United States
Environmental Protection
Agency

Environmental Research
Laboratory
Duluth MN 55804

Research and Development

EPA-600/S3-84-013 Mar. 1984

EPA

Project Summary

Structure and Organization of Persistent Aquatic Laboratory Communities Exposed to the Insecticide Dieldrin

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Sixteen aquatic communities composed of persistent populations of guppies *(Poecilia reticulata)*, amphipods *(Gammarus fasciatus)*, snails (family Planorbidae), planaria *(Dugesia* sp.*)*, and various microinvertebrates were established under laboratory conditions. Eight of these communities received low energy input with low habitat availability while the remaining eight communities had high habitat availability and received high energy input. At each level of input, guppy populations in two systems were exploited at either 0, 10, 20, or 40 percent of the population biomass each month. Macroinvertebrates were also sampled monthly for population counts and biomass measurements. After each system reached near steady-state conditions, 1 µg/l of dieldrin was introduced into one system of each treatment. These systems were allowed to reach new steady-state conditions.

The response of the systems was dependent upon both the energy input/habitat and exploitation levels. The low energy input/habitat systems were more sensitive to dieldrin particularly at higher levels of exploitation. The influence of organization and environment on population persistence and system structure is explored theoretically with isocline models, and the implications for aquatic ecology and environmental management strategies are discussed.

This Project Summary was developed by EPA's Environmental Research Laboratory, Duluth, MN, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Management of toxic substances should be based upon good understanding of their effects not only on individual organisms but also on populations and communities. The goal of the research summarized here was to advance understanding of the influence of toxicants on the structure and organization of aquatic communities. Persistent laboratory communities maintained under differing environmental conditions were exposed to the organochlorine insecticide dieldrin. The conditions included differing levels of invertebrate habitat availability, differing rates of energy and material input, and differing rates of population exploitation.

In simple communities, structure may be taken to refer to the kinds of species found in the system along with their distribution and abundance in space and time. Organization is taken to be more of a theoretical concept, in part entailing how species populations and their level-specific environments are interrelated and so incorporated into a system as a whole.

The theoretical perspective employed in designing the experiments and interpreting the results entailed the use of multisteady-state isocline models (Figure 1). In this perspective, under differing environmental states, a community will develop differing steady-state structures and organizations and can thus be understood as a multisteady-state system. Dynamics or changes in structure through time of an n-dimensional

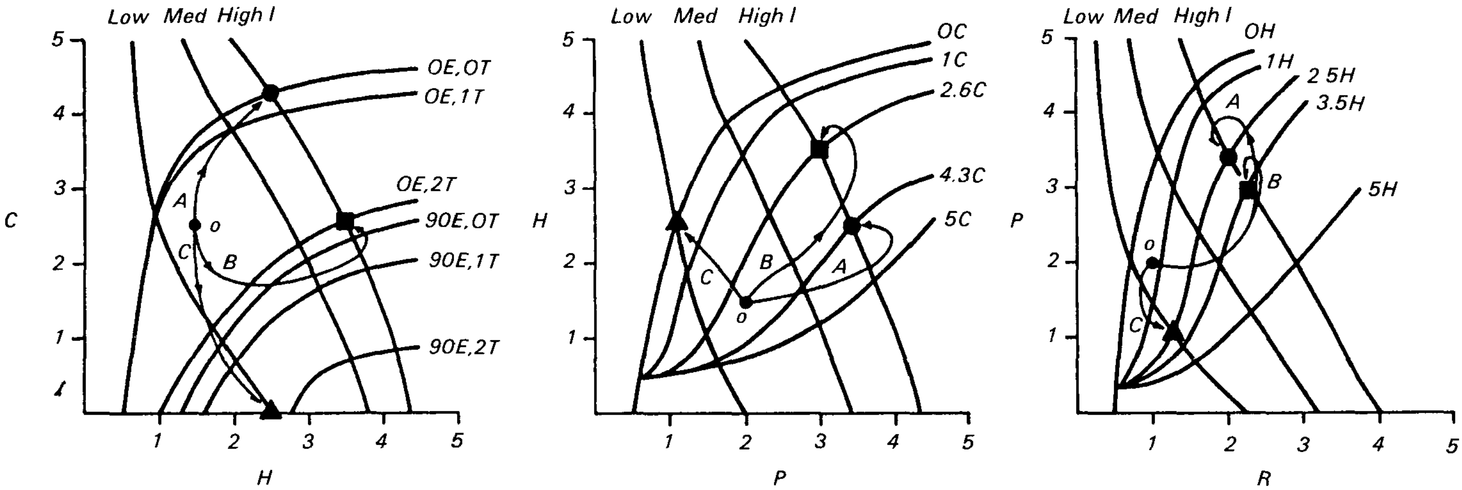

Figure 1. Phase planes and isocline systems modeling the interrelationships between populations in a system.

