LEE'S FERRY REACH: LOWER TROPHIC LEVELS AND RAINBOW TROUT
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Introduction

Trips were conducted in the Lee's Ferry reach (RM -15.5 to RM 0) during March to September 1997 in conformance with long-term monitoring and to assess influences of briefly-reduced releases from Glen Canyon Dam during the Labor Day holiday period on lotic biota.

LOWER TROPHIC LEVELS

I. Benthic macroinvertebrates, periphyton, submerged aquatic macrophytes, diatom epiphytes

Objectives were to determine: 1) standing stocks of benthic macroinvertebrates, periphyton, submerged aquatic macrophytes and diatom epiphytes at fixed transect locations in representative habitats (cobble bars and unconsolidated substrata) to provide baseline monitoring data, and 2) influences of briefly-reduced dam releases [Labor Day 227 m^3s^{-1} (8,000 cfs steady flows)] on lower trophic levels.

Methods

Discharge from the reservoir (Lake Powell) was increased from steady 596 m^3s^{-1} (21,000 cfs) to steady 777 m^3s^{-1} (27,000 cfs) on February 18 and reduced to ca. steady 596 m^3s^{-1} on March 15 through August 29. During August 30, 31 and September 1, discharges were maintained at steady 8,000 cfs. Releases from Glen Canyon Dam were reduced from 21,000 cfs to 8,000 cfs on August 29-30 [downramp = 28 m^3s^{-1}/hr (1,000 cfs/hr)] and maintained at the 8,000 cfs level until, when releases were upramped [85 m^3s^{-1}/hr (3,000 cfs/hr)] on September 2 to 21,000 cfs. Subsequent to September 2 (through September 21), daily discharge from the dam fluctuated between about 483 m^3s^{-1} (17,000 cfs) to 653 m^3s^{-1} (23,000 cfs).

We sampled (n=3 each site) benthic macroinvertebrates using a Hess sampler (0.09 m^2) on transects at three cobble bars (RM -14.0, RM -12.8, RM -8.0) and three depositional substrate sites (RM -14.5, RM -6.5, RM -3.5). We sampled benthos at the: 1) 18,000 cfs (511 m^3s^{-1}) flow elevation April 14, August 17 and September 17, and 2) 5,000 cfs (142 m^3s^{-1}), 8,000 cfs, 12,000 cfs (341 m^3s^{-1}) and 18,000 cfs flow elevations on August 30-31 [samples at the 12,000 cfs and 18,000 cfs flow elevations (varial zone; exposed to atmosphere) were collected using a template of equal area to the Hess sampler].

Macroinvertebrates were identified to the lowest practical taxonomic level, sorted into taxonomic groups and enumerated. We determined (August-September) ash free dry weights (AFDW) for *Gammarus lacustris* and total chironomids by loss on ignition, since these taxa comprise about 80 % or more (by volume) of animal matter in diets of rainbow trout in the reach (McKinney et al. 1996) and about 75% of the benthic macroinvertebrate mass at Lee's Ferry (Blinn et al. 1995).

Periphyton (0.415 cm^2 template) and macrophytes (Hess sampler, except that template = area of Hess was used for varial zone samples) were collected from the same transect sites and flow elevations as above, and AFDW (n=5/site/flow elevation) and chlorophyll *a* (n=5/site/flow elevation) were determined following standard procedures (McKinney et al. 1996). Samples were collected and preserved in Transeau's solution for determining composition and densities of filamentous algae and diatom epiphytes for periphyton using a 0.415 cm^2 template and from *Potamogeton* sp. by collecting stalk segments (McKinney et al. 1996). Three samples were collected from each of the above locations and flow elevations where possible and pooled (n=1/transect/flow elevation).

Benthic densities for April were not analyzed statistically. Macroinvertebrate densities during the August-September sampling periods were heteroscedastic and distributed non-normally. Densities at the 18,000 cfs flow elevation were compared between sampling periods prior to and following steady 8,000 cfs discharge for cobble bars and for unconsolidated substrata using the Mann-Whitney U-test. Densities at the 5,000 cfs, 8,000 cfs, 12,000 cfs and 18,000 cfs flow elevations during the period of steady reduced discharge were compared for each habitat type using the Kruskal-Wallis test (KW). If KW indicated significant differences among means, densities were compared within the exposed zone using the Mann-Whitney U-test. Ash free dry weight and chlorophyll *a* concentrations for periphyton at the 18,000 cfs flow elevation prior to and following steady 8,000 cfs discharge and at the 5,000 cfs, 8,000 cfs, 12,000 cfs and 18,000 cfs flow elevations during the period of reduced flows were compared using one-way ANOVA.

Changes in areal energy values were estimated using mean dry weights (DW; mg/m^2) for periphyton and benthic macroinvertebrates, previously determined energy content for *Cladophora glomerata* and macroinvertebrates (Blinn et al. 1995) and estimated cobble bar channel areas at different flow elevations (Blinn et al. 1992; 1995; Shaver 1995). We equated energy content of periphyton mass based on that for *Cladophora*, because mass of the alga likely comprises more than 90% of periphyton mass (Blinn et al. 1995) and epiphyton dry weights were not determined. Thus, estimates of energy loss for periphyton presented here are intended to provide approximations of relative magnitude.

Results

1) Benthic macroinvertebrates

April

Macroinvertebrates colonized at the 18,000 cfs flow elevation in April, but amphipod densities were particularly low (Table 1).

August-September

Mean densities of *Gammarus lacustris* and chironomids declined more than 90% and 72%, respectively, between August 17 and September 17 on cobble bars and unconsolidated substrata (Table 3). However, oligochaete densities did not differ between sampling periods on cobble bars ($P=0.1711$) or depositional sites ($P=0.0576$), and gastropod densities were lower in September on cobble bars but did not differ ($P=0.3314$) from August levels on unconsolidated substrata (Table 3). During the period of reduced discharge, densities on cobble bars differed among flow elevations for *Gammarus* ($P<0.004$) and oligochaetes ($P<0.004$) but not for chironomids ($P=0.1343$) or gastropods ($P=0.994$) (Table 4). In contrast, flow elevation significantly influenced densities on depositional sites for chironomids ($P<0.03$) and oligochaetes ($P<0.01$), but *Gammarus* ($P=0.2602$) and gastropod ($P=0.4342$) densities were independent of flow elevation (Table 4). Within the exposed zone above 8,000 cfs flow elevation, densities did not differ for *Gammarus* ($P=0.3099$) on cobble bars or chironomids ($P=0.3772$) on depositional substrata (Table 4).

Mean biomass (AFDW) concentrations of *Gammarus* declined about 93% on cobble bars and depositional sites, while mean biomass concentrations of chironomids declined more than 95% on cobble bars and about 62% on depositional sites, following the steady 8,000 cfs flows (Table 5). Based on mean DW and published energy content of *Gammarus* and chironomids (Blinn et al. 1995), the declines were associated with energy loss of 1.5×10^4 joules/m^2 for amphipods and 0.12×10^4 j/m^2 for chironomids on cobble bars. Densities and AFDW of *Gammarus* and chironomids did not differ significantly ($P>0.05$) within the exposed zone on cobble bars or unconsolidated substrata (Tables 4, 6), and we assumed uniform distribution within the area for purposes of energy estimations. If cobble bars comprise about 16% of the total littoral habitat in Glen Canyon (Angradi and Kubly 1993), the reduction in discharge resulted in a loss of about 10,000 m^2 of wetted channel associated with cobble substrata (Blinn et al. 1992; 1995; Shaver 1995). Based on this areal estimate and mean DW at the 18,000 cfs flow elevation, estimated ecosystem energy loss from the habitat in the reach for *Gammarus* and chironomids, respectively, was about 15.4×10^7 joules and 1.2×10^7 joules on cobble bars.

Declines in densities of *Gammarus* and chironomids, respectively, on unconsolidated substrata were associated with estimated energy losses of 2.0×10^4 j/m^2 and 0.42×10^4 j/m^2. Areal estimates for loss of wetted channel associated with depositional substrata are not presently available, precluding computation of ecosystem energy loss for this habitat.

2) Periphyton and macrophytes

April

Periphyton colonized extensively at the 18,000 cfs flow elevation in April, but macrophytes were absent from all transects (Table 2). *Cladophora glomerata* was absent from all transects, and *Oscillatoria* sp. and *Ulothrix zonata* were dominant filamentous algae on cobbles.

August-September

Biomass of periphyton was reduced following exposure to atmospheric conditions and re-inundation (Table 7). Ash free dry mass was nearly 40% lower than initial (August 17) levels on the first day of exposure and was 75% lower following re-inundation (Tables 7, 8). Chlorophyll *a* concentration of periphyton also declined 64% from initial values following re-inundation, but this effect was not apparent on the first day of atmospheric exposure (Tables 7, 8). During the steady 8,000 cfs flows, neither AFDW (P=0.2998) or chlorophyll *a* concentration (P=0.3421) differed among flow elevations in desiccated and inundated zones (Table 8).

Reduced periphyton standing stock in the exposed zone between 18,000 cfs and 8,000 cfs flow elevations may have resulted in a loss of about 7×10^6 j/m^2 on cobble bars. Following above estimates for dewatered area and energy content and assuming that reductions in periphyton standing stock and energy values were uniform throughout the varial zone, the steady 8,000 cfs flows may have been followed by a loss of about 72×10^{10} joules of ecosystem energy in the Lee's Ferry reach associated with periphyton on cobble bars by September 17. Our estimates do not include energy content of diatom epiphytes. Energy content for *Cladophora* and diatom epiphyton are comparable (Blinn et al. 1995), but the macroalga increased, while diatom densities declined, with water depth at Lee's Ferry (Hardwick et al. 1992). Standing stocks below the 18,000 cfs flow elevation prior to and following the reduced discharge period were inaccessible to sampling.

Colonization by aquatic macrophytes on transects was highly variable, and no statistical comparisons of standing stock prior to and following reduced flows were conducted. During August 17, macrophytes colonized at the 18,000 cfs flow elevation only at RM -3.5, and they were absent from all transects at that flow level in September (Table 7). Aquatic macrophytes also were absent from all transects at the 18,000 cfs flow elevation and were absent from the 12,000 cfs flow elevation at RM -14.5 during August 30-31 (Table 8). Ash free dry weight and chlorophyll *a* concentrations during the 8,000 cfs flows did not differ significantly (ANOVA; P>0.05) among 5,000 cfs, 8,000 cfs and 12,000 cfs flow elevations (Table 8). Thus, limited data indicate total loss of macrophytes on one transect following reduction of flows to 8,000 cfs. However, river surveys (see Trip Report below) demonstrated that macrophytes colonized above the 8,000 cfs flow elevation prior to (August) but not following (September) reduced flows. Energy content of macrophytes, and diatom epiphyte analyses are not completed, precluding estimates for loss of ecosystem energy associated with reductions in these communities.

3) Epiphytic diatoms

April

No macrophytes colonized transects in April, precluding sampling of epiphyton. Mean total diatom epiphyte density on cobbles was 25,819/m^2 (" 2580.6 SE). *Achnanthes minutissima* and *A. coffieformis* were dominant small/adnate taxa, and *Diatoma vulgare*, *Melosira* sp. (not epiphytic) and *Gomphonema olivaceum* were dominant large/upright forms.

<u>August-September</u>

Mean total diatom densities on cobbles did not differ between August 17 and September 17 sampling periods [August: 28,219/m^2 (" 6525.1 SE); September: 31,485/m^2 (" 3352.4 SE)]. *Cocconeis pediculus* was the dominant small/adnate taxon in both periods, and *D. vulgare*, *Synedra ulna* and *G. olivaceum* were dominant large/upright forms. *C. glomerata* was the dominant filamentous alga in August and September, but *Oscillatoria* sp. was newly colonized in September, and *U. zonata* colonized more abundantly in September than August.

C. pediculus and *A. minutissima* were co-dominant small/adnate forms on *Potamogeton* sp. in August, and *S. ulna*, *D. vulgare*, *Tabellaria fennestrata* and *G. olivaceum* were dominant large/upright taxa. Mean density of total diatom epiphytes on *Potamogeton* sp. in August ranged from 142,352/mg AFDW to 147,826/mg AFDW at the two sites sampled. No differences were apparent in diatom epiphyton densities at various flow elevations for cobbles or *Potamogeton* sp. during the period of reduced releases from the dam (Table 9).

II. River Surveys: Relative abundance and distribution of submerged aquatic macrophytes

The objective was to determine distribution and relative abundance of submerged aquatic macrophytes throughout the tailwater. Releases from the dam during surveys were: March 3-4--27,000 cfs (767 m^3s^{-1}); May 19 and 22 21,000 cfs; August 17 20,000 cfs; May 19 and 20--21,000 cfs (596 m^3s^{-1}) and September 21 ca. 17,000 cfs (483 m^3s^{-1}) to 21,000 cfs. Since about mid-1993, *Chara contraria* or *Potamogeton* sp. (probably *P. pectinatus*) have been dominant submerged macrophytes in the reach; *Egeria densa* has occurred infrequently and sparsely but intermittently in high abundance at some locations.

