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Project Summary

Organization and Adaptation of Aquatic Laboratory Ecosystems Exposed to the Pesticide Dieldrin

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A system of generalizations was formulated about the organization, development and persistence, adaptation, and productivity of ecological systems and their response to toxic substances. Laboratory ecosystems composed of persistent populations of guppies, amphipods, snails and various micro-invertebrates were used in examining the generalizations for their utility and conformity with field observation. Guppy populations in the ecosystems were exploited at different rates to simulate fishing, and the systems were provided with different levels of habitat availability and energy input rates. The laboratory communities developed different steady-state structures (population densities) at different guppy exploitation rates and different levels of habitat availability and energy input.

One part per billion (ppb) of dieldrin was continuously introduced into four ecosystems, one at each guppy exploitation rate, at the low level of habitat availability and energy input. It was determined in ancillary experiments that 1 ppb of dieldrin probably directly affected only the guppy populations. As exploitation rates increased, guppies exhibited increased growth and reproduction. Dieldrin altered life history patterns by reducing survival, growth, and reproduction. Thus, the toxicant may have caused the extinction of the heavily exploited population by effectively preventing it from exhibiting the life history pattern that adapted it to persist at high exploitation rates.

In aquarium experiments conducted in conjunction with the laboratory ecosystem studies, concentrations of dieldrin similar to those used in the laboratory ecosystems had effects on life history patterns similar to those observed in the ecosystems. It is less evident how the diversity of effects on guppy populations observed in the ecosystems—ranging from perturbation and recovery to extinction—could have been predicted from the aquarium experiments.

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

The performances of individual organisms, populations and communities are in continuous change. Any performance, such as structure, development, replication, or persistence is determined by the system's capacity and its environment. The capacity of such a system depends on its organization, which includes subsystems whose capacities and performances are concordant with the capacities and performances of their level-specific environments. Systems with a given capacity exhibit different performances under different sets of environment conditions. Development and evolution alter the capacities of these systems and thus also lead to different performances. Competition, predation, human exploitation and toxic materials alter the capacities of these systems and thus also lead to different performances. Competition, predation, human exploitation and toxic materials alter organization and therefore the adaptive capacities of both populations and communities. These factors are considered in setting up a system of generalizations.

Determinants of community structure and organization include level and kinds of energy and materials available, patterns of climatic conditions, colonization opportunities, species interactions (predation, competition, mutualism, habitat distribution), and the spatiotemporal distribution of primary physical habitats.

In order to gain a more general theoretical and empirical understanding of some of the primary determinants of community organization, an effort has been made to couple interactions of populations within an ecological system with one another and with environmental conditions and to display the outcomes of these interactions graphically by systems of isoclines on phase planes. Systems of populations are assumed to be multisteady-state systems. In Figure 1 a single steady-state point is shown on each phase plane for each set of environmental conditions. The set of these points defines the steady-state structure for a given environment. Changing conditions such as rate of exploitation or energy input bring about a change in system structure. Thus, at each energy input rate, increased rate of exploitation (E) reduces the steady-state biomass of C, increases H, reduces P, and increases R. Increases in I shift the steady-state relationships between predator and prey to the right on each phase plane, essentially increasing the biomass of C, H, P and R.

In Figure 1, individual species populations of carnivores, herbivores, plants and plant resources form the subsystems that are incorporated into the system. The position and form of isoclines on phase planes (and therefore steady-state points) are determined by the characteristics of the interacting populations. A complete set of isoclines on all phase planes provides at least a partial view of the structure and organization of a system of populations faced with varying rates of exploitation and energy or plant resource input.

Toxic substances can alter the structure and organization of systems of populations. The response of systems to toxic substances is affected by conditions in their environments such as rate of energy input and level of exploitation of their populations. In Figure 2, the carnivore population is able to persist at a low rate of energy input (low I) when it is heavily exploited (90E) if a toxic substance (T) is not present (the predator isocline identified by 90E, OT intersects the prey isocline identified by low I). But under these same environmental conditions at a toxicant concentration of 2T, the carnivore population is driven to extinction (C trajectory). The carnivore is able to persist, although at reduced biomass, at a toxicant concentration of 2T at low I when the carnivore is unexploited (OE), or at medium and high I when C is heavily exploited (90E). But toxicant at a concentration of 2T so altered carnivore adaptive capacity that it was no longer adapted to persist when heavily exploited at low I.

