Environmental Pollution Course

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ENVIRONMENTAL PROTECTION DEPARTMENT
IMPERIAL OIL LIMITED

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"The greatest problem

facing man today

is the ecological one

of harmonious adjustment

to the ecosystem

of which he is a part."

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PREFACE

There is today a great deal of concern about the deterioration of our environment. In some cases the concern is genuine, at other times it is exaggerated or untrue. In order to separate fact from fiction, it is necessary to first have a broad understanding of the principles and processes operating in an environment.

The "Environmental Pollution Course" presented on the following pages, was originally prepared for, and presented to Imperial Oil personnel across Canada, to add to their understanding of the environment and the effects of pollution on the environment.

Because of the general nature of the course, and its wide field of coverage, it was not possible to deal extensively and in great detail with specific topics. Rather, it was the intent to merely touch the surface of the subject content, and draw its outline, with the hope of providing an overall picture. The course content tends to be geared heavily to the water environment. But although the examples are predominantly oriented towards water, the underlying principles themselves apply generally to any type of environment - aquatic or terrestrial.

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INTRODUCTION

Pollution may be operationally defined in terms of its effects on living organisms. In this sense the assessment of pollution should be primarily a biological one. Most studies of pollution however, have been oriented toward chemical and physical standards, with the biological aspects either omitted or in low priority.

There are a number of reasons for this exclusion of biological data when assessing the effects of pollution. To begin with, chemical and physical data can usually be transformed into numerical expressions that are easy to use and express. Secondly, the collection of biological data is often considered time consuming, expensive, and difficult to express in a meaningful manner. Thirdly, there is often a lack of basic biological background experience among the very people concerned with pollution. This is unfortunate, for attempting to deal with a specific environmental pollution problem without fully understanding the underlying biological principles that operate in an unpolluted and polluted environment can often lead to misinterpretation, oversimplification, or gross error.

The content of "Environmental Pollution Course" is set up so that, in the first section, we may become familiar with the biological principles operating in a natural, unpolluted environment, including the individual, population, community, and ecosystem concepts. This is designed to provide a baseline from which we can then proceed to the second section on a polluted environment, and see the effects of pollution on these four levels of integration. The third section deals with biological information systems, and their importance as a source of biological data for assessing the effects of pollution. The fourth concluding section deals briefly with man and his environment.

UNPOLLUTED ENVIRONMENT

TERMINOLOGY

The relationship of a plant or animal to its surroundings is termed an ecological relationship, or more commonly the ecology of the organism. The phrase "ecology being damaged" does not refer to a physical destruction, but rather to the breakdown of relationships between various components of the environment.

All ecological relationships take place in a physical-chemical setting, i.e. a non-living or abiotic setting. Abiotic elements include the basic inorganic materials such as water, carbon dioxide, oxygen, etc. and physical factors such as moisture, wind, currents, temperature, light, etc. Within this abiotic setting there exists the plants, animals and microbes, that is the biotic components of the environment. The biotic components interact with one another and with the abiotic components in a fundamentally energy-dependent fashion.

The abiotic and biotic elements together comprise an ecological system, or an ecosystem. An ecosystem is a community of organisms interacting with one another plus all the external influences around them with which they live and also interact. These influences on an ecosystem are collectively called the environment. Used in its proper context, an environment is all the external influences and conditions that affect the life and development of an organism.

The concept of an ecosystem is an abstraction. It is abstract in the sense of being a conceptual scheme developed from a knowledge of real systems.Yet in spite of the great diversity in types of ecosystems - from small to large, terrestrial to aquatic, laboratory to field, and in spite of the unique combinations of particular abiotic and biotic components in any one ecosystem, there are certain general structural and functional attributes that are recognizable. The first of these structural attributes is the individual.

INDIVIDUAL CONCEPT

An individual, during its life time, has but one ultimate role - that of producing offspring. An individual is constantly subjected to stress and adversity from its environment that could result in death or a loss of reproductive capabilities. As such, one individual by itself is not an important factor in the over-all ecological system. It is a frail, vulnerable, and highly unstable entity. To overcome these limitations individuals tend to form groups, which are in turn combined with other groups of organisms, to form a particular community. When a group of similar individuals occur in close proximity to each other, they are referred to as a population.

POPULATION CONCEPT

A population is a group of potentially breeding individuals at a given locality. Each individual is a member of a natural population that is reproductively isolated from other populations of different types of individuals.

There are two opposing forces operating in the growth and development of a population: one of these is inherent, and characteristic of each species - the ability to reproduce at a given rate; opposing this is an inherent capacity for death. This opposition comes from all the forces of the physical, chemical and biological environment in which an individual exists. These two opposing forces are called respectively, biotic potential, and environmental resistence.

It is the role of the population to ensure that environmental resistence never exceeds a species biotic potential.

Populations typically follow a growth pattern that is sigmoidal in shape, (Fig. 1). The initial growth period is slow. This is followed by a period of rapid increase, and then finally a slowing down. When the growth rate levels off, and there is no net change in population, it has reached an equilibrium with the surrounding environment. That is, it has reached the limit at which the environment can support the population, a limit referred to as the carrying capacity of the environment. If some factor of the environment is shifted, a different equilibrium level may result, so that 'carrying capacity', like most other ecological concepts, is subject to change.

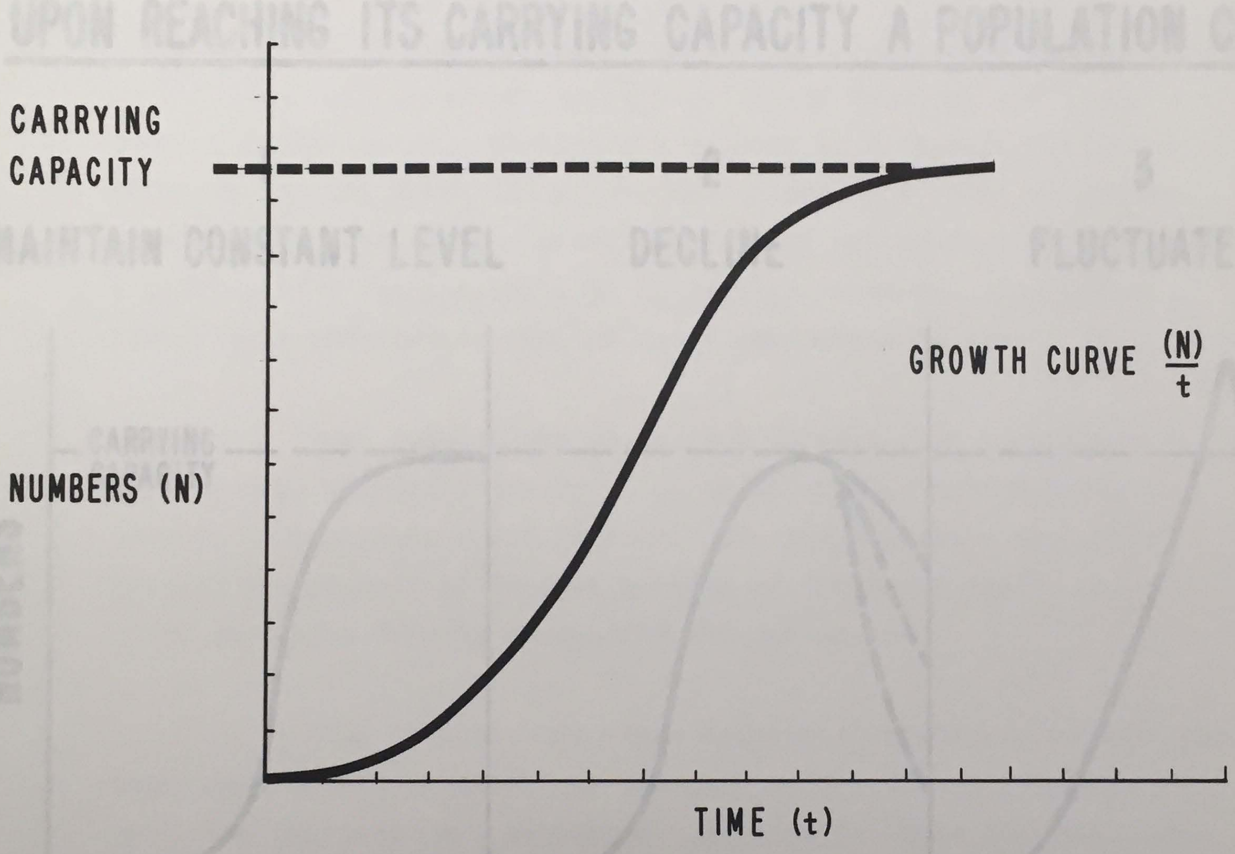
Once a population reaches its carrying capacity a number of possibilities exist, (Fig. 2):

1. the population will maintain itself at the same level for an infinite length of time.
2. the population will decline and may eventually succumb to extinction.
3. the population will fluctuate either regularly or irregularly.

The first type, in which a population maintains itself for a infinite length of time, is rare. It will occur only where the supply of food is unlimited, where harmful biproducts are continuously removed, and where all other environmental factors remain unaltered.

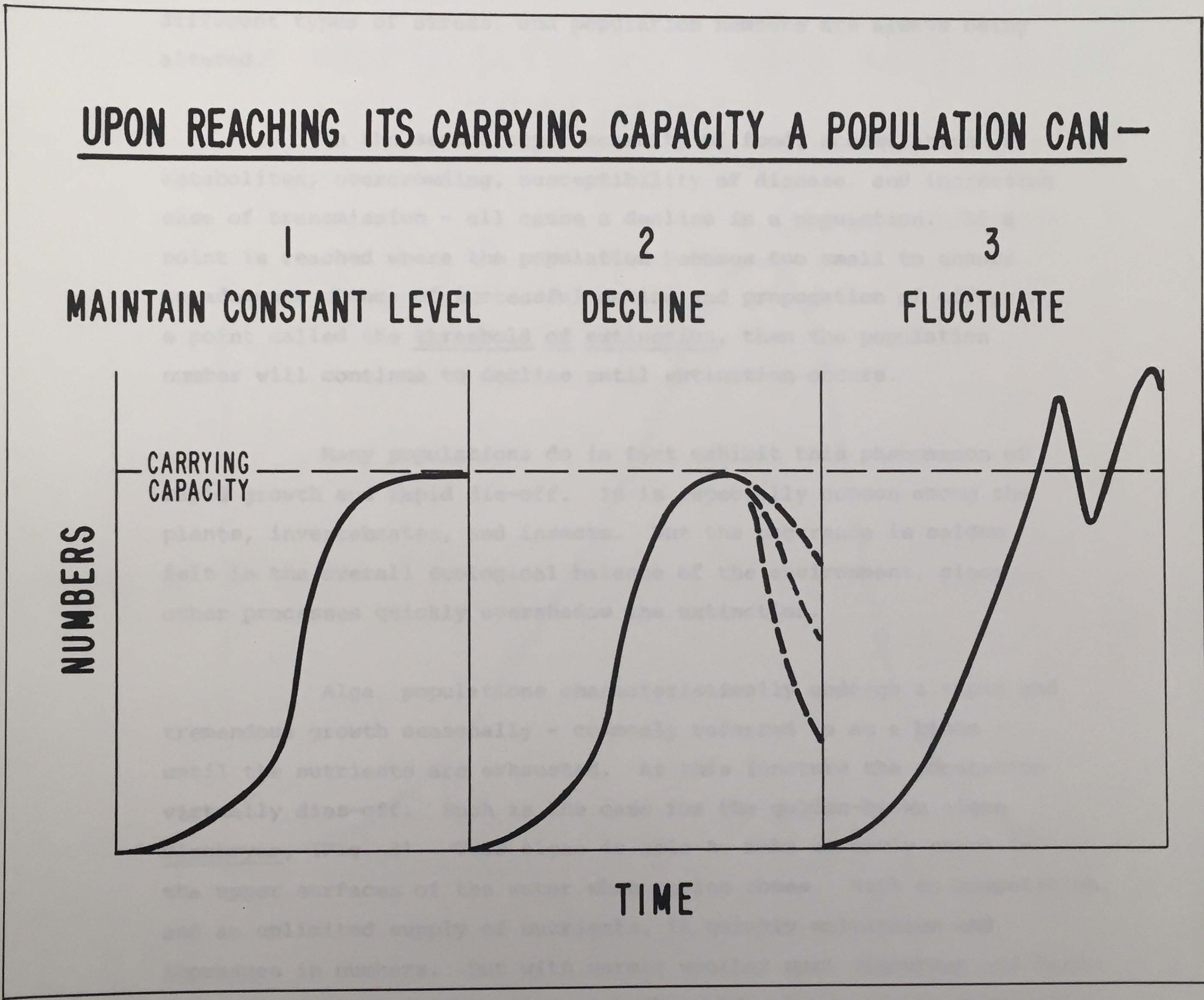
FIGURE I

POPULATION IN GROWTH PATTERN



CARRYING CAPACITY – THAT POINT IN THE GROWTH CURVE IN WHICH THE POPULATION IS AT EQUILIBRIUM WITH THE ENVIRONMENT, RESULTING IN NO NET CHANGE IN POPULATION NUMBERS.

FIGURE 2


UPON REACHING ITS CARRYING CAPACITY A POPULATION CAN—
1
MAINTAIN CONSTANT LEVEL
2
DECLINE
3
FLUCTUATE
CARRYING CAPACITY
NUMBERS
TIME

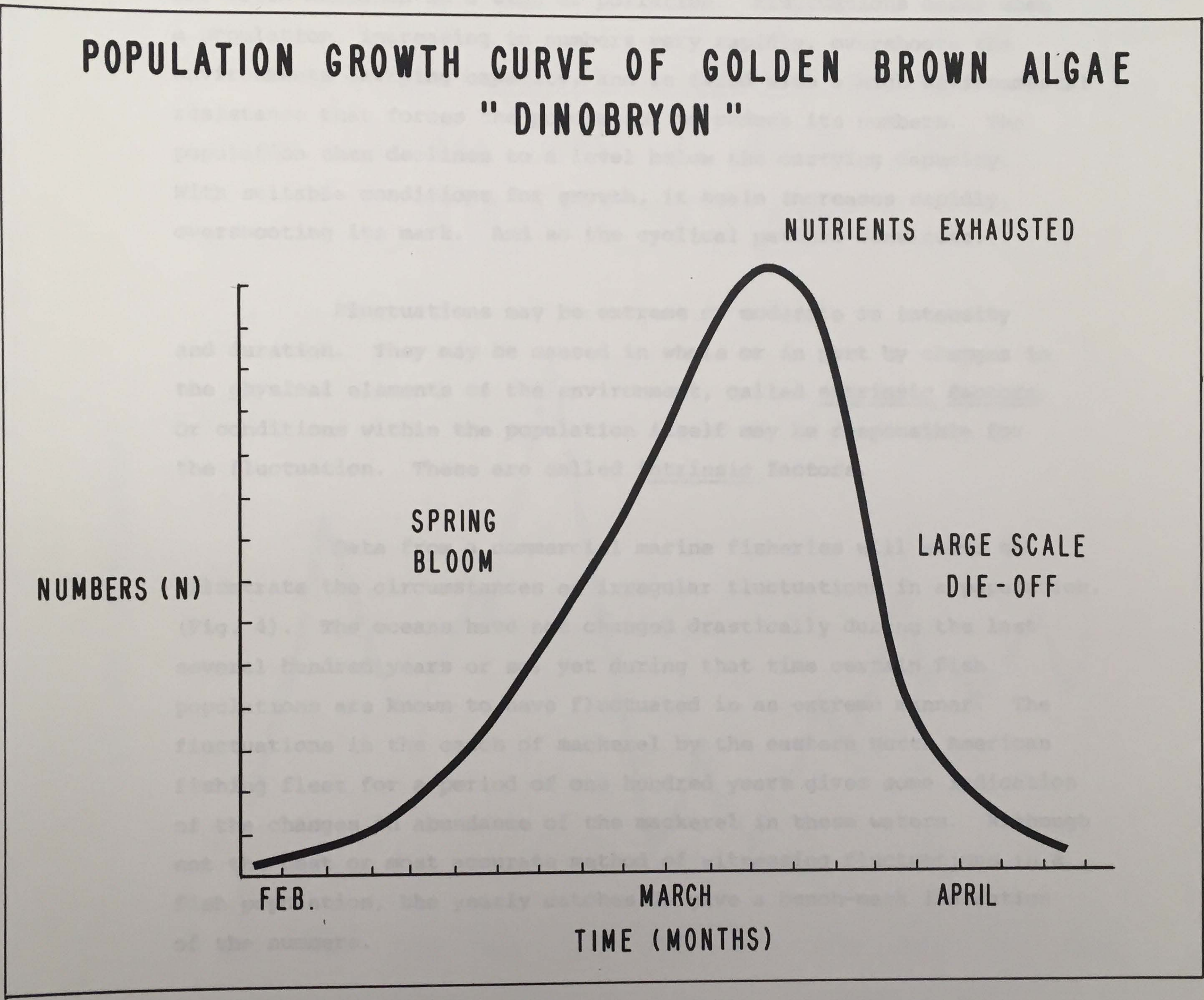
Such a situation is common only in controlled laboratory settings. In nature, environmental conditions are constantly changing over time. Individuals are continually being subjected to new and different types of stress, and population numbers are always being altered.

