

INTERPRETING DYNAMICS OF AQUATIC RESOURCES: A PERSPECTIVE FOR RESOURCE MANAGERS

RESEARCH/RESOURCES MANAGEMENT REPORT No. 34

U.S. DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
SOUTHEAST REGION

UPLANDS FIELD RESEARCH LABORATORY
GREAT SMOKY MOUNTAINS NATIONAL PARK
TWIN CREEKS AREA
GATLINBURG, TENNESSEE 37738



The Research/Resources Management Series of the Natural Science and Research Division, National Park Service, Southeast Regional Office, was established as a medium for distributing scientific information originally prepared for park Superintendents, resource management specialists, and other National Park Service personnel in the parks of the Southeast Region. The papers in the Series also contain information potentially useful to other Park Service areas outside the Southeast Region and often benefit independent researchers working in the parks. The Series provides for the retention of research information in the biological, physical, and social sciences and makes possible more complete in-house evaluation of non-refereed research, technical, and consultant reports.

The Research/Resources Management Series is not intended as a substitute for refereed scientific or technical journals. However, when the occasion warrants, a copyrighted journal paper authored by a National Park Service scientist may be reprinted as a Series report in order to meet park informational and disseminative needs. In such cases permission to reprint the copyrighted article is sought. The Series includes:

1. Research reports which directly address resource management problems in the parks.
2. Papers which are primarily literature reviews and/or bibliographies of existing information relative to park resource management problems.
3. Presentations of basic resource inventory data.
4. Reports of contracted scientific research studies which are reprinted due to the demand.
5. Other reports and papers considered compatible to the Series, including approved reprints of copyrighted journal papers and results of applicable university or independent research.

The Series is flexible in format and the degree of editing depends on content.

Research/Resources Management Reports are produced by the Natural Science and Research Division, Southeast Regional Office, in limited quantities. As long as the supply lasts, copies may be obtained from:

Natural Science and Research Division
National Park Service
Southeast Regional Office
75 Spring Street, SW
Atlanta, Georgia 30303

INTERPRETING DYNAMICS OF AQUATIC RESOURCES:
A PERSPECTIVE FOR RESOURCE MANAGERS*

Research/Resources Management Report No. 34

August 1980

Gary L. Larson
U.S. Department of the Interior
National Park Service
Southeast Region
Uplands Field Research Laboratory
Great Smoky Mountains National Park
Gatlinburg, Tennessee 37738

*Copyrighted and published by
Environmental Management, Vol. 4, No. 2, pp. 105-110.
Reprinted with permission from Springer-Verlag New York, Inc., 1980

Larson, Gary L. 1980. Interpreting Dynamics of Aquatic Resources: A Perspective for Resource Managers. U.S. Department of the Interior, National Park Service, NPS-SER Research/Resources Management Report No. 34.

(Copyrighted and published by Environmental Management, Vol. 4, No. 2, pp. 105-110; Springer-Verlag New York, Inc., publishers. Reprinted with permission.)

TABLE OF CONTENTS

	page
List of Illustrations	ii
Acknowledgments	iii
Abstract	iv
Definition of Terms	v
Introduction	1
Assessment of Aquatic Resources	2
Discussion	15
Literature Cited	18

LIST OF ILLUSTRATIONS

	page
Figure 1. Relationship between monthly concentrations of $\text{PO}_4\text{-P}$ and chlorophyll a in Lake Washington in 1950 and 1964	3
Figure 2. Hypothetical relationship between the prey biomass (density) and the consumer biomass	5
Figure 3. Hypothetical relationships between the prey biomass and the consumer biomass at three relative levels of productivity . . .	5
Figure 4. Hypothetical approximation of the relationship between consumer growth and biomass at a given level of productivity	7
Figure 5. Hypothetical relationships between consumer biomass and the growth and production of the consumer at a given level of productivity	7
Figure 6. Hypothetical relationships between consumer biomass and the growth and production of the consumer at two relative levels of productivity	7
Figure 7. Relationships between light energy and plants, plants and insects, insects and trout, and yield and trout in laboratory stream experiments	10
Figure 8. Diagrammatic illustrations of the dynamics of an aquatic system at one level of productivity (defined as high light)	11
Figure 9. Hypothetical relationships between insects and fish in a stream at two levels of productivity (defined by low and high light)	13

ACKNOWLEDGMENTS

I thank the staff members of the Uplands Field Research Laboratory, J. Wood, J. Gogue, R. Herrmann, and B. Evison for their critical and useful reviews of the original manuscripts. Many of the thoughts presented in this paper were developed during my tenure at the Oak Creek Laboratory of Biology, Oregon State University, working with C. Warren, G. Davis, and W. Liss. I thank them for their efforts in my behalf.

