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PHOTOSYNTHESIS/RESPIRATION RATIOS IN AQUATIC MICROCOSMS UNDER ARSENIC STRESS[1,2]

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ABSTRACT

The ratio of net photosynthesis (P) to total ecosystem respiration (R) usually declines when an aquatic ecosystem is subjected to various types of stress. P/R ratios were measured in 12 80-liter microcosms containing water, sediment, and entire biotic communities (dominated by Elodea sp.) from a shallow pond. P and R were estimated from changes in dissolved oxygen concentrations during the day and night, respectively. After 10 weeks, the microcosms were stressed by the addition of sodium arsenate at concentrations of 0, 0.066, 11.5, and 143 ppm (as arsenic). P/R ranged from 1.0 to 1.4 in all microcosms before arsenate was added. Under stress, both P and R declined in the 11.5 and 143 ppm microcosms, with negative net photosynthesis (i.e., decreases in dissolved oxygen during the day) observed on several occasions. P/R in these microcosms fell to zero or below, returning to 1.0 after three weeks. P/R remained above 1.0 in the 0.066 ppm and control microcosms. The P/R response could be used for screening suspected hazardous substances in microcosms, as well as for monitoring natural ecosystems.

INTRODUCTION

The ratio of primary production to total community respiration (P/R) is an integrative index of ecosystem metabolism which can be easily measured in many aquatic ecosystems. H. T. Odum (1956) proposed the use of P/R for classifying ecosystems as autotrophic (P/R > 1) or heterotrophic (P/R < 1), and noted that either type of system tends to approach P/R = 1 over time. E. P. Odum (1969) listed P/R = 1 as an attribute of mature ecosystems, concluding that the ratio could be used as an index of relative maturity. P/R ratios of approximately 1 have been found in many aquatic ecosystems (Riley 1956, Odum 1957, Odum and Hoskins 1958, Jordan and Likens 1975).

Studies with aquatic microcosms (Beyers 1963, Gorden et al. 1969) revealed that these model ecosystems behaved similarly to natural ecosystems, in that P/R approached 1 as the microcosms approached maturity. Furthermore, P/R was found to depart from 1 when a system was disturbed. This effect was observed whether the disturbance was in the form of temperature stress (Beyers 1962), light reduction (Copeland 1965), increased grazing (McConnell 1962, Beyers 1963), or toxicants (Whitworth and Lane 1969). P/R thus appears to be a sensitive indicator of stress-induced changes in ecosystem metabolism. The experiment reported here tested this response in microcosms, stressed by various concentrations of sodium arsenate, to evaluate the potential of the P/R ratio as an index of ecosystem-level contaminant stress.

MATERIALS AND METHODS

Twelve microcosms were established in 80-liter glass aquaria in July 1976. Each microcosm contained 5 cm (about 10 kg) of untreated sediment from a shallow pond, 40 g (wet weight) of a mixed Elodea-Potamogeton community from the same pond, and 70 liters of spring water. A diverse assemblage of animals was present in the sediment and the macrophyte inoculum, including protozoans, rotifers, copepods, cladocerans, oligochaetes, nematodes, snails, and insects. The microcosms were maintained in an environmental chamber at 18°C on a 12-hr light:12-hr dark cycle. Details of the microcosm technique may be found in Giddings and Eddlemon (1977).

Ten weeks after the microcosms were established, sodium arsenate was added to nine of them. Appropriate volumes of a sodium arsenate stock solution and a solution of carrier-free $H_3{}^{74}AsO_4$ were mixed with 100 ml of water from each microcosm. The mixture was slowly introduced into each microcosm through a glass tube so that the mixture entered in a horizontal stream approximately 10 cm below the water surface. The arsenic concentration in the sodium arsenate stock solution was measured by an arc-emission technique (Feldman 1977) and used to calculate specific activities of arsenic added at each treatment level. Arsenic concentrations in various components of the microcosms were then determined by gamma spectroscopy. The initial arsenic concentrations in water were 0.066, 11.5, and 143 ppm, with three replicates per treatment. These concentrations bracket the range of reported toxic concentrations for most freshwater organisms (Becker and Thatcher 1973). Three microcosms were left untreated as controls.

