical representation of the abundance of humpback chub > 150 mm (Total Length) contained within the Little Colorado River Population as estimated by Kaeding and Zimmerman (estimate germane for fish > 200 mm TL), Douglas and Marsh (using the null model from Program CAPTURE), USFWS (Chapman-Petersen Model), and Program Super-Tag.

Flannelmouth sucker - A project to develop a stock assessment model for the flannelmouth sucker (FMS), *Catostomus latipinnis*, has been recently initiated by AGFD. Preliminary results have indicated that recruitment occurring in the LCR, although variable has not declined like the pattern observed for HBC. Fig. 20, shows that between 1993-1995, recruitment was considerably higher in the LCR tributary. Unlike HBC these fish are known to move considerable distances throughout the CRE, and actively spawn in a number of tributaries [28, 33].

Even though this species is not limited to the LCR tributary for reproduction [32], it remains unknown whether or not adult FMS have high spawning fidelity to their natal streams.

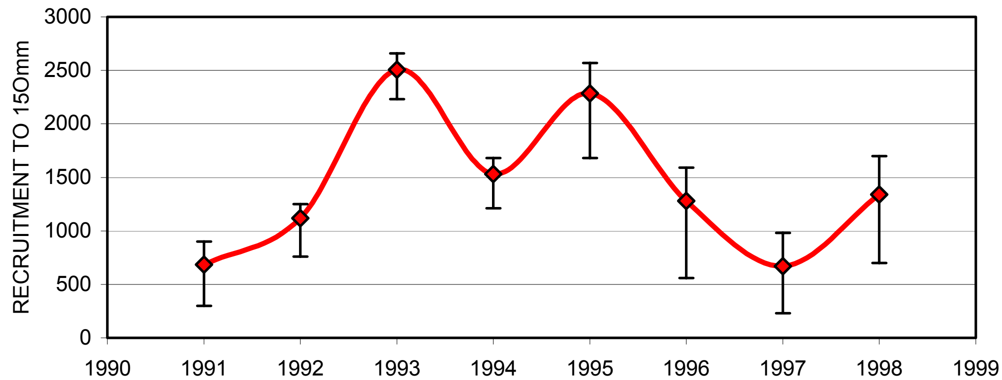


Figure 20, graphical representation of recruitment trends for flannelmouth sucker in the Little Colorado River. Trend reflects the abundance of a size class < 150 mm for a particular brood year.

Southwestern Willow Flycatcher - The southwestern willow flycatcher (SWFL); *Empidonax trailii extimus*, is a neotropical migrant, that is an obligate riparian insectivore [47], preferring habitat near open water [46]. The historical breeding range of the SWFL includes Arizona, New Mexico, southern California, and southern portions of Nevada, Utah, and perhaps southwestern Colorado, and extends east into western Texas. It probably winters from Mexico to Panama, with historical accounts from Colombia [48]. The SWFL is distinguished from other subspecies by its distribution, morphology and color, nesting ecology [46, 47, 49, 50], as well as singing behavior [45].

Surveys conducted during 2001, between Lees Ferry and Diamond Creek (0.0 to 225 RM) detected six individual birds at four different sites [31]. Yet, of the SWFL's surveyed this year only one breeding pair was confirmed. The remaining birds were suspected to be migrants or unsuccessful in establishing nesting territories. The single successful nesting pair was located at RM 50.4L downstream and contained two SWFL eggs and one brown-headed cowbird egg. Brown-headed cowbirds are brood nesting parasites that are implicated as being one of the major causes in the decline of this species. Fledgling success for this year was unknown. Since 1997, the inter-annual trend for SWFL nesting has been a single breeding pair per year (Fig 21). From 1982-2001, all of the willow flycatcher nests detected along the Colorado River corridor in Grand Canyon have occurred from RM 46 to RM 72 [31, 35, 51, 52, 53, 54, 55, 56].

