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Constraints and commitments in the development of American botany, 1880-1920

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CONSTRAINTS AND COMMITMENTS
IN THE DEVELOPMENT OF
AMERICAN BOTANY, 1880-1920

by

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TABLE OF CONTENTS

ABSTRACT

This thesis in the sociology of science analyzes the development of the profession of botany in the United States between 1880 and 1920. The development of this scientific discipline was characterized by the segmentation of several different types of research, whose practitioners competed for resources such as sites, technology, and personnel. The thesis argues that as the professionalization of botany continued, the clearly defined problems and disciplines which emerged rested on the successful jettisoning of other problems and disciplines not amenable to experimental methods.

Segmentation occurred at several levels of organization and was fundamentally shaped by the differentiation of research tasks in this period. As the process of segmentation continued, those institutions and lines of work best able to package the results of their work as saleable products were most successful in obtaining resources. At each level of segmentation, there remained institutions and lines of work without a clear mandate on which to base claims for resources. These residual disciplines and lines of work were unable or unwilling to define their problems in narrow terms and to screen out the uncertainties of their work. The professionalization of botany rested on the successful exclusion of each of these categories from

the arena of legitimate research.

This study is based on data from several sources, including botanical and historical literature, interviews with contemporary botanists, and fieldwork at botanical conferences, seminars, and in laboratories. The analysis stems from an interactionist/Pragmatist perspective which emphasizes the material constraints on social activities. Grounded theory, a comparative and inductive technique especially useful in qualitative analysis, was employed throughout the study.

The thesis is organized in five chapters which focus on the levels of organization at which segmentation occurred in botany. The first chapter examines the political and economic context; the second chapter analyzes the emergence of new types of institutions; the third chapter focuses on disciplinary segmentation; the fourth chapter looks at the differentiation of types of work in botany; and the final chapter analyzes the debates which arose around fundamental botanical concepts as the process of segmentation continued.

for

my mother

with all my love

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INTRODUCTION

"Our truth is the intersection of
independent lies"

(Levins, 1966)

Introduction

This report contains an analysis of a three-year research project in the sociology of science. The report consists of several parts: (1) an introduction to the sociological literature and to the analytic approach used, (2) an analysis of the substantive content of the research project, and (3) a summary of the findings and recommendations for further research. This introduction serves to orient the reader to the sociological traditions upon which I have drawn in researching and writing this report. I begin with a discussion of the literature in the sociology of science, work, and professions. This literature review is followed by an analytic discussion of the basic social processes emphasized in this research project. I conclude with a brief outline of the report which makes up the body of this dissertation.

Sociology of Science (1)

Sociologists of science have traditionally asked rather limited questions about this substantive area. This review presents the major lines of work in the sociology of science, classified according to their positions in a number of prominent debates. The intent of this review is to indicate how these positions ultimately have limited the usefulness of the major lines of work in the sociology of science. Through this review, and through the concrete example of the substantive report which follows, it is hoped that the outlines of an alternative approach to the sociology of science will become clear.

Issues in the sociology of science are far-reaching and extremely diverse. The boundaries of the groups working in this substantive area are often loose and ill-defined. "Social studies of science," broadly construed, include philosophy, economics, anthropology, and history as well as sociology. Materials relevant to the study of science include "participant histories," philosophical tracts, monographs, journal articles, working papers, and statistics gathered by scientists and social scientists, as well as observations of and interviews with working scientists. Sociologists of science have used most of these materials in their work of analyzing the worlds of science and scientists.

It is difficult to reconstruct the history of the sociology of science, since each group of investigators in this area comes from a different sociological tradition and most focus on different substantive areas within science. However, there are some lines of work in the sociology of science which are easily recognizable. Functionalist sociology of science is a continuation of functionalist analysis dating back at least to the work of Spencer. The British school of sociology of science has roots in British idealist philosophy. Interactionist approaches have only recently been applied to studies of science (%Gerson, 1983; %Star, 1983b), although the approach and some applications were laid out by Mead and Dewey in the 1920s and 1930s.

In the United States, sociology of science has been dominated by functionalists, particularly by R. K. Merton and his students. These sociologists claim a number of distinguished ancestors, including Comte, Saint-Simon, and Marx, whose interests in the natural sciences were related to their attempts to define the new social science as a legitimate member of the scientific tradition (%Merton, 1977). While the first functionalist study of science was done quite early (%Merton, 1938), this tradition in the sociology of science did not take off until after World War II. By the late 1950s, the economics of science gained tremendous popularity as evidenced by the work of Price (1962) and Machlup (1962). At about the same time, students of social stratification became interested in the scientific arena (%Hagstrom, 1965). The mid-1960s saw a surge in the number of doctoral students at Columbia University writing their dissertations on the subject of science. Students of Merton, including the Coles, Crane, Gaston, and Zuckerman, constituted the dominant school of sociology of science in this period.

The mid-1960s also saw the growing influence of Kuhn on social studies of science after the publication of his book, The Structure of Scientific Revolutions (1963). In this book, Kuhn argued that science proceeds via shifts in the paradigms in which scientists work. This argument prompted a storm of controversy as well as a number of attempts within sociology to operationalize the concept of paradigm (e.g. %Hargens, 1975). Critics called attention to the ambiguous and multiple uses of the concept in Kuhn's work (%Masterman, 1970; %Shapere, 1971). Other sociologists elaborated the normative presuppositions contained in the Kuhnian notion of the paradigm (%Mulkay, 1971).

Since the 1970s, there has been a steady growth in the numbers of sociologists investigating science as a whole and scientific specialties, both in Europe and the United States (%Spiegel-Roesing & Price, 1977). Much of this work reflects the same division of labor and interests seen in sociology as a whole. Functionalism and quantitative methods (particularly citation analysis) remain dominant in the United States. In Europe, the "Parex school" has claimed to take the opposing side in debates with European and American functionalists. While functionalists look at macro-scale phenomena, Parex looks at micro-scale phenomena. Where the functionalists make use of quantitative methods such as survey research and citation analysis, Parex uses qualitative methods including interviews and fieldwork. Functionalists tend to focus on the external forces affecting scientific development while Parex focuses on the internal dynamics of scientific ideas. Where functionalists assume a consensus of norms and values among the scientists they study, Parex often assumes that conflict forms the basis of the interactions they observe.

There are, of course, other schools of thought in the sociology of science. American functionalists and British and French idealists share the field with science policy researchers, such as Price (1963, 1965) and Ben-David (1960, 1978), as well as with Marxists, such as Boehme (1977). In recent years, a few interactionists have begun to address issues in the sociology of science. The interactionist approach to the sociology of science differs from those of the functionalists and the idealists. Rather than asking whether external or internal forces are more important to the development of science, interactionists focus on the <u>tasks</u> which scientists perform. This approach is valuable in revealing the relationships between levels of organization which affect the overall development of scientific institutions and scientific ideas.

Some earlier work in studies of stratification and conflict in science moved in the direction taken by more recent interactionist research. For example, Glaser (1964, 1968) focused on the ways in which the problem choices of scientists are shaped by a multitude of variables extraneous to the specific content of scientific knowledge. In another promising approach from conflict sociology, Collins (1975) discussed key organizational positions which intellectuals occupy and asserted that the structure of scientific organizations was based on information, validation and recognition, and material resources. Degrees of uncertainty, problems of co-ordination, and ease of communication were identified as additional constraints on the scientific enterprise. However, Collins's focus on conflict as the basis for social order prevented him from investigating the ways in which consensus among scientists is negotiated.

Sociology of Work and Professions

Interactionist sociology of science draws on two older sociological traditions. The first of these is pragmatic philosophy as articulated by George Herbert Mead and John

Dewey in the 1920s and 1930s. These philosophers did not themselves follow up the implications of their thought for the study of science. Mead deeply admired natural science and saw the shift from essentialist to experiential attitudes as a model for rational social change. Dewey also admired natural science, and he stressed the importance of knowledge as action and communication (%Fisher & Strauss, 1979). Like the Parex sociologists, interactionists view science as a relativist enterprise. Both Mead (1938) and Dewey (1929) took a nondeterminist stance toward natural science and their successors at the University of Chicago maintained this stance.

The second sociological tradition on which interactionists draw for their studies of science is the Chicago tradition of the sociology of work and professions. On the whole, the Chicago school of sociology paid little attention to studies of science, although there were some exceptions (e.g. %Becker & Carper, 1956; %Strauss & Rainwater, 1962). The focus of these sociologists was, rather, on the phenomenon of social change and the conditions under which this took place. Park's view of society as ceaseless change took communication among the members of society as fundamental to such change. Interactionists do not necessarily regard social change as progressive although most take the role of knowledge as central to such change (%Fisher & Strauss, 1978). The interactionist study of science, then, rests on the Chicago school's focus on the activities in which social actors engage and on the importance of communication in effecting social change.

Pragmatic philosophy and Chicago sociology have long informed the work of interactionists in a kind of parallelism (%Fisher & Strauss, 1979). The work of Becker (1982) and Strauss (1978a) reveals an important synthesis of these two perspectives. This synthesis involves several analytic premises:

(1) work cannot be understood without examining its products;

(2) products cannot be understood without reference to the work by which they were produced;

(3) work involves joint effort over time (i.e. work is interactive and processual); and

(4) meaning does not inhere in the products of work but is attributed by workers and consumers (%Star, 1983b).

The interactionist approach focuses attention on the cooperative efforts by which products and meanings are created. These cooperative efforts define <u>social worlds</u> which change, segment, and intersect with one another as problems, technologies, and approaches change (%Bucher, 1962; Strauss, 1978b). The fundamental unit of analysis in such an approach is the work itself, along with its adhering products and meanings.

Approaching science from a sociology of work rather than from a sociology of knowledge perspective allows us to view concepts as the products of lines of work within larger social worlds. The formulation and solution of problems generates tasks which cluster together to form recognizable lines of work. Allied lines of work, collected around related problems, are supported by organizations through which resources flow and are allocated according to more or less elaborate processes of negotiation. The segmentation and intersection of social worlds form the basic social processes upon which interactionist analyses of science focus (%Gerson, 1983). These basic processes provide opportunities for both change and stability through cooperation and conflict at many different levels of organization.

It is interesting to consider the different debates found in the three distinct <u>social worlds</u> which intersect in this report (i.e. biology, history, and sociology). In all three of these worlds, there were (and are) debates among participants on a number of issues. Crosscutting all of these worlds are the issues of where and how boundaries should be drawn around the fundamental unit of analysis. Also common to all three worlds are the issues of how change in these units of analysis occurs. Among biologists, there are controversies about how the "species" should be defined. Biologists are also concerned with questions of whether evolution is primarily an internal or an external process. Among sociologists and historians, there are controversies about how science should be defined (the relationship between science and technology is particularly important). Sociologists and historians are also concerned with questions of whether scientific change is chiefly due to internal or external forces. As this report shows, the issues of drawing boundaries and determining the importance of internal and external factors for change are usually settled politically rather than on the basis of empirical proof in biology. These issues are also settled politically among historians and sociologists.

Analytic Concerns

This report rests heavily on two analytic concepts developed recently by interactionists. These are the concepts of (1) social worlds, and (2) segmentation. A social world has been defined as a "universe of regularized mutual response ... in which there is a kind of organization ... (whose boundaries are) set neither by territory nor formal membership but by the limits of effective communication" (%Shibutani, 1955: 522). Social worlds feature a core activity as well as related clusters of activities, one or more sites where these activities occur, technologies for conducting the world's activities, and organizations which support and further the world's activities (%Strauss, 1978b).

As social worlds form around core activities, they undergo several basic processes of change, including intersection and segmentation (%Strauss, 1979). Segmentation "refers to the pervasive tendency for worlds to develop specialized concerns and interests within the large community of common activities which act to differentiate some members of the world from others" (%Kling & Gerson, 1978: 26). Segmentation takes place as competition develops among lines of work organized around related core activities for a variety of resources, including sites, technology, and personnel. Different segments of a social world intersect with segments of other social worlds around newly-defined core activities, common sites, and shared technology (%Strauss, 1979).

In a discussion of "going concerns," Hughes noted the need "to give full and comparative attention to the not-yets, the didn't quite-make-its, the not quite respectable, the unremarked" (%Hughes, 1971: 53). Processes of segmentation at several levels of organization characterized the development of botany between 1880 and 1920. As segmentation continued, residual categories of the older arenas and institutions, the older scientists, and older styles of work remained at each level of organization. These residual categories included resource conservation problems at the economic and political level, museums and botanical gardens at the institutional level, ecologists at the disciplinary level, and classification work at the intellectual level.