ABSTRACT

Since the presentation of the Leopold Report (Leopold et al. 1963) to the United States Secretary of the Interior, recommendations in the document for managing natural park resources on the ecosystem level have been included in the management policies of the National Park Service. In many instances, however, management programs have continued to focus on individual resource problems, without apparent concern for the ecological consequences on ecosystems. Without knowledge of the interrelationships of ecosystem components, solving one problem may result in other resource problems. Graphic approaches are presented as potential tools to view these complex relationships relative to the needs of the resource manager. Interpreting the dynamics of aquatic systems is emphasized.

DEFINITION OF TERMS

The following definitions serve to define the terms used in this document.

ecology: A study of the interrelationships which exist between organisms and their environment.

ecosystem: A functional system which includes the organisms of a natural community together with their environment. Also known as ecological system.

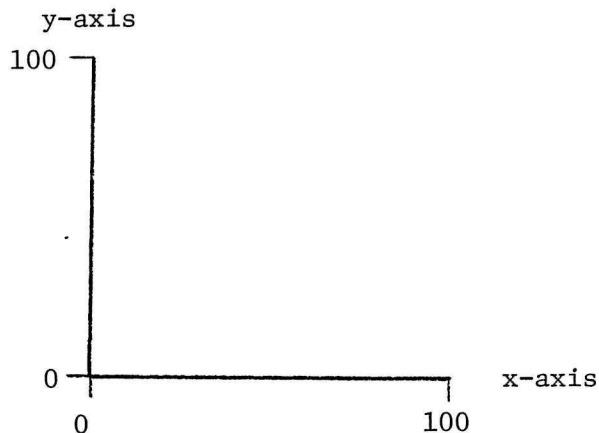
ecological interactions/interrelationships: The relation between species that live together in a community; specifically, the effect an individual of one species may exert on an individual of another species.

biomass: The weight of living matter, including stored food; expressed in terms of a given area or volume of habitat.

trophic level: Any of the feeding levels through which the passage of energy through an ecosystem proceeds; examples are photosynthetic plants, herbivores, and carnivores.

x-axis: A horizontal axis in a system of rectangular coordinates.

y-axis: A vertical axis in a system of rectangular coordinates.



- - All definitions from The Dictionary of Scientific and Technical Terms, McGraw-Hill Book Co., New York, 1972.

INTRODUCTION

This article presents some concepts concerning the complexity of ecological systems relative to the needs of National Park Service resource managers. The Leopold Committee Report, submitted to the Secretary of the Interior in 1963, recommended that the biological associations of national parks should be managed as nearly as possible in the condition they were when first viewed by European visitors. The report provided guidance for the National Park Service to manage resources by natural processes at the ecosystem level.

The National Park Service has recognized the importance of the Leopold Report in establishing resource management policy; however, actual application of the recommendations has been less than satisfactory. Most management programs continue to pursue solutions of individual resource problems while ignoring the ecological consequences of these programs on ecosystems. Resource managers must recognize the complexities of ecosystems if they expect successfully to manage park resources in the spirit of the Leopold Report. Solving one problem without considering its effect on other ecosystem components may create other resource problems. Furthermore, natural changes in park resources must be differentiated from unnatural changes--those stemming from man and exotic animals and plants. Park managers must interpret these changes and assess them in terms of park policy. Simple solutions to resource problems, however, will always be unsatisfactory unless the manager has a good understanding of some basic ecological concepts. Some of these are presented here for aquatic systems.

ASSESSMENT OF AQUATIC RESOURCES

In many parks the only information available to managers of aquatic resources is inventory data. This qualitative information is important because the manager must know what is present in a park. In terms of Park Service policy, however, this information is not very useful because the manager will know only if the resources are present or absent. What are needed are relative and quantitative measurements and determinations that provide managers with valuable information about the abundances, biomasses, and concentrations of particular resources. Repeated assessments of these parameters can help managers develop an understanding of the variability of park resources through time.

Unfortunately, routine collection of resource data may not clarify system dynamics. Data collected by W. T. Edmondson (1969) during his work on Lake Washington serves as an example. If water quality samples were taken annually only during July and August from 1950 to 1964, little change in the concentration of phosphate ($\text{PO}_4\text{-P}$), an important nutrient of algae, would have been observed. The concentration was always less than 5 ppm $\text{PO}_4\text{-P}$ during those months. Thus, based on July-August data the lake appears to have changed very little during the sampling years. However, as Figure 1 illustrates, the lake was oligotrophic (nutrient poor) in 1950, and eutrophic (nutrient rich) in 1964. Water samples taken at other times during each year would have shown changes in phosphorus concentration. Adequate sampling designs are of utmost importance in determining annual variations of a resource.