In the second type, scarcity of food, accumulation of metabolites, overcrowding, susceptibility of disease, and increasing ease of transmission - all cause a decline in a population. If a point is reached where the population becomes too small to ensure an adequate chance of successful mating and propogation of offspring, a point called the threshold of extinction, then the population number will continue to decline until extinction occurs.

Many populations do in fact exhibit this phenomenon of rapid growth and rapid die-off. It is especially common among the plants, invertebrates, and insects. But the occurence is seldom felt in the overall ecological balance of the environment, since other processes quickly overshadow the extinction.

Alga populations characteristically undergo a rapid and tremendous growth seasonally - commonly referred to as a bloom - until the nutrients are exhausted. At this juncture the population virtually dies-off. Such is the case for the golden-brown algae Dinobryon, (Fig. 3). This algae is able to make an early start in the upper surfaces of the water when spring comes. With no competition, and an unlimited supply of nutrients, it quickly multiplies and increases in numbers. But with warmer weather more vigourous and hardy types of algae begin competing with the golden-brown algae, eventually starving it out of the area.

FIGURE 3


POPULATION GROWTH CURVE OF GOLDEN BROWN ALGAE
" DINOBRYON "
NUTRIENTS EXHAUSTED
SPRING
BLOOM
LARGE SCALE
DIE-OFF
NUMBERS (N)
FEB.
MARCH
APRIL
TIME (MONTHS)

The third type, fluctuation of numbers, is the most usual situation. These fluctuations are significant in that they are often mistaken as a sign of pollution. Fluctuations occur when a population, increasing in numbers very rapidly, overshoots the environments carrying capacity, and is faced with a high environmental resistence that forces the population to reduce its numbers. The population then declines to a level below the carrying capacity. With suitable conditions for growth, it again increases rapidly, overshooting its mark. And so the cyclical pattern continues.

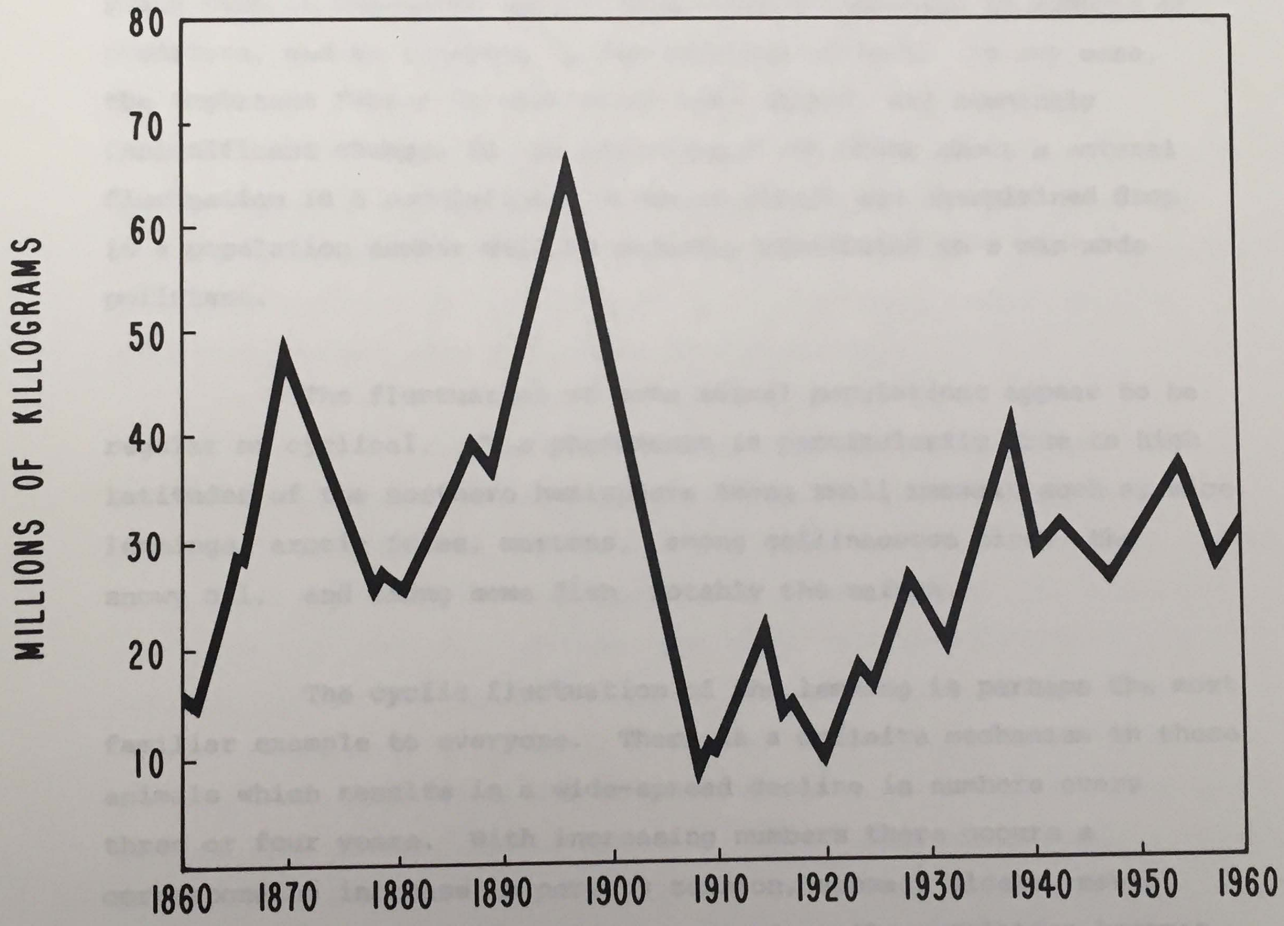
Fluctuations may be extreme or moderate in intensity and duration. They may be caused in whole or in part by changes in the physical elements of the environment, called extrinsic factors. Or conditions within the population itself may be responsible for the fluctuation. These are called intrinsic factors.

Data from a commercial marine fisheries will serve to illustrate the circumstances of irregular fluctuations in a population, (Fig. 4). The oceans have not changed drastically during the last several hundred years or so, yet during that time certain fish populations are known to have fluctuated in an extreme manner. The fluctuations in the catch of mackerel by the eastern North American fishing fleet for a period of one hundred years gives some indication of the changes in abundance of the mackerel in these waters. Although not the best or most accurate method of witnessing fluctuations in a fish population, the yearly catches do give a bench-mark indication of the numbers.

The fluctuations are due, at least in part, to the production of year-classes in which many more fish reach commercial size than in other year-classes. The causes of the varying success of different year-classes however are difficult to ascertain.

FIGURE 4

FLUCTUATIONS IN MACKEREL CATCH FROM EASTERN COAST OF NORTH AMERICA OVER LAST 100 YEARS



Usually plenty of eggs are spawned every year. Very rarely does unusual mortality occur after commercial size has been reached. The critical point comes somewhere in very early life. Since the general nature of the ocean does not change, some subtle variation in the environment must arise during a sensitive stage of the mackerel's development. Possibly it could be an abnormal temperature in the spawning area, or perhaps a serious change in the abundance of plankton in the ocean. Or possibly the survival of young fish is dependent upon a simultaneous reduction in numbers of predators, and an increase in availability of food. In any case, the important factor is that often very subtle, and seemingly insignificant changes in the environment can bring about a natural fluctuation in a population. Often an abrupt and unexplained drop in a population number will be unjustly attributed to a man-made pollutant.

The fluctuation of some animal populations appear to be regular or cyclical. This phenomenon is particularily true in high latitudes of the northern hemisphere among small mammals such as mice, lemmings, arctic foxes, martens, among gallinaceous birds, the snowy oil, and among some fish, notably the salmon.

The cyclic fluctuation of the lemming is perhaps the most familiar example to everyone. There is a definite mechanism in these animals which results in a wide-spread decline in numbers every three or four years. With increasing numbers there occurs a corresponding increase in nervous tension, stomach ulcers, mental disorder, and just plain restlessness. Once the population becomes so great as to reach some breaking threshold - mating ceases and no offspring are produced. Within one or two years the population has declined to acceptable numbers. With few natural predators, lots of room to expand and plenty of food, combined with a high birth rate, the population soon overshoots its carrying capacity again, thus triggering another die-off.

The lemmings cyclic fluctuations are caused by conditions within the population itself; that is, by intrinsic factors. In fact, the majority of regular, cyclic fluctuations in all populations are the result of intrinsic factors. Irregular fluctuations however are usually caused by extrinsic factors; factors outside the realm of the population itself.

The size of a population then, or its carrying capacity in the environment, is determined by the interplay of the biotic potential and the environmental resistence. Ordinarily the full biotic potential of plants and animals in nature is seldom reached. Environmental restraints keep a strong check on the population.

In some cases however even a slight variation in environmental resistence may produce a marked effect on abundance. Consider a hypothetical case. You are intending to do some year-class studies on a particular fish species in a lake. (Year-class studies are those that follow a species from birth through maturity). The species you are interested in spawns each year and produces about a million eggs, which is a fairly conservative number. In the first year the mortality rate among the eggs was 99.9%, also a fairly conservative number. The following year however, one of the environmental restraints was removed from the scene or lessened, and the percent mortality dropped from 99.9% to 99.8%. Now although the mortality dropped only 0.1%, a seemingly insignificant amount, the number of eggs left to develop and grow into adult fish increased from 1,000 the first year to 2,000 the second year, or an increase of 1,000 eggs per female spawned. Should this occur for every female spawned in the lake, or should the percentage drop from 99.9% to 99.5%, it's evident that the difference in numbers of surviving eggs between the two years would be exceptionally great.

Obviously many other environmental restraints work against the fish as it is growing and developing, thereby reducing the number of fish that eventually reach adulthood, so that the difference between the two years will not seem so great when viewing the adult year-classes. Nevertheless, some change in the two year-classes will be evident, caused by that 0.1% egg mortality.

To retrace our steps for a moment, we have looked at the individual, whose sole role in the environment is to produce offspring. Individuals are highly unstable and tend to clump together into groups. These groups are referred to as populations, and populations are designed to add some degree of stability to the individual, thereby increasing its reproductive potential.

Populations in turn tend to group together to form a community. They do this for the same reason that individuals group together - increased stability.

COMMUNITY CONCEPT

The plants and animals living in any natural area form an assemblage in which each individual finds the environment to be tolerable, and is provided with at least the minimum sustaining requirements. The presence of many populations are necessary for the continued life of other populations, and although antagonism does occur, the beneficial interactions outway the unfavourable interactions. Such groups or populations of mutually adjusted plants and animals inhabiting a natural area is known as a community.

The general concept of community as a number of populations of mutually adjusted organisms maintaining themselves in an area, is clear. But the conceptual isolation of specific communities and their limits is somewhat difficult. Part of this difficulty is due to the fact that although every plant and animal has functional interelations with a variety of other organisms in its environment, the host of mutually-dependent individuals are often not clearly distinguishable as a unit. In some instances the limits of a community as a functional entity are fairly definite, as is generally true of a pond, or small island. In other instances, the activities of the individuals in one community may overlap those of another community to such an extent that no specific margins can be set.

Yet in spite of the difficulties in delimiting communities, it is clear that community members share in common the ability to live under the conditions existing in the area, and to a greater or lesser degree they are dependent upon one another.

As with most other concepts, the community concept has developed its own unique set of terms. Only a limited few will be mentioned here. The first of these is the biotope. Any clearly distinguished unit of the environment showing uniformity of principle habitat conditions is known as a biotope. The term may be applied to any individual area. For example, a mud flat, beach, desert, or stream are all types of biotopes, and each supports a characteristic type of community.

Another term used when describing communities is dominant species. In many communities one species may be particularly conspicuous because it is the largest, or the most numerous, or because it exerts a controlling influence over the other members of the community. This species is referred to as the dominant species.

The last term of interest describes the transition zone of tension between adjoining communities. It is a situation of unique ecological interest, and is known as the ecotone. In some situations the transition between communities is abrupt, and the ecotone is correspondingly narrow. Such is the case for the transition zone between a forest and a stream. The ecotone may be a small marshy area, or it may be a narrow strip of sand or rock. In other circumstances one community may give way only gradually to the other community, resulting in a wide ecotone.

Communities may be large or small. Some may cover thousands of square miles, such as a spruce forest in Canada's north, a prairie community, tundra community, or an oceanic community. Others may be smaller such as a lake, or desert, while others may occupy a very restricted area, such as a pond, river, or meadow.