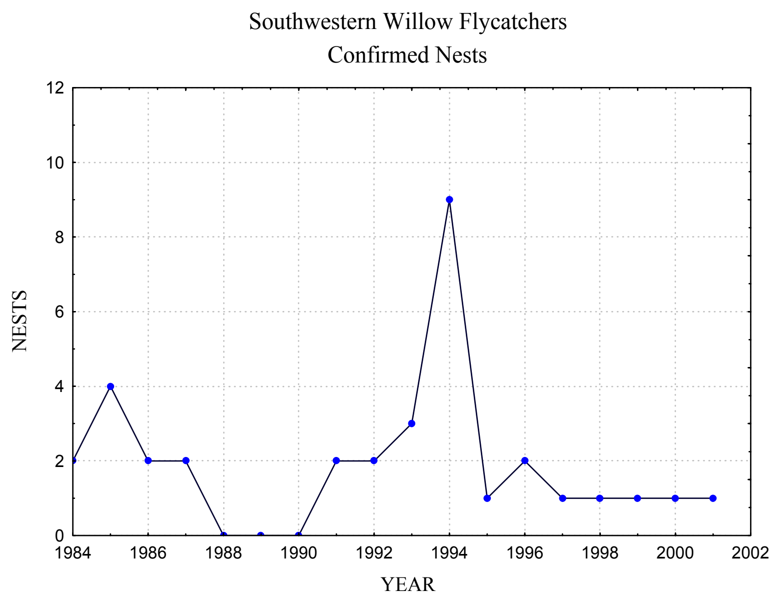


Fig 21, number of confirmed southwestern willow flycatcher (SWFL) nests detected along the Colorado River corridor in Grand Canyon from 1982-2001. No surveys were conducted between 1988-1990.

Kanab ambersnail – The Kanab ambersnail (KAS), *Oxyloma haydeni kanabensis* [57], was listed in 1992 as a federally endangered landsnail [58]. The extant populations of KAS are described from only a few localities: (1) Three Lakes, near Kanab Utah; (2) in seeps and springs along Kanab Creek, near Kanab, Utah; (3) at Vaseys Paradise, a spring in Grand Canyon, Arizona [59, 60], and 4) populations on the east slope of the Canadian Rocky Mountains in Alberta. In Grand Canyon, Vaseys Paradise (31.5 RMR) is a fast-flowing, cool, dolomitic-type spring, with abundant wetland and phreatophytic vegetation (e.g., crimson monkey flower, sedge, smartweed, and poison ivy, and non-native watercress). Although this site is recreationally popular, it is limited by access due to dense cover of poison ivy (*Toxicodendron rydbergii*) and vertical terrain [62].

Natural over-wintering mortality is considered approximately 20-80% of the population. Seasonal population estimates made for low-zone habitat (below 100,000 cfs) are derived using a mean bootstrap estimates (Fig. 22).

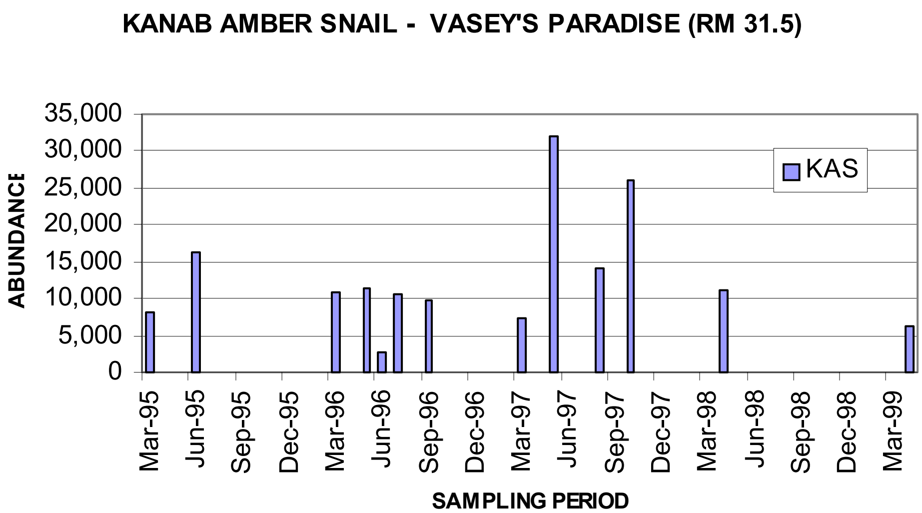


Figure 22, Kanab Amber Snail

For mitigative purposes, translocation efforts were conducted to establish and monitor secondary populations of KAS at three sites (Keyhole Spring, Upper Elves Chasm, and Lower Deer Creek) in Grand Canyon [61]. An additional captive breeding population was established at the Phoenix Zoo. Translocation and success in establishing a self-sustaining population is presently being monitored. Considerable taxonomic debate has centered on this species, where conventional taxonomy based on internal and shell morphology is being revisited using molecular genetic techniques [64]. Recent genetic findings [64], would suggest that large genetic distance exist between the Vaseys Paradise population and all other *Oxyloma* populations, yet taxonomic studies reveal certain populations are morphologically indistinguishable. This taxonomic debate has not been resolved.

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