Methods

Relative abundance and distribution of submerged macrophytes were estimated by traversing the shoreline area on river right (RR) and river left (RL) slowly by boat between Glen Canyon Dam and Lee's Ferry. Distributions of macrophyte beds were determined visually and plotted using topographic maps. Relative abundance (densities) within localized distributions was ranked ordinally (OV=ordinal value) as follows:

OV 0 = Absent (may be occasional small, isolated patches)
OV 1 = Low vertical growth and abundance per unit area and/or extreme patchiness
OV 2 =Relatively greater but moderate vertical growth and abundance per unit area; may be patchy
OV 3 = Highest vertical growth and abundance per unit area; little or no patchiness

Relative abundance and distribution of submerged macrophytes observed throughout the reach during March, May, August and September were compared qualitatively.

Results

March

The quarterly survey of submerged aquatic macrophytes on March 3-4 was the first following implementation of the 27,000 cfs steady flows on February 18, 1997. Inclement weather conditions since February 24 prevented effective survey prior to early March. Intermittent gusty winds hampered our work in March but did not preclude reconnaissance. Our observations were restricted to a maximum depth of about 3 m, due to combinations of water depth, poor light and murky water. We estimate that this permitted data collection generally to just below the 5,000 cfs flow elevation.

Comparing present results (Figure 1; Appendix 1) with our November 1996 survey, it appears that two weeks of the steady 27,000 cfs flows have greatly reduced abundance and distribution of macrophytes in the reach. In general, conditions appear to be remarkably similar to and reminiscent of those we observed following the 1996 spike flow. Abundance and distribution of macrophytes are low, and *Potamogeton* sp. is the only taxon present (not including bryophytes), with minor exception. No *Egeria densa* was present. *Potamogeton* appeared in many areas to colonize in small patches as fine-textured, new growth with low vertical profile (very short stem length). This growth form likely hampered our identification of patches in deeper water in some areas. Similarly, identification of *Chara* possibly was obscured in deeper areas. However, we believe that observations are reliable concerning general distribution and abundance of macrophytes in the reach.

Most observable drift in the reach was comprised of bryophytes, and this was particularly apparent in certain locations where bryophyte abundance was high. We have noticed that bryophyte concentrations in the observable drift often are high. During the past two years or so, abundance and distribution of bryophytes has apparently increased in the reach. The taxa (taxon?) often is difficult to discern and identify in situ, since it is similar and frequently grows in association with *Cladophora* (similar habitat, substrate). It also grows in association with macrophytes. Previous grab samples (periphyton) indicate that *Gammarus* densities in bryophytes may be quite high, and we believe that these higher plants may provide significant amphipod habitat in the reach. Grab samples of drifting bryophytes during the present survey, however, contained no macroinvertebrates. Water depth precluded sampling of bryophytes colonized on the substrata.

No colonization of macrophytes was observed in the newly-inundated zone associated with the 27,000 cfs flows (i.e., above estimated 20,000 cfs flow elevation). However, blue-green and unknown filamentous algae have colonized to some extent in this zone. Much of the reach consists of bare sand, but colonization of sand substrate by blue-green algae (no positive identification made) and unknown filamentous algae is extensive. This is similar to our observations following the 1996 spike flow. Also, high trout concentrations frequently occurred over bare sand substrate, and we observed this following the spike flow.

May

We conducted a survey of submerged aquatic macrophytes in the Lee's Ferry reach on May 19 and 22, 1997 (Figure 2; Appendix 2). Discharge from Glen Canyon Dam on these days was steady at ca. 21,000 cfs. Considerable bare sand substrate occurred on river right, but little was observed on river left. No *Chara contraria* was observed; two very small patches of *Egeria densa* were present at about RM -5.5 (RR) and RM -4.2 (RL). *Potamogeton* sp. colonized extensively throughout the reach. Colonization of the angiosperm generally was restricted within visible depth to the flow elevation zone between about 10,000 cfs (284 m^3s^{-1}) and 18,000 cfs and occurred primarily between about 15,000 cfs (426 m^3s^{-1}) to 18,000 cfs (estimated flow elevations). *Cladophora glomerata* colonized extensively from visible depths to about the water line (21,000 cfs), and blue-green algae (presumed) occurred extensively on sand substrata.

August-September

Relative abundance and distribution of *Potamogeton* sp. throughout the Lee's Ferry reach below the 8,000 cfs flow elevation differed little between August 19-20 (Figure 3; Appendix 3) and September 21 (Figure 4; Appendix 4) river surveys. In contrast to August, when aquatic macrophytes colonized extensively to about the 21,000 cfs flow elevation, macrophytes were absent above the 8,000 cfs flow elevation in September. Distribution of *Potamogeton* sp. during both sampling periods ranged from sparse, isolated clumps to very large and extensive beds in both months. Subjectively, angiosperm distribution tended to be more patchy in September (below the 8,000 cfs elevation) than in August, but this difference is consistent with temporal variations in abundance and distribution previously observed (personal observations) and likely reflects minimally, if at all, influences of the Labor Day period flow reductions. No *Chara contraria* was observed in September, but abundance and distribution of *Egeria densa* increased somewhat.

Discussion

Maximum releases from Glen Canyon Dam seldom inundated the 18,000 cfs flow elevation between the 1996 controlled flood and early 1997, and mean monthly releases generally were ca. 12,000-15,000 cfs. Colonization at the 18,000 cfs flow elevation by periphyton was extensive during April, but macrophytes did not colonize at that flow elevation until August. *U. zonata* and *Oscillatoria* sp. colonized earlier than *C. glomerata* in the "newly" inundated zone in April, but *C. glomerata* was the dominant filamentous alga by August. Our results support indications that *Oscillatoria* sp. tend to colonize relatively early in disturbed or newly-inundated zones, while colonization by *C. glomerata* is reduced or occurs more slowly

(Blinn et al. 1995; Stevens et al. 1997). High densities of diatom epiphytes on Oscillatoria sp. and U. zonata may enhance early colonization of benthic macroinvertebrates in these zones. However, *Gammarus lacustris* selected *C. glomerata* over *Oscillatoria* sp. in field experiments (Shannon et al. 1994).

C. pediculus replaced *Achnanthes* spp., and *S. ulna* replaced *Melosira* sp. in August when *C. glomerata* colonized on cobbles. Composition of dominant diatom epiphyte taxa was similar on *C. glomerata* and *Potamogeton* sp., except that the angiosperm hosted proportionally more *A. minutissima* and *Tabellaria fennestrata*. The brief period of reduced releases had no apparent effects on composition of dominant diatom epiphyton taxa or cell densities on cobbles, but the reduced discharges were followed by increased colonization by *Oscillatoria* sp. and *U. zonata*. Lack of differences in diatom cell densities on cobbles may not reflect changes in cellular constituents or metabolism which may be of ecological importance (Blinn et al. 1995).

Benthic macroinvertebrates colonized on both cobble bar and unconsolidated substrata, but amphipod densities were particularly low. Chironomids, however, colonized at comparatively at high densities on cobble bars and unconsolidated substrata, and gastropods and *Gammarus* appeared to colonize more rapidly on cobble bars than on unconsolidated substrata lacking macrophytes.

Three days of reduced releases from Glen Canyon Dam significantly impacted benthic communities negatively in the tailwater varial zone on cobble bars and unconsolidated substrata. We consider it unlikely that seasonal changes in macroinvertebrate, macrophyte and periphyton standing stocks contributed to declines observed between August and September sampling periods (Ayers and McKinney 1997a; 1997b; 1997c). Negative impacts throughout the varial zone are inferred from samples obtained at a high flow elevation. However, measurements at different flow elevations in the varial zone during the period of reduced flows indicated no differences in standing stocks of periphyton associated with flow elevation, and we presume comparable effects of exposure extended throughout the zone.

Fluctuating flow elevations adversely affect algal beds, rendering them unsuitable as habitat for benthic macroinvertebrates even after rewetting (Blinn et al. 1994; 1995; Fisher and LaVoy 1972; Trotzky and Gregory 1974). Experimental (Blinn et al. 1994; 1995) and field (Angradi and Kubly 1993; Ayers and McKinney 1997a; 1997b; Leibfried and Blinn 1987) studies in the Lee's Ferry reach have provided evidence of negative impacts of fluctuating flow elevations and atmospheric exposure on invertebrate assemblages. Our studies demonstrate that a single brief period of atmospheric exposure resulting from flow reduction within a regimen of steady releases from the dam also negatively influence standing stocks of some macroinvertebrate taxa. Densities and mass of *Gammarus* and chironomids were reduced significantly on re-inundated cobble bars and unconsolidated substrata following the brief period of desiccation due to reduced releases from the dam. However, oligochaete densities were unaffected by atmospheric exposure, and the taxa possibly avoided desiccation by burrowing (Kaster and Jacobi 1978). Snail densities were lower only on cobble bars, where concentrations generally are greater than in depositional habitat (Ayers and McKinney 1997a). Mortality of *Gammarus* stranded in the varial zone was high (personal observation), but refugia in localized wetted areas and the hyporheic zone may have reduced mortality (Mackay 1992; Power et al. 1988; Sedell et al. 1990; Stanford and Ward 1993; Waters and Hokenstrom 1980).

Rates of recolonization by benthic invertebrates following flow-related disturbance is variable (Blinn et al. 1994; 1995; Grimm and Fisher 1989; Kaster and Jacobi 1978; Meefe and Minckley 1987) but may be greater on substrates with large amounts of organic matter than on sandy substrata with little organic matter (Kaster and Jacobi 1978). *Gammarus* and chironomids comprise major components of the diet of rainbow trout in the Lee's Ferry reach (present data; Angradi 1994; McKinney et al. 1996) and tended to be more adversely affected by desiccation than other taxa examined. Reductions in discharge and losses of energy associated with amphipods and chironomids potentially impact rainbow trout production in the reach (Blinn et al. 1995).

Our results support previous research demonstrating that brief experimental desiccation of periphyton in the Lee's Ferry reach also reduces concentrations of mass and chlorophyll *a* (Angradi and Kubly 1993; Blinn et al. 1995; Usher and Blinn 1990), and lower concentrations persist following re-inundation of previously-exposed cobbles (Angradi and Kubly 1993; Blinn et al. 1995). Macrophyte standing stocks were more variable than periphyton within the exposed zone, but results indicate loss of standing stock on unconsolidated substrata exposed by flow reduction. The brief period of reduced flows in present studies may have negatively impacted benthic macroinvertebrates less, and periphyton more, than brief, repeated experimental exposures. Estimated energy losses for *Gammarus* and chironomids resulting from the three day reduction in flows generally were lower, while those associated with periphyton were higher, than declines resulting from five days of repeated experimental exposure of cobbles (Blinn et al. 1995). However, reduced densities of *Gammarus* in the varial zone (as compared to permanently-inundated substrata) associated with fluctuating flows on a cobble bar (Angradi and Kubly 1993) were proportionally comparable to declines which we observed.

The Lee's Ferry reach supports more than 60% of the benthic primary producer and macroinvertebrate mass in the Colorado River corridor through Glen and Grand Canyons (Blinn et al. 1994; Shannon et al. 1996; Stevens et al. 1997). We estimate than the brief reductions in releases from the dam likely resulted on cobble bars within the Lee's Ferry reach in a potential initial loss of ecosystem energy exceeding 72 x 10^{10} joules associated with periphyton, *Gammarus* and chironomids. Benthic standing mass in the reach contributes significantly to the food web of downstream aquatic communities (Angradi 1994; Angradi and Kubly 1994; Blinn et al. 1995; Shannon et al. 1996; Stevens et al. 1997), and organic drift associated with the rising hydrograph subsequent to 8,000 cfs flows likely provided available energy to downstream biota (Blinn et al. 1995; Shannon et al. 1996). Previous studies (Blinn et al. 1995; McKinney et al. 1996) suggest that recovery of benthic assemblages in the Glen Canyon tailwater following re-inundation of the Labor Day varial zone may be prolonged.

RAINBOW TROUT

We electrofished during April 19, 20 and 21 and during the 8,000 cfs steady flows (August 30, 31, September 1; Trip #56) to monitor population parameters, feeding and diets of rainbow trout. Objectives of electrofishing during increased releases from the dam on September 2 were to determine during a period of rising flows: 1) feeding and diets of rainbow trout, and 2) drift concentrations of *Gammarus lacustris* and chironomids.

Methods

We electrofished at night during April 19, 20 and 21 (Trip 55; dam discharge ca. 21,000 cfs) and during the reduced steady flows (August 30, 31 and September 1; Trip 56; dam discharge 8,000 cfs). Nine sites (standardized transects; Tables 10, 15) were sampled by single pass electrofishing, using a crew of five each night and following standardized procedures (McKinney et al. 1996). We also electrofished seven transects (sites 3, 4, 5, 9, 10, 13, 15) in daylight (07:15 hr-11:05 hr) on September 2 during the period when releases from the dam increased from 8,000 cfs to 21,000 cfs. Duration of electrofishing during upramp was limited to that required to collect approximately five rainbow trout from each transect (only one fish was captured from site 3 in 1,194 sec of effort).