As their worlds changed, older institutions and lines of work were left with no clear intellectual mandate on which to base their claims for resources and legitimacy. These institutions and lines of work were left without well-defined audiences or constituencies and were thus prey to alternative claims by other constituencies. The debates about classification in botany between 1895 and 1930 reflect the power of those institutions and lines of work with well-defined constituencies to define the intellectual issues in an arena. Residual institutions and lines of work became the _repositories_ for the unsolved problems of more successful institutions and lines of work. Jurisdiction over unsolvable problems reinforced the subordinate position of these institutions and lines of work.

Constraints, Commitments, and Social Worlds

Social worlds are made up of core activities conducted at different sites, using different technologies, and giving rise to varieties of organizations. The development of a social world involves _commitments_ by social actors to new activities, places, tools, and organizations. The concept of commitment has been used in studies of occupational careers although with little effort to analyze its meaning. Commitments can be defined as decisions which have consequences for other activities in which an individual is engaged. This definition of the concept of commitment is useful in "explicating situations where a person finds that his involvement in social organization has, in effect, made side bets for him and thus constrained his future activity" (%Becker, 1960).

As social worlds change, individuals find themselves committed to courses of action which are constrained by prior decisions. Choices made about engaging in particular activities, working in one kind of organization and with one set of tools rather than others, constrain subsequent decisions. Commitments are built into organizations and institutions by individuals making choices about what, where, and how they want to do things. As commitments are structured into organizations, they become more difficult to change. Commitments made at one point in time and at one level of organization about activities, sites, tools, and organizations become constraints on later courses of action.

Commitments and the constraints which these eventually build at the institutional level are the basis for the processes of segmentation and intersection by which social worlds change. The commitments that are built into institutions at one point in time do not disappear when new types of commitments begin to be made. Instead, new institutions are built on the basis of commitments to new types of activities, sites, tools, and organizations. Individuals change their commitments more rapidly than institutions because they are constrained by fewer side bets than those which institutions make to support a core activity.

Segmentation and Levels of Organization

There is relatively little sociological writing on questions of segmentation. Much of what has been written about social worlds deals tangentially with this problem. Work by interactionists has dealt in some detail with this important issue (%Becker, 1982; %Kling & Gerson, 1978; %Strauss, 1978a). In a brief analysis of general processes of segmentation, Strauss (1979) identified several sources of segmentation including differentiation of space, objects, technology and skills, ideology, and recruitment. Processes of segmentation including the formation of social worlds around types of activities, the differentiation of the social world from related social worlds, the legitimation of the new world, and competition for resources were also discussed. Segmentation processes are closely linked to intersection processes, but for analytic clarity, it is necessary to focus on one while leaving the other as a background theme.

Segmentation takes place at a variety of levels of organization. This report shows how segmentation at several different levels of organization affected the development of botany between 1880 and 1920. Segmentation occurred within economic and political arenas around various problems with development of the Western states after 1860. Segmentation took place at the institutional level as new organizations emerged to support the new experimental work in science. Networks of scientists segmented around institutional, technical, and intellectual issues. Segmentation among scientists was supported by the development of alternative professional societies and journals for academic and agricultural scientists. The fundamental basis for segmentation processes in botany lies in the segmentation of scientific tasks. Different types of uncertainty and differences in the level of control which could be achieved through various technical developments supported processes of segmentation at other levels.

In this report, I have chosen to emphasize the processes of segmentation which characterized the development of botany at the turn of the 20th century. Processes of intersection took place at the same time, as individuals and institutions committed themselves to different types of work and problems with new colleagues and audiences. Between 1880 and 1920, the disciplines of genetics, taxonomy, and ecology came to be characterized by very different institutional alliances, professional networks, and types of technical work and intellectual problems. To analyze the intersection processes which characterized the development of botany would mean leaving in the background the processes of segmentation examined here. Analysis of the intersection processes in the development of botany between 1880 and 1920 must therefore await later treatment.

<u>Segmentation and Residual Categories</u>

Social worlds and arenas are characterized by varying degrees of stability and change. Processes of intersection and segmentation take place at varying paces at different levels of organization. At every level of organization, however, processes of change result in new arrangements for getting things done. A crucial question in looking at these processes of change is: What happens to existing ways of doing things when new ways of doing these things emerge?

This report indicates that existing ways of doing things do not disappear when new ways emerge. Previous questions do not disappear, previous training is not forgotten, prior institutional commitments are not instantly transformed. Instead, existing institutional, individual, and intellectual commitments decline slowly and are sometimes invigorated by alliances with emerging social worlds. The formation of residual categories depends on where and how the resources for the older styles and commitments are appropriated by new styles and commitments.

As the core activities of an arena or social world change, the system of classification which reflects those activities also changes. Between 1880 and 1920, botanists gradually changed their focus from descriptive and classificatory problems to more analytic problems. Older problems of surveying existing natural resources and classifying geographic regions in terms of their possible and appropriate uses did not disappear (%Stegner, 1954). New problems of range and forest management (%Hays, 1959) as well as increasing agricultural productivity (%Harding, 1947) absorbed many of the growing resources channeled toward biological research in this period. Various government agencies and private interest groups formed arenas in which these problems were formulated and addressed. These political and economic interest groups varied in their ability to influence the commitment of resources to problems pertinent to their interests. By 1900, political commitments to solving the problems of large-scale commodity farmers set the stage for the type of botanical research sponsored by new types of institutions.

Problems in agriculture were more narrowly focused than problems in resource conservation. Problems in agriculture were focused around issues of increasing productivity and resistance to disease (%Harding, 1947). Problems in resource conservation were far more diverse, in spite of efforts by government scientists to present them as a single problem (%Hays, 1959). The narrow range of problems in agriculture undoubtedly contributed to the success of agricultural economic and political interest groups in obtaining funds and expertise to address their problems. The mobilization of resources to deal with agricultural problems meant that this arena attracted larger numbers of professional scientists. Reductionist research strategies developed by biologists in the 1880s and 1890s were also more suited to the types of problems in agriculture than to problems in the conservation of natural resources.

As the institutions supporting botanical research after 1880 underwent segmentation, existing resources were channeled to new rather than existing types of institutions. The museums and botanical gardens which supported early survey and classification work were joined first by colleges and universities, then state agricultural experiment stations and federal laboratories, and finally by private research institutions. The new institutions specialized in the support of experimental work and were most successful in obtaining resources and personnel. Other institutions which supported experimental work were less successful in screening their workers from demands for other types of work. These institutions were unable to attract the ablest students or provide the most modern equipment. The institutional hierarchy which developed reflected the abilities of different types of institutions to marshal resources and commit them to a particular style of work as well as to a narrow range of problems.

Commitments made at the institutional level formed constraints at other levels. The success of institutions specializing in experimental work and the success of this approach in solving a limited number of problems was an important constraint on young and established botanists. Experimental work was the province of a new generation of botanists in the 1880s and 1890s. These scientists learned new styles of work and were interested in very different problems than were the men who trained them. The first generation of professional botanists found employment in institutions devoted increasingly to the support of experimental work. Over the first two decades of the 20th century, academic botanists were able push the problems raised by the uncertainties of working with complex biological organisms into other lines of work. The control offered by experimental methods was in this sense illusory; the complexities hidden through the adoption of reductionist research strategies were pushed out and solutions sought in other arenas unable to pass these problems along to other lines of work.

Differentiation of the disciplines of genetics, ecology, and taxonomy out of botanical (and biological) research at the beginning of the 20th century placed strains on the system of classification in this social world. The audiences which this system of classification served increased and changed during this period. Methods of research also changed, shifting from an emphasis on survey and collecting work to an emphasis on experimental work. Changes in the types of problems faced by botanists further influenced the methods which were adopted.

While the biological system of classification was based on distinctions among _types of organisms_ before 1900, the needs for identification would probably have been equally well served by a system of classification based on _types of environments_. However, as biological work specialized and as new problems of _phylogeny_ drew on the resources of the arena, commitments to a system of classification based on types of organisms crystallized. Such a system was more useful to biologists working with a narrow range of organisms than to biologists concerned with a geographic region characterized by a multitude of types of organisms. The success of genetics in solving problems important in a number of arenas including agriculture, and the concomitant lack of success of ecology in solving problems important in the conservation of natural resources, led botanists and their audiences to opt for a system of classification based on types of organisms rather than on types of environments. The already institutionalized commitments to a system of classification based on distinctions among types of organisms further bolstered the intersection between genetics and taxonomy, the segmentation of taxonomy and ecology, and the overall commitment of biology to a system of classification based on types of organisms.

Outline of the Dissertation

The current organization of this report reflects an emphasis on the levels of organization within which segmentation in the discipline of botany took place. Implicit for the moment are two alternative emphases on (1) the segmentation of types of work which characterized the development of botany in this same period, and (2) the intersection of types of work in the development of botany. These alternative emphases are the result of the use of "grounded theory" as a research method in this project (2). These alternative emphases are not absent from the analysis presented here. Rather, they form background themes to the focus on segmentation at several levels of organization in this report.

The first chapter discusses the social, political, and economic context within which botanical research developed in the United States. The opening of the West and the sweep of migration across the continent after the Civil War formed the basis for widespread industrialization and urbanization in America in the last quarter of the 19th century. Exploitation and extraction of the natural resources of the continent formed the basis for a vast array of economic enterprises in this period. Regional economic interests contributed to political issues raised in this period. Different regions of the country were dominated by different economic activities. The play of these forces, striving with and against one another for financial resources and regulation of other interests, formed the context within which science developed in the United States.

The second chapter focuses on the emergence of several new types of institutions supporting biological research late in the 19th century. These institutions developed new sources of funding and employed professionals trained in new styles of work. Although most of these new institutions adopted the ideology of experimental research, some were more successful in acquiring funds and personnel as well as in pursuing specific research programs. Key administrators and institutional entrepreneurs were the crucial element in the success of institutions in gaining support for experimental work.

The third chapter moves from the institutional level to the level of scientific careers. The emphasis in this chapter is on the crucial role which institutional entrepreneurs played in the segmentation of lines of work in American botany. From the early herbaria based on the work of collectors throughout the West to the sophisticated laboratories of geneticists in the 1920s, new types of work relied for their successful adoption on vigorous advocates with access to crucial institutional and political resources. The intellectual segmentation which characterized botany after 1915 reflected the transformation of institutional footholds into far-reaching professional and political networks.

The fourth chapter analyzes the tasks pursued by botanists between 1880 and 1920. Three types of work are distinguished, including survey and collecting work, experimental work, and classification work. Different types of uncertainty are associated with each of these types of work. Scientists attempt to control the uncertainties of their work in different ways, depending on available institutional resources as well as on the types of uncertainties with which they are concerned. Classification work is particularly interesting because the uncertainties of other types of work are "triangulated" within the system of classification. Debates about control and uncertainty take place largely among scientists doing classification work since these are the professionals most often confronted with these issues.

The final chapter looks at the debates which took place among botanists between 1890 and 1920 over classification issues. Users of the system of classification struggled with the contradictions inherent in a system which had to be simultaneously stable and flexible. The fundamental unit of analysis in biology (i.e. the species) was not a robust concept although scientists behaved as though it were. The adoption of reductionist research strategies after 1880 meant that the uncertainties of classification were not addressed by experimental researchers. The criteria adopted by experimental researchers for defining the species with which they worked were less useful for scientists doing survey, collecting, and classification work.

Professionals were brought in to solve the ecological and economic problems of development throughout the country after 1900. These professionals developed institutional bases as well as constituencies for their expertise. In arenas where problems were narrowly defined, such institutional entrepreneurship was extremely successful. In arenas where problems were more difficult to define as well as to solve, institutional entrepreneurship was less successful in forming the basis for an expanding research program. Alliances with segments of more successful social worlds or with more successful institutions provided a few of the professionals dealing with residual problems a strong base. However, these commitments were difficult to transform into lasting lines of work since they lacked a well-defined constituency, a well-defined intellectual problem, and often a recognized technology.

In looking at the development of botanical lines of work, we find that taxonomy was able to transform existing institutional commitments to a system of classification into a successful alliance with genetic lines of work. Ecology was unable to establish a strong institutional base, in contrast to genetics, and was also unable to obtain sufficient institutional commitments to an alternative system of classification. This line of work was left with few resources and few effective alliances. It became the repository for many of the residual problems in botany in the first half of the 20th century. It was not until the 1950s that ecologists were able to transform an alliance with physical scientists and with a growing social movement into a successful line of work (%McIntosh, 1974; %Nelkin, 1977; %Volberg, 1981).

Conclusion

The physical and intellectual objects of our many worlds are all produced through joint efforts bound together by networks of communication. These networks tie together many levels of social organization, including arenas, institutions, and professional and occupational groups. These networks "continue through time in environments to which they must adjust themselves" (%Hughes, 1971: 62). The ways in which these adjustments are made at one level form the environment for other levels of organization within that social world.