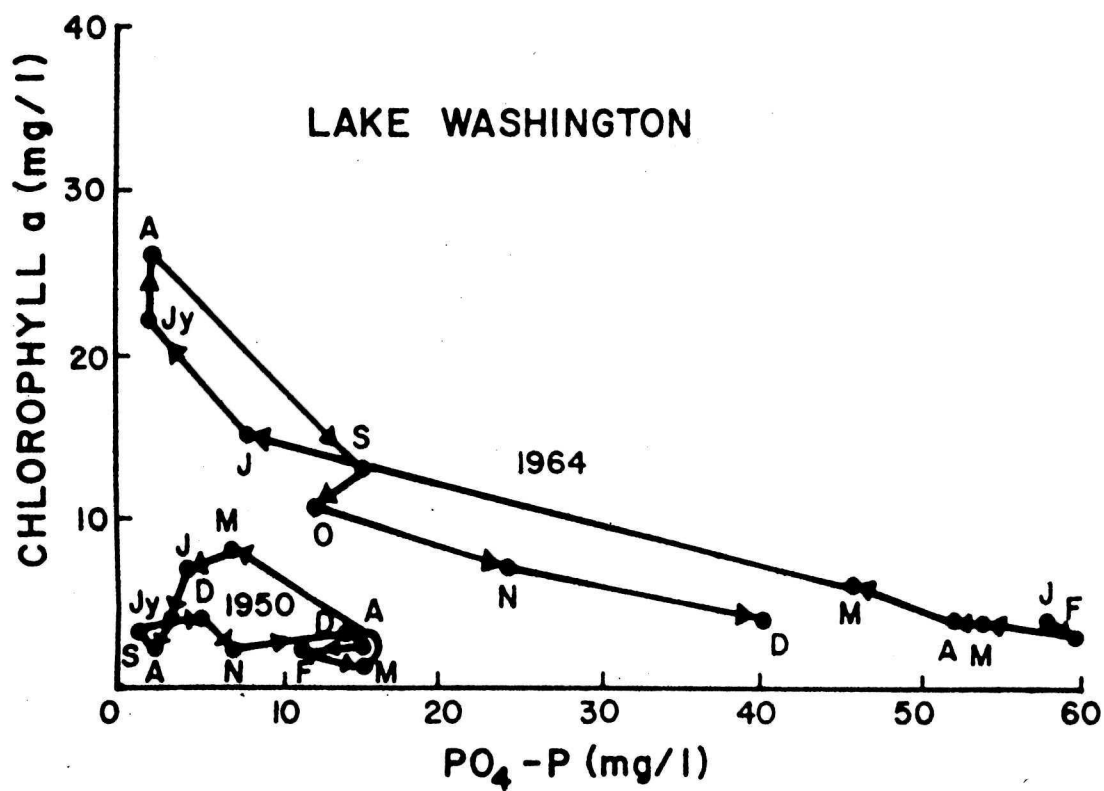


Figure 1. Relationship between monthly concentrations of PO₄-P and chlorophyll a in Lake Washington in 1950 and 1964.

The Lake Washington case also illustrates the usefulness of sampling more than one trophic level. The relationships between phosphate and algae (reported as chlorophyll) obviously changed from 1950 to 1964; the extent of the changes became clear when the data were plotted as shown in Figure 1. The immense difference between the 2 years was attributed to the increased input of nutrients into the lake (Edmondson 1969). This change in nutrient input increased algae productivity of the lake, which, in turn, raised the annual maximum-minimum boundaries of algal biomass in the lake (y axis, Figure 1). Since the change was manmade, however, the new boundaries were artificial.

Productivity can provide important insights into the dynamics of aquatic systems. For example, assume that a density (biomass) relation exists between the population of a consumed species (prey) and the population of a consumer species (predator). This is referred to as a density dependent relationship (Warren 1971). Figure 2 illustrates that as the consumer biomass increases, the prey biomass decreases, and vice versa for the one level of productivity shown. Although, for illustrative purposes, it is useful to assume a constant level of productivity for a system, natural systems differ in productivity. Figure 3 illustrates conditions for three systems with different levels of productivity for producing the particular prey and consumer relationship shown in Figure 2.

Recognizing that systems differ in productivity is essential for developing management policies; sampling only one side of a system can lead to erroneous interpretations. For example, if one sampled three

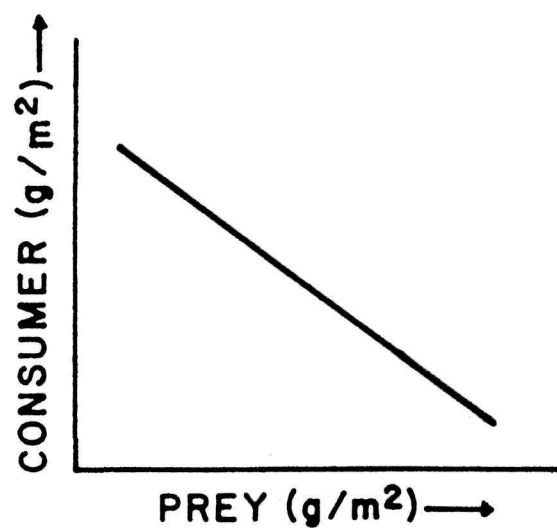


Figure 2. Hypothetical relationship between the prey biomass (density) and the consumer biomass.