Throughout the experiment, pH, conductivity, and dissolved oxygen (D.O.) were measured near the end of each light period. On three occasions before arsenic treatment, and weekly for six weeks thereafter, net primary production and nighttime community respiration were measured by the diurnal dissolved oxygen method (McConnell 1962). For measurement of P and R, each microcosm was covered with a sheet of polyvinyl chloride shortly before the end of the light period to inhibit oxygen diffusion across the air-water interface. Dissolved oxygen was measured with a YSI Model 54 D.O. meter at the beginning of the dark period, the beginning of the light period, and the beginning of the following dark period. The PVC sheet was then removed. The change in D.O. concentration during the dark period was termed nighttime community respiration. The D.O. change during the light period was a measure of net primary production. Both P and R were expressed in units of ppm D.O./12 hr.

RESULTS

Dissolved arsenic concentrations declined over time in all treatments. The 0.066 and 11.5 ppm microcosms reached mean equilibrium concentrations of 0.007 and 3.87 ppm, respectively, within two weeks. Arsenic concentrations in the 143 ppm microcosms did not equilibrate by the end of the experiment; the final concentrations averaged 99 ppm. As in previous experiments (Giddings and Eddlemon 1977), the major arsenic sink was the sediment.

Net primary production and nighttime community respiration in the four treatments are shown in Figure 1. Before treatment with arsenic, the mean net primary production for all 12 microcosms increased gradually from 3.7 ppm D.O./12 hr at week 6 (S.D. = 0.5) to 4.6 ppm/12 hr at

week 10 (S.D. = 0.7). This trend continued in the control and the 0.066 ppm microcosms, reaching 5.4 (S.D. = 0.5) at week 16. The two higher arsenic concentrations, however, resulted in immediate reductions in net primary production. In the 143 ppm microcosms, dissolved oxygen concentrations declined during the light period one week after treatment; i.e., gross photosynthesis was less than daytime community respiration in these microcosms. Net production remained near zero for two weeks in the 11.5 ppm microcosms, and for three weeks in the 143 ppm microcosms. Toward the end of the experiment, productivity recovered in both treatments; in fact, the net production at week 16 in the 143 ppm microcosms was considerably higher than in the controls. This high production rate was probably due to high PO_4 concentrations (up to 0.3 ppm, compared to < 0.04 ppm in the other treatments) which accumulated following arsenic treatment and were consumed again during the recovery. Recovery was accompanied by shifts in community structure. Macrophytes were replaced by Spirogyra in the 11.5 ppm microcosms, and by blue-green algae in the 143 ppm microcosms.

The effects of 11.5 and 143 ppm arsenic on nighttime community respiration were similar to, but less drastic than, effects on production. The decline in respiration was about one week behind the decline in productivity, and recovery was also slower. Respiration declined toward the end of the experiment in the 11.5 ppm microcosms; this effect is unexplained. Respiration increased very slightly during the experiment in the control and 0.066 ppm microcosms, averaging 3.4 and 3.9 ppm D.O./12 hr at week 6 and week 16, respectively.

The ratio of net primary production to nighttime community respiration averaged 1.2 for all microcosms before arsenic treatment. The ratio remained fairly constant (1.0-1.5, mean 1.4) in the control and 0.066 ppm microcosms throughout the experiment (Figure 2). In the 11.5 and 143 ppm microcosms, P/R dropped to zero or below for two weeks following arsenic addition. The decline was greater at 143 ppm than at 11.5 ppm. P/R increased by the third week after arsenic treatment, even in the 143 ppm microcosms where net production remained very low for an additional week. The highest P/R ratios recorded in the entire experiment were in the 11.5 ppm microcosms at week 16 (P/R = 2.5).

DISCUSSION

The lowest treatment in this experiment had no effect on the P/R ratio of the microcosms, while higher concentrations produced progressively greater reductions in P/R. While the arsenic concentrations used here were apparently at the extremes of the dose-response curve, the method appears useable for determining the response of an aquatic ecosystem to different concentrations of a contaminant.

The P/R recovery in both the 11.5 and 143 ppm treatments was similar to that observed by Copeland (1965) in marine microcosms exposed to a reduction in light intensity. In both cases, recovery was accompanied by changes in community structure. The ability to compensate for stress by species shifts is an important property of ecosystems. Until the theoretical relations between population dynamics and ecosystem dynamics are more fully understood, it will be difficult to predict the effects of a particular stress on a particular ecosystem (O'Neill and Giddings 1977). Certainly the P/R response of these microcosms to arsenic

treatment could not have been predicted by measuring the responses of the separate components.