This dissertation emphasizes the constraints and commitments affecting the development of the scientific discipline of botany. Commitments made at one level of organization form constraints at other levels of organization. Social actors commit themselves to particular courses of action within situations characterized by constraints of many kinds. This introduction has briefly reviewed the sociological traditions upon which this report draws, defined the key analytic concepts detailed in the chapters which follow, and presented an outline of those chapters. The constraints and commitments made at the national, institutional, professional, and day-to-day levels which affected the development of one scientific discipline form the substance of this report.

The development of scientific ideas, changes in scientific work, and changing economic, political, and social contexts within which these take place are tied to one another in complex ways. By making work central to our analysis, we transcend the debates which inform the sociology of science to ask how it is that science gets done. By focusing on how tasks constrain and commit people and organizations engaged in different types of work, we may begin to understand how it is that social worlds are constructed, develop, and are transformed over time.

Footnotes

(1) Discussion of the literature in the sociology of science draws heavily on a joint paper written with S. L. Star in 1981 (%Star & Volberg, 1981). My thanks to Dr. Star for permission to use sections of that paper here.

(2) A brief discussion of the methods used in this research project appears in Appendix I.

CHAPTER ONE

THE SOCIAL CONTEXT OF BOTANICAL RESEARCH IN THE UNITED STATES

Introduction

This chapter outlines the socio-economic context within which botanical research took place between 1880 and 1920. A number of important developments in the 19th century set the stage for the types of problems with which botanists became concerned after the 1890s. The pages which follow are intended to set the stage for later discussion of the institutionalization of botanical research, the development of scientific networks around patterns of commitments, changes in the work, and changes in the classification system in botany in the first decades of the 20th century.

A number of processes at several different levels characterize the emergence and development of botany in the United States. Although my focus later will be on the institutional and intellectual development of the sub-disciplines of genetics, taxonomy, and ecology, it is first necessary to outline the larger context within which botany as a whole developed. This chapter, therefore, paints in broad strokes the environmental, economic, and political context in which the development of botanical research in the United States took place.

In the economic development of the Western territories, settlers faced many problems related to the manner in which they made their living. After the beginning of the 19th century, the ways in which people supported themselves multiplied. From a basic subsistence economy characterized by the extraction of resources for sale in Europe, the American economy developed into a major source of food and materials for both European and American markets. The lumber industry, the fishing industry, the cattle and dairy industries, mining, and agriculture all developed in the wake of immigration to the Western territories and the emergence of urban and manufacturing centers (%Higgs, 1971).

Economic development in the West set the stage for a tremendous growth in a number of arenas, including the food-producing industries. The productivity of agriculture and stock-raising increased rapidly in the last three decades of the 19th century. Both government and private interests funded research in the biological sciences in this period, at least partly in hopes of further increasing the productivity of these industries. Federal support for agriculture increased rapidly after 1890, in response to enormous pressure from commodity interest groups and related industrial groups, such as banks and railroads. By 1910, support for agriculture far outweighed support for the conservation of natural resources.

These two arenas were characterized by very different types of problems. Conservation interests wanted to insure that existing resources, such as trees, rivers, metals, and minerals, were not exhausted by overuse. Agricultural interests were narrowly focused on increasing the productivity of many types of crops through improved breeding and disease-control programs. These increasingly distinct arenas relied upon very different kinds of information-gathering and information-generating work. Different interest groups formed alliances with the federal agencies responsible for the gathering of such information, in particular the Department of the Interior and the Department of Agriculture.

Different problems and approaches characterized these two arenas after 1900. Conservationists relied on survey work to catalog existing resources and classify these for later use. Agriculturists relied on experimental work to improve the productivity of many types of organisms. The pre-eminence of agriculture after the turn of the century was due to several factors, including the amenability of agricultural problems to experimental techniques and the influence of major interest groups concerned with problems in this area.

In the pages which follow, I outline the economic arenas which developed from the extraction and processing of natural resources in the United States after the Civil War. I look briefly at the emerging social movement which united conservationists and urban reformers at the beginning of the 20th century against economic and political elites. I discuss the political arenas which developed out of the competition among interest groups for state and federal funding and support as well as for protection from regulation. I conclude by pointing to the importance of problem definitions in the success of agriculture in gaining access to government support and resources.

The Development of Natural Resources

The exploitation and extraction of natural resources had an enormous impact on American life in general and on American science and technology in particular. Early economic activities of American settlers in the 18th century included fur-trapping, timbering, and the cultivation of cotton. These resources were funneled to Europe where they provided the basis for industrialization on that continent. By the 1850s, economic activities in the United States included besides timbering and the fur-trade, agriculture, horticulture, stock-raising, and mining of minerals as well as metals. The raw materials produced in the newly opened territories to the West after the Civil War flowed to urban centers in the Midwest and East, where they were transformed into saleable goods in factories powered by cheap steam, and later electrical power, as well as by cheap labor supplied by immigrant populations flowing to the United States from Europe. Urban centers like New York, Boston, and later Chicago and Detroit, began as centers of distribution. Manufacturing centers were established in those areas where hydrological formations provided cheap power for manufacturing processes and a convenient means of waste disposal. Both the settling of the West and the gradual shift from a rural to an urban population in the United States after the middle of the 19th century were associated with the economic opportunities offered by the continent's natural resources (%Broude, 1959; %Vatter, 1975).

Industrialization provided employment for the growing urban population as well as generating capital for further development. Between 1850 and 1900, manufacturing processes for producing steel, refining petroleum, preserving foods, and producing textiles were developed and improved (%Petulla, 1977). Increasingly sophisticated transportation and communication facilities developed along with the tremendous growth of other types of economic activity in the United States in this period (%Reps, 1965).

After the Civil War, settlement of the American continent expanded rapidly beyond the Mississippi River. Population movement was due, in no small part, to the federal government's desire to settle and claim all of the continent's vast territories. The Preemption Act of 1841 and the Homestead Act of 1862 led to massive migration into the Western territories after the Civil War. As the continent was settled, different agricultural and economic activities came to dominate various geographic areas. In the Midwest, farmers grew wheat and corn, as well as many different orchard crops. On the Western ranges, which were far more arid, stockmen ran cattle and sheep. In the Northern states, the lumbering industries flourished. The boundaries of these various land-uses overlapped and there were frequent disputes over such issues as land and water use throughout the 19th and 20th centuries. For example, large numbers of homesteaders tried to farm the dry plains of the Western states. Not only did these farmers clash with the cattlemen of the area, they also had disputes with railroad companies over the transportation of crops, and with lumber companies over access to water for irrigation (%Higgs, 1971; %Vatter, 1975).

The settling of the West changed the face of the

American continent. Fragile grasslands were plowed under or overgrazed by zealous homesteaders and stockmen (%Overfield, 1975). Clearcutting of timberlands led to mounting problems with erosion and river silting (%Kane, 1949). Mining activities led to the stripping of vegetation, and, again, to problems of erosion and water pollution. In urban industrial areas, air and water pollution became increasingly serious (%Petulla, 1977). New techniques in agriculture permitted the cultivation of new crops. New insect and fungal pests attacked these crops as well as the existing vegetation (%Rodgers, 1944a). The development of water resources for navigation, irrigation, and hydroelectric power contributed to flooding, erosion, and other environmental problems. With the booming economy came the innumerable problems associated with the alteration and destruction of public and private lands.

The Development of Agriculture

In spite of the proliferation of types of economic activity after the Civil War, the pursuit of agriculture remained the most important relationship of Americans to the land. Before the war, the North had begun some types of manufacturing as well as producing some of its food. The states in the South concentrated largely in the production of cotton for sale in Europe. Food and other necessary products were, for the most part, imported from Europe (%Vatter, 1975). After the Civil War, with the opening of the West beyond the 100th meridian, large tracts of land became available for cultivation as the Indians were driven further and further west. The development of the railroads and the invention and improvement of steel and iron forging provided important technological support for Western expansion (%Petulla, 1977). The second half of the 19th century saw dramatic growth in the development of natural resource extraction such as mining and forestry as well as agriculture.

By 1900, new metal forging techniques had led to an explosion in the technology available to the farmer. Innovations included the spring-tooth harrow, the twine-binder, the seed drill, the corn sheller, the combine, the steam tractor, and the sulky plow, as well as chilled iron and steel plows (%Vatter, 1975). Other innovations included commercial fertilizers and pesticides, improved seed stock and improved breeding methods for grains as well as livestock. The establishment of agricultural colleges and state experimental stations also contributed to the steep rise in agricultural productivity early in the 20th century (%Rossiter, 1979).

In the South, agricultural production was concentrated in cotton, although by the 1880s there was a shift toward logging and mining in this region. After 1915, when the ravages of the boll weevil became widespread, Southern agriculture shifted more and more to diversified crops. In the North and Midwestern states, there was a mixed agricultural economy consisting of cereal production (especially corn and wheat), dairy farming, and horticulture (including fruit orchards as well as large-scale production of berries). In the West, agricultural production was more concentrated on cattle raising and large-scale production of wheat. Mining was very important in the West as well; lead, copper, silver, and gold were extracted in immense quantities after the 1860s. Western farmers produced corn, wheat, and forage crops although livestock interests dominated the area. On the eastern side of the Great Plains, there was some overlap with the Great Lakes states in terms of dairy production, while agriculture in the Southwest region concentrated in livestock. Diversified farming was dominant in the Far West and on the West Coast. California invested heavily in citrus and other fruit crops, as well as dairy farming. The Northwestern states concentrated on fishing and lumbering.

In the East, water transportation continued to be important but in the Western territories it was the railroad which provided the link with urban markets. Development of the railroads, although technically a private enterprise, was heavily subsidized by federal land grants as well as aid from state and local governments (%Hibbard, 1965). Large-scale settling of the Western territories was made possible by the military suppression of the Indians and the establishment of reliable transportation routes for people moving West and products and raw materials moving East (%Vogel, 1968).

Urbanization and industrialization were based in the United States on the extraction and exploitation of natural resources of the continent. Urban centers developed at the conjunction of transportation routes, where raw materials and large supplies of cheap labor met. Improvements in agricultural productivity released large numbers of people from subsistence activities. These rural immigrants, together with immigrants from Europe and Asia, formed the labor pool on which American industrialization was based while the continent's natural resources provided the raw materials on which industrialization also rested.

The Emergence of Resource Arenas

As industrialization proceeded during the second half of the 19th century, various arenas developed around the economic activities which supported this process. Arenas, like social worlds, are organized around core activities, sites, technologies, and organizations. Within any arena, shifting commitments by actors at different levels of organization operate to affect the flow of resources through the arena (%Gerson, 1983; %Strauss, 1978). The resource arenas which developed in the United States after the Civil War were characterized by economic and political interest groups as well as a variety of educational institutions and government agencies. The alliances among these participants constrained the development of both agriculture and resource conservation in the United States after 1900.

In the Western states, numerous environmental as well as political problems soon developed in the arid lands opened to homesteading in the 1860s. Resistance to new economic activities came from cattlemen who were opposed to the nomadic sheep-herders whose animals were in competition for scarce grasses as well as to the homesteaders trying to farm the arid lands (%Mosk, 1943). During the 1880s and 1890s, cattle ranchers, sheep-herders, and homesteaders suffered drought, blizzards, cyclones, heatwaves, and insect invasions which financially destroyed many small farmers as well as large ranchers. By 1900, many homesteaders had given up and moved on, leaving their plowed and irrigated acres to the cattle, sheep, and insects.

By 1900, the top five industries in the United States included iron and steel production, meat packing, machine parts production, timber and wood production, and milling and processing of grains (%Petulla, 1977). Industrial demands for electrical power, metals, minerals, and ores grew rapidly. Improved manufacturing processes, including wire-making and the production of fertilizers and pesticides, were developed. Mechanization of food processing came after 1900 with the invention of canning and the improvement of other preservative techniques. National packaging, marketing, and advertising of foods and other commodities also developed rapidly. The marketing of the automobile after 1900 supported a variety of related industries, including the extraction and production of petroleum products, highway construction, and bridge and road building.

With industrialization came the development of scientific principles of production and marketing. The drive for greater productivity led to an emphasis in the economy on efficiency, vertical integration of industries (in which a single corporation owned all of the various production processes from extraction to distribution), specialization, the setting of production goals, and work speed-ups (%Petullla, 1977). Scientific management defined human labor in mechanical terms and efforts were made to manage the labor force in the same way as the machines which contributed to the production process. Nutritional studies to determine the minimum amount of food necessary for an individual to maintain a given pace of work began early in the 20th century (%Aronson, 1982). The establishment of trusts and monopolies was bolstered by the argument that such economic arrangements contributed to increasing productivity. Centralization of resources and capital permitted the emergence of huge corporate entities such as United States Steel and Standard Oil (%Petulla, 1977).