Trout captured were measured (" 1 mm), checked for presence of coded tags (stocked fish), weighed (" 0.1 g; fish <100 mm not weighed) and released unless sampled for stomach contents. Stomachs were removed (April 19-21: n= ; August 30, 31, September 1: n=45; September 2: n=36) in the field and preserved in 10% formalin (Bowen 1996). Stomach contents were removed from the portion of the gut between the anterior of the esophagus and the pyloric sphincter (Kimball and Helm 1971) and analyzed in the laboratory by identifying and sorting ingested matter to the lowest practical taxonomic level and measuring proportional composition of *Cladophora glomerata* and macroinvertebrates using volumetric displacement. Ash free dry weights (AFDW) of *Gammarus lacustris* and total chironomids were determined by loss on ignition (August-September only).

Drift samples were collected during August-September at the lower end of each electrofishing site by deploying a fixed net (0.5 m diameter; 1,000 :m mesh) at the river surface. Current velocity at the surface was measured with a Marsh-McBirney flow meter at the beginning of each tow and assumed to be constant during sampling. Duration of drift collection was 5 min/site during the 8,000 cfs steady flows but varied between 0.5 min to 5 min at sites during upramp on September 2, due to high drift concentrations of organic matter and clogging of the collecting cylinder at some sites. Mean volume of water passing through drift nets was 19.9 m^3 ("4.9 SE) for the steady 8,000 cfs steady flows and 11.8 m^3 ("4.4 SE) for upramp releases from the dam. Drift samples were analyzed in the laboratory by identifying and sorting material collected and measuring macroinvertebrates using volumetric displacement. Ash free dry weights of *Gammarus lacustris* and total chironomids in drift samples were determined by loss on ignition.

We calculated condition factor (K = weight x 10^5/length^3) and relative weight [Wr = weight/10**(-4.600 + 2.856*LG10(length)*100)] for all trout $\geq$ 100 mm long and relative gut volume [RGV = volume of stomach contents (mL)/fish length (m); Filbert and Hawkins 1995] and relative gut mass [RGM = AFDW of stomach contents (mg)/fish length (m)] for fish collected for food analyses. Chi-square was used to test for differences in frequency of empty stomachs and occurrence of items ingested by trout (August-September). Proportional volumes, relative mass of ingested items and macroinvertebrate drift concentrations were compared between steady 8,000 cfs and rising flows using the Mann-Whitney U-test.

Results and Discussion

April

1) Population indices

A total of 726 rainbow trout (RBT; *Oncorhynchus mykiss*) (Table 10) and one flannelmouth sucker (female; marked with PIT tag #1F7F1D4500; weight 1,704 g; length 544 mm; captured at site RM -12.5RL) were captured. One floy-tagged RBT was recaptured (tag # Y033782; length 376 mm; weight 508 g; RM -3.5 RL). Incidence of "snakey" RBT was low. Site-specific and total catch, electrofishing effort and catch per minute (CPUE) for RBT are presented in Table 8. The total CPUE for Trip 55 (CPUE = 2.36) was slightly higher than during April 1994 (Trip 44; CPUE = 2.04) but was lower than during May 1995 (Trip 47; CPUE = 2.75) and March 1996 (Trip 49; CPUE = 3.52) (Figure 6).

Trout captured during April (Table 11; no statistical analyses) tended to be heavier and longer but to have a lower condition factor (K = weight x 10^5 / length^3) than those captured during March 1996 (trip 49 means: weight = 198.5; length = 230.8; K = 0.961). About 9% of RBT captured during April were within the slot, and 97% of these were naturally-recruited (Table 12). In comparison, about 33% of RBT captured were within the slot during Trip 36 (November 1991), and fewer than 10% were within the slot in Trip 49 (March 1996).

About 90% of the RBT captured during April were wild-spawned (Table 12). Among recaptured fish, fewer than 11% of all trout were wire-tagged (WH), fewer than 1% were adipose-tagged (WA), and 0.14% were floy-tagged (Table 12). Length frequencies were distributed bimodally for RBT with no coded wire tags (WN) and unimodally for recaptured fish with coded wire tags (WH) (Table 13).

2) Feeding and food habits

Trout consumed primarily *Gammarus*, chironomids and *Cladophora* in April, and gastropods were eaten infrequently and in low volume (Table 14). Most trout were feeding, and total ingested volume and proportion of dietary components were within expected ranges.

August-September

1) Population Indices

We captured 1,836 rainbow trout ranging from about 30 mm to 559 mm in length during the 8,000 cfs steady flows (Table 15). Catch per minute of electrofishing effort was unusually high and greater than recorded since late 1991 (Table 15; Figure 4). Condition factor and relative weight were adequate (Table 16). We also captured one channel catfish (*Ictatulus punctatus*; RM -14.5RR; 162 mm) and two male flannelmouth sucker [*Catostomus latipinnis*; RM -3.0RR; PIT # 7F7B07013D (464 mm, 998 g) and PIT # 5116736401 (471 mm, 1290 g)].

We qualitatively surveyed cobble bars (RM -14, RM -12.8, RM -8) and the backwater at RM -2.5 to determine possible stranding mortality of fishes during the 8,000 cfs steady flows. One large carp (*Cyprinus carpio*) was observed at RM -12.8 and may have been a stranding or fishing-related mortality. Stranded small (ca. <152 mm) rainbow trout were observed in the varial zone on all cobble bars, but total numbers appeared to be low. No stranding was observed on depositional substrata (RM -14.5, RM -6.5, RM -3.5). We estimate that proportional mortality in the trout population due to stranding likely was insignificant. High percentages of trout <100 mm (31%) and <160 mm (45%) captured by electrofishing during the 8,000 cfs steady flows (Table 18) tend to support this conclusion.

Wild-spawned trout, fish <305 mm (<12 in) and fish <152 mm (<6 in), respectively, comprised about 97%, 63% and 45% of of the total catch (Tables 17, 18), reflecting recent trends toward increased percentage of wild-spawned fish and higher percentage of smaller trout in the reach (AGFD unpublished data; Reger et al. 1997). About 93% of fish within the slot (406 mm-559 mm) were wild-spawned (Table 17). Length frequency distributions of wild-spawned and stocked trout were bimodal (Table 18). About 4% of all trout captured were within the slot, which is consistent with lower catch within the slot by anglers (Reger et al. 1997) and lower capture of the size group by electrofishing since 1992 (AGFD unpublished data). However, proportional harvest by anglers and capture by electrofishing of fish within the slot increased in early 1997 (McKinney and Rogers 1997; Reger et al. 1997).

Catch per minute over the Labor Day 1997 period was about double that in March-April 1996 during 8,000 cfs steady flows prior to and following the 1996 controlled flood and about three times higher than during ca. 21,000 cfs discharges in April 1997 (Tables 10, 15; Figure 6). Results indicate that CPUE and total biomass caught per minute increase during briefly-reduced stable flows (Figure 6), likely due to concentration of fish accessible to electrofishing.(Figure 6).

Condition factor for the Labor Day 1997 8,000 cfs flows was slightly below that recorded in March-April 1996 and equivalent to that recorded in April 1997, while relative weight was comparable for March-April 1996 (McKinney et al. 1996), April 1997 (W_r=) and the present trip (Tables 11, 16). Mean length of trout captured in the present study (Table 16) was lower than during April 1997 (Table 11). However, mean weights were comparable during present studies and April 1997 and were greater than during the March-April 1996 steady 8,000 cfs flows (McKinney et al. 1996), consistent with a possible recent trend toward harvest of larger fish by anglers (Reger et al. 1997). In contrast, percentage of total fish captured within the slot by electrofishing over the Labor Day 1997 period (Table 17) was approximately 70% that for March-April 1996 steady 8,000 cfs flows (McKinney et al. 1996) and about half that for April 1997 (Table 12).

Proportional stock density (PSD) is a numerical descriptor of length-frequency data used in fish stock assessment (Anderson and Neumann 1996). We computed PSD's in a preliminary population analysis of rainbow trout captured by electrofishing in the Lee's Ferry reach during 1991 to 1997, using the following formula:

PSD = (number of fish $\geq$ minimum quality length/number of fish $\geq$ minimum stock length) X 100

We assumed for these calculations that minimum quality length = 406 mm (16 in) and minimum stock length = 305 mm (12 in). Quality and stock lengths, respectively, were defined as the minimum for the present slot limit and a presumed minimum for size of fish (i.e., "pan-size") that most anglers like to catch (Reger et al. 1997).

We define a "balanced population" as one that is intermediate between extremes in size and has satisfactory rates of recruitment, growth and mortality; high or low PSD values and wide variations over time are evident in populations with functional problems (Anderson and Neumann 1996). The PSD for trout captured by electrofishing declined from 1991, following widely varying research flows (Patten 1991), to 1997 (Figure 5). Within the overall 1991-1997 decline, PSD tended to increase seasonally during fall to spring each year, while during spring to fall it tended to decrease, likely reflecting seasonal dynamics of growth and recruitment (Figure 5). Interestingly, the seasonal periods of increase and decrease in PSD, respectively, correspond also with lower and higher periods of angler use (Reger et al. 1995). Handling and air exposure in "catch and release" fisheries may significantly influence survival of released fish (Ferguson and Tufts 1992), possibly affecting trout within the slot limit more than smaller sizes. The seasonal trends in PSD we observed correspond with results obtained in 1980-1981 (Persons et al. 1985) indicating greater angler harvest of fish >500 mm during August-February and lower catch of this size class during March-July. Results obtained during the August 1996 to Labor Day 1997 period conformed with both the overall declining trend and previous seasonal changes in PSD.

Based on our assumptions, PSD values suggest an imbalanced trout population (Anderson and Neumann 1996) following the 1990-1991 research flows to 1997. However, rate of decline in the PSD tended to be lower after 1993 (about two years following inception of the interim flow regime) and tended to stabilize after inception of the Modified Low Fluctuating Flow regime in September 1996 (Figure 5). Growth rate of trout in the Lee' Ferry reach also was comparatively low during 1990-1994 but increased after that time (Reger et al. 1995; 1997), and the percentage of wild-spawned fish captured by electrofishing has increased since 1992

(AGFD unpublished data). Relatively stabilized PSD values since the 1996 controlled flood also correspond with apparent trends (based on results from comparable seasons) toward lower and higher proportions, respectively, of fish <152 mm and between 304 mm-405 mm in electrofishing samples (AGFD unpublished data; McKinney et al. 1996; McKinney and Rogers 1997; Reger et al. 1997).

Our results generally agree with other studies (Kwak and Waters 1997) indicating that density and biomass correspond (Figure 6) and that younger age classes contribute most to biomass (Figure 7) in salmonid populations. Total biomass caught by electrofishing during August-September steady flows was 314 kg, and 17.4% of biomass occurred within the slot; trout ≥100- <152 mm, 152-306 mm and 307-407 mm, respectively, comprised 1.8%, 16.3% and 64.5% of total biomass (Figure 6). Trout <407 mm comprised more than 82% of biomass caught over the Labor Day 1997 period, and most biomass was comprised of fish 307 mm-407 mm in length (Figure 7).

Total biomass/min of electrofishing effort during the August-September reduced releases from the dam exceeded that for November 1991 and was about fivefold greater than during the low of October 1993 (Figure 6). Catch per minute and biomass/unit of electrofishing effort increased after 1993 in the Lee's Ferry reach (Figure 6). However, catch per unit effort, except for periods of 8,000 steady flows in 1996 and 1997, has remained comparatively stable since mid-1994, while biomass/min of electrofishing has tended to increase since 1995 (Figure 4). Over 1991-1997, relative abundance (CPUE) accounted for much of the variability in biomass [Pearson correlation coefficient (r) = 0.83; P<0.001].

2) Feeding and food habits

More trout were feeding and fish ate more during rising than during steady flows (Table 19). *Gammarus* comprised a greater proportion of the diet (Table 16), and RGV and RGM of the amphipod in trout stomachs increased during rising discharges from the dam (Table 20). In contrast, RGV and RGM of chironomids, proportional composition of chironomids, gastropods and *Cladophora,* and frequencies of occurrence of all ingested items did not differ significantly (P>0.05) between steady and rising flows (Tables 19, 20). Higher proportion of gastropods during steady flows than in April likely indicates increased epibenthic feeding (Angradi and Griffith 1990) during the period of low discharge, rather than seasonal change in availability in the drift (Ayers and McKinney 1997c).

Drift concentrations of *Gammarus* and chironomids (AFDW P=0.099) also increased during rising flows (Table 20), and results suggest that trout selected for *Gammarus* as releases from the dam and drift concentrations of the amphipod increased. Greater drift concentrations of macroinvertebrates during rising flows (Table 20) likely resulted from entrainment of organisms stranded during receding flows prior to steady 8,000 cfs discharge (Tables 4, 6; Blinn et al. 1995; Cushman 1985; Perry and Perry 1986; Scullion and Sinton 1983), since macroinvertebrate drift concentration at night typically exceeds that during the day (Brittain and Eikeland 1988). We found no terrestrial invertebrates in trout stomachs during 8,000 cfs steady flows, but they occurred in 11% of trout stomachs and comprised less than one percent of the diet during upramp releases.

