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DIVERSITY AS AN INDICATOR OF POLLUTION: CAUTIONARY RESULTS FROM MICROCOSM EXPERIMENTS

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SUMMARY. Data from two microcosm experiments (CEPEX and MERL) are examined to determine whether diversity measures can provide an appropriate indicator of environmental stress. It is concluded that diversity is a rather stable community parameter, relatively insensitive to both natural variation and pollution over the short-term. When a community is not in stationary equilibrium with its environment, it appears that changes in species composition and density are a more reliable indicator of stress than diversity measures.

KEY WORDS. marine pollution, microcosm, diversity.

1. INTRODUCTION

Both field and theoretical studies in ecology have emphasized the relationship between the species diversity of a community and the degree of environmental stress to which it is subjected. In general, it is thought that if two similar communities were exposed to different levels of stress, the community with the higher stress would have lower diversity. For instance, Fischer (1960), Simpson (1964), and others have documented the decline in diversity from high latitudes (high stress environment) to low latitudes (low stress environment). May and MacArthur (1972) and Dennis and Patil (1979) have developed theoretical models that predict a decrease in diversity with increasing randomness in the environment.

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1. INTRODUCTION

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All these studies assume that the community is in stationary equilibrium with its environment. This assumption is clearly violated in many environmental studies where community diversity is used as an indicator of pollution. In these studies, a comparison is made between an area that has received some form of transient environmental stress (such as a recent oil spill, dredging operation, or forest fire) and a control, unstressed area.

The relationship between community diversity and transient stress can be empirically investigated with microcosm experiments. In experiments of this kind, small contained systems are used as experimental units. Each experimental unit can be thought of as a replicate ecosystem. These experimental systems eliminate many of the problems of sampling and manipulating natural ecosystems with their range of spatial and temporal scales of variation. The small size of these systems, however, introduces difficulties with maintaining natural communities (Steele, 1979).

We will examine the use of diversity measures as an indicator of stress in two different microcosm experiments: the Controlled Ecosystem Pollution Experiment (CEPEX) research on the effect of copper on the zooplankton community, and the Marine Ecosystem Research Laboratory (MERL) study of the effects of chronic, low-level No. 2 fuel oil additions to a benthic community. We hope these examples will serve to indicate ways of using microcosm experiments to understand problems of measuring and interpreting community parameters such as diversity in field studies.

2. CEPEX

The study of planktonic communities living in a constantly moving water mass presents difficulties not encountered in communities occupying a fixed area. The CEPEX (Controlled Ecosystem Pollution Experiment) program was designed to isolate and contain natural plankton communities in relatively large plastic enclosures so that their response to perturbations could be studied.

The concept, objectives, and experimental facilities of CEPEX have been discussed in detail elsewhere (Menzel and Case, 1977; Grice *et al.*, 1977; Menzel and Steele, 1978). The data we will consider here are from a 1974 CEPEX experiment intended to evaluate the effects of copper on pelagic marine ecosystems.

This experiment employed small (68 m^3) CEPEX enclosures called Controlled Experimental Ecosystems (CEEs): flexible plastic bags filled with seawater and suspended *in situ* from acrylic flotation rings at the sea surface. On 14 June 1974, four CEEs were deployed by simultaneously raising the folded bags from a depth of 20 m in Saanich Inlet, British Columbia, so that, as they ascended to the surface, the bags unfolded and encapsulated a section of the natural water column and its biota. Two CEEs were treated with $CuSO_4$, and two remained undisturbed to serve as controls. The first treated enclosure received an initial dose of 10 µg Cu/ℓ, and this concentration was maintained by four subsequent additions of metal. The other experimental enclosure received an initial treatment of 50 µg Cu/ℓ, but no further additions were made, and over the next 26 days the metal in the water column gradually declined to about 40% of its initial concentration (Topping and Windom, 1977). Effects of the copper were studied on all trophic levels represented in the enclosures--from bacteria to carnivorous macrozooplankton, and results are given in a series of papers in Vol. 27(1) of the *Bulletin of Marine Science* (1977). The population dynamics of the mesozooplankton were analyzed by Gibson and Grice (1977) and some of these data can illustrate the application of diversity measurements to stressed environments.

Zooplankton samples were collected with a 202 µm-mesh Bongo net which filtered approximately 0.44 m^3 of water in a 14 m vertical tow. The sampling routine consisted of three replicate tows in the middle of each CEE every four days. Plankton was preserved in 8% buffered formalin, and aliquots typically containing 100-400 organisms were microscopically examined for each sample. Copepods were identified to species but other types of organisms were enumerated by general taxonomic category (gastropod larva, chaetognath, larvacean, etc.).