Social Reform and the Conservation Movement

Unbridled exploitation of natural resources in the United States during the second half of the 19th century led in the last years of the century to a widespread movement toward social reform. Human poverty and disease in the cities, political corruption at local, state, and federal levels, and industrial inefficiency and waste characterized many areas of the country. The 1890s were marked by the political stirrings of both the urban and rural poor. Riots and strikes, as well as the emergence of such political parties as the Farmers' Alliance, expressed the growing dissatisfaction of many American with the political *status quo*. An alliance between scientists and professionals concerned with the "wise use" of the existing resources of the nation and urban reformers also emerged in the 1890s. These two groups advocated the "scientific" management of the nation's resources in order to insure the prosperity of future generations (%Hays, 1959).

Urban reformers drew on the writings of American philosophers such as Emerson and Thoreau, as well as the larger Romantic tradition, to argue that social problems such as crime and delinquency had roots in the "inhuman" processes of industrialization and urbanization. They argued both for the improvement of conditions in the cities and for the preservation of wilderness areas which they felt were necessary to restore men's souls (%Worster, 1977). The conservationists were professional scientists and administrators rather than urban reformers. The conservationists' argument for the maintenance of wilderness areas was based on the more "utilitarian" notion of saving natural resources for future profitable use (%Hays, 1959).

The conservation movement grew out of the experience of administrators and politicians with the problems of Western economic growth. These problems included: (1) range and grasslands management in the Western states where the prairies were crumbling under the assault of cattle, sheep, and plowshares; (2) management of water resources in the Western states, where disagreements raged about whether water was to go primarily for irrigation or navigation; and (3) agricultural problems and issues, including the rising cost of farming without concomitant rise in farmers' profits (%McConnell, 1966). Debates over the best use of publicly-owned natural resources pitted the federal government against the various state governments, in terms of the control of these lands and their administration. These debates also formed the beginning of the split between urban reformers and the conservationists, when this alliance disintegrated just before the first World War.

The response of the federal government to the demands of conservationists and urban reformers was to establish an array of administrative and regulatory agencies. The Departments of Agriculture, of Commerce, and of the Interior were all charged with the duty to collect information as well as regulate the industries with which each was concerned. These agencies were important actors in the centralization of power at the federal level at the end of the 19th century. As had been the case earlier in Europe, survey and census data played a crucial role in the centralization of national power (%Mukerji, in prep). In Europe, government-sponsored surveys provided the basis for rational planning of military campaigns, land use, and transportation. In the United States, federal and state governments sponsored geological, geographical, vegetational, and wild-life surveys. Such surveys provided information about the existing resources available for private and public exploitation. These same surveys also provided an excellent opportunity for early American naturalists to catalog and classify the diversity of plant, animal, and insect life of the newly-opened continent.

Political Arenas and Government Agency Disputes

Within the arenas organized around the extraction and transformation of natural resources after the Civil War, there were a large number of competing interests. These included local agricultural and livestock producers, mineral and metal miners, fishers, and forestry and lumbering concerns (%Vatter, 1975). The processing industries concerned with agricultural and mining products, such as the meat packing, milling, and canning industries, were interested in the debates about how these resources were to be regulated. The railroads were also concerned with the extraction and disposition of natural resources, as were financial institutions such as banks, loan associations, and insurance companies.

In addition to these private economic interests, local, state, and federal government agencies were all interested in the disposition of public lands. Indeed, the different (and sometimes conflicting) concerns of these government agencies were an important part of the natural resource and agricultural arenas which emerged after the middle of the 19th century. Local elites in all regions of the United States had a great deal of control over the resources in one area. State governments were concerned with maintaining control over much larger regions, although even at this level competing local interests attempted to maintain control over local resources. Federal government agencies often had jurisdictional disputes with state governments. Shifting alliances among federal, state, and local interest groups set the scene for debates over administration and regulation of economic activities in different regions. Often, local and federal interests would coalesce to defeat attempts by state government agencies to assert control over particular resources, as the cases of rangelands, timber, and irrigation, discussed below, illustrate.

After the Civil War, the federal government became involved in collecting information about the natural resources of the newly-opened territories beyond the 100th meridian. While the Army Corps of Engineers had been principally responsible for surveying work before 1860, after the war a large number of survey expeditions moved into the Western territories. The Department of the Interior sponsored separate expeditions by two geologists, John Wesley Powell and F. V. Hayden. The War Department sponsored an expedition by the Yale-trained geologist, Clarence King, while the Army Corps of Engineers sent George M. Wheeler on a separate expedition (%Stegner, 1954; %Wilford, 1981). These expeditions worked in overlapping territories and there was intense competition among their leaders for government funding and sponsors. After an episode in 1873, when Hayden and Wheeler both mapped the same area in southern Colorado, the U. S. Congress was persuaded by the Secretary of the Interior to establish a single civilian survey agency. The United States Geological Survey was placed within the Department of the Interior in 1879 and headed first by King and then by Powell (%Stegner, 1954).

The continued dominance of local elites in resolving issues about resource exploitation in this period was due, in no small part, to the tendency of state and federal administrators to rely on these local elites for information as well as proposals for solving the array of problems which emerged from the use and abuse of natural resources in the second half of the 19th century. Administrative agencies established by the federal government, particularly in the Department of the Interior, were often inadequately funded. This forced federal administrators to rely for information on the very industries which they were intended to regulate. Professional scientists and other experts often came from these industries to work in a federal agency and went back to careers in these industries after their tenure of government service.

While the federal government initially sponsored surveys to provide maps of the new territories, later federal efforts were concentrated on regulation. From the beginning of the federal government's push for centralization, disputes occurred between various departments and agencies over the boundaries of administrative responsibility for different geographic regions. In the two decades after the Civil War, these disputes were particularly acute between the U.S. Geological Survey, the Army Corps of Engineers, and the U.S. Coast and Geodetic Survey (%Stegner, 1954). In the 1890s and early 1900s, the most vociferous disagreements were between the Departments of Agriculture and the Interior.

Jurisdictional disputes among federal agencies had an impact on the solution of regional problems, since local interest groups were able to take advantage of these disagreements to prosecute their own programs. Shifting alliances among directors of federal and state agencies, as well as among local elites, state agencies, and federal administrators, left the day-to-day supervision of public lands in the hands of private local interests which controlled them without owning them (%Hays, 1959). An example of the manner in which government disputes left control of resources in local hands is provided by the disposition of the forest reserves established throughout the country after clear-cutting led to problems with flooding and navigation of rivers in the East. Another example is the disposition of public lands in the West after the Civil

War.

Although forest reserves were established by the federal government in a number of Eastern states as early as the 1870s, it was not until the 1890s that the government actually gained control over these reserves from the individual states (%Kane, 1949). Administration of these reserves which, it was argued, were vital to the maintenance of watersheds, was initially placed in the General Land Office within the Department of the Interior. In 1901, Gifford Pinchot, a close friend of President Theodore Roosevelt, succeeded in transferring administration of the forest reserves to the Department of Agriculture (%Hays, 1980). Pinchot claimed that the Department of the Interior was too reluctant to grant permits for lumbering, mining, and grazing on these lands. In return for such permits, these industries supported Pinchot's efforts to transfer the forest reserves into the Department of Agriculture (%Petulla, 1977).

Both local and state interest groups lobbied for the establishment of federal agencies to solve the problems associated with resource exploitation and agriculture in the Western states in the 1870s (%Hays, 1959). Scientific expertise and management were the ideological tools used by the emerging professional middle classes to establish institutional bases for regulatory work. While they served in the beginning as a sop for the growing conservation and urban reform movement, these federal agencies eventually came to be dominated by the very industries which they were intended to regulate (%Petulla, 1977).

The United States Geological Survey was involved in a longstanding dispute with the Army Corps of Engineers over control of the development of water resources in the arid Western states. While the Army Corps of Engineers supported local interests involved in navigation and waterway maintenance, the Geological Survey supported a multiple-use policy intended to ensure the maintenance of watersheds and forests for irrigation as well as navigation. The Army Corps of Engineers was allied with navigation interests such the ship construction industry, while the Geological Survey had several constituencies including homesteaders and urban reformers interested in maintaining wilderness areas for recreational purposes. The rivalry between these two agencies, and their different alliances, led them to collect different types of information, often about identical regions. The geographic boundaries of many of the watersheds administered by these agencies crossed state boundaries, and this simply added to the complexity of the situation, as federal agencies vied with one another for support of different state governments as well as for the support of different local and industrial interests.

By the beginning of the 20th century, federal land-use policies dominated state interests as a result of alliances with local and regional elites. The Forest Service in the Department of Agriculture controlled the administration of forest reserves after 1900. The Department of Agriculture also took the lead in directing agricultural research by bringing the directors of the state agricultural experiment stations and agricultural colleges together for meetings in Washington (%Rossiter, 1979). The Department of the Interior was occupied with battling the Army Corps of Engineers over control of the nation's rivers and waterways. The Newlands Act of 1902, which established the Bureau of Reclamation within the Department of the Interior, demonstrated legislative support for the department's multiple-use policy. Together with the Forest Service, the Geological Survey presented President Roosevelt with a plan which defined the issues of irrigation, homesteading, grazing, and the establishment of forest reserves, as a single problem, to be solved by the elaboration of a comprehensive water resources plan.

The alliance between the Forest Service and the Geological Service set the Departments of Agriculture and the Interior in opposition to the Army Corps of Engineers, which still advocated a water-use policy based on navigation and construction industry interests. In spite of efforts to dismantle the Army Corps of Engineers, this agency was able to maintain control over the construction of dams and flood-control technology throughout the United States. Through alliances with several key members of Congress as well as with various arms of the construction industry interested in federal contracts for construction work, the Army Corps of Engineers was able to resist the efforts of the Departments of the Interior and Agriculture to dismantle it throughout the 1920s and 1930s (%McConnell, 1966).

Agriculture and Western Development

Tensions between local and state interests ran high after the Civil War. The most vociferous debates developed between conservationists and sectionalists in the Western states. Conservationists were allied in the last part of the 19th century with urban reformers interested in preserving some of the remaining wilderness areas in the East as well as much of the public domain in the West in pristine condition (%Hays, 1959). The sectionalists were local elites engaged in raising cattle, lumbering activities, and mining in the West. The sectionalists wanted control of resources to remain at the state level, where their influence was greater (%McConnell, 1966). After 1900, the federal government played an increasingly central role as mediator among various interest groups in the Western states. As uses of the land diversified, and as different types of resources came to be exploited, local agreements disintegrated and provided the federal government with opportunities to interfere in local and state disputes.

The arena which developed around agricultural activities was more unified than the arenas which developed around resource activities. There were a number of broad-based interest groups within the agricultural arena which influenced its direction after the beginning of the 20th century. These included diversified and commodity farmers, the Department of Agriculture, a large number of agricultural colleges established after the Morrill Act of 1862 provided funds for agricultural education (1), state agricultural experiment stations, and the manufacturing industries associated with the production of food-stuffs. There were, in addition, transportation and advertising interest groups. Although these last were peripheral to actual food production, they were important in the political arenas in which such issues as the subsidization of crops were decided.

In the arid Western states, there were major disagreements among cattle ranchers, sheep herders, and homesteaders attempting to raise cereal crops, such as wheat and corn. The Western cattle ranchers were also in competition for resources with Midwestern stockmen, and there were further disagreements among small ranchers and those running very large numbers of cattle (%McConnell, 1966). Negotiations in the 1890s and early 1900s around the issue of access to public lands for grazing illustrate all of these competitive interests clearly.

The settled, large-scale cattle ranchers dominated local and state political arenas. The Public Lands Commission was set up by the Federal government in 1904 to adjudicate the problems between stockmen and farmers. Although the commission called upon expert scientists to advise them regarding the best disposition of these lands, their efforts were contravened by their reliance upon local stockmens' associations for information about what types of land existed and what uses were being made of these lands (%McConnell, 1966). The result was that most of the public domain was classified as suitable for grazing. The transfer of the administration of vacant public lands to individual states by the Hoover administration in 1928 gave established cattle-men an even greater voice in the disposition of these lands. Early in the 1930s, problems of widespread erosion developed, due in no small part to overgrazing by cattle ranchers. In 1934, the Taylor Grazing Act established a system of grazing districts to be administered by the Department of the Interior. This move was strongly resisted by the Department of Agriculture which, up to that time, had administered these public lands. The Grazing Service, like the Public Lands

Commission, was required by law to cooperate with the local stockmens' associations. The effect of this government attempt to assert control over the public domain was simply to ensure the victory of the dominant cattlemen in the range wars in the Western states in the first three decades of this century (%McConnell, 1966).

