A STUDY OF PRIMARY PRODUCTION ON ARTIFICIAL SUBSTRATES IN A RIFFLE AND POOL AREA OF THE RED CEDAR RIVER

Thesis for the Degree of M. S.

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Robert Raymond Rawstron, Jr.

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A STUDY OF PRIMARY PRODUCTION ON ARTIFICIAL SUBSTRATES IN A RIFFLE AND POOL AREA OF THE RED CEDAR RIVER

By

ROBERT RAYMOND RAWSTRON, JR.

AN ABSTRACT

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1961

Approved Peter I. Tack

ABSTRACT

Studies of the primary production of both riffle and pool situations, using artificial substrates in the Red Cedar River, were carried out in the summer of 1960. Transplants from the pool to the riffle were made. Primary production was measured by the accumulation of phytopigments measured as AA x 10^3. Phytopigments were extracted in 95 percent ethanol and "read" on a Klett-Summerson colorimeter.

The riffles were found to be more productive, attaining higher maxima, and showing faster growth rates than the pool. The pool substrates reached their maximum standing crops within fifteen day cycles, whereas the riffle substrates did not. Transplants from the pool to the riffle showed an increased growth rate after the standing crop from the pool was accumulated for nine days. Current velocities between 1.0 feet per second and 3.0 feet per second showed higher growth rates on the artificial substrates than that of currents above or below these values.

Community composition differed; *Melosira sp.* being dominant in the riffle community, while *Synedra ulna* and *Navicula cryptocephala* characterized the pool community.

R. R. R.

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INTRODUCTION

The measurement of productivity is fundamental to the science of limnology. Productivity occurs on two levels. Primary productivity is defined by Odum (1953) as the rate at which energy is stored by the activities of primary producer organisms in the form of organic materials which can be used as food. Secondary productivity occurs as the consumer organisms utilize the energy produced on the primary level.

Most studies to date have centered on lentic environments, and much remains to be learned of the lotic situations. Odum's (1956) work in studying primary productivity of flowing waters in the natural artesian springs, using diurnal gas curves and community metabolism methods, is not generally useful in the warm-water streams in Michigan. The effects of rapid water temperature change, organic pollution and extreme variability in stream flow introduce other variables for which it is difficult to account, using Odum's methods.

The introduction of artificial substrates into both lentic and lotic situations is not new, and Cooke (1956) describes some of the history. Many substances have been used as artificial substrates. Keup (1958) used cedar shingles; others have used glass slides, stones, cinder bricks and plexiglass plates to collect the organisms that have become attached to them.

Much terminology has arisen to describe the complex of organisms which become attached to underwater objects. Newcombe (1950) and Cooke (1956) give definitive discussions of these terms. Ruttner's term "aufwuchs" seems to be more nearly correct than the others, referring only to the organisms which become firmly attached, but do not penetrate into the substrate. Grzenda and Brehmer (1960), using the same general techniques as in this study, use the term "periphyton" to describe this assemblage of organisms. Either term appears to be acceptable, but for the purposes of this study the term "aufwuchs" is preferred.

Recent use of plexiglass plates in studies at Michigan State University has demonstrated their validity as an artificial substrate (Peters, 1959). Investigations so far, however, have taken no cognizance of possible differences in productivity levels between pool and riffle conditions on such substrates. Stokes (1960) in his study of an artificial stream demonstrated slight differences between the two situations. Ruttner (1953), and Whitford (1960) discuss the "physiological richness" of current situations and demonstrate that differences do exist between productivity of pools and of riffles.

Peters (1959) gives two assumptions that must be made when using artificial substrates. "(1) The substrates are not selective for specific organisms and (2) the production on the artificial substrate is at the same rate as occurs on a natural substrate." For this study, the second assumption will be expanded to read, "the production on the artificial substrate in a given environment (pool, riffle) occurs at the same rate as on a natural substrate in that same environment."

This study was carried on to determine whether differences in rate of production occurred between the pool and riffle conditions on artificial substrates. Primary productivity was estimated for each situation by the accumulation of plant material as measured by phytopigment extracts over a period of time. Comparisons were made while trying to keep all other variables as nearly the same as possible, e.g. water temperature, available light, and nutrients, turbidity, and stream depth. Using the same standards for measurement, plexiglass plates were transplanted from the pool to the riffle to determine what the effects of velocity would be on the pool-grown communities.

Only limited taxonomic or quantitative work was done and this to determine whether the community structure of each community was similar.

DESCRIPTION OF STUDY AREA

The Red Cedar River is a typical southern Michigan warm-water stream, characterized by slow currents and pools with occasional rapids. The upper portions of the river have been dredged to straighten and deepen the channel while the major tributaries have been dredged for agricultural purposes. Both treated and untreated sewage enter the river throughout the watershed. Three artificial impoundments are located on the main river; in the town of Williamston, at Ferguson Park in Okemos, and on the Michigan State University campus.

The Red Cedar River begins at Cedar Lake in southeastern Livingston County in Sections 28 and 29. It runs a northwesterly course for approximately 18 miles, and then flows westward through Ingham County for 28 miles to its confluence with the Grand River within the city of Lansing.

The climate, geology, soils and land use practices are described by Meehan, 1958.

The sampling stations were located in the main stream 0.5 miles below the bridge at Dobie Road in Okemos. This choice of sites was made to take advantage of a strong riffle immediately adjacent to a long shallow pool and the presence of a water temperature thermograph. The stream at the sampling sites is approximately forty feet wide. The pool bottom is generally of thick sand, but at its downstream end gives way to large rock and gravel. A natural riffle occurs here, but the water flow was too low, so a double rock wing dam was built to increase the flow and consequently the velocity, in the middle of the river.

Station A was located in the pool 15 feet from the south bank of the river. The pool depth at this point is about three feet. Velocities ranged from 0.168 feet per second to 0.893 feet per second.

The riffle is approximately 35 feet long by ten feet wide, sweeping into another large pool. The bottom is of large rock and debris, and has a nearly uniform depth of three feet, varying with river flow. It lies approximately sixty feet downstream from the point at which Station A was established. Its velocity during the study ranged from 4.55 feet per second at its upstream end to 1.23 feet per second at its downstream end. Station B was established within this riffle.

The stations were chosen to provide similar ecological variables, leaving current velocity as the only recognized difference. Since the stations were so close together, turbidity, nutrients, and water chemistry were assumed to be similar. Both situations had similar shade cover. Both were covered most of the morning, and exposed two to three hours each afternoon, and shaded again in late afternoon and evening.

METHODS AND TECHNIQUES

The measurement of productivity can be carried out by many methods. At present more emphasis seems to be placed on a general method involving the measurement of photosynthetic activity rate through the quantitative estimation of gas production in light and dark bottles or the addition of various inorganic radioactive isotopes into the medium and measurement of it after fixation into organic form. C^{14}, P^{32} and other radioactive isotopes which are fixed in organic matter have been used.

Productivity can be measured by at least two other general methods. One involves the estimation of plant material growth and includes such techniques as the counting of cells within a unit volume or surface area, the isolation of single or mixed components characteristic of plants, the isolation of a single plant constituent, chlorophyll and/or other pigments having associated optical properties. The other involves measurement of the total weight of organic matter accumulated over a period of time. Often all or part of these general methods are combined in a single study.

It has been demonstrated that artificial substrates can be used to sample productivity. Peters (1959) establishes the validity of their use in the Red Cedar River. Cooke (1956) and Newcombe (1950) review the literature concerning fresh water community types and discuss the role of the aufwuchs community. The aufwuchs are those organisms except macrophytes which attach themselves to a substrate, but do not penetrate into it. Other terms are sessile benthos and periphyton. Benthos is a large category separating organisms on the bottom from those found free-floating or drifting as plankton. Sessile is applied to organisms which become attached to a substrate whether plant or animal. Periphyton is a term, often used synonymously with aufwuchs, which may include dead or alive plankters or drifting organisms of plant or animal origin caught in the attached forms on a substrate. Since this study is concerned only with attached forms and not the organisms caught up in them, the term aufwuchs is preferred.

Plexiglass plates were used as the artificial substrates. Each unit presents 1.4 square decimeters surface area for attachment. These plates are quite inert chemically. They were attached to wooden racks, which in turn were bolted onto steel fence posts, which had been driven into the river bed. Grzenda and Brehmer (1960) describe the technique and give pictures of similar apparatus.

During the summer of 1960 Stations A and B were composed of three sets of ten plexiglass plates, each on racks placed on the previously installed fence posts. Each post, with its attached rack, was designated a site. These sites were given the numbers 1, 2 and 3 to show from which rack a given plate had come. The plates, in turn, were given code numbers to indicate the position on the rack from which it had come. All those on the left as faced from behind were given odd numbers in order of increasing magnitude

from the end toward the middle, while those on the right were given even numbers in the same way. In addition, a subscript was given to each code number to indicate Station A or B. Thus, 16A was the third plate from the right at Site 1, Station A, while 23B was the second plate from the left at Site 2, Station B. The shingles at Station A were considered to be matched working inboard from each end.

At zero day, the beginning of a cycle, the 60 plates were lowered to 0.8 of the depth from the surface. This depth was chosen to eliminate the effects produced by sharply reduced current at the bottom (Welch, 1952), while at the same time allowing for possibly lowered flow. On the third day at Station A, the whole rack at each site was raised and the outer plates removed (11A, 12A; 21A, 22A; 31A, 32A). One of each of the pairs was taken to the laboratory; the other was kept wet and handled as little as possible and "transplanted" to the same position at the same site at Station B, whose corresponding plate had been removed prior to that of Station A.

To the open position at the sites at Station B a clean plate was placed. This plate was coded XY_{b_1}, where X and Y represent the site and position number respectively. They were placed here to try to determine the comparative growth rate in the riffle for the transplant period of a given shingle.

The procedure moving inboard at Stations A and B continued every third day for fifteen days. In addition, to

the regular removals, the previous transplant and the plate coded XY_{b1} were removed. Thus each transplant spent three days in the current and either 3, 6, 9 or 12 days in the pool, while all the XY_{b1}'s spent three days in the riffle. The preceding technique was carried out from July 2, 1960 to October 17, 1960.

To insure that only the aufwuchs were measured and not drifting phytoplankters either dead or alive, which had settled out, each shingle was thoroughly stream-washed to remove the loose materials. The plates were all washed four times to add some constancy to the maneuver.

The statistical relationships between the pairs assumed to be matched were carried out. Two separate matched pair tests were run in the pool; one for six days, and the other for nine days. The results of these tests are shown in Appendix I.

During the summer of 1959, a different scheme was used. The stations were the same, but Station A had only two sites while Station B had three. Each site was composed of two shingles and all positions at each site were removed and brought into the laboratory every eight days. No transplants were made. Direct comparisons were made for each period. Little use of these data can or will be made in this paper. During the eight-day interim the operator of the impoundment at Williamston often reduced the stream flow considerably, covering and uncovering the shingles for various periods of time. Either through experience or more

frequency on the stream during the summer of 1960, this condition was evaded completely, and more useful and quantitative information was obtained.

Current velocity was measured with a Gurley bucket-type current meter, Model 622 and the micro-unit Model 625-F. Three readings were made directly over the rack on each side of the fence post at each site and averaged for each site. Four distinct gradations of velocity were noted. Therefore, four general classifications were set up. The pool which always registered velocity less than 1.0 feet per second and greater than 0.16 feet per second was designated V_0. The riffle area velocity at the three sites was more varied, but in general Site 1 ranged between 3.5 feet per second and 4.4 feet per second. Site 2 ranged from 1.77 feet per second to 3.08 feet per second. Site 3 ranged from 1.23 feet per second to 1.93 feet per second. Three categories were set up for Station B and are as follows: 1.0 feet per second to 2.0 feet per second, designated as V_3, at Site 3; 2.00 feet per second to 3.00 feet per second, designated as V_2 at Site 2; and 3.00 feet per second to 4.55 feet per second at Site 1, designated as V_1. There was some overlapping in these categories, but in general they represent the true picture of the velocities present during the study. Appendix II shows the average currents present at each site and the dates.

During the summer periods as described above, the artificial impoundment at Williamston is in operation. Water

flow, and hence stream velocity, varied greatly with no aparent regularity. In addition, meteorological conditions caused fluctuations. In order to cope with such large changes over such short periods of time, it was felt that a random measuring of the current velocities would be more effective than trying to measure every day or at regular intervals. Ten random numbers were chosen from 1 to 120, the approximate length of the study in days. The current was then measured on the dates coinciding with the number chosen beginning July 2, 1960.

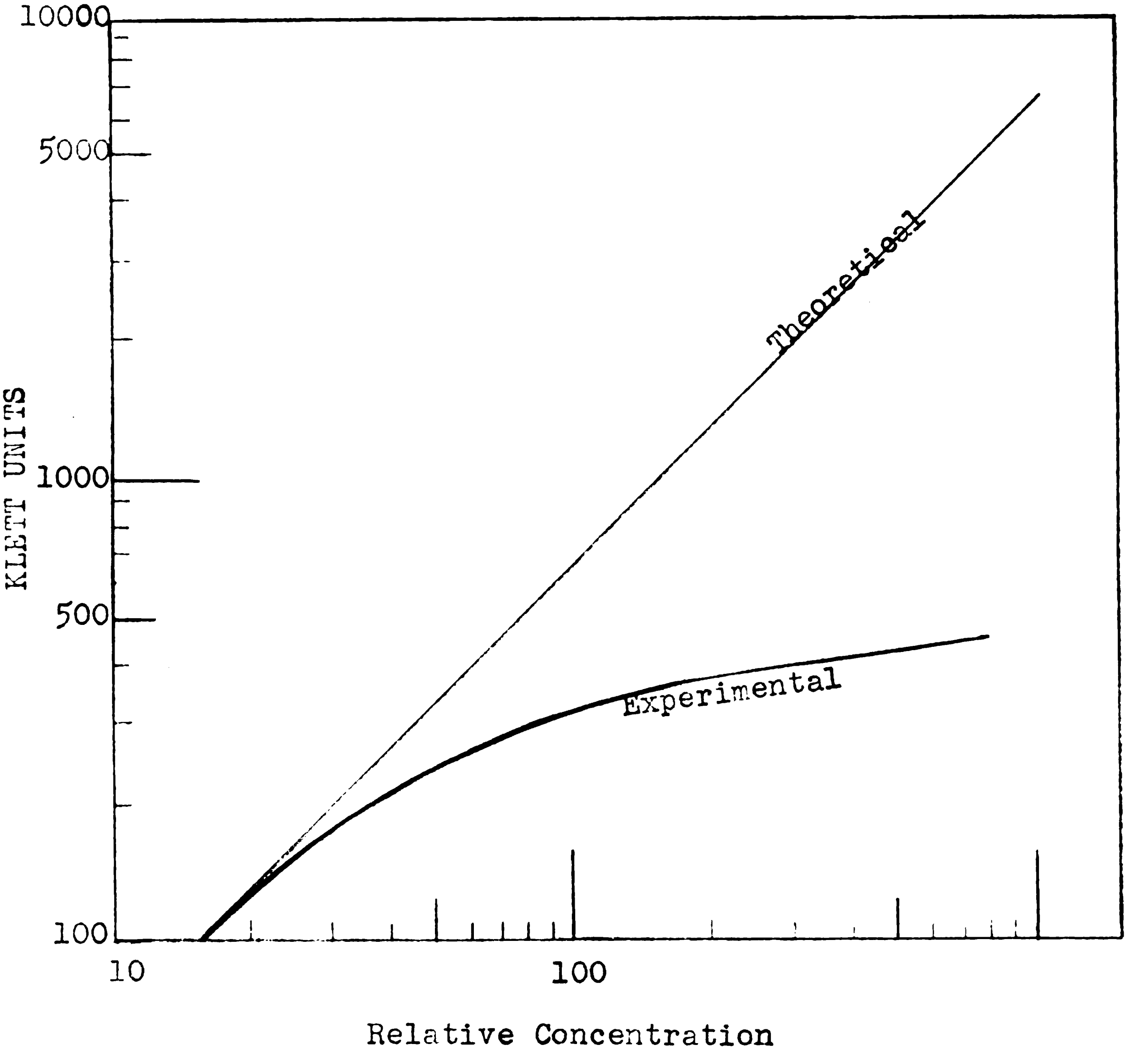
It must be pointed out that the currents as measured in this study are not instantaneous, but are taken over a period of time (Welch, 1948). Current rate is affected by a number of well-known variables such as water level, depth and bottom type, etc. (Longwell, et al., 1932). Since each shingle is in a different position in the current, differences in current rate, particularly in the riffle, must have occurred. The measurement of these differences would have been extremely difficult and not necessarily useful in this type of study. McConnell and Sigler (1959) used the rate of dissolution of standardized salt tablets as an indicator of current rate, but attained correlations only up to 0.9 meters per second. Since velocities recorded in this study are much higher than this value, little use could be found for this type of measurement. Currents may fluctuate from moment to moment within a given maximum-minimum range and even this range can shift a great deal over a short period of a few days as a response to changes in water level (Blum, 1956). These changes in rate could then have an effect on the productivity of the aufwuchs on the shingles. The random sampling of current velocity over a period of time was an attempt, then, not only to account for changing water levels and the consequent change in velocity, but also establishes a tentative maximum-minimum range for each site.