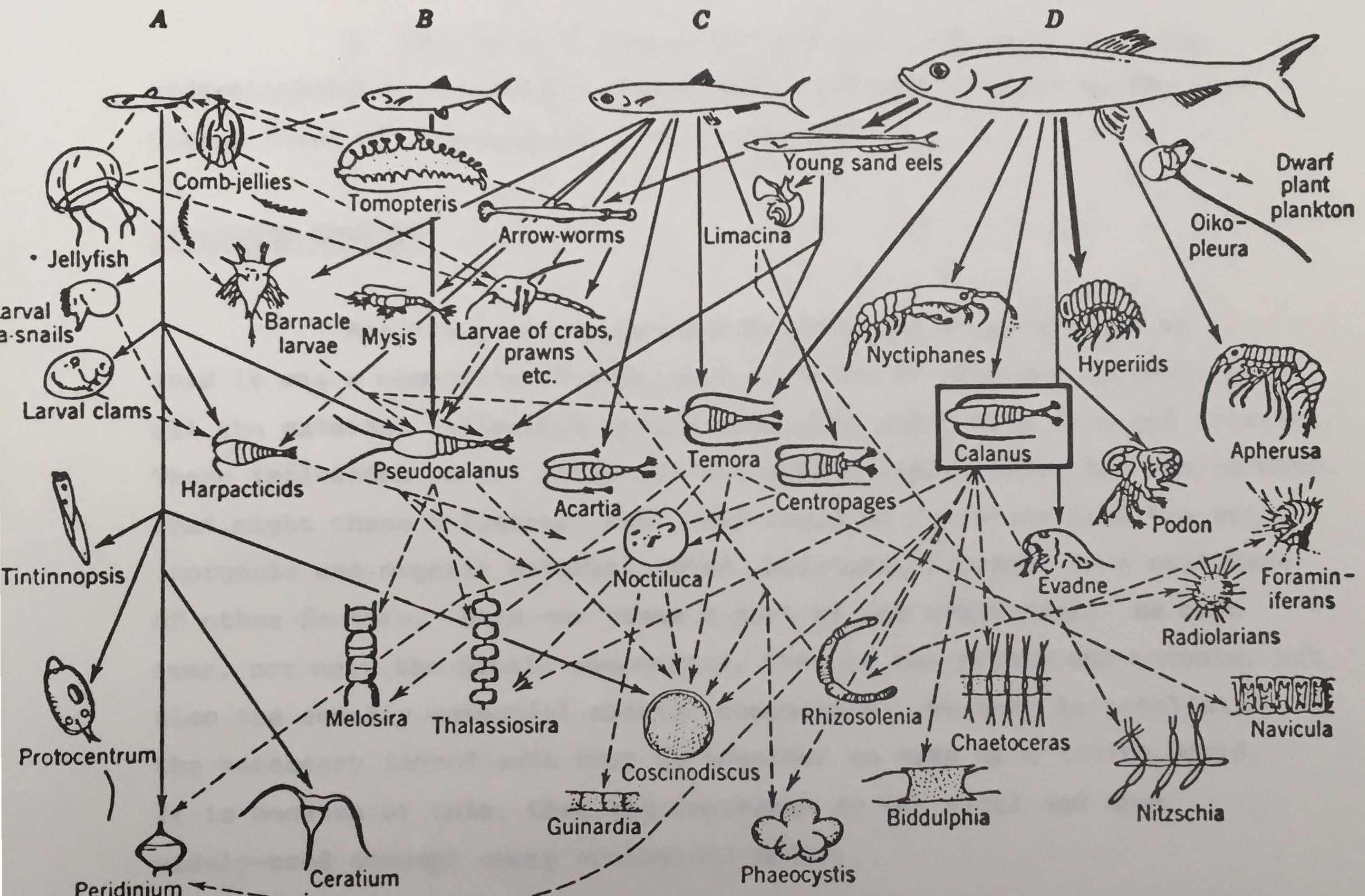
The number of species and population abundance can also vary greatly. Biotopes with extreme conditions and little food, as the deep ocean, generally supports few species and relatively few individuals in each species. Under more suitable conditions, large numbers of species generally become inter-related in community groups, and each species is usually rather meagerly represented.

Consider for example the Atlantic herring, (Fig. 5). It is a member of a community of organisms that live in the euphotic zone of the ocean, i.e. the lighted region that extends down from the water surface to the level at which photosynthesis fails to occur because of ineffective light penetration. The food relationships of the herring involve a great number of species. Possibly by examining these food relationships we can get our first indication as to why the existence of communities is so beneficial to the stability of the environment. Consider, for instance, that some natural environmental restraint removed the copepod Calanus from the community, (see box in Fig. 5). Would it be reasonable to suggest that the elimination of this population would completely disrupt the whole community? In actual fact, the chances are very slight that removing Calanus would significantly harm the community.

The reason is this - there is such a large number of species actively competing with one another for food and space, that the void caused by removal of one population will be quickly filled by other populations with similar requirements. Thus the overall ecological system will not be drastically altered.

So we find that whereas the individual is highly unstable, the population moderately stable, though prone to fluctuation, the community is a highly stable entity. But it is not stable in the sense of being uniform and static. Communities are dynamic, ever-changing in composition and function in response to both immediate and long-term environmental changes. The seeming stability of present-day communities is somewhat deceptive, for as a biological unit, they remain stable by not being static.

FIGURE 5



The food relations of the herring at different stages in its life. Sizes of herring indicated are (A) 0.6 to 1.3 cm, (B) 1.3 to 4.5 cm, (C) 4.5 to 12.5 cm, and (D) over 12.5 cm. Solid lines point to food eaten directly by herring; other links in the food chains are dotted.

When we talk about communities we are talking about the living components and their interactions with one another. But what about all the other non-living factors in an environment, such as energy intake, nutrient cycling, etc.

To include both biotic and abiotic components into the understanding of our natural environment, we must proceed to the next higher level of integration - the ecosystem.

ECOSYSTEM CONCEPT

Recalling our previous definition of an ecosystem, we said it was a community of organisms interacting with one another, plus all the external influences around them with which they live and interact. These influences on the ecosystem are collectively called the environment. What might these influences be? They could be radiation from the sun, inorganic and organic material, wind, moisture, current, or a multitude of other factors. When one views a part of his environment, he then sees, not only the biotic components, that is the plants and animals, but also the equally essential abiotic components. He sees in total all the necessary ingredients that go together to make up a living world. It is because of this, that the ecosystem is the vital and most widely-used concept among ecologists today.

The fundamental steps in the operation of an ecosystem are as follows:

1. reception of energy;
2. production of organic matter by producers;
3. consumption of this material by consumers;
4. decomposition to inorganic compounds;
5. transformation to forms suitable for the nutrition of the producers.

Biological activity involves the utilization of energy; energy which comes ultimately from the sun, and which is transformed from the radiant to the chemical form via photosynthesis, and from the chemical to mechanical and heat forms via cellular metabolism. These conversions are fundamental to the energetics of ecosystems.

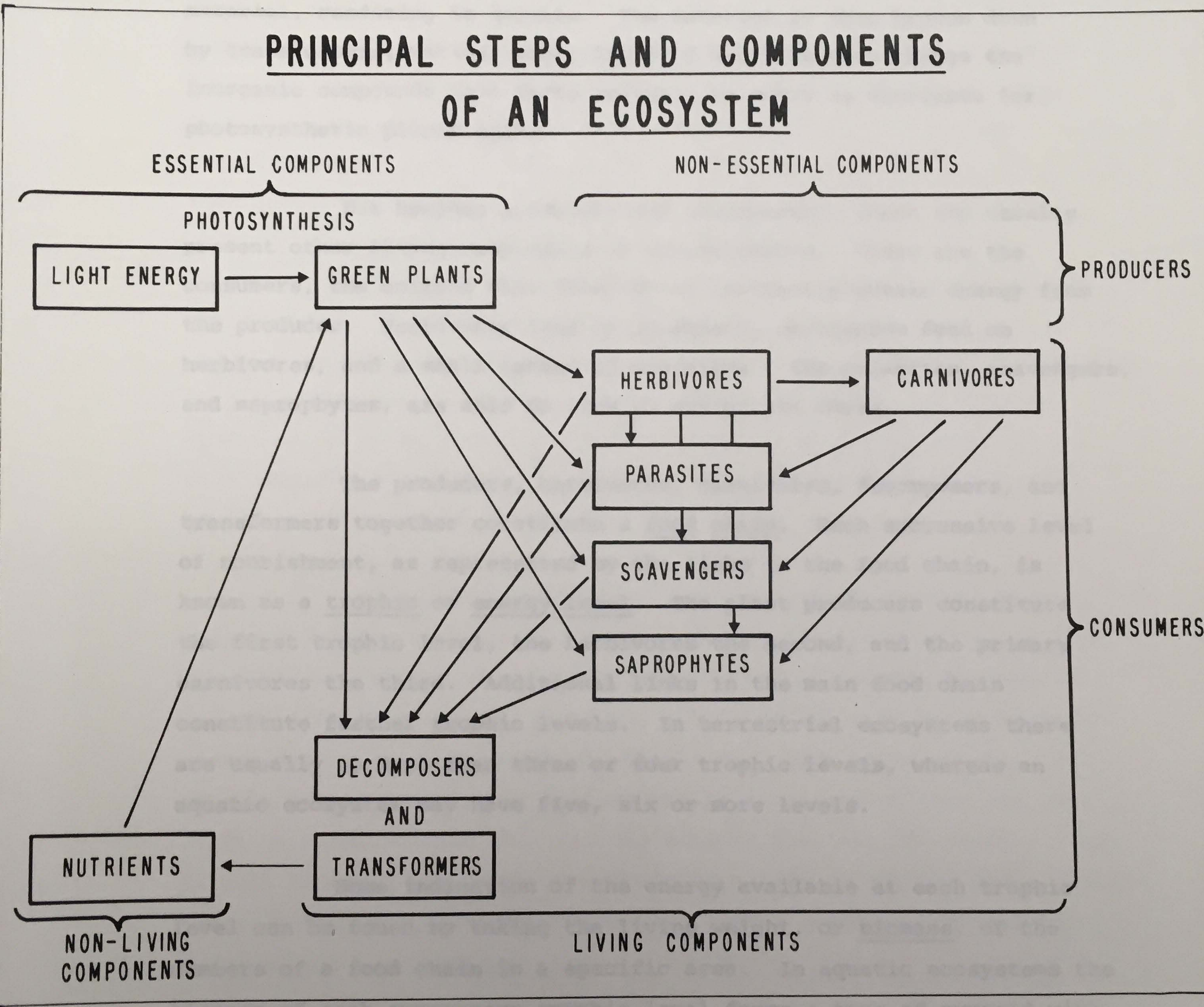
Radiant energy is used in the photosynthetic process whereby carbon dioxide is assimilated into energy rich carbon compounds. The basic photosynthetic process combines carbon dioxide and water, in the presence of radiant energy and chlorophyll, to form a carbohydrate molecule , with a bi-product of oxygen.

$$6\ CO_2 + 12\ H_2O \xrightarrow[\text{chlorophyll}]{\text{673 Kilocalories}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Those organisms that contain chlorophyll and perform this process are the producers. Since the energy produced by photosynthesis is subsequently synthesized into other molecules that serve the nutritional requirements of the producers own growth and metabolism, the producer is referred to as being autotrophic, or self-feeding. Organisms who's nutritional needs are met by feeding on other organisms are referred to as being heterotrophic, or other-feeding. Heterotrophic organisms are consumers. A primary consumer, or what we call a herbivore, derives its energy directly from the plants; a secondary consumer, commonly called a carnivore, derives its energy indirectly from plants by consuming the herbivore.

Looking at the principal steps and components of an ecosystem, (Fig. 6) we can start with the essential non-living components. Only two are needed - radiant energy from the sun and a supply of nutrients. With these two components, the green plants (the producers in this system) can synthesize organic material through photosynthesis. Theoretically only two other living components are

FIGURE 6


PRINCIPAL STEPS AND COMPONENTS OF AN ECOSYSTEM
ESSENTIAL COMPONENTS
NON-ESSENTIAL COMPONENTS
PHOTOSYNTHESIS
LIGHT ENERGY
GREEN PLANTS
PRODUCERS
HERBIVORES
CARNIVORES
PARASITES
SCAVENGERS
SAPROPHYTES
CONSUMERS
DECOMPOSERS
AND
TRANSFORMERS
NUTRIENTS
NON-LIVING COMPONENTS
LIVING COMPONENTS

essential - the decomposers and the transformers. Decomposers, consisting of bacteria and types of fungi, feed on dead organic material, rendering it soluble. The material is then broken down by transformers, various other types of bacteria that change the inorganic compounds into forms suitable to serve as nutrients for photosynthetic plants again.

But besides producers and decomposers, there are usually present other living components of the ecosystem. These are the consumers, the animals that directly or indirectly obtain energy from the producer. Herbivores feed on producers, carnivores feed on herbivores, and a small number of organisms - the parasites, scavengers, and saprophytes, are able to live on any of the three.

The producers, herbivores, carnivores, decomposers, and transformers together constitute a <u>food chain</u>. Each successive level of nourishment, as represented by the links in the food chain, is known as a <u>trophic</u> or <u>energy level</u>. The plant producers constitute the first trophic level, the herbivores the second, and the primary carnivores the third. Additional links in the main food chain constitute further trophic levels. In terrestrial ecosystems there are usually no more than three or four trophic levels, whereas an aquatic ecosystem may have five, six or more levels.

Some indication of the energy available at each trophic level can be found by taking the living weight, or <u>biomass</u>, of the members of a food chain in a specific area. In aquatic ecosystems the biomass of each successive trophic level forms a type of pyramid with the plants - the phytoplankton and bottom flora at the first trophic level; the herbivores - usually zooplankton, at the second trophic level; followed by macroscopic invertebrates and various sizes and species of fish at succeeding levels. In a typical ecosystem the size of the organism tends to increase with higher trophic levels; this is influenced simply by the predator-prey relationship. But whereas size increases, total biomass tends to become less - that is there is less living weight at each succeeding trophic level. Ipso facto, a reduction of numbers must take place in the food chain. A relationship of numbers, size, and biomass, then is another consequence in the operation of an ecosystem.

Implicit also in this producer-consumer relationship is the direction of energy movement. It is unidirectional and non-cyclic. Radiant energy in the form of sunlight is the only significant source of energy for any ecosystem. The rationelle for this non-cyclic behaviour is to be found in the fact that energy losses occur at each transfer along the chain because there is not 100% efficiency of energy utilization within each link of the chain.

In the photosynthetic system, usually 1% or less of the sunlight falling on green plants is actually converted to the kind of chemical bond energy that is available to animals eating the plants. Roughly 10% of that store of energy in plants may turn up as available energy in the chemical bonds of animals that have eaten plants. And roughly 10% of that energy in turn may be incorporated into the chemical bonds of other animals that eat the animals that eat the plants. Thus at each transfer of energy in a food chain, 90% or more of the chemical energy stored in organisms of the lower level becomes unavailable to those of the next higher level.

