INFLUENCE OF DREDGING AND

HIGH DISCHARGE ON THE ECOLOGY

OF BLACK CANYON

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EXECUTIVE SUMMARY

I. The Water and Power Resources Service is considering dredging in Black Canyon to create a larger forebay to accommodate higher peak-discharges and reverse flows for proposed modifications to Hoover Dam.

II. The Black Canyon area from Hoover Dam to Willow Beach supports a heavily utilized trout fishery and is important habitat for the razorback sucker (Xyrauchen texanus) and possibly bonytail chub (Gila elegans).

III. The Water and Power Resources Service initiated this investigation to determine what effect dredging and higher peak-discharges would have on the ecology of Black Canyon.

IV. Two permanent stations were established above Ringbolt Rapids and sampled approximately every six weeks to measure periphyton species composition and growth, invertebrate species composition and density and fish distribution. Four other stations were later established downstream and sampled for the same parameters.

V. The food chain in Black Canyon is relatively simple and consists of a few invertebrate and fish species that are wholly supported by periphyton productivity occurring in the canyon.

VI. Periphyton and invertebrate productivity were highest in the first three miles of river below the dam and decreased dramatically in downstream areas due to lack of suitable substrate and light. Light transparency was lower downstream because of increased turbidity from resuspension of silt and greater water depths.

VII. High discharges from Hoover Dam during the summer caused considerable scouring and shifting of substrates that reduced periphyton growth and invertebrate colonization in the deep river channel of Upper Black Canyon.

VIII. Underwater observations of razorback suckers indicated they were most abundant in the first 1 mile of river probably due to higher productivity.

IX. Dredging in the area above Ringbolt Rapids will significantly reduce periphyton and invertebrate productivity. Periphyton will reestablish within one-two months of dredging but at a lower level than currently exists due to increased water depths and decreased light penetration. Invertebrates will also invade the dredged area within a few months, but it may take several months or possibly a year for their population to fully recover. This is primarily because most of the invertebrate species will have to colonize from downstream sources. Reduction in periphyton and invertebrate productivity could reduce the trout and endemic fish populations because they are wholly dependent on these autochthonous resources for food.

X. Higher current velocities created by increased peak-discharges from Hoover Dam could have a more permanent impact on the ecology of Black Canyon than dredging. Siltation occurs below the tailrace during low discharge periods in the winter. These materials are flushed downstream during peak-discharge periods of spring and summer and scour the bottom of periphyton and invertebrates. The Water and Power Resources Service estimates that the bottom will become armored after two-three months of higher discharge which would allow periphyton growth to again increase. However, seasonal and annual variations in siltation (e.g. flashflooding) and in the rate and duration of peak-discharges may preclude permanent armoring of the bottom.

XI. If dredging is conducted, consideration should be given to disposal of dredge spoils (cobble and boulder size) along the river banks in Black Canyon, rather than in Lake Mohave as is currently being planned. Boulder and cobble substrate would probably enhance periphyton and invertebrate productivity in downstream areas thus providing more food resources and habitat for the trout and endemic fish populations. This could serve to mitigate losses in productivity and habitat that may occur in the upper canyon from dredging activities and higher peak-discharge from Hoover Dam.

1.0 INTRODUCTION

The Water and Power Resources Service is presently investigating the feasibility of modifying Hoover Dam to increase the present capacity of 1,340 MW by at least 500 MW and probably 1000 MW. The following alternatives are under investigation (USDI 1978):

(i) the addition of one or more conventional hydroelectric generating units to Hoover Dam.

(ii) the addition of reversible pump-storage hydroelectric units to Hoover Dam.

(iii) the uprating of existing generating units at Hoover Dam.

(iv) any combination of the above proposals.

Uprating of the existing generating units or addition of new units will require an increase in peak-discharge from the current level of 30-40,000 $ft^3 \cdot sec^{-1}$ to 49,000 and 62,000 $ft^3 \cdot sec^{-1}$. Operation of pump-storage units will require a peak-discharge of 76,000 $ft^3 \cdot sec^{-1}$ with periods of no flow and reverse flow. In order to accommodate the high peak-discharges and reverse flow, these power modifications could require dredging of Black Canyon below Hoover Dam to create a larger forebay. Disposal of dredge spoils from such activities would subsequently be made in the dead storage area of Lake Mohave.

The feasibility of dredging Black Canyon, in part, depends on the impact of these activities on the game and native fish species, and on recreational and other beneficial uses in this section of the Colorado River.

The Colorado River in Black Canyon supports a heavily utilized trout fishery that is maintained by annual stocking of 700,000 catchable-sized rainbow trout (*Salmo gairdneri*) from the Willow Beach Trout Hatchery. The hatchery is also used for propagation of several endangered fish species. The razorback sucker (*Xyrauchen texanus*) occurs in Black Canyon, and bonytail chub (*Gila elegans*), which was recently placed on the endangered species list, may utilize this area, although sightings have not been made in recent years. Consequently, the Water and Power Resources Service initiated this study in January, 1979 to assess the impacts of dredging on the ecology of Black Canyon.

The objectives of this investigation were to:

(i) review and analyze existing data on Black Canyon relating to dredging and spoiling activites.

(ii) gather additional information within the area to adequately evaluate the ecological impacts of dredging and spoiling activities.

(iii) make recommendations as to the best locations for the dredge spoil disposal including alternative sites within the active storage of Lake Mohave which may have beneficial environmental effects.

(iv) evaluate the potential impacts as to severity and duration of each dredging and spoiling alternative on the aquatic vegetation, benthic invertebrates, and fish populations.

Objective (i) was completed as an interim report (Miller et al. 1979) in April 1979, which is incorporated in this report. The objectives were further expanded in August, 1979, to:

(v) evaluate the effect of high current velocities on the stability of bottom substrates in Black Canyon.

(vi) evaluate the influence of high current velocities on periphyton and invertebrate colonization as well as fish distribution in Black Canyon.

(vii) determine the downstream gradients in periphyton and invertebrate production in Black Canyon as related to discharges from Hoover Dam.

(viii) determine the rate and extent of recolonization of periphyton and invertebrates after the summer peak discharge period from Hoover Dam.

2.0 DESCRIPTION OF THE STUDY AREA

Lake Mohave was formed in 1951 by the construction of Davis Dam. The reservoir extends 108 km south from Hoover Dam to Davis Dam (Fig. 2.1). The first 32 km, which includes the Black Canyon area, is characterized primarily by river conditions. Water temperatures within Black Canyon are virtually constant at 12-13°C due to the hypolimnetic discharges from Hoover Dam. Current velocities may reach 2.1 $m \cdot sec^{-1}$ (6.5 $ft \cdot sec^{-1}$) during periods of high discharge. There is considerable seasonal and daily variation in water level (1-3 m) due to discharge cycles from Hoover Dam.

The river is bordered by the Black Mountains to the east and the Eldorado Mountains on the west. The canyon walls extend several hundred meters above the river and shade the water for most of the day, greatly reducing incident solar radiation. The riparian community in Black Canyon is sparse except for a few stands of saltcedar (*Tamarisk gallica*) and creosote (*Larrea divaricata*).

Pertinent morphometric data for the reservoir are given in Table 2.1. The transition between river and true reservoir conditions in Lake Mohave occurs in Eldorado Canyon. This is especially evident in the summer when a sharp interface (convergence) develops as cold, nutrient-rich, river-water flows under warm lake-water. Mixing at the interface promotes high phytoplankton productivity in Eldorado Canyon, resulting in a marked change in water clarity between river and lake-water (Paulson, Baker and Deacon 1980). Below Eldorado Canyon, Lake Mohave expands into Eldorado and Little Basins. Cottonwood Basin, located 54 km downstream from Hoover Dam, is the widest point in the reservoir (6.4 km). There are few bays or coves in Lake Mohave, and it is best characterized as a "run of the river" reservoir.

The only significant inflow to Lake Mohave is from the Colorado River via discharge from Hoover Dam. There are some warm springs located in Black Canyon,

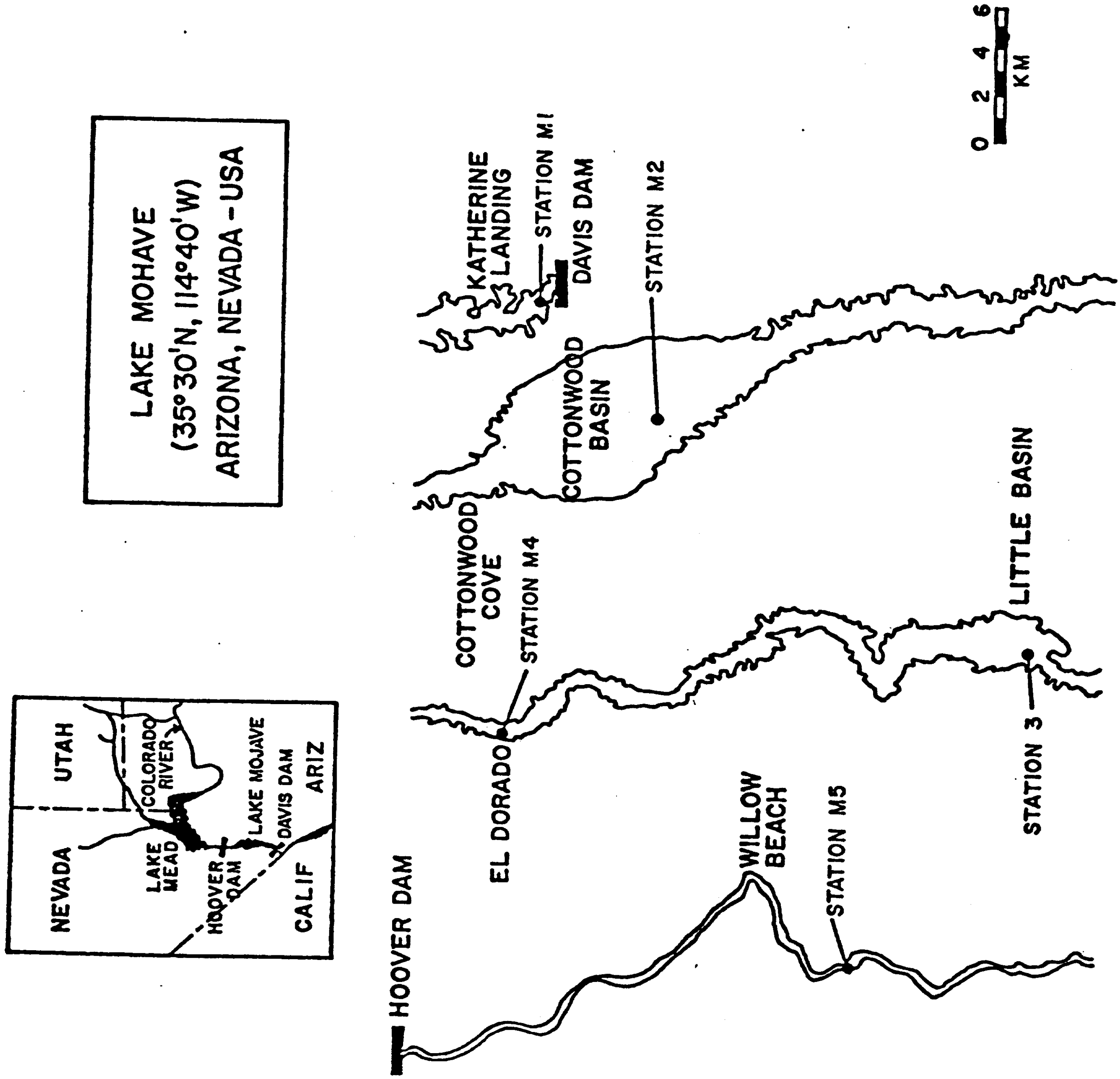

Figure 2.1. Map of Lake Mohave (stations are those used for the 1976-77 Limnological Study by Paulson et al. 1980).

Table 2.1 Morphometric characteristics of Lake Mohave [derived from USDI (1966), Lara and Sanders (1970), Hoffman and Jonez (1973)].

Parameter	Lake Mohave
Maximum operating level (m)	197.0
Maximum depth (m)	42.0
Mean depth (m)	19.5
Surface area (km^2)	115.0
Volume ($m^3 \times 10^9$)	2.3
Maximum length (km)	108.0
Maximum width (km)	6.4
Shoreline development*	3.0
Discharge depth (m)	42.0
Annual discharge (1977) ($m^3 \times 10^9$)	9.3
Replacement time at maximum operating level (years)	.24

*Unitless parameter to measure regularity of shoreline, value of 1 is equivalent to a lake shaped in a perfect circle.

but these are insignificant relative to the Colorado River. The Willow Beach Trout Hatchery located 18 km below the dam, uses river water which is directed back to the river. There are no major diversions of water from Lake Mohave.

The climate is arid with annual precipitation averaging about 8 cm. Mean annual temperature is about 19°C with a range from 45°C in the summer to -1°C in the winter. Winds are highly variable, but generally southerly winds prevail in the summer compared to north-easterly winds in the winter.

The terrestrial vegetation is typical of that in the Mohave desert, consisting of creosote bush (Larrea tridentata), mesquite (Prosopis odorata), eriogonum (Eriogonum sp.), salt bush (Atriplex sp.), arrow-weed (Pluchea oericea), prickley pear cactus (Opuntia sp.) and barrel cactus (Echinocactus sp.). Extensive growth of tamarisk (Tamarix gallica), an exotic phreatophyte, occurs along the shoreline.

The water of the Colorado River and Lake Mohave is alkaline (pH 8.3) with TDS averaging about 700 $mg \cdot l^{-1}$. The principal anions are sulfate, carbonate, chloride; major cations are sodium, calcium, magnesium and potassium. Nitrogen concentrations are moderate (ca. 0.2 to 0.5 $mg \cdot l^{-1}$) but phosphorous is low (ca. 0.010 $mg \cdot l^{-1}$) throughout the river. Silica concentrations are very high (ca. 7-8 $mg \cdot l^{-1}$).

2.1 ECOLOGICAL HISTORY OF THE LAKE MOHAVE AREA

The construction of Hoover Dam in 1935 significantly altered the physical characteristics of the Colorado River in the area that is now Lake Mohave. Stabilization of flows and temperatures and reductions in suspended sediments in the river created an environment suitable for development of a cold-water fishery. Rainbow trout (Salmo gairdneri) were planted in the river during 1935-1941. Moffet (1942) conducted a fisheries investigation in 1941 and found that rainbow trout were doing extremely well, particularly in the area from Hoover Dam to Eldorado Canyon. Although the native fishes in the Colorado River began to decline in the 1930's (Moffet 1944), the bonytail chub (Gila elegans), razorback sucker (Xyrauchen texanus) and squawfish (Ptychocheilus lucius) were all collected or observed below Hoover Dam by Moffet (1942). He also collected largemouth bass (Micropterus salmoides), carp (Cyprinus carpio) and channel catfish (Ictalurus punctatus).

The swift current from Hoover Dam scoured sand from the rock and gravel substrate and increased water clarity in the first 4 miles of river by 1932, and in the next 18 miles by 1941. By 1942, this extended 42 miles below Hoover Dam (Jonez and Sumner 1954).