Water temperatures were recorded daily on a thermograph placed on a bridge abutment between the two stations.

The single qualitative study was carried out in October to determine the species composition of the aufwuchs communities of each situation. The method involved using the relative frequency of occurrence, i. e. the number of times an organism was seen in 50 fields. Before extraction in alcohol, two shingles, one each from the pool and riffle, were examined by scraping approximately two square centimeters from each shingle onto separate microscope slides.

For quantitative determinations of the phytopigment extract the shingles were brought from the sampling stations to the laboratory in plastic freezer bags. The shingles were placed in the freezer compartment of a refrigerator for twenty-four hours. The aufwuchs were scraped off the shingle into 95 percent ethanol, using a glass slide and a rubber policeman. Freezing facilitated the removal of the aufwuchs. The bags were then flushed out with ethanol to remove any aufwuchs which might have been dislodged from

Figure 1. Correction graph for phytopigment extracts.


10000
5000
1000
500
100
KLETT UNITS
10
100
Relative Concentration
Theoretical
Experimental

the substrate. The use of ethanol rather than acetone prevented the dissolution of the plexiglass, while at the same time dissolving the phytopigments. The solutions were allowed to stand another twenty-four hours in the dark and then filtered through glass wool. After filtration the samples were adjusted to fifty milliliters.

The resulting phytopigment extract solutions were then "read" on a Klett-Summerson colorimeter, using a 640-700 mu red filter. Grzenda and Brehmer (1960) found that in only small concentrations did these phytopigment solutions follow the theoretical Lambert-Beer Law. As the concentration of the phytopigments in the 95 percent ethanol increases the observed and theoretical absorbancy values at 640-700 mu become widely divergent. They prepared a graph, using various concentrations obtained through dilution. The correction values are obtained from Figure 1 by reading the observed Klett units on the ordinate and extending it horizontally to the experimental line. Vertical extension from the point of interception of the experimental line to the theoretical Lambert-Beer line and reading of the Klett units directly perpendicular to it gives the adjusted Klett units. This value is then multiplied by 2×10^3 to convert to adjusted absorbancy AA $\times 10^3$ and to avoid the use of the decimal. The method is more fully described by Grzenda and Brehmer (1960).

It is obvious from Figure 1 that observed values above 550 Kletts become impossible to interpret and hence all values above this figure in the raw data and accompanying figures are only of the proper order and are not exact. These values, when converted to AA x 10^3 were interpreted as 15,000 . It seems that if the sample solutions were diluted to the point where the theoretical and experimental lines are coincident, then multiplication by the dilution factor should produce the theoretical Lambert-Beer values. The few times that this was tried resulted in different values than when using Figure 1, so it was felt that a slight error in magnitude would be justified in the case of the higher observed values if some indication of order could be shown. The writer feels, however, that more work should be done on this dilution method because, at least, in theory, it should work.

Only seven complete cycles are shown in Appendix III, but several others were interrupted due to high water in June, which made the pickup of the substrates impossible and again in October when the heavy leaf fall tended to accumulate on the surface of the shingles. Data from such collections were discarded.

RESULTS AND CONCLUSIONS

Since the current rates in the pool were generally the same, always less than 1.0 feet per second, the absorbancy units (AA x 10^3) for the three sites have been averaged for each three day period and depicted as one line in Figures 2-8. The three sites at Station B have distinct differences in velocity and are depicted as separate lines for each site in these figures.

With the exception of Figure 6, which depicts Cycle V, the pool appears to reach a maximum within the fifteen-day cycle and in some cases shows a moderate decline between the twelfth and fifteenth days. In general, they also reach much lower maxima than do those in the riffle in spite of a rapid initial increase during the first three days of a cycle. These facts are attributable to the almost "immediate" colonization of the pool substrates and the comparative ineffectiveness of the slow current velocities to sweep away the metabolic wastes and to bring in nutrients and gases to the community, hence inhibiting reproduction after the initial colonization. In addition, much clay and silt is deposited along with dead organic matter and these particles occupy space and perhaps cover the community on the substrate. They then act as a shield and prohibit adequate light penetration to the community. This last effect would be more inhibitory as the length of time the particular shingle was in the water increased, since accumulation of the inorganic and dead organic particles on the shingle

Figures 2-8. AA x 10^3 per square decimeters for pool and riffle sites. V_0; pool sites averaged: V_1, V_2, V_3, depicted as separate lines. Cycles I-VII.