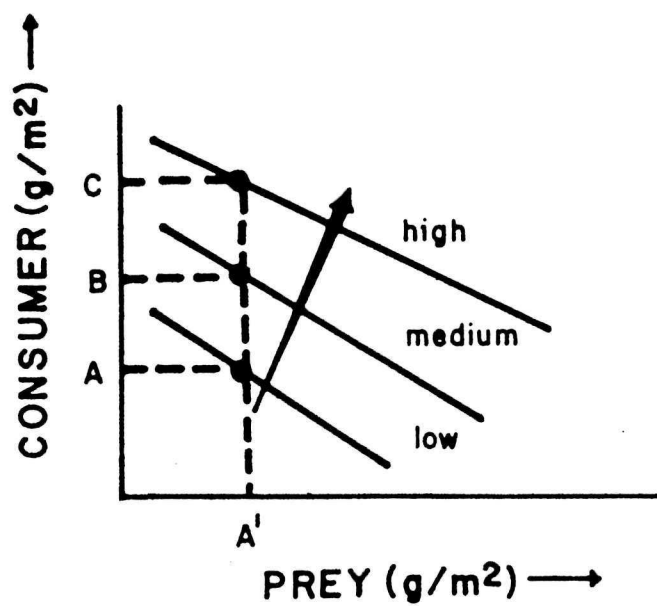


Figure 3. Hypothetical relationships between the prey biomass and the consumer biomass at three relative levels of productivity.

lakes for a particular prey species and concluded that the lakes were of similar productivity because there was little difference in the prey biomass among the lakes, the conclusion might be incorrect owing to differential capacities among the lakes to support various consumers. The value A' in Figure 3 represents a constant prey biomass. It should be apparent that the lake supporting consumer C has a much higher productivity level than the lake supporting consumer A, because the consumer-plus-prey biomass sum is much larger in the lake supporting C. Thus, an adequate sampling design includes not only varied sampling times, but also varied trophic levels.

The assumption that constant productivity occurs in nature is not particularly useful in establishing management policies and programs because of seasonal and yearly environmental variability. However, this assumption may be applicable for short periods: certain seasons or portions of seasons. If so, then production of a consumer should be related directly to the biomass of its prey. To understand this relationship better, let us examine consumer growth in relation to prey biomass. As consumer biomass increases and that of the prey decreases, consumer growth will decrease as its biomass increases at a given productivity level. This theoretical relationship is presented in Figure 4. Production of the consumer at this fixed level of productivity can be calculated as the biomass of the consumer multiplied by its growth (Figure 5). Thus, as its biomass increases from zero, production increases, attains a maximum, and then decreases. If the productivity of a system increased or decreased, then more production curves would be drawn. Two production curves, representing two

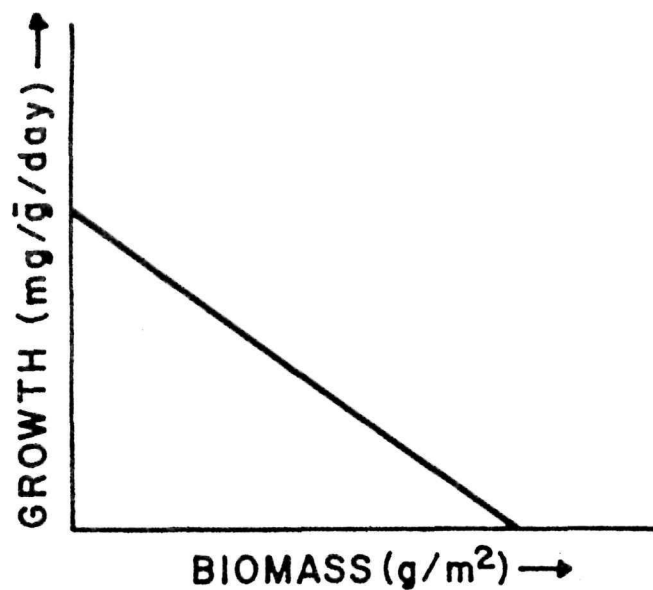


Figure 4. Hypothetical approximation of the relationship between consumer growth and biomass at a given level of productivity.

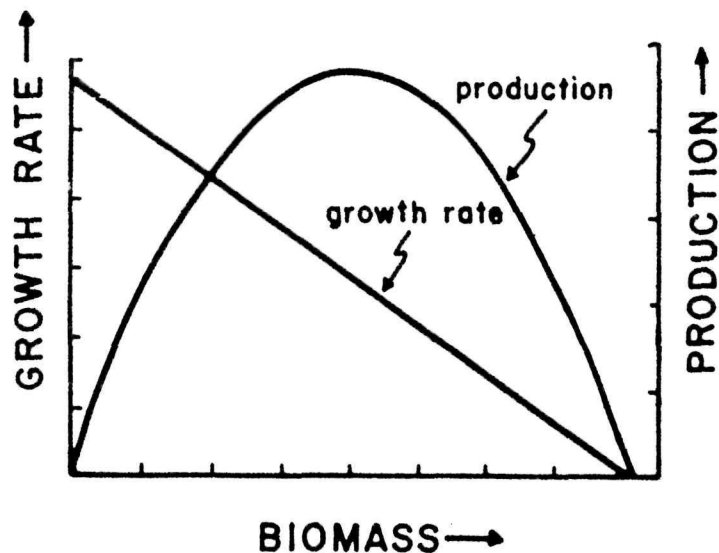


Figure 5. Hypothetical relationships between consumer biomass and the growth and production of the consumer at a given level of productivity.