The years before and during the First World War saw an unprecedented expansion of agriculture in the United States. As the grain markets in Europe disintegrated, American farmers were able to fill the demand for wheat and corn overseas. In 1914, the Smith-Lever Act provided funds for a joint state and federal Agricultural Extension Service to provide farmers with instruction about improved farming techniques. By 1917, county agricultural agents, based at the local agricultural colleges, were teaching local farmers new techniques of pest control as well as methods for dealing with animal disease and human nutrition problems (%Aronson, 1982). The work of these county agents tied farmers more closely to the research work being done at the state agricultural experiment stations. At the same time, the agents tied farmers more closely to local, state, and federal politics and to ideas of scientific management.

These county agents were in the interesting position of serving multiple constituencies. They operated simultaneously as a field service for the Department of Agriculture and as paid organizers for the American Farm Bureau Federation. The agents were

> ... most closely tied to the local counties where they worked, where they were beholden to county government and even more the Farm Bureaus they had organized and which they served as partial employees. Officially, their status was more ambiguous: they were national, state, and local officials; they were also privately employed. Informally, there was little doubt where their effective political responsibility lay --- to the locally influential farmers. And these were well knit into the Farm Bureaus (%McConnell, 1966: 233).

County agents were the political agents of the local elites, most of whom were large-scale commodity farmers. This powerful lobby was opposed without much success by the National Farmers Union. This organization emerged as an alliance between the small wheat farmers of the prairies and the cotton growers of the Deep South. These two groups had little in common apart from their rural poverty and their opposition to the Farm Bureaus. Lack of common interests as well as financial resources within the Farmers Union meant that the power to define political and technical problems remained in the hands of the large-scale commodity farmers throughout the 1920s and 1930s.

Agriculture and Conservation: Contrasting Cases

Agriculture and conservation arenas were both concerned with the management of environmental resources in the United States. After the first World War, agriculture continued to receive massive funding from the federal government while conservation did not. What was the basis for the success of agriculture and the failure of conservation in gaining resources and prestige at all levels of government? Historians interested in these arenas remain specialized in one or the other (%Crabb, 1947; %Hays, 1959) so the analysis offered here is simply hypothetical.

After 1918, the booming grain market overseas collapsed and farmers were left with huge surpluses as well as glutted markets (%Busch, 1982). Surpluses led to falling prices for farmers, widespread unemployment, and continued high levels of production to compensate for falling prices. Small-scale farmers were most severely affected. Many went out of business and moved to urban areas looking for employment in the manufacturing sector in the 1920s. Those who remained adopted improved strains of wheat and corn developed at the agricultural experiment stations. Improved machinery for large-scale farming operations further increased yields in this period. Prices for grains remained extremely low throughout the 1920s, partly as a result of these improvements and partly as a result of increasing competition from other nations engaged in grain production, including Canada, Argentina, Australia, and Russia (%Petulla, 1977).

When the Depression struck in 1929, existing political alliances in the agricultural arena shifted very little. The arena had already developed several well-entrenched interests, including the Farm Bureaus made up of local, large-scale commodity farmers, the Farmers Union consisting of smaller, less successful farmers allied in a loose national network, the Department of Agriculture whose various bureaus and divisions were engaged in promoting agricultural research and scientific expertise, business groups concerned with agricultural production such as railroads, banks, and food processing industries, and commodity organizations such as the National Association of Wheat Growers, the National Cotton Council, the National Milk Producers Federation, and the American National Cattlemen's Association.

The Farm Bureaus and the commodity organizations often had overlapping memberships as well as close relationships with the Department of Agriculture's county agents. Local elites also had the benefit of long-term and close working relationships with agricultural scientists, whose concerns about high productivity, high yields, and efficiency mirrored those of the commodity farmers as well as of the state and federal politicians. Small-scale, diversified farming operations suffered the greatest attrition as the Depression, heightened in its effects by a drought which lasted from 1931 to 1935, spread bankruptcy across the

Midwest and Western states (%McConnell, 1966).

The response of the New Deal politicians to environmental and economic problems reflected the interests of the dominant groups in these arenas. Price supports enacted by the Agricultural Adjustment Act of 1933 benefitted the large-scale commodity farmers of the West and Midwest. In fact, the legislation was drafted in the offices of the American Farm Bureau Federation (%McConnell, 1966). This legislation guaranteed that farmers would be paid for acreage that was <u>not</u> planted as well as providing a guaranteed market (i.e. the federal government) for those crops which were produced. The government began to accumulate storehouses of wheat, corn, cotton, and tobacco. Marketing agreements were legalized between producers and processors of fruits, vegetables, and milk, establishing minimum prices and quantities for these goods (%Petulla, 1977). These agricultural policies, established in the 1930s, remain substantially in effect today (2).

Conservation policy underwent an eclipse after 1910 and the defeat of the Progressives. In the 1930s, conservation was resurrected as an essential aspect of New Deal legislation. Relying on skillful administrators such as Secretary of the Interior Ickes, and Secretary of Agriculture Wallace, President Roosevelt established a wide variety of new conservation programs as well as expanding the budgets of already existing programs. Like his uncle, Franklin Roosevelt was a close friend of Gifford Pinchot, former head of the Forest Service and chief architect of the conservation movement in the early years of the 20th century (%Hays, 1980). Support for conservation in the 1930s came from the strong liberal base in the states as well as from a Congress willing to cooperate with the leadership provided by the Roosevelt administrators.

Between 1910 and 1935, little attention was paid by private interests or public agencies to conservation problems. While the federal government provided huge resources for agricultural research and education, conservation received few resources. In part, this was due to ongoing disagreements within this arena regarding the priority of various problems and how these were best handled. The definition of environmental problems varied according to the geographic region. In contrast, there was a high level of agreement among those involved in the agriculture arena regarding top priorities for action. Increasing productivity and eliminating diseases constituted the most important problems among all the interest groups involved in agriculture. Although there was concern with a wide variety of organisms within the agriculture arena, there was far greater variety among the phenomena which concerned the conservation arena. After 1935, support for conservation issues developed rapidly as a result of the massive environmental and economic problems which emerged in this period. Lack of employment opportunities in the private sector created a huge labor pool. The productivity of the industrial sector declined at the same time (%Potter, 1974). Problems of drought and erosion affected most of the Western states. The conservation policies of the 1930s were emergency measures designed to deal in the short term with both the economic and environmental problems faced by the federal government.

In spite of support by the federal government, conservation policies in the 1930s continued to suffer from the same problems which had plagued the early conservation movement. The same interest groups that had become entrenched early in the century (reformers, conservationists, and developers) maintained their ideological and institutional positions. The conservation arena in the 1930s looked much the same as it had in the early 1900s. In spite of attempts by Ickes and Wallace to establish a comprehensive conservation agenda, continuing battles between reformers and developers, with the conservationists mediating between the two, sabotaged the government's efforts and diluted the programs which were passed (%Koppes, 1982).

There were other reasons for the failure of the conservationists to achieve results consonant with the vision they projected. Entrenched economic interests, including power companies, the lumber, fishing, and canning industries, and commodity farmers blunted the impact of many New Deal initiatives through local resistance as well as state and federal action. Bureaucrats in federal and state agencies, who had been responsible for the decline of conservation issues in the years after the First World War, remained to sabotage these new programs. Bureaucrats in regulatory agencies were often more responsive to the industries they were supposed to regulate than to the conservation principles endorsed by the New Deal administration (%Koppes, 1982; %Potter, 1974).

Just as entrenched economic and political interests continued to shape conservation and agricultural policies, rivalries among state and federal agencies continued to affect these same policies. As example is the continuing battle between the Departments of Agriculture and the Interior, both headed by strong Roosevelt appointees. In 1918, the Department of Agriculture was authorized to establish a program in soil erosion research to be headed by Bennett, from its Bureau of Soils. During the 1920s, this research was shifted into the Department of the Interior. In 1935, while Ickes was out of town, Wallace was able to persuade Congress to fund a permanent Soil Conservation Service within the Department of Agriculture. Within a year, this bureau had 147 demonstration projects, 48 nurseries, and 23 research stations. Techniques of terracing, contour plowing, crop rotation, and fertilization were demonstrated and taught to farmers. The two Departments also traded charges and countercharges over which agency should manage grazing on public lands (then administered through the Department of the Interior) and on forest reserves (then under the control of the Department of Agriculture). Different definitions of the problems facing these regions, as well as different alliances with political and economic interest groups, formed the basis of the on-going disagreements between these two federal agencies.

Conclusion

The arenas in which agriculture and conservation problems emerged were characterized by increasing centralization of power after the beginning of the 20th century. Industry leaders, politicians, scientists, and professional managers were closely allied in their interests as well as their actions. The research sponsored by federal agencies, in particular, was shaped by the problems faced by elites in business and agriculture. These problems were the subject of negotiations whose outcome was dominated by those interests whose economic bases were broadest and whose political connections were most extensive. These arenas were made up of multiple economic interest groups, each bent on extracting some very specific commodity from the economic and environmental resources of the country. These arenas were also characterized by political interest groups, at the local, state, and federal levels, allied with one another in multiple ways.

A number of scientific disciplines owe their initial development and importance to growing opportunities for employment in industries and in government agencies concerned with problems of management of natural resources. Geology is associated with the survey work sponsored by government and private interests as well as groups interested in metal and mineral mining (%Rudwick, 1976). The development of limnology was associated with the fishing industry as well as hydrological research in the United States and Europe (%Frey, 1966; McHugh, 1977). Entomology grew out of research in insect taxonomy and investigations by government and academic scientists into insect pests and plant diseases (%Rossiter, 1979). Forestry was also connected to an economic arena; depredations of lumbering industries of timber resources in Eastern and Western states led to governmental and educational responses (%Kane, 1949; %Rodgers, 1951). Demands for knowledge about and expertise in dealing with the problems of mining, water-use, dam construction, pollution, lumbering, and farming of many different crops provided the "raison d'etre" for many of these disciplines. Scientists and professionals who claimed the license to handle these problems also became involved in the political arenas in which such problems were defined and addressed.

A variety of governmental agencies and educational institutions were established after the Civil War to address the problems of various groups in American society. Powerful local constituencies in different regions of the continent demanded funds and expertise to address the problems associated with their economic activities. While the constraints which responsibility to local constituencies placed on scientists were not strong enough to prevent these professionals from doing more abstract and theoretical work, the institutions which emerged to support scientific research were affected in important ways by their ties to economic and political arenas.

Agriculture was successful in obtaining institutional commitments to solving its problems because the consensus among the constituencies involved regarding the most important problems in the arena was extremely high. In addition, these problems appeared to be amenable to new styles of experimental work which scientists were beginning to adopt at the end of the 19th century. In contrast, the conservation arena did not have high consensus among its constituent groups around problem definitions. Nor were these problems amenable to reductionist research strategies. These features of the two arenas contributed to the decline in support for conservation after 1910 and the concomitant rise in support for agriculture. The segmentation of agricultural research from academic research in the early 1900s was at least partly due to the well-defined mandate available to these scientists from agricultural constituencies. Conservation, without a well-defined constituency, without well-defined problems, and with inadequate levels of funding remained the repository of problems and approaches which did not fit into academic or agricultural research.

Footnotes

(1) Busch (1980, 1982) argues that the establishment of the agricultural colleges during the 1860s was an early attempt to contain rural dissatisfaction in the Midwest. While this may have been an important element in the establishment of these institutions, it was not the only reason for the passage of the Morrill Act nor for the establishment of a large number of many colleges and universities in the East. Veysey (1965) has an alternative explanations as does Rodgers (1944a).

(2) "One-Third of Farmland to Lie Idle," San Francisco Chronicle (23 March 1983): 1.

CHAPTER TWO

THE INSTITUTIONALIZATION OF BOTANICAL RESEARCH IN THE UNITED STATES

Introduction

Scientists and professionals coping with the problems of development in America after the Civil War often found themselves involved in the political arenas in which even the most technical problems were defined and solved. The professionalization of science after the middle of the 19th century was tied to both institutional and intellectual developments. Some of the changes in the wider economic and political context which affected the development of the biological sciences included the growing support for narrowly defined problems among powerful local constituencies and federal government administrators. Issues of resource conservation and agriculture were particularly important in creating a demand for scientific expertise by various economic and political interest groups, government agencies, and other professionals. Several scientific disciplines developed in response to the growing opportunities for employment in government, industry, academia, and private research institutions. Demands for knowledge and expertise in handling economic and environmental problems associated with development of the West after 1860 supported scientific specialization.

Popular interest in Natural History was widespread even before the middle of the 19th century. After the Civil War, such interest surged and courses in Natural History and Natural Philosophy were taught at colleges and universities throughout the country. Interest in rural areas was high among the urban middle and upper classes. City-dwellers took weekend and summer trips to the White Mountains and the Adirondacks (already scarred by lumbering activities) (%Petulla, 1977). Even before the war, societies and museums of Natural History had been established in many small towns and cities. Natural History courses were taught at local high schools as well as at colleges and universities (%Cravens, 1978).