Figure 2

CYCLE I July 2-17

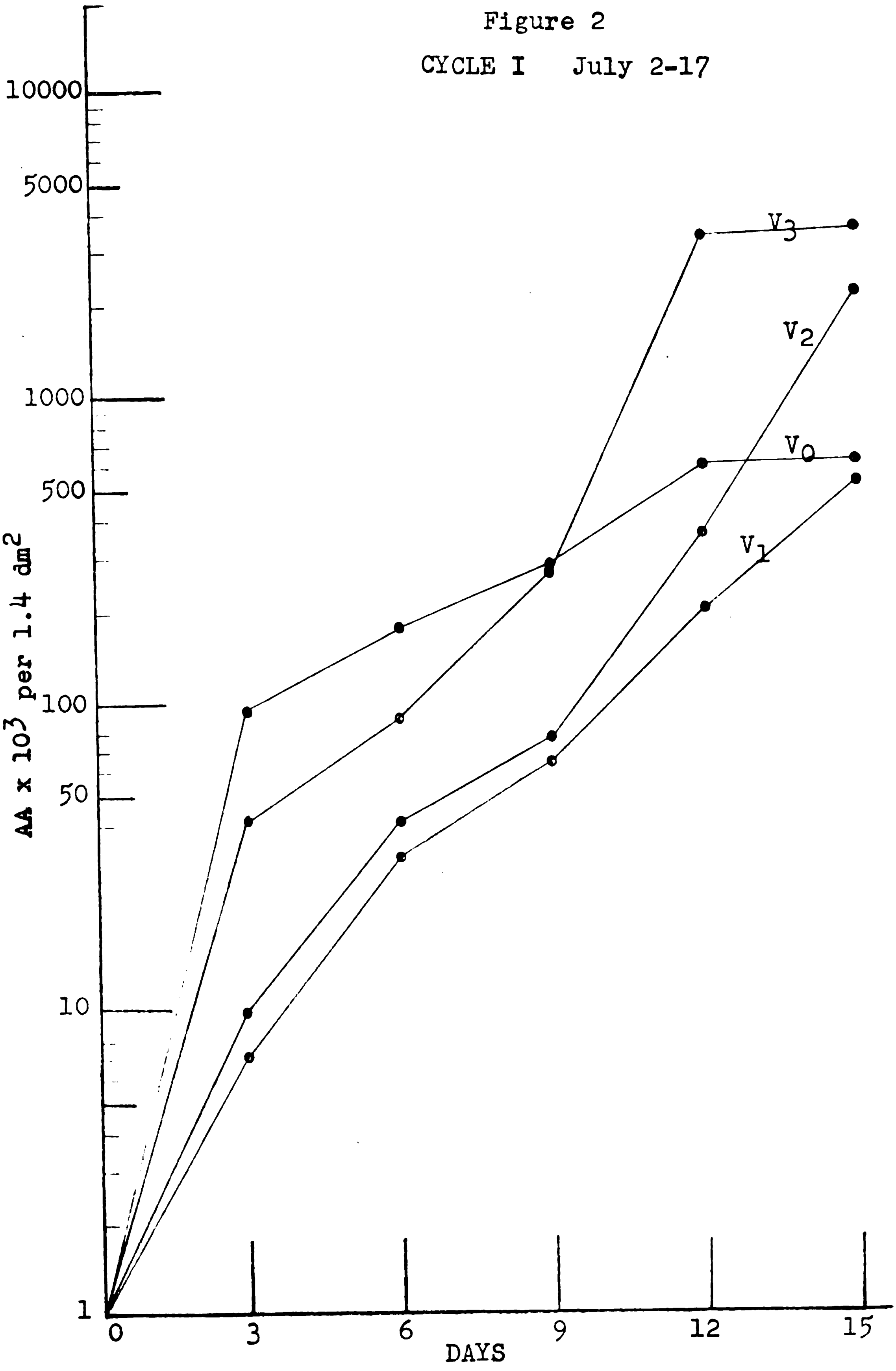


Figure 3

CYCLE II July 17-August 2

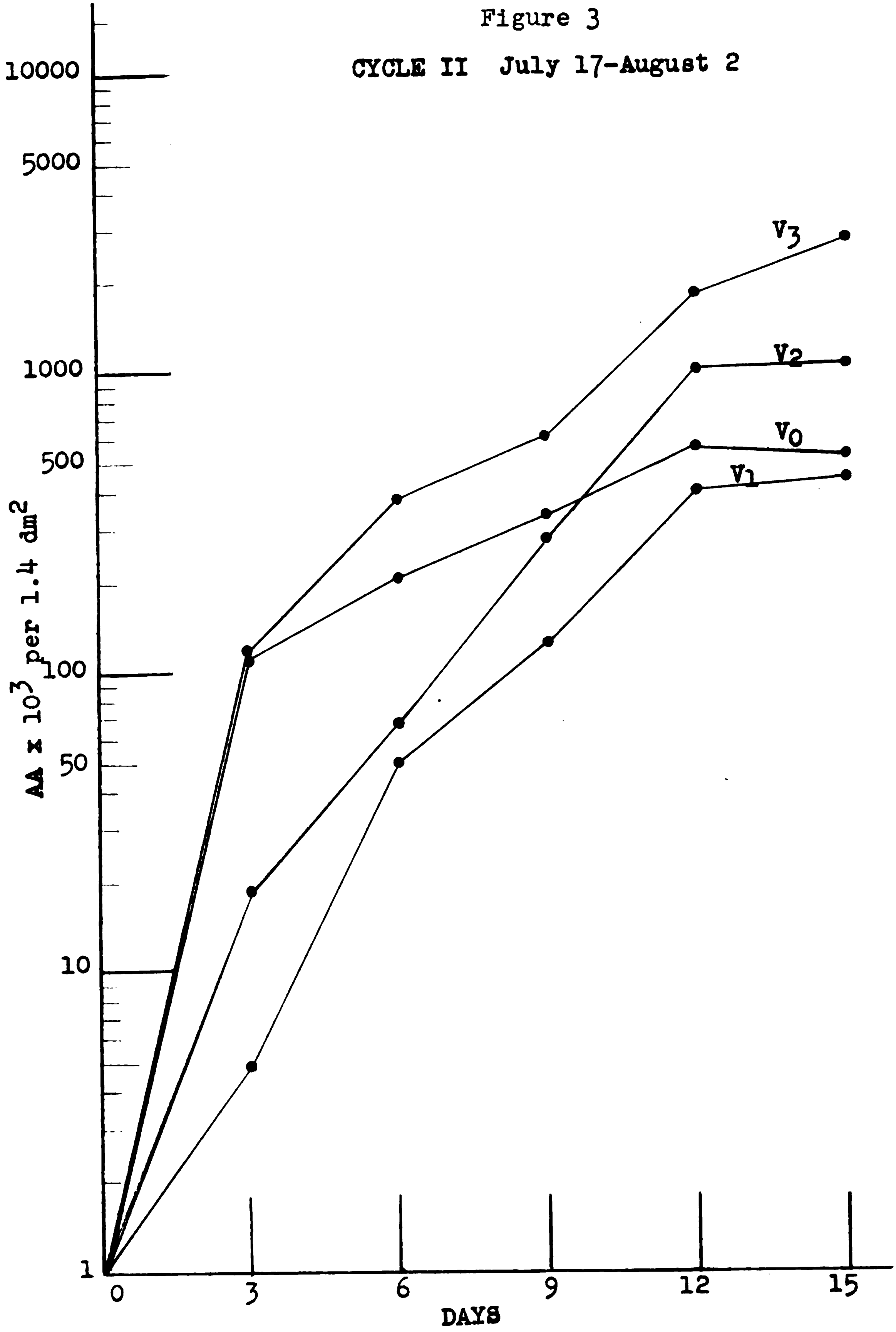


Figure 4

CYCLE III August 2-17

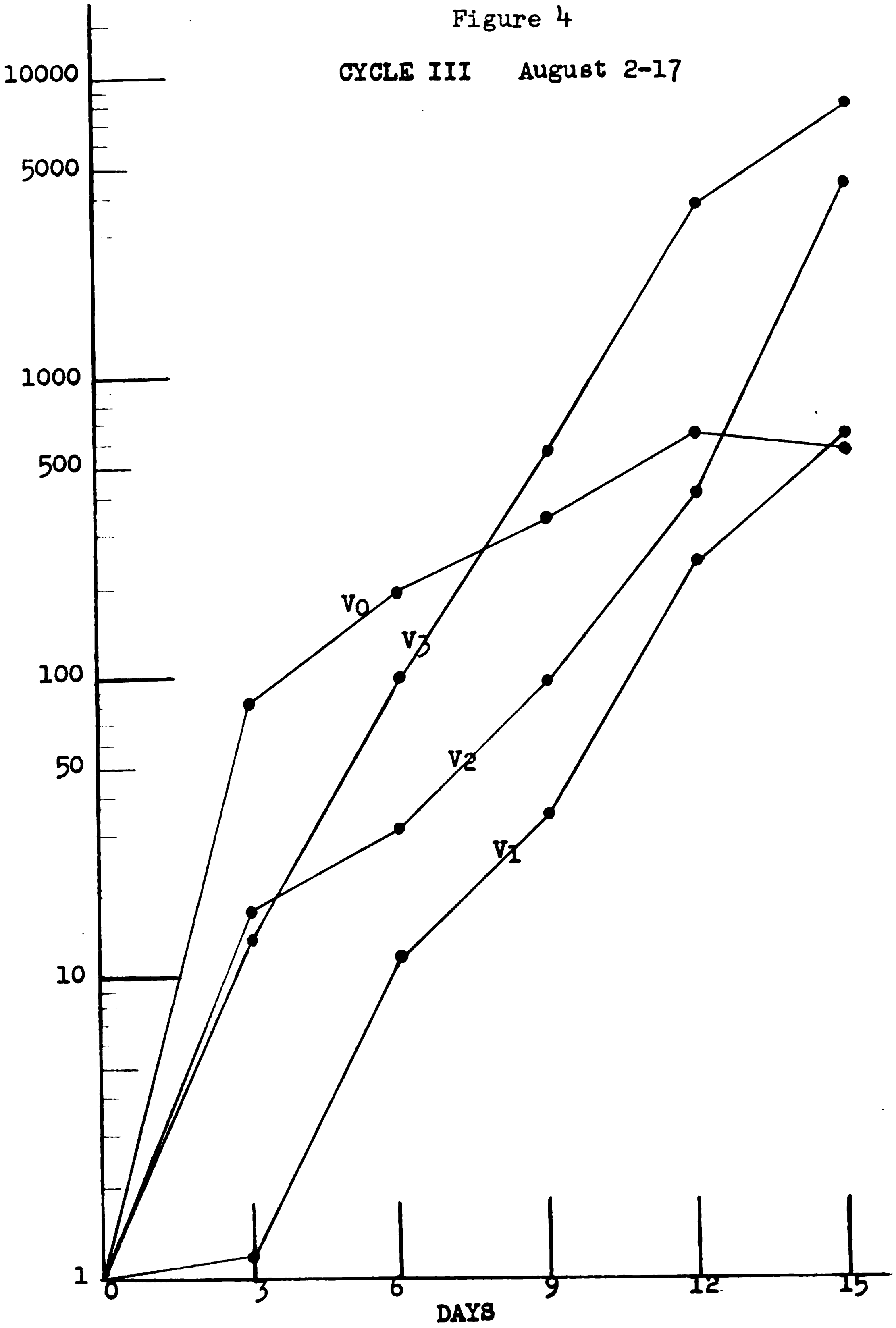


Figure 5

CYCLE IV August 17-September 1

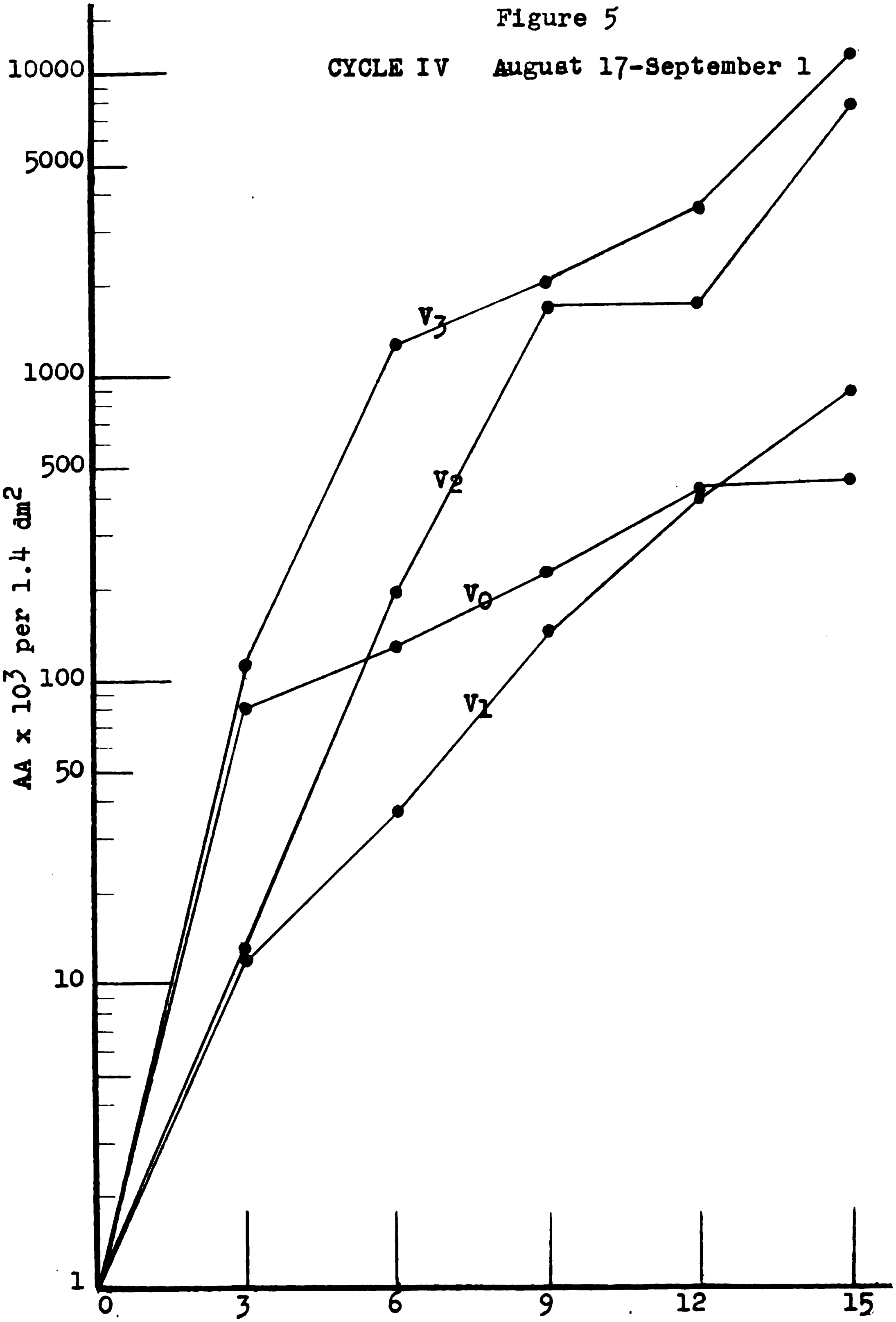


Figure 6

CYCLE V September 3-18

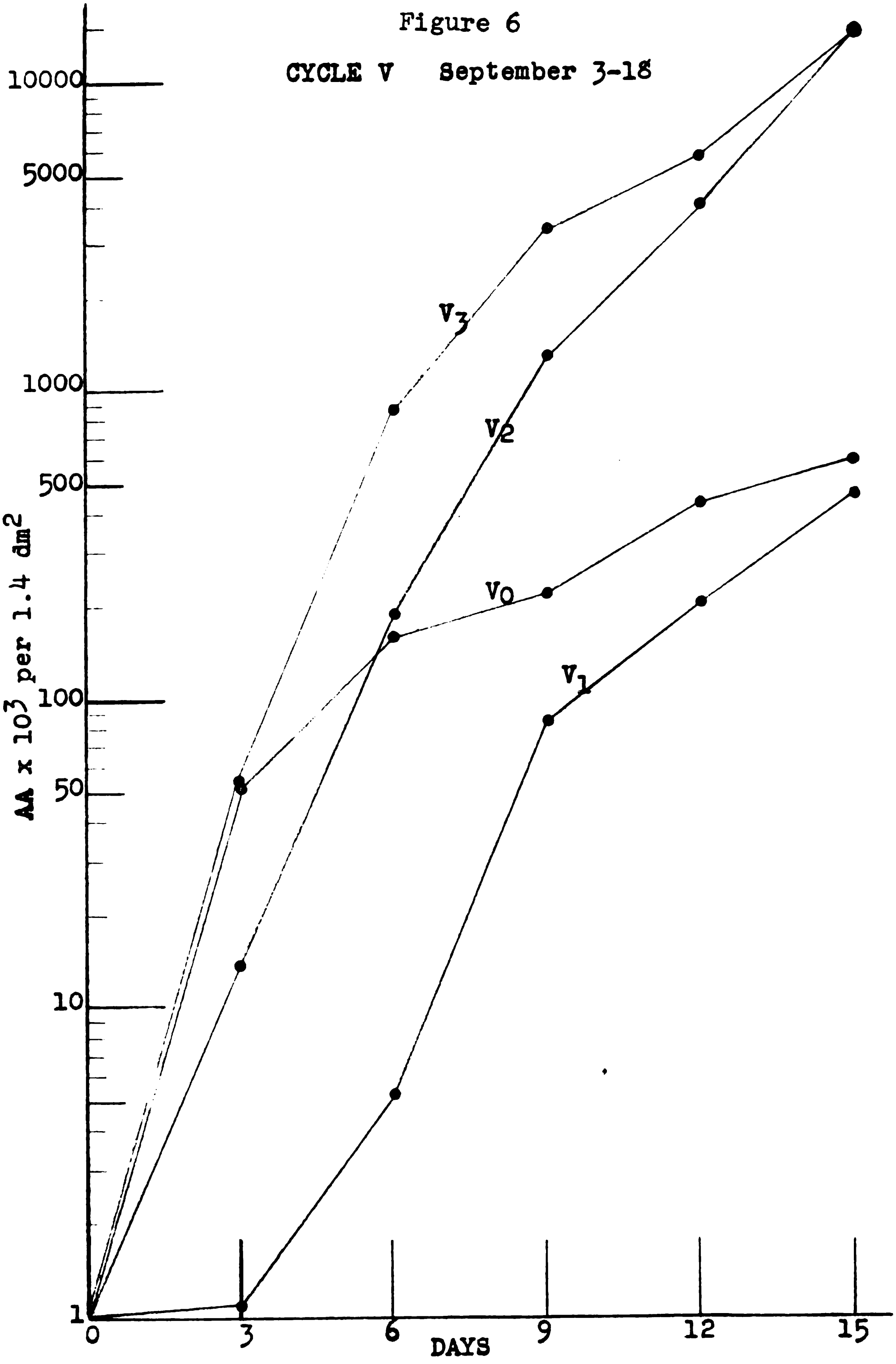
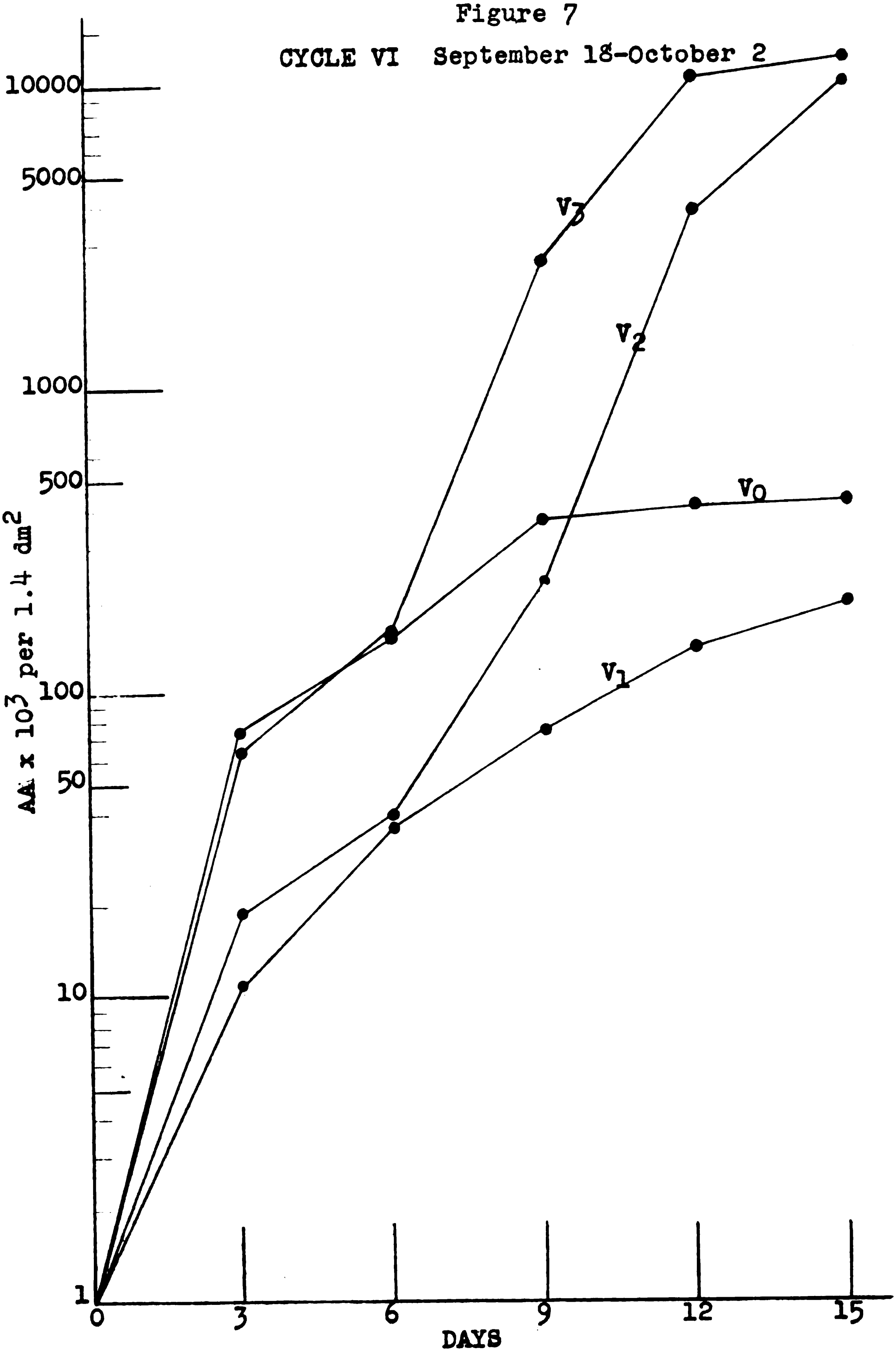