While further refinement of this technique is necessary, the P/R ratio appears to be a useful indicator of ecosystem response to stress. The P/R response of aquatic microcosms of standard design could be used to screen potential environmental contaminants for hazardous effects. It must be recognized that the response is ecosystem-specific. As in conventional bioassay with single species, extrapolation of laboratory results to a particular natural environment introduces a degree of uncertainty. Prediction of the effects of a given contaminant on a specific target ecosystem will be best achieved by selecting microcosm components from that ecosystem, rather than relying on a single standard microcosm design. The P/R ratio may also prove to be a useful monitoring parameter for detecting the effects of stress in natural aquatic ecosystems.

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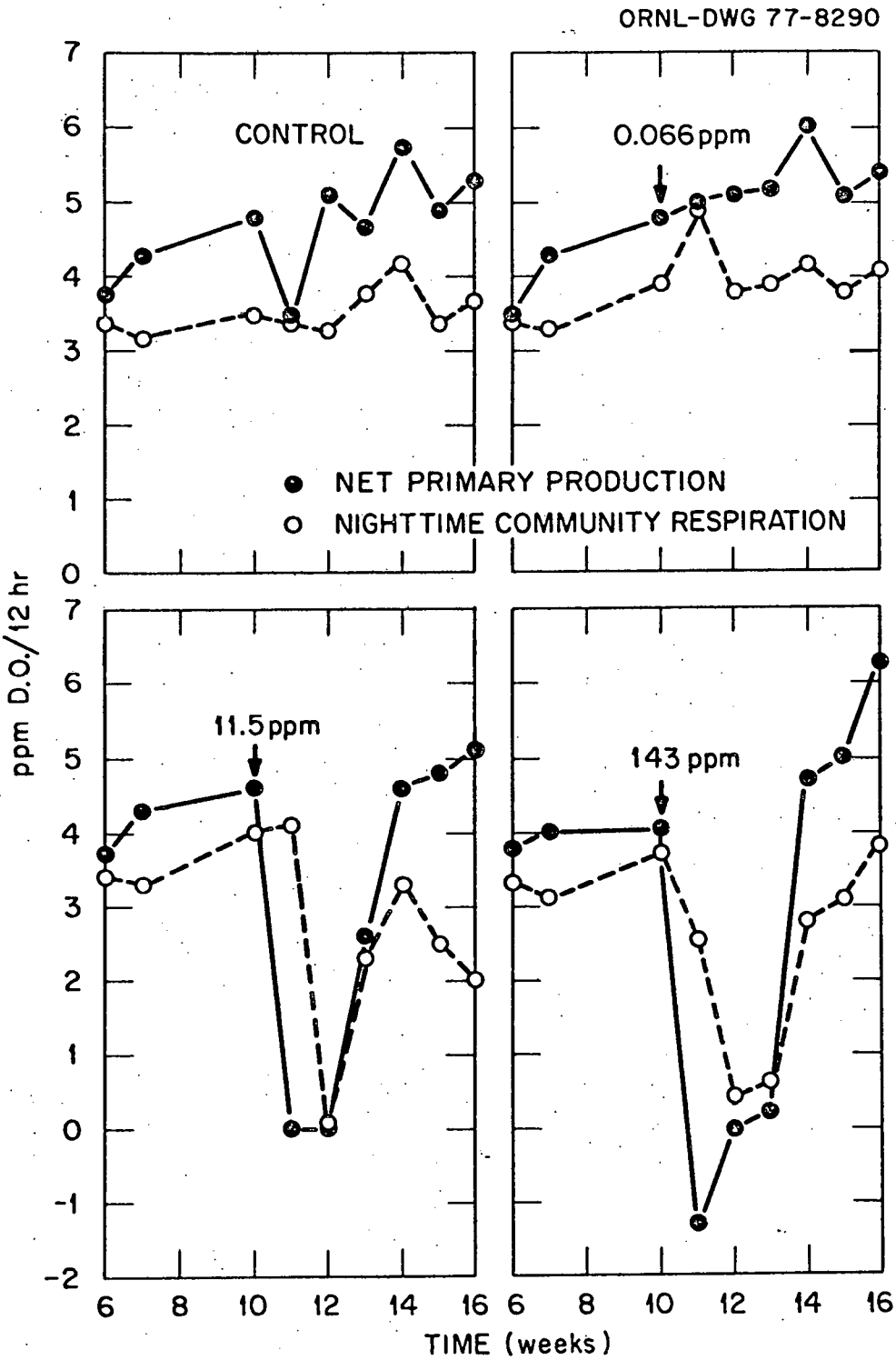
Fig. 1. Net production and nighttime community respiration in microcosms at 3 arsenic levels. Open circles: nighttime community respiration. Filled circles: net production. P and R are in units of ppm D.O./12 hr. Each point represents the mean of three microcosms. Arsenic was added, in the concentrations indicated, immediately following P and R measurement at week 10.

