pose of them. "We can't burn them in incinerators any more," said a spokesman as he showed pictures of piles of brown paper bags—presumably containing dead top-secret material—being fed into a shredder.

D'Emidio estimates that only $8.4 million of the Navy's $65.3 million goes to research. Research activities include solving the ship sewage problem, controlling oil spills, and cleansing bilge and ballast water. The only project in which electronics are extensively used is a $2-million comprehensive pollution data bank system "so we know where we're polluting and how much."

In the present fiscal year, the Army will be able to spend $32.7 million for "water pollution abatement" and $35.5 million for "air pollution abatement." The $32.7 will be distributed in lots of about $100,000 to small companies for building sewage treatment plants on a contract basis. George C. Cunney, chief of the Environment Office, and a one-time builder of sewage treatment plants himself, says, "In the 1940's, all the money in sewage treatment was in design and engineering. The process itself was invented in the 1920's or 1930's." Is the DOD researching more modern methods? "We would not now sponsor research in domestic requirements. We only would do research on problems which are peculiar to DOD, such as portable things to carry with the troops. After all, every city in the country has got a domestic sewage problem.

"We are doing research on helicopters to eliminate noise signature, so the enemy won't be able to hear a helicopter coming and shoot at it. But we've been doing that for years. The helicopter we buy today is quieter than the one we bought several years ago."

Other Army R&D is working on the problem of disposing of toxic substances and explosives. One research project on this problem for fiscal 1971 was $200,000.

The Air Force has 13,646 aircraft or 60 percent of the country's aircraft engines. But most of the Air Force's cleanup money will go to purchase already-existing, already-marketed products, rather than to R & D on new ones.

Colonel Clifford Whitehead, director of the Air Force's Environmental Protection Group and a nuclear engineer by training, estimates that the Air Force has spent $90 million on pollution control since 1968. For fiscal 1972, it will have a budget of $48.2 million of which $35.9 million will be for facilities cleanup—chiefly sewage treatment plants—and $4.8 million will buy sound suppressors for jet engine test cells and stands. Only $7.5 million will be for research and development, including studies of the upper atmosphere, noise, solar flares, and jet engine test cell development.

The Environmental Protection Group itself has hired nine professional scientists or engineers (there is still one post unfilled), but otherwise, the Air Force's environmental spending isn't creating very many new scientific jobs. One effort, for example, is work toward developing a quiet and smokeless engine. Although aspects of this work are now billed under the pollution heading, the strategic goal of a quiet, trailless airplane has been a military project for about 5 years.

DOD spending to comply with the NEPA seems to be constructive. By cleaning up bases, installations, and ships, the armed forces will probably put themselves far ahead of the average U.S. city in terms of environmental purification.

However the pattern of big spending on here-and-now technology is but one side of a debate on who are the proper consumers of environmental funds. One view commonly held in the technical community is that R&D efforts are vital to environmental protection. This view is based principally on that article of faith among some scientists that given national problem *X*, more and better R & D will solve it.

The other school of thought, however, holds that a lot of new technology and research in the environment is neither urgent nor even necessary. New sewage treatment processes, for example, are said to be costlier and less efficient than the present ones. In this view, what is needed is construction of more of same—not embarkation on lengthy R & D programs.

Whether more or less R & D is justified, however, the fact remains that the amounts of environmental dollars now flowing to scientists and engineers are far lower than the sums lavished on them during the space effort. It seems that the expectation that the environment cause would produce work for the technical community was inflated.

An official at the Office of Management and Budget who looks at the environment budgets of many agencies commented, "There seems to be quite a lot of misconceptions of the possibilities of things that will happen in terms of new technology. We've had lots of proposals from aerospace companies to work in the environmental area. But it doesn't work out that way. There are jobs, but they are different kinds of jobs."—DEBORAH SHAPLEY

RESEARCH TOPICS

Ecosystem Analysis: Biome Approach to Environmental Research

In *Silent Spring*, Rachel Carson warned of the dangers of accumulating pesticides in the food chain, and others have called attention to similar gradual and possibly irreversible changes in the environment. To determine the long-range effects of man-made changes in the environment, however, requires a better understanding of ecological systems than is now available; both basic theory and quantitative measurements of ecological changes are lacking.