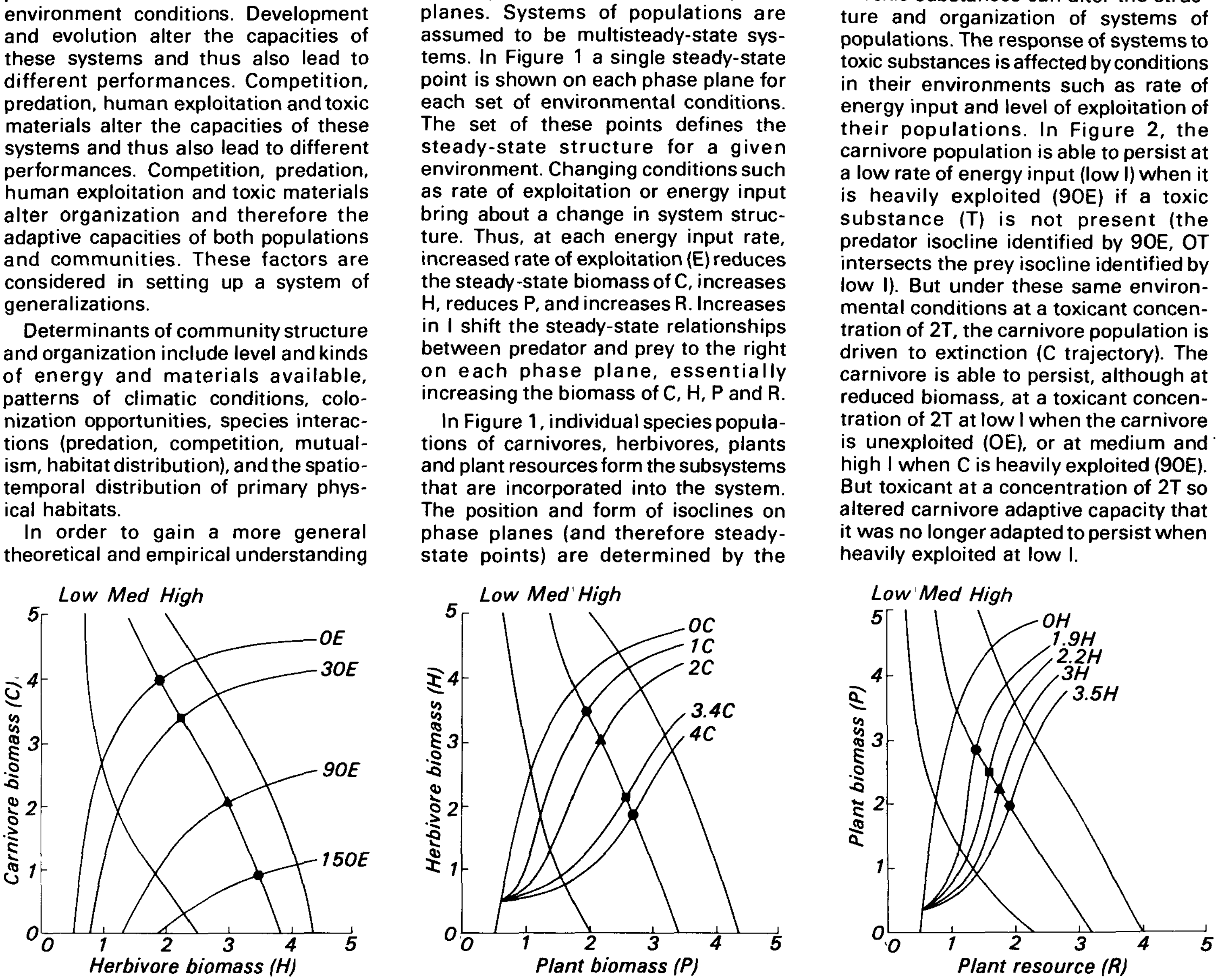

Figure 1. *Phase planes and isocline systems representing the inter-relationships between populations in a system represented as* $E \underset{+}{\overset{-}{\rightleftharpoons}} C \underset{+}{\overset{-}{\rightleftharpoons}} H \underset{+}{\overset{-}{\rightleftharpoons}} P \underset{+}{\overset{-}{\rightleftharpoons}} R \underset{+}{\longleftarrow} I$*, where C,H,P and R comprise the system and E, exploitation rate, and I, rate of energy or plant resource input, are factors in the environment of the system. Predator biomass is plotted on the y-axis of each phase plane and prey biomass is plotted on the x-axis. On each phase plane, 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 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 reduced from response functions representing the rates of gain and loss of each of the populations. At a particular level of I and E, a single steady-state point exists on each phase plane, the set of these points defining the steady-state biomasses of C, H, P, R at Med I and OE (circles), 30E (squares), 90E (triangles) and 150E (hexagons) are shown.*

The goal of this study is to advance the understanding of adaptive and other capacities and performances of individual organisms, populations and systems of populations exposed to dieldrin. Laboratory ecological systems composed of guppies, amphipods, snails, and various microinvertebrates were exposed to different environments—different exploitation rates, levels of habitat availability and energy input and exposure to the toxicant. Under each set of conditions, systems were allowed to reach steady-states. The specific objectives are as follows:

1) Determine and explain, under different sets of environmental conditions, the impact of dieldrin on the persistence, structure and organization of laboratory ecosystems in terms of concordance of the capacities and performances of the incorporated populations.
2) Determine and explain the impact of dieldrin on the adaptive capacity, life history patterns, production and yield, as well as density of the exploited population, and relate these to community structure and organization and environmental conditions.