The most striking feature of this experiment was the sharp decline in herbivorous zooplankton that occurred in all four CEEs (Figure 1). This phenomenon was more marked in the experimental enclosures than in the controls, and the CEE which received the higher initial dose of copper (50 µg/ℓ) exhibited the most precipitous decrease. Reductions were severe by the ninth day of the experiment, and on the final day of sampling (Day 25), the controls had declined to 15% and 5%, and the experimental enclosures 6% (the 10 µg/ℓ CEE) and 0.5% (the 50 µg/ℓ CEE) of their initial zooplankton populations.

The expected number of species (Hurlbert, 1971) was computed for each sample. The variance of Hurlbert's index was estimated as described by Smith and Grassle (1977) and 95% confidence intervals were constructed for the expected number of taxa in the samples of size 32, each replicate treated separately. It is apparent from Figure 2 that fluctuations in diversity cannot be correlated with copper concentration.

Gibson and Grice (1977) were able to demonstrate satisfactory replication among initial zooplankton populations in the four

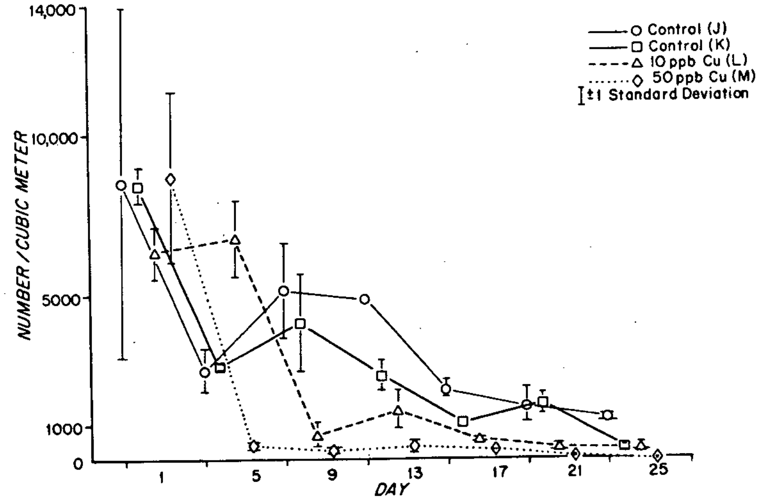

FIG. 1: Herbivorous zooplankton abundance (no./m^3) *in control and copper treated CEEs during the June/July* 1974 *CEPEX copper experiment. Confidence intervals represent* ± *one standard deviation of the mean value for all replicates.*

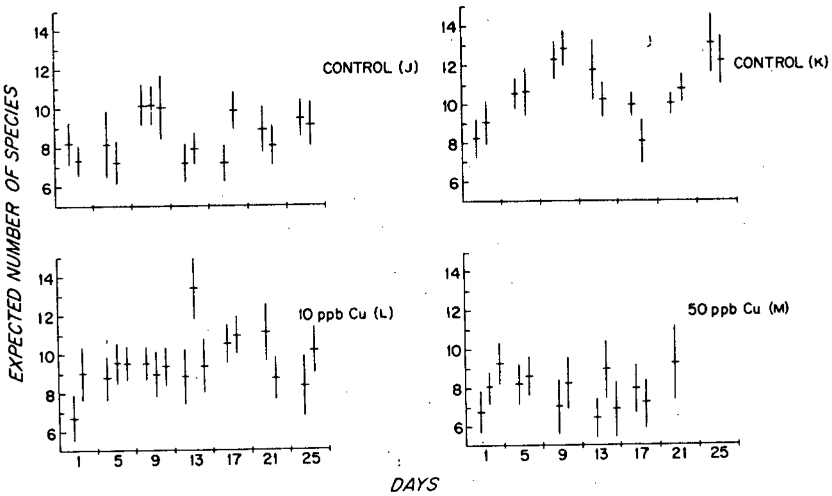

FIG. 2: Hurlbert's estimate of the expected number of taxa for a random sample of size 32 *for samples from control and copper treated CEEs during the June/July* 1974 *CEPEX copper experiment. Values for each replicate are bracketed by confidence intervals at approximately the* 95% *level. The total number of individuals in the* 50 *ppb CEE was too small to permit rarefaction to size* 32 *on Day* 25.

enclosures. Subsequent variations in zooplankton abundance and species composition cannot, therefore, be attributed to differences in the captured water columns. Several authors (Gibson and Grice, 1977; Menzel, 1977; Reeve *et al.*, 1977) examined possible explanations for the decline of zooplankton in the control enclosures and concluded that predation by ctenophores and medusae was the primary cause. Differences between control and experimental enclosures can be ascribed to the effects of the pollutant. This result could be produced either directly, through toxic effects on the zooplankton themselves; or indirectly, through alterations produced at lower trophic levels of the ecosystem.

3. MERL

The response of benthic communities to pollutants is difficult to study in field situations, partly because of the variable nature of the water circulation over the benthos. The Marine Ecosystems Research Laboratory was established at the University of Rhode Island to study the relationship between the benthos and its overlying water as well as the effect of pollutants on this relationship. The experiment we will consider here was designed to investigate the effect of chronic low levels of No. 2 fuel oil on the benthic community.