Retrogression (scouring of sand and silt) caused by high discharge from Hoover Dam exposed coarse bottom materials (smallest 2 - 3 inches in diameter) in the river, especially from the dam to Willow Beach (Moffet 1944). Extensive growth of attached algae (periphyton) occurred on shoals and riffles to depths of 5-7 m (Moffet 1942). Ringbolt Rapids (mile 3) and Roaring Rapids (mile 16) were covered with luxuriant growth of Cladophora. The Cladophora and associated invertebrates (Daphnia and Diaptomus) were important foods for the trout populations. Cladophora comprised 70-98% of the stomach volume of trout examined by Moffet (1942). The mayfly, Callibaetis, was the most common invertebrate in the trout diets. Razorback suckers also utilized Cladophora as their principal food source (Moffet 1944).

The formation of Lake Mohave in 1951 further altered the ecology of the Colorado River. Filling of the reservoir and subsequent reductions in light penetration, resulted in marked decreases in growth of periphyton and macrophytes in lower Lake Mohave (Jonez and Sumner 1954). At high elevation, Lake Mohave water also backs up into Black Canyon, which resulted in a decrease in plant life in parts of that area. However, from Hoover Dam to Willow Beach, water depths did not increase appreciably, and *Cladophora* growth remained high even after Lake Mohave was formed (Jonez and Sumner 1954).

The formation of Lake Mohave was also accompanied by changes in the fish populations in the river. Centrarchids increased in abundance in the lower end of Lake Mohave (Table 2.2). Channel catfish were extremely abundant. Bonytail chub and razorback suckers were observed in large schools in the Eldorado Canyon area of the reservoir. Trout were pretty much restricted to the cold-water areas from Eldorado Canyon to Hoover Dam (Jonez and Sumner 1954). The mayfly, *Callibaetis*, was greatly reduced in abundance due to loss of breeding habitat when Lake Mohave was filled. *Gammarus*, which was introduced into the river in 1942, and midges became the principal invertebrates in the diet of rainbow trout (Jonez and Sumner 1954).

No detailed ecological investigations have been conducted in Lake Mohave since Jonez and Sumner's (1954) study. However, a fisheries survey was conducted in Black Canyon in August and September, 1976 (Bryant 1977). They found that carp and bluegill were the most abundant fish in the canyon (Table 2.3).

Several invertebrates were also collected, including the freshwater sponge (Porifera), *Hydra*, turbellarians, oligochaetes, snails, *Gammarus* and chironomids.

Recent gill netting conducted in Lake Mohave by W.L. Minckley and members of the U.S. Fish and Wildlife Service resulted in the capture of 5 bonytail chubs and several razorback suckers, providing confirmation that they still exist in the reservoir. Several razorbacks were also observed spawning on shoals above Cottonwood Basin. Minckley (1973, 1979) has summarized the present-day status and ecological relationships of the native fishes of the Colorado River.

Table 2.2. Introduced (I) and native (N) fishes of Lake Mohave (Jonez and Sumner 1954)

Common Name	Scientific Name	Relative Abundance	Status	Year of Introduction
Rainbow trout	(*Salmo gairdneri*)	A	I	1935
Brown trout	(*Salmo trutta*)	R	I	UNK
Largemouth black bass	(*Micropterus salmoides*)	A	I	1935
Bluegill sunfish	(*Lepomis macrochirus*)	A	I	UNK
Green sunfish	(*Lepomis cyanellus*)	A	I	UNK
Black bullhead	(*Ictalurus nebuiosus*)	R	I	UNK
Channel catfish	(*Ictalurus punctatus*)	C	I	1892
Black crappie	(*Pomoxis nigromaculatus*)	C	I	UNK
Carp	(*Cyprinus carpio*)	C	I	1881
Bonytail Chub	(*Gila elegans*)	C	N	-
Razorback sucker	(*Xyrauchen texanus*)	C	N	-
Squawfish	(*Ptychocheilus lucius*)	R	N	-
Dusky mountain sucker	(*Catostomus discobulus*)	R	I	UNK
Flannelmouth sucker	(*Catostomus lattipinnis*)	R	I	UNK

Table 2.3 Total number of fish sampled by gill net, Fyke net, hoop net and SCUBA observations in the Colorado River from Hoover Dam to Willow Beach in August and September, 1976 (Bryant 1977).

Species	Scientific Name	Caught	Sighted
Rainbow trout	(*Salmo gairdneri*)	1	1
Razorback sucker	(*Xyrauchen texanus*)	0	40
Carp	(*Cyprinus carpio*)	23	40
Channel catfish	(*Ictalurus punctatus*)	4	2
Largemouth bass	(*Micropterus salmoides*)	2	5-11
Green sunfish	(*Lepomis cyanellus*)	1	0
Bluegill	(*Lepomis macrochirus*)	11	0
Hybrid sunfish		1	0

3.0 MATERIALS AND METHODS

3.1 Sampling Stations

Six stations were established in the river from mile 1 through 12. The general location and bottom morphometry of each station is illustrated in Figure 3.1. The river is approximately 120 m wide at Station 1, but the main channel is very distinct and runs adjacent to the Arizona bank. A shallow (from 0 to 2 m in depth, depending on the surface elevation of Lake Mohave and discharge from Hoover Dam), gravel-cobble reef extends for approximately 90 m from the Nevada side of the river, where a sharp incline occurs to a depth of approximately 12 m (Fig. 3.1). Three substations (designated 1-A, 1-B, and 1-C) were selected at various depths along this incline at Station 1 (Fig. 3.1). Substation 1-A was located at the top of the slope in water fluctuating from 0 to 2 m in depth. The surrounding substrate consisted of approximately 90% cobble (6.4 - 25 cm dia.) and 10% gravel (.8 - 1.6 cm dia.). Substation 1-B was located midway down the slope in 6-8 m of water. The surrounding substrate consisted of about 80% cobble and 20% gravel until early May when the substrate became very unstable and changed to about 95% gravel and 5% cobble. Substation 1-C was located in the deepest part of the river channel. The depth varied from 11-12 meters, and the substrate consisted of about 60% cobble, and 40% boulder, except for a period in May when this material was temporarily covered by unstable cobble from upslope and upstream sources. The extreme flows and low surface elevation of Lake Mohave precluded the possibility of collecting a complete set of data at these stations throughout most of May.

Two substations (A & B) were also established at Station 2. Substation 2-B was located in a relatively deep hole directly adjacent to the bedrock wall on the Nevada bank in 8-10 m of water (Fig. 3.1). Substation 2-A was located in approximately 5 m of water. The substrate consisted of about 90% cobble and 10%

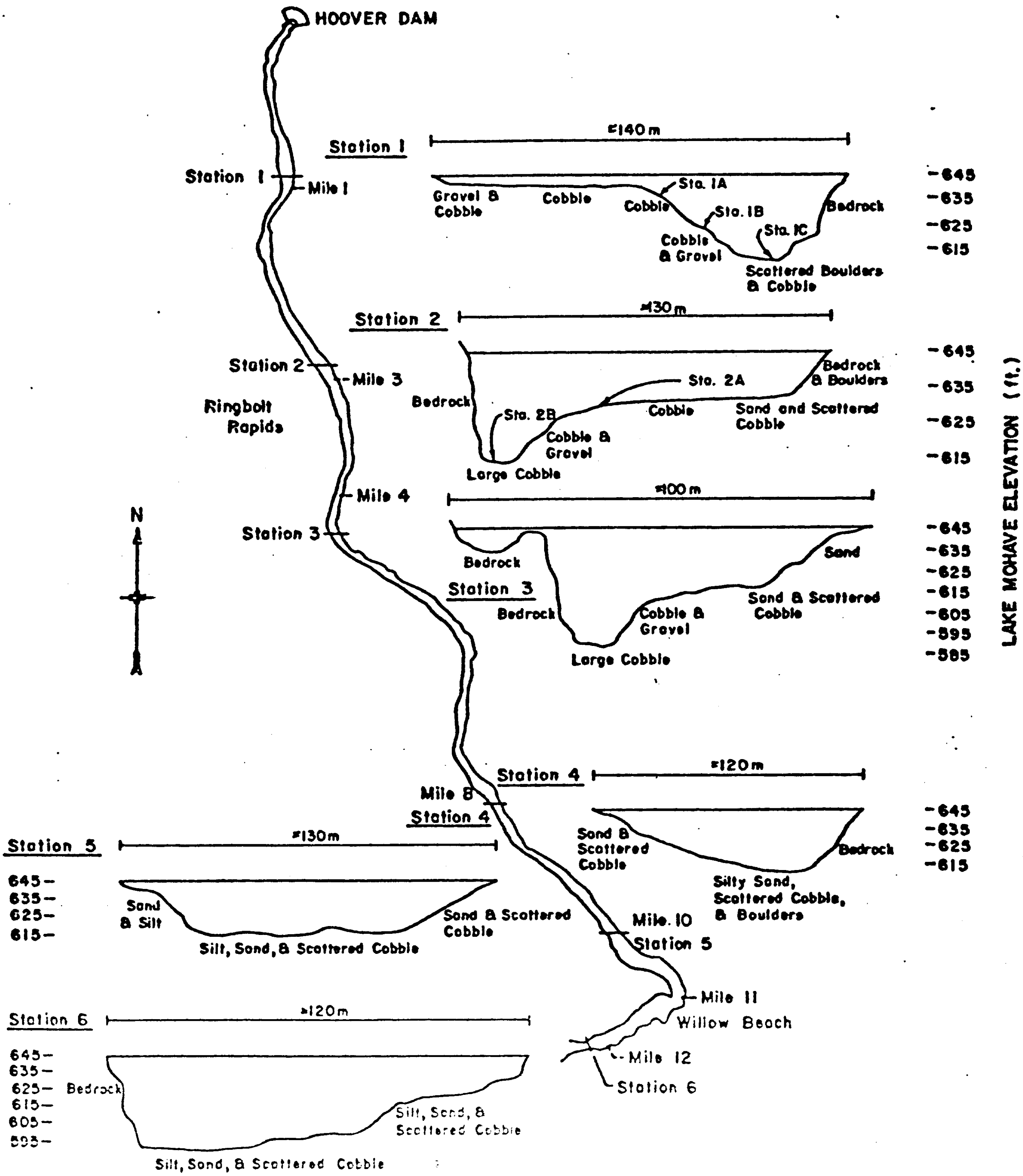

Figure 3.1. Sampling stations, bottom configuration and substrate types in Black Canyon.

gravel at Substation 2-B and 80% cobble and 20% gravel at Substation 2-A. The cobble at 2-B was generally much larger than at 2-A, and the substrate appeared to remain stable throughout the study.

During May, four additional stations were established downstream. Station 3 was located between river-miles 4 and 5. Stations 4, 5 and 6 were located at river miles 8, 10 and 12, respectively. The substrate at Stations 3-6 consisted of sand and scattered cobble which became silted over periodically during times of low discharge.

3.2 Periphyton and Benthic Invertebrate Sampling

Large flat boulders were used as natural substrate samples for periphyton. Holes were drilled and eyebolts placed on opposite sides of the rock samplers so that they could be raised and lowered with a winch. Three rock samplers were placed at each of the three substations at Station 1 and at the 10 m depth at Station 2. Periphyton subsamples were collected by scraping a known area of the rocks. Three such subsamples were collected from each rock and combined to form a composite sample for biomass determination. A fourth sample was preserved in Lugol's solution for identification of periphyton. The entire rock was then scraped as clean as possible and replaced at the particular substation.

A box sampler (Rutter-Ellis Assoc.), which is similar in design to a Surber sampler, was used to sample periphyton biomass on the natural substrates at each station. The sampler was randomly placed (by allowing it to fall 1-2 m) on the bottom, and all substrates were collected and taken to the surface. Periphyton were then scraped from the rocks, placed in bottles, packed in ice and taken to the laboratory where ash-free dry weights were determined (APHA 1971). Three replicate determinations were made on samples collected at each substation of Stations 1 and 2 and at Stations 3 and 4.

Benthic invertebrates were collected using two methods. Basket samplers

(USGS 1973) were filled with small cobble and placed at the substations of Station 1 and Station 2. Invertebrates were allowed to colonize the cobble for an 8-week and a 9-week period at Station 1 and for 10 weeks at Station 2. When sampled, the baskets were carefully placed in a benthos bucket to prevent the loss of organisms. All organisms were collected from each individual rock. The rocks were then placed back in the basket and replaced on the bottom of the river.

Box sampling for invertebrates was also conducted routinely at each substation of Stations 1 and 2 and periodically at Stations 3-6. Three replicates were collected at each substation of Stations 1 and 2 and at Stations 3-6. Invertebrates were identified, enumerated and weighed (dry weight). Box sampling at Stations 3-6 was initiated after instability of the substrate developed at these stations with high discharge during the late spring and summer. Substrate as large as .25 - .5 m in diameter was moved in the area of Station 1-C and instability of the sand and silt material was evident at least to river mile 12. Thus, it was determined that more intensive sampling was required at downstream stations to assess the influence of increased seasonal discharge on substrate and invertebrates.

