FINAL REPORT TO WATER RESOURCES
RESEARCH INSTITUTE

OREGON STATE UNIVERSITY

TITLE: Plant Production in Experimental Streams: A Cooperative Research Project with Weyerhaeuser Company

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INTRODUCTION

During the winter of 1974, representatives of the Research Department of Weyerhaeuser Company contacted C. David McIntire, Department of Botany and Plant Pathology, for the purpose of establishing a cooperative research program at the Company's experimental stream facility, about eight miles northwest of the town of Cougar, Washington. This facility was constructed by Weyerhaeuser Company on the St. Helen's Tree Farm in 1964. The general objectives of research conducted at this experimental station are: (1) to provide a contribution to the fundamental knowledge of stream processes; (2) to investigate ways in which productivity can be managed in fresh-water streams to enhance their value to man; and (3) to study the effects of the Company's forest management strategy on water resources. Research in the experimental streams has been underway since 1965, and the initial work emphasized life history studies of aquatic insects and fish.

Investigators in the Research Department of the Company at Longview, Washington, have recognized the importance of beginning experiments to help understand patterns of energy flow in lotic (stream) systems as such patterns relate to the activities of man. Of particular interest to the Company is the effect of nutrient enrichment on the bioenergetics of stream organisms. The experimental streams are autotrophic systems, the dynamics of which are essentially controlled by the rate of primary production and the properties of the algal assemblages that grow in these systems. It was a need for professional assistance in the areas of primary productivity and algal taxonomy and ecology that prompted the proposal by the Company for a cooperative research project with the Department of Botany and Plant Pathology at Oregon State University.

The initial funding period for this project was supported by the Weyerhaeuser Company and covered the period from September 1, 1974 to August 31, 1975. In the early part of 1975, it became apparent that additional funding for some equipment items, supplies, and computer time would contribute to the success of the project and enhance the cooperative arrangement with the Weyerhaeuser Company. At that time a proposal was submitted to the Water Resources Research Institute, Oregon State University, for a modest sum to help us supplement the very limited resources available for this project. We are sincerely grateful to the Institute for their support during the period from July 1, 1975 through June 30, 1976. It is quite probable that the additional funds from Oregon State University provided the stimulus for two additional years of funding from the Weyerhaeuser Company (through summer of 1977), and that a project originally funded at $7,500 has, in fact, been expanded into a program with total support slightly over $31,000.

DESCRIPTION OF EXPERIMENTAL STREAM FACILITY

The Experimental Stream Facility is located on the Weyerhaeuser St. Helen's Tree Farm in the Cascades, about eight miles northwest of the town of Couger, Washington. The elevation is about 1,200 feet, and the snow cover can vary from a few inches to almost four feet during the period from December through March. The study area includes about five acres and is adjacent to the Kalama River. The site is surrounded by a nine-foot fence, and the terrain slopes gently towards the river. The soil is of volcanic origin with large pyroclastic rocks overlying finely-divided pumice. There is a single building on the site with living quarters and a small laboratory area.

A large natural spring provides the water for the experimental streams. The water flows over a weir into a distributing pond and from there to each of three stream beds. The volume of water which flows into each stream varies from about 0.5 c.f.s. in the fall to 0.8 c.f.s. during the winter. The streams are four feet wide and range in length from 400 to 700 feet. The streams consist of a series of riffles and pools, and the stream beds are filled with small stones (0.75 to 1.5 inches) covered by larger rubble. Water velocity in the streams varies from about 1 to 1.75 feet per second, depending on the gradient.

RESTATEMENT OF OBJECTIVES

The general objective of this research project is to determine the effects of nutrient enrichment and other environmental changes on rates of primary production and on the structure of algal communities in experimental streams. Nutrient enrichment--primarily nitrogen-will simulate introductions related to forest management policies practiced by Weyerhaeuser Company, namely forest fertilization and nutrient introductions resulting from logging activities. Effects of shading on plant production also will be monitored and related to the Company's management policies. Results of work with the aquatic plants will be integrated with results of concurrent studies of insect and fish production by scientists at the Company's laboratory at Longview. Final interpretation of the combined set of data will be synthesized into a view of the bioenergetics of lotic ecosystems as influenced by various management strategies.

Specific Objectives:

The specific objectives of this project are:

1. to determine effects of nutrient enrichment on the structure of plant communities in experimental streams;
2. to determine effects of nutrient enrichment on the primary productivity and energy budget of experimental streams;
3. to determine the effects of shading on plant production and energy flow in experimental streams;
4. to relate the structure and primary production of algal assemblages to animal production and the trophic ecology of experimental streams;
5. to interpret the results of the experimental work within the context of management policies and interests of the Weyerhaeuser Company;
6. to interpret the results of the experimental work within a theoretical context of lotic ecosystem dynamics.