A major attempt to understand how entire ecosystems function and, by modeling the behavior of these systems, to predict how they will respond to man-made stresses is under way as part of the United States participation in the International Biological Program (IBP). The ecosystem analysis program is having a major impact on the way that many scientists perceive ecological problems, and it appears likely to produce some practical results that will aid in the management of natural resources. It is less certain that the effort will, by itself, lead to major improvements in the scientific understanding of ecosystems. In order to cope with the diversity and tremendous complexity of ecological relationships, the research is focused on empirical analysis and greatly simplified models, and there is concern among some ecologists that more basic studies are being neglected. Nonetheless, even the critics of the program see it as a necessary first step toward understanding ecosystems.

More than 600 scientists, including specialists in many fields of biology, in hydrology and meteorology, and in systems engineering, are participating in the ecosystem analysis program, which is now receiving some $6 million in federal funding a year. As such, the effort constitutes the first attempt to conduct ecological research with large interdisciplinary programs of directed research rather than with the traditional individual investigator. Research is being conducted on five major habitat types or biomes—grasslands, deciduous and coniferous forests, deserts, and arctic tundra (Fig. 1). A sixth biome, tropical forests, is in the planning stage. In each biome, intensive field studies are under way to identify the processes that control the dynamics of the system and to measure the flow of energy, nutrients, and other materials through the system. The information obtained then provides the bases for the construction of mathematical models that can be used in computer simulations of the temporal and spatial variations of biota, of the response of the system to weather- and man-imposed stresses, and of the interactions between components within the system. Additional fieldwork will be done to check predictions of the models and to ascertain their applicability to several sites within the ecosystem.

The development of predictive models is a central goal in all of the biomes. But because ecological research of this type is still relatively new, there is some disagreement as to what approach will produce the most realistic models. Ecologists have varying opinions, for example, as to whether models should deal with the interactions between individual organisms—which would be impossible for an entire ecosystem—or with species, or groups of similar species; it is not yet known if a model can produce realistic information with more generalized ecological groupings such as trophic levels. Biome scientists point out that neither the computers nor the modeling capability for developing entire ecosystem models with fine resolution are available; as a result, the biomes have chosen somewhat different approaches to ecosystem modeling.

In the grasslands biome, for example, the scientists, headed by biome director George Van Dyne of Colorado State

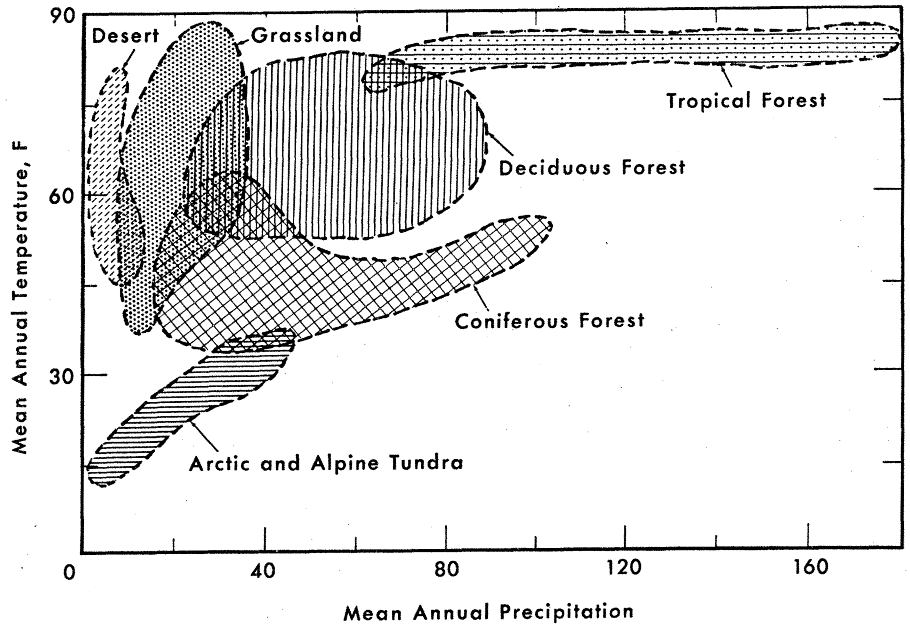

Fig. 1. The six biomes of the ecosystem analysis program characterized by mean annual temperature and mean annual precipitation. [National Science Foundation]