This experiment ran from November 1976 to October 1977. Nine tanks 5.5 m deep and 1.8 m in diameter, each containing approximately one ton of Narragansett Bay sediment were used. Sea water from the Bay was pumped into each tank at a slow flow rate of 20 liters per hour, resulting in a turnover time of thirty days. A complete description of the facility is given in Pilson *et al.* (1977).

Three of the tanks were controls (tanks 1, 5, and 8) and three were treated with additions of No. 2 fuel oil from February 14 through April 1 (tanks 2, 7, and 9); and three tanks not discussed here were left on 'batch mode', with no water flowing through them. In the experimental tanks the concentration of oil in the water column was maintained at 100-600 $\mu g/\ell$ by twice weekly additions of an oil-water dispersion.

Ten 4.135 cm^2 samples were taken monthly in each tank in a stratified random scheme. In order to adequately sample both central and peripheral areas of the benthos in the tanks, five samples were taken in each area. All samples were sorted under a dissecting microscope and all macrofauna retained by a .3 mm screen was counted and identified to species.

If Figure 3 we have plotted expected species diversity for 20 individuals for the three control and three experimental tanks.

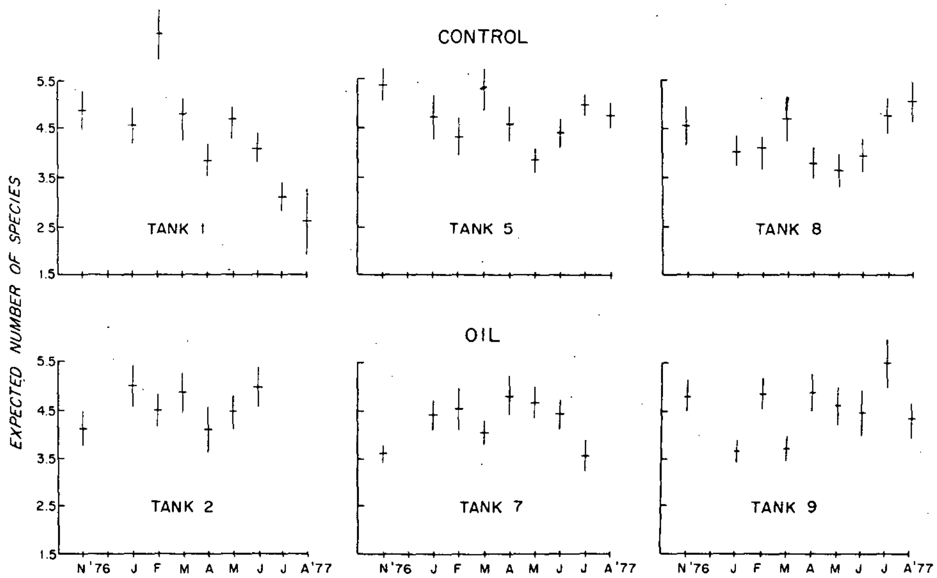

FIG. 3: Hurlbert's estimate of the expected number of species in a random sample of size 20 *drawn from the community in the MERL experiment. Oil was added to the experimental tanks after the February sampling data.*

The bars indicate ± one standard deviation, estimated using the results in Smith and Grassle (1977). It is apparent that there was no consistent decrease in diversity within the experimental tanks. Smith, Kravitz, and Grassle (1979), however, have shown that community similarities between control and experimental tanks diverged during the summer months. In addition, Grassle *et al.* (1979) have shown that the density (number of individuals) per core was also less for the experimental tanks (see Figure 2, Smith *et al.*).

As in the CEPEX experiment, diversity measurements failed to demonstrate a stress response, although changes in density and composition provided evidence that the experimental communities were, in fact, responding to environmental stress.

4. CONCLUSIONS

A by-product of microcosm experiments is that they provide a novel means of investigating the usefulness of quantitative ecological measures such as community diversity and similarity.

These indirect statistical methods have been developed because direct observation and control of many ecological processes is impossible in the field. Microcosm experiments allow more direct observation and control of a community and thus provide an opportunity to empirically investigate these indirect ecological measures.

An ecological community's response to pollutants is complex, varying both with the kind of pollutant and the community exposed. In nature, this response is also confounded by natural sources of variation. Community diversity has been proposed as an indirect indicator of pollution because it is assumed to have two important, but contradictory, properties: insensitivity to natural sources of variation and sensitivity to pollution. The experimental ecosystems that we investigated tend to confirm the former property while denying the latter. That is, diversity was found to be a relatively stable property of a community--insensitive to both natural variation and transient pollution events. Changes in species composition and density over time appear from these examples to be better indicators of pollution than community diversity. Since both CEPEX and MERL experiments were of relatively short duration, these results do not rule out the possibility that these systems, when fully accommodated to chronic pollution, would have a reduced diversity.

ACKNOWLEDGMENTS

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