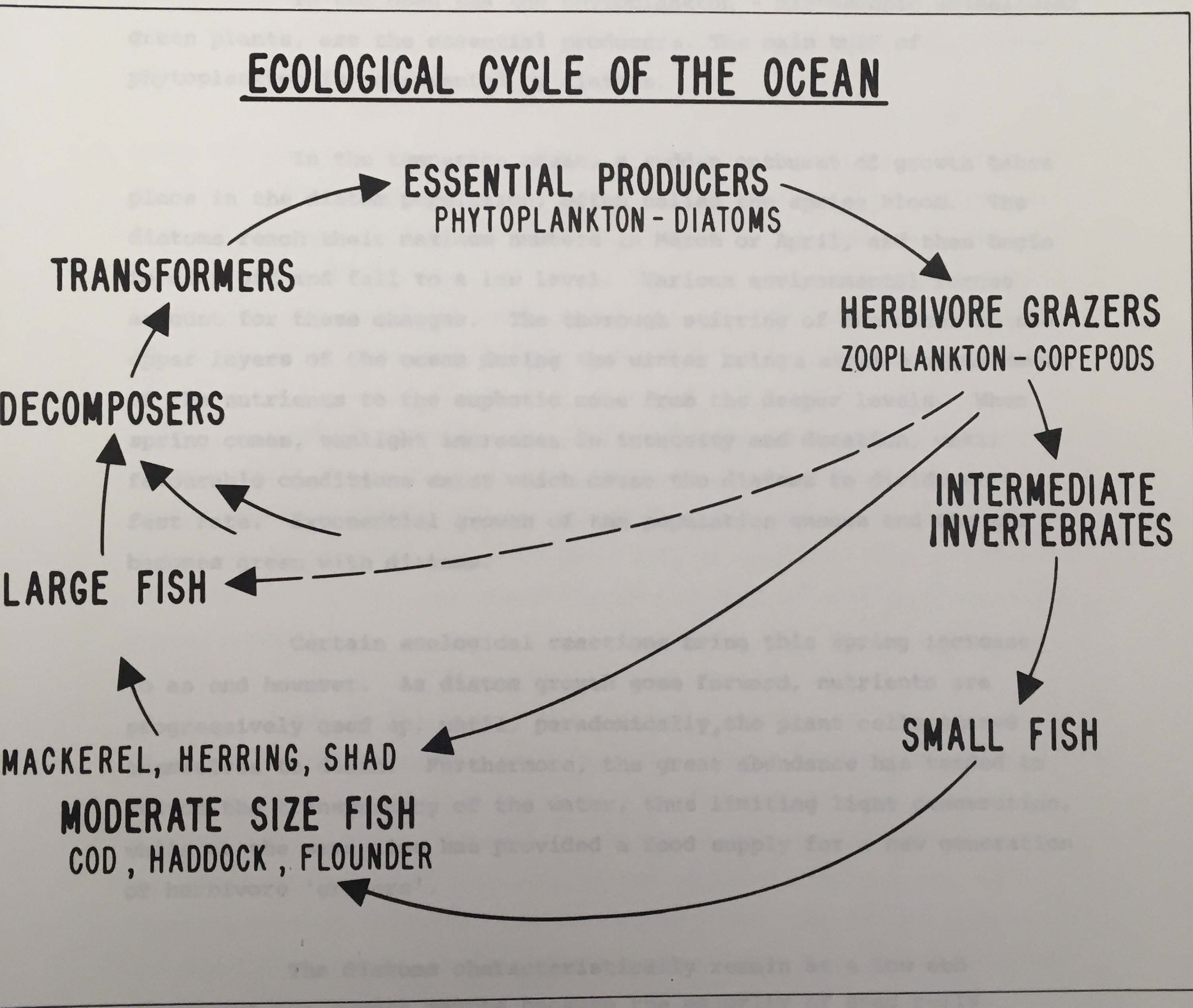
To illustrate this, an organism derives its energy from some source. It uses that energy for cellular metabolism and for motion. Cellular metabolism captures energy in the form of chemical bonds, but through motion some of this energy is lost in the form of heat dissipation. If that organism is subsequently eaten by another organism, part of the available energy will be used in cellular metabolism, and part will be lost through motion. The same process occurs at each transfer along the food chain. So although energy does not disappear at each level, part of it becomes transformed into a state that cannot be used by the next trophic level. And since energy is being continually lost at each level, it must be replenished continually at the start of the food chain. This one-way flow of energy constitutes one of the cardinal principles of the ecosystem.

Although there is a progressive diminishing of energy at each trophic level, the nutrient component is not diminished; in fact, some may even become concentrated in certain steps of the food chain.

In any event, nutrients are not lost in the same manner in which energy is, for when nutrient-containing protoplasm is eventually subjected to decomposition and transformation, it is released back into the environment into a form that is potentially available for re-use.

A specific example might help to clarify some of the ecosystem principles we have been discussing. The ocean ecosystem is illustrative since it is frequently the final end-point for many pollutants, and because all life on the planet is ultimately dependent on the ocean, (Fig. 7).

FIGURE 7


ECOLOGICAL CYCLE OF THE OCEAN
ESSENTIAL PRODUCERS
PHYTOPLANKTON - DIATOMS
HERBIVORE GRAZERS
ZOOPLANKTON - COPEPODS
INTERMEDIATE INVERTEBRATES
SMALL FISH
MODERATE SIZE FISH
COD, HADDOCK, FLOUNDER
MACKEREL, HERRING, SHAD
LARGE FISH
DECOMPOSERS
TRANSFORMERS

ECOLOGICAL CYCLE OF THE OCEAN

In the open sea the phytoplankton - microscopic,unicellular green plants, are the essential producers. The main bulk of phytoplankton is represented by diatoms.

In the temperate ocean, a sudden outburst of growth takes place in the diatom population, often called the spring bloom. The diatoms reach their maximum numbers in March or April, and then begin to drop off and fall to a low level. Various environmental forces account for these changes. The thorough stirring of the water in the upper layers of the ocean during the winter brings about a replacement of the nutrients to the euphotic zone from the deeper levels. When spring comes, sunlight increases in intensity and duration, until favourable conditions exist which cause the diatoms to divide at a fast rate. Exponential growth of the population ensues and the sea becomes green with diatoms.

Certain ecological reactions bring this spring increase to an end however. As diatom growth goes forward, nutrients are progressively used up, until, paradoxically,the plant cells starve themselves to death. Furthermore, the great abundance has tended to reduce the transparency of the water, thus limiting light penetration, while at the same time has provided a food supply for a new generation of herbivore 'grazers'.

The diatoms characteristically remain at a low ebb throughout the summer months because the majority of dead cells decompose and release nutrients at levels below the euphotic zone. Because thermal stratification prevents deep stirring, the euphotic zone remains depleted of its nutrients during the summer. In the autumn, when stronger winds and lower surface temperatures allow effective stirring, nutrients are restored to the upper layers. A rather sudden increase in the diatom population may then take place, known as the autumn bloom. Reduction of nutrient supply, and reduced illumination stops phytoplankton growth during the winter.

Now that we've discussed the producers in the food chain of the open sea, let us turn to the consumers. Here we come across a situation of special interest. The fact that plants at the base of the aquatic food chain are microscopic, has far reaching repercussions on the oceaneonic ecosystem. Most of the larger animals in the sea are unable to use phytoplankton as food, they must depend for their nutrition upon a chain of smaller to larger animals.

In the open sea the first consumers are the zooplankton. These animals, most abundant being the copepods, possess feeding mechanisms that enable them to filter the small phytoplankton from the water and incorporate the substances into their body cellular material. Zooplankton, in turn represents parcels of food of sufficient size for larger animals.

The herbivores in the typical community of the open sea are these small filter feeding animals. The primary carnivores, representing the third link in the food chain, are confronted with the problem of obtaining food that is often less than a centimeter in length. Nevertheless, certain fish, such as the mackerel, herring and shad, are able to feed directly upon the zooplankton. One of the largest animals in the world, the whalebone whales, live entirely on plankton. The fact that the food chain of these whales is relatively efficient, being composed of no more than three links, may account for the successful maintenance of such large, warm-blooded mammals in the sea.

Most marine carnivores, however, are dependent on longer food chains. Various invertebrates consume large quantities of zooplankton, are eaten by small fish, which are in turn eaten by larger fish such as cod, haddock, or flounder. A very large carnivore, such as a shark, may represent a food chain of five, six or more links.

The ecological cycle of the ocean is completed by the activities of a large, diverse group of decomposers and transformers, that turn the dead organic material from the plants and animals into forms suitable for the nutrition of the green plants once more. But before the nutrients can be assimilated again by the phytoplankton the water containing them must be restored by the currents to the euphotic zone. As a matter of interest, the most biologically active area of the world, in terms of biomass produced per unit area, occurs in the Antarctic Ocean, where large permanent upwellings continually supply nutrients to the plankton populations growing in the euphotic zone.

It is commonly thought that the oceans of the world are a virtually limitless source of food. In truth, the open ocean, about 90% of the total ocean surface, is essentially a biological desert.

It produces a negligible fraction of the world's fish catch at present, and has little potential for yielding more in the future. The reason is this - the upper layer of the open ocean lacks the nutrients necessary for high productivity. Not only are the basic mineral resources in short supply, but the energy loses in the repeated transfers up the food chain, result in further reductions in the potential energy harvest.

Only in coastal zones and coastal upwelling areas, where nutrients are brought to the surface, is productivity high. It is these areas that supply man with virtually all of his fishes. Unfortunately, these are the areas where pollution is the most prevalent. This is why many prominent marine biologists are so concerned about the shape our oceans are in. Many predict the oceans will be dead in fifty years if current pollution practices continue. This dire statement is not as far-fetched as one might think.

The oceans are not indestructable despite their size. Virtually all of the oceans biological activities take place in only 10% of the total water surface. This 10% is the coastal zone, and is subject to nearly all of man's marine pollution activities: It's a question of 10% of the water receiving 99% of the pollution, in the forms of domestic sewage, industrial effluents, synthetic detergents, heavy metals, chlorinated hydrocarbons, pesticides, radioactive wastes, tanker spills, etc.,etc. The effects do not stop there. Primary productivity in the oceans supplies the earth with a large part of its available atmospheric oxygen. Once our oceans become biologically dead, our land masses will soon follow suit.

There is one other trait of ecosystems that should be mentioned since it demonstrates the fine line that can often be drawen between an unpolluted and polluted environment.

EUTROPHICATION

A major characteristic of ecosystems is that they age; they undergo succession. An aquatic ecosystem proceeds ultimately to a semi-terrestrial or fully terrestrial state. They initiate typically as nutrient deficient, hence unproductive systems, and develop into ones with increasing amounts of nutrients, hence productive systems, with considerable deposits of organic material. This aging process from low production or oligotrophy, to high production, or eutrophy, as the result of enrichment, is often referred to as eutrophication. Successional change of ecosystems, including the eutrophication of lakes, is as natural a process as is individual development or population growth.

Succession is accompanied by significant changes in biotic and abiotic components of the environment. Some nutrients increase, or become more readily available, while others are depleted through long-term storage. Dissolved oxygen tends to be decreased, especially in deeper waters. Electrical conductivity and thermal properties are also altered. There are corresponding changes in the biota, the two major, or at least most obvious changes, involve plankton and fish. Plankton is sparse in oligotrophic lakes. Their absence is responsible for the characteristic deep blue of such lakes.

As enrichment proceeds through input of nutrients, the original dominant phytoplanktons - the desmids, are replaced by diatoms. Succeeding the diatoms are the flagellates, the green algae, and finally in highly-eutrophic water, the blue-green algae. Major population blooms of blue-green algae create most of the problems associated with eutrophication - obnoxious and objectionable aromas and flavours, skim on surface of water, etc.

Oligotrophic lakes are the source of such species as trout, char, lake herring, whitefish and walleye. As eutrophication proceeds these fish are replaced gradually by bass, perch and pike; and still later by generally less favoured types such as carp and sunfish.

The eutrophication process is one that is measured on a geological time scale; the amount of natural eutrophication in a moderate-sized lake during a human lifetime is virtually imperceptible. The changes are slow, but nonetheless relentless.

This natural process of aging is accelerated by pollution, even by highly purified effluents. This raises the question in some peoples minds as to whether an increase in the rate at which a perfectly normal process occurs, is an acceleration in the natural quality of water. Their logic is that the condition of an oligotrophic lake which is rendered more eutrophic by pollution is no more 'unnatural' than that of another lake which has reached the same state without human assistance.

Because of this, lakes often present difficult problems of classification from a biological point of view. It is very difficult at times to assess how much of the alteration is natural and how much has been caused by pollution.

We will return to eutrophication when discussing Lake Erie.

SUMMARY TO UNPOLLUTED ENVIRONMENT

In summary, four levels of integration have been looked at - the individual, population, community and ecosystem. There are other levels above and below these four; namely the organ, tissue, cell, organelle, and molecule below, and the bioclimate and biome above. The bioclimate and biome are of particular interest when studying climatology, meteorology, hydrology, etc. The levels of integration below the individual enter into the fields of anatomy, physiology, histology, genetics, molecular and cellular biology. But the real understanding of our environment, its principles and processes, comes when we view the individual, the population, community and the ecosystem. It is at these higher levels of integration that the drama of natural selection, evolution, extinction, and all the peculiar, dynamic patterns of the environment take place.

The environment supplies the energy and materials which become mobilized into a living individual. Individuals themselves are relatively transient entities, through which materials and energy flow and eventually return to the environment. The individual is, in a sense, at the mercy of the environment. The ultimate role that any individual plays in the environment is to produce offspring - to ensure propogation of the species. In order to accomplish this, individuals tend to form into populations. Populations may be loosely bound or they may be a tight, coherent group of organisms, but no matter what characteristics each possesses, a population will increase the stability of the species as a whole by increasing the reproductive potential.

To look at it another way, the formation of a population may not necessarily reduce the individuals vulnerability - it may even increase it in some cases. For example, schools of fish are more obvious to predators than if each fish swam about alone. Yet despite the increased vulnerability of each individual, the population as a whole remains in a higher level of fitness. Why is this? More adults are able to successfully spawn because of their close proximity. Adults possessing higher qualities of strength, size, vigour, etc. are able to mate more often, thus increasing the flow of desirable genes through the population; while weaker or older fish are less able to escape from the predators, falling prey rather than the more genetically-fit fish.

This situation occurs in all populations, terrestrial and aquatic. In each case, increased stability and propogation of the species results from grouping individuals together to form populations.

Populations too are subject to stress in the form of environmental restraints which continually keep check on the population's biotic potential. It is the role of the population to ensure that this environmental resistence does not exceed a species biotic potential. This is often difficult to accomplish, and often times the two forces are shifting back and forth in strength around a mean - the carrying capacity of the environment - resulting in a fluctuation of numbers.

But whereas the population is moderately stable, the community is highly stable. Most natural, unpolluted environments will support many different kinds of populations, but because of predation and competition for food and space, the number of individuals represented will be low. This high diversity of individuals results in a highly stable system.

In a community with high diversity, the constantly changing environment will probably only affect a small portion of the complex flora and fauna at any one time. Since there are many different kinds of organisms present, the role of those eliminated due to natural environmental change will be quickly filled by other organisms. The food chain and the system as a whole remains stable.

Although high diversity and low numbers in the more usual situation, there are notable exceptions - the most important one being the arctic. Arctic waters contain fewer species than temperate or tropical waters. The same applies to the tundra as contrasted with our temperate regions.The communities of organisms living in the arctic are lacking the built-in stability factor that is characteristic of the more hospitable environments. Any change in environmental conditions, whether natural or man-made could drastically alter the communities stability in these regions.

Our final level of integration, the ecosystem, encompasses the biotic and abiotic components. It is within the ecosystem that we find all the ingredients necessary for the continued existence of life on this planet.

The reception and subsequent utilization of energy for synthesis and motion, the cyclic activity of nutrients and other material, the production of organic matter and its later decomposition and transformation, all takes place within the sphere of the ecosystem.

This is why the ecosystem is regarded as the basic unit of nature. It is responsible for maintaining a harmonious equilibrium among the biotic and abiotic components of the environment. This inherent importance of the ecosystem concept is the principle theme behind ecology, for it is in this biological system that day-to-day orderly and systematic life takes place.

POLLUTED ENVIRONMENT

TERMINOLOGY

Organisms can generally be classified as to their ability to withstand or tolerate changing environmental conditions. Stenotopic organisms have only a narrow range of tolerance for some particular factor. Organisms with a wide range of tolerance are referred to as eurytopic organisms. Both types of organisms, and all the grades between the two, are able to live together in an unpolluted environment. Such an association, is characterized by high diversity and low numbers. In the aquatic environment this is simply known as a clean-water association.

If some element was added or removed from the environment, thereby decreasing the range of tolerance, the stenotopic organisms would not be able to tolerate the conditions, and would disappear. When such a situation occurs, the clean-water association of the aquatic environment becomes a polluted-water association, in which only eurytopic organisms are able to live. The diversity would be low, and numbers in each population high.

When such a change takes place in the environment from the addition of some element, that element is called a pollutant. Used in this context, pollution means any event, or continuing circumstance whereby there is introduced into the environment, some substance or substances in such quantity that the environment is not able to sustain the load without adversely affecting the general balance of nature.

Such a definition takes into account the natural pollution that takes place in many circumstances. Natural events continually occur which act to kill off a number of individuals, be it drought, flood, excessive heat, rapid drop in temperature, sudden rise in organic debris or inorganic compounds. But in one way or another the environment is usually able to absorb the impact. What constitutes pollution is the addition of some element in such large quantities, or over such an extended period of time, that not only is the individual affected, but also higher levels of integration.