3.3 Benthic Invertebrate Sampling and Echo Sounding in Lake Mohave

Benthic invertebrates in Cottonwood Basin were sampled on 3 dates at 4 different locations (Fig. 3.2). Three samples were collected from each site with a ponar bottom sampler, sieved through a benthos bucket and preserved in 5% formalin. Echo sounding was used at each general location to determine depth and bottom configuration. The areas surveyed were:

(i) Eldorado Basin from river miles 18 through 27,

(ii) Eldorado Canyon near river mile 27 (Ponar samples were also collected at this station in April, June, and October.),

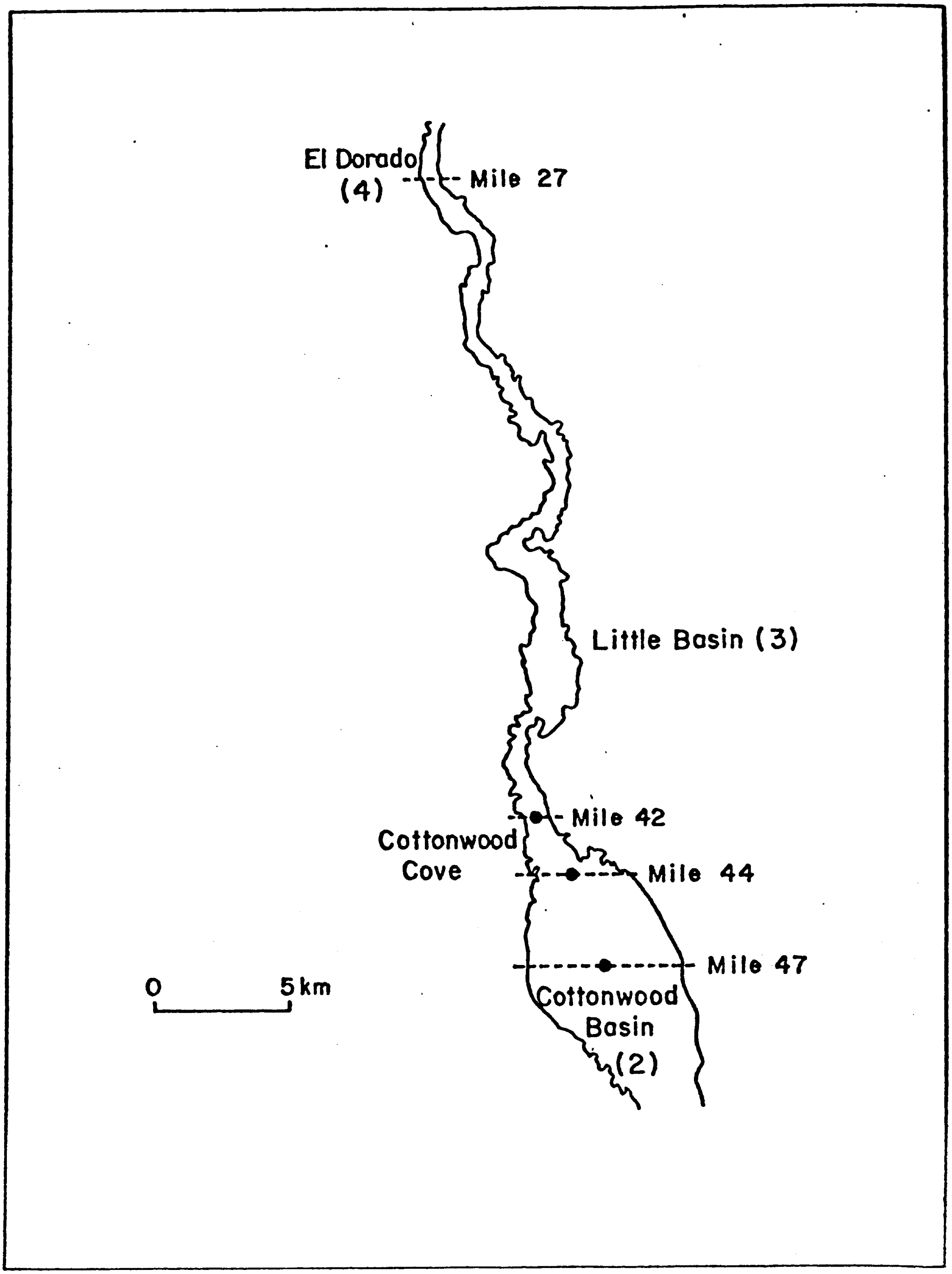

Figure 3.2. Benthic invertebrate and echo sounding sampling stations in Lake Mohave (Station numbers in parentheses are from the 1976-77 limnological investigation of Paulson et al. 1980).

(iii) River mile 42 which is at the head of Cottonwood Basin (Ponar samples were collected in June at this station.),

(iv) River mile 44 in the upper end of Cottonwood Basin (Ponar samples were taken in April, June and October at this station.),

(v) River mile 47 in the middle portion of Cottonwood Basin (Ponar samples were taken in October at this station.).

3.4 Analysis of Data

Due to the complexity and variation of the substrate of the Colorado River, it is difficult to apply rigorous statistical analyses to these data. The temporal and spatial heterogeneity of the substrate and currents caused extreme fluctuations in the plant and animal communities. Sampling techniques are by necessity variously selective, and the variance among the samples is usually quite large. At the beginning of the study, many techniques were used and while some proved to provide good data, others did not and were discontinued. For these reasons, results of invertebrate data collection are reported as the mean of the samples. Statistical analyses of such variable data show little significance. Therefore, the interpretation of invertebrate data is based on major trends or differences observed in our samples. Periphyton biomass and productivity data were less variable.

4.0 RESULTS

4.1 Periphyton Community

The periphyton community in the Colorado River below Hoover Dam was fairly typical of that found in most reservoir-regulated rivers (Table 4.1). *Cladophora glomerata* was usually the dominant (biomass) member of the community in shallow upstream areas where light transmittance was high. Rheophilic (current tolerant) species of diatoms, *Diatoma vulgare* and *Melosira varians*, typically dominated the periphyton in deeper parts of the river. Although there

Table 4.1. Periphyton species found in the upper end of Black Canyon.

GREEN FILAMENTOUS ALGAE

Cladophora glomerata
Stigeoclonium tenue

DIATOMS

Amphora sp.
Cymbella cistula
Diatoma vulgare
Melosira varians
Navicula sp.
Phormidium sp.
Rhoicosphenia curvata
Synedra acus

were some changes in species composition during the study, there was no apparent seasonal succession in the periphyton community.

4.2 Vertical Distribution and Seasonal Growth of Periphyton

The daily growth rate of periphyton on artificial samples installed at different depths of Station 1 is reported in Fig. 4.1. Periphyton growth was usually highest at the shallow station (1A), primarily because *Cladophora*, which is a large organism, was the dominant species. In June, a bloom of *Cladophora* occurred at the deep station (1C), which accounts for the high growth during that period (Fig. 4.1). Otherwise, the mid-depth station (1B) and the deep station were dominated by diatoms and their growth was considerably lower than *Cladophora* at the shallow station.

The seasonal growth pattern of periphyton on the artificial samples differed considerably at each depth (Fig. 4.1). At Station 1A, periphyton growth increased in June, reached a maximum in August and then decreased slightly in September and November. Growth at the mid-depth station did not vary appreciably throughout the study. Except for the peak in June, growth at the deep station was very low. This was largely due to scouring of the sampler by sand and other unstable substrates particularly during the summer when Lake Mohave elevations were low and discharge from Hoover Dam was high (Fig. 4.2). Stations 1A and 1B were less affected, apparently because they were located on shelf-like areas that were less subject to scouring.

The standing crop of periphyton on natural substrates generally showed the same growth pattern as the artificial samplers. The highest standing crop occurred at the shallow station and then decreased with increasing depth (Fig. 4.3). The low standing crop at the deep station (1C) was also related to scouring and to substrate instability. There was considerable instability of gravel and small cobble substrates during the summer peak discharge period. This appeared to be a major factor in reducing periphyton growth on small substrate.

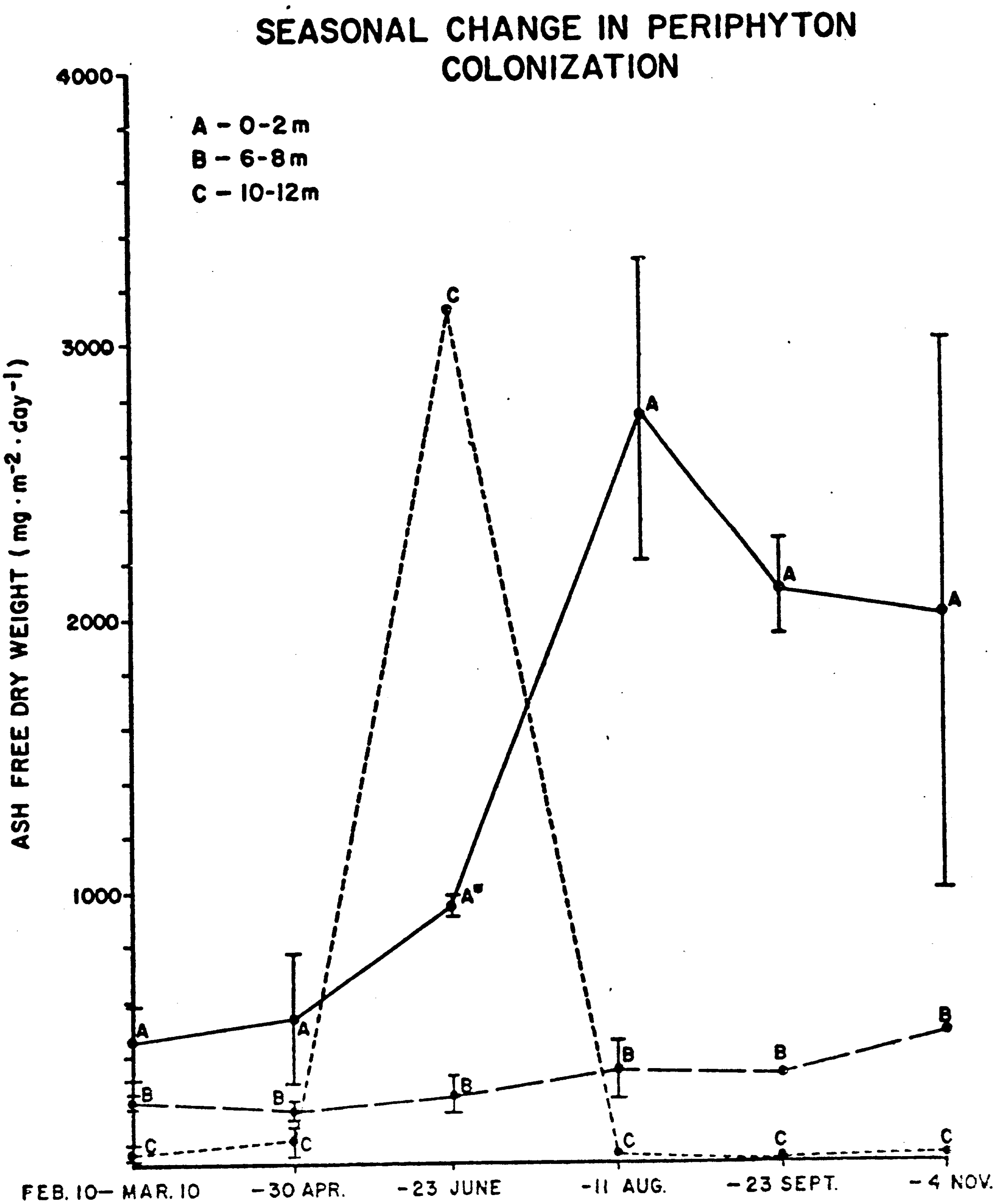

Figure 4.1. Periphyton growth rates on artificial substrate samplers installed at different depths of Station 1. (Estimates for Station C in August, September and November are visual estimates because samples were scoured clean by high current velocities).

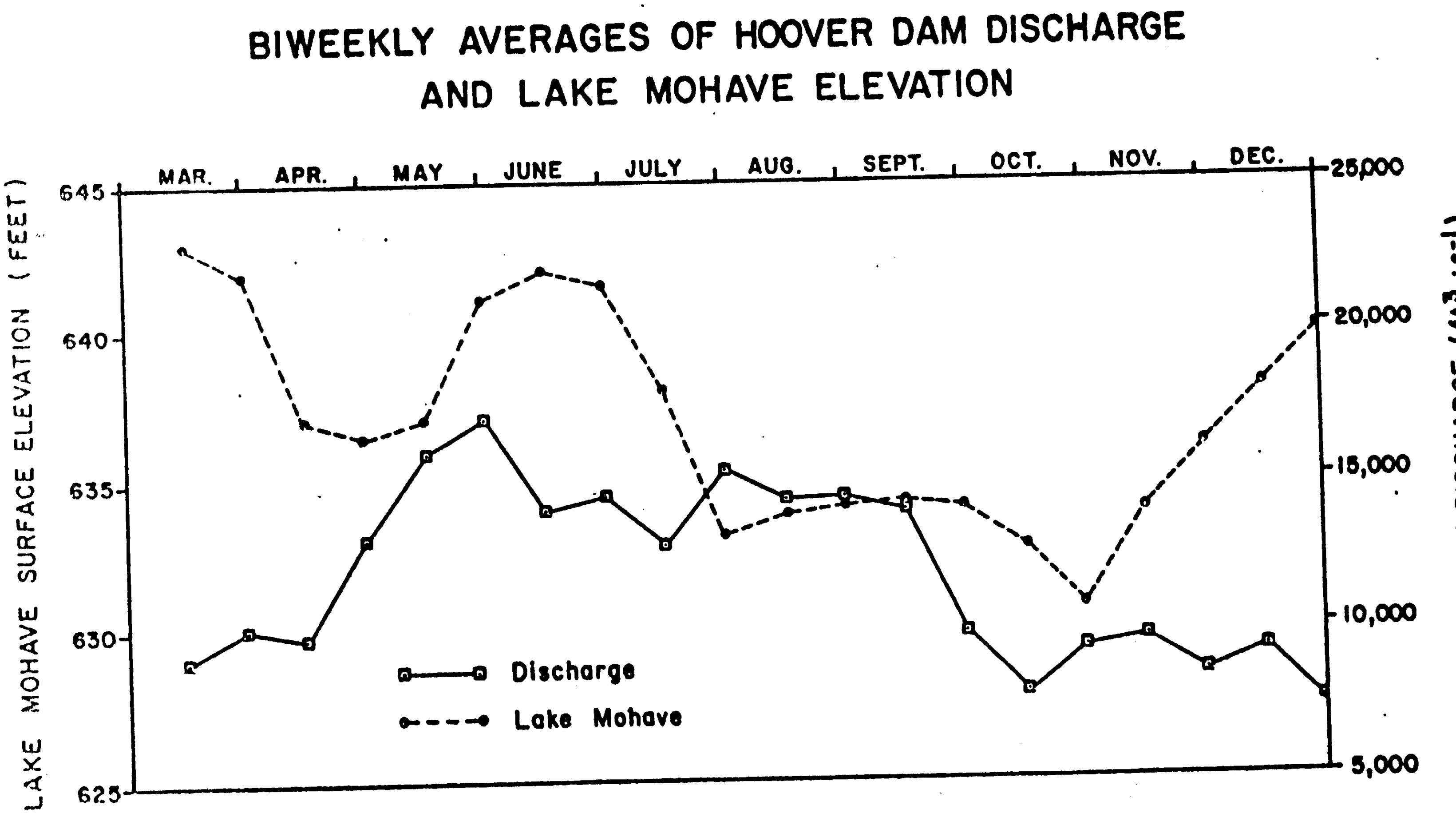

Figure 4.2. Mean daily discharge from Hoover Dam and surface elevation of Lake Mohave from March - December, 1979.