We electrofished at night during steady flows to maintain continuity of monitoring data, but scheduling of releases from the dam during rising flows necessitated sampling in daytime. Angradi et al. (1992) suggested that feeding by trout in the Lee's Ferry reach may be reduced at night. Although invertebrate drift generally is greater at night (Brittain and Eikeland 1988), trout often feed more in daylight hours (Angradi and Griffith 1990; Bisson 1978; Young et al. 1997). Differences in relative abundance and size among food items also influence trout feeding behavior (Bres 1986; Ware 1972). However, intensity of predation by fish tends not to be proportional to their food supply (Ware 1972). Increased feeding and food intake during rising flows in the present studies were comparable in relative magnitude to expected values associated with diel feeding behavior of trout (Angradi and Griffith 1990; Beauchamp 1990; Elliott 1973; Jenkins et al. 1970). We conclude that diel feeding behavior, increased invertebrate drift and rising discharge potentially interacted to influence our results, precluding assessment of relative importance of variables influencing feeding and diets of trout.

SUMMARY

1) Benthic macroinvertebrates (particularly *G. lacustris*), submerged macrophytes and *C. glomerata* colonized slowly in areas newly-inundated by increased releases from Glen Canyon Dam. *Oscillatoria* sp. and *Ulothrix zonata* colonized rapidly in nearshore areas following increased flow levels and hosted abundant diatom epiphytes. Composition of dominant diatom epiphytes on periphyton changed following replacement of *Oscillatoria* and *Ulothrix* by *C. glomerata*. Composition of dominant diatom epiphytes was similar on *C. glomerata* and submerged macrophytes, except that *Potamogeton* sp. hosted more *A. minutissima* and *T. fennestrata*.

2) Three days of reduced releases from the dam during August-September within a regimen of steady releases from the dam negatively influenced densities and mass of periphyton, macrophytes, *Gammarus* and chironomids on re-inundated cobble bars and unconsolidated substrata, but total densities of diatom epiphytes on periphyton were unaffected.

3) Electrofishing results indicate that catch and biomass per unit of electrofishing effort tended to stabilize or increase since about 1992. Reduced flows during August-September had no apparent immediate effects on electrofishing results except that catch and biomass per unit effort were unusually high during the period of low discharge. Wild-spawned trout comprised more than 90% of electrofishing samples during 1997.

4) Drift concentrations of *Gammarus* and chironomids increased during rising flows following reduced discharge from the dam over the Labor Day period. Results suggest that trout selected for *Gammarus* as releases from the dam and drift concentrations of the amphipod increased. Greater drift concentrations of macroinvertebrates during rising flows likely resulted from

entrainment of organisms stranded during receding flows prior to steady 8,000 cfs discharge.

Literature Cited

Anderson, R.O. and R.M. Neumann. 1996. Length, weight, and associated structural indices. *In*: B.R. Murphy and D.W. Willis, editors. *Fisheries techniques*. American Fisheries Society, Bethesda, MD. Pp.447-481.

Angradi, T.R. 1994. Trophic linkages in the lower Colorado River: multiple stable isotope evidence. Journal of the American Benthological Society. 13:479-495.

Angradi, T.R. and D.M. Kubly. 1993. Effects of atmospheric exposure on the chlorophyll *a*, biomass, and productivity of the epilithon of a tailwater river. Regulated Rivers. 8:345-358.

Angradi, T.R. and J.S. Griffith. 1990. Diel feeding chronology and diet selection of rainbow trout (*Oncorhynchus mykiss*) in the Henry's Fork of the Snake River, Idaho. Canadian Journal of Fisheries and Aquatic Sciences. 47:199-209.

Angradi, T.R. and D.M. Kubly. 1994. Concentration and transport of particulate organic matter below Glen Canyon Dam on the Colorado River, Arizona. Journal of the Arizona-Nevada Academy of Science. 28:12-22.

Angradi, T.R., R.W. Clarkson, D.A. Kinsolving, D.M. Kubly and S.A. Morgensen. 1992. Glen Canyon Dam and the Colorado River: response of the aquatic biota to dam operations. Report to the Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff. Arizona Game and Fish Department, Phoenix.

Ayers, A.D. and T. McKinney. 1997a. Algae and invertebrates in the Glen Canyon Dam tailwater during interim flows. Final Report to the Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, AZ. Cooperative Agreement No. 9-FC-40-07940. Arizona Game and Fish Department, Phoenix.

Ayers, A.D. and T. McKinney. 1997b. Effects of Glen Canyon Dam operations on *Gammarus lacustris* in the Glen Canyon Dam tailwater. Final Report to the Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff. Arizona Game and Fish Department, Phoenix.

Ayers, A.D. and T. McKinney. 1997c. Lake Powell forebay and Glen Canyon Dam tailwater to Lee's Ferry during interim flows: particulate organic matter transport, nutrient content and periphyton standing stock. Final Report to the Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff. Arizona Game and Fish Department, Phoenix.

Beauchamp, D.A. 1990. Seasonal and diel food habits of rainbow trout stocked as juveniles in Lake Washington. Transactions of the American Fisheries Society. 119:475-482.

Bisson, P.A. 1978. Diel food selection by two sizes of rainbow trout (*Salmo gairdneri*) in an experimental stream. Journal of the Fisheries Research Board of Canada. 35:971-975.

Blinn, D.W., L.E. Stevens and J.P. Shannon. 1992. The effects of Glen Canyon Dam on the aquatic food base in the Colorado River corridor in Grand Canyon, Arizona. Final Report II-02 to the Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Arizona.

Blinn, D.W., L.E. Stevens and J.P. Shannon. 1994. Interim flow effects from Glen Canyon Dam

on the aquatic food base in the Colorado River in Grand Canyon National Park, Arizona. Final Report to the Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Arizona.
Blinn, D.W., J.P. Shannon, L.E. Stevens and J.P. Carder. 1995. Consequences of fluctuating discharge for lotic communities. Journal of the American Benthological Society. 14:233-248.
Bowen, S.H. 1996. Quantitative description of the diet. *In*: B.R. Murphy and D.W. Willis, editors. *Fisheries techniques*. American Fisheries Society, Bethesda, MD. Pp.513-532.
Bres, M. 1986. A new look at optimal foraging behaviour; rule of thumb in the rainbow trout. Journal of Fish Biology. 29(Supplement A):25-36.
Brittain, J.E. and T.J. Eikeland. 1988. Invertebrate drift--a review. Hydrobiologia. 166:77-93.
Cushman, R.M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American Journal of Fisheries Management. 5:330-339.
Elliott, J.M. 1973. The food of brown and rainbow trout (*Salmo trutta* and *S. gairdneri*) in relation to the abundance of drifting invertebrates in a mountain stream. Oecologia. 12:329-347.
Ferguson, R.A. and B.L. Tufts. 1992. Physiological effects of brief air exposure in exhaustively exercised rainbow trout (*Oncorhynchus mykiss*): implications for “catch and release” fisheries. Canadian Journal of Fisheries and Aquatic Sciences. 49:1157-1162.
Filbert, R.B. and C.P. Hawkins. 1995. Variation in condition of rainbow trout in relation to food, temperature, and individual length in the Green River, Utah. Transactions of the American Fisheries Society. 124:824-835.
Fisher, S.G. and A. LaVoy. 1972. Differences in littoral fauna due to fluctuating water levels below a hydroelectric dam. Journal of the Fisheries Research Board of Canada. 29:1472-1476.
Grimm, N.B. and S.G. Fisher. 1989. Stability of periphyton and macroinvertebrates to disturbance by flash floods in a desert stream. Journal of the American Benthological Society. 8:293-307.
Hardwick, G.G., D.W. Blinn and H.D. Usher. 1992. Epiphytic diatoms on *Cladophora glomerata* in the Colorado River, Arizona: longitudinal and vertical distribution in a regulated river. Southwestern Naturalist. 37:148-156.
Jenkins, T.M., Jr., C.R. Feldmeth and G.V. Elliott. 1970. Feeding of rainbow trout (*Salmo gairdneri*) in relation to abundance of drifting invertebrates in a mountain stream. Journal of the Fisheries Research Board of Canada. 27:2356-2361.
Kaster, J.L. and G.Z. Jacobi. 1978. Benthic invertebrates of a fluctuating reservoir. Freshwater Biology. 8:283-290.
Kimball, D.C. and W.T. Helm. 1971. A method of estimating fish stomach capacity. Transactions of the American Fisheries Society. 100:572-575.
Kwak, T.J. and T.F. Waters. 1997. Trout production dynamics and water quality in Minnesota streams. Transactions of the American Fisheries Society. 126:35-48.
Leibfried, W.C. and D.W. Blinn. 1987. The effects of steady versus fluctuating flows on aquatic macroinvertebrates in the Colorado River below Glen Canyon Dam, Arizona. Glen Canyon Environmental Studies, Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah. Report GCES/15/87.

Mackay, R.J. 1992. Colonization by lotic macroinvertebrates: a review of processes and patterns. Canadian Journal of Fisheries and Aquatic Sciences. 49:617-628.
McKinney, T. and R.S. Rogers. 1997. Electrofishing trip report: Lee's Ferry reach trip #55--April 19, 20, 21, 1997. Arizona Game and Fish Department, Phoenix.
McKinney, T., R. S. Rogers, and W.R. Persons. 1997. Trip report: Lee's Ferry tailwater, trips August 17 and 19-20, 1997. Arizona Game and Fish Department, Phoenix.
McKinney, T., R. S. Rogers, A. Ayers and W.R. Persons. 1996. Effects of experimental flooding on algae, macroinvertebrates, rainbow trout and flannelmouth suckers in the Glen Canyon Dam tailwater. Final Report to the Bureau of Reclamation, Glen Canyon Monitoring and Research Center, Flagstaff. Arizona Game and Fish Department, Phoenix.
Meefe, G.K. and W.L. Minckley. 1987. Persistence and stability of fish and invertebrate assemblages in a repeatedly disturbed Sonoran Desert stream. American Midland Naturalist. 117:177-191.
Patten, D.T. 1991. Glen Canyon Environmental Studies research program: past, present and future. *In*: Colorado River and Dam Management. National Academy Press, Washington, DC. Pp. 239-253.
Perry, S.A. and W.B. Perry. 1986. Effects of experimental flow regulation on invertebrate drift and stranding in the Flathead and Kootenai Rivers, Montana, USA. Hydrobiologia. 134:171-182.
Persons, W.R., K. McCormack and T. McCall. 1985. Fishery investigation of the Colorado River from Glen Canyon Dam to the confluence of the Paria River: assessment of the impact of fluctuating flows on the Lee's Ferry fishery. Final report, Federal Aid in Sport Fish Restoration, Dingell Johnson Project F-14-R-14. Arizona Game and Fish Department, Phoenix.
Power, M.E., R.J. Stout, C.E. Cushing, P.P. Harper, F.R. Hauer, W.J. Matthews, P.B. Moyle, B. Statzner and I.R. Wais de Bagden. 1988. Biotic and abiotic controls in river and stream communities. Journal of the American Benthological Society. 7:456-479.
Reger, S., C. Benedict and D. Wayne. 1995. Colorado River--Lee's Ferry fish management report 1989-1993. Federal Aid Project F-7-M-36 report. Arizona Game and Fish Department, Phoenix.
Reger, S., C. Benedict, J. Niccum, Y. Magnuson, A. Ayers and W.R. Persons. 1997. Colorado River Lee's Ferry fish management report 1994-1997. Arizona Game and Fish Department, Phoenix.
Scullion, J. and A. Sinton. 1983. Effects of artificial freshets on substratum composition, benthic invertebrate fauna and invertebrate drift in two impounded rivers in mid-Wales. Hydrobiologia. 107:261-269.
Sedell, J.R., G.H. Reeves, F.R. Hauer, J.A. Stanford and C.P. Hawkins. 1990. Role of refugia in recovery from disturbances: modern fragmented and disconnected river systems. Environmental Management. 14:711-724.
Shannon, J.P., D.W. Blinn, P.L. Benenati and K.P. Wilson. 1996. Organic drift in a regulated desert river. Canadian Journal of Fisheries and Aquatic Sciences. 53:1360-1369.
Shaver, M.L. 1995. The role of turbidity and desiccation in structuring benthic communities in the Colorado River, Arizona. Unpublished M.S. Thesis, Northern Arizona University, Flagstaff.
Stanford, J.A. and J.V. Ward. 1993. An ecosystem perspective of alluvial rivers: connectivity and the hyporheic corridor. Journal of the American Benthological Society. 12:48-60.

Stevens, L.E., J.P. Shannon and D.W. Blinn. 1997. Colorado River benthic ecology in Grand Canyon, Arizona, USA: tributary and geomorphological influences. Regulated Rivers. 13:129-149.

Trotzky, H.M. and R.W. Gregory. 1974. The effects of water flow manipulation below a hydroelectric power dam on the bottom fauna of the upper Kennebec River, Maine. Transactions of the American Fisheries Society. 2:318-324.