Popular interest spurred the development of biological and geological science in the United States. However, these disciplines gradually became more isolated from broad social, economic, and political currents. In this chapter, I discuss the development of a variety of institutions which specialized exclusively in support of biology and contributed to the increasing segmentation of hobbyists and amateurs from professional scientists interested in problems of evolution as well as more applied problems of agriculture and conservation. The institutions which supported biological research after 1860 were established at different times and for a variety of different purposes. Their relationships to the larger political and economic arenas with which biological research was associated were also quite distinct.

All of these institutions were characterized by clusters of tasks which together came to define the work of biology. These tasks included: research (both basic and applied, although this distinction was not clearly made until the 1920s), teaching and training of novices, publication of the results of professional work, administration, and professional activities (especially membership in professional scientific societies). Scientists working in these institutions were involved in other arenas, including social reform, legislation, and political work (%Engel, 1983; %Overfield, 1975; %Young, 1922). However, the clustering of research, teaching, and publication, together with the support given to developing specialized professional societies, seems to define the "core" of biological work.

The Segmentation of Audiences and Tasks

Between 1880 and 1920, the institutional structure which supported biological research underwent several dramatic changes. First, federal support of agricultural research created employment opportunities for large numbers of more or less well-trained young scientists. Funding for federal research laboratories, state agricultural experiment stations and agricultural colleges quadrupled over this period (%Rossiter, 1979; %True, 1937). The institutions which supported the training of scientists underwent both expansion and change as the "research ideal" imported from Europe (and associated with the utilitarian ideology of the American middle and upper classes) was incorporated into educational institutions, in the form of both physical facilities and resident expertise (%Cravens, 1978; %Shils, 1979). This period saw the emergence of institutions devoted exclusively to basic scientific research and the publication of its results. All of these changes had consequences for the groups interested in the results of scientific research and for the array of tasks associated with research.

The earliest institutions to support biological research were museums and botanical gardens. These institutions developed a "public" function after the middle of the 19th century. By the 1880s, museums and botanical gardens devoted a considerable portion of their resources to providing for public displays of their collections. Areas in the gardens and special display halls were designed to communicate graphically developing ideas about the evolution of organisms. At the same time, these institutions supported work in the classification and description of a wide variety of organisms. Their publications reflect this specialized type of work and were largely directed to specialists in various types of organisms.

Recruitment into this type of institution was largely through the educational system, although this still reflected the narrow social networks associated with this work in museums and botanical gardens. In England, for example, the first three directors of the Royal Botanical Gardens at Kew were Sir William J. Hooker, his son Sir Joseph D. Hooker, and Joseph's son-in-law, W. T. Thiselton-Dyer (%Brockway, 1979). In the United States, lineages were not as obvious. However, the directors of museums and botanical gardens were usually succeeded by one or more of their students. Nathaniel Lord Britton, for example, who founded the New York Botanical Garden was succeeded by his student H. A. Gleason (%Wyman, 1947). The Museum of Comparative Zoology, founded by Louis Agassiz at Harvard University was directed by his son, Alexander, after his death in 1873 (%Allen, 1978). Even today, museums and botanical gardens, as well as the tasks of description and classification, remain the province of a very small group of scientists. Between 1880 and 1920, while other biologists relied heavily on this type of research in identifying the organisms with which they worked, young researchers became increasingly reluctant to work in this type of institution.

As institutions of higher education developed in the second half of the 19th century, the distinction between graduate and undergraduate education became more important. Teaching was gradually separated from research and a separate set of rewards became associated with each of these activities. As research accelerated, rewards came to be based on publication, and universities that supported research activities by their faculty often supported a scholarly press for the distribution of the results of this work. Individual university departments were sometimes willing to allocate part of their budgets to the publication of specialized journals, as was the case with the Botany Department of the University of Chicago (%Rodgers, 1944b). With the developing emphasis on research, a series of specialized audiences developed, in addition to lay audiences which provided the recruits for advanced education.

Professional scientific societies, which focused on a set of research problems, a geographic region, or on a limited set of organisms, emerged clearly after 1900 along with journals in which specialists in these areas could communicate with one another. These new, scientifically specialized networks initially crosscut the institutional networks in which individual scientists were involved. However, the separation of research and teaching had the effect of separating lay constituencies from more specialized, scientific audiences. Academic administrators (drawn initially from the ranks of young faculty) supported the division between research and teaching by establishing separate undergraduate colleges within universities or by concentrating exclusively on graduate education and leaving undergraduate education to smaller, liberal arts colleges.

The complexities of dealing with a variety of audiences were probably most severe in those institutions which supported agricultural research. Scientists working at agricultural experiment stations were worse off than those working at federal research laboratories, which were characterized by centralized facilities and specialized communities. In the agricultural experiment stations, researchers were expected to meet the demands of lay constituencies for routine chemical analyses and regulatory work, teach new, usually undergraduate students, and educate local farmers (although this last strain was largely removed when extension work was separately funded after 1914), and conduct basic research. This last demand for research was at least in part a consequence of the station administrators' attempts to ensure funding; the success of a station scientist in conducting research often rested on the ability of the station administrator to protect his staff from budgetary "raids" by the educational institutions with which many of these stations were associated (%Rosenberg, 1976).

In the case of the federal laboratories, the position of the chief administrator was of primary importance in ensuring funding as well as continued organizational existence. Researchers at federal laboratories were, to some extent, shielded from direct demands by lay constituencies, but the exigencies of federal funding meant that for these scientists, too, there were strong pressures to pursue research which appeared to have a more or less immediate applications to existing problems. Between 1890 and 1920, a hierarchy was established with the federal bureaus at the top, the top-ranked experiment stations (usually those with administrators best able to protect their staff from constituency demands) in the middle, and the lesser-ranked stations where work continued to be prey to the intervention of local elites at the bottom. As these audiences and institutions segmented, there emerged different outlets for publication. Station scientists published bulletins for lay audiences, agricultural reports for federal scientists and administrators, and specialized research reports in agricultural science journals for other researchers working in the same intellectual arena.

The crystallization of research as a clear set of tasks came with the emergence of the private research institution. It was in these private institutions that the conscious effort to separate research problems from other, more practical issues was most successful. The critical audience for researchers working in this type of institution was no longer an academic administrator, a station director, or even a lay constituency. For these scientists, the development of professional autonomy meant that other scientists, in research-oriented, graduate universities or in other private research institutions, were the critical audience. Networks built among research universities and professional scientific societies, and supported by specialized channels of communication, channeled graduate students from major universities into the private laboratories of these institutions. Students at smaller universities and colleges were left to pursue employment opportunities in the agricultural colleges, experiment stations, and for the most promising, in the federal research laboratories.

The variety of tasks associated with the production and distribution of knowledge gradually segmented out into separate institutions. A monopoly on basic research, once in the hands of the museums and botanical gardens in Europe, passed by the beginning of the 20th century to the research-oriented universities which emerged in the 1880s and 1890s and to the private research institutions established through the largesse of private philanthropists. Other institutions where biological research was conducted were unable to protect themselves effectively from the demands of lay constituencies, and to varying degrees, found themselves caught in the dilemma of responding to a multiple demands from a variety of audiences. Many educational institutions made no attempt to engage in research and concentrated instead on teaching. In fact, this set of tasks was not immune to the controversies which informed more specialized research circles. For example, between 1900 and 1940 the controversy about the relative influence of heredity and environment on the ability to learn was an important issue in liberal arts colleges (%Cravens, 1978).

The segmentation of tasks in biological research can be separated analytically from the segmentation of the audiences concerned with biological research. Once these scientists had succeeded in extricating themselves from the demands of lay constituencies, segmentation continued along the lines of substantive specialization. The strains between societies representing different disciplines began to played an growing role in the differentiation of types of researchers after 1900. The strain was most apparent between academic and agricultural scientists, as a distinct set of professional agricultural science societies developed after 1900 (%Rossiter, 1979). These strains were only partly related to the variety of audiences to which these scientists were expected to respond. They were also related to differences in the success with which these different scientists managed to protect themselves from lay audiences.

While academic scientists freed themselves from the demands of lay audiences, they were as much involved in the acquisition of funds, and the recruitment and training of students, as researchers working at experiment stations. The different audiences to which these scientists remained responsive, and their success in establishing institutional bases for research, formed the basis for segmentation in biology after 1900. It is only when we examine carefully the differences in these audiences and tasks and compare these differences across a number of contexts that we can understand the intellectual debates in which these scientists became involved.

In the sections which follow, I discuss the different types of institutions in which botanical research was done in the late 19th and early 20th centuries. My discussion focuses on the clusters of tasks pursued in different institutional settings, including research, training, publication, and the development of specialized scientific networks. My concern is to indicate some of the constraints which operated in these different institutional settings and the impact of these constraints on the tasks which were pursued in these different settings.

Museums and Botanical Gardens

Until the middle of the 19th century, most biological research consisted of the description and classification of different types of organisms. During the 18th and 19th centuries, the amount of information about organisms from around the world increased tremendously (%Brockway, 1979; %Farley, 1982). Through the activities of surveyors, explorers, and collectors, innumerable living and preserved specimens of plants and animals found their way into museums, zoological gardens, and botanical gardens in Europe and the United States. As professional naturalists became a standard part of exploratory and military expeditions, and with growing popular interest in regional floras and faunas, the institutions housing such collections increased in both numbers and importance.

In contrast to the amateur collections established during the 18th century, the 19th century was characterized by the rise of large, serious working collections which became centers for scientific research (%Farber, 1982). These large, public collections provided new employment opportunities for naturalists without independent income and, at the same time, influenced the scope and direction of research through the extent and focus of their collections. For example, the American Museum of Natural History, founded in 1869, was extremely influential in the development of the discipline of paleontology in the United States, largely as a result of the extensive collection of fossil vertebrates which was housed at this institution (%Young, 1922).

Early botanical gardens were associated with medicine and pharmacy. Apprentices of apothecary societies were required to identify a wide variety of "simples" or drug plants as the culmination of their lengthy training (%Allen, 1976). Apothecary societies and guilds established many botanical gardens in the 1700s, where living plants were propagated while preserved specimens were stored in herbaria attached to the gardens. The pharmacists and naturalists who worked at botanical gardens after the beginning of the 19th century were often involved in both classification and early experimental work (%Olby, 1966). It was not until the last quarter of the 19th century, however, that major botanical gardens developed firm relationships with academic institutions (%Young, 1922).

Most museums and botanical gardens encompassed a variety of tasks. By the middle of the 19th century, the description and classification of new varieties of organisms formed the core of the research activities conducted at both museums and herbaria. Public displays of these organisms were an important part of the work at these institutions. While the Royal Botanical Garden at Kew was unusual in the size and scope of its activities, it served as a model to many others established in Europe and the United States. In particular, the close relationship between Sir Joseph Hooker, the second director of the Kew Gardens and Asa Gray, the leading American botanist in the 1860s and 1870s, led the directors of a number of American botanical gardens, including the Missouri Botanical Garden and the New York Botanical Garden, to organize their institutions along lines suggested by Kew (Rodgers, 1944a).

The importance of the influence of Kew on American botanical institutions is difficult to estimate; as the clearinghouse for botanical information and specimens from all over the British Empire, Kew influenced the development of agriculture around the world while its directors, close friends of Darwin and other English, European, and American scientists, were responsible for revising the botanical system of classification developed first by Linnaeus in the 1730s and revised by de Candolle in the 1840s (%Farley, 1982). Through the agency of Asa Gray and his students, the new system of classification was adopted by the U.S.

National Museum (which received thousands of specimens from military and survey expeditions through the Western territories) as well as by the major American botanical gardens (%Gager, 1938; %Dupree, 1959).

Since museums did not include living organisms among their collections, these institutions were supportive of disciplines which relied heavily on fossil and stratigraphic evidence, such as geology and paleontology. Botanical gardens, in contrast, supported both classification work and the propagation and hybridization of plants with possible economic value. American botanical gardens were heavily involved in plant introduction and distribution after the Civil War, supported in part by funds from the Department of Agriculture. While the federal government made only sporadic attempts to procure useful plants for cultivation in the United States before 1875, with the establishment of permanent facilities for propagation and experimentation at botanical gardens in the 1870s and 1880s these efforts began to affect American agriculture (%Rodgers, 1951). Plant explorers and collectors sent out by both the government and the botanical gardens returned with numerous specimens of plants that appeared commercially promising. Seeds and cuttings of mulberry, lacquer, pistachio, and rubber trees, cereals and grains such as corn, wheat, and rice, citrus and dates, and ornamental flowering plants such as rhododendrons were brought back to the United States and cultivated by botanists working at botanical gardens as well as for the federal government after 1880 (%Fairchild, 1938; %Rodgers, 1944a).