Fig. 2. Production/respiration ratios in microcosms at three arsenic levels. Each point represents the ratio of mean net production to mean nighttime community respiration for three microcosms. Arsenic was added, in the concentrations indicated, immediately following P and R measurement at week 10.



Net Production and Nighttime Community Respiration in Microcosms Treated with Sodium Arsenate.

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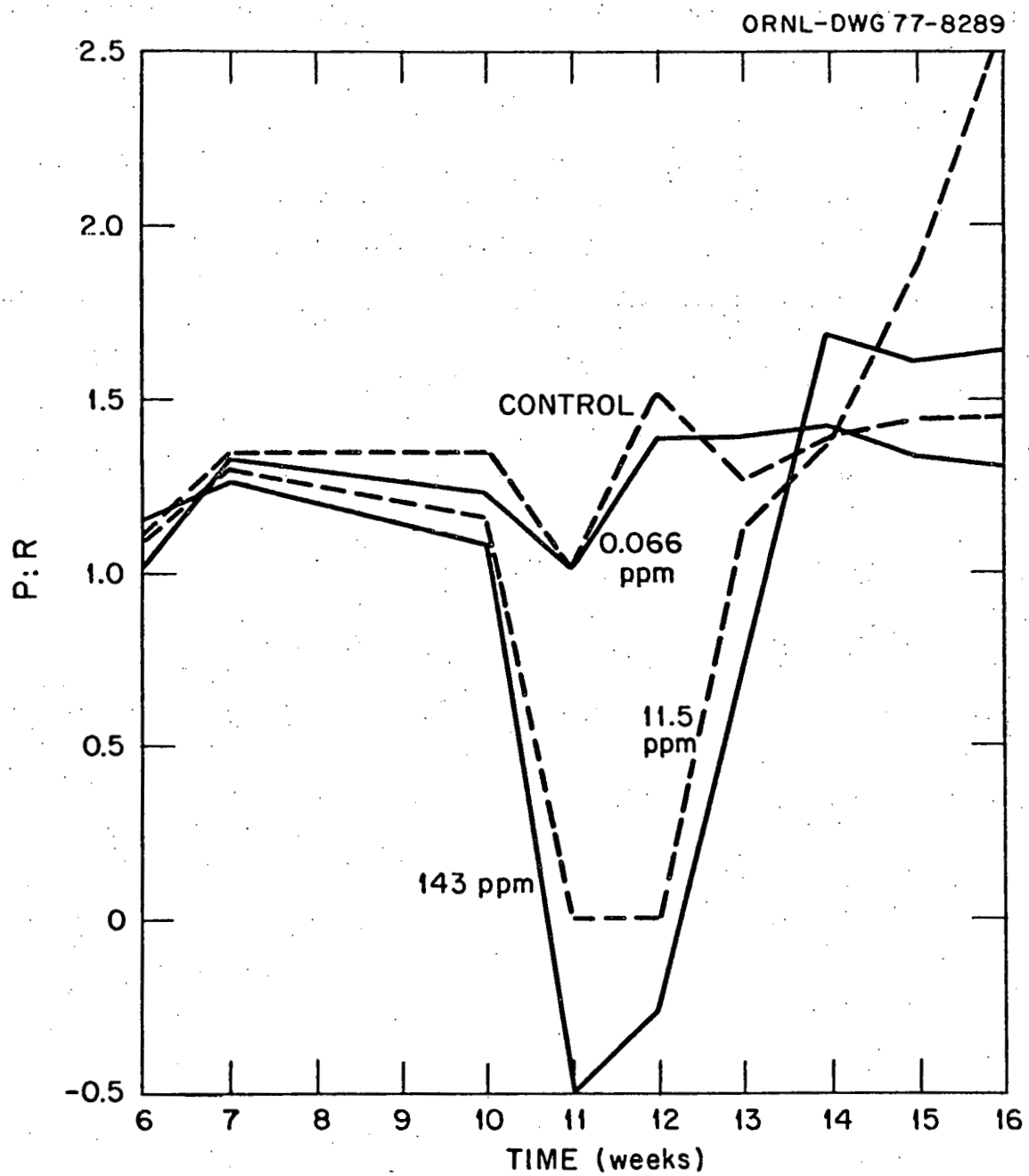
FIG. 1



Production: Respiration Ratios in Microcosms Treated with Sodium Arsenate.

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FIG. 2