Usher, H.D. and D.W. Blinn. 1990. Influences of various exposure periods on the biomass and chlorophyll *a* of *Cladophora glomerata* (Chlorophyta). Journal of Phycology. 26:244-249.

Ware, D.M. 1972. Predation by rainbow trout (*Salmo gairdneri*): the influence of hunger, prey density, and prey size. Journal of the Fisheries Research Board of Canada. 29:1193-1201.

Waters, T.F. and J.C. Hokenstrom. 1980. Annual production and drift of the stream amphipod *Gammarus pseudolimnaeus* in Valley Creek, Minnesota. Limnology and Oceanography. 25:700-710.

Young, M.K., R.B. Rader and T.A. Belish. 1997. Influence of macroinvertebrate drift and light on the activity and movement of Colorado River cutthroat trout. Transactions of the American Fisheries Society. 126:428-437.

Table 1. Mean ("SE in parentheses) densities (number/m^2) of benthic macroinvertebrates in samples (n=9) collected at the 18,000 cfs flow elevation, Lee's Ferry reach, April 14, 1997.

	Gammarus lacustris	Chironomids	Gastropods	Oligochaetes
Cobble Bar Sites	44.4 (7.6)	1507.4 (377.2)	51.9 (9.1)	355.8 (83.0)
Depositional Sites	21.0 (8.8)	1819.8 (830.7)	7.4 (3.2)	459.3 (340.8)

Table 2. Mean ("SE in parentheses) concentrations (n=15) of ash free dry weight (AFDW; g/m^2) and chlorophyll *a* (mg/m^2) for periphyton and *Potamogeton* sp. samples collected at the 18,000 cfs flow elevation, Lee's Ferry reach, April 14, 1997.

	AFDW	Chlorophyll *a*
Periphyton	118.6 (26.6)	1068.0 (196.8)
Potamogeton sp.	0	0

Table 3. Mean ("SE in parentheses) densities (number/m^2) of benthic macroinvertebrates in samples (n=9) collected at the 18,000 cfs flow elevation, Lee's Ferry reach, August 17 and September 17, 1997. Asterisks indicate level of statistical significance for within-habitat comparisons between sampling periods. * P<0.03; ** P<0.01; *** P<0.001.

Cobble Bar Sites	*Gammarus lacustris*	Chironomids	Gastropods	Oligochaetes
August	451.9 (103.0)	433.3 (98.0)	74.1 (21.5)	196.3 (60.9)
September	32.1*** (12.6)	119.8** (33.5)	12.3** (5.4)	396.3 (108.2)
Depositional Sites				
August	746.9 (218.6)	1901.3 (627.7))	153.1 (54.1)	1332.1 (399.0)
September	63.0* (27.7)	35.8*** (17.6)	95.1 (46.5)	669.1 (314.4)

Table 4. Mean ("SE in parentheses) densities (number/m^2) of benthic macroinvertebrates in samples (n=9) collected at the 5,000, 8,000, 12,000 and 18,000 cfs flow elevations, Lee's Ferry reach, August 30-31, 1997.

Cobble Bar Sites	*Gammarus lacustris*	Chironomids	Gastropods	Oligochaetes
5,000 cfs	1312.3 (315.3)	580.2 (188.3)	49.4 (19.4)	30.9 (9.8)

8,000 cfs	1702.5 (309.8)	1142.0 (369.2)	17.3 (7.2)	84.0 (35.2)
12,000 cfs	575.3 (175.6)	1523.5 (570.7)	13.6 (6.1)	80.2 (28.8)
18,000 cfs	640.7 (133.8)	1930.9 (652.3)	35.8 (11.7)	181.5 (25.0)
<u>Depositional Sites</u>				
5,000 cfs	1688.9 (236.4)	353.1 (75.5)	1012.3 (312.3)	5016.0 (1166.1)

8,000 cfs	2043.2 (643.3)	1370.4 (320.9)	2016.0 (1296.7)	5039.5 (1865.3)
12,000 cfs	3748.1 (1539.3)	600.0 (108.4)	1123.5 (370.7)	2342.0 (1376.6)
18,000 cfs	2881.5 (2449.7)	929.6 (216.4)	525.9 (281.7)	7254.3 (7149.0)

Table 5. Mean ("SE in parentheses) ash free dry weights (AFDW; mg/m^2) of benthic macroinvertebrates in samples (n=9) collected at the 18,000 cfs flow elevation, Lee's Ferry reach, August 17 and September 17, 1997. Asterisks indicate level of statistical significance for within-habitat comparisons between sampling periods. * P<0.05; ** P<0.02; *** P<0.001.

	Gammarus lacustris	Chironomids
Cobble Bar Sites		
August	732.47 (231.78)	60.99 (14.56)
September	35.31*** (14.53)	23.09* (7.72)
Depositional Sites		
August	980.25 (404.10)	138.03 (29.79)
September	62.10** (35.59)	10.00*** (4.01)

Table 6. Mean ("SE in parentheses) ash free dry weights (AFDW; mg/m^2) of benthic macroinvertebrates in samples (n=3) collected at the 5,000, 8,000 and 12,000 and 18,000 cfs flow elevations, Lee's Ferry reach, August 30-31, 1997.

	Gammarus lacustris	Chironomids
Cobble Bar Sites		
5,000 cfs	1185.2 (285.3)	83.6 (33.5)
8,000 cfs	1770.5 (308.6)	201.1 (72.0)
12,000 cfs	1683.6 (475.0)	203.8 65.0)

18,000 cfs	938.0 (174.0)	219.1 (59.3)
<u>Depositional Sites</u>		
5,000 cfs	2602.7 (674.1)	52.1 (11.5)
8,000 cfs	2692.2 (1176.0)	277.9 98.6)
12,000 cfs	6191.4 (2958.6)	88.8 (25.7)

18,000 cfs	4049.6 (3208.6)	125.2 (32.3)

Table 7. Mean ("SE in parentheses) concentrations (n=15) of ash free dry weight (AFDW; g/m^2) and chlorophyll *a* (mg/m^2) for periphyton and *Potamogeton* sp. samples collected at the 18,000 cfs flow elevation, Lee's Ferry reach, August 17 and September 17, 1997. Asterisks indicate level of statistical significance for within-habitat comparisons between sampling periods. *P<0.01; **P<0.001.

Periphyton	AFDW	Chlorophyll *a*
August	358.1 (85.6)	1885.9 (187.3)
September	90.3 (14.6)*	675.1 (79.3)**
Potamogeton sp.		
August[a]	139.5 (14.0)	988.5 (207.5)
September[b]	0	0

a) RM -3.5 only; no macrophytes colonized at other transects; n=5
b) No macrophytes colonized at any transect

Table 8. Mean ("SE in parentheses) concentrations (n=15) of ash free dry weight (AFDW; g/m^2) and chlorophyll *a* (mg/m^2) for periphyton and *Potamogeton* sp. samples collected at the 5,000 cfs, 8,000 cfs, 12,000 cfs and 18,000 cfs flow elevations, Lee's Ferry reach, August 30-31, 1997.

	AFDW	Chlorophyll *a*
Periphyton		
5,000 cfs	233.5 (48.6)	2098.4 (253.7)
8,000 cfs	181.8 (18.7)	1733.8 (289.9)
12,000 cfs	170.3 (11.1)	2535.6 (401.9)

18,000 cfs	222.3 (12.7)	1835.0 (375.2)
Potamogeton sp.		
5,000 cfs	127.6 (10.4)	760.0 (104.9)
8,000 cfs	114.7 (10.2)	663.9 (56.4)
12,000 cfs*	82.5 (17.9)	643.4 (143.7)
18,000 cfs**	0	0

*Macrophytes sampled at RM -3.5, RM -6.5; none colonized at RM -14.5
**No macrophytes colonized at any transect

Table 9. Mean ("SE) total densities of diatom epiphytes on filamentous algae (number/mm^2) and *Potamogeton* sp. (number/mg AFDW) at the 5,000 cfs, 8,000 cfs, 12,000 cfs and 18,000 cfs flow elevations, Lee's Ferry reach, August 30-31, 1997, during 8,000 cfs steady releases from Glen Canyon Dam.

Flow Elevation	N	Filamentous Algae	N	*Potamogeton* sp.
5,000 cfs	3	12,391 (3,053.2)	3	242,015 (49,262.7)
8,000 cfs	3	16,220 (5,677.9)	3	258,412 (48,332.4)
12,000 cfs	3	9,573 (2,426.0)	2	302,919 (40,515.0)

18,000 cfs	3	17,230 (3,790.8)	---	---

Table 10. Electrofishing transect (Site) numbers and locations (RM = river mile; RR = river right; RL = river left), total rainbow trout captured (N), shocking effort (E = seconds) and catch per minute (CPUE), April 19-21, 1997, Lee's Ferry reach.

Site	Location	N	E	CPUE
3	RM -14.5 RR	54	2,031	1.60
4	RM -13.0 RL	99	2,132	2.79
5	RM -12.5 RL	86	2,000	2.58
6	RM -10.0 RR	87	2,231	2.34

9	RM -7.0 RL	47	2,289	1.23
10	RM -6.0 RR	134	2,178	3.69
12	RM -4.1 RL	94	1,810	3.12
13	RM -3.5 RL	78	1,860	2.52
15	RM -1.0 RL	47	2,016	1.40
All Sites	- - -	726	18,547	2.36

Table 11. Electrofishing sites, sample sizes (N) and mean ("SE in parentheses) lengths (mm), weights (g) and condition factors (K) for rainbow trout captured during April 19-21, 1997, Lee's Ferry reach.

Site	N	Length	N	Weight	K
3	47	271.4 (15.7)	47	262.2 (33.7)	0.96 (0.03)
4	87	241.1 (11.7)	87	207.0 (23.7)	0.95 (0.02)
5	84	314.4 (12.9)	84	363.5 (29.5)	0.89 (0.02)
6	78	232.0 (13.6)	78	185.2 (24.4)	0.91 (0.02)

9	44	299.0 (15.3)	44	288.8 (30.5)	0.91 (0.06)
10	120	226.1 (9.5)	120	173.6 (17.0)	0.97 (0.02)
12	92	304.2 (8.4)	92	284.7 (16.5)	0.89 (0.02)
13	78	333.8 (7.1)	78	335.0 (18.0)	0.84 (0.02)
15	40	258.7 (14.9)	40	204.6 (26.6)	0.90 (0.02)
All Sites	726	259.4 (14.3)	670	252.8 (8.3)	0.91 (0.01)

Table 12. Length frequencies for size classes of non-tagged (WN) and previously-marked wire-tagged (WH = coded wire tag in head) and adipose-tagged (WA) rainbow trout captured by electrofishing, April 19-21, 1997, Lee's Ferry reach.

Size Classes	WH		WA		WN	
Length (mm)	N	Percent	N	Percent	N	Percent
<152 (<6 in)	0	---	1	0.5	214	99.5
152-303 (6-12 in)	26	14.7	1	0.6	150	84.7
304-405 (12-16 in)	49	18.3	1	0.4	217	81.3

406-558 (16-22 in)	2	3.0	0	---	65	97.0
>558 (>22 in)	0	---	0	---	0	---
Totals	77	10.6	3	0.4	646	89.0

Table 13. Length frequencies for total and unmarked (no coded wire tags [WN]) rainbow trout and recaptured fish with coded wire (WH) and adipose (WA) tags, April 19-21, 1997, Lee's Ferry reach.

Length (mm)	Total	WN	WH	WA
40-49	6	6	0	0
50-59	5	5	0	0
60-69	5	5	0	0
70-79	8	8	0	0
80-89	10	10	0	0
90-99	12	12	0	0
100-109	13	13	0	0
110-119	39	39	0	0
120-129	39	39	0	0
130-139	40	39	0	1
140-149	27	27	0	0
150-159	32	31	1	0
160-169	14	14	0	0
170-179	16	15	1	0
180-189	12	11	1	0
190-199	11	11	0	0
200-209	3	3	0	0
210-219	3	2	1	0
220-229	4	4	0	0
230-239	2	2	0	0
240-249	6	3	3	0
250-259	11	9	1	1
260-269	14	13	1	0
270-279	11	9	2	0
280-289	11	9	2	0
290-299	24	12	12	0
300-309	29	25	4	0
310-319	30	22	8	0
320-329	20	14	6	0
330-339	34	29	5	0
340-349	41	37	4	0
350-359	30	19	10	1
360-369	22	16	6	0
370-379	26	24	2	0
380-389	21	19	2	0
390-399	19	17	2	0
400-409	17	16	1	0
410-419	17	16	1	0
420-429	13	13	0	0
430-439	9	8	1	0
440-449	7	7	0	0
450-459	4	4	0	0

Table 14. Frequencies of occurrence (%), mean ("SE in parentheses) total relative gut volume (RGV) and mean ("SE in parentheses) proportional volume (P = % of total volume for stomach contents) of predominant items in stomachs (n=45) of rainbow trout April 19-21, 1997, Lee's Ferry reach. EPT = % empty stomachs.

