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Cladophora Drift and Planktonic Crustaceans
in the Colorado River:
Lee's Ferry to Diamond Creek

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INTRODUCTION

From 18 June until 1 July 1980, the River Unit of the National Park Service, Grand Canyon National Park, conducted a routine patrol of the Colorado River between Lee's Ferry and Diamond Creek, Arizona. Several scientific programs were carried out during the patrol; this report describes the results of two of these. One was an attempt to quantify the drift of the normally attached macroalga, Cladophora glomerata, as a function of distance down river from Lee's Ferry. The second program was a survey of the composition and abundance of planktonic crustaceans found in the Colorado River and some of its tributary terminal pools.

Because of the preliminary nature of these studies, and because of limitations of equipment and time, the same sampling gear was used simultaneously to collect Cladophora and plankton. The experience gained from this trip demonstrated that the techniques were not optimal for either study. The trip also pointed out several scientific problems of relevance, but which could not be approached at the time. Sampling improvements and suggestions for further work are described in the Appendix.

During the sampling period, the flow of the Colorado River, controlled by the discharge from Glen Canyon Dam (Figure 1), was exceptionally variable and, at times, high relative to the conditions existing over the previous years since the closing of the dam. The results presented below may therefore not represent the normal situation for Cladophora transport and

zooplankton presence and abundance.

METHODS

The primary collecting tool for the studies was a 30 cm diameter plankton net with a mesh size of 366 μm . This mesh size collected most of the Cladophora drift and adult and larger juvenile stages of copepods and cladocerans; male cyclopoid copepods were undersampled due to escapement through the mesh. It was large enough to allow passage of most of the suspended sediment load. Occasionally, a net of the same size but with 212 μm mesh was used in places where the sediment load was low. Besides adults, this net collected most naupliar and copepodid stages of the copepods, as well as juvenile instars of cladocerans.

A General Oceanics flow meter in the net mouth measured the volume filtered by each tow. During early tows, river sediment sometimes jammed the meter, resulting in an underestimate of volume filtered. On one occasion, the tow speed was below the threshold speed of the meter; this again resulted in an underestimate of volume filtered.

Tows were taken 1) from boats in the mainstream or its backeddies, 2) from the river bank in the passing mainstream or backeddies, and 3) by pulling the net by hand through tributary pools, either from the bank, from boat, or by walking through the pools pulling the net. Tows from boats and from the edge of the river used a 14 lb depressor to permit fishing the net to near the bottom of the river.

Two tows were taken at each sampling location in the main-

stream and sometimes in tributary pools. Each collection was settled in the plastic jar serving as the cod end. The Cladophora was then removed and weighed in a fine-mesh bag hung from a hand-held Ohaus spring scale (0-50g, 2g divisions) to an accuracy of about $\pm 1g$.

The water and debris remaining in the cod end was then poured through a small 212 μm mesh concentrating net to collect the plankton and free-swimming invertebrate larvae. The invertebrates from both tows were combined and preserved in a single vial with 5% formalin. This technique did not collect all the zooplankton captured by the net, as the sediments and debris were not washed repeatedly before disposal, and the initial removal of Cladophora could have removed some organisms. Thus the results can only be considered as semi-quantitative.

The samples of invertebrates were returned to the laboratory where the separation, identification, and enumeration of crustaceans was made under a binocular microscope. Identification to species and sex was made for all adult crustaceans (except Gammarus lacustris, ostracods, and a chydorid cladoceran). Identifications were made using Pennak (1978) and Ward and Whipple (1959). The number of egg-bearing females was noted, as well as the number of individuals in poor condition. Poor condition was defined as those individuals parasitized by fungus or protists (?), or whose carapaces were characterized by partial or complete lack of musculature, internal structures, etc, or were partially damaged due to decay (not net damage). Since Daohnia pulex appeared to suffer heavy net damage in all tows, no attempt was

made to categorize its condition.

RESULTS

Table 1 lists the particulars for all net collections made. The results for the Cladophora sampling are discussed separately from those for the crustaceans.

Cladophora drift

Table 2 presents the quantitative estimates of Cladophora drift, based on 22 collections from Mile 20 to Mile 223. Figure 2 presents the same data graphically. The wide scatter, plus the limitations of the quantitative estimates due to flow meter problems, make any statistical evaluation of the data questionable. The trend, however, is for decreasing quantities with distance down river. The very low values at Mile 73 (22 June) are probably due to the low river flow of 21 June (Figure 1), which could have reduced the rate of detachment and permitted much of the remaining drift to settle.

Regardless of the presence or absence of quantitative changes, the numerical data do not describe the obvious qualitative changes in the Cladophora that occurred as distance down river increased. At Lee's Ferry, the Cladophora drifted down river in distinct clumps with filaments many centimeters long. By Diamond Creek, the algae had been broken down into small, short-filamented aggregates or individual strands less than 1 cm in length, all dispersed among other components of the detritus. The difficulty in separating the Cladophora from detritus in the

downstream reaches of the river makes these quantitative estimates too large, i.e., the decline in biomass (Figure 2) probably would be greater and more apparent had an efficient separation technique been available.