Figure 7

CYCLE VI September 18-October 2



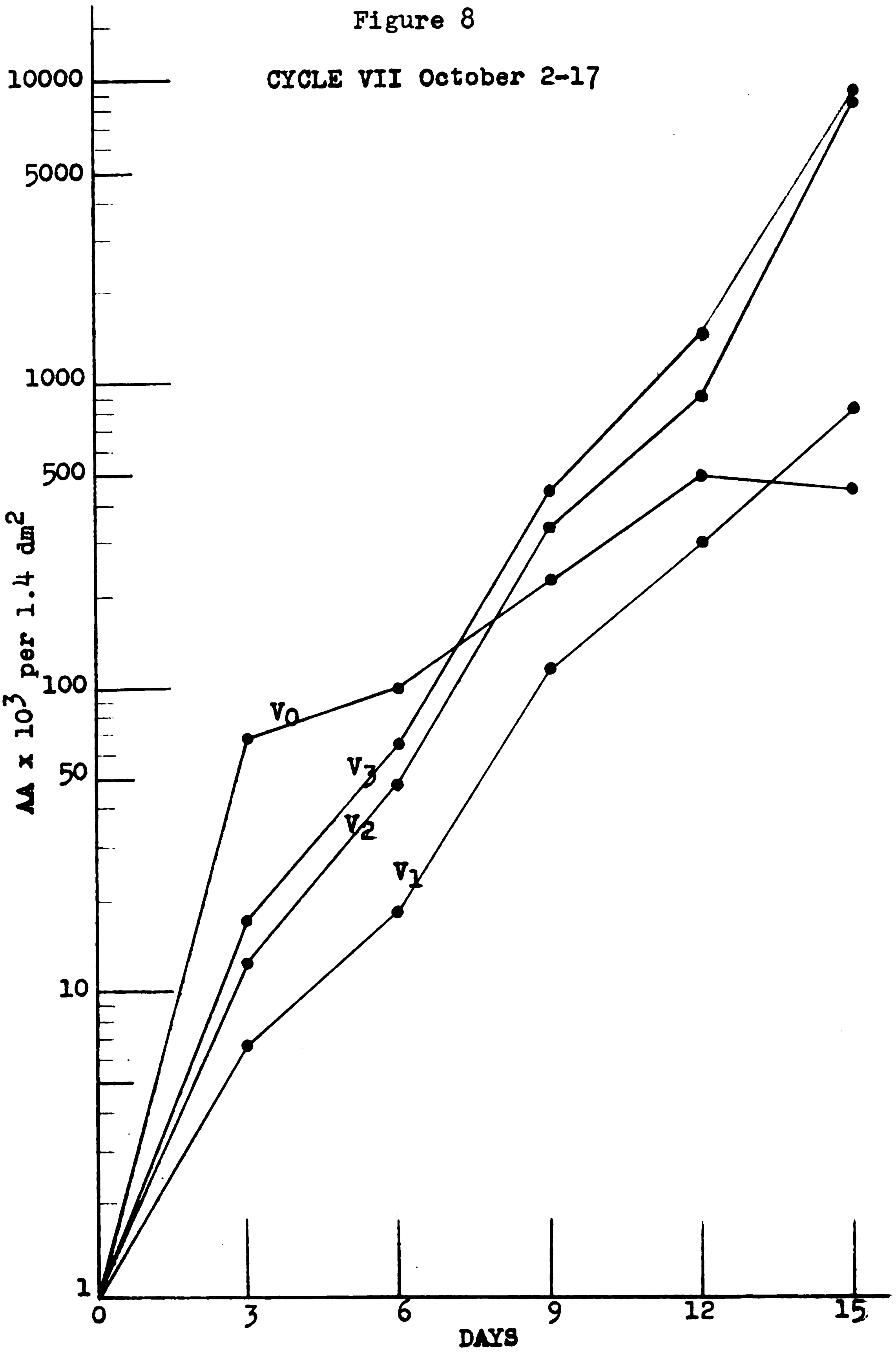


Figure 8

CYCLE VII October 2-17

would also increase.

The riffle areas, on the other hand, demonstrate a slow initial growth (except Site 3), but rise rapidly to reach higher maxima. The higher current velocities, V_1, at Site 1, Station B, sometimes appeared to be inhibitory, reducing growth rate and reaching a lower minimum. At the other two sites, however, the growth rate was generally greater and development of higher maxima was apparent. From this study it might be concluded that the higher currents are inhibitory in some way, and that the optimum current lies between 1.00 feet per second and 3.00 feet per second. Both Sites 2 and 3, with velocities of V_2 and V_3 respectively, show parallel growth rates generally, with Site 3 growing at a more rapid rate and reaching higher maxima. Figure 3 concerning Cycle II is apparently an anomaly, with each site showing a leveling off at about the twelfth day. Field notes for July 29 and July 30 show that the stream was exceptionally turbid, with much vegetative debris, although water levels were up only one inch. Maximum current velocities were measured on the afternoon of July 28, reaching 4.55 feet per second at Site 1, Station B. These conditions undoubtedly arose from the opening of the dam in Williamston. The high turbidity reduced the available light, while the vegetative debris and molar particles caused attritional losses.

The absence of a leveling off in the riffle situation maxima except occasionally at Site 1 indicates that a longer period of time is needed to reach equilibrium levels. Since this technique involves the measurement of an accumulated standing crop over a period of time, it is felt that even at Site 1, Station B, which characteristically was lower, the inhibitory effect which has been attributed to the higher velocities is only apparent. During the fall of 1959, the steel fence posts were pushed over by duck hunters and were impossible to retrieve due to high water. In the spring of 1960 the shingles which had remained attached through the fall and winter (October 8, 1959-May 17, 1960) were recovered. One shingle from each site in the riffle was extracted and measured on the Klett-Summerson colorimeter. The observed values in uncorrected Klett units were as follows: Site 1, 806; Site 2, 787; Site 3, 819. These values were not converted to AA x 10^3 units, but are certainly of the same order. The writer feels that such values would be obtained if a longer time were allowed and that small differences would occur even at Site 1, which would eventually reach the same maximum standing crop as at the other two sites. Clarke (1946) describes the relation betweem standing crop and rate of growth of population. Although the rates of production may differ, he shows that the equilibrium level may eventually be the same over a longer period of time. At this point no rate of growth can be determined from the magnitude of the standing crop.

This study does not show an equilibrium level except for the pool. This level appears to be between 550 AA x 10^3

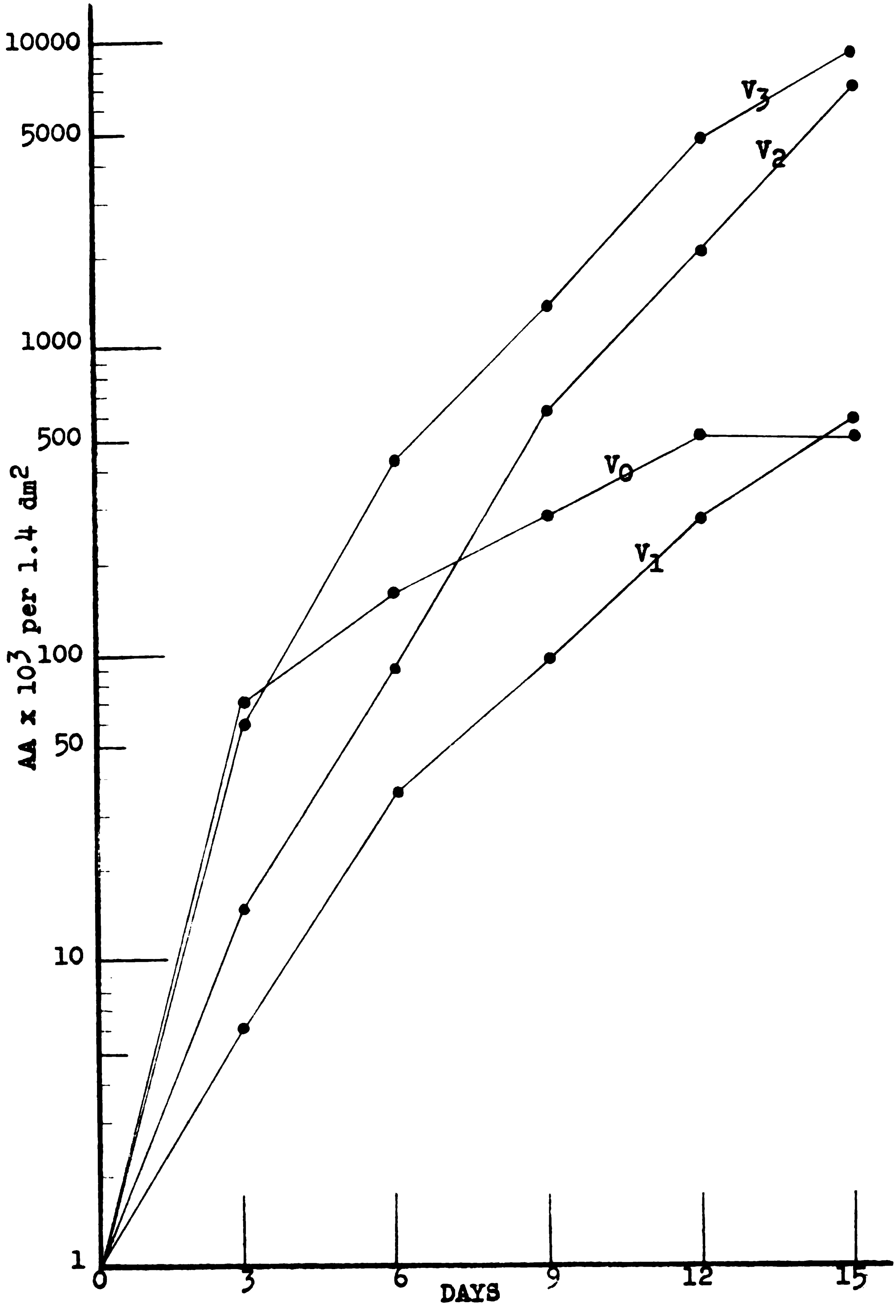
and 600 AA x 10^3 in the pool. The absence of an equilibrium level for the riffle may actually present more useful information. Past studies using artificial substrates tended to rely on accumulated standing crop as an index to productivity. Although it is true that accumulated standing crop was used as a measurement in this study, the rate of growth (productivity) can be determined from the changes over a period of three days. By comparison of these growth curves then, the riffle appears to be more productive than the pool with larger attained maxima and a more rapid rate of growth. The grand average graph, Figure 9, shows the aforementioned to be true.

From Figures 10-16 it can be shown that the transplants from the pool to the riffle also were affected by the "physiological richness" of the riffle. The values for the change between the unmatched shingles are derived from the algebraic difference between the controls used in the matched pair. The value for the change between the transplant and the control was arrived at similarly. Both values represent the changes over the same period. The values of the pool change were averaged since they were generally quite close, and compared to the change which occurred between the control member of the matched pair and its "transplanted" counterpart for each site.

In the early stages, three to six days, growth increase of the transplants was generally behind that of the controls in the pool. As the period of accumulation in the pool was

Figure 9. Grand average of accumulation of phytopigments measured as AA x 10^3 against time at V_0, V_1, V_2, V_3.

Figure 9


AA x 10^3 per 1.4 dm^2
10000
5000
1000
500
100
50
10
1
0
3
6
9
12
15
DAYS
V_3
V_2
V_0
V_1

Figures 10-16. Changes in accumulation of phytopigments measured as AA x 10^3 per 1.4 square decimeters after "transplant". Pool values from average change between controls over same three day period. Riffle values from change between control and "transplant".

