

fish, and insects will be estimated as well as production by plants. All of the kinds of production that are significant in man's economy are also significant in the analysis of ecological systems.

Of greater significance will be the knowledge gained on interactions between species within systems. We know already that green plants, herbivores, predators, and decomposers are all interconnected. Production at one level may be influenced greatly by activities in other parts of the system. As yet we know very little about such processes. Studies with mathematical models of systems suggest that interrelations may be much more pervasive than we appreciate. In models, for example, the presence or absence of predators has a profound effect upon the economy of not only the herbivores, but also of the plants, and even of the decomposers. Such repercussions undoubtedly exist in natural systems. They must also have their counterparts in agricultural systems, and they have strong implications for the field of biological control.

The proposed research includes extensive manipulation in ecological systems, since their responses to treatments comprise a powerful method of analysis. Treatments affecting production are among the most critical manipulations. For example, in the proposed grassland study, the performance of the whole system will be studied under various levels of grazing, fertilization, and irrigation. The responses of insects, rodents, soil fungi, etc. will be studied as well as those of grass and cattle. Thus a classical experiment in range management is incorporated in the design. Since irrigation adds a dimension not often used, these experiments will contribute directly to our knowledge of range management. In addition, we will learn where those nutrients go that fail to show up in beef, and will gain a much more complete picture of the entire grassland system. Knowledge of production in all components of the system will surely improve our understanding of production in particular components, even though the research required is several times more complex than that of the best studies to date on range management.

Manipulations of this kind will be repeated in the other ecological systems. They will yield information on methods for increasing production, as a by-product of each program. Thus, in addition to our assessment of the present level of worldwide production, we will learn a great deal about its potential for improvement in the future.

Resource management

All management programs for living resources contain, somewhere in them, ecological concepts that attempt to describe the response of the managed population to its management. At present, the ecological theory that serves this function relates to individuals or to populations, not to systems as wholes. This has been reasonably satisfactory so long as the goals of management have been centered on single species or populations. In many cases, such programs may be satisfactory for years to come. Our contribution to this approach rests in the manipulation planned in ecological systems, and the production data that will result. The relation of such experiments to programs of resource management are obvious.

In addition, we hope to make a contribution of another kind. The multiple use of natural resources is increasing steadily, often combining timber production, hunting, fishing, recreation, etc. Management programs are in use that attempt to optimize or maximize these several uses simultaneously.

These programs are complex enough to involve systems analysis, and have developed very well in the direction of including the human socioeconomic systems in the program. The ecological base, however, remains largely a collection of principles at the population level, representing an aggregate of unrelated populations rather than a system.

The principles of ecological systems that we will produce will serve as a much more appropriate theoretical base on which to design complex management programs. They will be much more amenable to problems of multiple use, much more reliable for predictive purposes, and much more adaptable to changes in use that may occur with time.

Management practice is, in fact, a manipulation of an entire ecological system, whether it is conceived as such or not. Thus, the only level of ecological theory that is completely compatible with management is at the system level. Even simple problems involving a single use may be solved more reliably if they could be framed against the operation of the entire system.