		Gammarus		Chironomids		Gastropods		*Cladophora*	
EPT	RGV	Frequency	P	Frequency	P	Frequency	P	Frequency	P
13.7	9.4 (2.0)	39.2	21.6 (5.2)	52.9	12.0 (2.7)	5.9	0.4 (0.3)	49.0	34.4 (5.9)

Table 15. Sites, location (River Mile; RR=river right; RL=river left), total catch (N), catch per minute (CPUE) and sampling effort (E=seconds) for rainbow trout captured by electrofishing in Lee's Ferry reach, August 30, 31 and September 1, 1997.

Site No.	River Mile	N	E	CPUE
3	-14.5 RR	175	1,655	6.34
4	-13.0 RL	191	2,197	5.22
5	-12.5 RL	61	839	4.36
6	-10.0 RR	280	2,093	8.03

9	-7.0 RL	112	1,242	5.41
10	-6.0 RR	319	1,957	9.78
12	-4.1 RL	229	1,583	8.68
13	-3.5 RL	284	1,823	9.35
15	-1.0 RL	185	1,681	6.60
All Sites	---	Total=1,836	Total=15,070	Mean=7.09

Table 16. Sites, sample size (N), mean ("SE in parentheses) lengths (mm), weights (g), condition factors (K) and relative weights (W_r) for rainbow trout captured by electrofishing, August 30, 31 and September 1, 1997, Lee's Ferry reach.

Site No.	N*	Length	N**	Weight	K	W_r
3	175	199.1 (24.8)	113	264.4 (24.8)	0.91 ("0.02)	80.11 ("1.23)
4	191	183.7 (20.4)	130	198.3 (20.4)	1.01 ("0.02)	85.70 ("1.38)
5	61	304.5 (32.2)	51	456.2 (32.2)	0.90 ("02)	82.82 ("2.02)

6	280	221.0 (14.7)	211	233.9 (14.7)	0.89 ("0.01)	77.53 ("0.81)
9	112	241.0 (19.9)	87	262.7 (19.9)	0.89 ("0.01)	79.55 ("1.14)
10	319	174.4 (12.5)	187	184.6 (12.5)	0.95 ("0.01)	81.92 ("0.89)
12	229	228.7 (15.5)	164	276.0 (15.5)	0.91 ("0.01)	81.01 ("0.84)
13	284	220.1 (11.8)	180	286.0 (11.8)	0.87 ("0.01)	78.27 ("0.98)

15	185	219.2 (15.1)	130	240.2 (15.1)	0.91 ("0.02)	80.52 ("1.20)
All Sites	1,836	211.6 (2.9)	1,253	250.3 (5.9)	0.91 ("0.1)	80.50 ("0.36)

Table 17. Sample size (N) and percent of wild-spawned (WN) and previously-marked wire-tagged (WH=coded wire tag in head) in size-related and total catch of rainbow trout captured by electrofishing, August 30, 31 and September 1, Lee's Ferry reach.

Length (mm)	WH		WN	
	N	Percent	N	Percent
<152	26	3.1	805	96.9
152-306	42	11.4	328	88.6
306-407	93	16.8	460	83.2
407-559	6	7.3	76	92.7
>559	0	0	0	0
Totals	167	9.1	1,669	90.9

Table 18. Length frequencies (mm) for total, unmarked (WN) and marked (WH=coded wire tag in head) rainbow trout captured by electrofishing, August 30, 31 and September 1, 1997, Lee's Ferry reach.

Length (mm)	Total	WN	WH
30-39	1	1	0
40-49	21	21	0
50-59	77	77	0
60-69	133	133	0
70-79	131	131	0
80-89	108	106	0
90-99	100	100	0
100-109	50	48	2
110-119	55	51	4
120-129	56	47	9
130-139	43	34	9
140-149	48	46	2
150-159	35	35	0
160-169	32	31	1
170-179	34	33	1
180-189	21	20	1
190-199	24	24	0
200-209	21	19	2
210-219	17	17	0
220-229	10	9	1
230-239	13	11	2
240-249	14	12	2
250-259	12	9	3
260-269	21	18	3
270-279	26	23	3
280-289	41	30	11
290-299	44	35	9
300-309	51	41	10
310-319	61	48	13
320-329	62	49	13
330-339	72	57	15
340-349	55	44	11
350-359	55	45	10
360-369	65	57	8
370-379	45	39	6
380-389	44	38	6
390-399	34	32	2
400-409	32	29	3
410-419	14	14	0
420-429	15	14	1
430-439	20	17	3
440-449	6	6	0
450-459	9	8	1
460-469	4	4	0
470-479	2	2	0
480-489	3	3	0
550-559	1	1	0

Table 19. Frequencies of occurrence (%), mean ("SE in parentheses) total relative gut volume (RGV) and mean ("SE in parentheses) proportional volume (P = % of total volume for stomach contents) of predominant items in stomachs of rainbow trout August 30, 31 and September 1 (227 m^3s^{-1} flows; n=45) and September 2 (rising flows; n=36), 1997, Lee's Ferry reach. EPT = % empty stomachs. Asterisks indicate level of statistical significance for between-flow comparisons. *P<0.05; **P<0.02; ***P<0.01.

Dam discharge			*Gammarus*		Chironomids		Gastropods		*Cladophora*	
	EPT	RGV	Frequency	P	Frequency	P	Frequency	P	Frequency	P
227 m^3s^{-1} flows	13.3	12.9 (2.7)	76.9	54.9 (7.2)	12.8	1.0 (0.5)	28.2	4.1 (2.0)	51.3	33.5 (6.9)

Rising flows	0*	25.6*** (4.7)	97.2	67.2** (6.5)	19.4	0.1 (0.04)	22.2	0.2 (0.1)	52.8	30.9 (6.5)

Table 20. Mean ("SE in parentheses) concentrations of macroinvertebrates in drift and rainbow trout stomach samples collected during August 30-31 and September 1 (227 m^3s^{-1} flows) and September 2, 1997 (rising flows), Lee's Ferry reach. GL = *Gammarus lacustris*; CH = Chironomidae; RGV = relative gut volume; RGM = relative gut mass. Asterisks indicate level of statistical significance for between-flow comparisons. *P<0.03; **P<0.01; ***P<0.001.

Dam discharge		Drift					Stomach			
	N	GL		CH		N	GL		CH	
		Volume (mL/m^3)	AFDW (mg/m^3)	Volume (mL/m^3)	AFDW (mg/m^3)		RGV	RGM	RGV	RGM
227 m^3s^{-1} flows	9	0.011 (0.006)	0.08 (0.04)	0.004 (0.003)	0.34 (0.20)	45	5.98 (1.79)	403.7 (112.1)	0.06 (0.04)	7.9 (3.9)
Rising flows	6	0.269** (0.145)	12.45** (8.39)	8.02* (2.38)	0.78 (0.26)	36	16.48*** (3.84)	1143.7*** (232.1)	0.02 (0.01)	2.6 (1.0)

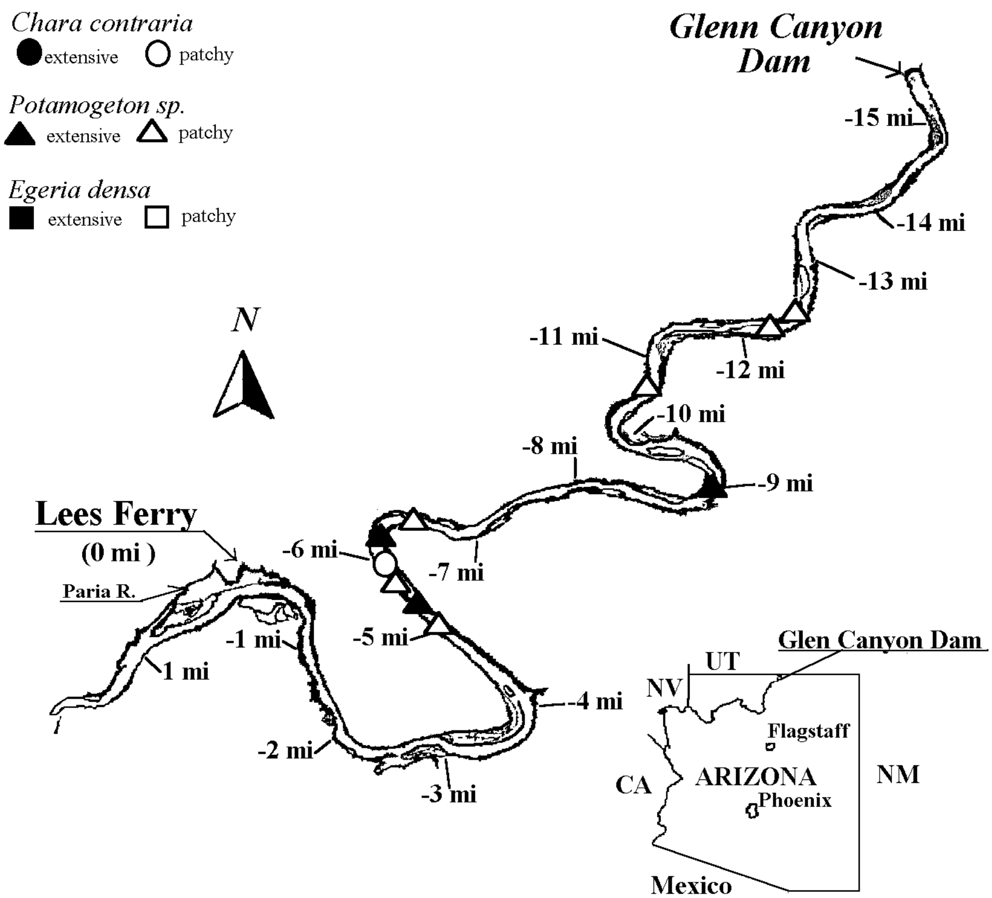

Fig 1. Distribution and relative abundance of *Chara contraria*, *Potamogeton* sp. and *Egeria densa* in the Lee's Ferry reach, March 3-4, 1997.

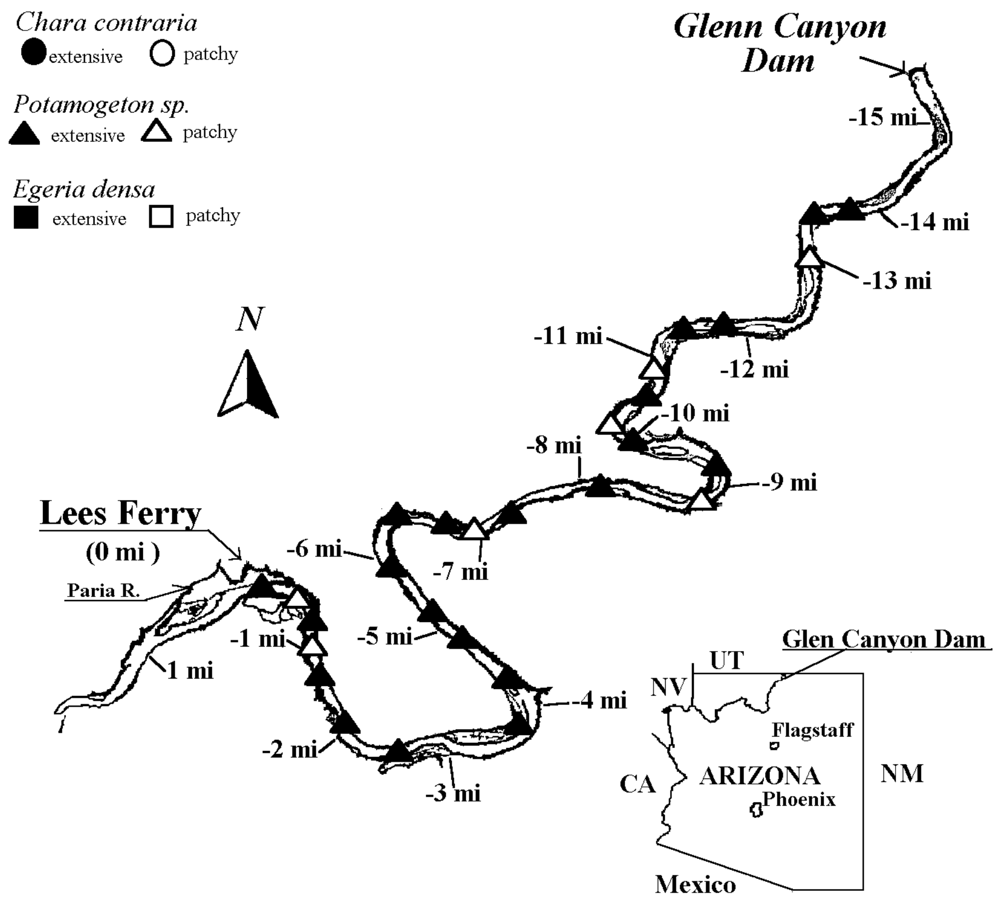

Figure 2. Relative abundance and distribution of *Potamogeton* sp. in the Lee's Ferry reach, May 19 and 22 1997; no *Chara contraria* and only two very small patches of *Egeria densa* observed.