University at Fort Collins, have chosen to construct a systems model. Modeling began with a conceptual plan of the entire ecosystem; more detailed submodels for components were then developed specifically to fit into the overall model. In its crudest, low-resolution version, the model is organized by trophic levels—producers, consumers, decomposers, and abiotic features such as the weather. More detailed versions of the grasslands model contain 20 to 30 subcomponents for both producers and consumers; but the decomposer model, which must represent the effects of both soil bacteria and surface-dwelling microorganisms, is still very simplified. In fact, trials with the model have shown that subsurface biological and chemical processes exercise significant controls over the dynamics of the system, an indication of the need for further research on this subcomponent.

Field experiments are under way at the principal site in the Pawnee National Grasslands of northern Colorado. Initial findings indicate, for example, that soil moisture is a key variable in the grasslands, with even small variations causing large seasonal changes in the amounts of photosynthesis, invertebrate activity, and microorganism activity. Moisture content also appears to be important in determining the response of prairie grasses to fertilizers, and the retention of soil moisture was found to vary greatly from one grassland to another. For many species of grassland vegetation, those plants that had been grazed survived the dry summer season better than those that were not.

Perhaps more important than the flood of individual findings from the grassland study and from other biomes is the changing type of observations and the way in which they are reported, under the impetus of the biome programs. Increasingly, observational studies are focusing on the flows of both material and energy within an ecosystem and on the basic processes which control those flows, rather than just on the components of the ecosystem themselves. In all the biomes, data is deposited in a central facility for use by all the participating scientists.

The grasslands project has been in operation for a longer time than any of the other biomes, and the models are beginning to be tested and refined. Early tests showed, perhaps not surprisingly in view of the complexity of the system and the preliminary nature of the models, that the predictive ability of the grasslands models are not yet very great. But the grasslands scientists are confident of their approach; they believe, for example, that models of isolated components of an ecosystem will not add up to a complete model of the system unless they are explicitly designed to do so. They have developed computer programs that allow more rapid processing of simulation models, so that changes in a model can be readily incorporated.

In the deciduous forest biome, headed by Stanley Auerbach of the Oak Ridge National Laboratory in Tennessee, the ecosystem model is being built from the bottom up, rather than from the top down. Some 10 to 15 models of fundamental processes, such as primary production by photosynthesis in relation to light, temperature, and available moisture, or the cycling of carbon within a forest, have been constructed. At a later stage, the investigators plan to integrate the submodels into an overall model, but for the present they believe that their method will result in more accurate models. Because deciduous forest covers much of the heavily populated areas of the eastern United States where water pollution problems are severe, the scientists are emphasizing land-water interactions. A hydrological model has been constructed which can be used to predict the transport of water, nutrients, and other material from watersheds into lakes and streams.

The data are not yet available to verify the models, although the scientists believe that their emphasis on the underlying mechanisms will allow them to understand the controlling processes readily. In simulating a forest, for example, the energy balance for a generalized "model" leaf is related to atmospheric and soil conditions, so that the transfer of energy to and within the forest can be explicitly calculated.

Fieldwork in the deciduous forest biome is concentrated on five different sites, and the resulting diversity and the lack of a unifying model have led to organizational problems in coordinating the research program. Coordination is being improved by grouping research efforts on common processes throughout the biome. Among the processes being studied is photosynthesis in a forest; instruments for continuously collecting and analyzing the gases given off by the foliage have been placed on trees and other instruments are placed within the canopy to measure micrometeorological properties. Other studies have focused on fish populations in lakes and streams.