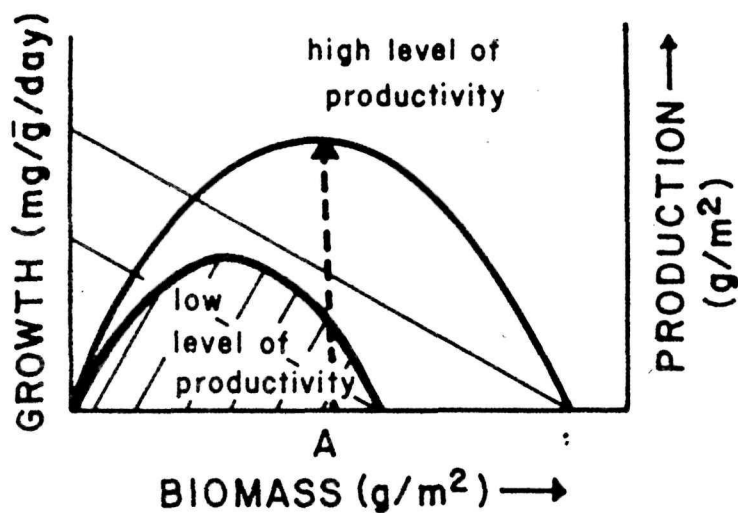


Figure 6. Hypothetical relationships between consumer biomass and the growth and production of the consumer at two relative levels of productivity.

productivity levels, are shown in Figure 6.

This approach provides one view of the complex nature of ecosystems, but it is difficult to determine the productivity level of a system by sampling on a particular date because productivity is not constant through time. Nonetheless, knowledge of this variability will provide a useful starting point for understanding that a given consumer biomass can actually have more than one level of production, as shown in Figure 6 at A. Thus, determining consumer biomass without determining production can be of questionable value. Similarly, production values alone do not mean very much. Production of a species can be lower in a system of high productivity than in a system of low productivity, depending on the position of the biomass relative to the production curves. Warren (1971) provided empirical examples of these relationships.

National Park Service policy states that low production of a species in park waters is acceptable so long as it is the result of natural processes. However, management actions that alter the processes must be taken into account. An example of such actions for aquatic systems would be fishing (harvest) and fish stocking. Harvest and stocking can alter fish production by changing the position of the fish biomass relative to a production curve (refer to Figure 5). The changes will depend upon the initial fish biomass and the amount of biomass added or removed.

The preceding illustrations show that aquatic systems--and all individual systems--vary in productivity. Furthermore, productivity of a

system at one trophic level affects the productivity at other levels. Warren (1971) provided an example of this from studies of laboratory stream communities. He recorded light, plant biomass, insect biomass, and fish biomass. The dependent variable was light level; each stream community received one of three light levels. Warren's results showed that the amount of light entering each community directly affected the productivity of the system. As the amount of light increased, the plant biomass increased (Figure 7A). These levels were transferred to the next steps in the food chain, aquatic insects (Figure 7B), and from the insects to the trout (Figure 7C). If fishing had been allowed, Warren speculated that relation (Figure 7D). Although Warren defined only one point at each productivity level, it is clear that different productivity levels at one step of a food chain affect the entire chain. Thus, one can expect variations in system productivity when ecosystem changes alter the rate of input or output of a component of an aquatic food chain (or web).

Environmental changes can also affect components of food chains at a given productivity level. Any alteration that changes the biomass of a component at one trophic level can alter the biomasses at other trophic levels. To illustrate this, a simple food chain is presented in Figure 8A-C. The defined system is light, nutrients, algae, insects, fish, and fishing harvest (yield). The trophic components are arranged so that each successive level (y axis) is plotted against the next lower level (x axis), such as nutrients versus algae, algae versus insects, and insects versus fish. The single productivity level is defined by high light.