TOLERABILITY

Different organisms have different tolerances to pollution. Why should one organism be more susceptible than another? Generally the answer lies in the anatomical and physiological make-up of the organism, its behavioural patterns, life cycle complexity, and its position in the community.

Many organisms are susceptible because of their anatomy. Animals which breathe through large, unprotected, external gills are prone to asphyxication because the gills can become easily clogged by suspended material. In contrast, organisms lacking gills which breathe by diffusion across their surface membranes are less apt to be affected by suspended material. As a rule of thumb, the more specialized and complex the organism, the more susceptible it is to pollution.

The type of respiration will also determine tolerability. Organisms that are completely aerobic, i.e. able to live only in the presence of oxygen, will be less able to tolerate a changing environment than ones which are facultative, i.e. able to live for a short time in the absence of oxygen. This situation is particularily true in biological waste treatment systems, where completely aerobic bacteria are seldom able to tolerate the rapidly fluctuating changes in the system. Instead, the predominant type of bacteria is facultative, since it is more able to adjust to changing environmental conditions. Organisms that are able to adapt themselves to widely fluctuating changes in the environment, are more apt to tolerate the addition of a pollutant.

In the second case, individuals which are dependent on specific behavioural patterns to illicit proper responses, tend to be highly intolerant of certain pollutants that interfere with, or block the response. Many fish species, notably the minnow and stickleback, have evolved specific behavioural patterns when courting, mating, nest building, and caring for young. Failure of a stimulus at any stage will terminate the ritual and no offspring will be produced. Behavioural responses are also involved in predator-prey relationships, feeding, attacking, fleeing, schooling, etc.

In the third case, organisms with simple life cycles tend to be more tolerable to pollution. This is simply because the more complex the life cycle of an organism, the greater the number of specific environmental conditions it requires, and thus the increased probability that a pollutant will affect one of these conditions.

Lastly, what position an organism holds in a community will affect its degree of tolerability. Organisms that are higher in the trophic levels of a food chain tend to be more susceptible to pollution. In many cases this comes from the cumulative effects of pollutants in the food chain.

In the section on unpolluted environment we looked at four levels of integration and some of the principles that operated at each level. Let us return to these, and find the effects of pollution on each level. The first is the individual.

INDIVIDUAL

A pollutant can affect an individual in two basic ways:

1. by direct lethal action.
2. by sublethal action.

Lethal Action

Lethality may be acute or fast acting, or it may be chronic. Acute lethality is generally taken to be less than four days, whereas chronic lethality is taken as being longer than four days. Lethality is an easy symptom to observe; an organism is either dead or it's alive, and is usually the criterion used in bioassay tests. The more common symptoms however, involve sublethal responses to a pollutant.

Sublethal Action

Many biologists stress that the study of acute lethality is not sufficient, that there must be more concern with sublethal effects. This point of view can hardly be argued against. Yet it is relatively easy to document small changes within an organism, but it becomes increasingly difficult to decide whether the changes are deleterious. Studies on sublethal effects must always be carried far enough to show whether or not the changes are ecologically meaningful, i.e. whether they reduce the animals chances for success in the environment, thereby reducing its reproductive potential.

A pollutant can show no adverse effects on an individual, but still be adverse to the population, or even to higher levels of integration. For example, some pollutants will cause damage to the peripheral sense organs of fish. One of these sense organs is responsible for detecting movements in the water close to the fish, through minute pressure changes.

Schooling fish use this devise to keep the same distance from their neighbours, and to keep grouped closely together. If a pollutant inhibits this detection of movement through pressure changes, it will not directly harm the individual fish, but the population will become disorganized and scattered, thereby reducing its stability.

Evaluating the significance of sublethal changes is often more meaningful if one thinks in terms of the effect the pollutant has on succeeding levels of integration; that is, what effect a pollutant will have on an individual, what effect that individual will have on a population, and what effect that population will have on the community.

Understanding the action of a pollutant is the key to predicting important sublethal effects. Knowledge about the modes of action can sometimes help prevent incorrect generalizations about the toxicity of a pollutant. There are a number of ways by which a pollutant can affect an organism; only the more common ones will be mentioned here.

1. <u>Nervous System Interference</u> - The most common mode of action of a pollutant is on the nervous system. Many pollutants can enter the nervous system and block the movement of acetylcholine. Acetylcholine is a body chemical common to all animals with nervous systems, and is involved in the transmission of impulses across nerve junctions. When acetylcholine is blocked the nerve impulses fail to travel up the nerve tract. Thus the individual looses an important body defense system.

2. Peripheral Sense Organ Disorders - A pollutant can, in a similar manner, interfere with the peripheral sense organs that an individual requires to keep in contact with the outside world. For example, fish have lateral line systems running the length of their body that are responsible for detecting minute pressure changes, and keeping the organism in equilibrium. Blockage of the nerve impulses from this lateral line effectively causes the organism to loose all sense of equilibrium.

3. Respiration Disorders - The initial reaction of an individual to a pollutant may be an increase or decrease in rate of respiration depending upon whether the pollutant is a depressent or a stimulant.Pollutants that stimulate respiration rate are usually chemical compounds that interfere with the homeostasis of the individual. Pollutants that depress respiration usually do so by means of physical destruction of the oxygen-handling mechanisms.
   Although respiration rate is easily measured,it is of a somewhat obscure significance as a response to a pollutant, since other factors, often not related to the pollutant may be influential in causing a change in rate.

4. Internal Disorders - Within the body, a pollutant can cause endocytosis, a condition arising from the inclusion within a cell of a material which doesn't properly belong there. Ulcerations may result, or a large number of cells may rupture and cause edema.
   Internal poisoning can also result, or a pollutant may become carcinogenic, ie. capable of causing tissue to become cancerous. Most internal sublethal disorders can become lethal to the organism if the ailment persists.

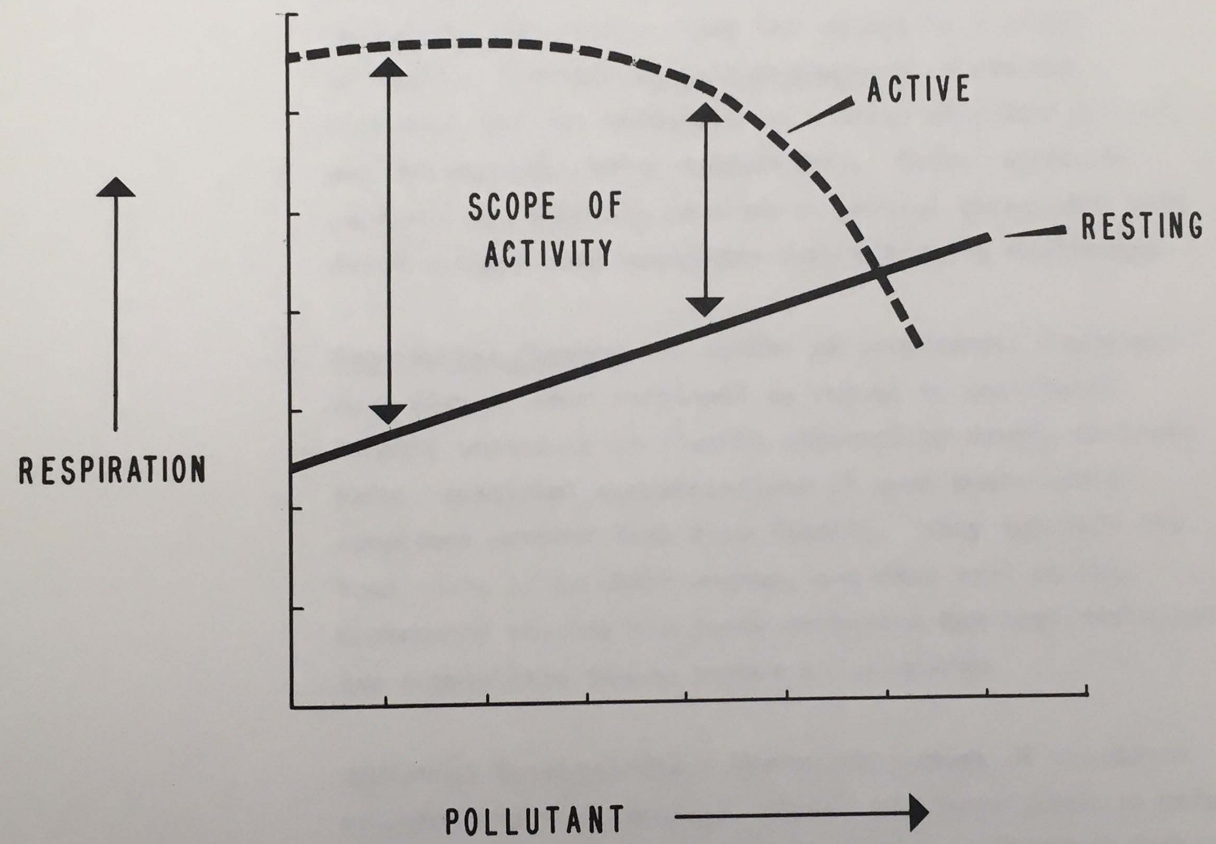
5. Growth - In many cases growth integrates all sublethal effects operating on an animal. For instance, growth is extremely sensitive to reduced oxygen. Growth is easily measured, and is an important criterion to show the presence of a pollutant.However, it does not show the most sensitive sublethal effects.

6. Performance - For active organisms performance simply means the ability to move. This is of primary importance; salmon on a spawning run will expend energy at a rate equivalent to 80% of their maximum on swimming alone. Since performance is easily reduced by toxic substances, its measurements are a good means of evaluating sublethal effects.

7. Scope of Activity - When comparing respiration and performance one meaningful approach is to study the scope of activity, (Fig. 8). This is the metabolic capacity available for activity, and is estimated as the difference between standard oxygen consumption, (an individual at rest), and the active oxygen consumption, (an individual at maximum activity). A pollutant can reduce this scope of activity by either raising the standard oxygen consumption, or by lowering the active oxygen consumption. In either case, or both together, the individual would have less "extra" energy available. In nature this would presumably mean the lessened ability to stem fast currents, escape from predators, catch and assimilate food, etc. Changes in the scope of activity become useful for evaluating effects of a pollutant on respiration and performance.

FIGURE 8

SCOPE OF ACTIVITY - THE METABOLIC CAPACITY OF AN INDIVIDUAL THAT IS AVAILABLE FOR ACTIVITY



8. Stress Syndrome - Sublethal pollution concentrations can contribute to a general stress syndrome that makes an individual more prone to disease. Sublethal levels of suspended solids can result in body ulcerations, sores, fin-rot, etc. Fish that have been exposed to toxic concentrations have a weakened ability to combat parasites and disease. In one of the major salmon spawning rivers on the west coast, an epidemic occured in the sockeye inhabiting the river. This was caused by a lethal ulceration from *Aeromonas liquefacrens*, a disease bacteria, and was triggered by a surge of pollution and accompaning high water temperature. These causative bacteria are normally present in natural water, but only cause disease when organisms have a lowered resistence.

9. Behavioural Changes - A number of behavioural responses have already been mentioned in regard to pollutants. Feeding behaviour is clearly affected by damage to taste buds. Sublethal concentrations of some hydrocarbon compounds prevent fish from feeding; they approach the food, take it in their mouths, and then spit it out, apparently because the taste mechanism has been destroyed and a palatable signal cannot be triggered.

   Sublethal levels prevent the establishment of avoidance responses in many animals, making them more prone to attack by predators. And as discussed earlier, sublethal levels also affect social interactions between individuals, as in the schooling of fish.

10. Reproductive Disorders - Sublethal levels of pollutants can cause harm to an individuals reproductive potential in a number of ways. Since the ultimate role of the individual is to produce offspring, it follows that direct reproductive damage is the most harmful effect, and it is regarded as the most important criterion in determining whether or not a substance is detrimental to nature.

Pollution can interfere with reproduction at many stages:

(a) A female may concentrate a toxic substance in its bloodstream, and although it may not have an effect on her, the substance may be transferred to the yolk and be detrimental to the egg.
(b) A pollutant may directly kill sperm and egg by permeating their membranes.
(c) A pollutant may interfere with the endocrine glands, blocking hormal cycles, and upsetting the reproductive system.
(d) A pollutant may inhibit spawning by blocking the necessary stimulants. Animals can influence other animals of the same species by chemical substances known as pheromones. Sex pheromones are substances emitted to the environment that illicit responses in opposite members of the sex. These chemical substances can be blocked, inhibited, or mimicked by certain organic pollutants.
(e) Pollutants can delay sexual maturity of an individual - a process called neotony.
(f) Pollutants can destroy spawning grounds, nesting material, or other physical features needed to successfully reproduce.

Studying an individual shows the immediate effect of pollution on the environment. But it does not reveal the long-term effects. To find these, it is necessary to proceed to higher levels of integration, the next one being the population.

POPULATION

Populations are moderately stable entities, though subject to fluctuation. The effect of a pollutant is to change the intensity and/or the amplitude of these fluctuations. It does this by either:

1. directly increasing the environmental resistence of a population, whereby the population number declines.
   or
2. indirectly increasing the biotic potential of the population by lowering the environmental resistence, in which case the population number increases.

In the first case, a pollutant can impose environmental restraints in a large number of different ways, as outlined in the section on the individual. Should the restraints be detrimental to a large sector of the population, the threshold of extinction will be reached. When this situation takes place it is looked upon as an ecological disaster. Only if a pollutant greatly overloads a system does such a disaster take place. Ordinarily, pollutants are discharged into the environment in loads that are not in sufficient concentration to produce extinction. Rarely does a pollutant per se totally wipe-out a population from an area. There are usually a small number of individuals left that are able to increase if and when the pollutant is removed.

The second case, increasing the biotic potential, occurs when a pollutant does not harm the individuals in a population, but rather removes some part of their environmental resistence. Removal of a predator can increase a population's biotic potential since it will be able to move in search of food and living space with greater freedom. Removal of a competing species will provide a population with additional habitat and food, since it can expand into the vacancies left behind by the susceptible species.

Often the introduction of pollution to an environment will cause both situations to occur simultaneously in two different populations. A pollutant that is detrimental to one population and causes it to decline, may in turn indirectly cause another population to increase through the removal of competition. This situation is seen frequently in waters where the disappearance of susceptible fish such as trout, char, walleye, etc. occurs simultaneously with an increase in tolerant fish such as carp, sunfish, perch, etc.

A Lake Erie example further demonstrates this reciprocal effect of pollutants. Lake Erie's bottom fauna composition has changed dramatically in the last fifty years. In 1930 the bottom fauna consisted of pollution-sensitive species such as caddisfly larvae, mayfly nymphs, dragonfly nymphs, etc. along with the more tolerant species, such as the oligochaete worms, nematodes, snails, leeches, etc. By 1965, dissolved oxygen had become so low that the pollution-sensitive species faced extinction. Meanwhile some of the more tolerant populations increased in numbers tremendously. The oligochaete worm Tubificidae has increased from 10 organisms per square meter in 1929 to 550 per square meter in 1957, and today constitutes 84% of all bottom fauna on Lake Erie. Before Lake Erie became polluted, the Tubificidae population had to compete for food and habitat with a great many other organisms.

Once those other organisms disappeared, it was able to reach full biotic potential, and become the dominant species.

Pollution can act then on the two forces operating in any population, the biotic potential and the environmental resistence. Since it can effectively increase or decrease the population numbers, pollution ultimately affects the entire community of which that population is a part.

COMMUNITY

To go back for a moment to natural communities, we mentioned they are highly stable entities. They are stable because of the high diversity of species that inhabit them, and the low number of individuals per species.