3) In a separate aquarium experiment, determine and explain the impact of dieldrin on maturation, growth and reproduction of individuals of the exploited population, and relate these results to effects on life history patterns and population density of the exploited population and on system structure and organization observed in the laboratory ecological systems.

Figure 3 summarizes the relationships of predation and/or competition observed in the laboratory ecosystems. Exploitation and dieldrin, which in part decreased the survival of young, result in a decreased guppy population, as indicated by the negative signs. Alfalfa and light energy were both introduced into the ecological systems, as indicated by the positive signs.

Conclusions and Recommendations

1. The system of generalizations developed by the authors broadly conforms with observations of the laboratory ecosystems. Communities composed of persistent populations of guppies, snails, amphipods and assorted microinvertebrates established near steady-states. Conditions in the environments of the communities such as rate of exploitation of their populations, level of habitat availability and energy input, and exposure to dieldrin in part determined the steady-state structure that the system developed.
2. The capacities of ecological systems depend upon the way they are organized. Trophic organization entails interactions between populations such as competition, predation, mutualism and commensalism. Population interactions can be represented on phase planes, as summarized in Figure 4. In the laboratory ecosystems, populations of guppies, snails and amphipods competed for a common food source, the organic sediment. Amphipods were also prey of guppies. As a consequence of this organization, increases in exploitation rate resulted in reductions in near steady-state guppy biomass and increases in the near steady-state biomasses of their snail competitor and amphipod competitor/prey. Increases in habitat availability and energy input increased the biomasses of guppies, amphipods and snails at each exploitation rate.
3. One ppb of dieldrin continuously introduced into the laboratory ecosystems at the low level of habitat