Crustacean plankton

Table 3 lists the crustacean species found in the net tows. Only the truly planktonic forms will be discussed. The other species are normally inhabitants of littoral vegetation and were not collected in sufficient numbers or in appropriate places to say anything about the relationship of their occurrence in the plankton to their normal ecology.

Table 4 is a compilation of all the counts of species abundance, standardized to numbers per 10 m^3 . Also included are the data for the numbers of copepods in poor physical condition and females carrying eggs. These data have also been presented graphically (Figures 3 - 5) to more clearly show the relationship of abundance of the species (Figure 3), percent carrying eggs (Figure 4), and total percent in poor condition (Figure 5), to distance down river. No obvious relationship of abundance (Figure 3) to discharge rate (Figure 1) is evident. As with the Cladophora data, no statistical tests for the significance of the relationships have been made.

Not counted, or shown here, were the considerable numbers of naupliar and copepodid stages of copepods captured by the $212\text{ }\mu\text{m}$ net in the mainstream at Miles 24, 64, and in the Kanab Creek terminal pool.

DISCUSSION

Cladophora Drift

Both the quantity and quality of the Cladophora drift changed with distance down river. The coarseness of the sampling intervals down the river, together with the inherent variability of the quantity transported, the extreme fluctuations in river flow, and the limitations of the sampling method, make it impossible to say whether or not the changes observed represent a continuous gradient. If discontinuities could be shown to occur, this would suggest the importance of looking for localized sources and sinks of the drift, some or all of which could have biological causes. Czarnecki et al (1976) list Cladophora as the dominant periphytic alga (excluding diatoms) at the confluence of 12 tributaries from the Paria River to Diamond Creek. These are certainly not the only sources. Clearly, however, the principal source region, in a general sense during this study, was the upper reaches of the river.

The pattern of both the quantity and quality of the Cladophora would be important factors in its significance as a food source for invertebrates and fishes, as well as its role in nutrient cycling through direct organic or remineralization links as a result of mechanical breakdown.

Rough calculations can be made pointing to the importance of Cladophora as a food source or nutrient sink. Assuming that the river transports a mean wet weight of Cladophora of 1.5 g/m^3 (from Table 1) and a river flow of 10,000 cfs, about 1500 kg/hr of algae are carried downstream from some undefined source regions.

For steady state conditions, this should equal the production rate at the sources. The abnormally high discharge rates which were occurring before and during the sampling period could make this an overestimate due to the possibility of excessively high rates of loss caused by the high flow.

If one assumes that a regression line can be drawn through the data of Figure 2 and that it reasonably represents the loss of Cladophora as it drifts downriver, an estimate of loss can be made. Assuming 2.0 g/m^3 at Lee's Ferry and 0.5 g/m^3 at Diamond Creek, 1.5 g/m^3 is somehow lost in transit. Coincidentally, this again amounts to 1500 kg/hr. Thus approximately 36 metric tons a day of Cladophora appear to be lost through actual (grazing, mechanical and biological degradation) and/or apparent (lack of capture by the net) causes.

Zooplankton

The only study that reports on planktonic crustaceans of the Colorado River within the Grand Canyon is that of Cole and Kubly (1976). Their Table 27 lists Daphnia sp., Bosmina longirostris, Diaptomus pallidus, Cyclops bicuspidatus thomasi, and Mesocyclops edax for the mainstream Colorado, and Acanthocyclops vernalis, found only at Elve's Chasm. Since they do not say how or when (seasonally) the samples were collected, or in what abundance, it is not possible to make any comments other than to note the two cyclopoid species caught in both studies (Table 3).

The obvious source of the planktonic crustaceans found in the river is Lake Powell. The Lake's suspected large resident populations could supply both the species and numbers of individuals observed. However, I have not seen the only study of Lake Powell zooplankton known to me (Stone and Rathbun 1968, 1969) and no comparisons can be made here.

It is possible that the Glen Canyon Dam penstock discharge contributes little or no plankton to the river, since the water came from an average depth of about 70 meters during the sampling period and the plankton would probably occur in abundance much above this depth. The spillway discharge during the period came from ~~the same layer~~ an average ^{depth} of 15 meters ~~deep~~. This flow may have contributed much or all of the plankton. Plankton would have continued to be present during the periods of no spillway discharge (Figure 1) due to losses from backeddies which had received plankton from the previous spillway releases. Since there is usually no spillway discharge, it is likely the high abundances observed in the river are exceptional.

An important question, however, is how to explain the continued presence of abundant plankton throughout the 225 miles of river to Diamond Creek. One would intuitively expect a sharp decrease with distance due to the turbidity and great turbulence. In fact, from evidence in the literature (reviewed by Hynes 1970) one might expect the populations to be reduced to negligible numbers after only a few 10's of kilometers. Perhaps the flow rate was high enough, relative to loss rates, to explain the presence. It is clear, however, that successful reproduction,

or at least hatching and growth, occurs for the length of the river sampled. This could have supplied at least some of the numbers captured. The evidence for this is the presence of egg-bearing females, of nauplii and copepodids in some of the 212 μ m net samples from the river and tributary terminal pools, and of fully developed spermatophores ready for extrusion in healthy Diaptomus males (only one female was found with spermatophore attached). No comparison can be made between the percentages of egg-carrying females in the mainstream and backeddies because sampling was not done in both environments at the same river mile. At Kanab Creek, National Beach, and Mile 220, samples were taken in both the mainstream and the tributary pools (an isolated backeddy pool at Mile 220). At these locations, the agreement between mainstream and pool percentages is striking (boxed in points in Figure 4). This agreement suggests that the exchange rate between terminal pools and the mainstream is high and the populations sampled are essentially the same. Thus these areas probably do not represent significant sources for plankton in the river, at least during the time of sampling.