With this in mind, it becomes obvious that pollution acts to disrupt this stability by lowering the diversity of species, while increasing the numbers tolerant species that remain. (Of course, this increase of tolerant species only goes so far. There will come a point, in extremely polluted areas, when even the more tolerant forms will vanish. One has only to observe an area immediately below an effluent discharge, or some of our industrial harbours, to see this.)

If a pollutant were to only affect one population, the overall consequences might not appear so great, since closely competing populations would soon take over the vacancy. Unfortunately, this seldom happens. Pollutants that affect one population are likely to affect other populations with similar anatomy, behaviour, food requirements, breathing devices, etc. When a large number of similar populations have disappeared the vacancy will be filled by more tolerant existing species.

This is precisely the situation described in the population section. A large number of populations in Lake Erie that needed a considerable amount of dissolved oxygen for survival disappeared, and were in turn replaced by those populations requiring little dissolved oxygen for survival. These populations promptly increased in numbers. The result is a community with low diversity, and high numbers.

At the next level of integration - the ecosystem - the full detrimental ramifications of pollution can be examined.

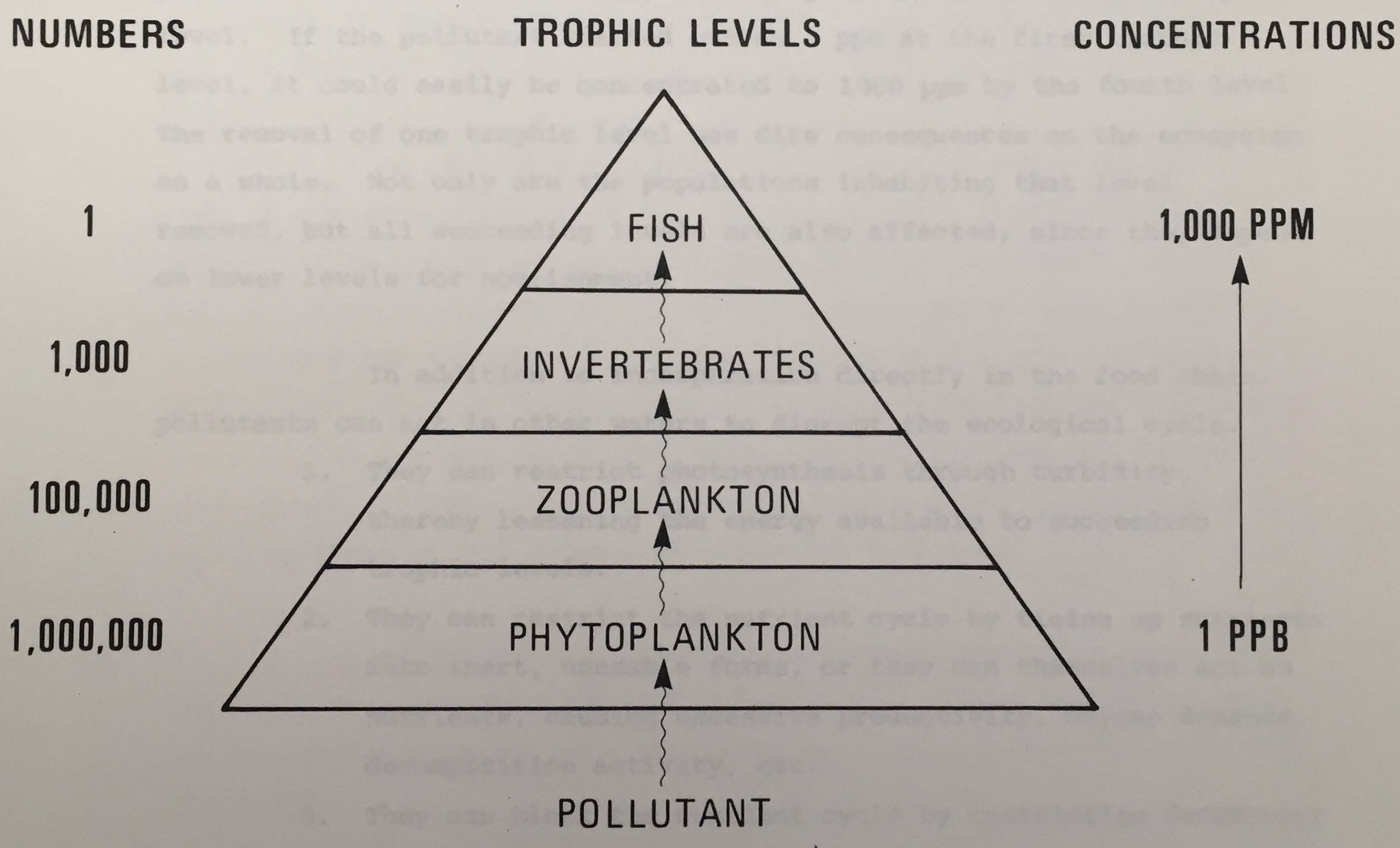
ECOSYSTEM

An ecosystem was defined as a community of organisms interacting with one another, plus all the external influences around them with which they live and interact. These influences on the ecosystem are called the environment.

Whenever a pollutant is added to water, air, or land, it becomes part of the organism's environment. It becomes one of the external influences with which an organism must live and interact. Pollution in most cases constitutes the addition of particulate substances into the environment. These toxic substances tend to behave in the same manner as nutrients do when they ender a medium. To give an illustration of this mimicking behaviour of some pollutants, let us follow the path of a pollutant as it enters the environment, (Fig. 9).

FIGURE 9

EFFECT OF POLLUTION ON ECOSYSTEM



Upon introduction to the abiotic environment, the pollutant enters the biotic environment through ingestion, absorption, diffusion or photosynthesis. If a pollutant enters the aquatic food chain at the first trophic level - the phytoplankton, its concentration per organism is likely to be insignificant. The phytoplankton is then consumed by the zooplankton, the zooplankton by macroinvertebrates and small fish, and those by the larger fish. With each consecutive trophic level the concentration of pollutant increases, until at some point a toxic limit can be met, resulting in the death of that trophic level. If the pollutant started out as 1 ppb at the first trophic level, it could easily be concentrated to 1000 ppm by the fourth level. The removal of one trophic level has dire consequences on the ecosystem as a whole. Not only are the populations inhabiting that level removed, but all succeeding levels are also affected, since they depend on lower levels for nourishment.

In addition to incorporation directly in the food chain, pollutants can act in other waters to disrupt the ecological cycle.

1. They can restrict photosynthesis through turbidity, thereby lessening the energy available to succeeding trophic levels.
2. They can restrict the nutrient cycle by tieing up nutrients into inert, unusable forms, or they can themselves act as nutrients, causing excessive productivity, oxygen demands, decomposition activity, etc.
3. They can block the nutrient cycle by restricting decomposer and transformer activity.
4. They can cause physical damage to any part of the abiotic or biotic environment.

In other words, pollutants are able to alter any one of the steps in the operation of an ecosystem - the reception of energy, the production of organic matter, the consumption of this matter, and the decomposition, transformation and release of this matter.

Are the end results of these alterations the same? When viewed at the level of the ecosystem, yes, the results are identical - a change from a complex ecosystem to a simplified ecosystem. A simplified ecosystem might be acceptable if it were not for the fact that simplification results in instability.

As mentioned previously, in a natural community the loss of one population tends not to disrupt the overall ecological balance, since there are many different kinds of organisms, and the role of those eliminated due to environmental changes will be quickly filled by other organisms. But what happens in a simplified community when a population is removed because of natural environmental changes. In this case the community might have 1/4, 1/2, or even 3/4 of its total number of individuals wiped out. Such a state would bring a total collapse to the balance of nature in that area.

In the section on unpolluted environment, the ecological cycle of the ocean was described. Now we will return to that example and follow the movement of a pollutant as it passes through the cycle, (Fig. 10).

MOVEMENT OF A POLLUTANT THROUGH THE ECOLOGICAL CYCLE OF THE OCEAN

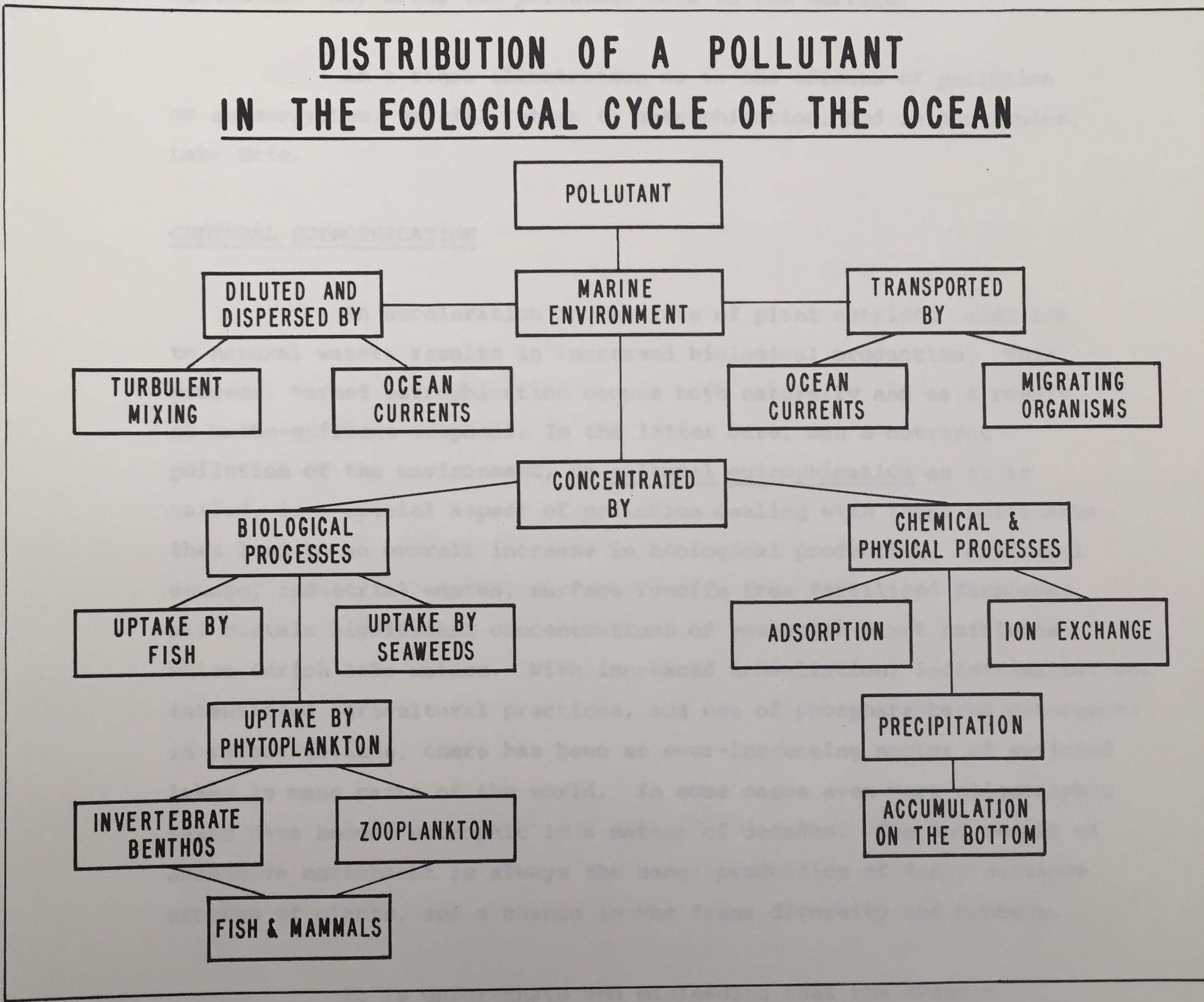
As soon as a pollutant is added to the water it becomes part of the organism's environment. It is diluted and dispersed by turbulent mixing and ocean currents, and transported away from the source by currents and migrating organisms. The sea is vast and all of man's present pollution problems would probably be immeasurable if it could be uniformly diluted throughout the ocean's depth. The problem is that oceans are not thoroughly mixed, and we find high local concentrations which produce the undesirable environmental changes.

A pollutant may become concentrated by biological, chemical or physical processes. The biological processes cause the most direct harm. The major concentration by biological processes involves the uptake by phytoplankton. At this stage a pollutant could either depress growth, stimulate growth causing blooms, or have no effect because of its minute quantities. But a pollutant may be concentrated by moving up the food chain until it hits toxic levels. Often a pollutant will reach the final trophic level of the marine environment and show no toxic effects. However, should the final consumer in the aquatic food chain be eaten by a terrestrial consumer, such as shore birds, or even man, death or injury could result.

Two other processes by which a pollutant can become incorporated into the food chain are by direct absorption into fish, and through uptake by seaweeds. Pollutants can sometimes be directly absorbed by organisms higher in the food chain, such as fish. But this seldom takes place because rarely do fish encounter such high concentrations. Fish, and most active animals, tend to avoid areas with high concentration of pollutants. Some seaweeds can also directly absorb amounts of pollutants, but rarely do animals feed on these types of plants, so the pollutant does not proceed to higher levels of the food chain.

Pollutants can also be concentrated by chemical and physical processes that ultimately find their way into a food chain.

FIGURE I


DISTRIBUTION OF A POLLUTANT
IN THE ECOLOGICAL CYCLE OF THE OCEAN
POLLUTANT
MARINE ENVIRONMENT
DILUTED AND DISPERSED BY
TRANSPORTED BY
TURBULENT MIXING
OCEAN CURRENTS
OCEAN CURRENTS
MIGRATING ORGANISMS
CONCENTRATED BY
BIOLOGICAL PROCESSES
CHEMICAL & PHYSICAL PROCESSES
UPTAKE BY FISH
UPTAKE BY SEAWEEDS
ADSORPTION
ION EXCHANGE
UPTAKE BY PHYTOPLANKTON
PRECIPITATION
ACCUMULATION ON THE BOTTOM
INVERTEBRATE BENTHOS
ZOOPLANKTON
FISH & MAMMALS

Most important of these is the precipitation and accumulation on the bottom. Mixing of this during spring and fall and subsequent upwellings may bring the pollutant back to the surface.

As a final illustration as to the effects of pollution on an ecosystem, we will return to eutrophication, and in particular, Lake Erie.

CULTURAL EUTROPHICATION

An acceleration in the rate of plant nutrient addition to natural waters results in increased biological production. This process, termed eutrophication occurs both naturally and as a result of waste-effluent disposal. In the latter case, man's nutrient pollution of the environment, or cultural eutrophication as it is called, is a special aspect of pollution dealing with those pollutants that lead to an overall increase in biological production. Municipal sewage, industrial wastes, surface runoffs from fertilized farmlands, all contain significant concentrations of essential plant nutrients which enrich lake waters. With increased urbanization, industrialization, intensified agricultural practices, and use of phosphate-based detergents in recent decades, there has been an ever-increasing number of enriched lakes in many parts of the world. In some cases even very oligotrophic lakes have become eutrophic in a matter of decades. The end result of excessive enrichment is always the same: production of dense nuisance growths of plants, and a change in the fauna diversity and numbers.

It is unfortunate and misleading that the drastic eutrophication in lakes affected by man is so often referred to as a mere acceleration of the natural phenomenon. This analogy often gives the impression that eutrophication is irreversible. This is not true, and has been demonstrated in a number of cases, where man's wastes have been diverted away from lakes and where they have subsequently recovered to a less eutrophic condition.

LAKE ERIE

Over the past 50 years a number of profound changes have taken place in Lake Erie because of the increase in nutrient elements from man-made sources. Significant changes have occured in the amount of calcium, sodium, potassium, chlorides , sulfates, phosphates, nitrates, dissolved organic matter, etc. The western and eastern basins of Lake Erie have remained at about 70-80% oxygen saturation for the last 70 years. The central basin, however is subject to severe oxygen depletion affecting about 70% of the total bottom water.