Beginning in the 1880s, many botanical gardens undertook physiological research on plants in their "living" collections. The Jodrell Laboratory at Kew Gardens, established in 1876, served as an example, once again, to American institutions (%Brockway, 1979). Both the Missouri and New York Botanical Gardens, established early in the 1890s, included laboratory facilities in their original physical plant (%Rodgers, 1944a). However, physiological research remained a small part of the research activities of naturalists working at botanical gardens. Far better laboratory facilities were available at graduate, research-oriented universities during this period and scientists interested in experimental research worked at these institutions rather than at botanical gardens.

Most museums and botanical gardens provided for the publication of the results of research done under their auspices. The establishment of new species entails the preservation, mounting, description, identification, classification, and storage of a large number of preserved specimens. The results of this work must be published in a journal devoted to such communications along with detailed drawings and, after the camera was invented, photographs

(%Gleason, 1960). A number of American botanical gardens published both lengthy technical monographs and journals, including the New York, Brooklyn, Missouri, and Harvard institutions (%Wyman, 1947). Such publications were extremely important to naturalists concerned with classification, since these journals and monographs were the single means for establishing priority in the naming of new species of organisms.

The size and scope of the training programs provided by museums and botanical gardens was limited. When contrasted with the numbers of students graduating from colleges and universities in the same period, these programs appear even more limited. For example, between 1850 and 1900, Kew Gardens trained a total of 700 botanists and gardeners (%Bean, 1908 in Brockway, 1979). The number of trainees at even the most prestigious American botanical gardens was equally small (%Gleason, 1960).

The audiences to which museums and botanical gardens catered changed little between 1880 and 1920. These institutions continued to appeal to two important types of users: (1) lay audiences and (2) professional scientists. The halls, walkways, and greenhouses accessible to the general public at these institutions constituted only a small part of the entire physical plant of such organizations. Museums and botanical gardens acted as educators to the general public, assembling exhibits and displays of various organisms and their environments. These same institutions acted as repositories for professional researchers, preserving and storing collected materials, and assembling a wide array of information on organisms and their environments . As repositories, it was important for such institutions to develop and maintain a system of classification which professional scientists could use to gain access to and retrieve information easily. Issues of preservation, classification, and distribution of knowledge played an important role in these institutions, as they do more generally in libraries (%Volberg, 1981).

By the beginning of the 20th century, there were several prominent museums and botanical gardens established in the United States, as well as many smaller ones. Many of these institutions were modelled on similar institutions in Europe where large numbers of American students travelled after the middle of the 19th century. Both museums and botanical gardens supported work in the classification and description of organism after the early 1800s. Botanical gardens also supported experimental work on plant physiology, plant breeding, and hybridization since their collections included living material as well as preserved specimens. Priority in naming species was an important issue for scientists working in such institutions. Providing outlets for publication was an important part of the work of these institutions. Training programs provided enough students to fill administrative positions at smaller gardens and museums, but there were limited opportunities in this field, particularly when compared with the opportunities available to graduates of universities and colleges after the beginning of the 20th century.

Colleges and Universities

In the period between 1860 and 1900, American institutions of higher education moved from a minor to a predominant position in the pursuit of scientific research. There are several important reasons for this change in the institutional basis for science, including the emergence of the graduate university after 1875, the segmentation of research and graduate training from teaching of undergraduates, and the development of networks of scientists working in universities. While a great deal of research continued to be done by private industry, as well as state and federal agencies, graduate universities became centers for advanced training as well as for the pursuit of basic research in a number of fields. By the turn of the century, graduates of university departments were filling positions in government agencies, private industry, and other educational institutions. Graduate universities gained control of the production of new scientists while at the same time maintaining their pre-eminence in research.

At the beginning of the 19th century, most biological research was done either in medical schools or in museums and botanical gardens. During the first half of the 19th century, there was a tremendous expansion in the number of liberal arts colleges established in the newly-settled Western territories. Although many of these survived for only a short time, they provided the foundation for a transformation in higher education in this country (%Guralnick, 1979). In this same period, popular interest in Natural History, spurred by both European and American expansion and exploration, penetrated institutions of higher education in the form of classes in Natural History and Natural Philosophy. Courses in geology and taxonomy soon formed an important part of the college curriculum and new faculty were hired by colleges to teach these new subjects. Professors of Natural History taught during the winter months and spent their summers accompanying state and federal survey expeditions throughout the Western territories. By 1850, popular support for the study of science, including Natural History as well as chemistry and geology, was high enough that both Yale and Harvard had established "scientific schools" (%Young, 1922).

In spite of growing popular interest in science, most research continued to be done outside institutions of higher education until after the Civil War. After 1840, the federal government became enthusiastic about the possibilities of agricultural chemistry for controlling insects and plant disease. Funding was provided which made the employment of numerous chemists by federal and state agencies possible (%Rossiter, 1979). A large number of scientists were engaged in geological and geographic surveys funded by state and federal government agencies as well as in private scientific and engineering ventures (%Guralnick, 1979). While the second half of the 19th century was characterized by an exponential increase in private and public support of scientific and engineering research, institutions of higher education were limited in terms of supporting such work. The focus on education led colleges and universities to concentrate on teaching and training rather than on the pursuit of research.

Until the 1870s, higher education in the United States was limited to a relatively small number of elite Eastern colleges and universities. A large number of "scientific" (i.e. engineering and vocational) schools were established by state governments between 1850 and 1875 with the help, after 1862, of federal funds authorized by the Morrill Act (%Rossiter, 1979). These schools offered an important alternative to the standard liberal arts curriculum required at most private and denominational schools. The faculty at these scientific schools continued to spend the majority of their time teaching although they were able to spend the long summer vacations working for survey expeditions as well as collecting for private sponsors and for themselves (%Veysey, 1965). The increase in the numbers of institutions of higher education represented by these new schools provided an important source of employment for the graduates of universities and colleges.

By 1875, a new emphasis on research in the universities around the country had emerged. This was partly due to increasing numbers of American students travelling abroad, particularly to Germany, for post-graduate education. With the establishment of Johns Hopkins in 1876, this new style of research was given an American focus (%Veysey, 1965). There were other reasons for the emergence of research as an important and legitimate activity for university and college faculty. For example, the reorganization of faculty into academic departments and the development of graduate schools at a number of universities contributed to the new emphasis on research (%Guralnick, 1979). Since many of these faculty also served their institutions as administrators, opportunities for implementing changes based on experiences in Europe were abundant. Gradually, over the last quarter of the 19th century, research and teaching came to be done in separate departments of the same institution and later at separate institutions. The growing segmentation of research and teaching was supported by the emphasis given to research at private and state-funded universities while liberal arts and undergraduate colleges emphasized teaching.

Another factor in the emergence of scientific research in the last quarter of the 19th century was the growing competition among major universities. Competition was fostered by the tendency of university governors to draw their top administrators from the ranks of the young faculty. These scientists, many of them trained in Germany, were able to convince their governors to provide generous support for their own research as well as that of other faculty. Men like Gilman at Johns Hopkins, White at Cornell University, Hall at Clark University, Harper at the University of Chicago, and Eliot at Harvard University were also able to elicit financial and political support from state legislatures and philanthropic businessmen for research, particularly in areas that offered practical applications such as geology and botany (%Shils, 1979). The competition among universities was framed in terms of the ability of an institution to attract well-known scientists and provide adequate (if not luxurious) facilities for the pursuit of research. As the emphasis on research grew, the work of teaching undergraduates increasingly fell on smaller, less prosperous institutions.

During the 1890s, as a result of rising costs of travel in Europe, disillusionment with the German system of higher education, an increasing opportunities in the United States, graduate study in American universities became more popular. The number of students at major institutions such as Johns Hopkins, the University of Chicago, Columbia, Harvard, and Yale, as well as Stanford, and the Universities of California, Illinois, Wisconsin, and Indiana began to climb (%Veysey, 1965). Graduate departments developed an autonomous existence and most benefited from the growing interest of students and faculty in pursuing research. By 1910, American institutions of higher education could claim as many as 40,000 faculty members (%Veysey, 1965), while it is estimated that upwards of 75% of all American scientists were employed at educational institutions (%Guralnick, 1979).

Another element in the emerging pre-eminence of institutions of higher education in the pursuit of research was the growing number of publishing houses associated with universities. During the 1890s, Johns Hopkins, Cornell University, Columbia University, Harvard University, and the Universities of Chicago and California all established scholarly presses for the publication of research results done by their faculty and students. These university presses vied with various museum presses (in particular the Field Museum in Chicago and the American Museum of Natural

History in New York) as outlets for the results of scientific research (%Shils, 1979). By the 1910s, these university presses had become the primary means, apart from journal publications, by which scientists communicated with one another.

The graduate universities served as the institutional foundation for scientific professionalization. Links among researchers were established through communication, including publication and participation in specialized scientific societies. Such societies often included the publication of a journal as part of their charter. Various sections of the American Association for the Advancement of Science, founded in 1848, gradually split away to form more specialized societies, although memberships continued to overlap for several decades into the 20th century (%Guralnick, 1979; %Moulton, 1948). As new societies formed, they established journals which reflected the increasingly narrow concerns of more specialized groups. Many scientific journals, although supported by membership dues, were also partially supported by university departments or even by the federal government (%Rodgers, 1944b; %Rossiter, 1979).

The incorporation of research into institutions of higher education, and the specialization of these institutions research, meant that universities and colleges increasingly participated in different arenas after 1900.

By the turn of the century, three types of institutions of higher education can be identified, including local liberal arts colleges, private graduate universities such as Harvard and Columbia, and state universities can be identified (%Veysey, 1965). The state universities were able to avoid the problem faced by private universities where the teaching of undergraduates remained important by creating separate agricultural colleges. The internal divisions within these institutions reflected several major interest groups: while the greatest conflicts were between students and faculty, and between faculty and administrators, faculty members often developed closer relationships with their graduate students than with faculty in other departments. Disputes among academic departments increased after the turn of the century, with administrators sometimes involved on one side and sometimes on another, depending on the social, intellectual, and political alliances of both faculty and administrators. Another source of tension among graduate university faculty was the far heavier teaching load which young members of the faculty were expected to carry, while older professors concentrated on research (%Guralnick, 1979).

By 1910, the structure of American institutions of higher education had taken the form maintained until after World War Two. Undergraduate teaching was done in elite

Eastern colleges and in less prestigious Western agricultural colleges and state universities. Research and graduate teaching were done at private universities as well as at private and state-supported universities in the Western states (%Cravens, 1978). While administrators of these institutions were initially recruited from the ranks of the faculty, administration soon became separate from research and administrative salaries gradually rose to reflect the power of these individuals within the universities (%Guralnick, 1979). The publication of research results was an integral part of the institutional structure by the 1890s, while the specialization of faculty (via departmentalization as well as support for membership in specialized societies) fostered new tensions among changing interest groups within these institutions.

By 1910, institutions of higher education dominated the pursuit of research in the United States. These organizations were able to provide a congenial environment and suitable tools and materials for the pursuit of increasingly specialized research questions. These institutions also provided a pool of students from which new members of the professions could be recruited. Many of these new scientists were employed in government or private industry before finding academic positions which tied these segmenting arenas together in new ways. Institutions of higher education provided outlets for the publication of scientific research as well as fostering the development of networks among specialists in the same intellectual area. In sum, universities assumed a pre-eminent position in the pursuit of research by providing an institutional basis for this type of work as well as dominating both the training of new recruits and the dissemination of the research results.

Federal Sponsors of Research

The involvement of the United States government in scientific research grew largely out of the political and economic development of the West. By the middle of the 19th century, there were hundreds of surveyors mapping these territories and reporting the results of their work to several different federal agencies, including the General Land Office, the United States Geological Survey, and the Army Corps of Engineers as well as to private sponsors (%Wilford, 1981). Much of this survey work was poorly done, through lack of training for those doing the work as well as lack of control by the agencies sponsoring it (%Dunham, 1937; %Harrington, 1949). A single agency for geological and geographical exploration was not established until 1879. This agency, the United States Geological Survey, served to centralize many of the various geological and natural history surveys conducted after about 1840 (%Guralnick, 1979; %Stegner, 1954).

After the Civil War, the federal government was involved in several major resource arenas in which scientific "experts" played a part. Local and state constituencies as well as scientists interested in these problems, lobbied for the establishment of federal agencies to regulate access to public lands, manage water resources for navigation, irrigation, and recreation, and deal with a variety of problems associated with agriculture (%Hays, 1959; %McConnell, 1966). By the 1880s, the federal government had established an array of agencies to address these various problems, including bureaus in the Departments of Agriculture and the Interior. Many of these federal agencies remained dependent for information on the industries which they were supposed to regulate. Nevertheless, the federal government's response to economic and political problems provided an excellent opportunity for employment of large numbers of new graduates from the colleges and universities of the East and West. Increasing numbers of scientists found employment in the new bureaus of administrative and regulatory agencies.