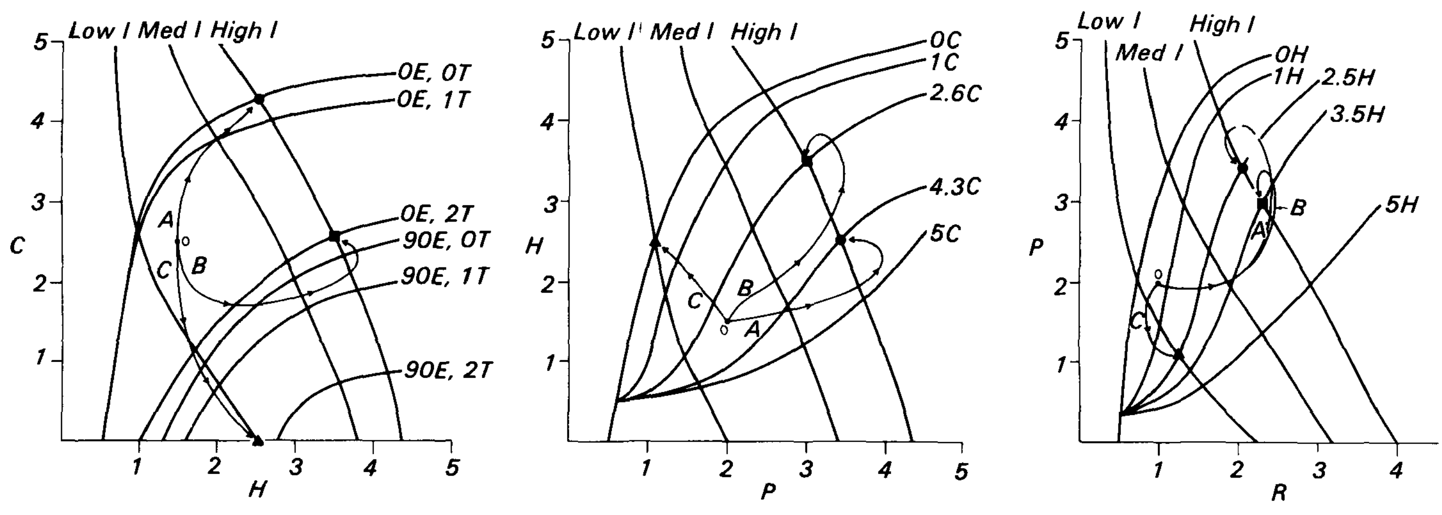

Figure 2. ***Phase planes and isocline systems illustrating a possible effect on different concentrations of a toxicant (T) on the structure of a simple community. In this example the toxicant directly affects only the carnivore population. Steady-state structure at high I and OE, OT (circles); high I and OE, 2T (squares); low I and 90E, 2T (triangles) is shown. Trajectories of biomasses of carnivore (C), herbivore (H), plant (P), and plant source (R) converging on each of these steady-states are shown. Introduction of toxicant at a concentration of 2T reduced carnivore biomass, increased herbivore biomass, reduced plant biomass and increased plant resource at high I, OE (compare circles and squares on all phase planes). At low I, in the absence of toxicant (OT), the carnivore is able to persist at 90E (prey isocline identified by low I intersects predator isocline identified by 90E, OT). But, at a concentration of 2T, the carnivore population is driven to extinction at 90E (prey isocline identified by low I does not intersect predator isocline identified by 90E, 2T). At higher I the carnivore is able to persist at 90E, 2T.***