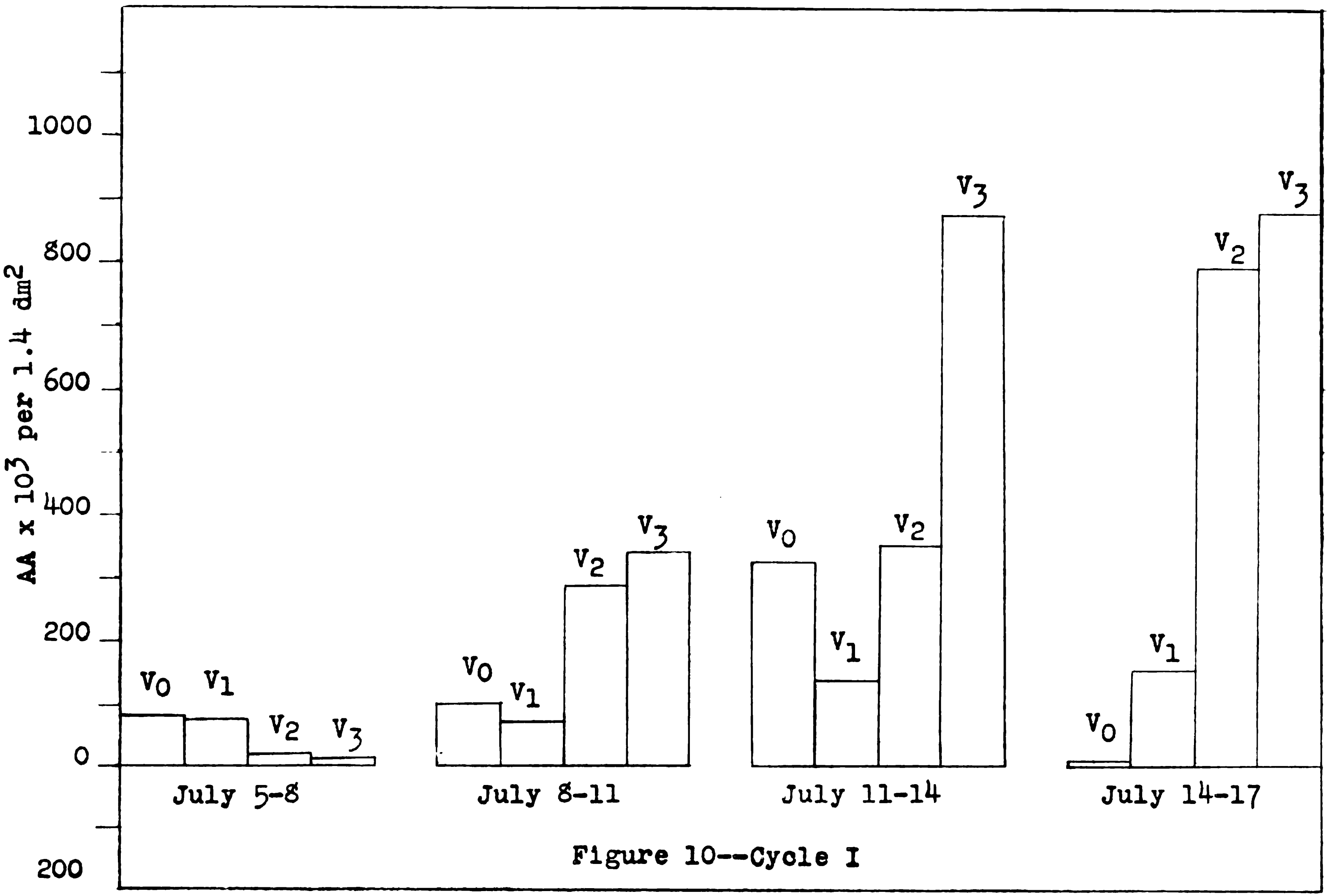


Figure 10--Cycle I

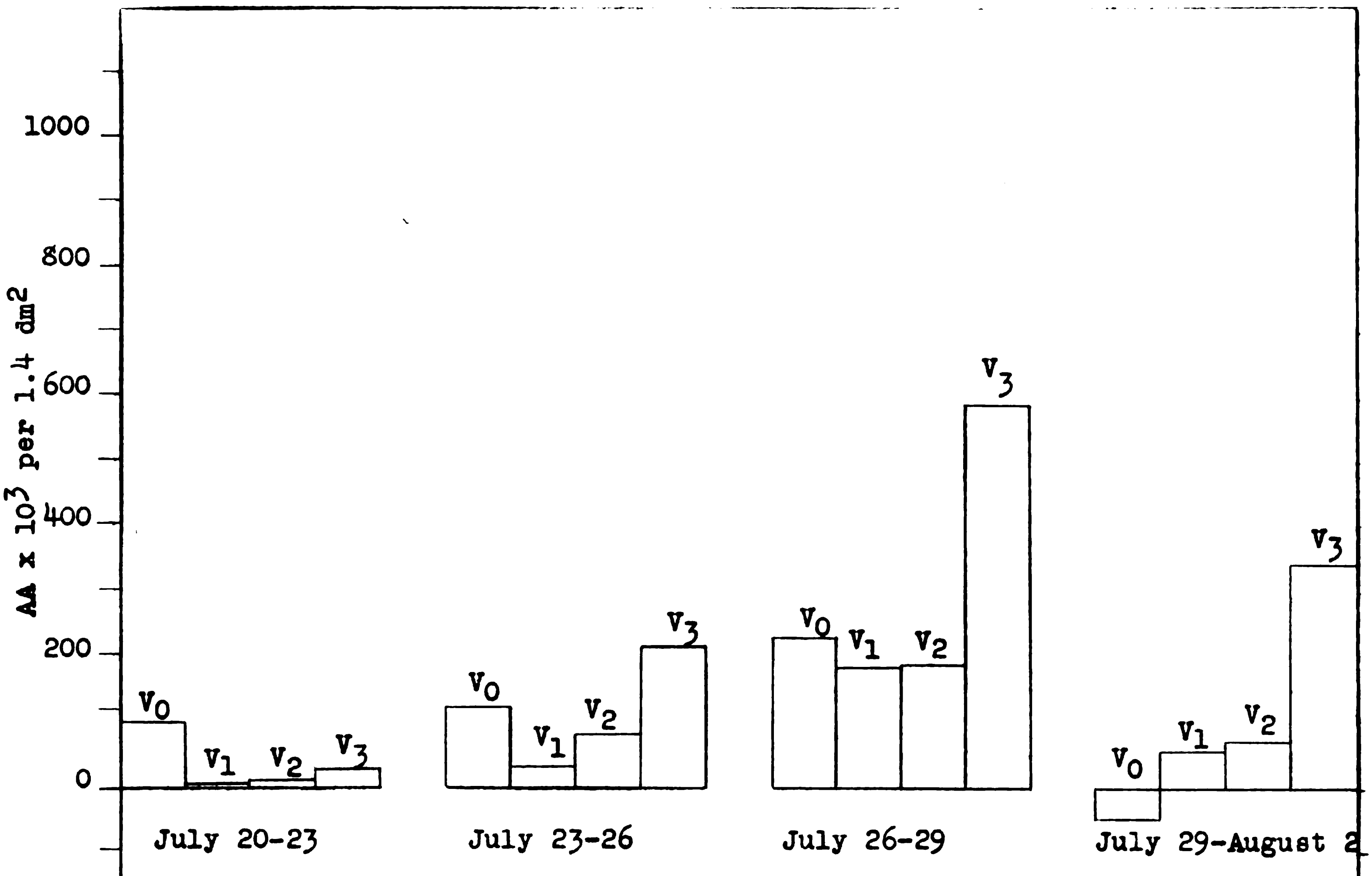


Figure 11--Cycle II

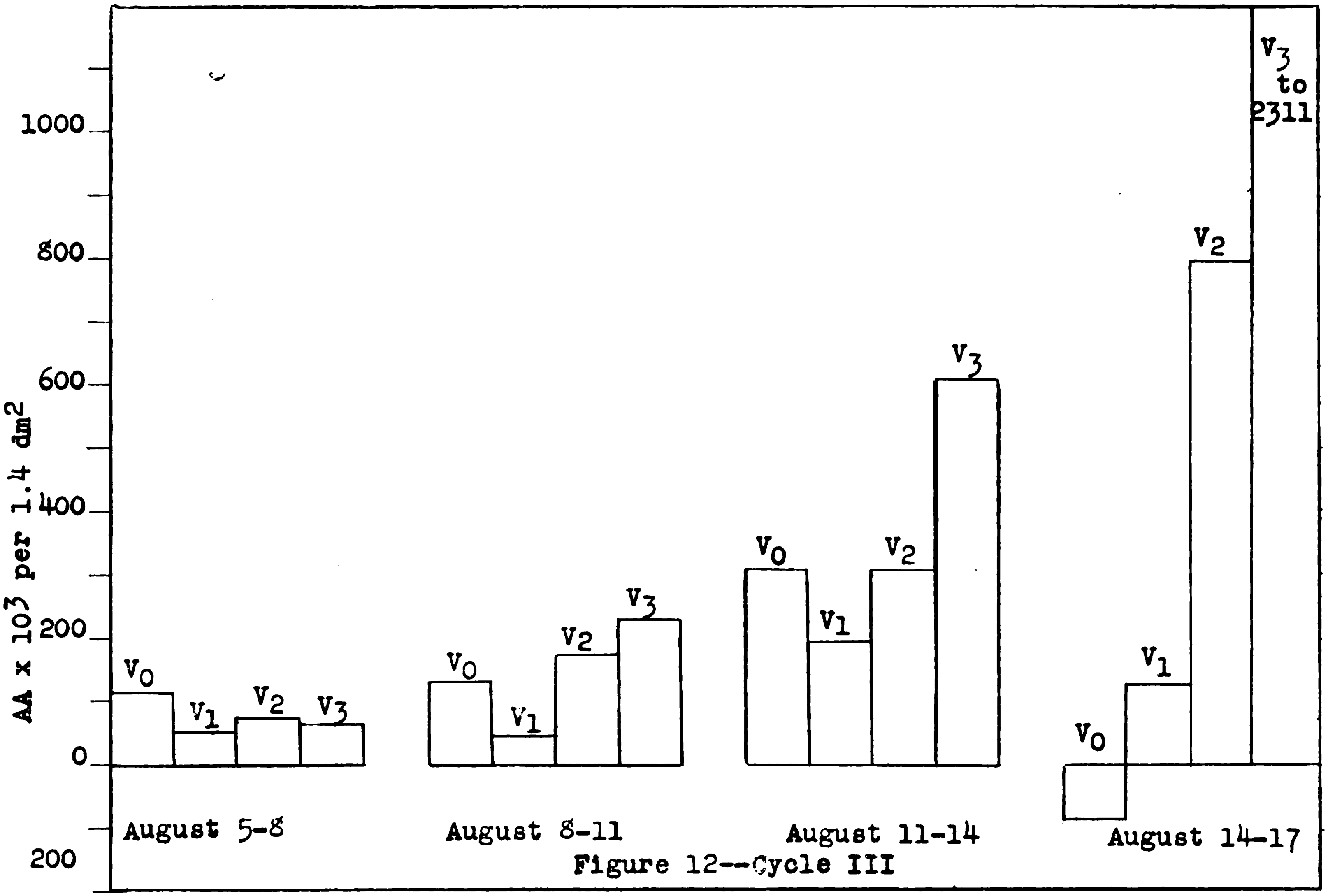


Figure 12--Cycle III

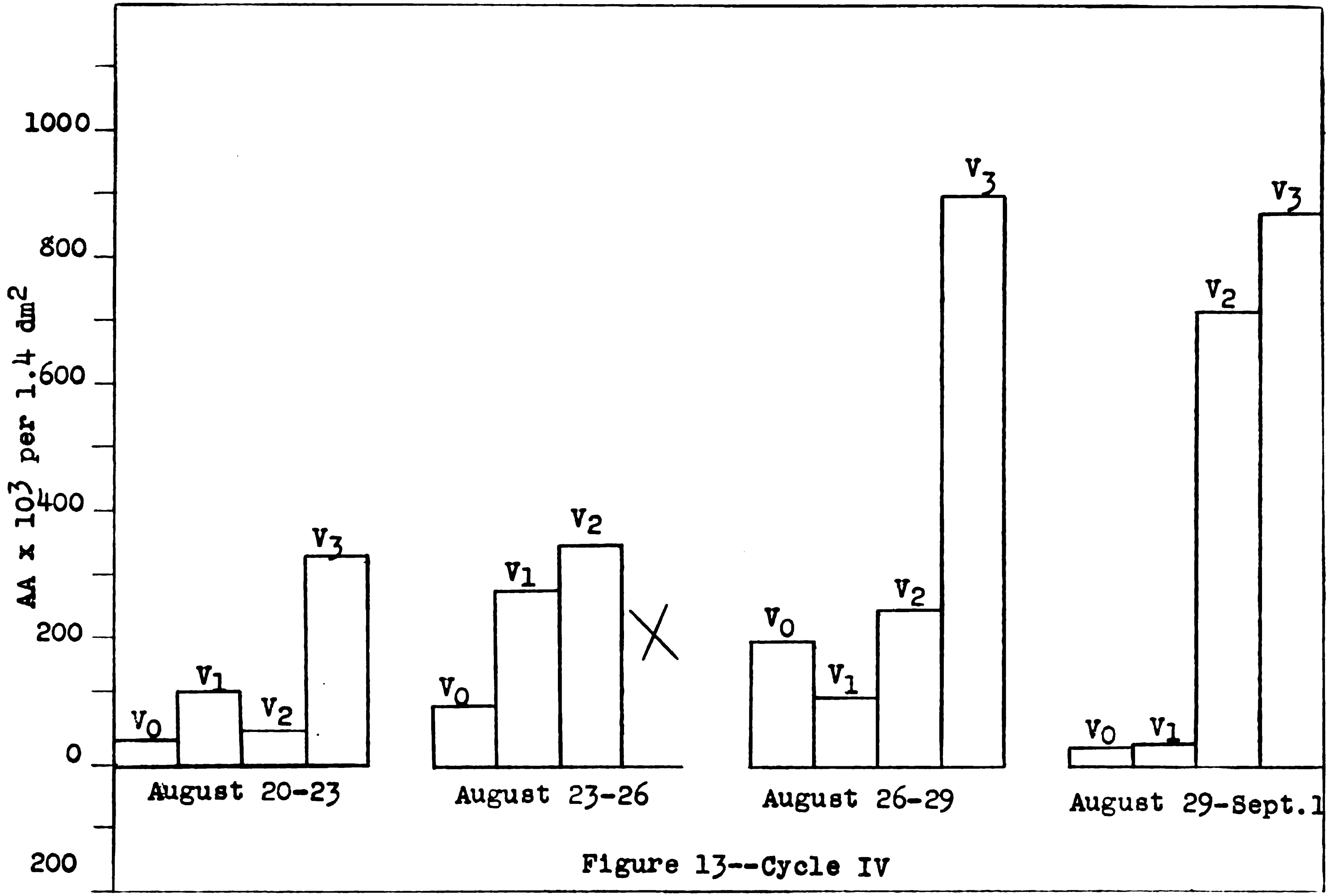


Figure 13--Cycle IV

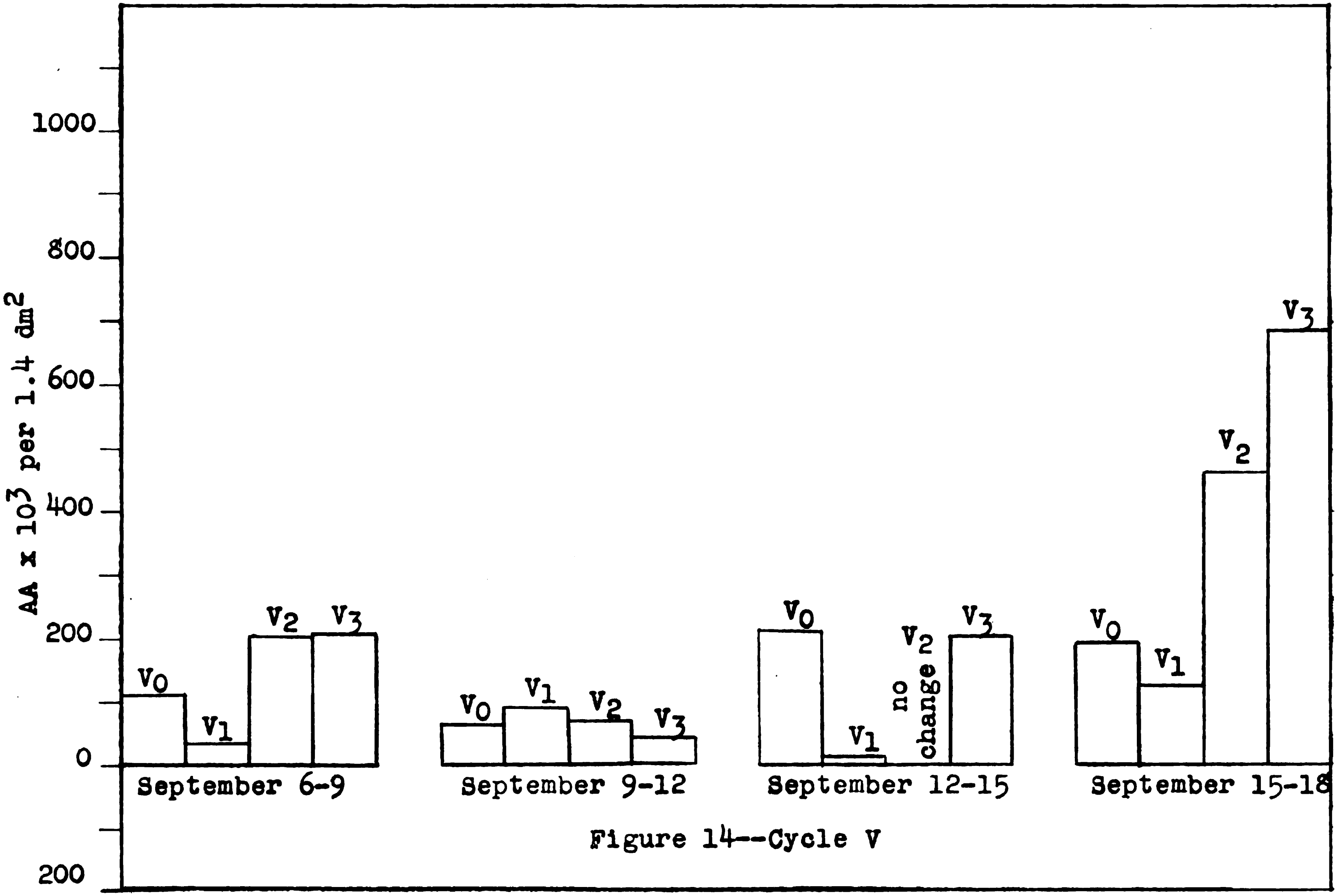


Figure 14--Cycle V

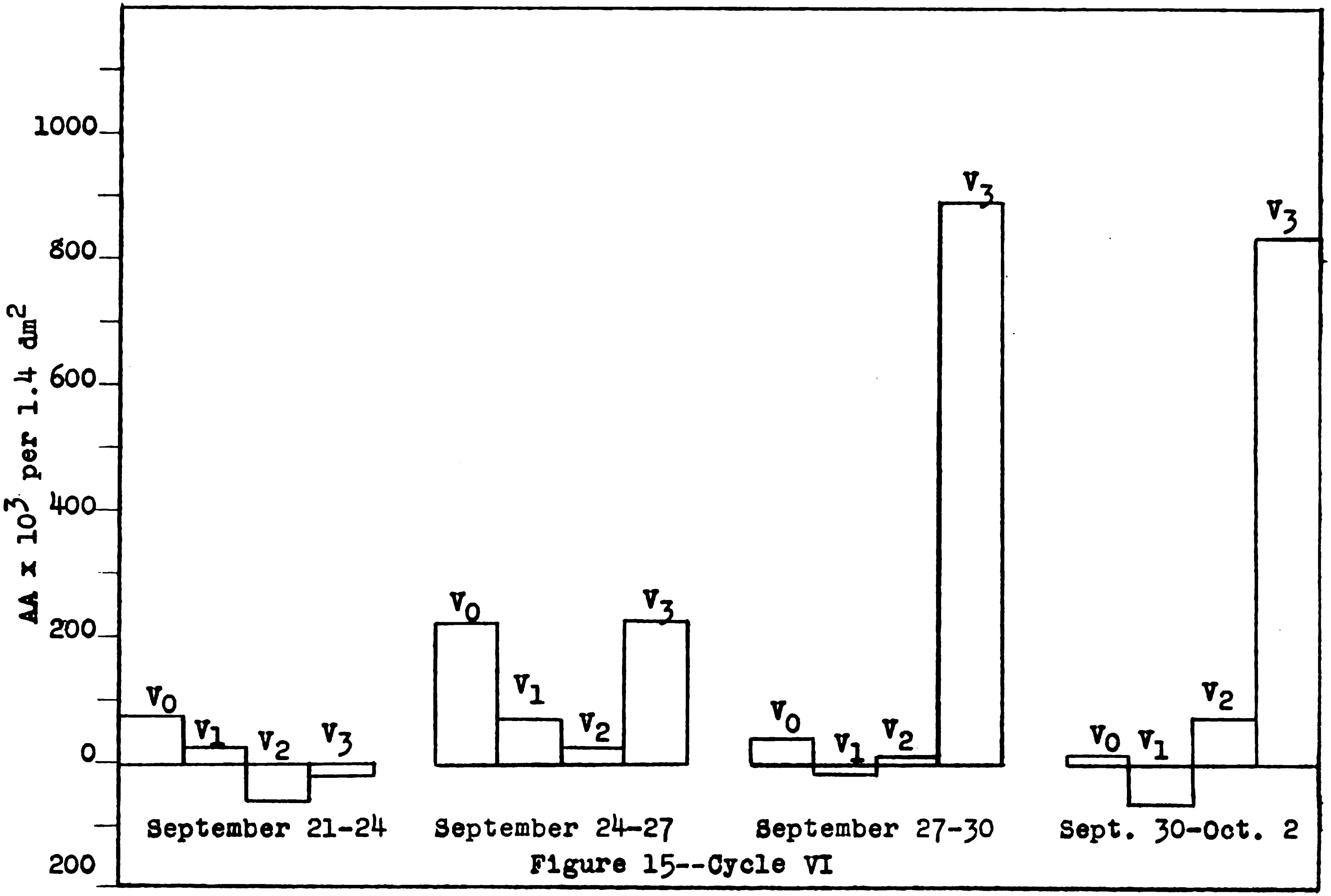


Figure 15--Cycle VI

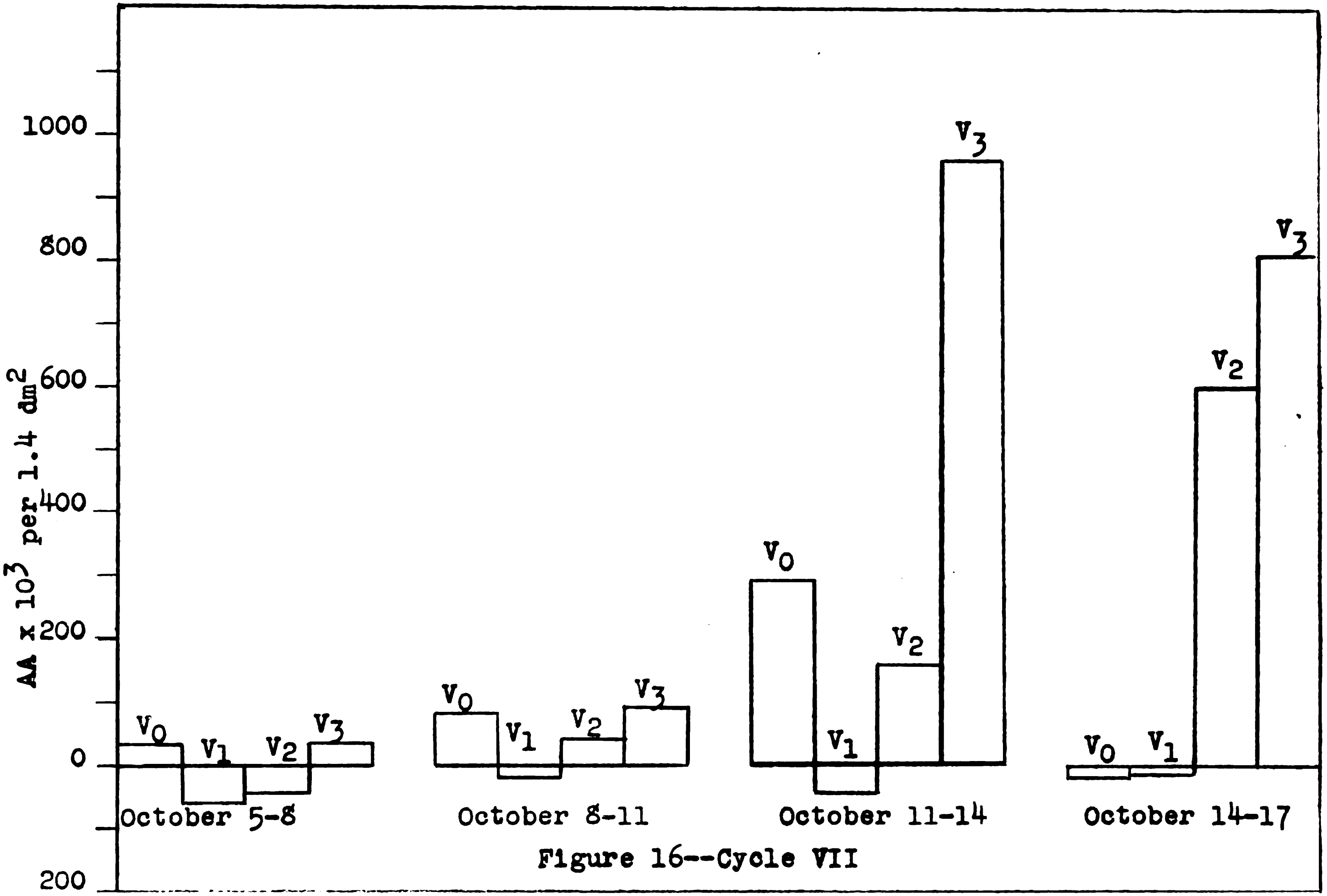


Figure 16--Cycle VII

increased and larger standing crops transplanted, increases in productivity resulted. Not only was the rate increased, but also higher maxima were attained. No changes were noted in community structure in the transplants, but this may have occurred. The effects of "physiological richness" may overcome the ability of the species in the pool to make secure purchase on the substrate. After the whole substrate has been colonized in the pool, attritional losses may be reduced when moved to the riffle or the increased diffusion gradient may provide more nutrients and gases for increased reproduction and cellular growth. Blum (1956) notes that certain algae which cannot live in rapid current in the spring and fall seasons, and must live in slow water during these seasons, are able to attain good growth in the riffles in the summer.

Although some organisms have inherent current demands as Welch (1952), Blum (1956), and others show, certain organisms appear to be able to produce increased growth in the current, but are incapable initially of colonizing a bare substrate successfully where excess velocities occur. Once having successfully established themselves in relatively quiet situations however, they are capable of increased productivity in the riffle environment. This is demonstrated by the slow or negative growth shown in the transplants of three and six days from the pool, and the increasing growth as the age of the transplanted community increases. Since no transplants were made for longer than three days, it is possible that these organisms from the pool may have shown only initial rapid growth and might not have sustained it. Eventually these transplanted organisms would have been replaced by other organisms which can compete more successfully.

Even among the transplants from the pool to the riffle, the effects of different velocities can be seen. Generally, the increase in production is less in V_1 than in the less rapid currents of V_2 and V_3. Much of this difference may have been derived from attritional losses from the transplanted pool community. It is possible that productivity is as high on the V_1 transplanted shingles as on the others, but as soon as growth and multiplication occur, the cells are swept off the substrate.

The one qualitative study made on October 14, 1960 shows that the communities differed. The organisms found in the pool were characterized by two diatoms, <u>Navicula cryptocephala</u> and <u>Synedra</u> <u>ulna</u>, with the last named species occurring in 76 percent of the fields examined. In the riffles, the filamentous diatom <u>Melosira</u> <u>sp</u>. occurred in 100 percent of the fields examined. No other species were seen in the riffle samples. The presence of <u>S</u>. <u>ulna</u> and <u>N</u>. <u>cryptocephala</u> throughout the summer as characteristic species of the pool community is unknown, but Peters' (1959) study showed this community to be a dominant for much of the summer and early fall. <u>Melosira</u> <u>sp</u>., however, was present all through the study. This species grew in dense, brown, gelatinous masses on all the riffle shingles and was easily recognized in the field.

There is no reason to believe that the phytopigments derived from the different species should exhibit any wide differences. Some differences, both quantitative and qualitative, certainly exist, but evidence of these differences between species is lacking in the literature. Riley (1938) discusses the pigments of the various classes of algae, but points out that differences exist not only between classes, but also may exist within a single organism due to its physiological state. Gardiner (1943) seems to feel that the phytopigment extract method depends for its reliability on the constancy of the ratios of common pigments in different classes and in the different seasons. Tucker (1949) establishes a high correlation between number of phytoplankters and phytopigment density in samples containing over 90 percent diatoms. Little published research is available for phytopigment quantity and/or quality in taxonomic groups lower than classes. Strickland (1960) lists phytopigments present in the various classes of algae and discusses the problems involved in determining the amount of pigments present in the classes. He states that the pigments found in the various classes have probably evolved before many orders and genera. All genera encountered in this study are of the Bacillariophyceae and any differences in phytopigments that might exist are considered to be only transitory and not real, but rather due to the age of the algae involved, inhibition or exhibition by sunlight, or other ecological factors affecting their physiological state with regard to their phytopigments.