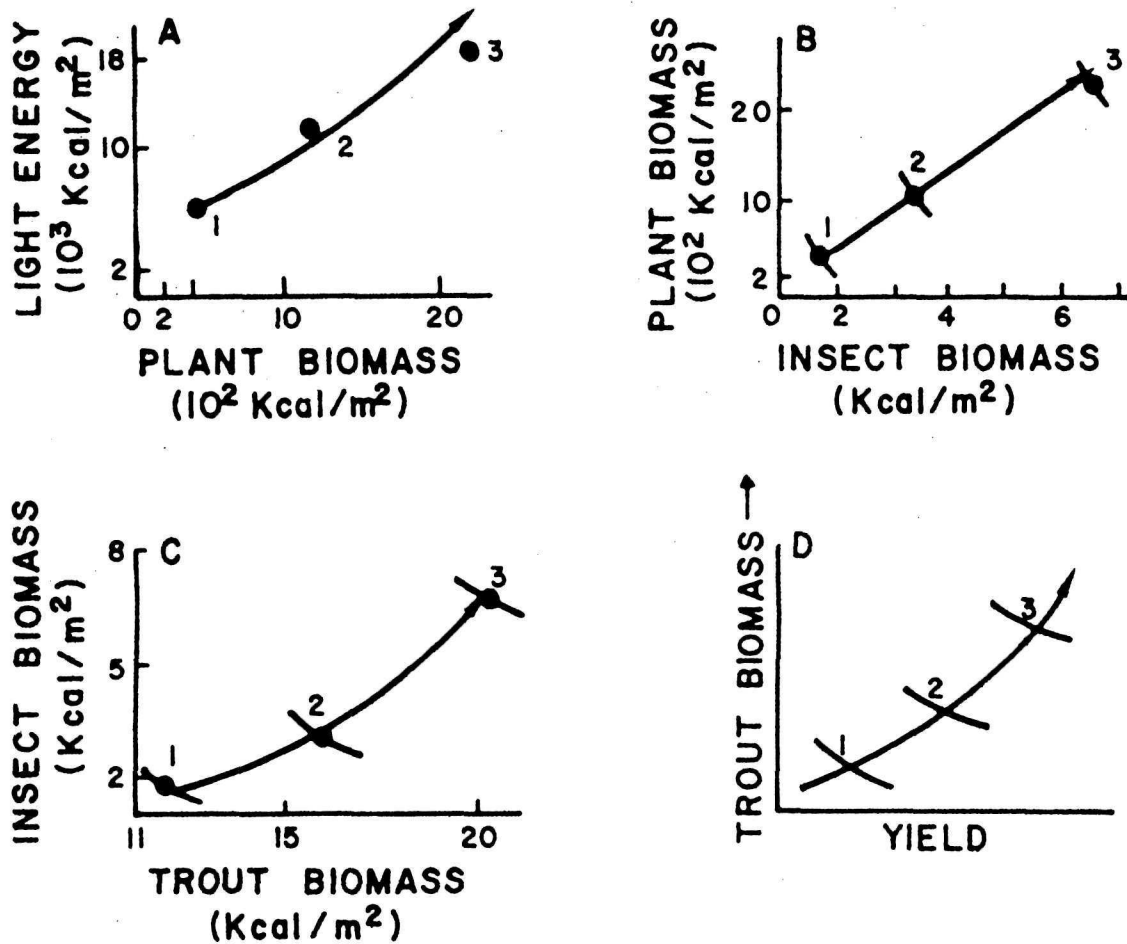


Figure 7. Relationships between light energy and plants (A), plants and insects (B), insects and trout (C), and yield and trout (D) in laboratory stream experiments. Different light levels are indicated as 1, 2, and 3, with 3 being the highest. (Modified after Warren 1971, with permission from W.B. Saunders Co.)

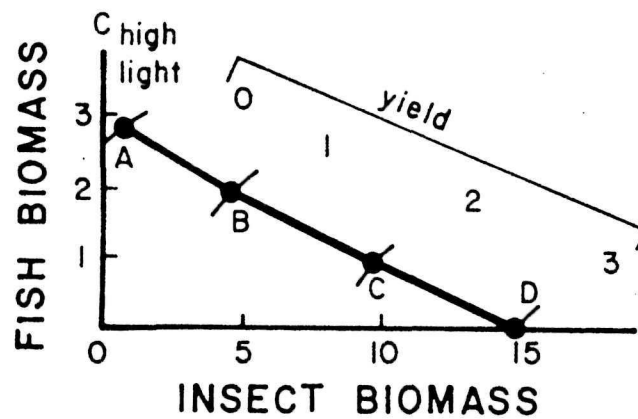
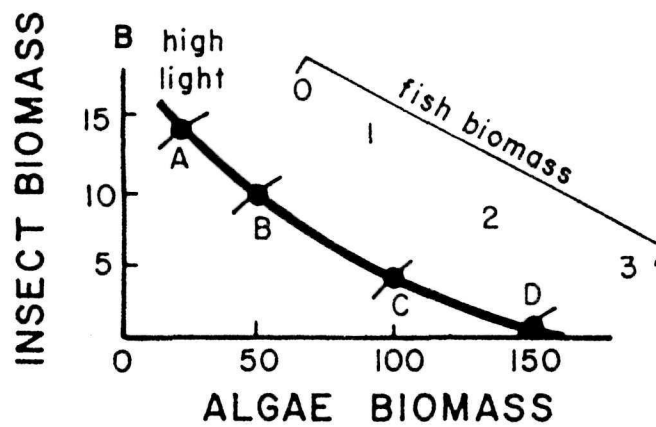
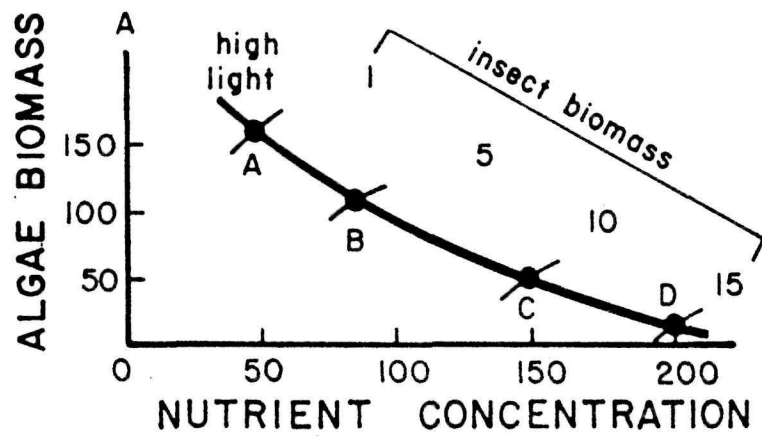