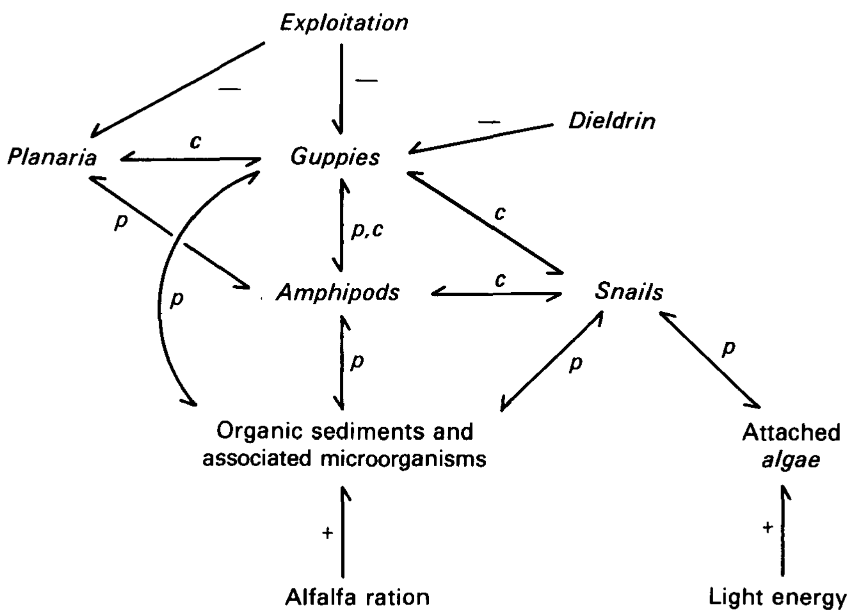

Figure 3. Kinetic diagram representing inferred trophic interrelations in the laboratory ecosystem. Population interactions are designated as predation (p) or competition (c). Exploitation, dieldrin, alfalfa ration, and light energy are variable.

availability and energy input directly affected only the exploited guppy populations. Other populations in the systems were affected only indirectly as a result of changes in guppy biomass. The response of the system to dieldrin ranged from initial reduction in biomass and subsequent recovery of the unexploited guppy population to extinction of the heavily exploited guppy population. Amphipods, a competitor and prey of guppies, increased in biomass as a result of the toxicant-induced reduction of guppy biomass.

4. Different near steady-state community structures were generated by different rates of exploitation and levels of habitat availability and energy input. Guppies developed different near steady-state life history patterns at different exploitation rates and levels of habitat and energy input. Thus, there was a correspondence between guppy life history pattern and community structure. At each level of habitat availability and energy input rate, increased exploitation rate reduced guppy population density and induced the following changes in life history pattern: reduced lifespan, reduced number of clutches per lifetime, increased growth, increased size of first reproduction, increased fecundity. Increases in growth and reproduction of individuals can be interpreted as life history adaptations enabling the population to persist at high levels of exploitation (or mortality), where longevity and clutch number are reduced. Guppy production and yield bear dome-shaped relationships to population biomass. Increases in habitat availability increase the magnitude of these curves.
5. Dieldrin altered guppy life history patterns by reducing survival, growth and fecundity. These alterations in guppy life history resulted in reductions in the magnitude of guppy production and yield curves. At the 40 percent exploitation rate, dieldrin may have caused population extinction by effectively preventing individuals from exhibiting life history patterns—more rapid growth, higher fecundity, increased offspring survival—that adapt the population to persist at high exploitation rates. Such heavily exploited populations, where rapid growth, high fecundity and good juvenile survival are essential for persistence, may be more "sensitive" to reductions in growth, fecundity and survival caused by toxicants than population exploited at lower rates. The density of the unexploited guppy population was reduced by exposure to dieldrin but recovered to pre-dieldrin levels while toxicant was still being introduced. This population was apparently able to adapt evolutionarily to the pesticide, with natural selection favoring individuals with more "resistant" life histories. The "recovered" population may have been composed of individuals with quite different life history capacities than the population prior to dieldrin introduction.
6. Separate aquarium experiments were conducted to evaluate effects of dieldrin on guppy life history patterns at different food rations. Dieldrin concentrations in these experiments were similar to the concentration to which the guppies in the laboratory ecosystems were exposed. Guppy life history patterns observed at different food rations were broadly similar to near steady-state life history patterns observed at different exploitation rates and community structures in the laboratory ecosystems. Thus, different food rations in aquarium experiments generated life history patterns similar to those occurring at different exploitation rates. Perhaps life history patterns observed in these simple experiments can be *thought of*, in the broadest sense, as steady-state life history patterns that would exist in some steady-state community structure generated by some fixed set of environmental conditions. Thus, using ecological theory, perhaps meaning can be written onto the results of such simple experiments.
7. Effects of dieldrin on life history patterns observed in aquarium experiments resembled effects observed in laboratory ecosystems—reduced juvenile survival, decreased growth and reproduction. However, it is not as evident how the diversity of effects of population abundance, ranging from perturbation and recovery at zero percent exploitation to extinction at 40 percent exploitation, could have been predicted from these simple aquarium experiments. Perhaps, with appropriate theory, such effects would have become apparent. Interpretation of simple aquarium experiments is not a matter of direct extrapolation to complex systems. Ecological theory should be used as a "vehicle" of extrapolation,

and it is in the context of such theory that results of simple aquarium experiments can be given meaning.