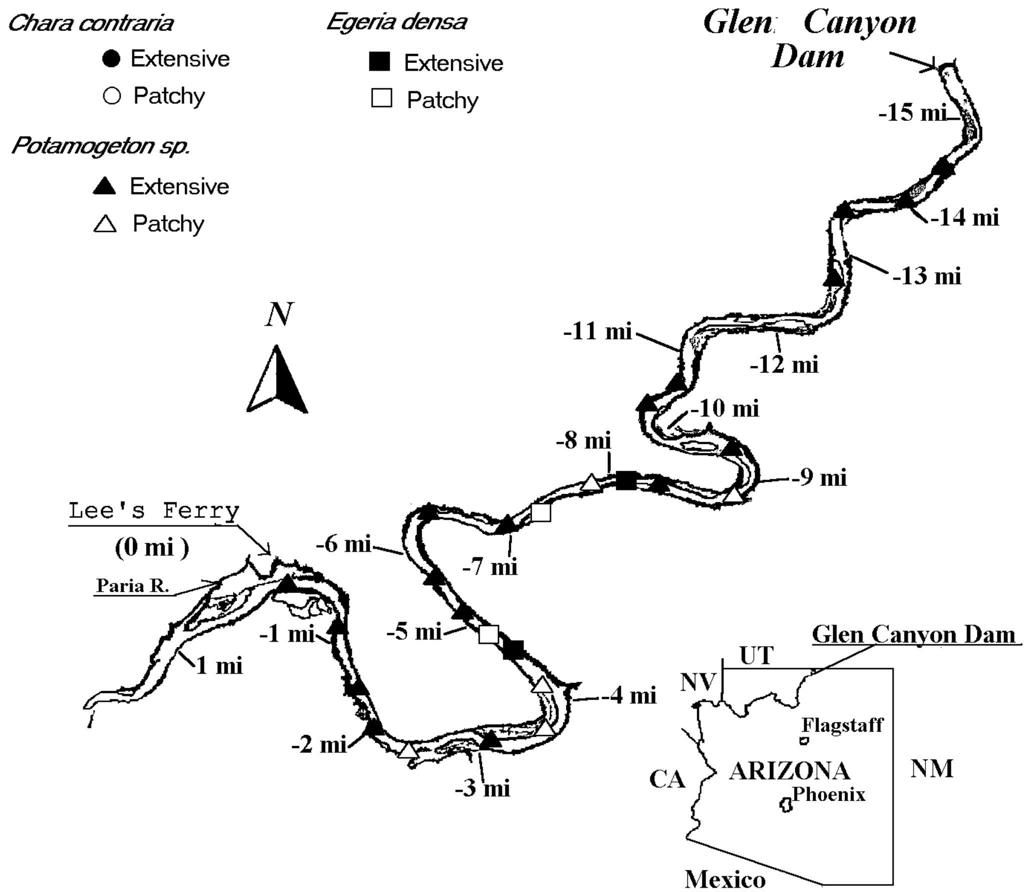

Figure 3. Distribution and relative abundance of submerged aquatic macrophytes in the tailwater between Glen Canyon Dam and Lee's Ferry, August 19-20, 1997.

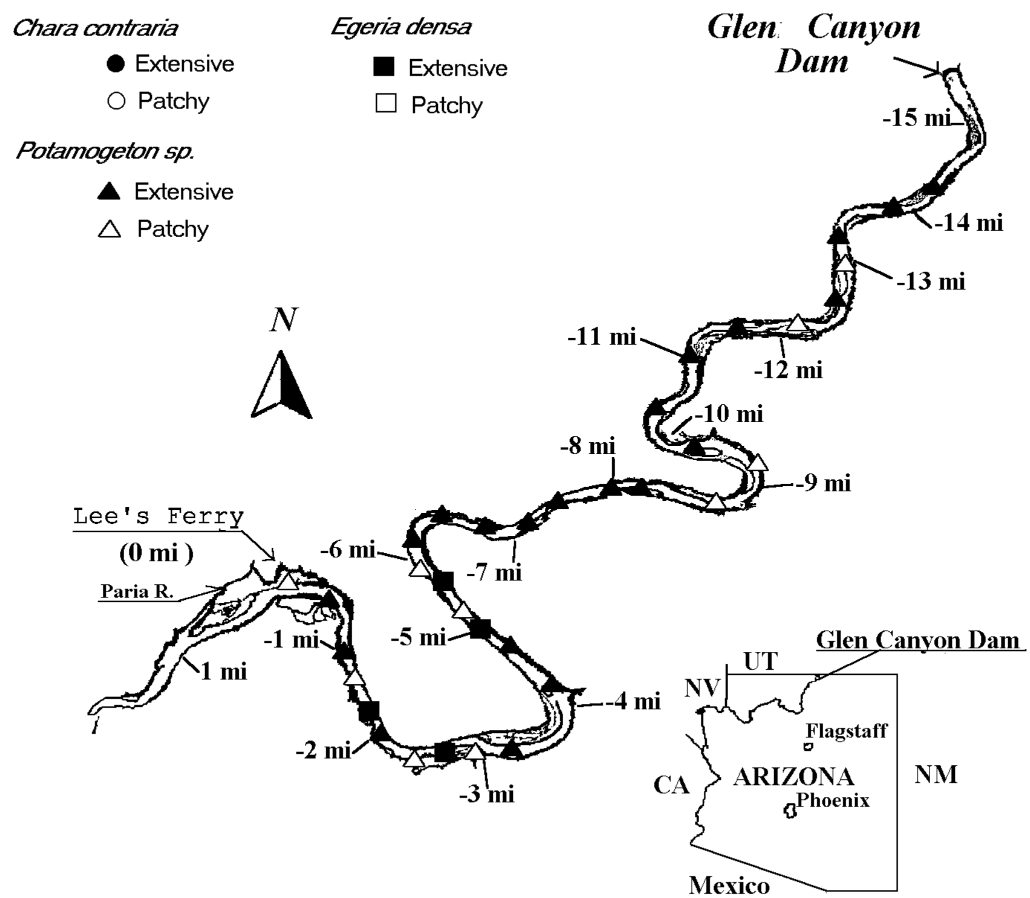

Figure 4. Distribution and relative abundance of submerged aquatic macrophytes in the tailwater between Glen Canyon Dam and Lee's Ferry, September 21, 1997.

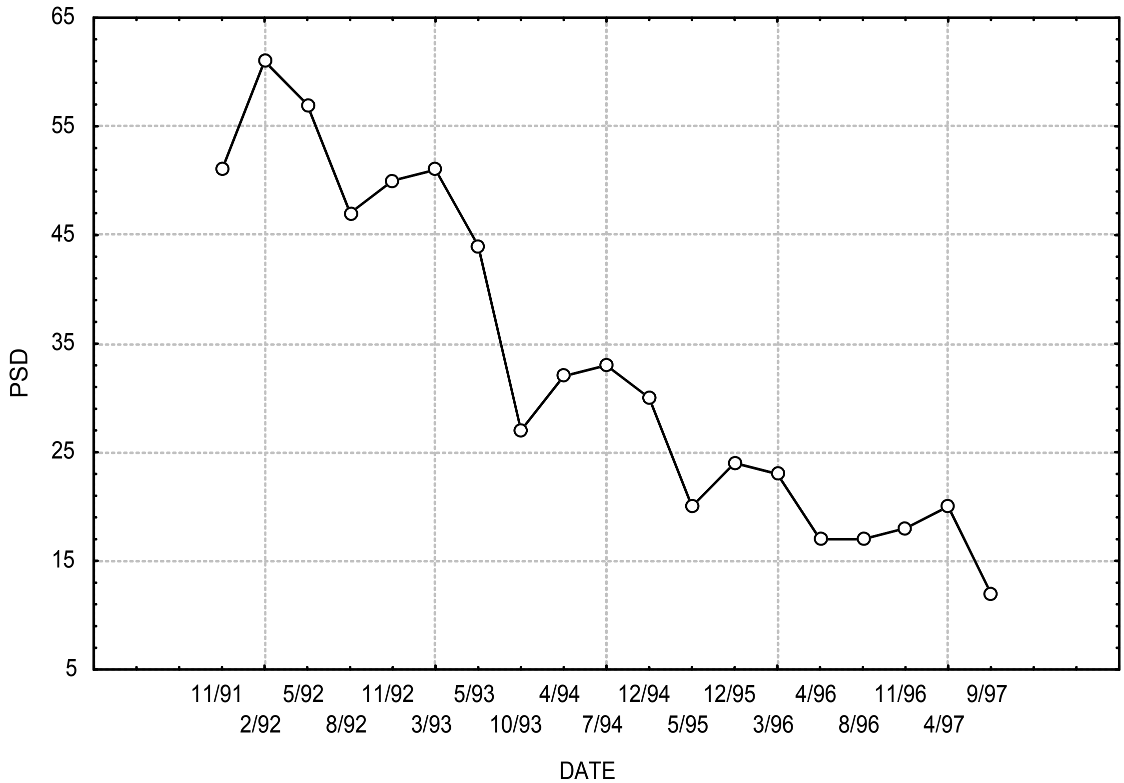

Figure 5. Proportional stock densities (PSD) for rainbow trout captured by electroshocking, Lee's Ferry reach, November 1991 - September 1997.

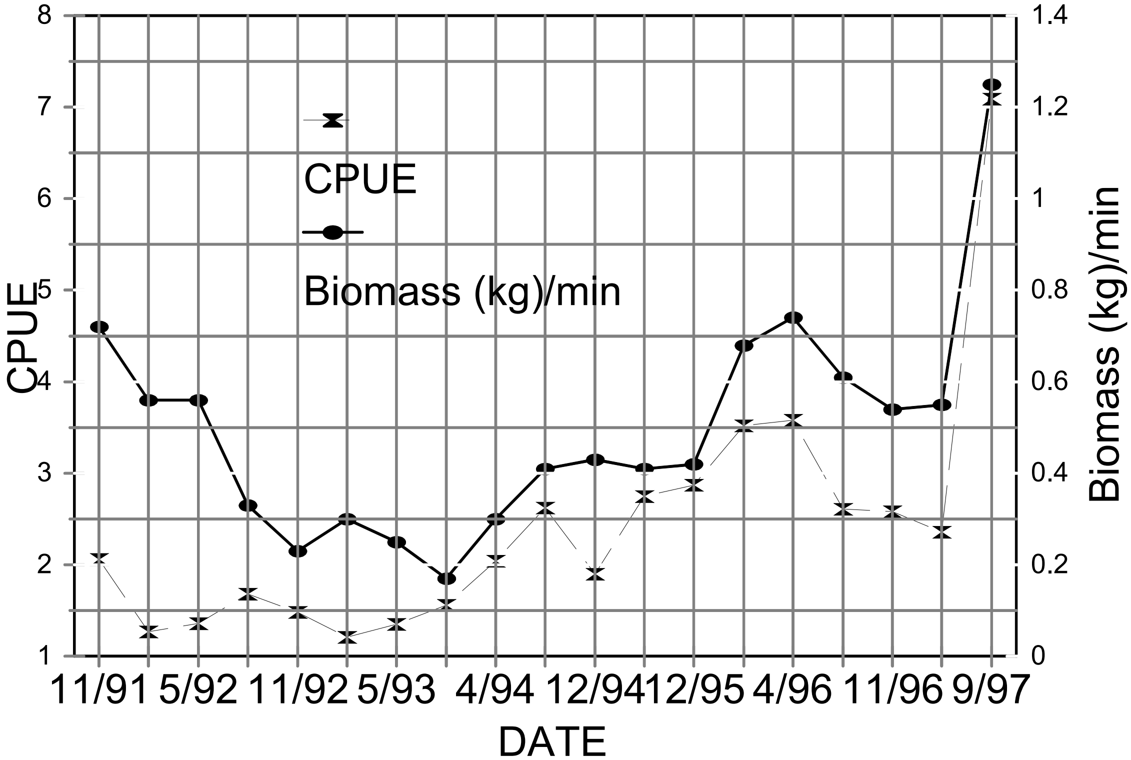

Figure 6. Catch per minute (CPUE) and total biomass of rainbow trout captured per minute for electrofishing, Lee's Ferry reach, November 1991 - September 1997.