PROGRESS THROUGH SPRING 1976

Scientific Background

The dominant energy source for woodland streams is allochthonous organic matter (Petersen and Cummins, 1974), and this energy input in detrital form from the watershed is usually much greater than the autochthonous input by aquatic plants. Man's activities on the watershed vegetation tends to change the dynamics of lotic ecosystems. For example, logging increases the light energy and inorganic nutrients available to lotic plants (Bormann et. al., 1974), and these increases stimulate the production of aquatic plants (autotrophy) in streams. Therefore, managers of woodland streams are faced with such questions as: (1) What will be the magnitude of the vegetational response? (2) What form will an increase in stream autotrophy be manifested -- algal biomass, insect biomass, or export? (3) How efficiently will greater energy input by stream vegetation be transferred to a product of interest (e.g., fish biomass)?

An experimental approach utilizing laboratory streams is sometimes useful for the examination of hypotheses relating to the bioenergetics and structure of lotic ecosystems. However, such studies are often conducted at the expense of reality (Warren and Davis, 1971), and the value of the results is sometimes difficult to determine relative to biological processes in natural streams. While the investigation of plant and animal dynamics after perturbation is confined by the recirculating nature of most laboratory streams, the Weyerhaeuser corporation's experimental streams offer a flow-through design that permits a more realistic interpretation of experimental results.

Recovery from perturbation is of critical importance in understanding stream systems. The low constancy of environment typical of natural streams prevents the establishment and persistence of climax communities in the manner of terrestrial systems. The extent that communities can advance from immature to more mature stages will differ among and within streams. Also, changes in community composition will affect the biomass and production of vegetation and consumer organisms, as well as environmental modification by the biological components of the system. The system's resilience and resistance to perturbation are inevitably tied to community composition and its changes through time. The results presented below contribute to the understanding of stream system responses to perturbation relative to light intensity and nutrient enrichment.

Experimental Procedures

The project was designed as a sequence of two experiments, designated the winter and summer experiments. The winter experiment involved reducing light intensity, while the summer experiment was concerned with nutrient (nitrate) enrichment at different light intensities.

The winter experiment was run from December, 1975, through May, 1976. The upper riffle of the three streams was shaded (85%), while the lower riffle received full sunlight. Six sets of data were obtained during this period. The summer experiment was started in July, 1976, and will run through October, 1976, while collecting eight sets of data. The light treatments were retained for the summer experiment, but the ambient nitrate concentration was increased from 25 to 100 ppb in two streams - at the initiation of the experiment in one and after high herbivore standing crops developed in the other. Before both experiments most of the plant (algal) and animal biomass was removed by physically agitating the stone substrates with a rake. This agitation simulated a freshet of water scouring biomass off substrates in a natural stream.

The collection of each set of data involved measurements of periphyton and invertebrate components in a riffle; fish were not stocked in the stream during these experiments. Periphyton measurements included ash-free dry weight, pigment concentration, export, taxonomic composition of algae, and primary production according to the methods of McIntire (1968). Measurements of invertebrates included taxonomic composition of standing crop and export with estimations of herbivore and carnivore biomass, according to the methods of Bisson et. al. (1975). Periphyton samples were collected and analyzed by O.S.U. personnel, and invertebrate samples were collected and analyzed by Weyerhaeuser personnel.

Results and Discussion of the Winter Experiment

The recovery of the stream system after the catastrophic reduction of biomass in the riffles was characterized by a rapid accumulation of algae and invertebrates. Figures I-III present measures of total biomass (ash free dry weight), algal standing crop (chlorophyll _a_ concentration), and animal standing crop (dry weight estimated from observed body size). These patterns of accumulation do not indicate a steady, continual increase in living material with distinct differences between streams receiving different intensities of light. Total biomass (Figure I) exhibited an increase, decrease, and subsequent increase after the perturbation for both the shaded and unshaded streams. This pattern was also observed in the estimates of algal density in the riffles (Figure II). However, the unshaded riffles showed a faster accumulation of algae than the shaded riffles during the first 70 days. Standing crop of invertebrates (Figure III) differed from this pattern. Invertebrate biomass increased and then gradually decreased in both streams during the experiment.

The patterns of algal, invertebrate, and total biomass represented biological responses to an increase of resources. The removal of biomass increased a critical resource (space) for periphytic algae under constant physico-chemical conditions. The subsequent accumulation of algae increased the food resource for the invertebrates. Grazing reduced algal density, and reduced algal density supported a lower invertebrate standing crop. Estimates of herbivore and carnivore biomass (Figure III) indicated herbivore response to algal increase followed by carnivore response to herbivore increase.