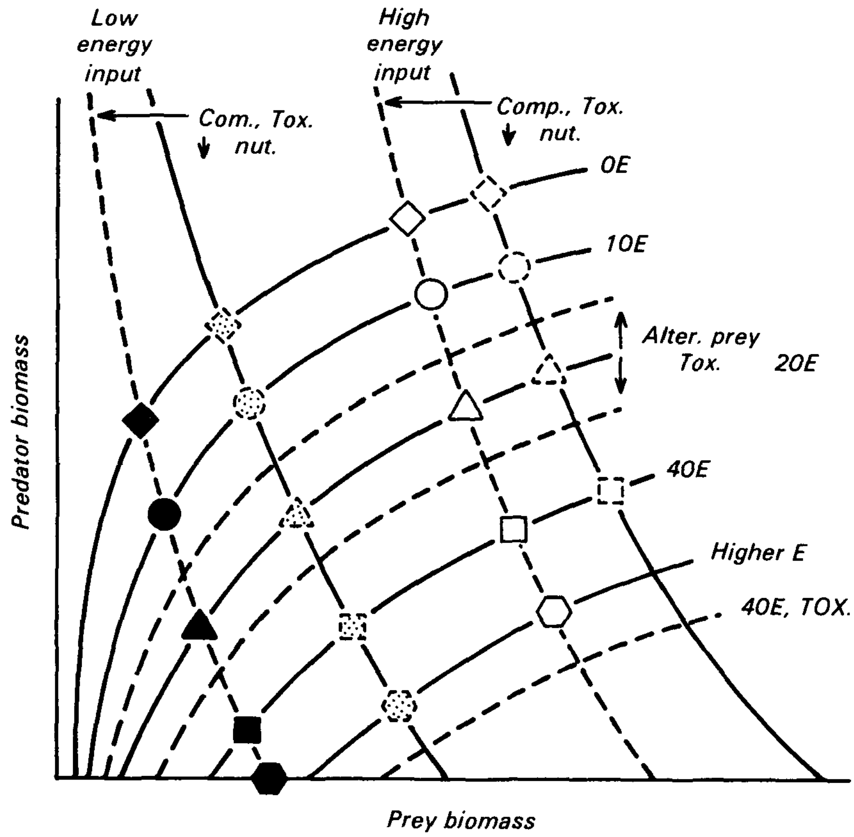

Figure 4. *Generalized phase plane and isocline systems representing the interaction between predator and prey, and some possible effects of energy input rate (I), competition (comp.), toxic substances (tox.), plant nutrients (nut.), exploitation (E), and alternative prey (alter. prey). Steady-state points are indicated at th intersections of predator and prey isoclines. At each rate of energy input, prescence of a competitor, toxic substances, or decrease in plant nutrients can shift the prey isocline to the left on the phase plane and can cause reduction insteady-state predator and prey biomass at each exploitation rate, presence of alternative prey can increase and toxic substances lower a predator isocline as shown at 20E. If a predator isocline identified by a particular level of environmental factor (e.g. higher E or 40E, TOX.) does not intersect a prey isocline identified by another environmental factor or factors (e.g. low energy input with competitor present -- dashed prey isocline), then the predator population cannot persist under that set of environmental conditions (solid hexagon).*

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The complete report, entitled "Organization and Adaptation of Aquatic Laboratory Ecosystems Exposed to the Pesticide Dieldrin," (Order No. PB 82-219 122; Cost: $12.00, subject to change) will be available only from:
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