Neel (1951) states that greater consumption of nutrients occurs in the rapids than in the pool. It would follow that this is true, particularly since the nutrients are in greater "physiological" abundance. That is, more individual molecules are contacted by an individual organism growing in the riffles over the same period of time. The rate of consumption then, would depend on the organisms' ability to utilize these nutrients, the particular biota present, and their biomass. In the case of the filamentous diatom, Melosira, it seems probable that volumes of water essentially stationary, but in close contact with moving water are enclosed within the filaments. This moving water then can renew the supplies of nutrients and gases. Although Ruttner's "physiological richness" appears to be true, it does not offer a real explanation of the differences exhibited. Blum (1953) in his work on the Saline River in Michigan, states that no differences in oxygen content between riffles and pools were detected either day or night. It has not been demonstrated that differences in nutrient or gas levels exist between pool and riffle situations, but it seems obvious that over a given period of time more nutrients and gases are presented to a given community of algae in a riffle. Hence if they have the ability to utilize the nutrients in reproduction and growth, then the riffle should be more

productive. Whitford (1960) feels that the difference is a physical one and that Ruttner's discussion of "physiological richness" is correct, but does not go far enough. Ferrell, et al. (1955) used both organic and inorganic molecules to show an increased diffusion gradient in water velocities greater than 0.5 feet per second. This current is able to reduce the distance between the cell wall and the nutrients involved to less than 0.25 millimeters. The greater this proximity, the more able the cell is to capture the molecule for use in its metabolism. It follows from Whitford's (1960) study, then, that the higher the current velocity, the higher the diffusion gradient, and hence increased growth. This study does not demonstrate this and the writer feels that excessive velocity might cause greater attritional losses in spite of increased growth rate, but that at some time their equilibrium level might be similar..

Another ecological factor which might have produced the better growth of the riffle aufwuchs are differences in light quality. No evidence can be presented concerning the exact amount of light penetrating to the substrates in the pool or riffle. Both received approximately the same amount and time of shading. Butcher (1946) noted that the number of algae appearing on his submersed slides was always greater when the amount of sunlight was greater. Both stations received the full noon sun for two to three hours throughout the summer. More exact measurements might have shown differences in light intensity, but the difference in growth rate cannot be attributed only to light quality.

Other ecological factors such as turbidity, depth and water temperature offer little explanation for the differences exhibited. The depth at both stations was essentially the same and all shingles were placed at the same depth from the surface (0.8). The proximity of the stations rules out major differences in either water temperature or turbidity. Peters (1959) found temperatures at a station upstream to vary less than one degree from that on the thermograph positioned between the two stations of this study.

The writer feels that if the length of the cycles were increased and "transplants" made from the riffle to the pool, a more complete and useful study might result. It seems clear, however, that any future studies using artificial substrates as a device for gaining information on productivity should take into account current velocities which exceed 1.0 feet per second.

SUMMARY

1. Differences in growth rate and attained maxima between aufwuchs communities in pool and riffle situations on artificial substrates were demonstrated. The riffle, in general, had a faster growth rate and attained higher maxima than the pool.
2. Aufwuchs communities grown in the pool for 3, 6, 9, or 12 days were transplanted to the riffle for three days. Only slight or negative growth were observed from the 3 and 6 day pool-grown transplants. The 9 and 12 day transplants showed greatly increased growth after three days in the current.
3. Differences in growth rate cannot be attributed to differences in gas content, nutrients, turbidity, depth, temperature or community structure. Light quality and intensity may have varied, but both received approximately the same amount of shading and full sun.
4. Differences exhibited are, therefore, attributed to the effects of a current with its attendant "physiological richness" and to an increased diffusion gradient between the diatom cell walls and a particular nutrient or gas molecule, which puts this molecule closer to the cell and as a consequence, becomes more available for metabolic use.
5. Any future studies using artificial substrates for productivity studies should take into account the presence or absence of a current above 1.0 feet per second.

Appendix I

Matched pairs tests

Test 1 - Six days

Test 2 - Nine days

$AAx10^3$		d	d^2
RIGHT	LEFT	(R-L)	$(R-L)^2$
85	77	8	64
86	90	- 4	16
103	103	0	0
104	100	4	16
86	82	4	16
122	125	- 3	9
110	91	19	361
105	106	- 1	1
113	107	6	36
114	116	- 2	4
124	138	-14	256
89	99	-10	100
140	132	8	64
141	126	15	225
110	106	4	16
		34	1084

$$\bar{d} = \frac{\epsilon d}{n} = 2.267$$

$$s_{\bar{d}} = \sqrt{\frac{\epsilon d^2 - \frac{(\epsilon d)^2}{n}}{(n)(n-1)}}$$

$$\frac{\epsilon i^2}{n} = \frac{1084}{15} = 76.267$$

$$= \frac{1084 - 77.067}{(14)(15)}$$

$$= 2.190$$

$$t = \frac{\bar{d}-0}{s_{\bar{d}}} = \frac{2.267-0}{2.190} = 1.035$$

No significant difference at five per cent level.