The frequently-quoted statement that Lake Erie is dead is based on this low-oxygen area. In truth, Lake Erie is far from dead, with production nearly double that of ten years ago. Unfortunately the presently abundant species are not as desirable, both in their ability to keep the community stable, and in their commercial value, as in the case of fish species.

A number of the more sensitive flora populations have disappeared; replaced by more tolerant populations such as the blue-green algae Cyanophyta, or the filamentous green algae Cladophora, which in turn have resulted in large spring and fall 'blooms'.

Some types of zooplankton, notably the Cladocera have increased in the last few years, while others have disappeared. The same is true for the invertebrates. The more pollution-sensitive species have all but become extinct, while the more tolerant species have flourished.

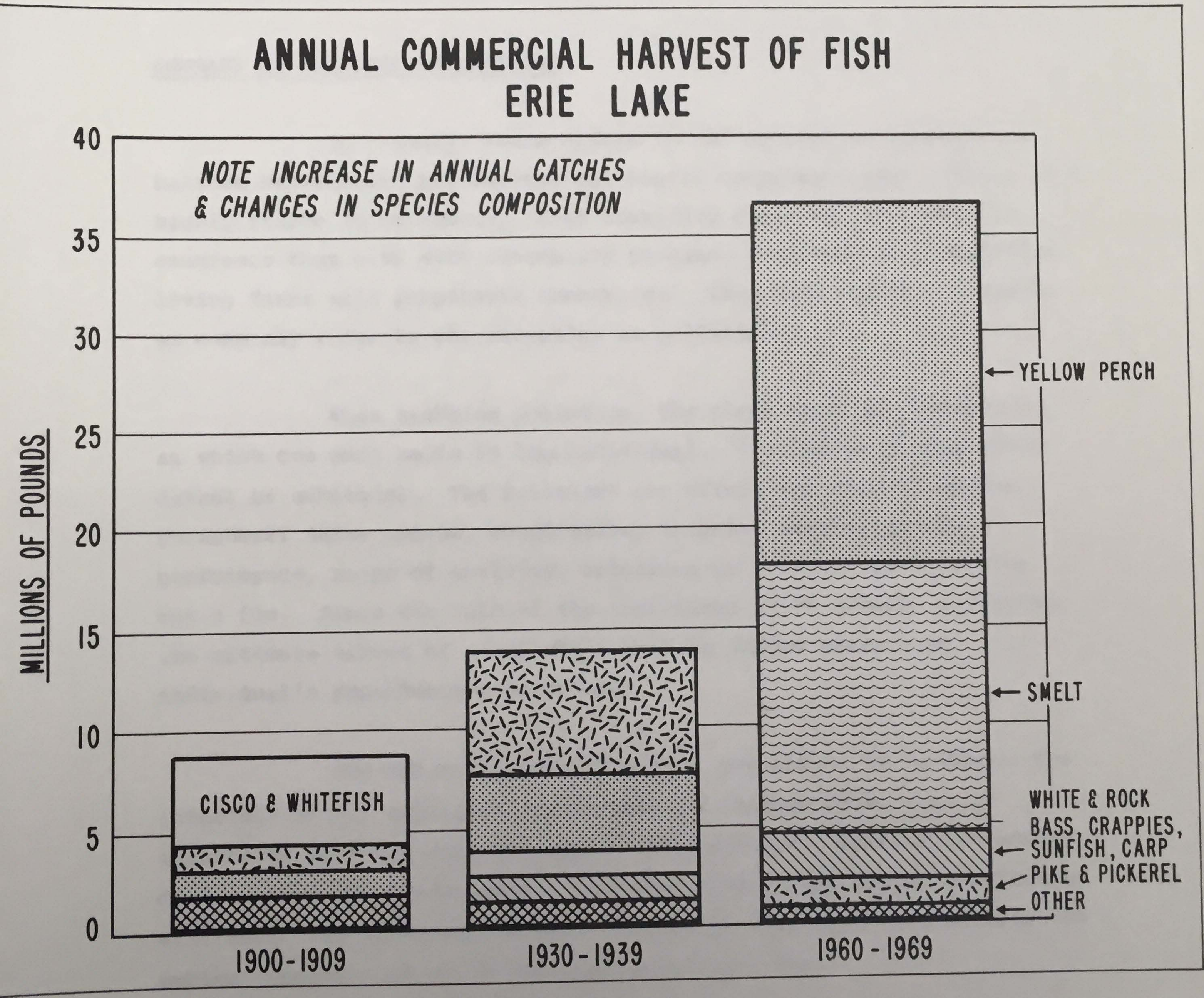
The mayfly larvae was the most common invertebrate in the western basin before 1950. By 1967 however, no mayflies were found in Lake Erie. Sludgeworms, on the other hand, have increased from 10 organisms per square meter to 500 per square meter. Bloodworm larvae have increased from 60 to 300 organisms per square meter. Other species with large numbers include the fingernail clams, nematodes, leeches, snails, and most notably the oligochaete worms.

Fish species composition has also changed drastically over the last few years. Commercial fish production has doubled in Lake Erie in the past decade, (Fig. 11). The composition of the catch has changed, but not the ability to produce fish flesh. Unfortunately, the presently abundant species do not have the commercial value of the species present a few years back. Since 1940 the sturgeon, cisco, whitefish, blue pike, lake herring, and walleye have all declined dramatically. The failure to reproduce has been sited as the reason for the decline of many of these desirable species.

But while some species declined, others increased - the yellow perch, smelt, carp, sunfish, and crappies have all increased in abundance. Why have fish populations changed so drastically? It is probable that eutrophication has acted to limit reproduction by altering and reducing spawning areas. Also the production of certain fish food organisms, notably the mayflies and their larvae, have been reduced. To the extent that pollution has affected the larger fish, such as pike and walleye, it has also upset the balance of predator and prey species. This has resulted in excessive dominance by yellow perch, smelt, etc. in the community.

The total effect of all these changes in the flora and fauna communities of Lake Erie, have resulted in a decreased diversity

FIGURE II


ANNUAL COMMERCIAL HARVEST OF FISH
ERIE LAKE
NOTE INCREASE IN ANNUAL CATCHES
& CHANGES IN SPECIES COMPOSITION
MILLIONS OF POUNDS
40
35
30
25
20
15
10
5
0
CISCO & WHITEFISH
YELLOW PERCH
SMELT
WHITE & ROCK
BASS, CRAPPIES,
SUNFISH, CARP
PIKE & PICKEREL
OTHER
1900-1909
1930-1939
1960-1969

of species, and large numbers of pollution-tolerant organisms. So while production of the aquatic ecosystem might increase, stability of the system progessively decreases.

SUMMARY TO POLLUTED ENVIRONMENT

In summary, there exists in all natural environments a balance between all the abiotic and biotic components that results in a highly stable co-existence. This stability gives to the earth the assurance that even with constantly changing environmental conditions, living forms will perpetuate themselves. When this balance is upset, we commonly refer to the situation as pollution.

When studying pollution, the first level of integration at which one must begin is the individual. The effect can be either lethal or sublethal. The pollutant can affect the nervous system, peripheral sense organs, respiration, internal organs, growth, performance, scope of activity, behaviour or reproduction, to name but a few. Since the role of the individual is to produce offspring, the ultimate effect of a pollutant must be judged against an individual's reproductive potential.

The effect of pollution on a population is to change the intensity and/or amplitude of the numbers fluctuations, i.e. it interferes directly with the population dynamics. Whether increasing or lessening the environmental resistence on a population, a pollutant will cause the same end results - a loss of stability that affects the entire community of which the population is a part.

It is by examining communities that we find the long-range impact of pollution. The ultimate effect is to simplify the community. This leads to a situation very prone to environmental change.

With the concept of the ecosystem, the full consequences can be seen. Pollution can act at any or all stages of the ecological cycle by disrupting the reception of energy, photosynthetic process, consumption of organic material, or the decomposition and cycling of the material.

The end result is the same - a simplified community of organisms in the polluted area. A simplified community denotes instability. Instability breeds disaster.

This sequence of events - the application of a stress that leads to a simplification, that causes instability, and which in turn results in a detrimental outcome - can take many different forms, and can occur in many different situations or locations. But nowhere is this sequence more detrimental to life as we know it, than within the balance of nature.

BIOLOGICAL INFORMATION SYSTEMS

PARAMETERS OF POLLUTION

There are a number of ways to detect pollution in the environment:

1. Physical Parameters - can include colour, odour, turbidity, particulate matter, salinity, temperature, density, etc. Physical parameters do not measure the concentration of specific pollutants; rather they assess the changes that take place in the abiotic components of the environment.

2. Chemical Parameters - can include hydrogen ion concentration, dissolved gases, chlorine, nitrogen, COD, BOD, phosphates, sulfates, etc. Chemical parameters only measure the concentration of the pollutant in the water. They cannot assess the effects that a pollutant will have on the living components of the environment.

3. Biological Parameters - can include primary productivity, standing crop, biomass, species range and diversity, bioassays, etc. Biological parameters will not measure the concentration of a pollutant, but they will assess the effects that a pollutant has on the biota.

Biological parameters have a number of advantages over and above physical and chemical parameters. Aside from answering the fundamental question on the immediate effects of a pollutant, biological parameters have other advantages.

Of greatest significance is the potential of biological parameters for reflecting adverse conditions over extended periods. Often pollutants are released into the environment intermittently. With constant monitoring devices these discharges may go unnoticed. However, damage to the biota is easily detected long after the discharge occured.

Another advantage of biological parameters are their ability to monitor gradual changes in the environment. Subtle changes in concentration of nutrients may not be detected by chemical parameters, but may be readily detected by regularly monitoring phytoplankton populations.

A further advantage is that a pollutant may be identified in a water sample well away from the source of contamination. The pollutant may have been translocated and diluted by currents so that chemical or physical parameters would be useless. However, a survey of the biota may yield the necessary information to pin-point the source.

Finally, biological parameters are useful in monitoring pollutants that are in low concentration, but which have the ability to accumulate at each trophic level of the food chain. Some pollutants may not be detectable by chemical parameters, and may not be perceived as an immediate threat to the environment or to human well-being. However, their accumulation into organisms at higher trophic levels is of considerable significance for the survival of the ecosystem and man.

But if useful data is to be gained from these biological parameters, and used in any decision-making role in the effort to prevent or reduce pollution, it must often be accomplished through the interpretation of facts based on something less than a complete understanding of the ecological principles involved. In short, people must form judgements based on knowledge of only a portion of the ecosystem; that is, on specific biological information systems.

Biological information systems can be classified into two types:

1. artificial or in-plant monitoring systems
2. natural or out-plant monitoring systems

In-plant systems commonly employ bioassay tests, while out-plant systems encompass various diversity tests.

BIOASSAY

A bioassay is a type of biological test that involves determining the concentration of a given material necessary to affect a test animal under stated laboratory conditions. A bioassay consists of three essential parts: the stimulus, such as a drug or industrial waste, which when applied to a subject, such as a tissue, organ, or animal, evokes a response, such as death, change in weight, oxygen consumption, enzyme activity or other sublethal symptoms.

Bioassay tests have become increasingly more important and necessary as a means of determining official water quality criteria for aquatic life. Proper, efficient methods can yield meaningful results, and are currently the most effective and accurate method of assessing potential danger.

Basically a bioassay consists of exposing a sample of test animals, usually fish, to a series of solutions, varying only in the concentration of the pollutant under study. A set of guidelines are followed so that standardization of the work results. The number of animals, their relative size, type of test tank, diluting solution, etc. - all are uniform from sample to sample. Only the concentration of the pollutant changes in each sample.

Upon commencing the test, the investigator takes frequent recordings of the response he is measuring, usually death, in each sample at specific time intervals. After measuring the responses for a length of time, usually 48 or 96 hours, or until no further changes are evident in the samples, the investigator then terminates the test.

He then follows a set of standard procedures, using his data obtained from the test, and extracts an LC50 value. The LC50, or TLm, is the concentration of a substance evoking a 50% response (e.g. mortality) in a sample of test animals, within a prescribed exposure interval, usually 48 or 96 hours. For example, the 96 hour - LC50 value for ammonia, using trout, is 25 mg/l. This means that a solution of 25 mg/l of ammonia will, over the course of 96 hours, kill approximately 50% of the trout exposed to the solution.

A number of uses can be made of the LC50 value of a pollutant, including joint toxicity studies, multivariable analysis, and application factors.

The application factor is the degree of dilution applied to the LC50 value to ensure a safe discharge rate of waste into the receiving water. For many years now, 0.1 of the 48-hour LC50 has been used in the U.S.A. as an indication of safe levels. As tighter controls are being enforced the recommendations are for maximum levels of 0.05 of the 96-hour LC50 for non-persistent pollutants, and 0.01

for persistent pollutants. That would mean a 96 hour bioassay test would be run on the pollutant or effluent discharge under question. An LC50 value would be obtained from the data, and 0.01 of that value would be taken as a safe concentration. It must be emphasized here that these application factors of 0.1, 0.01, and 0.05 are for the most part, arbitrary numbers.

Since no single value can be expected to fit all types of pollutants, it is hoped that within time an application factor for each particular kind of waste will be available.

The bioassay test has a number of advantages and limitations. Among its advantages are:

1. The toxicity of different pollutants can be compared easily and meaningfully.
2. The LC50 value serves as a basic measuring unit for predicting joint toxicity of two or more pollutants.
3. The LC50 value can be used to estimate a safe level by using application factors.
4. The bioassay test can be used for determining sublethal effects.

Some of the limitations to the bioassay method are as follows:

1. There is a difficulty in setting down rigid standards of procedure because of the complexities involved.
2. There are a large number of modifying factors in the natural environment that can act to increase or decrease the effect of a pollutant, but which are not considered in the bioassay test.

3. It is difficult to determine the safe long-range level of a pollutant by using a short-term bioassay.
4. Because a bioassay makes use of living organisms, it is difficult to guarantee precise uniform results if the test is repeated under identical conditions. Therefore, the interpretation and prediction of biological systems have not yet reached the level of reliability that now exists in the physical and chemical sciences.

The second type of biological information system involves out-plant monitoring, i.e. testing within the environment itself.

DIVERSITY TESTS

As discussed previously, most forms of pollution cause a reduction in the complexity of the ecosystem, or a simplification. Organisms vary greatly in their sensitivity to various types of pollution. The introduction of a pollutant reduces the number of species by eliminating those sensitive to the pollutant, until only those organisms which can survive the adverse conditions remain.

Tolerant organisms are found in both clean and polluted environments, and their presence does not necessarily mean a body of water is polluted. A population of tolerant organisms combined with an absence of intolerant organisms is a good indication of pollution. These pollution-sensitive organisms can be used, or rather their absence can be used, as an indication of pollution, and they are consequently called indicator organisms.

Monitoring within the natural environment is based on the principle that a clean, unpolluted community has a high diversity of species, while a dirty, polluted community, has a low diversity of species.

This type of monitoring is accomplished through diversity tests.

There are a number of different diversity tests, and methods of presenting diversity data on paper:

1. Tabulation - the most frequent method of presentation is simply a tabulation of the number of organisms and their composition by species. This method is cumbersome, and difficult to interpret.

2. Graphing - the presentation of data can be vastly improved by the application of log-normal curves. For example, after graphing the data from diatom species present in a polluted and unpolluted stream, it is noted that the curve for the polluted stream has a lower mode and extends further to the right, (Fig. 12). This indicates that few diatom species are able to live in that environment. In contrast, the unpolluted stream presents a greater variety of species where the majority are represented by a relatively small number of individuals. Curves such as these visually illustrate the difference between the two environments.