Other evidence supporting Lake Powell as the only important source of river plankton during the sampling period is the condition of the organisms captured (Figure 5). The percentage in poor condition increased significantly with distance down river for mainstream, backeddy and terminal pool samples. As with egg carrying females, terminal pool percentages were about the same as in the mainstream, indicating the plankton in both places experienced the same conditions and are thus not separate populations.

The change in the condition of the plankton is probably a result of several coacting causes: mechanical damage due to extreme turbulence in passage through the dam and many subsequent rapids; lack of food (no gut content studies have been done); or simply an increase in water temperature. This latter factor would especially encourage the growth of the fungal and protist parasites. Not shown in Figure 4, or Table 4, is the fact that these parasites were not seen until Kanab Creek (Mile 144); their numbers then increased to Diamond Creek, becoming the dominant reason for considering individuals in poor condition.

If the healthy juveniles and reproductively-capable adults present at Mile 220 survive the remaining distance to Lake Mead, then the Lake Powell plankton may make a direct contribution to the composition of Lake Mead plankton..

In addition to the question of their role in contributing to the mainstream plankton, the terminal pools present several other interesting problems. The Little Colorado pool(s) appear to be a unique environment. Not only were only three individuals of one cyclopoid species (Eucyclops speratus; only one other individual was caught, in the Kanab Creek terminal pool) captured there, but also very few insect larvae were present. Two factors may account for this depauperate fauna. One, the unique chemistry of the Little Colorado water may not allow survival of most invertebrates (perhaps E. speratus is more tolerant than the other plankton). Secondly, the terminal bars, with rapid, shallow outflow, may preclude a significant introduction of plankton from the Colorado River. Cole and Kubly (1976) also noted the Little

Colorado as being impoverished in both species and numbers of invertebrates. They attributed this to periodic flooding and to the high calcium carbonate precipitation present.

The paucity of invertebrates in the Little Colorado terminal pools suggests that the humpback chub living there might have to forage at the boundary region between the Little Colorado and mainstream Colorado waters in order to find sufficient animal food.

In the National Canyon and Kanab Creek terminal pools, the Daphnia populations were much reduced (factors of 4 to 20) over those occurring in the adjacent mainstream. Those that did occur in the pools were all small individuals. A possible explanation for this observation would be predation due to fish (feeding selectively on larger individuals) and/or to other invertebrate carnivores. No crustaceans were found in the stomachs of four small speckled dace from Kanab Creek. Several cyclopoids were captured and preserved with partially consumed Daphnia in their feeding appendages (other samples had cyclopoids consuming cyclopoids).

Several other incidental observations from the samples are: 1) Diaptomus ashlandi individuals from Kanab Creek and below were slightly to distinctly orange, while all those from above Kanab Creek were a translucent white; 2) benthic ostracods (unidentified and uncounted) were collected in two samples; and 3) Gammarus lacustris was regularly caught in the plankton but in very low numbers.

All the above data, observations, and inferences are based

on the results of one set of samples taken during a unique flow regime of the Colorado River. They may represent an anomalous situation; only further sampling can resolve the question of the generality of the results.

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Table 1.

SAMPLE RECORD

Colorado River: Lee's Ferry to Diamond Creek

Date 1980	Approx. Time (Local)	Tow #	Net Mesh Size (um)	Vial #	Max Tow Depth (m)	Boat (B) or Shore (S)	Location	Approx. River Miles	Est. River Flow 1000 cfs	Remarks
19	0900	2 & 3	212	12	1	S	Above North Canyon	20.2	24	In Shallow Mainstream
19	1300	3a & 4		11	2	B	Shinumo Wash	29.5	?	In eddy fence
20	1510	5 & 6		4	1	B	Nankoweap	53.2	30+	In broad back eddy
21	1230	7	212	3	1/2	S	In Little Colorado River	61.4	---	Repeated hand tows from edge of terminal pool
21	1300	8	212		Surf.	S	Exit channel of L.C.R. into C.R.	61.4	---	At color break rapid outflow
21	1700	9	212	10	1/2	S	1 mile below Hopi Salt Caves	64.0	?	In back eddy
22	1700	10 & 11		5	4	B	Unkar Camp	72.5	8	In mainstream
23	1200	12	212	6	Surf.	S	In Bright Angel Creek	87.6	---	Nonquantitative
23	1500	13 & 14		8	3	B	Granite Rapids	93.3	?	Edge of Mainstream
24	1400?	15		13	1/2	S	114 mile beach	114	30+	Nonquantitative
26	1300	17 & 18		14	Surf.	S	Kanab Creek	143.6	30+	In mainstream bypass channel
26	1415	19 & 20		15	Surf.	S	Kanab Creek	143.6	30+	In mainstream bypass channel
26	1500	21	212	17	1-1/2	S	Kanab Creek	---	---	In Kanab Creek terminal pool
26	1515	22	212	18	1	S	Kanab Creek	---	---	In Kanab Creek terminal pool
26	1615	23	212	19	Surf.	S	Kanab Creek	---	---	In rapid flow of Kanab Creek into terminal pool
27	1230	24 & 25		21	2	B	Havasupai Creek	156.7	---	Vertical tows in terminal pool
28	0745	26 & 27		22	1/2	S	Upper National Beach	166.4	30+	In edge of mainstream
28	0830	28		23	Surf.	S	Upper National Beach	166.4	---	In backwater pool at Creek mouth
29	1200	29 & 30		24	Surf.	S	1 mile above Parashant Canyon	197	30+	In mainstream running through tamarisks
30	1500	29a		24a	Surf.	S	219 mile	219	32	Edge of mainstream running through tamarisks and over gravel
30	1600	30a		25	1	S	Upper 220 mile camp	220	32	In backwater pool
1 July	0800	31		26	Surf.	B	Mainstream	221	30+	Middle of river through eddies and rapids
1	0815	32		27	Surf.	B	Mainstream	223	30+	Middle of river through eddies and rapids
1	0915	33		28	Surf.	S	Diamond Creek	225	---	In rapid flow of creek. Nonquantitative.