At this point, the analysis of data is restricted by a backlog of samples. OWRT's involvement in this project was instrumental in the initiation of sampling. The scope of the project and the Weyerhaeuser-O.S.U. involvement extend to August, 1977. While interpretation of the experiments is conjecture, the preliminary results of the winter experiment tend to support the following generalizations:

1) The initial algal response is a function of physical factors (i.e., light and nutrient availability). The initial difference in algal biomass accumulation according to light intensity (the winter experiment) and according to nitrate concentration (unpublished O.S.U.-Weyerhaeuser research) support this contention.

2) Predation by invertebrates has a severe impact on the accumulation of algae biomass, obscuring differences in standing crop relative to light treatments. This ability of invertebrates to rapidly consume an algal growth is similar to the observations of Dickman (1973).

3) Community composition changes are continual through the time frame of the experiment. Figure IV shows that the ratio of chlorophyll _c_ to chlorophyll _a_ decreased with time. In this case, chlorophyll c indicates the abundance of diatoms relative to the filamentous green algae, both groups of which are the primary constitutents of the periphyton assemblages in the experimental streams. Changes in the pigment ratio during the experiments indicated an initial dominance by diatoms followed by a gradual shift in dominance to filamentous chlorophytes, principally through the growth of _Zygnema_. Figure IV also indicates a larger concentration of carotenoids relative to chlorophyll _a_ in the unshaded riffles. This larger concentration is consistent with the protective role of carotenoids for chlorophyll _a_ molecules at high light intensities.

4) Invertebrate biomass may be a better estimate of autotrophy than algal biomass. The relatively low chlorophyll _a_: herbivore ratios (Figure V) with the high absolute abundances of herbivores (Figure III) in the unshaded riffles suggested that algal biomass is a conservative quality in lotic ecosystems and that increases in light and nutrient resources are manifested in herbivore biomass.

5) Export of algal material is an important mechanism for stability in autotrophic systems. Figure VI indicated that export is not a linear function of standing crop. Increased export at higher algal densities suggested that

less autrophic production was assimilated by grazers. Oscillations in herbivore biomass will be of lower amplitude than algal biomass oscillations with export as a dampening mechanism. Furthermore, export appeared to have a diurnal pattern similar to the observations of Mueller-Haeckel (1973).

CONCLUSIONS

Considerable research effort at the Weyerhaeuser Corporation and at O.S.U. has been directed toward the interpretation of biological phenomena necessary for the effective management of public and private stream resources. Biological processes in stream ecosystems are relatively difficult to understand. Experimental results from this project to date emphasize some problems. Periphyton biomass, an easily measured quantity, appears to be a conservative quality of streams, of little diagnostic value of both autotrophy or environmental conditions. Pigment, invertebrate biomass, and export analyses are informative with distinct trends in the context of the experiment and the experimental streams. However, these patterns are likely to be modified by the spatial heterogeneity common in natural streams. The critical measurements necessary for adequate interpretation of lotic system behavior-community composition analysis and production - are time-consuming, expensive, and constrained by the limitations and artifacts of the equipment used. To interpret stream phenomena, conceptualization of the components, processes, and functions in lotic systems must supersede problems of sampling and spatial heterogeneity.