Yet a third approach is being taken by scientists, headed by D. W. Goodall and F. W. Wagner of Utah State University in Logan, who are studying the desert biome. The models being developed in this biome are designed to answer specific questions or deal with particular problems; only detail that is relevant to a given problem is included in a model. The desert-biome scientists are thus not now attempting to model the entire ecosystem, and because their more restricted models are of very fine resolution and often deal with individual species, they believe that this approach will offer the best chance to cope with ecological complexity.

Extremely practical problems, both of a theoretical nature and from a land management point of view, are being studied. One model, taking into account human control efforts, food needs, weather, vegetation limitations, and disease, simulates interactions between coyote and rabbit populations. Another deals with annual plants, which the scientists believe are extremely important to southern deserts, because this type of vegetation shows the most variation with rainfall, and because many rodent and insect species depend on the annuals for their food.

Field studies are being carried out in three southern deserts, the Chihuahuan in New Mexico, the Sonoran in Arizona, and the Mohave in California, and in the northern Great Basin deserts. Research on the nitrogen and phosphorus cycles in desert soils have indicated that, in some areas, substantial amounts of nitrogen fixation takes place, but that the nitrate may be rapidly reduced and volatilized in the same season, leaving the system close to being nitrogen deficient. The studies have also reaffirmed the extent to which many aspects of desert ecology are tied to the amount of rainfall.

Coniferous Forest Biome

The coniferous forest biome is the most recent to begin operations, and like the deciduous forest biome, is emphasizing process models. The initial models are based on data that were available from the literature and from prior studies made at the two principal field sites. Early experiments have indicated that the lichens that grow on many of the Douglas fir trees are important in the nitrogen cycle of the forest. The scientists, headed by Stanley Gessel of the University of Washington, are finding, as was the case in the other biomes, that substantial amounts of time must be spent in workshops, meetings, and other communication activities in order to make a large interdisciplinary program work.

In the tundra biome, headed by Jerry Brown of the Cold Regions Research and Engineering Laboratory of the U.S. Army in Hanover, New Hampshire, the research effort has a unique international component and a strong focus on man's environmental impact. In polar research, biome participants have been cooperating with scientists from the U.S.S.R. and other countries for several years. The discovery of Alaskan oil and the possibility of an oil pipeline has resulted in a special awareness of practical problems. The tundra biome, like the grasslands biome, is attempting a total systems model of its ecosystem. Several submodels to predict primary production, depth of thaw, and soil temperature have been completed. Fieldwork at a site near Point Barrow, Alaska, has established that lichens are the most important sources of nitrogen in the wet tundra.

The emphasis on modeling in the U.S. ecosystem analysis program makes it unique within the IBP, and the biome research efforts have attracted considerable attention among scientists in other countries. The diversity of approaches to modeling among the different biomes is seen by many observers as a fortunate development that will increase the chances of eventual success. But, although biome scientists have constructed and operated initial versions of many models, many ecologists expect that several more years of research at the least, will be needed before the models will be sufficiently developed to have predictive value or to simulate entire ecosystems.

Many biologists initially opposed the move to "big biology" as exemplified by the biome programs, and some still have doubts about the engineering style and what one described as the "brute force" approach of the effort, which has drastically changed the nature of ecological research. But others believe that society, and by implication ecologists, cannot afford to wait for more detailed knowledge before beginning to study whole ecosystems. Within the program the participants are enthusiastic, and many expected problems, such as the traditional reluctance of biologists to share data with other investigators before publication, have largely not materialized; the advantage of having access to the wide range of data in the biome centers appears to have convinced most participants. Supporters of the biome program also report that, as familiarity with modeling and mathematical techniques increases, the resistance among old-fashioned biologists to the more quantitative biome approach is decreasing. The ecosystem analysis program may substantially improve man's ability to manage his environment and to predict long-term changes; and even if it does not achieve these goals, the training of a new type of ecologist seems certain to advance the attempt to understand ecological processes.—ALLEN L. HAMMOND