3. For reference only, two other tests seldom used today are the biological score, and the biotic index. Both techniques were dependent on a large number of control sites which were not always available.

4. Diversity Index - this is the most quantitative and widely used test available at present. This index is based on the permutation theory of mathematics. It is one of the better

diversity tests in that it can be used for any type of indicator organism. The test can compare the diversity indices of different populations. The technical drawback to this test is that it requires the availability of a computer.

As a concrete example, the diversity index for a zooplankton species was graphed against the distance away from the source of an effluent discharge, (Fig. 13). In this particular study, preliminary tests at control sites, similar to the site of the effluent discharge, revealed only small changes in diversity from the shoreline to four miles out over the continental shelf. Yet when the diversity index test was done at the site of the effluent discharge, it revealed a substantial increase in diversity the further away one went out from the source of the pollution.

5. <u>Sequential Comparison Index</u> - this test was designed specifically for non-biologists to estimate the differences in biological diversity. This method is useful in that it requires no taxonomic expertise on the part of the investigator. It utilizes the innate ability of the investigator to recognize differences such as shape, colour, and size between organisms. Basically the test involves taking samples of the bottom fauna in an area, and by random mixing and placing of the sample on a flat surface, determining the number of runs of similar and different organisms. The basic principle is - the greater the number of runs - the higher the diversity.

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FIGURE 12

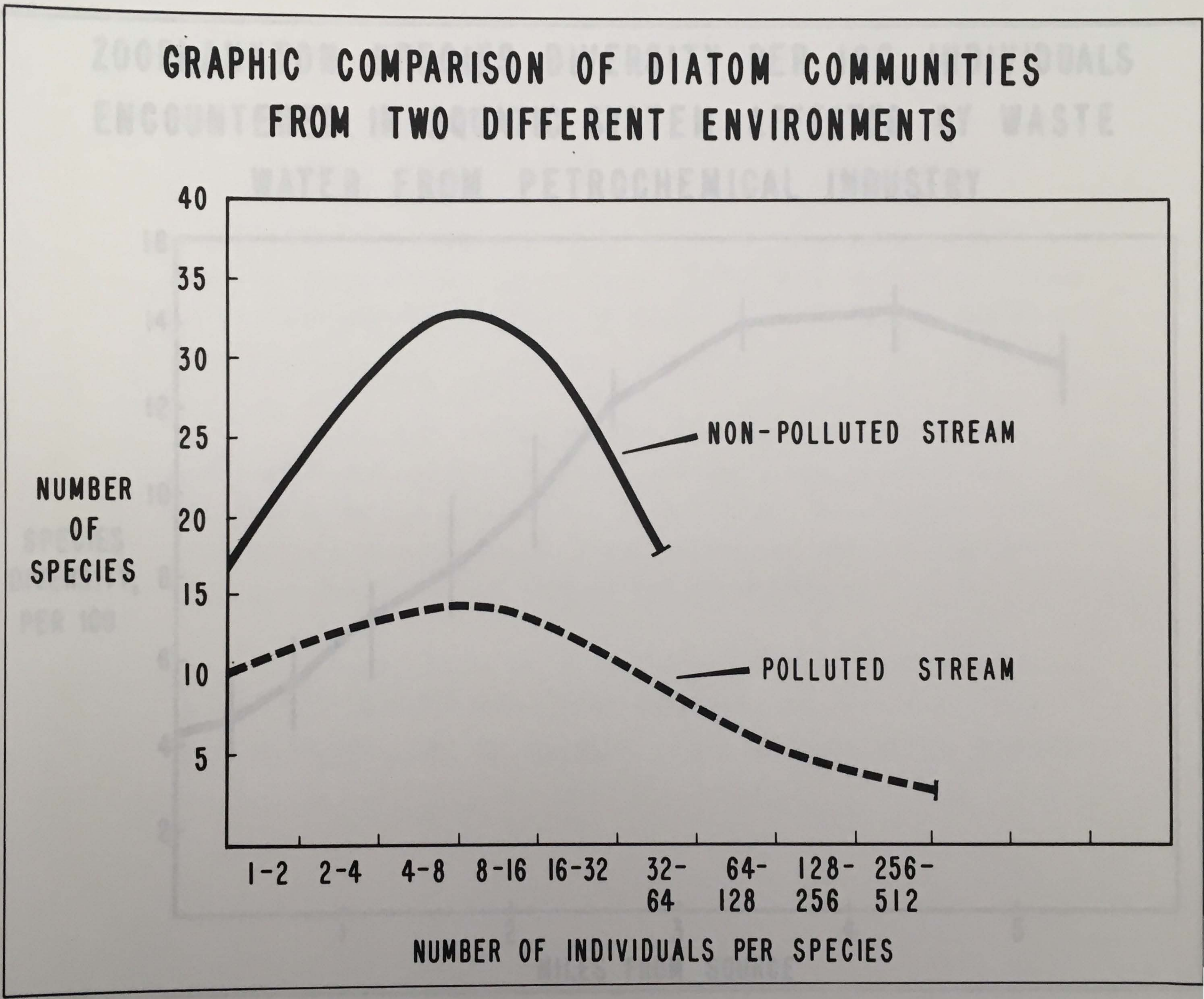
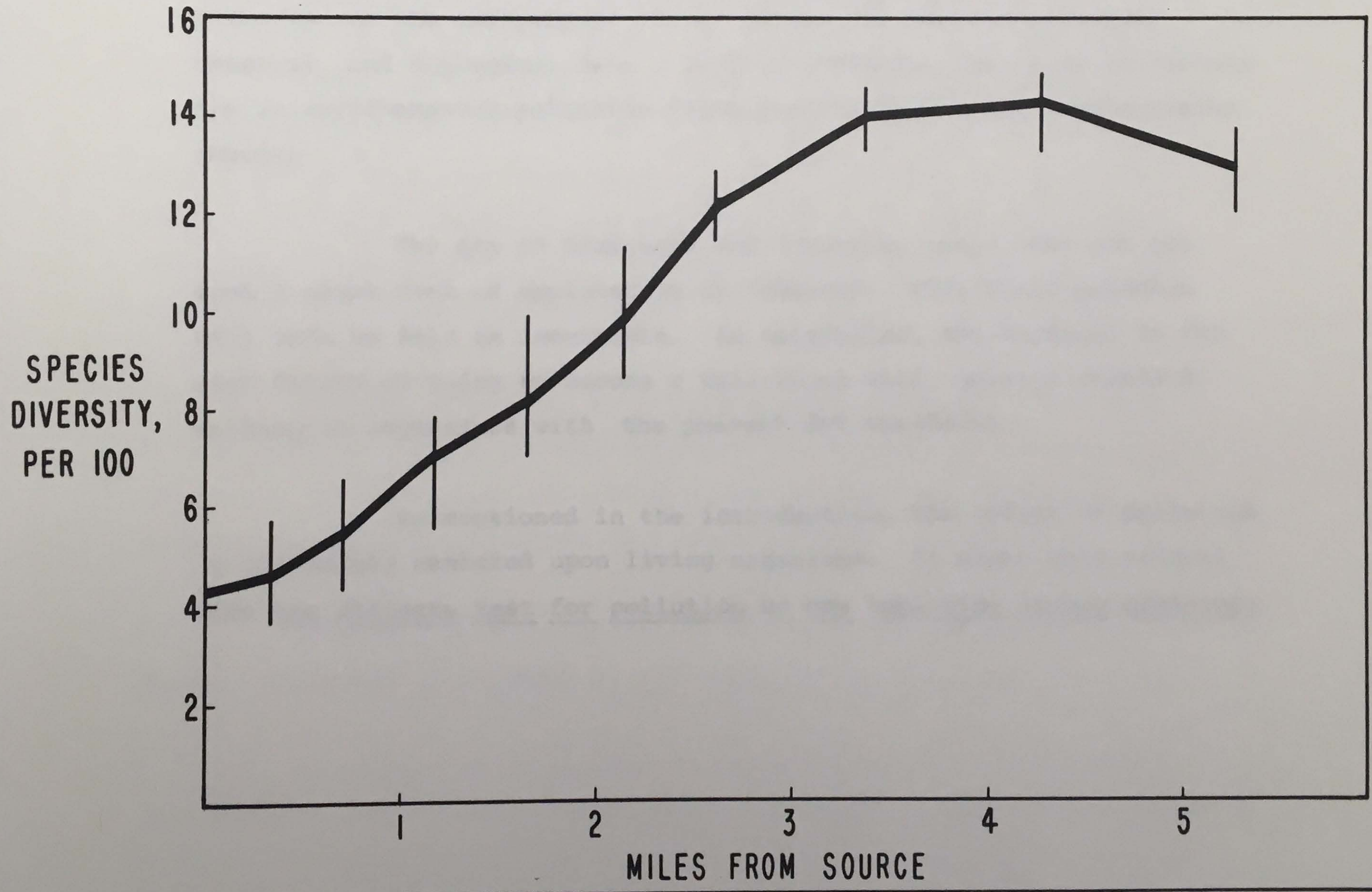

GRAPHIC COMPARISON OF DIATOM COMMUNITIES
FROM TWO DIFFERENT ENVIRONMENTS
NUMBER OF SPECIES
40
35
30
25
20
15
10
5
NON-POLLUTED STREAM
POLLUTED STREAM
1-2
2-4
4-8
8-16
16-32
32-64
64-128
128-256
256-512
NUMBER OF INDIVIDUALS PER SPECIES

FIGURE 13

ZOOPLANKTON SPECIES DIVERSITY PER 100 INDIVIDUALS ENCOUNTERED IN AQUATIC SYSTEM AFFECTED BY WASTE WATER FROM PETROCHEMICAL INDUSTRY



CONCLUSIONS TO BIOLOGICAL INFORMATION SYSTEMS

It has not been the intent of this section to give a complete and comprehensive survey of biological information systems. Rather it is an attempt to show that biological data can indeed be acquired; and further, that it can be expressed numerically in many cases and can be meaningful to the engineer, chemist, or other non-biologists. The best approach when determining the effects of pollution on the environment is, of course, to combine physical, chemical, and biological data. Only by combining the three parameters can an environmental pollution study yield complete and comprehensive results.

The use of bioassays and diversity tests have not yet seen a great deal of application in industry. That their presence will soon be felt is inevitable. In particular, the bioassay in the near future is going to become a well-known water quality standard, ranking in importance with the present day standards.

As mentioned in the introduction, the effect of pollution is ultimately centered upon living organisms. It seems only natural that the ultimate test for pollution be one employing living organisms.

MAN AND HIS ENVIRONMENT

The welfare and future of the human species present very compelling demands for answers about the organization of the earth's ecosystems, and about man's interactions with all of their components. As his numbers and technology have increased, man has achieved the ability to influence the earth's ecosystems in a vast way, without simultaneously gaining an adequate understanding of how they function. Such knowledge is imperative if man is to persist at a desirable level of existence in an environment where his activities are an increasingly dominant factor. Unfortunately, man has enormously and often recklessly modified ecosystems. He is polluting his environment with increasing quantities of waste products from his technology, as his numbers and technical know-how increase. Further, there is the inescapable fact that human population increase poses a serious problem that must be approached in an ecological context.

In sum, we live in an ecological world that is increasingly dominated by man's activities. There are few land areas and few coastal areas that have not been altered by these activities. The world population increase indicates that these effects will multiply.

The greatest problem facing man today is the ecological one of harmonious adjustment to the ecosystem of which he is a part.

In no way is it possible or even desirable to maintain the environment in a primeval state. The environment is, and will, constantly change. The propogation, proliferation, and prosperity of each life form on this planet exerts some influence on the environment. Man is no exception. The development of his civilization, economy, and his way of life as we know it today, must inevitably have an impact on the whole environment. It is the duty however, of man in every walk of life to minimize this impact. Our lives, our childrens lives, and the very life of the planet earth depend on it.

SUGGESTED READING LIST

GENERAL ECOLOGY

Clarke, G.L. 1965. Elements of Ecology. John Wiley & Sons, Inc. New York. (a basic ecological text)

Kormandy, E.J. (ed.) 1965. Readings in Ecology. Prentice-Hall, Inc., Englewood Cliffs, N.J. (a number of interesting papers)

Kormandy,E.J. 1969. Concepts of Ecology. Prentice-Hall, Inc., Englewood Cliffs, N.J. (a small condensed text on ecology)

Mayr, E. 1963. Animal Species and Evolution. Belknap Press of Harvard University Press, Cambridge. (one of the better texts in the field of ethology)

Phillipson, J. 1966. Ecological Energetics. Edward Arnold Ltd., London, England. (describes ecosystem concept in terms of energy movement)

Ward, H.B. and G.C. Whipple. 1959. Fresh-water Biology. 2nd. Ed., John Wiley and Sons, New York. (the best fresh-water taxonomic source available)

POLLUTION

Carson, Rachel. 1962. Silent Spring. Houghton-Muffin, Boston. (a classic, although somewhat out of date)

Cowell, E.B. (ed.) 1971. Ecological Effects of Oil Pollution. Institute of Petroleum, Elsevier Publishing Co. Ltd. N.Y. (a number of papers on work being done in Wales)

Hepple, Peter, (ed.) 1971. Water Pollution by Oil. Institute of Petroleum, Elsevier Publishing Co. Ltd. N.Y.

POLLUTION cont'd...

Hynes, H.B.N. 1960. The Biology of Polluted Waters. University Press, Liverpool, England. (good basic text on water pollution)

Marx, W. 1967. The Frail Ocean. Coward-McCann, Inc. New York. (excellent book on the pollution taking place in our oceans)

Olson, T.A. & F.J. Burgess, (eds.). 1967. Pollution and Marine Ecology. Interscience Publishers, New York. (good text on marine pollution)

Wilber, C.G., 1969. The Biological Aspects of Water Pollution., Charles C. Thomas Publisher, Springfield, Illinois. (a basic text on all types of water pollution)

RESOURCES AND HUMAN POPULATION

Borgstrom, G. 1969. Too Many, A Story of Earth's Biological Limitations. Macmillan, New York.

Ehrlich, P.R. & A.H. Ehrlich. 1970. Population, Resources, Environment. W.H. Freeman & Co., San Francisco. (an excellent text on humans and their relations with the environment)

Rattray-Taylor, G. 1969. The Biological Time Bomb. World Publishing Co., New York. (interesting reading)

Watt, K.E.F. 1968. Ecology and Resource Management: A Quantitative Approach. McGraw-Hill, New York.

BIOLOGICAL INFORMATION SYSTEMS

Alderdice, D.F. 1967. The detection and measurement of water pollution - biological assays. Canada Dept. Fisheries: Can. Fish. Rept. No. 9, 33-39.

Cairns, J. Jr., Albaugh, D.W., Busey,F. and M.D. Chaney. 1968. The Sequential Comparison Index. J. Wat. Pollut. Cont. Fed., Washington, D.C.

Sprague, J.B. 1969. Measurement of pollutant toxicity to fish - I. Bioassay methods for acute toxicity. Water Research 3:793-821.

Sprague, J.B. 1970. Measurement of pollutant toxicity to fish - II. Utilizing and applying bioassay results. Water Research 4: 3-32.

Sprague, J.B. 1971. Measurement of pollutant toxicity to fish - III. Sublethal effects and safe concentrations. Water Research. (not yet in print)

Stein, J.E. & J.G. Dennison. 1967. Limitations of Indicator Organisms, In: Pollution and Marine Ecology. Interscience Publishers, New York.

Wass, M.L. 1967. Indicators of Pollution, In: Pollution and Marine Ecology. Interscience Publishers, New York.