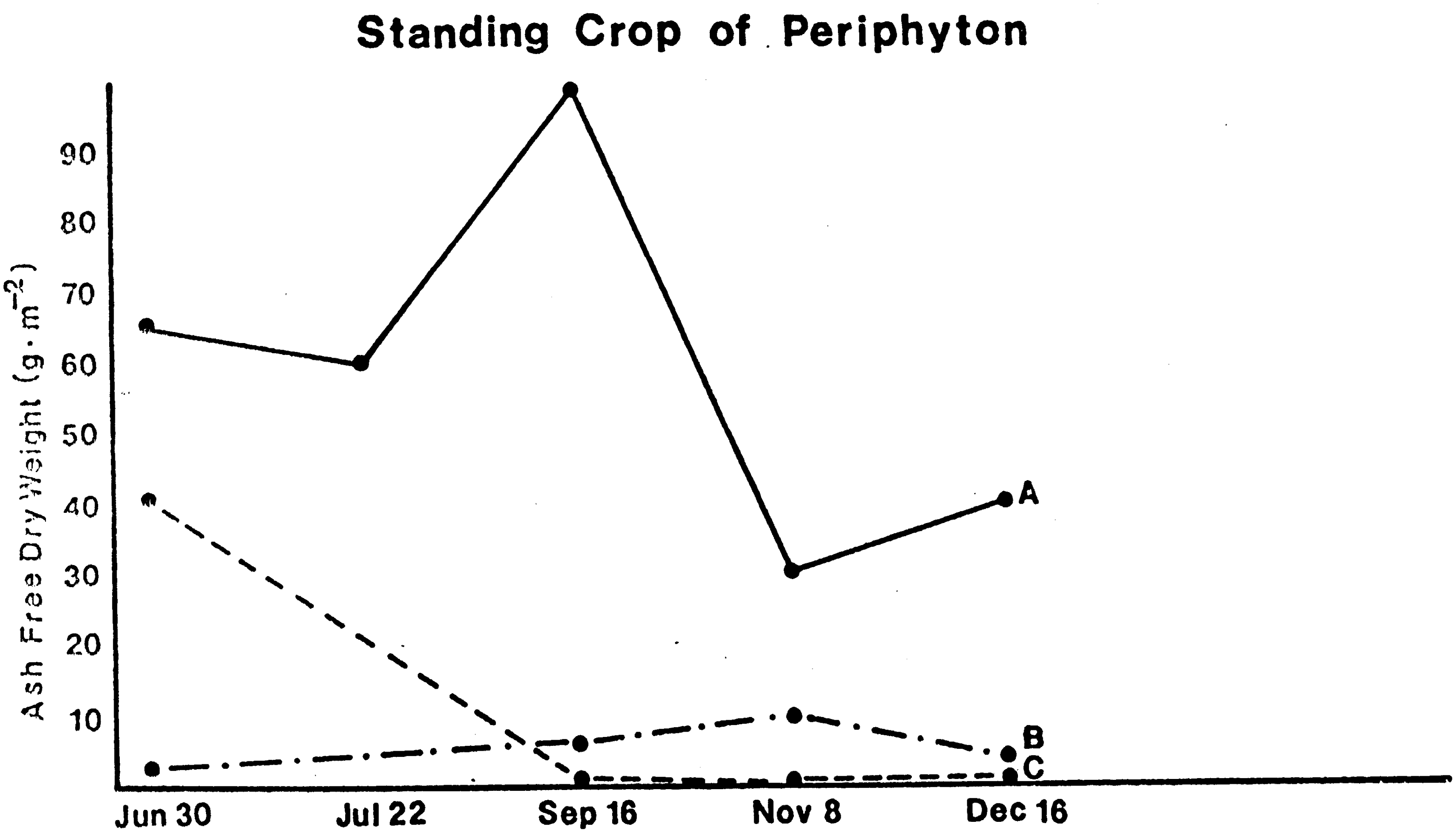

Figure 4.3. The standing crop of periphyton collected with a box sampler at Stations 1-A (0-2 m depth), 1-B (6-8 m) and 1-C (10-12 m) from June to Dec., 1979. Station 1-A was exposed for several hours daily. Substrates at Stations 1-B and 1-C were unstable and scoured when Lake Mohave elevations were low during late summer.

4.3 Longitudinal Distribution of Periphyton Standing Crop

There was a marked decrease in periphyton standing crop downstream from Station 1 (Fig. 4.4). This occurred consistently throughout the summer and fall. At and below Willow Beach (Stations 5 and 6), only small amounts of periphyton were found on boulder size substrates which were extemely rare in this area. It was, therefore, not possible to quantify growth at these two stations. The periphyton community at the downstream stations was dominated by diatoms. *Cladophora* were not observed at any of the downstream stations during the study.

4.4 Invertebrate Community

The invertebrate fauna collected during the study included members of eight classes. The class Crustacea was represented by two amphipods, *Hyalella azteca* and *Gammarus lacustris*. *Gammarus* were only found rarely at stations 2-5. The only aquatic insects found in the river were the chironomids; *Chironomus salinarius* and *Criptopus tremulus* occurred throughout the first 10 miles of river, and a much larger species of *Chironomus* was found at Station 6. The gastropods *Physa* and *Lymnaea* were found throughout the river. Oligochaetes were uncommon in upstream areas but became increasingly more numerous at downstream stations. Turbellarians, *Phragocata* and *Dugesia*, the hydrazoan, *Hydra*, and a Hydracarina were also present in the river. *Corbicula manilensis*, an introduced pelecypod, was restricted to lower Lake Mohave.

4.5 Vertical Distribution and Abundance of Invertebrates

The abundance and biomass of invertebrates were measured with a box sampler at Stations 1A, 1B and 1C between March and December 1979. Biomass was low at all those stations in March (Fig.4.5). By June, growth increased at the shallow

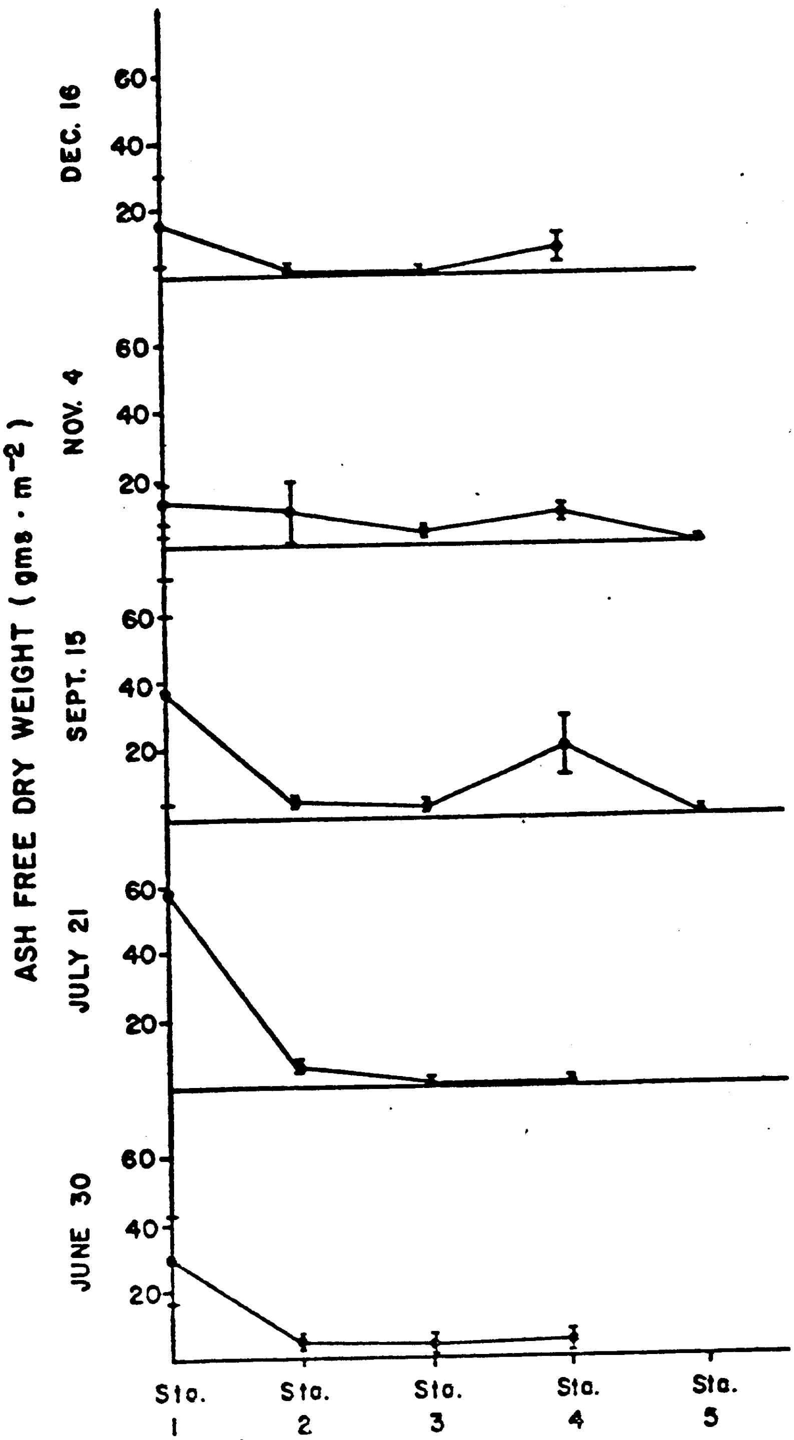

Figure 4.4. Average biomass of periphyton natural substrates in Black Canyon for June, 1979-December, 1979. (Data are reported as the mean and standard error of three samples, except on July 21 when only one substation (1A) was sampled at Station 1).

(1A) and deep stations (1C) and remained relatively unchanged at the mid-depth (1B) station. Biomass remained high at 1A but decreased considerably at 1C in September and remained low through December.

Hyalella were prevalent at the shallow station, but chironomids were more abundant at the deeper stations in March (Fig. 4.6). In June, chironomids increased in abundance at the shallow station, whereas Hyalella became more abundant at the deeper stations. The chironomids and Hyalella both decreased in abundance at the deep stations in July (Figs. 4.6, 4.7) and remained low through December. However, both populations were fairly abundant at the shallow station throughout the summer and fall.

4.6 Invertebrate Colonization

Colonization rates of invertebrates were measured at Stations 1A, 1B, and 1C using basket samplers filled with rock substrates (USGS 1973). The basket samplers were colonized by the same invertebrate groups that were collected from natural substrates (Table 4.2). In the first experiment (3 March - 22 April), chironomid larvae and pupae were numerically dominant at the shallow (1A) and mid-depth (1B) stations, but Hyalella were most abundant at the deep station (1C). This pattern was reversed in the 22 April - 23 June colonization experiments (Table 4.3). The biomass and numbers of invertebrates in the basket samplers were usually lower than the natural substrates (Figs. 4.5, 4.7), indicating that the populations had not reached saturation after the 50 and 63 day colonization periods.

4.7 Longitudinal Distribution of Invertebrates in Black Canyon

Invertebrate populations were also sampled at Stations 3-6 on five occasions from June through mid-December. The total weight and species composition were determined from three samples collected at each station.

In the initial sampling period (June - July) the amphipod population

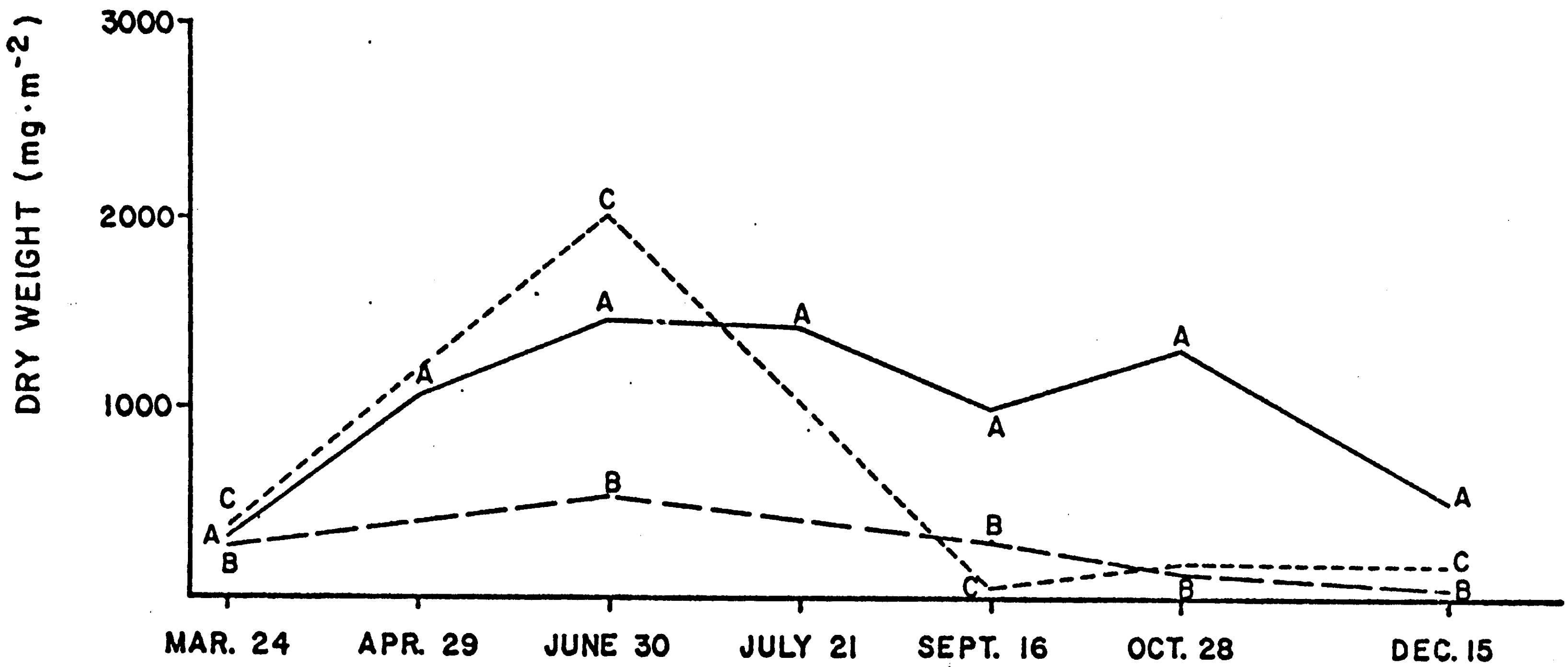

Figure 4.5. Invertebrate biomass at Station 1-A, 1-B and 1-C. Station 1-A was subject to almost daily exposure to air from mid-June until December. Station 1-B and 1-C were subject to unstable conditions from mid-May until December.

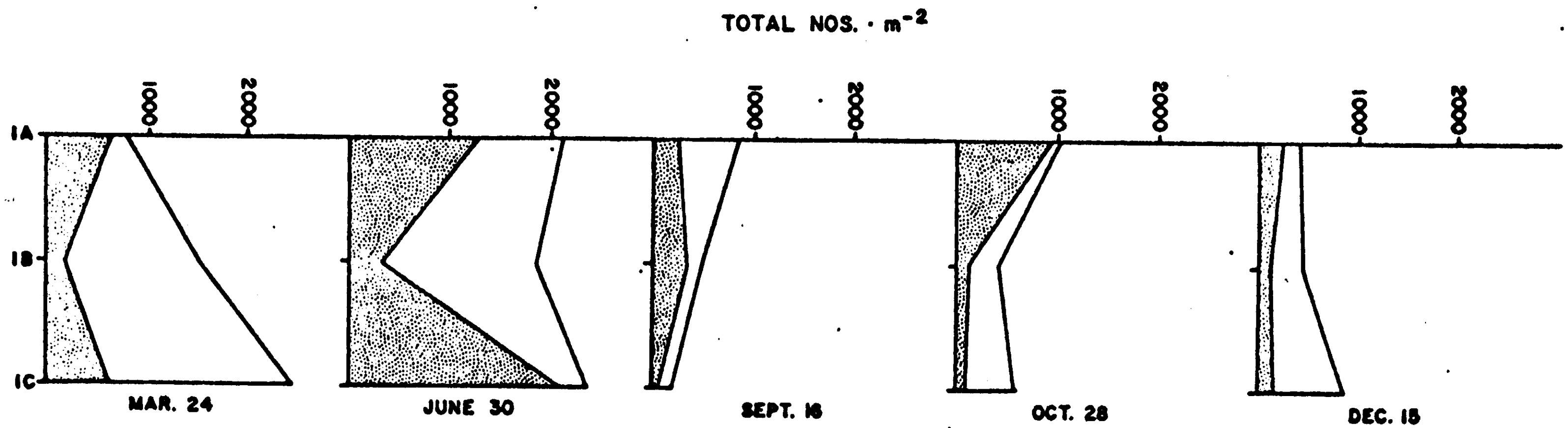

Figure 4.6. Relative abundance of <u>Hyalella</u> (shaded) and chironomids at Station 1-A, 1-B and 1-C from March - December, 1979. The depth at Station 1-A varied from 0-2 m, 1-B from 6-9 m and 1-C from 10-13 m.