SIX DAY TEST

$AA \times 10^3$		d	d^2
RIGHT	LEFT	(R-L)	$(R-L)^2$
230	226	4	16
220	222	- 2	4
229	221	8	64
258	249	9	81
243	253	-10	100
247	228	19	361
229	234	- 5	25
222	229	- 7	49
226	218	8	64
216	222	- 6	36
		18	800

$$\bar{d} = \frac{\Sigma d}{n} = \frac{18}{10} = 1.800$$

$$s_{\bar{d}} = \sqrt{\frac{\Sigma d^2 - \frac{(\Sigma d)^2}{n}}{(n)\ (n-1)}} = \sqrt{\frac{800-\ 32.4}{90}}$$

$$\frac{\Sigma d^2}{n} = \frac{800}{10} = 80$$

$$= 2.921$$

$$t = \frac{\bar{d}-0}{s_{\bar{d}}} = \frac{1.800-0}{2.921} = 0.616$$

No significant difference at 5 per cent level.

NINE DAY TEST

APPENDIX II--CURRENT DATA

Station and Site	Side	Velocity ft./sec.	Average Velocity For Site ft./sec.	Date
1B	R	4.10	4.17	July 3, 1960
"	L	4.23		
2B	R	3.03	3.06	
"	L	3.08		
3B	R	1.67	1.63	
"	L	1.59		
1A	R	0.525	0.519	
"	L	0.513		
2A	R	0.568	0.573	
"	L	0.578		
3A	R	0.564	0.566	
"	L	0.568		
1B	R	4.36	4.41	July 13, 1960
"	L	4.45		
2B	R	2.68	2.66	
"	L	2.63		
3B	R	1.29	1.31	
"	L	1.32		
1A	R	0.525	0.532	
"	L	0.538		
2A	R	0.566	0.572	
"	L	0.578		
3A	R	0.559	0.590	
"	L	0.621		
1B	R	4.35	4.40	July 16, 1960
"	L	4.45		
2B	R	2.68	2.65	
"	L	2.63		
3B	R	1.29	1.31	
"	L	1.32		
1A	R	0.717	0.711	
"	L	0.705		
2A	R	0.621	0.629	
"	L	0.638		
3A	R	0.808	0.816	
"	L	0.823		
1B	R	4.55	4.47	July 28, 1960
"	L	4.38		
2B	R	3.19	3.17	
"	L	3.15		
3B	R	1.73	1.70	
"	L	1.67		
1A	R	0.731	0.750	
"	L	0.768		
2A	R	0.814	0.828	
"	L	0.842		
3A	R	0.846	0.856	
"	L	0.866		

APPENDIX II--CURRENT DATA, Cont.

Station and Site	Side	Velocity ft./sec.	Average Velocity For Site ft./sec.	Date
1B	R	3.82	3.83	August 6, 1960
"	L	3.85		
2B	R	2.90	2.87	
"	L	2.84		
3B	R	1.39	1.36	
"	L	1.32		
1A	R	0.537	0.531	
"	L	0.525		
2A	R	0.559	0.585	
"	L	0.612		
3A	R	0.638	0.627	
"	L	0.616		
1B	R	3.33	3.30	August 8, 1960
"	L	3.28		
2B	R	1.87	1.83	
"	L	1.79		
3B	R	1.32	1.37	
"	L	1.43		
1A	R	0.509	0.514	
"	L	0.522		
2A	R	0.516	0.523	
"	L	0.530		
3A	R	0.541	0.548	
"	L	0.555		
1B	R	3.04	3.05	August 24, 1960
"	L	3.06		
2B	R	2.01	1.89	
"	L	1.77		
3B	R	1.36	1.30	
"	L	1.23		
1A	R	0.211	0.191	
"	L	0.162		
2A	R	0.361	0.391	
"	L	0.421		
3A	R	0.283	0.382	
"	L	0.481		
1B	R	3.91	3.82	September 5, 1960
"	L	3.74		
2B	R	2.78	2.73	
"	L	2.69		
3B	R	1.69	1.70	
"	L	1.71		
1A	R	0.561	0.541	
"	L	0.521		
2A	R	0.599	0.604	
"	L	0.608		
3A	R	0.624	0.631	
"	L	0.638		

APPENDIX II--CURRENT DATA, Cont.

Station and Site	Side	Velocity ft./sec.	Average Velocity For Site ft./sec.	Date
1B	R	4.20	4.10	September 22, 1960
"	L	4.00		
2B	R	2.87	2.84	
"	L	2.81		
3B	R	1.89	1.91	
"	L	1.93		
1A	R	0.616	0.625	
"	L	0.633		
2A	R	0.671	0.657	
"	L	0.643		
3A	R	0.666	0.683	
"	L	0.700		
1B	R	3.30	3.17	October 1, 1960
"	L	3.04		
2B	R	2.04	1.91	
"	L	1.79		
3B	R	1.47	1.40	
"	L	1.34		
1A	R	0.324	0.345	
"	L	0.366		
2A	R	0.369	0.371	
"	L	0.393		
3A	R	0.404	0.396	
"	L	0.388		

Appendix III

Phytopigment extract data

Table I. Changes in phytopigment extract measured as AA x 10^3 between control member of matched pairs from pool. Includes change in AA x 10^3, percent change, and logarithm of percent change.

Table I

CYCLE I

Days	Site	Change AAx10^3	% Change	Log % Change
0-3	1	81	8100	3.00849
	2	103	10300	4.01284
	3	97	9700	3.98677
3-6	1	98	120.0	2.07918
	2	82	78.8	1.89653
	3	56	57.1	1.75664
6-9	1	88	49.0	1.69020
	2	109	58.6	1.76790
	3	101	65.5	1.81624
9-12	1	252	94.0	1.97313
	2	305	103.3	2.01410
	3	415	162.7	2.21139
12-15	1	9	1.7	0.23045
	2	53	8.8	0.94448
	3	- 47	- 4.9	0.69020

CYCLE II

0-3	1	111	11100	4.04532
	2	117	11700	4.06819
	3	107	10700	4.02938
3-6	1	110	98.2	1.99211
	2	100	84.7	1.92788
	3	92	85.1	1.92993
6-9	1	37	16.6	1.22011
	2	188	86.2	1.93551
	3	137	68.5	1.83569
9-12	1	267	64.4	1.80889
	2	234	57.6	1.76042
	3	192	56.9	1.75511
12-15	1	- 12	- 1.9	0.27875
	2	-152	- 23.7	1.37475
	3	24	4.7	0.67210

CYCLE III

0-3	1	97	9700	3.98677
	2	73	7300	3.86332
	3	76	7600	3.88081
3-6	1	110	112.2	2.04999
	2	124	167.5	2.22401
	3	112	147.3	2.16820
6-9	1	47	22.5	1.35218
	2	174	87.8	1.94349
	3	230	122.3	2.08743

Table I Cont.

CYCLE III Cont.

Days	Site	Change AAx10^3	% Change	Log % Change
9-12	1	330	129.4	2.11193
	2	254	68.2	1.83378
	3	349	83.4	1.92117
12-15	1	-101	- 17.2	1.23553
	2	- 49	- 7.8	0.89209
	3	-106	- 14.9	1.17319

CYCLE IV

0-3	1	81	8100	3.90849
	2	67	6700	3.82607
	3	93	9300	3.96848
3-6	1	40	48.7	1.68753
	2	42	61.7	1.79029
	3	56	59.5	1.77452
6-9	1	167	136.8	2.14239
	2	88	80.0	1.90309
	3	32	21.3	1.32838
9-12	1	227	78.5	1.89487
	2	217	109.5	2.03941
	3	149	119.2	2.07628
12-15	1	- 33	- 6.3	0.79034
	2	48	11.5	1.06070
	3	75	22.6	1.35411

CYCLE V

0-3	1	45	4500	3.65321
	2	55	5500	3.74036
	3	51	5100	3.70557
3-6	1	86	208.6	2.31931
	2	122	217.8	2.33806
	3	112	215.3	2.33304
6-9	1	74	52.1	1.71684
	2	92	117.9	2.07151
	3	26	15.8	1.19866
9-12	1	316	146.2	2.16495
	2	133	78.2	1.89321
	3	198	52.1	1.71684
12-15	1	276	50.1	1.69984
	2	142	79.8	1.90200
	3	167	57.4	1.75891

Table I Cont.

CYCLE VI

Days	Site	Change AAx10^3	% Change	Log % Change
0-3	1	39	3900	3.59106
	2	91	9100	3.95904
	3	93	9300	3.96848
3-6	1	54	135.0	2.13033
	2	96	104.3	2.01828
	3	82	87.2	1.94052
6-9	1	237	126.0	2.10037
	2	252	134.0	2.12710
	3	176	100.0	2.00000
9-12	1	61	18.4	1.26482
	2	15	11.8	1.07188
	3	44	12.5	1.09691
12-15	1	6	1.5	0.17609
	2	13	2.8	0.44716
	3	15	3.7	0.56820

CYCLE VII

Days	Site	Change AAx10^3	% Change	Log % Change
0-3	1	77	7700	3.88649
	2	71	7100	3.85126
	3	65	6500	3.81291
3-6	1	44	56.4	1.75128
	2	20	27.7	1.44248
	3	28	42.4	1.62737
6-9	1	125	102.4	2.01030
	2	116	126.0	2.10037
	3	165	175.5	2.24428
9-12	1	297	120.2	2.07990
	2	257	123.5	2.09167
	3	326	125.8	2.09968
12-15	1	- 46	- 8.4	0.92428
	2	- 21	- 4.5	0.65321
	3	2	0.34	-1.47712

Table II. Change in phytopigment extract between riffle controls measured as AA x 10^3. Controls averaged for each site and day. Includes change in AA x 10^3, percent change, and logarithm of percent change.

Table II

CYCLE I

Days	Site	Change AAx10^{3}	% Change	Log % Change
0-3	1	6	600	2.77815
	2	9	900	2.95424
	3	40	4000	3.60206
3-6	1	24	342.8	2.53504
	2	32	320.0	2.50515
	3	47	114.2	2.05767
6-9	1	31	100	2.00000
	2	134	319.0	2.50379
	3	179	203.4	2.30835
9-12	1	136	219.3	2.34104
	2	172	97.7	1.98989
	3	3067	1149	3.059791
12-15	1	310	156.5	2.19451
	2	1767	507.7	2.70561
	3	165	4.90	0.69020

CYCLE II

Days	Site	Change AAx10^{3}	% Change	Log % Change
0-3	1	4	400	2.60206
	2	18	1800	3.25527
	3	118	11800	4.07188
3-6	1	46	92.0	1.96379
	2	48	252.6	2.40243
	3	269	226.0	2.35411
6-9	1	73	143.1	2.15564
	2	213	317.9	2.50229
	3	230	59.2	1.77232
9-12	1	284	222.0	2.35984
	2	742	263.0	2.41996
	3	1262	204.2	2.31006
12-15	1	37	9.0	0.95424
	2	46	4.4	0.64345
	3	945	50.2	1.70070

CYCLE III

Days	Site	Change AAx10^{3}	% Change	Log % Change
0-3	1	1	50	1.69897
	2	16	1600	3.20412
	3	13	1300	3.11394
3-6	1	10	500	2.69897
	2	15	88.2	1.94547
	3	86	614.2	2.78831
6-9	1	24	200	2.30103
	2	66	206.2	2.31429
	3	459	459.0	2.66181

Table II Cont.

CYCLE III Cont.

Days	Site	Change $AA\times10^3$	% Change	Log % Change
9-12	1	209	580.5	2.76380
	2	314	320.4	2.50569
	3	3269	584.7	2.76693
12-15	1	210	85.7	1.93298
	2	4073	988.5	2.99498
	3	4495	109.5	2.03941

CYCLE IV

Days	Site	Change $AA\times10^3$	% Change	Log % Change
0-3	1	11	1100	3.04139
	2	12	1200	3.07918
	3	114	11400	4.05690
3-6	1	25	208.3	2.31869
	2	179	1377	4.13893
	3	1184	1030	4.01284
6-9	1	106	286.4	2.45697
	2	1485	773.4	2.88840
	3	711	54.7	1.73799
9-12	1	247	172.7	2.23729
	2	18	1.0	0.00000
	3	1495	74.3	1.87099
12-15	1	501	128.4	2.10857
	2	6945	409.7	2.61247
	3	7920	225.9	2.35392

CYCLE V

Days	Site	Change $AA\times10^3$	% Change	Log % Change
0-3	1	0	0.00	
	2	18	1800	3.25527
	3	53	5300	3.72428
3-6	1	51	5100	3.70757
	2	176	926.3	2.96675
	3	745	1380	3.13988
6-9	1	35	67.3	1.82802
	2	1140	584.6	2.76686
	3	2680	335.4	2.52556
9-12	1	122	158.4	2.19976
	2	2849	213.4	2.32919
	3	2496	71.7	1.85552
12-15	1	264	126.3	2.10140
	2	10816	258.5	2.41246
	3	9025	151.0	1.17898

Table II Cont.

CYCLE VI

Days	Site	Change AAx10^3	% Change	Log % Change
0-3	1	10	1000	3.00000
	2	18	1800	3.25527
	3	63	6300	3.79934
3-6	1	25	227.3	2.35660
	2	19	100.0	2.00000
	3	94	146.8	2.16673
6-9	1	40	111.1	2.04571
	2	195	513.1	2.71020
	3	2490	1576	3.19756
9-12	1	65	85.5	1.93197
	2	3666	1573	3.19673
	3	8302	313.5	2.49624
12-15	1	55	39.0	1.59106
	2	1666	42.7	1.63043
	3	1300	11.8	1.07188

CYCLE VII

Days	Site	Change AAx10^3	% Change	Log % Change
0-3	1	6	600	2.77815
	2	12	1200	3.07918
	3	17	1700	3.23045
3-6	1	12	171.4	2.23401
	2	38	292.3	2.46583
	3	50	277.7	2.44358
6-9	1	124	652.6	2.81465
	2	305	598.0	2.77670
	3	399	586.7	2.76842
9-12	1	174	121.6	2.08493
	2	614	172.4	2.23654
	3	1063	227.6	2.35717
12-15	1	551	173.8	2.24005
	2	7105	732.4	2.86475
	3	8180	534.6	2.72803

Table III. Change in phytopigment measured as AA x 10^3 between control from pool and transplant from pool to riffle. Includes change in AA x 10^3, percent change, logarithm of percent change.

Table III

CYCLE I

Days	Site	Change AAx10^3	% Change	Log % Change
3-6	1	70	85.3	1.93095
	2	18	17.3	1.23805
	3	10	10.2	1.00860
6-9	1	69	38.4	1.58433
	2	284	152.6	2.18355
	3	338	219.5	2.34134
9-12	1	135	50.4	1.70243
	2	350	114.9	2.06032
	3	875	343.1	2.53542
12-15	1	150	28.8	1.45939
	2	788	131.3	2.11826
	3	874	130.4	2.11528

CYCLE II

3-6	1	8	7.1	0.85126
	2	14	11.8	1.07188
	3	30	27.7	1.44248
6-9	1	33	14.8	1.17026
	2	185	84.8	1.92840
	3	218	109.0	2.03743
9-12	1	186	71.8	1.85612
	2	189	46.5	1.66745
	3	591	175.3	2.24378
12-15	1	59	11.2	1.04961
	2	72	11.2	1.04961
	3	346	65.4	1.81558

CYCLE III

3-6	1	52	53.0	1.72428
	2	46	62.1	1.79309
	3	66	86.8	1.93852
6-9	1	47	22.5	1.35218
	2	232	117.1	2.06856
	3	230	122.3	2.08743
9-12	1	195	76.4	1.88309
	2	308	82.7	1.91751
	3	612	146.4	2.16554
12-15	1	127	21.7	1.33646
	2	798	127.4	1.10517
	3	2311	301.3	2.47900

Table III Cont.