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FIGURE I

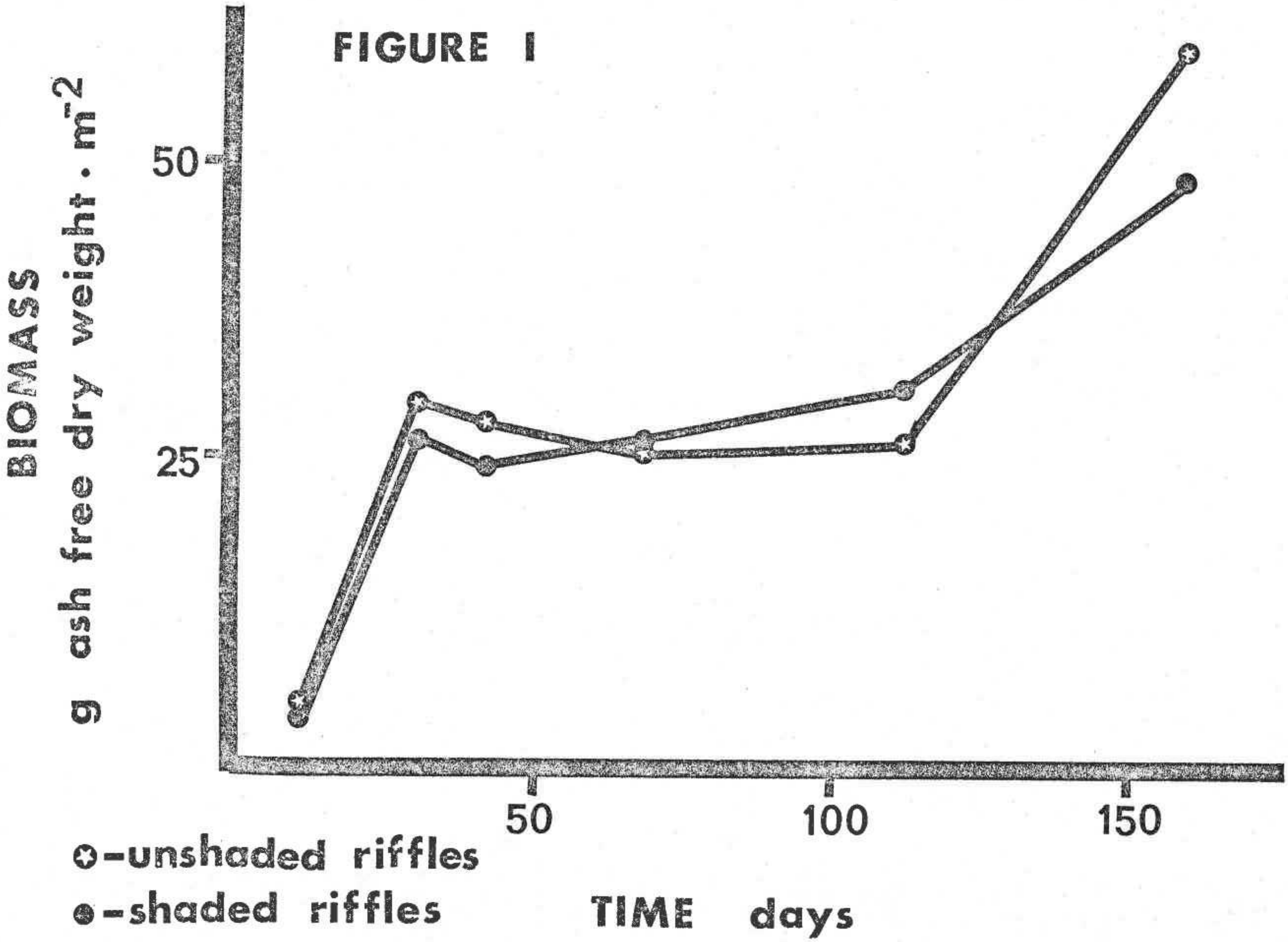

BIOMASS
g ash free dry weight . m^{-2}
50
25
50
100
150
TIME days
✪-unshaded riffles
●-shaded riffles