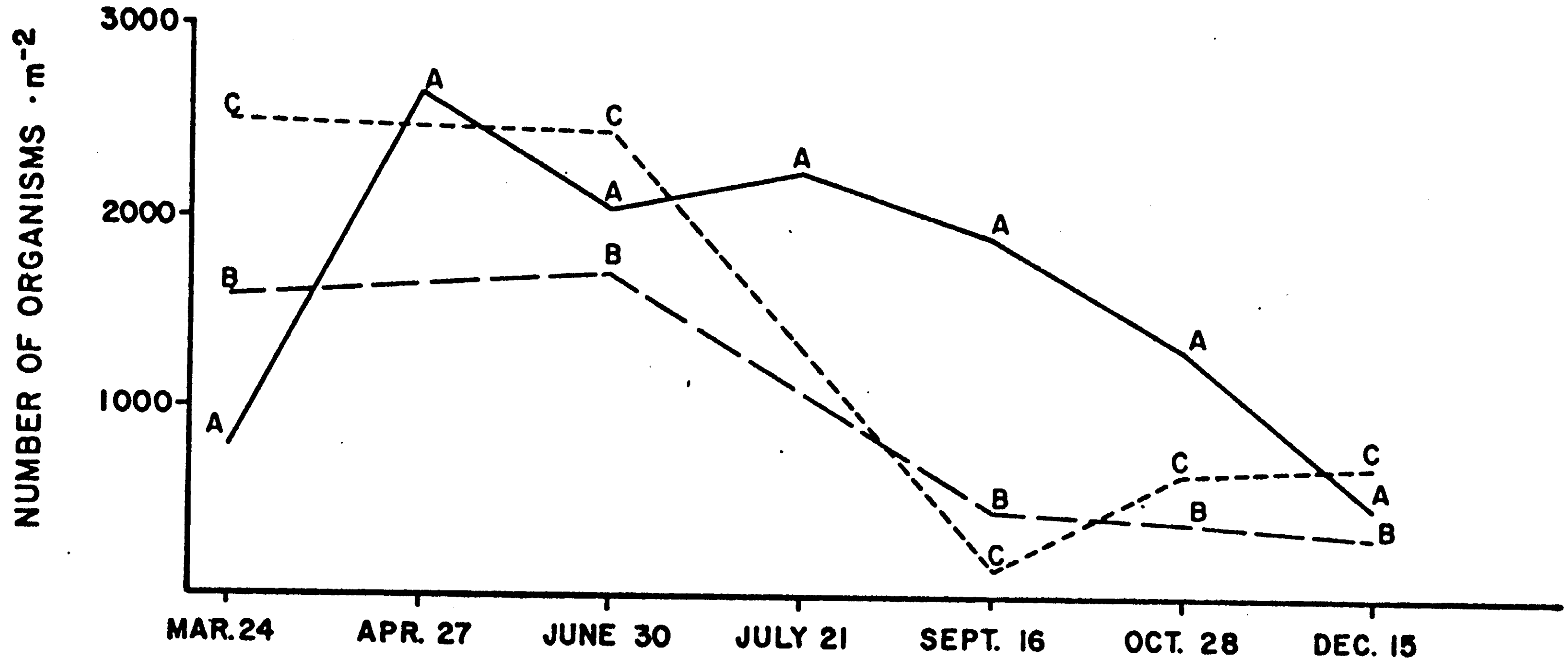

Figure 4.7. Invertebrate abundance at Station 1-A, 1-B and 1-C from March 1979 - December 1979.

Table 4.2 Invertebrate colonization of basket samplers installed at stations 1A, 1B and 1C from 3 March - 22 April 1979. All values are means of 3 samples.

	3 March - 22 April 50 days					
	Sta. 1 - A *		Sta. 1 - B		Sta. 1 - C	
Organism	$\bar{x}$ Number·m^{-2}	%	$\bar{x}$ Number·m^{-2}	%	$\bar{x}$ Number·m^{-2}	%
AMPHIPODA						
Hyalella azteca	50	14.8	113	30.4	24.0	58.5
DIPTERA						
Chironomidae						
larvae	229	68.6	225.3	60.6	8.7	21.2
pupae	44	12.8	21.0	5.6	4.7	11.5
MOLLUSCA						
Physa	9	2.7	10.0	2.9	1.3	3.2
ARACHNOIDEA						
Hydracarina	2	0.6	1.7	0.5	0.3	0.7
ANNELLIDA						
Oligochaeta	-	-	1.0	0.3	-	-
TURBELLARIA						
Phragocata	-	-	1.0	0.3	-	-
COELENTERATA						
Hydra	-	-	-	-	0.3	0.7
$\bar{x}$ Total wt. (mg)	141.6		245.2		22.8	

* Station 1A, 3 March - 22 April was exposed when Lake Mohave level dropped.

Table 4.3. Invertebrate colonization of basket samplers installed at stations 1A, 1B and 1C from 22 April-23 June, 1979.

	22 April - 23 June	63 Days				
	Sta. 1 - A*		Sta. 1 - B		Sta. 1 - C	
Organism	$\bar{x}$ Number$\cdot m^{-2}$	%	$\bar{x}$ Number$\cdot m^{-2}$	%	$\bar{x}$ Number$\cdot m^{-2}$	%
AMPHIPODA						
Hyalella azteca	707.6	77.9	171.0	49.4	16.7	9.3
DIPTERA						
Chironomidae						
larvae	132.0	14.5	131.5	38.0	148.7	83.0
pupae	29.7	3.3	40.5	11.7	11.7	6.5
MOLLUSCA						
Physa	18.0	2.0	1.0	0.3	0.7	0.4
ARACHNOIDEA						
Hydracarina	1.0	0.1	0.5	0.1	-	-
ANNELLIDA						
Oligochaeta	-	-	-	-	-	-
TURBELLARIA						
Phragocata	20.0	2.2	-	-	0.3	0.2
COELENTERATA						
Hydra	-	-	-	-	-	-
$\bar{x}$ Total wt$\cdot$(mg)	901.6		145.5		39.5	

(Hyalella) showed a progressive decrease in abundance at downstream stations (Fig. 4.8). However, the oligochaetes and chironomids increased significantly at Stations 3 and 4 but then decreased further downstream. During the rest of the study, chironomids and amphipods usually decreased in abundance from upstream to downstream stations. Oligochaetes, however, typically increased in abundance equally at Stations 5 and 6 (Figs. 4.8-4.12). This was usually accompanied by an increase in total biomass. In the fall and winter, the maximum invertebrate biomass occurred at the downstream stations.

4.8 Observations on Razorback Suckers

In an effort to monitor the distribution of the razorback sucker population, underwater observations were made at all stations throughout the study. Although razorback suckers were sighted at all stations, only rare sightings of individuals or small schools were made at Stations 3-6. Throughout the period of study, only adults were observed, although individuals 25-30 cm (10-12 in.) in length were sighted in October. The greatest concentration of razorbacks was consistently found from Ringbolt Rapids to the Station 1 area. Thus, only data from Station 1 and Station 2 sightings are reported. Razorback suckers were most abundant at Station 1 in March and decreased until the end of May (Fig. 4.13).

Razorback suckers were not observed at Station 2 during April or early May. However, from mid-May through June and early July, increasing numbers were sighted at this station. On July 22, during the period when Lake Mohave elevations were very low, 320 razorbacks were counted between the 2 and 3 mile markers.

The number of razorbacks sighted at Station 1 remained very low until September and October, but large numbers (ca. ≃ 500) were sighted between mile 1.5 and mile 3 on October 28. There appeared to be a general movement upstream during this time as no razorbacks were sighted between mile 2 and 3 during the December sampling. Approximately 50 were sighted at mile 1. While the number of

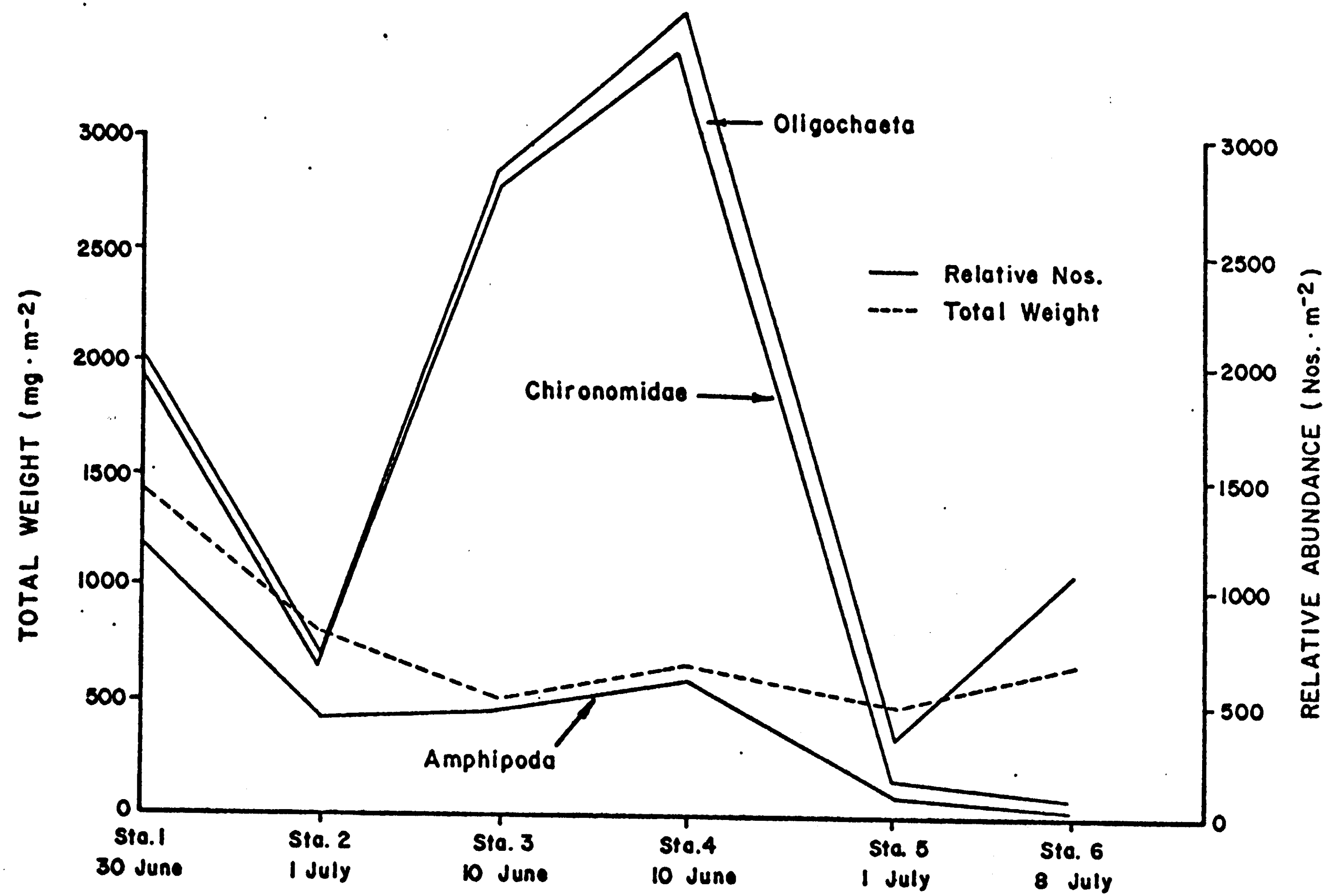

Figure 4.8. Relative abundance and biomass of major invertebrate groups in Black Canyon. Samples were collected with a box sampler during June and July, 1979.

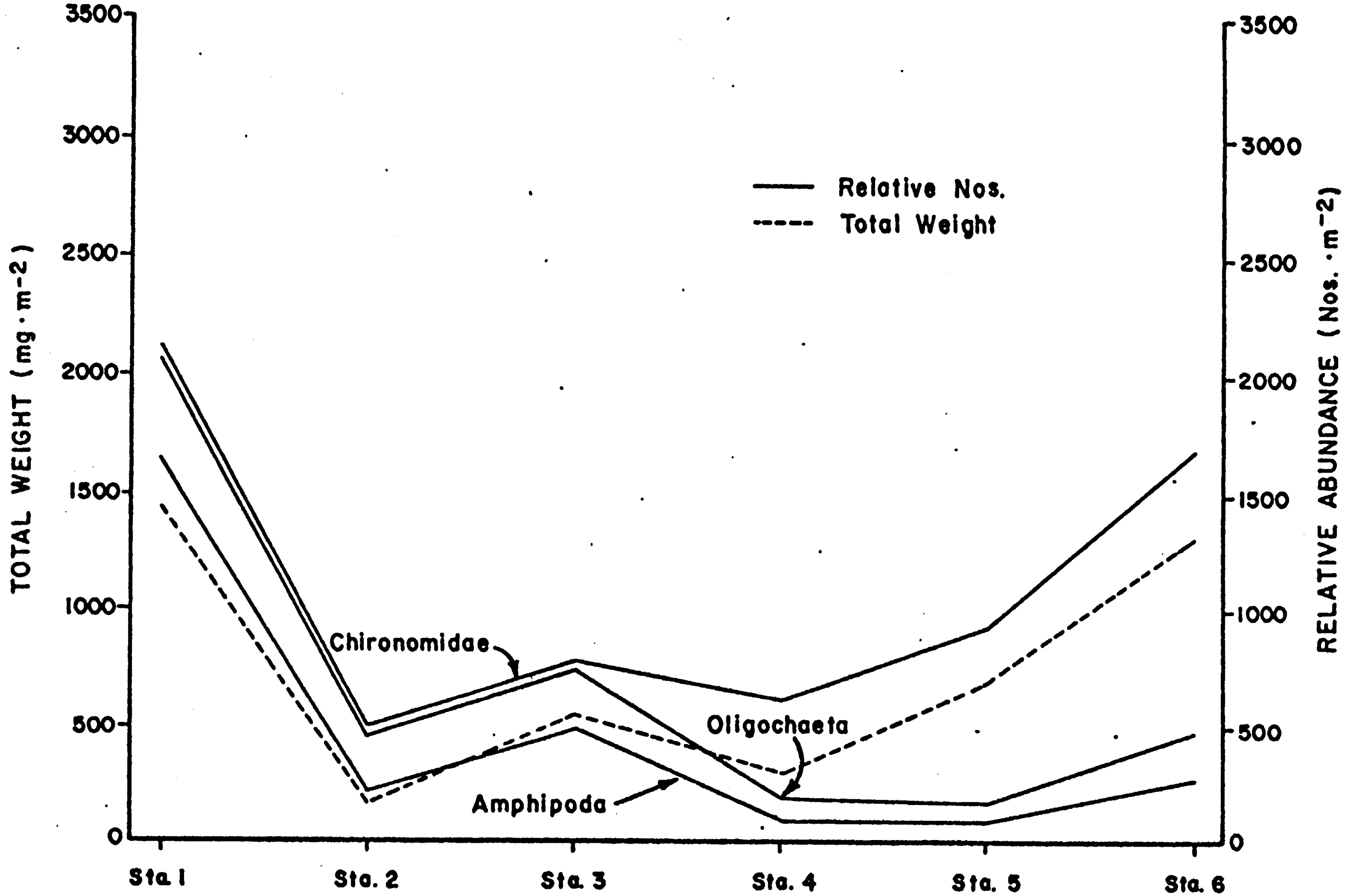

Figure 4.9. Relative abundance and biomass of major invertebrate groups in Black Canyon. Samples were collected with a box sampler on July 21, 1979.