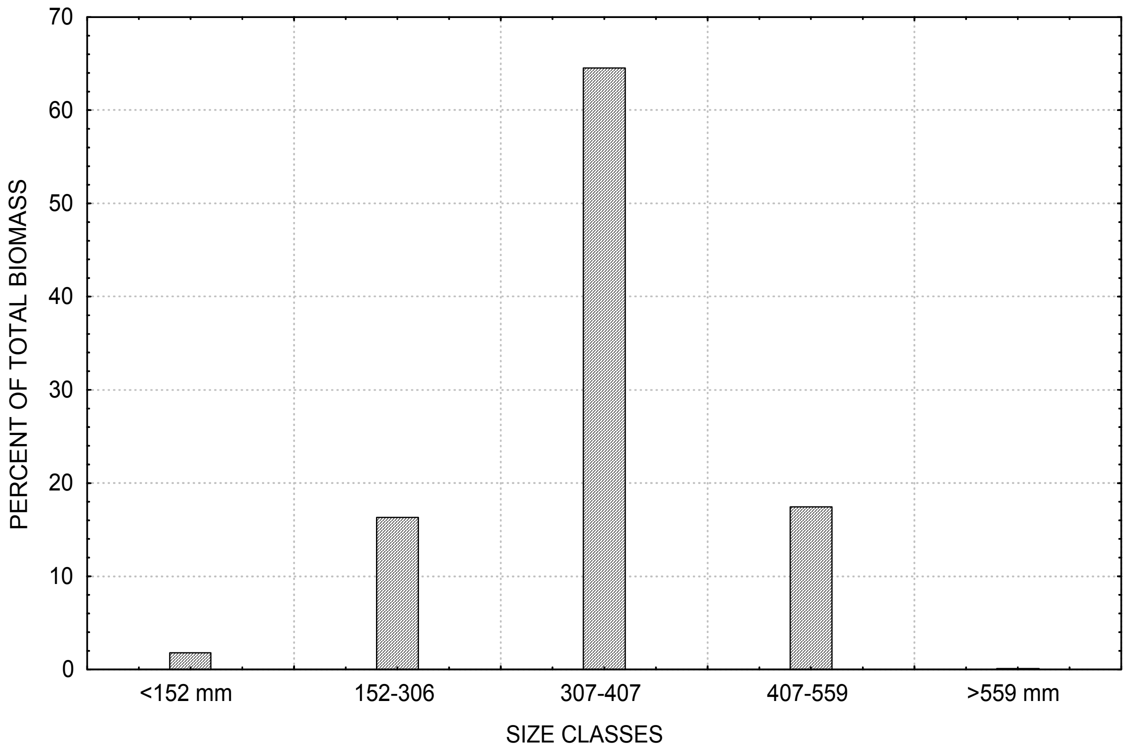

Figure 7. Proportional contribution of specific size-classes (mm) to total biomass caught by electrofishing during steady $227 m^3 s^{-1}$ flows, Lee's Ferry reach, August 30, 31 and September 1, 1997.

APPENDICES

Appendix 1. Relative abundance and distribution of submerged aquatic macrophytes, Lee's Ferry reach, March 3-4, 1997.

River Right

River Miles	Densities	Distribution
0 to -5.3	0	Very few small, sparse clumps of *Potamogeton*. Substrate almost wholly bare sand. Often blue-green and unknown filamentous algae present.
-5.3 to -5.5	1-2	Large bed *Potamogeton*, patchy but generally extensive.
-5.5 to -5.8	0-1	Occasional small patches, clumps *Potamogeton*.
-5.8 to -6.1	1-2	Three medium-large beds *Potamogeton*, occasional small patches. One small patch *Chara* consisting of a few small clumps.
-6.3 to -6.5	0-1	Occasional small-medium patches *Potamogeton*.
-9.0	2	Medium bed *Potamogeton*.
-10.5 to -10.6	1	Extensive patchy bed *Potamogeton*, occasionally small clumps.
-10.8	0	Very few small clumps *Potamogeton*.
-11.0	---	Extensive bryophyte bed on gravel and small stones on mid-river bar.
-12.3 to -12.5	1	Small patches *Potamogeton*.
-12.8	1	Moderate *Potamogeton* bed, patchy.
-12.8 to -14.5	0	No visible beds or patches.

River Left

River Miles	Densities	Distribution
0 to -10.3	0	No visible macrophytes, except one very small patch at -7.1 mi in old backwater area.

-6.1	---	Extensive bryophyte bed; too deep for positive identification.
-10.3 to -10.7	0-1	Extensive *Potamogeton*, but comprised only of widely-spaced small clumps and patches; mostly bare sand.
-13.0	0	Much bare sand. Algae apparent in deep water, but no positive identification possible. Grab sample consisted only of unknown filamentous forms, and this type appeared to persist to depth. No growth of macrophytes apparent. This previously has been a major persistent *Chara* bed, with considerable *Potamogeton* nearby, following the spike flow.
-10.7 to -14.5	0	No visible macrophytes.

Appendix 2. Relative abundance and distribution of submerged aquatic macrophytes, Lee's Ferry reach, May 19 and 22, 1997.

River Right

River Miles	Densities	Comments
0 to -2.8	2-3	*Potamogeton* occasionally in medium-sized beds, often density 3 but generally patchy; abundant small but dense (3) beds.
-3.3 to -3.5	3	Very large, extensive *Potamogeton* bed of variable density (1-3).
-5.0 to -5.8	2	*Potamogeton* generally extensive im medium-sized beds, generally patchy, occasionally density 3.
-6.0 to -6.2	1-3	*Potamogeton* occasionally in large beds of variable density.
-6.4 to -6.8	3	Very large, extensive bed *Potamogeton*.
-8.0 to -8.2	2-3	Intermittent medium-sized beds *Potamogeton*.
-9.2	2	One medium bed *Potamogeton*.
-10.0	1	Occasional small patches, clumps *Potamogeton*.
-10.1 to -10.5	2-3	Several large beds *Potamogeton*, often patchy.
-11.2 to -11.8	3	Three large beds *Potamogeton*, few clumps and small patches.
-12.5 to -12.8	1	*Potamogeton* in sparse clumps and small patches. One medium bed density 2.
-13.0 to -13.2	2-3	Occasional clumps *Potamogeton*.
-13.6 to -14.0	3	Several large, extensive beds *Potamogeton*.

River Left

River miles	Densities	Distribution
0 to -0.5	0	Bare sand, much blue-green algae
-0.5 to -1.0	1	Occasional small-medium beds *Potamogeton*, patchy, occasional small clumps.
-1.0 to -3.0	3	Generally continual distribution of *Potamogeton*, but beds sometimes intermittent medium to large size and density 2 some areas.
-3.6 to -4.1	0	Very occasional small clumps and patches *Potamogeton*.
-4.1 to -4.5	3	Large, intermittent beds (n=3) *Potamogeton*.
-4.5 to -6.1	3	Occasional small to medium beds (n=26) beds *Potamogeton*.
-6.1 to -6.4	2	Two extensive but narrow beds *Potamogeton*.
-7.0	1	Medium-sized, sparse bed *Potamogeton*.
-7.4 to -7.5	2	Intermittent medium-sized beds *Potamogeton*, one small

		bed.
-8.0 to -8.3	2	One long, narrow strip, one medium bed *Potamogeton*.
-8.9	1	One small bed *Potamogeton*.
-9.4 to -9.8	0	Occasional small patches clumps *Potamogeton*.
-9.8	3	Medium-sized bed *Potamogeton*.
-9.9 to -10.0	0-1	Two medium-sized beds *Potamogeton* density 2; occasional thin patches.
-10.6	1	Medium bed *Potamogeton*.
-10.7 to -11.2	2	Three large, patchy but extensive beds *Potamogeton*, often narrow.
-12.9	2	One narrow, patchy medium-sized bed *Potamogeton*.
-12.9 to -13.1	1	Generally extensive area of *Potamogeton*, often in deeper water (ca. 10,000 cfs zone), but occurring primarily in intermittent small clumps and patches; occasional smaller beds.
-13.1 to -13.2	2	Large, extensive but patchy area of *Potamogeton*.

Appendix 3. Relative abundance and distribution of submerged aquatic macrophytes, Lee's Ferry reach, August 19-20, 1997.

River Left

River Miles	Densities	Distribution
0 to -3.0	3	Extensive *Potamogeton* beds extending generally from river's edge to maximum visible depth**.** *Egeria densa* in eight medium beds and in several small patches mixed with *Potamogeton*.
-3.0 to -3.3	0-3	One medium bed (OV 3), mainly occasional clumps (OV 0) *Potamogeton*.
-3.5 to -4.0	1-2	Frequent strips, patches, small beds *Potamogeton*.
-4.1 to -4.4	2	Extensive *Potamogeton*, occasional *E. densa*.
-4.4 to -4.5	3	Extensive bed *E. densa*, *Potamogeton* mixed in it.
-4.5 to -5.9	3	Extensive *Potamogeton* beds small to medium size, occasional patches *E. densa*.
-5.9 to -6.5	2	*Potamogeton* generally very patchy in clumps to small beds.
-7.5 to -7.8	1-2	Extensive but narrow, patchy *Potamogeton*.
-7.8 to -7.9	0	Occasional *Potamogeton*.
-8.1 to -8.2	3	Extensive *Potamogeton* bed.
-9.5 to -10.5	2-3	One large and several medium size beds *Potamogeton*; often occurring in small beds, patches and clumps.
-10.5 to -10.7	0-1	*Potamogeton* sparse, patchy beds and strips.
-10.7 to -10.9	2	Extensive *Potamogeton* bed.
-10.9 to -11.0	1	Thin strips *Potamogeton*, some large, patchy beds.
-12.5	1	Backwater; *Potamogeton* extensive but sparse.
-12.8 to -13.0	2	Extensive *Potamogeton* bed.

River right

River miles	Densities	Distribution
0 to -2.0	3	Extensive *Potamogeton* with occasional large patches *E. densa*.
-2.0 to -2.5	1-2	Narrow strips, patches *Potamogeton*.
-3.0 to -3.5	3	Extensive *Potamogeton*.
-3.5 to -4.1	2	Extensive *Potamogeton*.
-5.0 to -7.5	2-3	Frequent medium to large beds *Potamogeton*; three large beds, occasional patches *E. densa*.

-6.5	1	Backwater; *Chara* and *Potamogeton* mixed.
-7.7 to -7.9	3	Small to medium beds *Potamogeton*.
-8.0	3	Large bed *E. densa*.
-9.0 to -9.3	1	Extensive sparse beds *Potamogeton*.
-10.0	2	One medium bed *Potamogeton*.
-10.5 to -10.7	2	Two large, two small, beds *Potamogeton*.
-12.5 to -12.6	2	Medium to large beds *Potamogeton*; some sparse *Chara* in one area.
-13.4 to -13.8	2	Extensive beds and strips *Potamogeton*.
-14.1 to -14.5	2	Several large beds *Potamogeton*.

Appendix 4. Relative abundance and distribution of submerged aquatic macrophytes, Lee's Ferry reach, September 21, 1997

River Left

River miles	Densities	Distribution
0 to -1.5	1-2	Intermittent but generally continual patches, strips and smaller beds *Potamogeton*.
-1.5 to -2.0	2	Large bed *Egeria densa*.
-2.0 to -3.0	1	*Potamogeton* continual small-medium beds. Occasional small-medium patches *Egeria*.
-3.3 ti -3.4	2	One large bed *Potamogeton*; angiosperm generally distributed in small patches.
-3.5 to -4.1	0	Occasional *Potamogeton*.
-4.1 to -4.9	2	One each small, medium and large beds *Potamogeton*. Occasional small patches *Egeria*.
-4.9 to -5.2	3	Extensive bed *Egeria* throughout area. *Potamogeton* intermittent in small patches, two medium beds.
-5.2 to -6.0	2	*Potamogeton* extensive in four large beds. Occasional small to large patches *Egeria*.
-6.0 to -6.4	1	One large and one very extensive *Potamogeton* bed.
-6.5	2	Large bed *Potamogeton*.
-7.0 to -7.5	2-3	Two large beds *Potamogeton*; elsewhere generally small patches.
-7.5 to -8.0	2	Four small beds *Potamogeton*; often small clumps elsewhere.
-8.2 to -8.3	2	Large bed *Potamogeton*.
-9.0	2	One medium bed *Potamogeton*.
-9.7 to -9.8	2	One small, two medium beds *Potamogeton*.
-9.8 to -10.0 narrow	3	One large bed *Potamogeton*; elsewhere often patches, strips.
-10.5 to -10.6	1	Large bed *Potamogeton*.
-10.8 to -11.0	1	One large, two medium beds *Potamogeton*; occasional clumps and patches elsewhere.
-12.0	1	Backwater--*Potamogeton* extensive.
-12.5 to -12.8	0	Occasional small clumps, patches *Potamogeton*.
-12.8 to -13.5	1-2	One medium, two very large beds *Potamogeton*.

River right

River miles	Densities	Distribution
0 to -1.8	1-2	*Potamogeton* intermittent but generally continual in patches and strips.
-2.0	2	One small bed *Potamogeton*.
-3.1 to -3.3	1	One large bed *Potamogeton*.
-3.3 to -3.5	2	Extensive bed *Potamogeton*.
-6.0 to -6.8	2	One large, two medium, two small beds *Potamogeton*. One patch *Egeria*.
-7.3 to -7.6	2	One each small and medium beds *Potamogeton*.
-8.0 to -8.7	1	One large bed *Potamogeton*.
-9.0 to -9.1	1	Two small beds *Potamogeton*.
-10.5 to -10.8	2	Four large, one medium beds *Potamogeton*.
-10.9	3	One medium bed *Potamogeton*.
-11.9	2	One medium bed *Potamogeton*.
-12.6 to -12.7	2-3	One large, two medium beds *Potamogeton*.
-12.7	1	One medium bed *Potamogeton*.
-13.0	3	One medium bed *Potamogeton*.
-13.6 to -13.8	3	Generally continual but narrow bed *Potamogeton*.
-14.2 to -14.4	2	One large, two medium beds *Potamogeton*.