Table 2
Colorado River: Lee's Ferry to Diamond Creek

Quantitative estimate of Cladophora drift

Tow #	Flow Counts*	m ³ † filtered	wet weight (g)	Weight m ³	River Mile	Remarks
2	969	1.83	5.5	3.0	20	
3	1680	3.18	3.5	1.1	20	
3a	1590	3.01	4.5	1.5	30	
4	854 (3100)	5.86	12.5	2.1	30	Flow meter jammed (est)
5	2760	5.22	7.0	1.3	53	
6	1720 (3400)	6.43	5.0	0.8	53	Flow meter jammed (est)
9	1560	2.95	5.5	1.9	64	212um mesh net; over- estimate, slow current
10	1940	3.67	1.0	0.3	73	Low river flow, ~8K cfs
11	1870	3.53	1.5	0.4	73	" " " "
13	1800	3.40	10.0	2.9	93	Overestimate, sticky flowmeter
14	1030	1.95	8.5	4.4	93	" " " "
17	3952	7.47	8.5	1.1	144	
18	3325	6.28	8.0	1.3	144	
19	1575	2.98	4.5	1.5	144	
20	2500	4.73	7.5	1.6	144	
26	1134	2.14	9.0	4.2	166	
27	1892	3.58	8.5	2.4	166	
29	3225	6.09	2.5	0.4	197	Much detritus
30	3275	6.19	3.5	0.6	197	" "
29a	5850	11.06	5.0	0.5	219	" "
31	1735	3.28	3.5	1.1	221	" " and sedime
32	1940	3.67	2.0	0.5	223	" " " "

* Calibration factor .00189 m³/count

† 366um mesh net

Table 3. Crustacean species collected in net tows in the Colorado River mainstream and tributary pools.

Copepoda

Calanoida

Diaptomus clavipes Schacht

Diaptomus ashlandi⁺ Marsh

Cyclopoida

Cyclops bicuspidatus thomasi^{**} Forbes

Eucyclops speratus⁺ (Lilljeborg)

Mesocyclops edax^{**} (Forbes)

Cladocera

Daphnia pulex Leydig

Leydigia quadrangularis^{*} (Leydig)

Alona affinis^{*} (Leydig)

Unidentified chydorid

Amphipoda

Gammarus lacustris^{*} Sars

* Normally benthic or in littoral vegetation; not reported on here.

** Reported for Colorado River by Cole and Kubly (1976).

+ Not reported in Lake Mead by Paulson et al (1980).

TABLE 4

SPECIES COUNTS

No. / 10 m³

[illegible]