Figure 8. Diagrammatic illustration of the dynamics of an aquatic system at one level of productivity (defined as high light).

Superimposed above each productivity curve is the biomass of the next trophic level. Figure 8C shows that if fish biomass at a given time is 2 and insect biomass is 5, then the defined relationship between the two levels is point B. Note that the relationship defined by point B is not maintained only because of the relationships between fish and insects; it is also influenced directly by the lower trophic levels and the amount of yield. At point B yield is at level 1. With yield at 2, the relationship between fish and insects changes to point C. With this shift from B to C, the other components of the food chain would also shift: insects would now be at 10, causing the algae biomass to decline to 50 (Figure 8B) and nutrient concentration to increase to 150 (Figure 8A). This very simple food chain illustrates the interaction dynamics of trophic components. In real systems, food chains are usually food webs, and changes of the type just illustrated are not usually so dramatic or direct.

Because ecological systems do not remain at constant productivity levels, it is not easy to make sense out of the dynamics of aquatic systems. But an insect-fish relationship like that in Figure 8C serves to illustrate one approach, shown in Figure 9. The defined system used here includes light, plant biomass, insect biomass, fish, and fishing yield. With the consumer-prey relationship at point A, and productivity constant (i.e., low light and low plant biomass), any change in the consumer-prey relationship will be dependent on the other components. Point A is defined by the intersection of the low light and low yield curves. Clearly, point A will remain constant so long as the system's

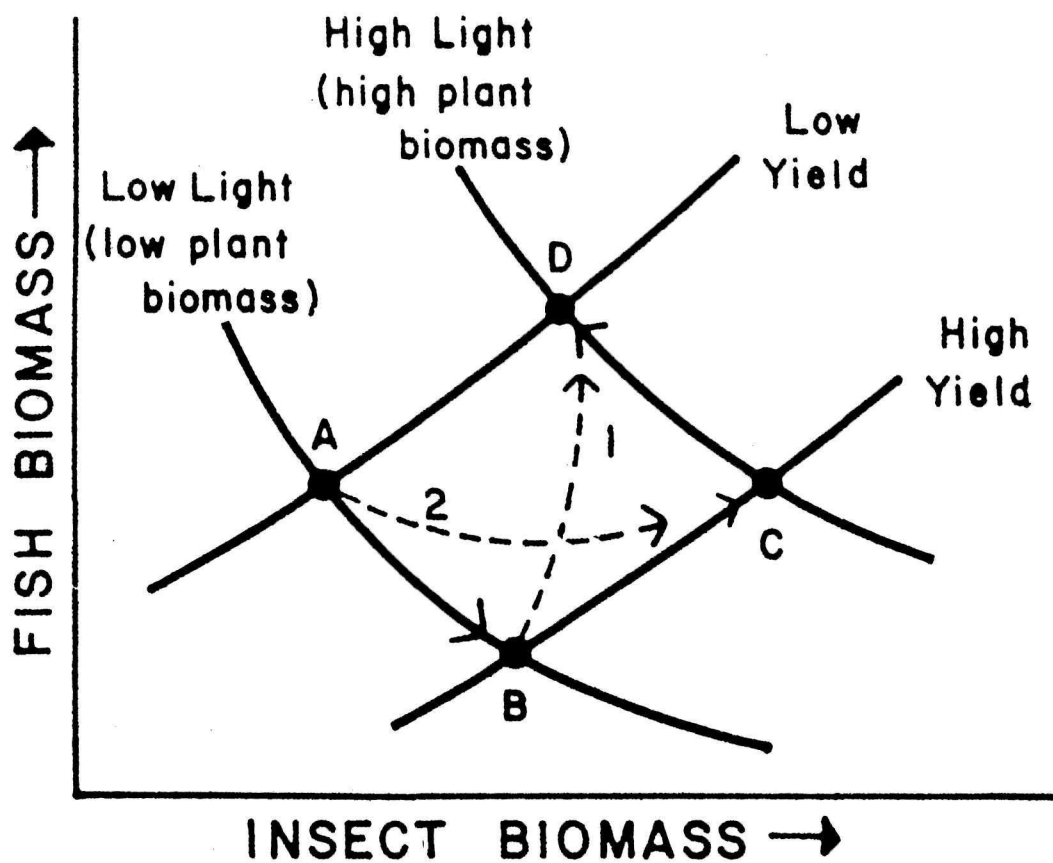


Figure 9. Hypothetical relationships between insects and fish in a stream at two levels of productivity (defined by low and high light).