FIGURE II

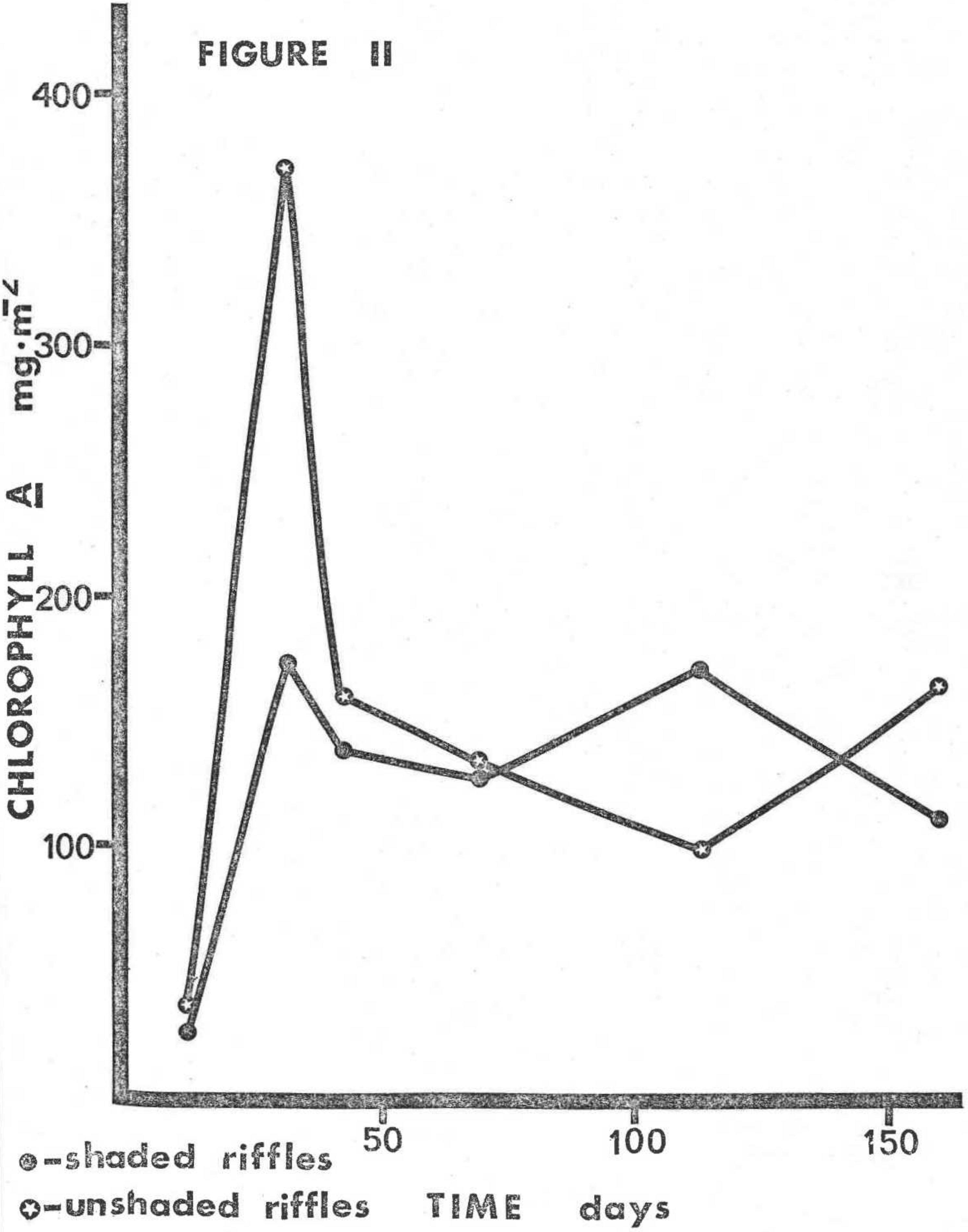

400
300
200
100
CHLOROPHYLL A mg·m⁻²
50
100
150
● -shaded riffles
✪ -unshaded riffles
TIME days