FIGURE 1

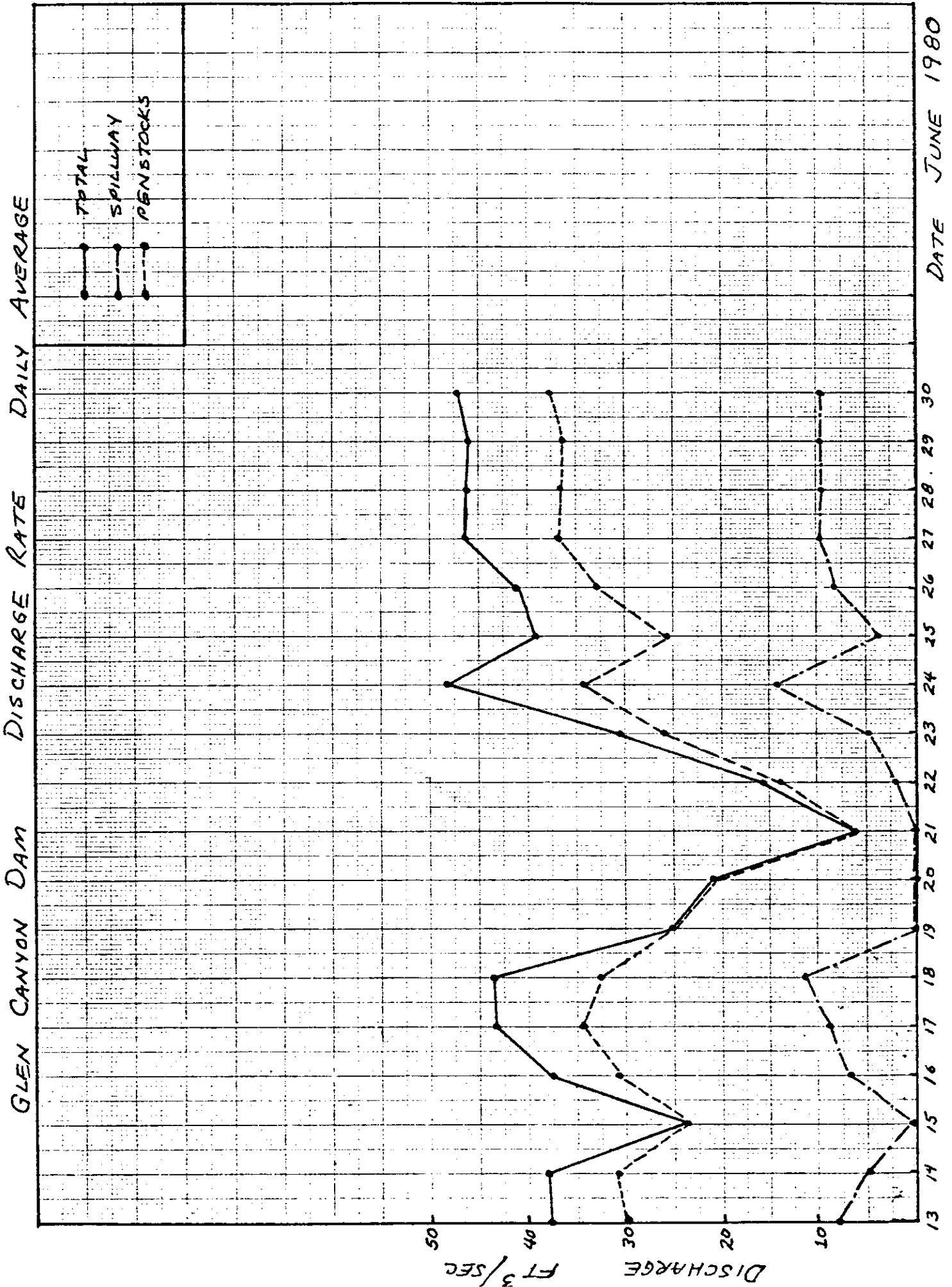


FIGURE 2

CLADOPHORA DRIFT AS FUNCTION OF RIVER MILES