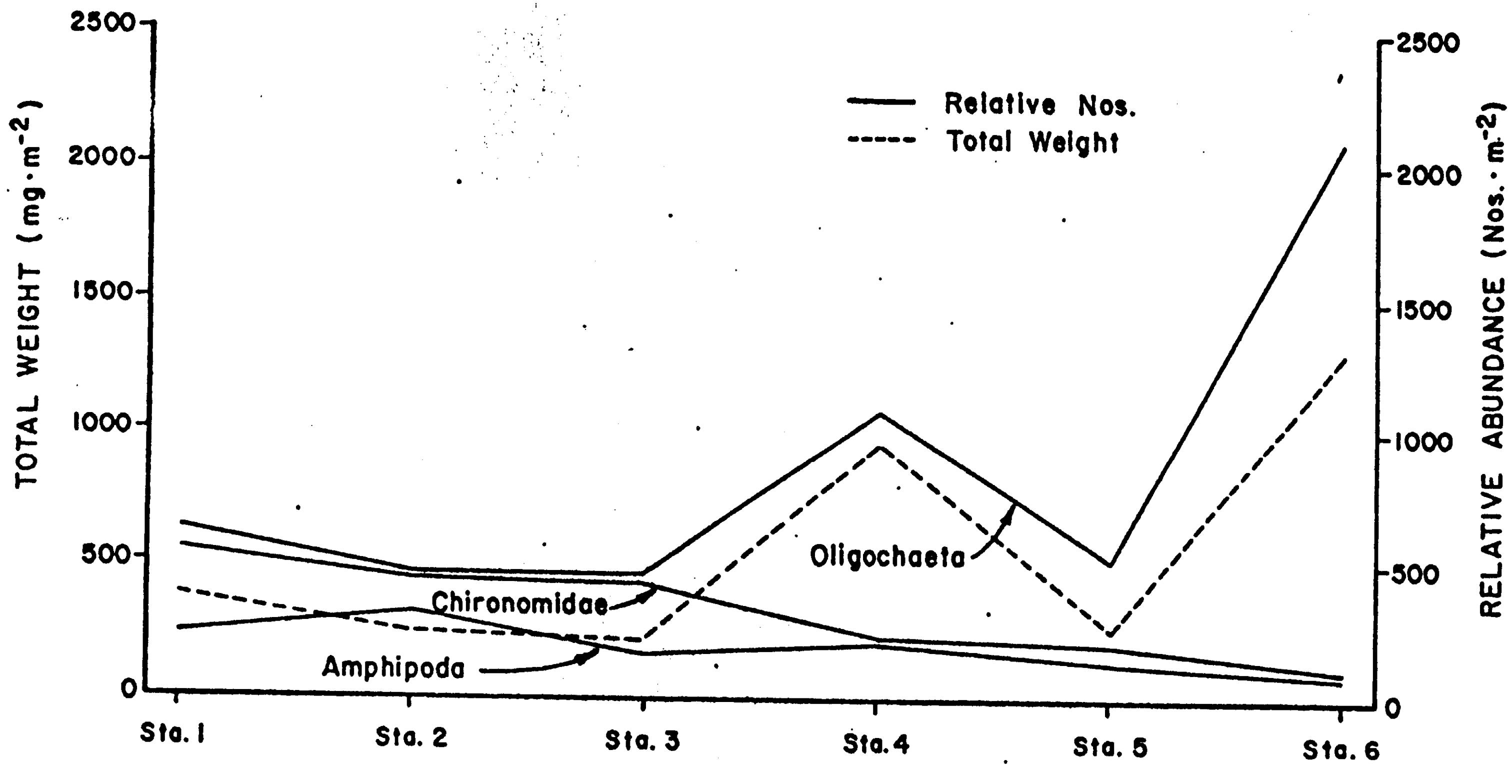

Figure 4.10. Relative abundance and biomass of major invertebrate groups in Black Canyon. Samples were collected with a box sampler on September 15, 1979.

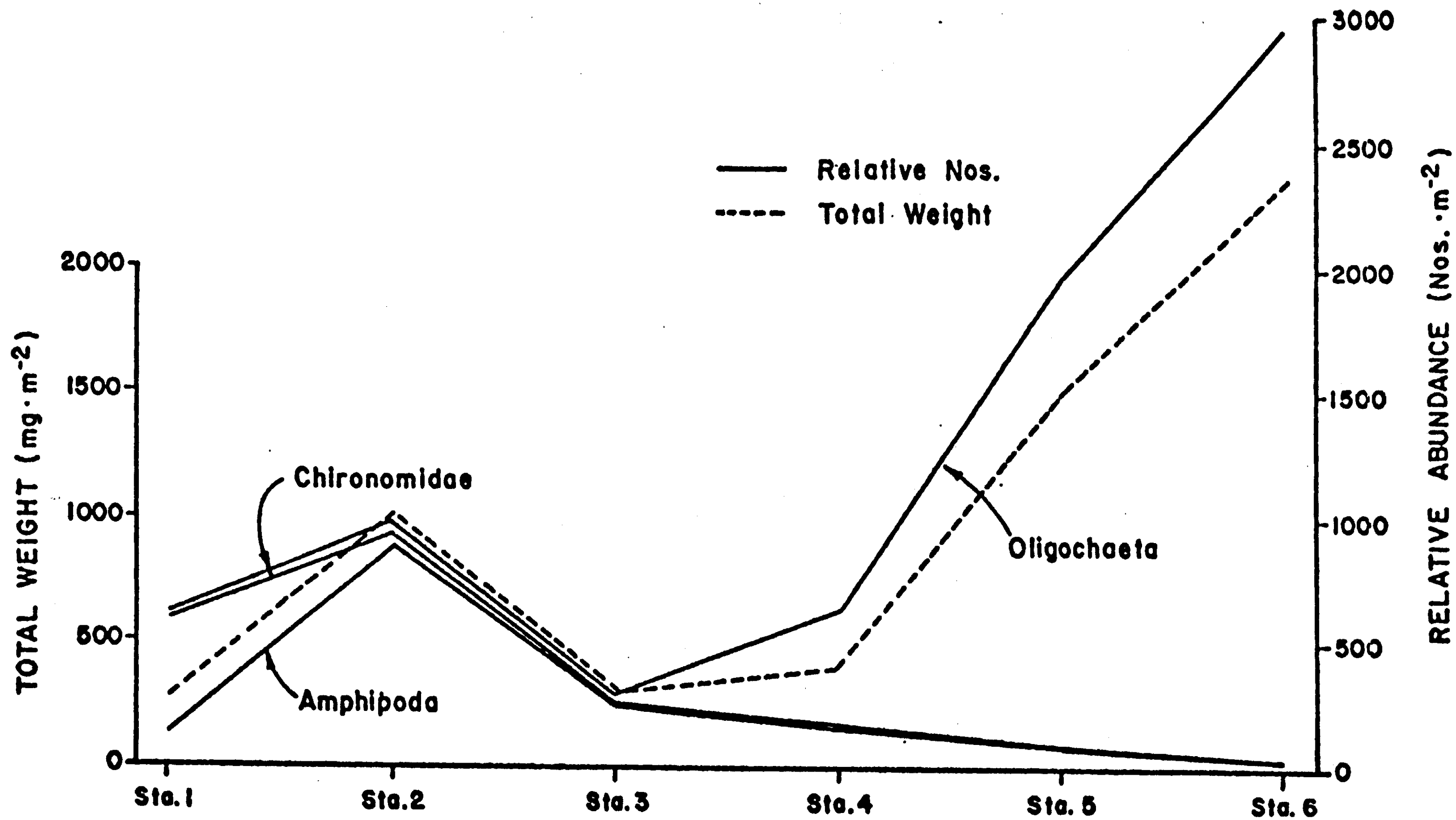

Figure 4.11. Relative abundance and biomass of major invertebrate groups in Black Canyon. Samples were collected with a box sampler on October 28, 1979.

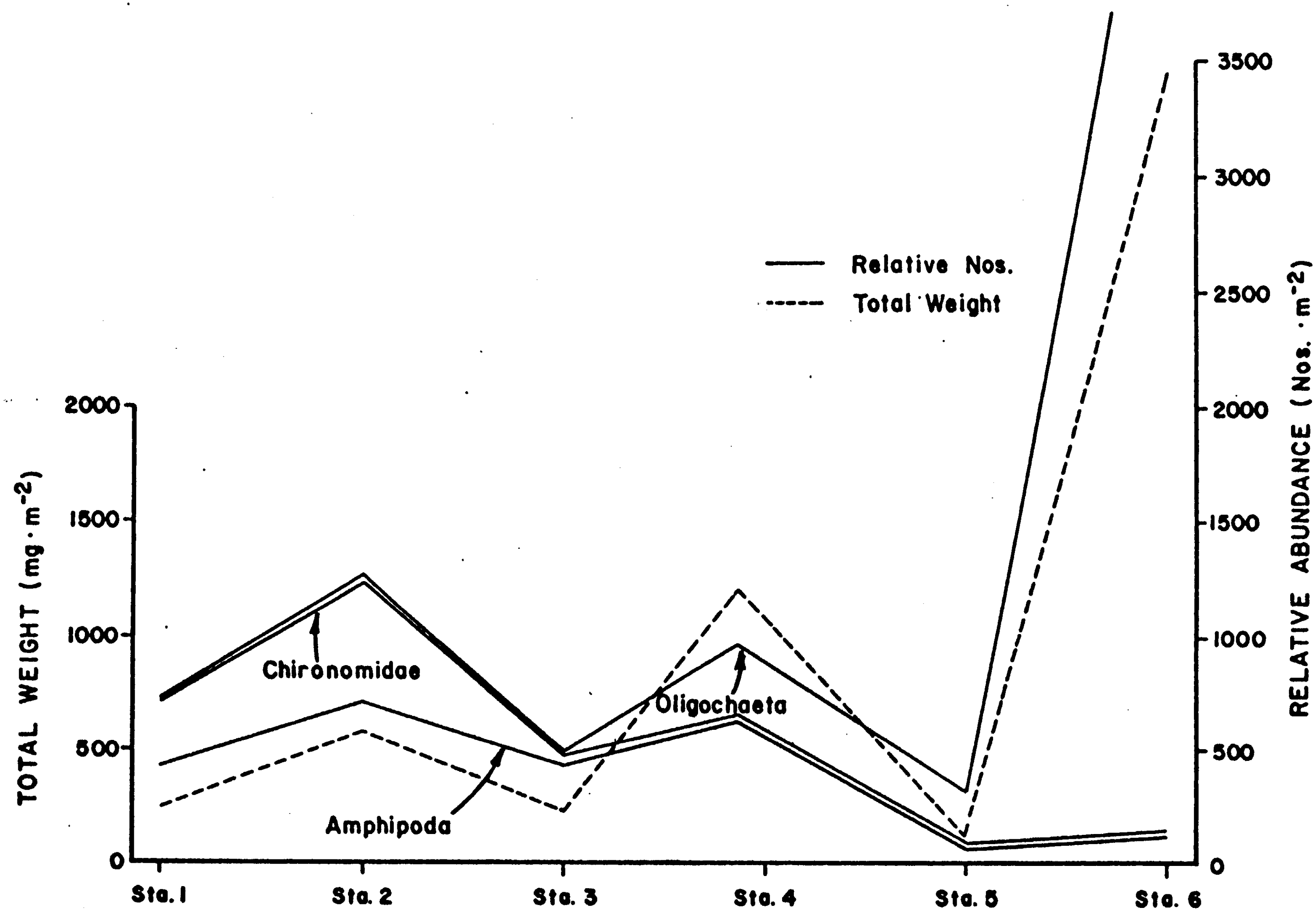

Figure 4.12. Relative abundance and biomass of major invertebrate groups in Black Canyon. Samples were collected with a box sampler on December 16, 1979.

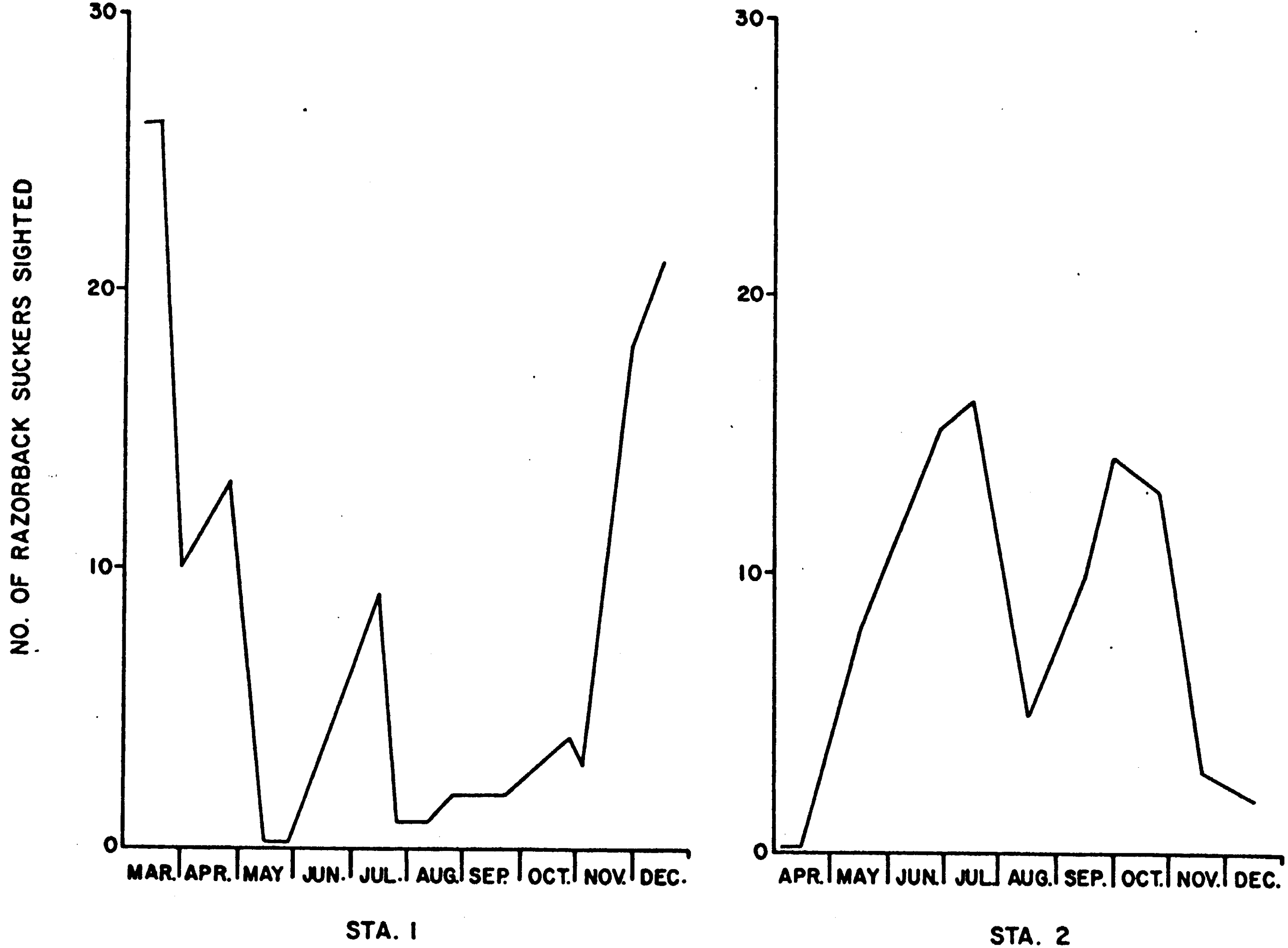

Figure 4.13. The number of razorback suckers sighted at Stations 1 and 2 from March through December, 1979. Observations were made by SCUBA.