FIGURE III

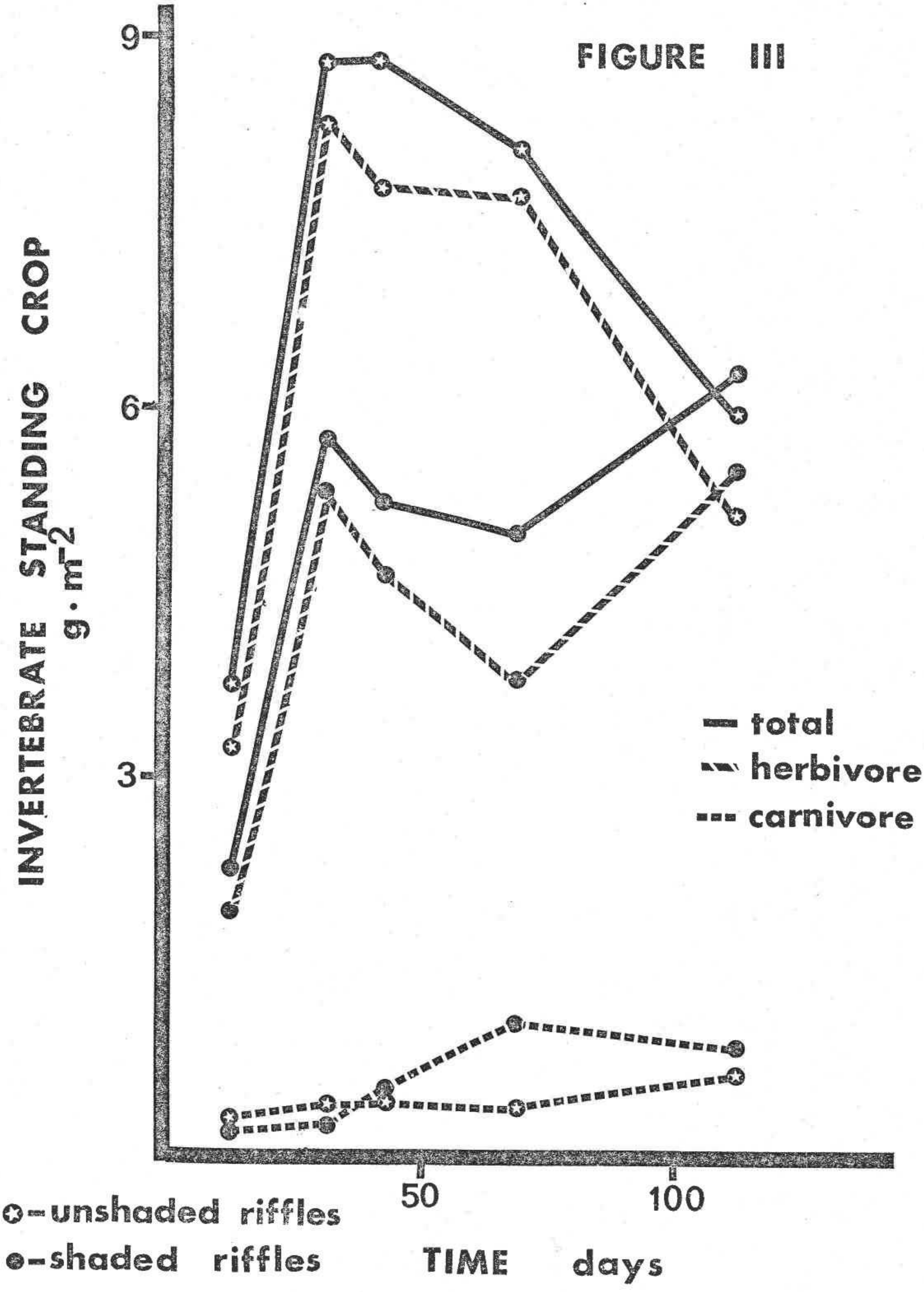
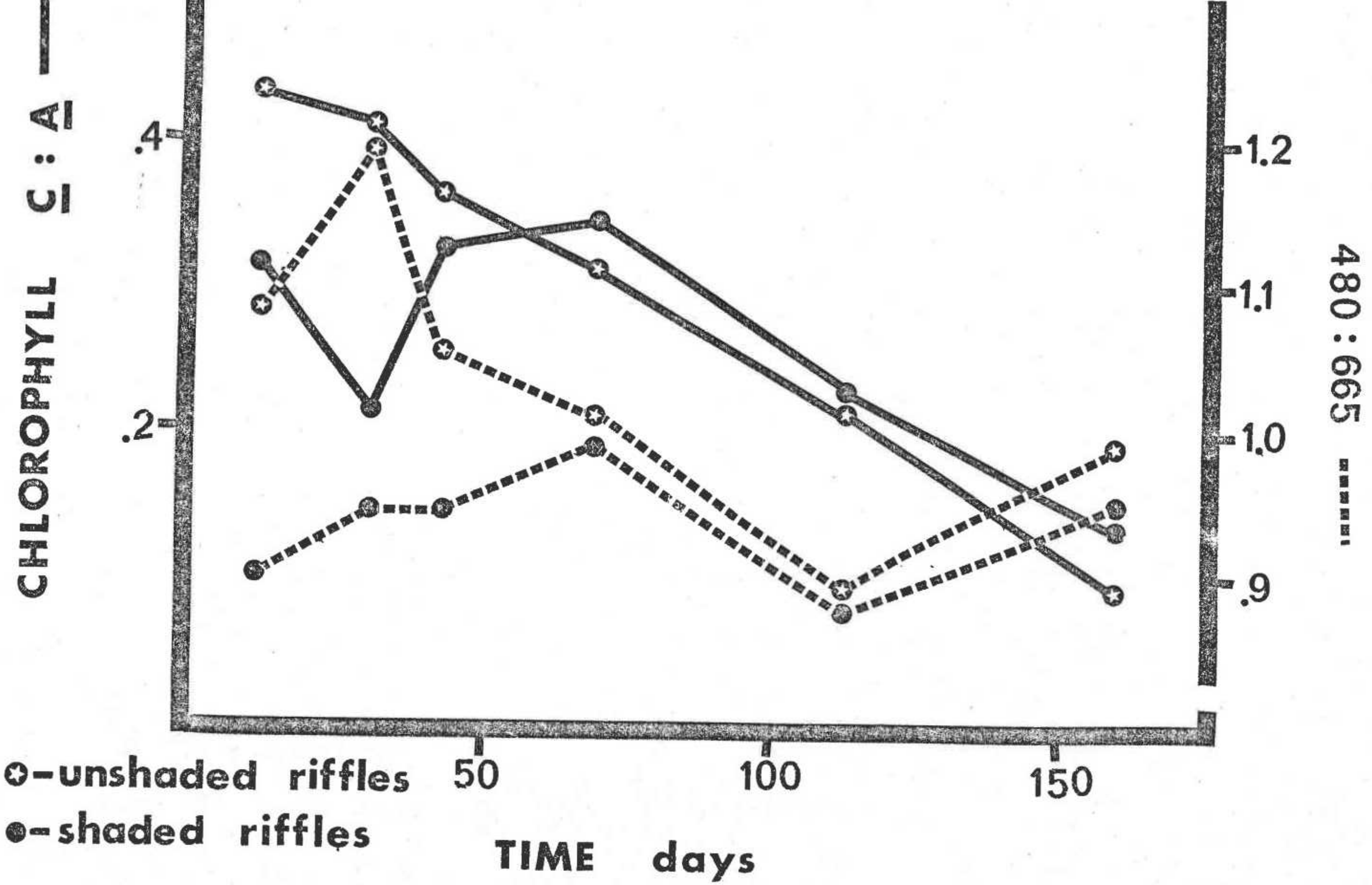