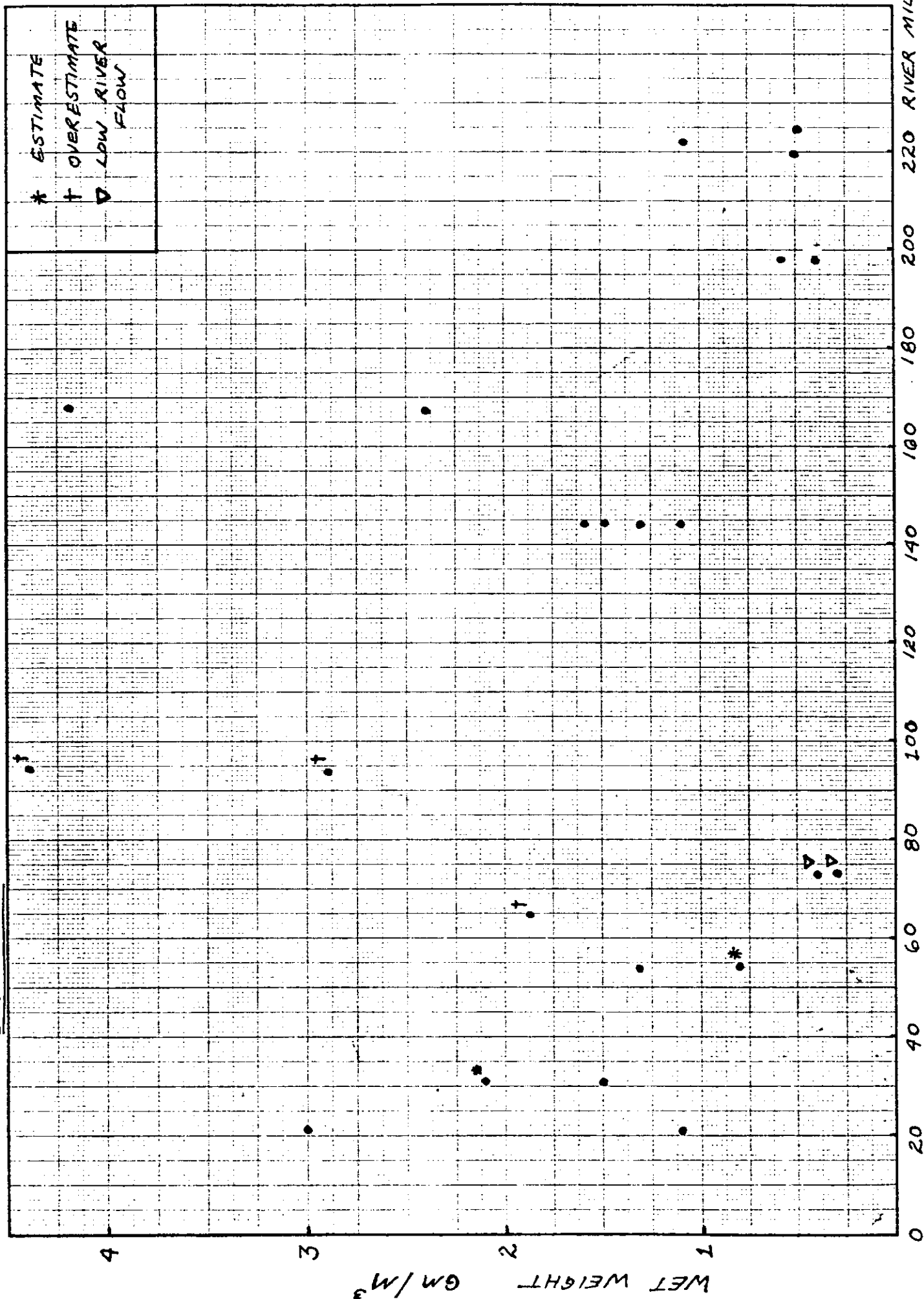
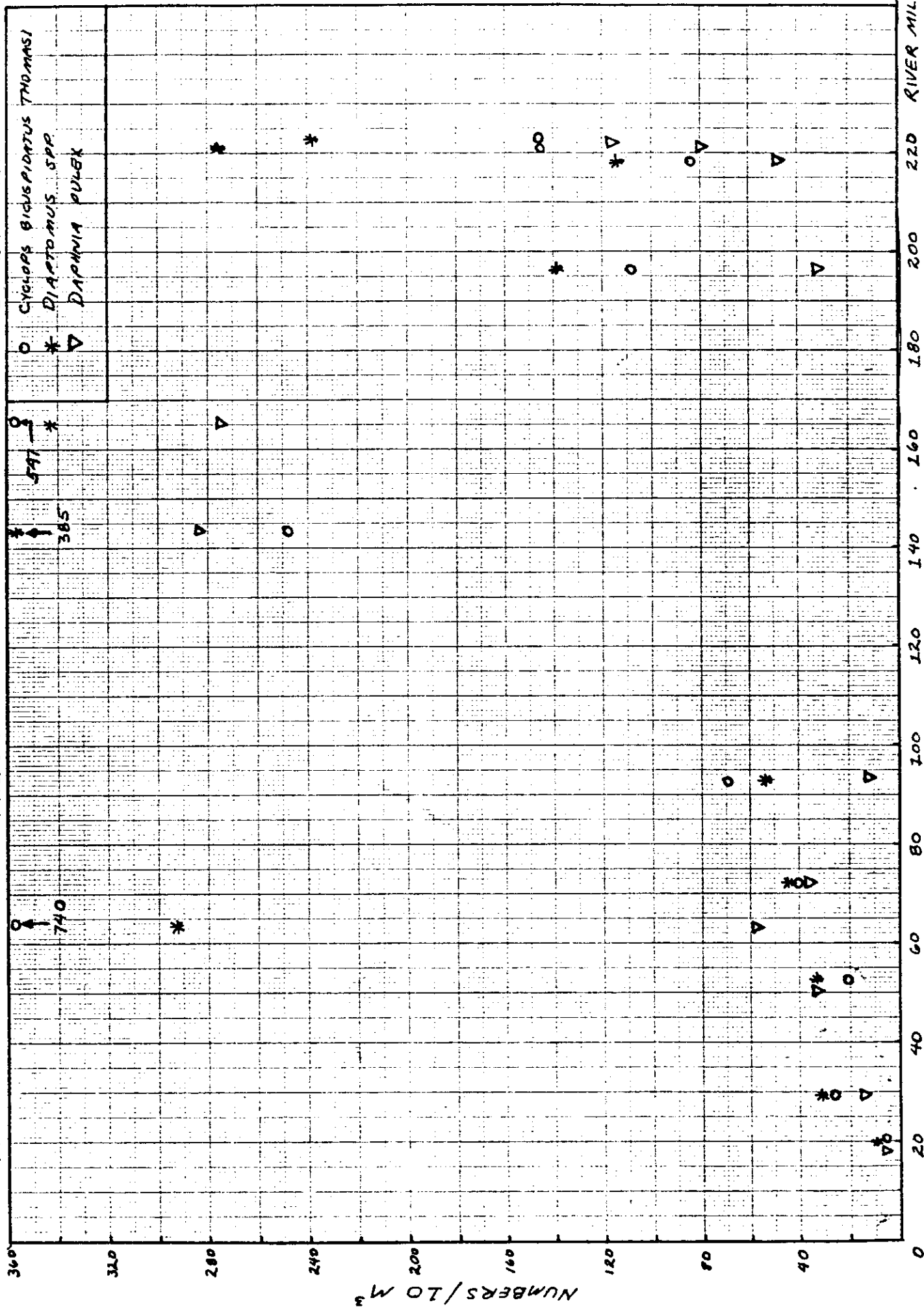