$$E \rightarrow C \rightleftarrows H \rightleftarrows P \rightleftarrows R \leftarrow I, \quad T \rightarrow C$$

where C,H,P, and R comprise the system and E, units of harvesting effort, and I, rate of input of plant resources, are factors in the environment of the system. A toxicant directly affects only the carnivore population On each phase plane predator biomass is plotted on the y-axis and prey biomass is plotted on the x-axis. The descending lines identified by different rates of plant resource input, I, are prey isoclines Each prey isocline is defined as a set of biomasses of predator and prey where the rate of change of prey biomass with time is zero. The ascending lines on each phase plane are predator isoclines. Each predator isocline is defined as a set of biomasses of predator and prey where the rate of change of predator biomass with time is zero. Each intersection of a predator and prey isocline is a steady-state point where the rate of change of both predator and prey biomass with time is zero. The positions and forms of the isoclines can be deduced from equations or sets of graphs representing the rates of gain and loss of each of the populations. The presence of the toxicant lowers the predator isocline at each E on the C-H phase plane, the extent to which it is lowered depending upon the effect of the particular toxicant concentration on carnivore growth, reproduction and survival. Steady-state system structure at HIGH I, OE, OT (circles); HIGH I, OE, 2T (squares); LOW I, 90E, 2T (triangles) is shown. Trajectories of biomasses of carnivore (C), herbivore (H), plant (P), and plant resource (R) originating at point O are shown to converge on each of these steady-states under each particular set of environmental conditions

community can be understood as a trajectory in constant pursuit of an n-dimensional steady-state point whose location in phase space is continually changing as a result of changes in environmental conditions. Toxic substances change the structure and organization of systems; these changes can be understood as alterations of the location of the system steady-state point in phase space. The response of the system to a toxicant is jointly determined by its organization and conditions in its environment. Under differing sets of environmental conditions, a system will respond differently to a given concentration of toxicant.

Description of Research

Sixteen aquatic communities were established, each composed of persistent populations of guppies *(Poecilia reticulata)*, amphipods *(Gammarus fasciatus)*, snails (family *Planorbidae)*, planaria *(Dugesia* sp.), and benthic microinvertebrates including flagellates, rotifers, nematodes, gastrotrichs, and protozoans. Habitat and escape cover for invertebrates were provided by a substrate of quartzite gravel. A gelatinous mixture of 60 percent alfalfa and 40 percent Oregon Test Diet served as the primary source of energy and materials.

Each laboratory system was maintained in a fiberglass tank holding 560 liters of water, which was continuously exchanged by a 600 milliliter per minute flow of heated well water. Fluorescent lighting was placed above each tank, and light was maintained at a relatively low level to prevent the formation of blue-green algae blooms.

Eight laboratory systems were established with three circular nests of quartzite gravel covering 20 percent of the bottom area of each tank. Each system received a 0.6 gram per tank daily alfalfa-OTD ration. This treatment is identified as low energy and material input and low habitat availability, or LOW I.

In the remaining eight systems, gravel habitat covered 95 percent of the tank bottom. Each system received 4.0 grams of alfalfa-OTD ration daily. This treatment is identified as HIGH I. In four systems at HIGH I, planaria, which are effective predators on amphipods and capable of completely eliminating them from a system, were abundant. In the remaining four, planaria were controlled, their numbers being kept at very low levels.

At each I, guppy populations in two systems were exploited at one of four rates, 0, 10, 20, or 40 percent of the biomass of the population present at the time of sampling (0E, 10E, 20E, and 40E, respectively).

Every 28 days the systems were sampled and the guppy populations were exploited at their assigned rates. All macroinvertebrates were removed, counted, weighed and replaced in the systems. Number, biomass, and yield of guppies were determined.

Dieldrin was introduced into four systems, one at each exploitation rate, at both LOW I and HIGH I. When these systems established near steady-states (NSS), continuous introduction of one ppb of dieldrin was begun. NSS structure at each combination of levels of I and E was assumed when the trajectories of biomasses of the interacting populations fluctuated in a very restricted region of phase space relative to previous fluctuations

Additional experiments were conducted to determine the extent to which simpler models of complex systems could provide some understanding and prediction of toxicant effects in the more complex laboratory systems. Accordingly, laboratory systems composed of only guppies, only snails, and guppy and snail populations together were established These systems, though smaller and simpler than the complex laboratory systems, were still capable of exhibiting population and simple community response. Effects in these simpler systems were to be compared to effects in the more complex systems. Guppy populations were exploited at three different rates Two levels of energy and material input in the form of an alfalfa-OTD ration were maintained. Protocol for sampling, exploitation, and toxicant introduction into these systems was to be the same as in the more complex systems. The funding period for the Cooperative Agreement was shortened, and time was not available during the period of the agreement to introduce toxicant into the simpler systems.