INVERTEBRATE STANDING CROP
g · m^{-2}
9
6
3
50
100
TIME days
total
herbivore
carnivore
○-unshaded riffles
●-shaded riffles

FIGURE IV



CHLOROPHYLL C : A —
.4
.2
480 : 665 ------
1.2
1.1
1.0
.9
50
100
150
TIME days
✪–unshaded riffles
●–shaded riffles

FIGURE V

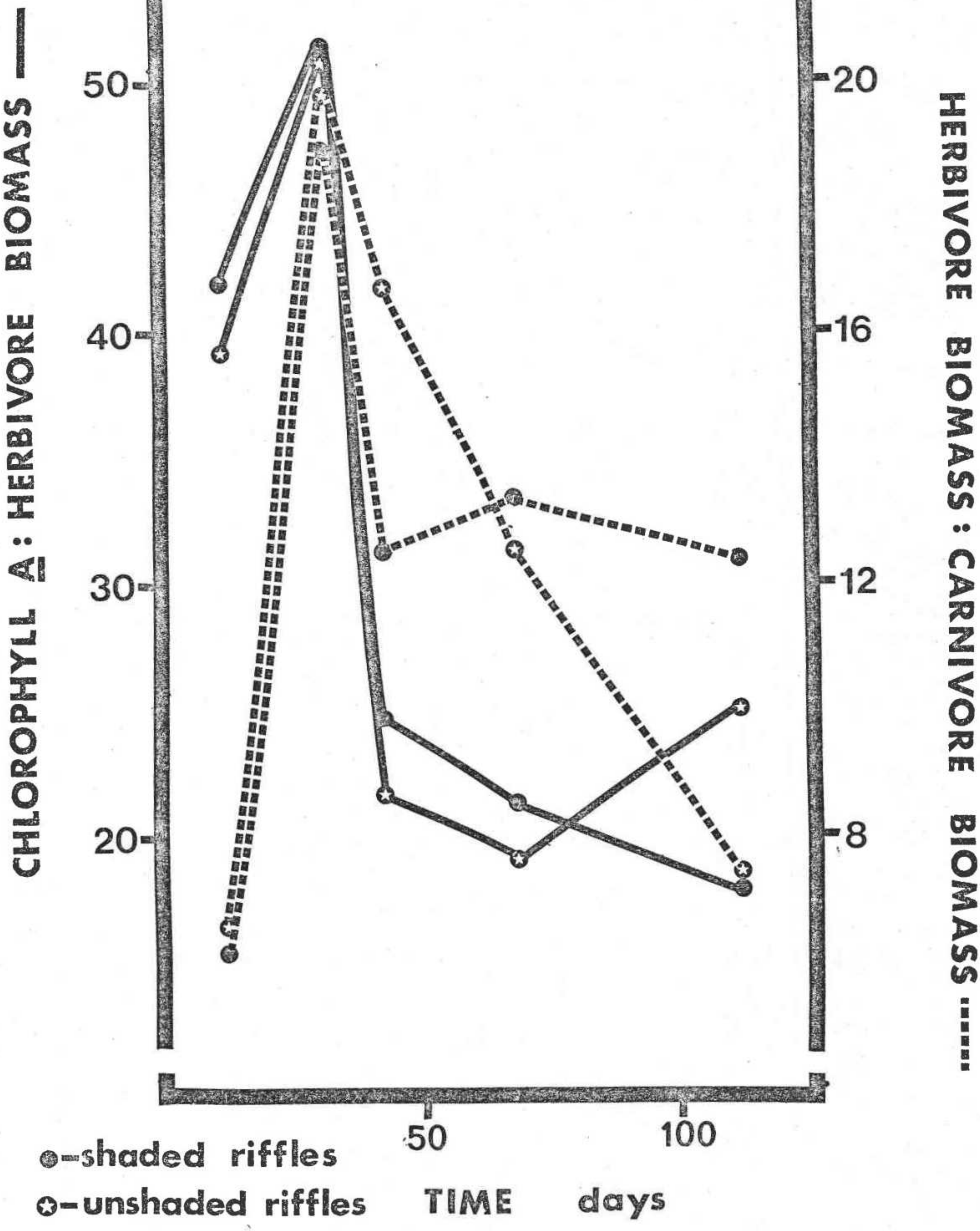
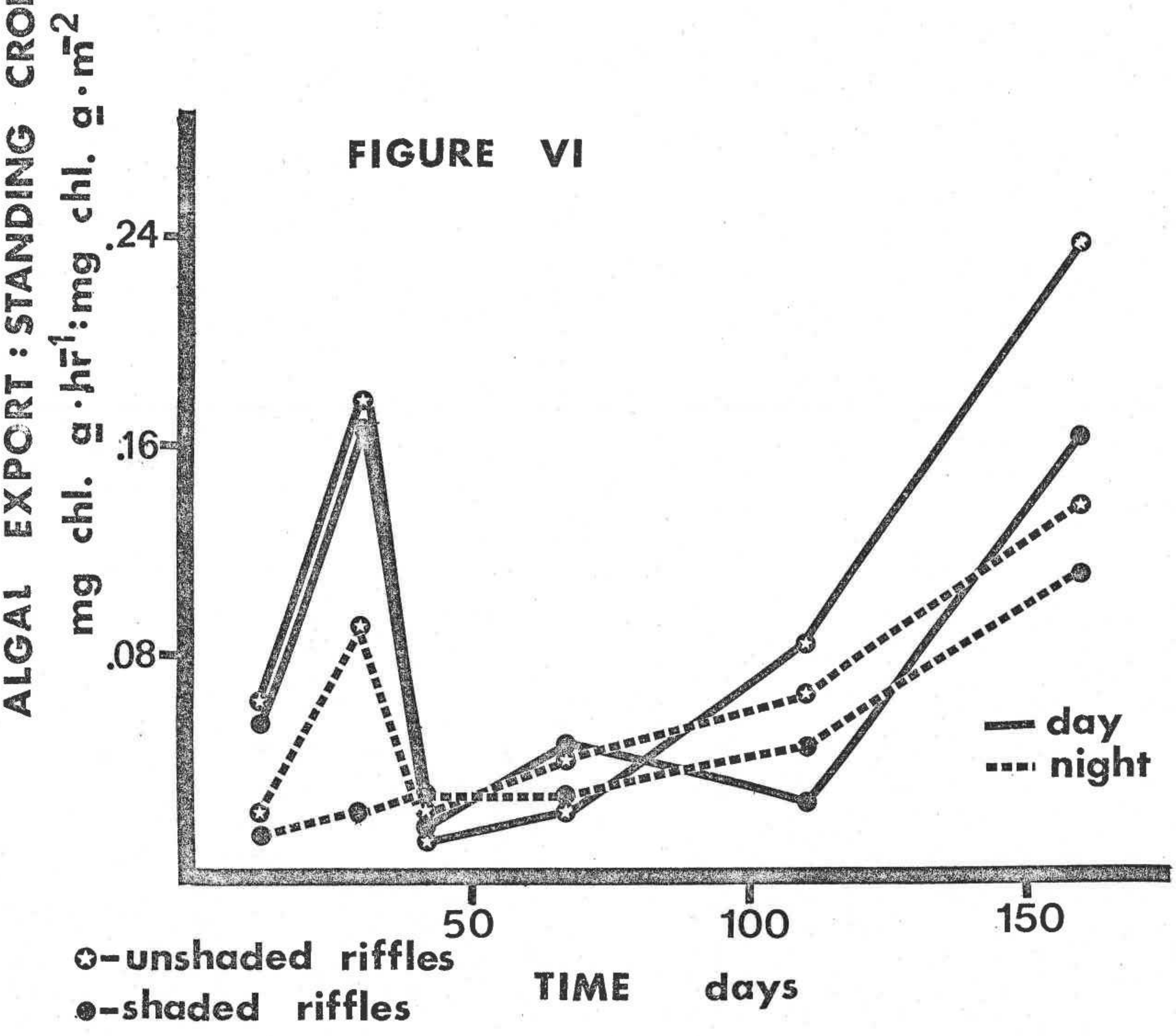

CHLOROPHYLL A : HERBIVORE BIOMASS —
50
40
30
20
20
16
12
8
HERBIVORE BIOMASS : CARNIVORE BIOMASS .....
50
100
TIME days
●–shaded riffles
✪–unshaded riffles

FIGURE VI


ALGAL EXPORT : STANDING CROP
mg chl. a · hr^{-1} : mg chl. a · m^{-2}
.24
.16
.08
50
100
150
TIME days
— day
--- night
✪-unshaded riffles
●-shaded riffles