capacity to produce low plant biomass and to sustain a low fishing yield is constant (i.e., so long as the two curves that form point A remain constant).

If one or more of the curves shift, then point A would no longer exist. For example, if the fishing yield increases to a high level, fish biomass will decrease and insect biomass will increase, shifting the consumer-prey relationship to point B. If there were corresponding increases in light and in plant biomass (increased productivity), however, then the system would shift from point B to point C. And if fishing yield declined at this increased level of productivity, then fish biomass would increase and insect biomass would decrease; the system would then shift to point D. Theoretically, it is possible to move vertically or horizontally, as shown by the dashed lines in Figure 9. Note that for line 1 in this example, two biomasses of fish are maintained by about the same biomass of insects, and that for line 2, two biomasses of insects support about the same biomass of fish. Also, increased fishing yield causes a reduction in fish biomass at both levels of productivity and corresponding increases of insect biomass--but increased plant biomass and light cause an increase in fish and insects at each level of fishing yield. Note that increased light and plants shift to the right on the graph while increased fishing yield shifts down. The mathematical definition for positioning these ecological parameters is given in Warren and Liss (1977). The relationships shown in Figure 9 provide a conceptualized view of the complexity of interactions between aquatic organisms and their

environment. Of course, interactions among ecological components in real systems are more complex than shown.

DISCUSSION

The management policy of the National Park Service is to provide for public enjoyment of the parks and to preserve and conserve--and restore when necessary--the resources of the parks. The goal of this policy is to encourage nonconsumptive resource uses that permit natural processes to prevail. Paradoxically, this management concept seems to emphasize a "no-management" philosophy. But parks are not islands of wilderness in which only natural processes occur. The very presence of man affects natural processes. In view of such impacts as increasing visitation, consumptive resource uses, conflicting uses on adjacent lands, and air and water pollution inroads, it would be naive to suggest a no-management course for parks in all cases. These impacts require management intervention in order to maintain the natural processes in parks. But one must be careful to interpret the causes and effects of changes in park resources. To do this one must identify which conditions and changes in parks are natural and which are unnatural.

There is a need to establish an intensive and extensive resource data base in national parks. When combined with an understanding of the major natural processes and their roles within ecosystems, management strategies and objectives can be developed which are as dynamic as the processes at work in parks.

The conceptual approaches presented here provide useful tools with which to view the complexity of nature. Managers should improve their understanding of the products of natural processes, the effects of impacts, and the ramifications of management policies and actions. Science can help refine our understanding by selecting appropriate studies to fill in gaps in our knowledge. These studies will improve the overall definition of the functions of each part in the whole. The importance of studying at least two consecutive trophic steps, and preferably steps which are immediately above and below the step of interest in a food chain, have been emphasized as a means of establishing the dynamics of the ecological component of interest. In this sense, the collection of data without the development of understanding is of limited value.

The most important concept presented in this article is productivity. This theoretical concept is far more complex than illustrated. Nonetheless, it was shown that productivity and production are not synonymous. Each term refers to very different concepts, the former being the inherent capacity to produce; the latter being the realized amount which was produced no matter its fate. Confusion of these two concepts is common in science as well as in management.

Management of aquatic resources in national parks without some understanding of the operation of the system will obviously not provide much information on how the resources "work." Cures to particular problems independent of system operation will be of short-term value, because changes at one end of a food chain (or web) result in changes at

the other end, even if the other end is a "long distance away." One can never understand how the natural processes affecting abiotic and biotic resources of parks are changing if we lack an explanation of how these processes function.

LITERATURE CITED

Edmondson, W. T., 1969. Eutrophication in North America. In Eutrophication: Causes, consequences, correctives. National Academy of Sciences, Washington, D.C. Pp. 124-149.

Leopold, A. D., S. A. Cain, C. M. Cotton, I. N. Gabrielson, and T. L. Kimball, 1963. Wildlife management in the national parks. Advisory Board on Wildlife Management. Special Rept. to the Secretary of the Interior.

Warren, C. E., 1971. Biology and water pollution control. W. B. Saunders Co., Philadelphia.

Warren, C. E., and W. J. Liss. 1977. Design and evaluation of laboratory ecological system studies. Environmental Protection Agency, EPA Ecol. Res. Series EPA-600/3-77-022.



As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environment and cultural value of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