Table 4.4 Invertebrate abundance in bottom samples collected from Lake Mohave with a ponar sampler, in April, June and October, 1979.

		April		
Taxa	Eldorado Canyon	mile 42	mile 44	mile 47
Oligochaeta	365	-	418	-
Chironomidae	458	-	371	-
Corbicula	146	-	0	-
Gastropoda	0	-	86	-

		June		
Taxa	Eldorado Canyon	mile 42	mile 44	mile 47
Oligochaeta	696	385	219	-
Chironomidae	179	385	272	-
Corbicula	106	0	0	-
Gastropoda	0	0	100	-

		October		
Taxa	Eldorado Canyon	mile 42	mile 44	mile 47
Oligochaeta	484	-	153	72
Chironomidae	20	-	391	46
Corbicula	40	-	0	0
Gastropoda	0	-	0	7

razorbacks increased dramatically in November and December at Station 1, a reduction was observed at Station 2.

4.9 Benthic Invertebrates of the Lower Portion of Lake Mohave

Data from the collection of invertebrates in Lake Mohave for spring, summer and fall are presented in Table 4.4. All collections, except the June sample at river mile 44 were made in the Colorado River channel.

Samples collected at Eldorado Canyon contained 3 classes of invertebrates. In April, chironomid larvae were dominant, followed by oligochaetes and *Corbicula manilensis*. This was the only station where *Corbicula* were found.

Oligochaete numbers substantially increased from ($365 \cdot m^{-2}$ to $696 \cdot m^{-2}$) in Eldorado Canyon from April to June. Chironomid larvae had decreased from $458 \cdot m^{-2}$ to $179 \cdot m^{-2}$; there were 20 chironomid pupae$\cdot m^{-2}$. Adult *Corbicula* had decreased from $146 \cdot m^{-2}$ to $106 \cdot m^{-2}$, of which 33 were immature *Corbicula*. Immature *Corbicula* had not been present in the earlier samples.

The October samples revealed that chironomid larvae and pupae densities had again decreased ($13 \cdot m^{-2}$ and $7 \cdot m^{-2}$, respectively). Oligochaetes remained relatively stable while *Corbicula* decreased substantially.

At river mile 44, located in the upper part of Cottonwood Basin, the April samples indicated the presence of the gastropods *Physa* and *Lymnaea*. Oligochaetes and chironomid larvae were also present in the samples at densities similar to those in Eldorado Canyon.

In the June collections at river mile 44, the same 3 invertebrate groups were present, but densities were substantially lower for oligochaetes and chironomids and slightly higher for gastropods (Table 4.4).

Another location sampled in June was near river mile 42 (at the head of Cottonwood Basin). Both chironomid larvae and oligochaetes occurred in the same numbers ($385 \cdot m^{-2}$), but no gastropods or *Corbicula* were found.

The October samples at river mile 44 revealed still lower densities of oligochaetes but chironomid larvae increased again to levels similar to those for April.

In October, samples were collected at river mile 47 located in the middle portion of Cottonwood Basin. Chironomids were markedly less abundant than at river mile 44, but the density of oligochaetes was similar. A few gastropods were also present.

4.10 The Morphometry of Cottonwood Basin

Echo sounding was conducted during each sampling period in transects parallel and perpendicular to the historic river channel. The channel is 200 - 300 m wide and 4 - 7 m deeper than the surrounding flood plane throughout the upper end of Cottonwood Basin, down to the area near river mile 45. In this section, the bottom of the channel is 152 - 171 m (500-560 ft.) above sea level. Most of the surrounding flood plane lies between elevation 172 - 175 m (564-574 ft.). These data indicate that sedimentation in this portion of the basin is occurring at a very slow rate since the bottom elevations are similar to preimpoundment levels.

Throughout the middle and lower portions of Cottonwood Basin, the river channel is wider, ranging from 400 - 800 m in width. The bottom of the channel is between 165 and 198 m (540-650 ft.) in elevation, except at the approximate midpoint of the basin. A distinct rise was discovered in the bottom of the river channel beginning in the area of river mile 44. This extended downstream for approximately 1000 m. The rise was generally symmetrical with a peak approximately 172 m (564 ft.) above sea level. Samples collected by ponar at river mile 44 revealed organic debris overlying a layer of dark anaerobic mud, thus indicating that this elevation peak is probably comprised of organic sediment. Thus, this area appears to be the major site of silt deposition in Lake Mohave. The deposition of suspended solids in this area is probably caused by a decrease in the velocity of the river-inflow as the channel widens in the vicinity of river mile 44. Little change in morphometry in the rest of Cottonwood Basin has occurred.

5.0 DISCUSSION

5.1 Factors Regulating Periphyton Distribution and Growth in Black Canyon

The periphyton community in Black Canyon was dominated either by *Cladophora glomerata* or by rheophilic species of diatoms, *Diatoma vulgare* and *Melosira varians*. *Cladophora* was confined primarily to the shallow depths of upstream areas (Station 1) whereas diatoms were prevalent in deep depths and elsewhere in the river.

Historically, *Cladophora* occurred throughout Black Canyon and as far downstream as Eldorado Canyon (Moffet 1942; Jonez and Sumner 1954). Retrogression of the river bottom by swift currents after the formation of Hoover Dam exposed stable substrate in the first 42 miles of river (Jonez and Sumner 1954). After Lake Mohave was filled in 1951, depths were increased and current velocities were reduced in the river. Jonez and Sumner (1954) reported that *Cladophora* only occurred from Hoover Dam to Willow Beach in the period immediately after the formation of Lake Mohave. They attributed this to the greater depth of the river which reduced light transparency. Since then, it appears that significant siltation has occurred throughout Black Canyon and covered most of the stable substrates. Flooding from side canyons periodically results in considerable input of sand and silt into Black Canyon. The high elevations of Lake Mohave buffer the discharge from Hoover Dam and current velocities are no longer sufficient to keep the bottom scoured. Extensive siltation has occurred in lower Black Canyon and even occurs in the Upper Canyon during the winter when discharge from Hoover Dam is low and Lake Mohave elevations are at a maximum. This is the principal reason for the historical demise and present-day distribution of *Cladophora* in the river.

Siltation prevents *Cladophora* from attaching to suitable substrates

(Blum 1960). Moreover, after periods of high turbidity, Cladophora filaments become loaded with silt which either suppresses their growth or results in mechanical detachment of the thallus (Blum 1960). The fluctuating discharge from Hoover Dam often results in resuspension and deposition of silt in the river and even if suitable substrate were available downstream, this would limit Cladophora growth. Consequently, the distribution of Cladophora is limited to shallow depths in the upper end of Black Canyon. Light penetration is usually not sufficient to allow Cladophora to grow in the deeper parts of the upstream areas. Also, the substrate in the deep channel becomes unstable and scoured during the summer when discharge from Hoover Dam is high. The deep channel is only suitable for growth of the rheophilic diatoms. Blum (1956) found that Diatoma vulgare was the dominant alga in areas of the Saline River where current velocities were high, as was also the case in the Colorado River. This species is well adapted to cold, swift flowing waters where nutrient concentrations are high (Patrick and Reimer 1966). Melosira varians is apparently similarly adapted. Czarnecki and Blinn (1978) found it was one of the dominant periphyton in the Colorado River and tributaries of the Grand Canyon.

Our data reveal that periphyton distribution and growth in Black Canyon are governed by three related factors: substrate, light penetration and current velocity. The area from river mile 4 to 12 is largely limited by suitable substrates, most of which have been covered by sand and silt depositions since Lake Mohave was formed in 1951. Most of the periphyton growth occurs in the first 3 miles of river below the dam. In the later winter and early spring, when Lake Mohave elevations are high and discharge from Hoover Dam is low, light is the principal limiting factor in this area. As Lake Mohave levels recede in late spring and summer, and discharge increases to meet irrigation and power demands, the high current velocities disrupt substrates in the area below the dam. Sand and gravel material deposited upstream during the winter is flushed downstream and scours the substrate of periphyton. This, plus the shifting of gravel and cobble substrates, reduces periphyton colonization and growth. These conditions persist until fall when the elevation of Lake Mohave increases and discharge from Hoover Dam decreases. However, during this period, light penetration is again reduced due to the greater depth of the river and shading from the canyon walls.

5.2 Factors Regulating the Distribution and Abundance of Invertebrates in Black Canyon

The invertebrate fauna in Black Canyon was extremely low in diversity which is characteristic of rivers below deep-discharge reservoirs (Ward and Stanford 1979). The fauna was overwhelmingly dominated by *Hyalella azteca* and chironomid larvae in the first 4-5 miles of river and by oligochaetes downstream from there. Hargrave (1970) described *Hyalella azteca* as a bottom feeder which consumes primarily epibenthic algae and sediment microflora. Spence and Hynes (1971) found that *H. azteca* occurred in large numbers below a dam where periphyton production was high but was non-existent elsewhere in the river. The tremendous decrease in *Hyalella* abundance in lower Black Canyon was apparently caused by the significant decrease in periphyton productivity.

Chironomids can also utilize plankton and periphyton (Usinger 1963), but they are primarily scavengers. It does not appear that decreased periphyton productivity caused their decrease in abundance in downstream areas. However, it may be that they could not persist in these areas due to the periodic resuspension and deposition of silt. Oligochaetes, however, appeared to do well on this substrate especially in the fall when Lake Mohave elevations increased and discharge from Hoover Dam decreased. This resulted in more stable conditions downstream that apparently allowed the oligochaete population to increase during that period.

The standing crop of invertebrates in the upper end of Black Canyon was generally lower than that reported for other rivers below lakes or reservoirs (Table 5.1). This was largely due to the lack of aquatic insect fauna in the Colorado River. Members of the Ephemeroptera, Trichoptera and Plecoptera were absent in Black Canyon during our study. Moffet (1942) reported that Callibaetis, a mayfly, was common in the river during his study. Jonez and Sumner (1954) noted that this species was present in 1951-1953, but their abundance was apparently lower than during Moffet's (1942) study. The loss of mayflies and other common aquatic insects from the Colorado River is probably due to the lack of a seasonal temperature cycle in the river after the formation of Hoover Dam.

Annual temperatures in the river used to range from 2°C to 26°C before the impoundments were built (USGS data). Discharge temperatures from Hoover Dam are now virtually constant at 12-13°C. Hynes (1970) states that most aquatic insects require a seasonal temperature cycle to complete their life cycles. Several studies have since demonstrated that constant temperatures reduced aquatic insect diversity below dams (Spence and Hynes 1971; Lemkuhl 1972; Ward 1974, 1976; Armitage 1978; Gore 1977). The constant temperature from Hoover Dam is probably the major reason for low diversity in Black Canyon. However, this was probably also aggravated by the formation of Lake Mohave which prevented insects from drifting downstream to areas where river temperatures were more suitable for reproduction.

One other factor that could contribute to the low diversity of invertebrates in Black Canyon is predation by rainbow trout. Moffet (1942) reported that rainbow trout, which were introduced in 1935, extensively utilized mayflies as a food source. Jonez and Sumner (1954) found that mayflies occurred in 81% of the trout stomachs they examined. The intense trout stocking program from the Willow Beach Hatchery has placed additional pressure on the aquatic insect populations and probably contributed to their disappearance from the river.

Table 5.1 Estimates of standing crop of total invertebrate fauna below reservoirs and lakes (from Armitage 1978).

Location	Sampling Period	Biomass ($g \cdot m^{-2}$) (wet weight)	Dominant Taxa
Annsjön Lake	September	4.14	*Hydropsyche*
Anajaure Lake	July	54.24	Simuliidae
Gautcäsk Lake	May - September	11.64	Simuliidae
Stora Tjultcäsk	May - September	36.06	Simuliidae
Stevens Creek (reservoir)	October - June	3.76	Ephemeroptera
Vic Reservoir	Annual Mean	10.73	Trichoptera
Kanaskis River (reservoir)	April - November	2.91	Ephemeroptera
Cheesman Dam (reservoir)	Annual Mean	15.3	Diptera/ Ephemeroptera
River Tees (reservoir)	May, August, Sept.	11.06	Gastropoda
Colorado River (upper Black Canyon)	March - December	7.85*	*Hyalella*, Chironomids

* wet weight = dry weight /.10

The invertebrates in Black Canyon are, and probably will remain, low in diversity as a result of these factors. Only those organisms that can adapt to cold-water, fluctuating currents and unstable substrates can exist in the river. The invertebrates that can tolerate these environmental conditions are ultimately limited in abundance by the limited periphyton productivity and possibly fish predation.

5.3 The Benthos of the Lower Portion of Lake Mohave

The benthic invertebrate community of Lake Mohave typified those found in other southwestern reservoirs, being composed primarily of chironomid larvae and oligochaetes. In his study of the Salt River reservoirs in Arizona, Rinne (1973) found chironomid larvae and oligochaetes to be the dominant species with *Corbicula* being less common. This was also true of Lake Mead (Melancon 1977).

In this study, oligochaetes and chironomid larvae were dominant at all stations during each sampling period. However, *Corbicula* was only found in Eldorado Canyon. It was absent in Cottonwood Basin which was probably due to substrate type. Rinne (1973) found the greatest concentration of *Corbicula* on slopes comprised of rock and rubble. Since *Corbicula* is a filter feeder, large quantities of silt may restrict its occurrence in this area. "Shifting sands and mud, with their accompanying high turbidity, are unsuitable for bivalves" (Pennak 1978). Thus, while the sandy but relatively stable bottom at Eldorado Canyon provides adequate habitat, the silt and clay-mud in Cottonwood Basin precludes the occurrence of *Corbicula*.

Similarly, gastropods (*Physa* and *Lymnaea*) were only found at river mile 44. This location was a major site of deposition of organic debris, the primary food source of these gastropods.