Approximately 18 to 24 months were required for the more complex laboratory communities to establish NSS. At different levels of habitat (I) and exploitation (E), the systems established different NSS structures, in conformity with the expectations of the multisteady-state perspective Guppies and snails were competitors for the alfalfa-OTD ration. At each I there was an inverse relationship between NSS guppy and snail biomasses. Increased E brought about a reduction in NSS guppy biomass, which was accompanied by an increase in the NSS biomass of the snail competitor. Increased I led to an increase in the NSS biomasses of both guppies and snails at each E.

The relationship of amphipods to guppies and snails is rather complex and not well understood. Amphipods were apparently a competitor of guppies and snails as well as prey of guppies At LOW I, NSS amphipod biomass was inversely related to guppy biomass. At HIGH I, in systems in which planaria were controlled, changes in NSS guppy biomass brought about by changes in E had no discerned effect on amphipod biomass. Because of the large amount of rock substrate available as an amphipod refugium at HIGH I and the greater availability of their preferred food, the alfalfa ration, guppies may not have preyed as effectively on amphipods and thus had little direct effect on their biomasses

At HIGH I in systems where planaria were not controlled, amphipod populations were maintained at very low levels or driven to extinction by planaria predation. At each E, snail populations maintained higher NSS biomasses in these systems than in systems where planaria were controlled and the amphipod competitor was abundant.

The simpler laboratory systems also established NSS. The time required for these systems to come to NSS was nearly as long as that required by the complex laboratory systems. The NSS relationships between guppies and their snail competitors were similar to those observed in the more complex systems. The simpler systems aided in clarifying the role of guppy-snail competition in organizing the more complex systems. Further, these systems and the more complex laboratory communities were useful in illustrating that system productivity, expressed as energy and material input I, predation, exploitation, and competition operate together to determine system structure.

Results and Conclusions

Dieldrin altered community structure and organization, nearly all systems establishing new NSS's during exposure. Individual organism experiments conducted at our laboratory indicated that a dieldrin concentration of one ppb in the laboratory systems probably directly affected guppy survival, growth, and reproduction and only indirectly affected other populations through reduction in guppy predation and/or competition intensity resulting from reduction in guppy biomass.

The response of the laboratory systems to continuous exposure to one ppb of dieldrin was dependent upon the levels of both I and E. At LOW I, system response to dieldrin ranged from perturbation and recovery at OE to guppy populations extinction at 40E. At LOW I, OE, over a period of about 12 months of continuous exposure, guppy biomass was reduced about 30 percent and amphipod biomass was slightly increased. While dieldrin was still being introduced, however, the system began to recover from perturbation with guppy biomass gradually increasing. The structure of the recovering system eventually overlapped the NSS structure that existed prior to dieldrin introduction.

At LOW I, 10E, and LOW I, 20E, guppy biomass was reduced about 30 and 50 percent, respectively Amphipod biomass increased in both systems, presumably as a result of reduction in predation and/or competition intensity resulting from the decrease in guppy biomass. Dieldrin was continuously introduced into these systems for over 18 months. Unlike the system at OE, these communities did not show any indication of recovery until dieldrin introduction was terminated.

At LOW I, 40E the guppy population became extinct following 15 months of continuous exposure to dieldrin. After this, amphipod biomass increased considerably. Evidence indicates that extinction may have been related to dieldrin exposure. The NSS density that guppies maintained prior to dieldrin introduction was very low. For several months prior to extinction there was no recruitment to the population, even though females carried sufficient eggs to replenish the adult stock. Perhaps offspring survival had been reduced as a result of dieldrin accumulation in eggs. In the community at LOW I, 40E into which dieldrin was not introduced, the guppy population persisted for 65 months until the termination of the experiment.

The response of the laboratory communities to dieldrin was dependent upon the level of I as well as E. At HIGH I, all systems established new NSS's after introduction of dieldrin. The alteration of system structure and organization at each exploitation rate was much less than at LOW I. At HIGH I, during dieldrin introduction, the guppy population at each E maintained a somewhat lower NSS biomass than it maintained prior to dieldrin introduction Amphipod and snail biomasses were only slightly altered. At HIGH I, 40E the guppy population persisted until the experiment was terminated, a period of nine months under continuous exposure to the toxicant. This population maintained substantial recruitment and a much higher density than the population at LOW I, 40E and was apparently in no danger of extinction.