FIGURE 3

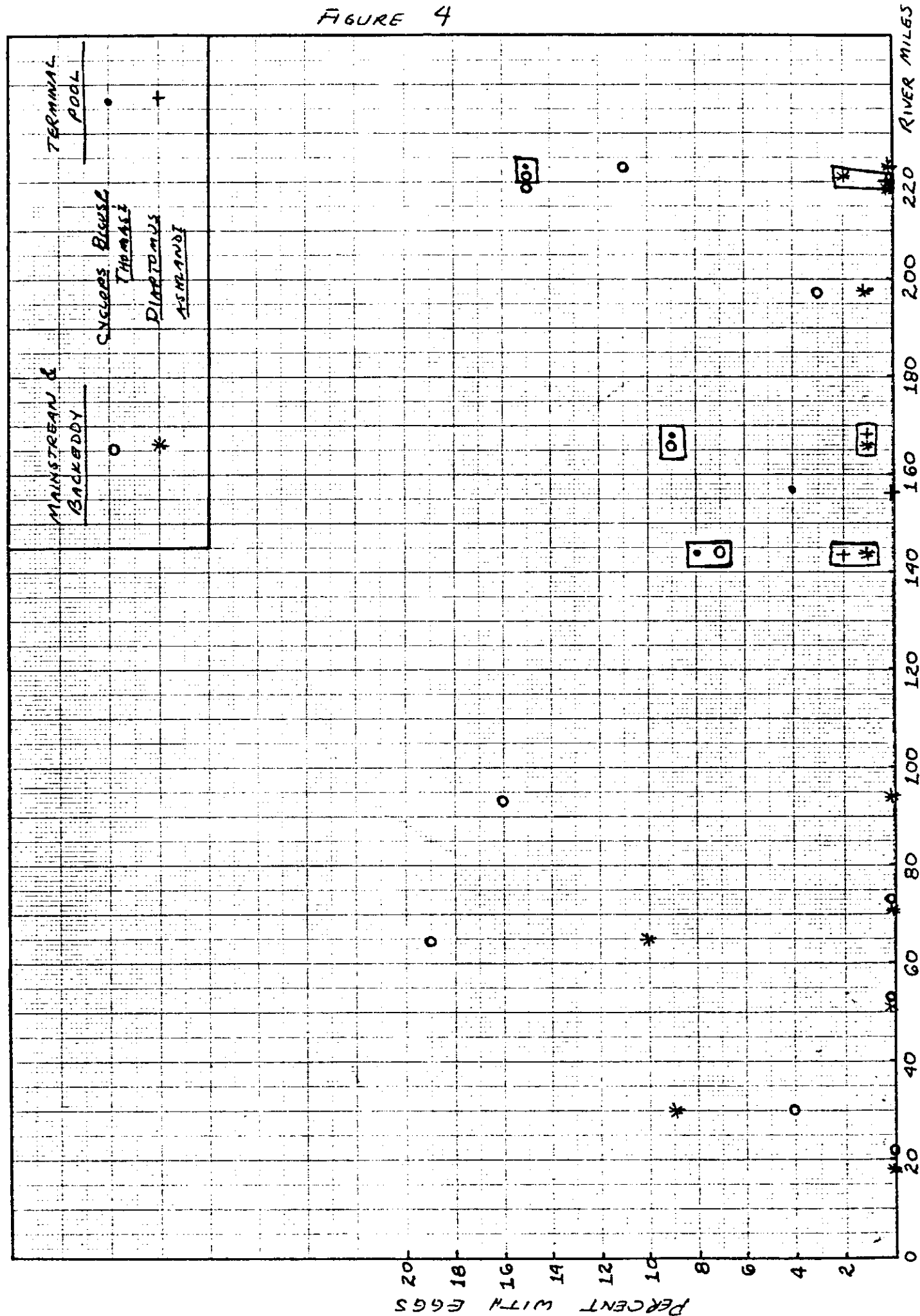
SQUARE 10 X 10 TO THE CENTIMETER AS 8014-Q1