6.0 POTENTIAL IMPACTS OF THE PROPOSED DREDGING

61.1 Impacts on the Periphyton and Benthic Invertebrate Community

The effects of dredging and spoil disposal in aquatic environments have been studied in several areas. Although most of this work has assessed the impacts on marine and estuarine environments (Morton 1977), the impacts of such physical alterations are generally universal. Morton (1977) discussed these impacts in an extensive review of the literature. These impacts include:

(i) a temporary increase in turbidity and decrease in light penetration in both the dredging and spoil disposal sites,

(ii) physical displacement and burying of benthic organisms which directly destroy many organisms through suffocation,

(iii) habitat alteration resulting from changes in the physical characteristics of the substrate, loss of vegetative cover and changes in the circulation or flow patterns at the dredge or disposal site.

Dendy (1958) reported that deposition of sand or silt may convert the bottom of a reservoir into a sterile, biologically poor environment for aquatic animals. All of these impacts will result from the dredging and spoiling activities below Hoover Dam. In addition to these impacts, there are some potential problems unique to dredging in Black Canyon.

Water discharged from the hypolimnion of Hoover Dam is rich in inorganic nutrients but contains essentially no organic material. In most river and stream systems, organic matter input from upstream areas of the watershed are important energy sources for sustaining invertebrate and fish populations. In the absence of this input, periphyton production below Hoover Dam is vital for sustaining the herbivorous invertebrates and, in turn, the razorback sucker and trout populations that inhabit Black Canyon.

Moreover, the highest production occurs in the upper Black Canyon, and this is an extremely important area for providing energy to maintain the relatively simple food web.

Dredging in the upper end of Black Canyon is being considered to facilitate peak discharges and, possibly, periods of reverse flows through the canyon. The extent of the dredging has not yet been determined, but this will largely depend on the elevation of Lake Mohave. Under the present operating regime, the elevation of Lake Mohave decreases to 631 ft. in late summer and fall. However, this could decrease to 600 ft. if the level in Lake Mohave is reregulated to accommodate the higher peak-releases from Hoover Dam for the proposed power modifications. Dredging would be limited primarily to the area from Ringbolt Rapids to the dam if Lake Mohave is maintained above the 631 ft. elevation. We would estimate that 3-5 m of riverbed, primarily boulder and cobble substrates, would have to be dredged under this alternative. However, at a Lake Mohave elevation of 600 ft., dredging would have to be done throughout 18 miles of river below the dam. It would be necessary to remove up to 10 - 12 m of material in the first 3 miles, 5 - 8 m below Ringbolt Rapids, and 2 - 3 m in downstream areas. These estimates are based on the amount of dredging required to maintain the depth of the river near the current levels.

Dredging of substrate in the area above Ringbolt Rapids will initially remove the basic components of the river ecosystem. Periphyton and associated benthic invertebrates will be totally disrupted both from the removal of the substrate and the disturbances caused by the blasting and dredging. Re-establishment of the periphyton and invertebrate communities above Ringbolt Rapids upon completion of the dredging, will depend primarily on the type of substrate remaining, water depth and clarity, and current velocity.

Boulder and cobble size substrates are required to provide stable surfaces for colonization by periphyton. If this substrate is available, periphyton will colonize within a one-two month period provided there is sufficient light to allow for their growth. Periphyton growth, especially Cladophora, was limited by light at depths greater than 5 m throughout the summer, except during June. Light penetration was greatly reduced in the fall and winter months due to the shorter photoperiod, lower solar radiation, and shading from canyon walls. However, during May, June and July, when light conditions are most favorable, high current velocities may limit periphyton growth to only the most stable substrates. Ultimately, the general increase in depth due to dredging will cause a reduction in the annual productivity and standing crop of periphyton.

The invertebrate community above Ringbolt Rapids was dominated by the herbivorous Hyalella azteca and several species of chironomids. The rate of colonization by these invertebrates will be strongly influenced by re-establishment of the periphyton community. Invertebrate colonization will lag behind the periphyton because of the life cycle of the invertebrates and sources of colonization within the river. The chironomids, which have an adult flying stage, will be the first invertebrates to colonize the area. They emerge and lay eggs primarily in the summer, and, if dredging is conducted prior to then, colonization of dredged areas will occur rapidly. If dredging is conducted after their peak reproductive season, colonization will be minimal until the following year. It is unlikely that a substantial chironomid population will persist at or above the dredge site, and the only other source for colonization would be from chironomid populations downstream. However, since they are not mobile, colonization from downstream populations would be minimal and largely dependent on eggs deposited in the dredge site during the reproductive season.

Hyalella is totally aquatic, and, therefore, the principal seed populations would be located downstream from Ringbolt Rapids. Their colonization would be much slower than chironomids and be limited to periods when current velocities were low. Invertebrate colonization experiments conducted in basket samplers revealed that high current velocities greatly reduced the ability of *Hyalella* to invade suitable substrates, regardless of the amount of periphyton growth. *Hyalella* density was also low on natural substrates subject to high current velocities. It is, therefore, improbable that *Hyalella* colonization will occur in the dredged area during the summer, peak-discharge periods. However, they could invade the area fairly quickly (within 1-2 months) during fall, winter and early spring when the elevation of Lake Mohave is high and discharge from Hoover Dam is low. A stable population would probably be established within 1-2 years.

Dredging above Ringbolt Rapids would thus have an immediate impact on the ecology of Black Canyon. There would be an abrupt decrease in periphyton and invertebrate production during and after dredging. The periphyton community would recover within a 1-2 month period, but it could take up to a year or more to re-establish the invertebrates due to their reproductive cycles and distribution of seed populations.

The reregulation of Lake Mohave to an elevation of 600 ft. could require dredging of the entire river section of Black Canyon. The impacts would be similar to that for dredging above Ringbolt Rapids but of a much greater magnitude. In addition, dredging throughout the entire river would probably cause temporary extinction of several invertebrates because seed populations would not survive the dredging activities. It could thus take several years for the invertebrate community to re-establish, and some species could permanently be lost from the river.

6.2 Impacts on Endemic Fish Species

The razorback sucker (*Xyrauchen texanus*) in Lake Mohave comprises one of the largest remaining populations in the Colorado River. This species has persisted in this area since Hoover Dam was constructed in 1935 and Davis Dam in 1951, despite severe alterations in environmental conditions of the river. Our underwater observations of the distribution of razorback suckers throughout Black Canyon indicate that most of the population is concentrated in the first three miles of river below Hoover Dam. We observed as many as 200-500 razorbacks in this area during the summer and fall. This appears to be important habitat for the razorback sucker population, most likely due to the greater periphyton and invertebrate production.

Moffet (1944) reported that *Cladophora* comprised the principal part of the razorback sucker diets. Our observations also indicate they feed extensively on *Cladophora* and other periphyton. Dredging in the first 3 miles of river will reduce periphyton productivity that, in turn, could have a detrimental impact on the razorback sucker population. Productivity is already low downstream and food resources in Black Canyon may not be sufficient for the razorbacks should periphyton growth in the upper area be temporarily lost or reduced due to dredging. The same would apply to the rainbow trout that also feed on periphyton and associated invertebrates.

6.3 Impacts of Higher Current Velocities

The increased peak discharge required for modifications to Hoover Dam may have greater long-term impacts than dredging on the ecology of Black Canyon. Current velocities vary in relation to discharge from the dam and elevations in Lake Mohave. Velocities in Black Canyon are highest during the summer months when Lake Mohave is low and discharge is high. Peak discharge from Hoover Dam currently ranges to 25-35,000 cfs during the summer. Estimates made by the Water and Power Resources Services show that these rates of discharge at a Lake Mohave level of 630 ft. result in average current velocities of 2.9 $mi \cdot h^{-1}$. This will increase to 3.5 $mi \cdot h^{-1}$ for a projected discharge of 49,000 cfs and 3.9 $mi \cdot h^{-1}$ for 60,000 cfs required for the power modifications to Hoover Dam. The maximum current velocities at certain locations could exceed 4-5 $mi \cdot h^{-1}$ at peak discharge on a power cycle.

The existing discharge in the summer caused considerable scouring and disturbance of substrates below the dam (Station 1). Approximately 95% of the substrate at this station and generally in the area above Ringbolt Rapids was comprised of cobble and gravel. There was continued instability of this substrate in the vicinity of mile 1 from July through September. Periods of high discharge caused scouring and shifting of substrates enough that periphyton and invertebrate colonization were inhibited or greatly reduced in the main river channel. According to Hynes (1970) the projected flows are sufficient to initiate the movement of substrate up to 25 cm until it becomes armored. This would influence virtually the entire river bottom throughout the first 3 miles, and consequently, substantially reduce periphyton growth. In the present study, periphyton growth only occurred on large substrate (greater than 10-15 cm) that was stable enough to resist movement by the currents. Current velocities progressively decreased downstream, and at Station 2 the substrate became stable enough to permit periphyton to exist here during the peak discharge periods. Further downstream, current velocities had no direct influence on periphyton, but did cause periodic resuspension and deposition of silt on the substrate, thus reducing periphyton growth.

The influence of current velocity on the substrate and periphyton growth is limited primarily to the summer months. High lake elevations in Lake Mohave at other times of the year are sufficient to buffer the discharge from

Hoover Dam. However, light conditions for periphyton growth are most optimum during the spring and summer, and those periods are extremely important to the ecology of the river.

The increase in peak discharge required for the power modifications to Hoover Dam will create even greater instability in the substrates above Ringbolt Rapids and possibly extend this unstable zone even further downstream. Because of the short duration of peak discharges (5-7 hrs per week during spring and summer), an indefinite time will be required to remove the sand and gravel which cover larger substrates.

Depending on the discharge velocity and thickness of these substrates, it could take several months to armor the river bottom and stabilize substrates under the new discharge regime. Jonez and Sumner (1954) reported that it took two years to scour sand from the first four miles of river after Hoover Dam was formed in 1935. With formation of Lake Mohave, and the buffering that it provides on the discharge from Hoover Dam, it will take even longer to remove the sand. The sand and gravel are supplied to the river during periodic flash flooding of washes, which occurs every year, even in the uppermost parts of the river. The material that enters the river during the winter remains on the bottom during this period. As discharge increases, and Lake Mohave elevations decrease in the summer, current velocities become sufficient to scour the bottom. However, when this happens, it causes a reduction in periphyton growth due to substrate instability and abrasive scouring of the larger, stable substrates. The increased discharge required for the proposed power modifications will cause greater instability of the small substrates and increase scouring of the larger substrates. If flooding does not occur during the summer, the sand may possibly be scoured out by late summer and thus provide stable substrates for periphyton growth during that period. Similarly, if Lake Mohave were drawn down early in the spring and discharge from Hoover

Dam were elevated, stable substrate could probably be exposed for periphyton colonization in the summer when optimum growth conditions exist in the river. However, it is unlikely that these criteria can be met due to the operating constraints on Hoover Dam and Lake Mohave for power generation and supply of irrigation waters.

Therefore, the net result of increased peak-discharge from Hoover Dam will be a decrease in periphyton productivity in the deep channel of the upper Black Canyon for most of the summer. This could have a detrimental impact on the invertebrate and fish populations which rely on the periphyton as a food resource.

In addition, the razorback sucker populations may be directly influenced by current velocities. There was considerable upstream and downstream movement of the razorbacks that coincided with the seasonal discharge cycles. The razorbacks seemed to prefer the area near Station 1 but moved further downstream when the discharge increased during the summer. Conversely, there was an upstream movement in the fall as the discharge decreased. Since we did not conduct any tagging experiments, it is difficult to determine if apparent movement represents a response to changing discharge regimes or possibly some sort of seasonal migration of the razorbacks.

6.4 Effects of Dredge Spoil Disposal in Lake Mohave

Dredging in the area above Ringbolt Rapids or throughout the river would necessitate disposal of large amounts of spoil material. The Water and Power Resources Service is currently considering disposal of this material in the dead storage area (below elevation 570 ft.) near Cottonwood Basin of Lake Mohave.

Echo sounding conducted in Cottonwood Basin indicated that the dead storage area exists only in the old river channel. An extensive deposit of sediments exists in the upper end of Cottonwood Basin and therefore fine spoil material should be disposed of below this point. This would prevent resuspension of silt by the hypolimnetic underflow that occurs upstream from this area. Boulder, cobble and gravel substrates could be disposed of anywhere in Cottonwood Basin without significant impact. Disposal of the spoil materials in these areas would cause a decrease in the benthic production. However, because of the uniform and wide distribution of the benthos, the community would recover rapidly and disposal of dredge spoils would not cause a severe impact.

6.5 Potential Mitigation Factors for Black Canyon

Dredging or high peak discharge from Hoover Dam will substantially reduce periphyton and invertebrate production in the upper portion of Black Canyon. The system should recover from dredging within a few months, but higher peak discharge from Hoover Dam could permanently alter the ecology of the river. The food chain is simple in that it is comprised of a few producer and consumer organisms that are adapted to this unique environment. However, it is also a very sensitive system because the loss of one key element could disrupt the ecological balance that currently exists.

Substrate, current velocity and light appear to be the key factors that control the level of productivity in Black Canyon. However, in the upper end of the Canyon, where there is suitable substrate, current velocities are seasonally high and limit productivity. Further downstream, current velocities decrease to tolerable levels, but substrate is either silted over or occurs at depths where no appreciable productivity occurs. Thus, if suitable substrate can be located in areas where currents and light are more optimal, the productivity could be expected to increase.

We suspect that this can be achieved by disposal of large boulder and cobble dredge spoils along the shallow areas of Black Canyon, rather than in Lake Mohave. Our data indicate that these substrates would be colonized by periphyton and thus enhance the productivity of the river. Since this is the basis of the entire food chain, invertebrate and fish production would probably increase accordingly.

Habitat enhancement in this manner would impart more stability on the delicate ecological balance that currently exists in Black Canyon. If the upper canyon became unsuitable in the summer due to high discharge, other productive areas downstream would be available to sustain the invertebrate and fish populations. This could even increase the abundance of rare species in the system due to greater habitat diversity. In particular, Gammarus, which currently exists in low densities in the upper canyon area, would probably increase in abundance if the habitat were expanded. Due to their large size, Gammarus are usually the preferred food items for trout in lakes and rivers where they occur at high densities.

Serious consideration should therefore be given to investigating the possiblity of disposing dredge spoils in Black Canyon. Even if dredging is not required for modifications to Hoover Dam, it might be desirable to bring in substrate from elsewhere so that suitable habitat is present in downstream areas to compensate for habitat losses that could be incurred in the upper canyon due to high peak discharge.

6.6 Recommendations for Further Study

Our ecological predictions here are based on less than one year of data, but this system is highly variable from year to year due to fluctuations in discharge from Hoover Dam. It is not known to what degree the ecological conditions observed during our study reflect long-term patterns in the river. There is, therefore, some uncertainty in our predictions regarding changes in periphyton productivity, and the data do not allow for a quantitative estimate of these changes.

Further research needs to be conducted to determine the levels of discharge from Hoover Dam that create unstable conditions in various sizes of substrate. This could be done experimentally by installing various sized substrates (painted different colors) and monitoring their movements during the summer power cycles. Additional mapping needs to be done to determine the areal extent (% cover) of periphyton growth in upper Black Canyon. This is crucial to developing quantitative estimates of changes in productivity. Finally, more investigation is required to determine to what degree periphyton, especially Cladophora, contribute to the diets of razorback suckers and trout, and whether the movements we observed for razorbacks represent a seasonal migration pattern or simply a response to discharge cycles from Hoover Dam.

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