CYCLE IV

Days	Site	Change AAx10^3	% Change	Log % Change
3-6	1	120	146.0	2.16435
	2	58	85.0	1.92942
	3	333	354.0	2.54900
6-9	1	277	227.1	2.35603
	2	350	318.1	2.50243
	3	---	-----	-------
9-12	1	107	37.0	1.56820
	2	247	124.7	2.09587
	3	898	493.4	2.69408
12-15	1	34	6.5	0.81291
	2	715	172.2	2.23603
	3	869	262.5	2.41913

CYCLE V

Days	Site	Change AAx10^3	% Change	Log % Change
3-6	1	32	69.5	1.84198
	2	201	358.9	2.55497
	3	207	398.0	2.59988
6-9	1	93	65.4	1.81558
	2	71	91.0	1.95904
	3	44	26.8	1.42878
9-12	1	14	6.4	0.80618
	2	- 100	- 37.0	1.56820
	3	202	106.3	2.02694
12-15	1	128	24.0	1.38021
	2	364	90.3	1.95569
	3	588	125.7	2.09934

CYCLE VI

Days	Site	Change AAx10^3	% Change	Log % Change
3-6	1	26	65.0	1.81291
	2	- 60	- 65.2	1.81425
	3	- 20	- 21.2	1.32634
6-9	1	70	74.4	1.87157
	2	24	12.7	1.10380
	3	228	129.5	2.11227
9-12	1	- 16	- 4.8	0.68124
	2	10	2.2	0.34242
	3	890	252.8	2.40106
12-15	1	- 64	- 16.3	1.21219
	2	- 138	- 30.3	1.48144
	3	832	210.1	2.32243

Table III Cont.

CYCLE VII

Days	Site	Change AAx10^3	% Change	Log % Change
3-6	1	- 60	- 76.9	1.88593
	2	- 48	- 66.7	1.82413
	3	34	51.5	1.71181
6-9	1	- 16	- 13.1	1.11727
	2	46	50.0	1.69897
	3	94	100.0	2.00000
9-12	1	- 45	- 18.2	1.26007
	2	160	76.9	1.88593
	3	955	368.7	2.56667
12-15	1	- 18	- 3.3	0.51851
	2	595	127.9	2.09687
	3	803	137.2	2.13735

Table IV. Raw data. Conversion to AA x 10^3 from Klett units as determined from Figure 1 times 2 x 10^3.

Table IV

CYCLE I July 2-17, 1960

Days	Code No.	Kletts	$AAx10^3$
0-3	11a	41	82
	21a	52	104
	31a	49	98
	11b	3	6
	12b	4	8
	21b	6	12
	22b	4	8
	31b	19	38
	32b	22	44
3-6	13a	90	180
	23a	93	186
	33a	77	154
	12a*	76	152
	22a*	61	122
	32a*	54	108
	13b	18	36
	14b	13	26
	23b	26	52
	24b	16	32
	33b	41	82
	34b	13	26
6-9	15a	131	268
	25a	140	295
	35a	125	255
	14a*	122	249
	24a*	188	470
	34a*	193	492
	15b	33	66
	16b	29	58
	25b	47	94
	26b	29	58
	35b	141	299
	36b	153	334
9-12	17a	200	520
	27a	214	600
	37a	226	670
	16a*	171	403
	26a*	223	645
	36a*	283	1130
	17b	102	204
	18b	96	192
	27b	168	392
	28b	142	303
	37b	394	3118
	38b	406	3550

CYCLE I Cont.

Days	Code No.	Kletts	$AAx10^3$
9-12	19a	205	550
	20a	197	508
	29a	211	685
	30a	218	620
	39a	214	600
	40a	227	665
	18a*	226	670
	28a*	304	1388
	38a*	316	1544
	19b	194	496
	20b	200	520
	29b	364	2430
	30b	334	1800
	39b	398	3328
	40b	410	3670

CYCLE II July 17-Aug. 2, 1960

Days	Code No.	Kletts	$AAx10^3$
0-3	12a	56	112
	22a	59	118
	32a	54	108
	11b	2	4
	12b	3	6
	21b	8	16
	22b	11	22
	31b	58	116
	32b	61	122
3-6	14a	111	222
	24a	109	218
	34a	100	200
	11a*	60	120
	21a*	66	132
	31a*	69	138
	13b	22	44
	14b	29	58
	23b	38	76
	24b	31	62
	33b	164	376
	34b	170	400
	12b,	0	0
	22b,	1	2
	32b,	5	10
6-9	16a	121	259
	26a	172	406
	36a	154	337

Table IV Cont.

CYCLE II Cont.

Days	Code No.	Kletts	AAx10^3
6-9	13a*	125	255
	23a*	171	403
	33a*	176	418
	15b	66	132
	16b	58	116
	25b	141	299
	26b	130	265
	35b	212	590
	36b	223	645
	14b$_1$	6	12
	24b$_1$	14	28
	34b$_1$	22	44
9-12	18a	201	526
	28a	222	640
	38a	202	529
	15a*	183	445
	25a*	213	595
	35a*	261	928
	17b	182	440
	18b	164	376
	27b	278	1080
	28b	266	968
	37b	332	1780
	38b	342	1980
	16b$_1$	1	2
	26b$_1$	9	18
	36b$_1$	16	32
12-15	19a	200	520
	20a	197	508
	29a	199	516
	30a	186	460
	39a	204	544
	40a	207	562
	17a*	211	585
	27a*	234	712
	37a*	255	875
	19b	191	484
	20b	172	406
	29b	282	1120
	30b	272	1020
	39b	382	2850
	40b	380	2800
	18b$_1$	2	4
	28b$_1$	11	22
	38b$_1$	32	64

CYCLE III Aug 2-17, 1960

Days	Code No.	Kletts	AAx10^3
0-3	11a	49	98
	21a	37	74
	31a	38	76
	11b	1	2
	12b	1	2
	21b	1	2
	22b	16	32
	31b	2	4
	32b	12	24
3-6	13a	104	208
	23a	99	198
	33a	94	188
	12a*	75	150
	22a*	60	120
	32a*	71	142
	13b	--	---
	14b	6	12
	23b	23	46
	24b	9	18
	33b	30	60
	34b	70	140
	11b$_1$	0	0
	21b$_1$	4	8
	31b$_1$	4	8
6-9	15a	125	255
	25a	163	372
	35a	176	418
	14a*	125	255
	24a*	180	430
	34a*	176	418
	15b	10	20
	16b	26	52
	25b	43	86
	26b	55	110
	35b	147	319
	36b	247	809
	13b$_1$	3	6
	23b$_1$	4	8
	33b$_1$	5	10
9-12	17a	211	585
	27a	218	626
	37a	241	767
	16a*	184	450
	26a*	230	680

Table IV Cont.

CYCLE III Cont.

Days	Code No.	Kletts	AAx10^3
9-12	36a*	273	1030
	17b	112	226
	18b	129	263
	27b	109	218
	28b	215	605
	37b	422	3880
	38b	425	3775
	15b$_1$	1	2
	25b$_1$	7	14
	35b$_1$	36	72
12-15	19a	203	538
	20a	180	430
	29a	216	610
	30a	204	544
	39a	211	585
	40a	237	736
	18a*	234	712
	28a*	307	1424
	38a*	392	3078
	19b	195	500
	20b	247	809
	29b	397	3170
	30b	467	5800
	39b	510	8015
	40b	518	8050
	17b$_1$	2	4
	27b$_1$	3	6
	37b$_1$	14	28

CYCLE IV Aug 17-Sept 1, 1960

Days	Code No.	Kletts	AAx10^3
0-3	12a	41	82
	22a	34	68
	32a	47	94
	11b	6	12
	12b	6	12
	21b	6	12
	22b	7	14
	31b	35	70
	32b	80	160
3-6	14a	61	122
	24a	55	110
	34a	75	150
	11a*	101	202
	21a*	63	126

CYCLE IV Cont.

Days	Code No.	Kletts	AAx10^3
3-6	31a*	179	427
	13b	22	44
	14b	15	30
	23b	73	146
	24b	116	237
	33b	258	902
	34b	326	1696
	12b	1	2
	22b	10	20
	32b	21	42
6-9	16a	138	289
	26a	99	198
	36a	91	182
	13a*	173	409
	23a*	186	460
	33a*	---	---
	15b	63	126
	16b	80	160
	25b	335	1810
	26b	316	1544
	35b	371	2620
	36b	305	1400
	14b$_1$	18	36
	24b$_1$	24	48
	34b$_1$	37	74
9-12	18a	199	516
	28a	175	415
	38a	152	331
	15a*	169	396
	25a*	183	445
	35a*	278	1080
	17b	165	380
	18b	170	400
	27b	333	1790
	28b	320	1600
	37b	490	4035
	38b	387	2975
	16b$_1$	7	14
	26b$_1$	22	44
	36b$_1$	38	76
12-15	19a	200	520
	20a	183	445
	29a	183	445
	30a	190	480
	39a	173	409

Table IV Cont.

CYCLE IV Cont.

Days	Code No.	Kletts	AAx10^3
12-15	40a	171	403
	17a*	205	550
	27a*	283	1130
	37a*	290	1200
	19b	250	830
	20b	264	952
	29b	510	8580
	30b	520	8700
	39b	574	11900
	40b	556	10950
	$18b_1$	11	22
	$28b_1$	14	28
	$38b_1$	42	84

CYCLE V Sept 3-18, 1960

Days	Code No.	Kletts	AAx10^3
0-3	11a	23	46
	21a	28	56
	31a	26	52
	11b	1	2
	12b	0	0
	21b	8	16
	22b	6	12
	31b	18	36
	32b	36	72
3-6	13a	71	142
	23a	89	178
	33a	82	164
	12a*	39	78
	22a*	126	257
	32a*	127	259
	13b	27	54
	14b	26	52
	23b	76	152
	24b	116	237
	33b	214	600
	34b	268	984
	$11b_1$	4	8
	$21b_1$	4	8
	$31b_1$	24	48
6-9	15a	108	216
	25a	133	270
	35a	95	190
	14a*	115	235
	24a*	122	249

CYCLE V Cont.

Days	Code No.	Kletts	AAx10^3
6-9	34a*	104	208
	15b	60	120
	16b	27	54
	25b	230	680
	26b	343	1990
	35b	392	3118
	36b	426	3840
	$13b_1$	3	6
	$23b_1$	4	8
	$33b_1$	12	24
9-12	17a	202	532
	27a	171	403
	37a	167	388
	16a*	115	230
	26a*	85	170
	36a*	168	392
	17b	107	214
	18b	102	204
	27b	392	3118
	28b	457	5250
	37b	530	9600
	38b	360	2350
	$15b_1$	2	4
	$25b_1$	8	16
	$35b_1$	8	16
12-15	19a	252	848
	20a	241	767
	29a	212	590
	30a	195	500
	39a	188	470
	40a	182	440
	18a*	226	660
	28a*	241	767
	38a*	267	976
	19b	180	430
	20b	199	516
	29b	600	15000
	30b	624	15000
	39b	638	15000
	40b	636	15000
	$17b_1$	4	8
	$27b_1$	6	12
	$37b_1$	21	42

Table IV Cont.

CYCLE VI Sept 18-Oct 2, 1960

Days	Code No.	Kletts	AAx10^3
0-3	11a	20	40
	21a	46	92
	31a	47	94
	11b	4	8
	12b	7	14
	21b	12	24
	22b	7	14
	31b	20	40
	32b	44	88
3-6	13a	47	94
	23a	94	188
	33a	88	176
	12a*	33	66
	22a*	16	32
	32a*	37	74
	13b	18	36
	14b	18	36
	23b	25	50
	24b	13	26
	33b	79	158
	34b	--	--
	11b$_1$	3	6
	21b$_1$	3	6
	31b$_1$	6	12
6-9	15a	152	331
	25a	183	440
	35a	158	352
	14a*	82	164
	24a*	106	212
	34a*	202	536
	15b	32	62
	16b	45	90
	25b	49	98
	26b	162	368
	35b	326	1696
	36b	408	3600
	13b$_1$	8	16
	23b$_1$	8	16
	33b$_1$	8	16
9-12	17a	168	392
	27a	167	455
	37a	169	396
	16a*	145	315
	26a*	189	450
	36a*	293	1242

CYCLE VI Cont.

Days	Code No.	Kletts	AAx10^3
9-12	17b	79	158
	18b	62	124
	27b	353	2248
	28b	462	5550
	37b	556	10950
	38b	556	10950
	15b$_1$	---	-----
	25b$_1$	8	16
	35b$_1$	12	24
12-15	19a	170	400
	20a	169	396
	29a	188	470
	30a	187	465
	39a	170	400
	40a	177	421
	18a*	151	328
	28a*	146	317
	38a*	292	1228
	19b	96	192
	20b	100	200
	29b	423	5180
	30b	614	15000
	39b	527	9450
	40b	473	5950
	17b$_1$	6	12
	27b$_1$	10	20
	37b$_1$	9	18

CYCLE VII Oct 2-Oct 17, 1960

Days	Code No.	Kletts	AAx10^3
0-3	12a	39	78
	22a	36	72
	32a	33	66
	11b	4	8
	12b	3	6
	21b	5	10
	22b	8	16
	31b	8	16
	32b	10	20
3-6	14a	61	122
	24a	46	92
	34a	47	94
	11a*	9	18
	21a*	12	24
	31a*	45	90

Table IV Cont.

CYCLE VII Cont.

Days	Code No.	Kletts	AAx10^3
3-6	13b	7	14
	14b	12	24
	23b	30	60
	24b	21	42
	33b	33	66
	34b	35	70
	12b	7	14
	22b	7	14
	32b	15	30
6-9	16a	121	247
	26a	104	208
	36a	127	259
	13a*	53	106
	23a*	69	138
	33a*	94	188
	15b	51	102
	16b	72	144
	25b	187	465
	26b	121	247
	35b	199	516
	36b	176	418
	14b$_1$	4	8
	24b$_1$	6	12
	34b$_1$	13	26
9-12	18a	204	544
	28a	187	465
	38a	211	585
	15a*	101	202
	25a*	162	368
	35a*	291	1214
	17b	144	311
	18b	149	323
	27b	234	712
	28b	292	1228
	37b	278	1080
	38b	342	1980
	16b$_1$	0	0
	26b$_1$	4	8
	36b$_1$	6	12
12-15	19a	198	512
	20a	191	484
	29a	179	427
	30a	186	460
	39a	214	600
	40a	209	574

CYCLE VII Cont.

Days	Code No.	Kletts	AAx10^3
12-15	17a*	201	526
	27a*	276	1060
	37a*	304	1388
	19b	266	968
	20b	241	767
	29b	514	8680
	30b	498	7500
	39b	555	10880
	40b	512	8620
	18b$_1$	7	14
	28b$_1$	11	22
	38b$_1$	14	28

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