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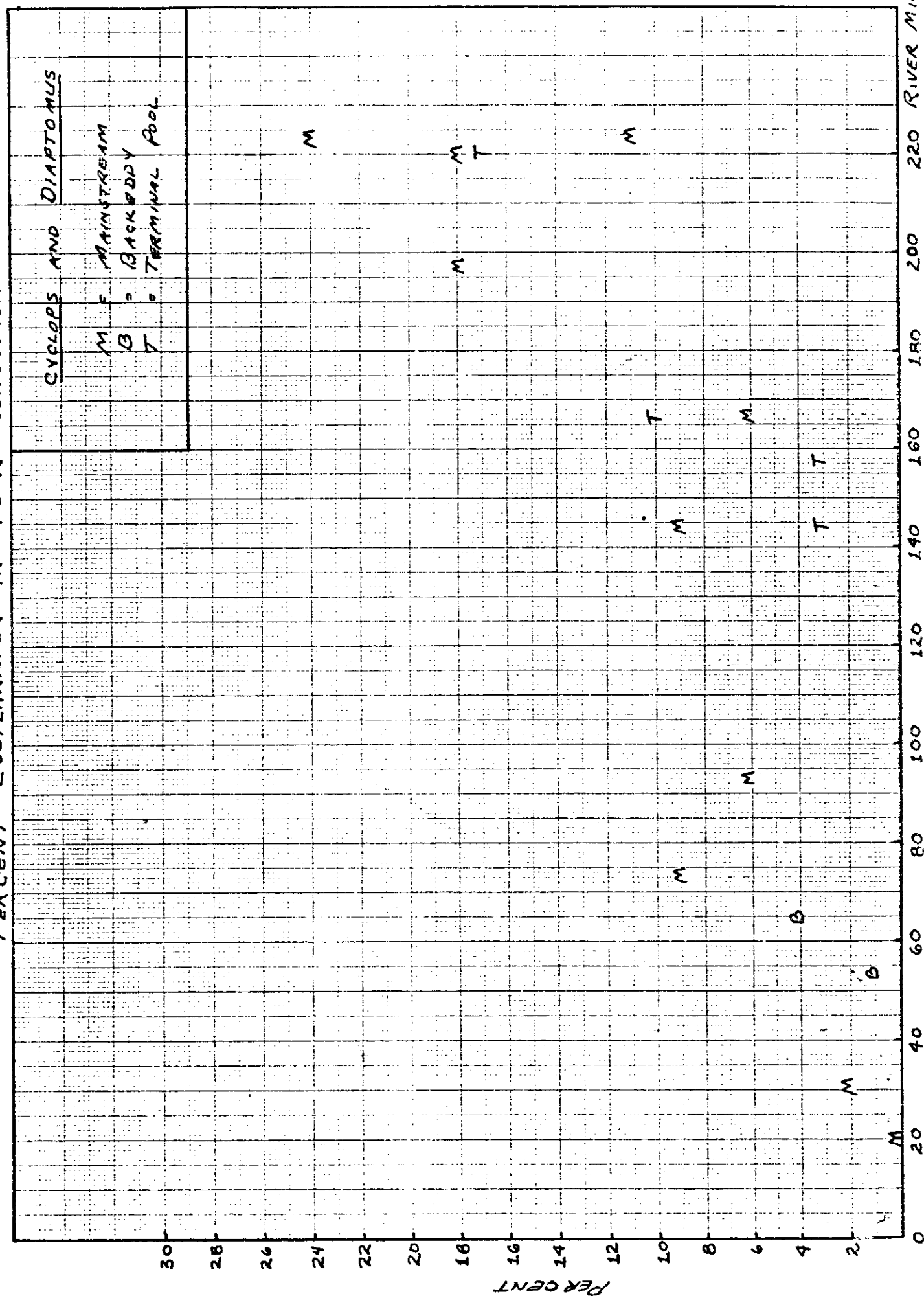
ADULT CRUSTACEAN ZOOPLANKTON AS FUNCTION OF RIVER MILES MAINSTREAM AND BACKEDDIES ONLY



PERCENT ZOOPLANKTON WITH EGGS AS FUNCTION OF RIVER MILES



PERCENT ZOOPLANKTON IN POOR CONDITION



APPENDIX

SAMPLING IMPROVEMENTS NEEDED

CLADOPHORA

Equipment:

- 1) Net of about 1 to 2 mm mesh to reduce clogging problems.
- 2) Two flow meters, preferably of different types to insure volume filtered is measured.

Techniques:

- 1) Replicate samples (2-3 minimum) at each station.
- 2) A measure of quality, both physical (size?) and chemical (nutrient content, degradation products?).

PLANKTON

Equipment:

- 1) Two flow meters, as with Cladophora.
- 2) Fine mesh net (180 μ m or less) for smallest stages (usable only in low sediment waters).

Techniques:

- 1) Replicate samples.
- 2) More midstream samples, if possible above and below rapids (deep holes).
- 3) Samples from the Glen Canyon Dam discharge.

FURTHER RESEARCH

CLADOPHORA

Attempt at a Cladophora "budget".

- 1) Measure quantity and quality of drift better.
- 2) Sources: benthic sampling, along mainstream and in confluence with tributaries; relative importance of each.
- 3) Sinks
 - a) Where does breakup occur; vegetation, rapids, etc?
 - b) What is residence time in backeddies?
 - c) Quantify loss to hangup in vegetation during high water.

- d) Animal consumption: amphipods, trout, etc.
- e) Useability as function of form.
- 4) Recycling through degradation and consumption back to nutrient pools.

ZOOPLANKTON

Study of Lake Powell plankton, both for its own interest and as source of the Colorado plankton.

- 1) Seasonality
- 2) Depth distribution

Time series over a year of mainstream and tributary plankton (quarterly or more often).

- 1) To see if the results reported here are abnormal.
- 2) Are there endemics in tributary pools--implies successful reproduction.
- 3) Quantify mortality and identify its sources down river.
- 4) Relationship of zooplankton to larval fish.

Short-term time series (several times a day for week or more).

- 1) Quantify variability in mainstream to relate to the Glen Canyon Dam discharge.
- 2) Establish exchange rates (water, sediment, plankton) between mainstream and tributary pools, backeddies and flushing rates for tributary pools.
- 3) Evidence of reproductive success in tributary pools.

"Lab" type experiments done in the field.

- 1) Survival of mainstream plankton in Little Colorado water.
- 2) Larval and juvenile fish feeding on zooplankton.