Changes in community structure and organization after termination of dieldrin introduction were examined in the four systems at LOW I to determine if the systems would recover structures they had maintained prior to dieldrin introduction Recovery was evaluated for nearly two years. System structures during recovery were different from those maintained during dieldrin introduction. But the systems did not return to the structures they had maintained prior to dieldrin introduction Inadvertent colonization by the amphipod *Hyallela azteca*, a competitor of *Gammarus*, and leeches, an effective predator on snails, made it difficult to ascertain whether exposure to dieldrin was responsible for the failure of several of the systems to return to their original structures.

Responses of the laboratory communities to exposure to dieldrin are related to changes in the life history patterns of the individuals composing the populations. Individual organisms alter their life history patterns in response to changes in their environment. The community provides the environmental context in which individuals develop and populations must be adapted to persist. Changes in *factors such as I and E bring about* changes in community structure and associated changes in individual organism life history patterns. For example, at each I, increased exploitation rate (mortality rate) reduces length of life and number of reproductions per life time. But, due to reduction in density of the exploited population and an increase in the density of its food resources, any of the following "density-dependent" changes in life histories of individuals in the exploited population may also occur: faster juvenile and adult growth, increased size at first reproduction (or perhaps decreased age at first reproduction), and increased fecundity. Some of these kinds of changes in guppy life history patterns occurred in response to increase E. Life history changes of this kind have been observed in natural populations. Development of such life history characteristics can be understood as adaptations enabling populations to persist in high mortality environments.

Toxic substances may so alter life history patterns of individual organisms that populations are no longer able to persist in their environments, or the populations may persist only at reduced densities. In the laboratory communities, dieldrin apparently altered guppy life history patterns by reducing growth and fecundity and also, at LOW I, 40E, by increasing mortality of offspring. At LOW I, 40E, *dieldrin may have contributed to* extinction of the population by effectively preventing individuals from exhibiting the life history patterns—more rapid growth, higher fecundity, increased offspring survival—that would have adapted the population to persist at this high exploitation rate. At HIGH I, greater food availability brought about more rapid growth and reproduction, and thus may have enabled the guppy population to persist when exposed to dieldrin and exploited at 40E. But there surely would have been some exploitation rate higher than 40E at which a population even at HIGH I would not have been able to persist.

Not only changes in the life history patterns of individual organisms, but also evolutionary changes in populations—changes in their genetic organization—can be brought about by exploitation and exposure to toxic substances. At LOW I, the guppy population exploited at 0E was able to adapt developmentally and perhaps evolutionarily to the presence of dieldrin and so recover from dieldrin pertubation. Natural selection could have favored those individuals that had the life history capacity to survive, grow, and *reproduce most efficiently in the presence* of dieldrin—the so-called "resistant" individuals. However, in adapting to the toxicant, the population at 0E may have lost some of its capacity to adapt to other kinds of changes in environmental conditions.

In the laboratory communities at LOW I, populations exploited at 10E and 20E did not recover from toxicant pertubation throughout the time that dieldrin was being introduced. The unexploited population maintained a greater density than the populations exploited at 10E and 20E. Perhaps greater population density increased the probability that "resistant" genes or sets of genes were present in the population and so speeded evolutionary adaptation and recovery. The population exploited at 40E, which maintained a very low density, was apparently particularly sensitive to dieldrin and was driven to extinction.

Several workers have argured that, for genetic reasons alone, reduction in density, as occurs with increased E, leads to increased inbreeding and reduction in genetic variation, especially in isolated populations in which gene flow is limited. Life history traits severely affected by inbreeding are those associated with survival and reproduction. Inbreeding and its negative effects on life history traits would act in opposition to any adaptive density-dependent increases in these performances. Toxicants that themselves reduce growth, survival, and reproduction would, in effect, reinforce the negative effects of inbreeding at low *population densities. Further, loss of* genetic variation would amount to reduction in the capacity of a population to adapt to changes in environmental conditions, including toxicant introduction. Thus, populations in systems of low productivity that are subjected to high mortality rates and are maintained at low densities may be especially sensitive to toxic substances for life history reasons. The individuals need to maintain high growth and reproduction rates for the population to persist but due to the effects of both toxicants and inbreeding, the populations have a severely reduced adaptive capacity.

At HIGH I, 40E, guppies were able to survive, grow, and reproduce better than fish at LOW I, perhaps due to greater food availability. The density of the population at HIGH I, 40E was much greater than the density at LOW I and, thus, perhaps genetic diversity was also greater. These factors may have enabled this population to better withstand toxicant exposure.

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The complete report, entitled "Structure and Organization of Persistent Aquatic Laboratory Communities Exposed to the Insecticide Dieldrin," (Order No. PB 84-141 183; Cost: $11.50, subject to change) will be available only from:
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