Resource arenas varied in terms of their susceptibility to the new "scientific" styles of management. Issues of water shed and forest reserve management remained extremely politicized, with high levels of participation by industry and reform groups as well as federal and state agencies. Range management and agriculture, on the other hand, saw a much lower level of popular participation in the decision-making process and issues in these arenas moved quickly into the province of scientific management. Needless to say, this style of management was heavily dependent on local elites in different geographic regions both for information-gathering and regulatory action.

Agricultural problems presented the greatest opportunities for federal administration and scientific participation after the Civil War. One historian points out that

> By the late 1880s, agricultural leaders had demanded and won a vast infrastructure of one or more colleges in every state, agricultural experiment stations across the country (supported by a guaranteed annual appropriation of $15,000 for research), and a central agency with a staff of specialists in Washington, D.C. Not medicine, engineering, forestry, or any science ... could boast such massive funding on a guaranteed annual basis in the 1880s. In the late 1890s federal appropriations jumped even higher as the USDA greatly expanded its bureaus in Washington. After 1900 and the passage of the Adams Act in 1906, the amount spent on both stations and the USDA more than doubled again (%Rossiter, 1979: 212).

Considering the generous funding of agricultural science after 1880, it is hardly surprising that many young scientists focused their attention on problems important to this federal agency and its powerful constituency. For young men and women unable or unwilling to undertake graduate education, federal employment offered a promising alternative career.

The Department of Agriculture was selectively responsive to the variety of agricultural problems with which it was faced. This was partly the result of its political affiliations and partly the result of levels and areas of scientific expertise within the agency. For instance, economic entomology, plant and animal pathology, and agronomy were all fields where the Department played a significant role in supporting basic as well as applied research. In other fields, such as horticulture and soil science, federal support was less generous and research was more often farmed out to scientists at other institutions, including colleges and universities as well as agricultural experiment stations (%Rossiter, 1979).

The number of agricultural colleges expanded rapidly in the 1870s as did the numbers of agricultural experiment stations. The Department of Agriculture experienced its greatest expansion between 1895 and 1915. For example, the number of scientists employed by the department soared from 2,270 in 1897 to 13,575 in 1912 (%True, 1937). Different bureaus in the department experienced different rates of growth, depending largely on the administrative and political skills of the bureau chiefs. Men such as Galloway, Pinchot, and Howard were able to ensure the success of their bureaus through skillful maneuvering among private interest groups, scientific networks, and politicians within and outside the federal agencies.

The Department of Agriculture focused its efforts in two directions: improving productivity through introductions and breeding programs and preventing and treating plant and animal diseases. After the Civil War, there was a strong emphasis on the development of the fruit and wine industries in states with suitable climates, such as California and Florida. In addition to importing new varieties of fruits and vegetables, the federal government sponsored expeditions by "plant explorers" who travelled around the world, searching out and returning to the United States drought-resistant grasses and grains, as well as new varieties of fruits, nuts, and flowering plants and trees. Between 1875 and 1900, these federally-sponsored expeditions brought back an estimated 65,000 different types of plants which were distributed by the department to botanical gardens, state experiment stations, and colleges and universities for breeding and hybridization (%Rodgers, 1949). The introduction of new varieties of plants, along with the control of diseases, formed the crux of the Department of Agriculture's research after 1900.

The Department of Agriculture also engaged in educational activities after 1890. These efforts were not aimed at professional scientists, but rather at rural populations engaged in a variety of agricultural activities. Federal funding for education came from several different sources, although the Smith-Lever Act of 1914 was the only legislation specifically targeted for agricultural extension work (%McConnell, 1966). The Department of Agriculture did not control these educational activities as it did with agricultural research. Rather funds were disbursed to various state agencies and colleges which then provided the home economists and agriculturalists demanded by local rural elites.

The Department of Agriculture participated directly in the publication of results of research done in its various laboratories as well as much of the research done at state agricultural experiment stations. Department publications were mostly aimed at knowledgeable farmers rather than at scientific audiences. Between 1900 and 1940, the Department of Agriculture was responsible for the publication of a huge volume of literature addressed largely to specific problems in different regions of the continent. Until 1930, most of these publications concentrated on promoting new varieties of plants for cultivation and on the control of insect, fungal, and bacterial pests. With the drought of the 1930s, more attention was paid to soil control, erosion-prevention techniques, and methods for improving irrigation (%Harding, 1947; %Tobey, 1981).

Like the graduate and research universities, the research laboratories of the federal government fostered the development of specialized communities focused on narrow sets of research interests. Groups like the Association of Economic Entomologists, the American Society for Horticultural Science, the American Society for Agronomy, and the American Phytopathological Society all owed their existence to growing numbers of federally-employed scientists. As with the more academically oriented societies, many of these associations sponsored a journal in which research reports as well as editorial opinions were exchanged. In a number of cases, the Department of Agriculture itself provided funds for the publication of these specialized journals (%Rossiter, 1979).

Relations between agricultural and academic societies varied from cordial to acrimonious. In a number of cases, the agricultural societies were viewed as a challenge to more "basic" research-oriented societies. With the decline in overlapping memberships after 1910, relations among these various societies became less and less cordial. The Botanical Society of America, for example, was extremely sensitive to the frequent "secessions" of the new specialties of horticulture, mycology, bacteriology, and forestry in the 1890s, while relations between the Association of Economic Entomologists and the Entomological Society of America reveal similar strains (%Rossiter, 1979).

The federal government played a major role in the development of scientific research after the Civil War. While the Department of the Interior was involved even before this period in surveying the Western territories, it was only after the 1860s that federal funding was generous enough to support both survey work and experimental work. By the last quarter of the 19th century, federal funding for agricultural research had far surpassed funding for survey work. This was partly the result of the changes in the economic, political, and social arenas associated with settling of the Western states and partly the result of shifting priorities in scientific research.

Unlike their academic colleagues, federal scientists did very little teaching. Recruits to the federal agencies came from universities and colleges, where they were often trained by men belonging to the same networks as the administrators of the agencies where they were hired. Publication of the results of research done in the federal laboratories was sometimes difficult, since articles had to be written for lay audiences rather than scientific audiences (%Rosenberg, 1977). With the development of specialized groups, based on narrowing research interests as well as specialized commodity industries, more outlets for publication became available. There was continuing pressure on federal scientists to frame their work in terms of "practical" problems although in fact they were looking simultaneously at "basic" research questions. Problems in breeding and genetics were most amenable to this dual constituency, although questions about physiology were also given a great deal of attention.

Agricultural Experiment Stations

If the situation of the federal agricultural researcher was difficult, in terms of the multiple demands of lay and professional audiences, the position of researchers at state agricultural experiment stations was worse. Conflicts of meeting the needs of lay constituencies while simultaneously investigating more abstract problems were particularly acute for station scientists. Unlike federal scientists, there was little to protect the station scientist from direct demands by local farmers for routine soil and chemical analyses. These scientists often had dual appointments at agricultural colleges through which station funds were disbursed. The scorn of more fortunate colleagues with academic positions at state universities and the resources to engage in theoretical and experimental research simply made the position of the station scientists more difficult (%Rosenberg, 1976).

The earliest experiment stations in the United States were established in Connecticut in 1875 and in California in 1876. These early stations were modelled on stations established even earlier in Europe (%Rodgers, 1949). Many of the agricultural colleges established in the 1870s and 1880s had a model farm where students could conduct breeding and nutrition experiments. When the Hatch Act was passed in 1887, generous funds were provided for the establishment of an agricultural experiment station in every state. These federal funds were secured through the efforts of a number of station administrators (%Rossiter, 1979).

The Department of Agriculture organized a number of national meetings of station administrators during the 1880s. These meetings served two purposes: they provided the federal agency a central role in directing agricultural research, and they provided an opportunity for station administrators to present their demands to a federal legislature trying to dispose of an embarrassing budget surplus. The success of the station administrators in obtaining funds for the support of agricultural research was undeniable. However, the conditions under which these funds were obtained placed the experiment stations within the jurisdiction of the agricultural colleges, whose administrators often diverted these funds for other purposes (%Rosenberg, 1976).

The pursuit of basic research at the agricultural experiment stations was constrained by several circumstances. First, there was the difficulty of ensuring that federal funds actually found their way to the experiment stations. Second, there was the rather diverse set of problems associated with meeting the demands of local or, occasionally, regional constituencies. Third, station scientists were constrained in their research activities by the need to justify such research to the station's supporters in the local community, in the agricultural college, and at the USDA. For these reasons, experiment station research tended to focus on problems of plant and animal diseases and on improving the productivity of domesticated plants and animals. Many stations also tested plants introduced to new geographic regions by the Department of Agriculture, testing them for resistance to disease and the ability to adapt to new environmental conditions (%Harding, 1947).

Scientists who staffed the experiment stations often held appointments in agricultural colleges or in state university departments. Dual appointments brought station scientists into contact with scientists engaged in other types of work. There were frequent disagreements between station and academic scientists about how to conduct research. Dual appointments provided a further excuse for college and university administrators to "raid" the budgets of experiment stations. Academic institutions often engaged a single individual to run the experiment station, teach classes in botany and horticulture, and administer both the academic department and the experiment station (Crabb, 1947).

Gradually over the 1880s these various duties segmented into distinct organizational positions. By the 1890s, administration, teaching, and research were all done by different individuals. Within the experiment stations, the working scientist and the research-entrepreneur had become two distinct positions by 1900. Working scientists handled the routine chores of soil and chemical analysis, as well as basic research in physiology, pathology, and bacteriology. Research-entrepreneurs acted as administrators and raised funds as well as doing experimental research. These entrepreneurs varied in their success in raising money and in protecting working scientists from the demands of local constituencies. They also varied in terms of their reputations as researchers within the professional scientific community (%Rosenberg, 1976).

There were continuing difficulties in filling positions at all types of agricultural institutions, including colleges and experiment stations. This was at least partly due to the huge influx of funds for agricultural research after the 1880s. Experiment stations required staff for routine work as well as more basic research; these staff required training in the agricultural colleges which, in turn, required faculty to handle these growing numbers of students. After 1914, when the federal government provided funding for agricultural extension work, research positions went empty as students chose to pursue more lucrative extension work outside the experiment stations (%Rossiter, 1979).

By 1900, the best conditions for pursuing basic research in agriculture existed at the federal laboratories and at a few of the agricultural experiment stations, such as Connecticut and Wisconsin (%Rosenberg, 1976). At these stations, skillful administrators ensured the possibility and productivity of "basic" research. At the federal laboratories, financial support was even greater than at the state experiment stations. These organizations, however, only provided a model toward which smaller, less generously financed stations could strive. Smaller stations continued to suffer from the conflicting demands made by local constituencies, political interest groups, and professional academic societies.

Publishing the results of research was a particularly difficult problem for experiment station scientists. Even when the Adams Act of 1906 doubled the funds for agricultural research, scientists remained responsible for producing bulletins and reports for lay constituencies. Reports of specialized research had to be phrased in non-technical language which lessened its appeal to scientific colleagues. Occasionally, authors were prevented from putting their names on research reports, so that station administrators could claim credit for the work. Responsibility for preparing station bulletins meant that many station scientists were unable to find the time to write reports for more technical journals in their specialized disciplines (%Rosenberg, 1976). For station scientists, the strains of working in multiple organizational contexts, on multiple problems, and reporting to multiple audiences were endemic.

Nevertheless, in concert with federal researchers, station scientists were able to develop powerful professional communities of like-minded workers with journals directed at increasingly specialized audiences. Experiment stations gradually became financially and intellectually distinct from agricultural colleges and departments of agriculture at state universities. By 1910, numerous agricultural science societies held annual meetings and published journals regularly (%Rossiter, 1979). Agricultural scientists suffered from the same problems experienced by scientists working for the federal government. These problems included multiple alliances with lay constituencies, agricultural colleges, state university departments, and professional scientific groups; conflicts in publishing reports for two or more distinct audiences; and professional rivalries with academic scientists. The lack of a clear "mandate" over the problems of a well-defined constituency contributed to the problems of agricultural scientists in general, and station scientists in particular.

Private Research Institutions

Widespread popular interest in biological questions was evident in the growth of books and journals devoted to this subject after the turn of the century (%Cravens, 1978). Out of this popular interest grew the final important organizational element in the support of experimental research after 1900. Private research institutions, established by wealthy philanthropists such as the Carnegies and Rockefellers, provided a setting where a small number of researchers could conduct basic research without, it was argued, undertaking administrative or teaching duties. The mission of these institutions was to separate teaching from research, and to provide an environment free of the demands made of college and university faculty or federal and station scientists.

Wealthy businessmen in America frequently evinced the philanthropic desire to establish institutions. Philanthropists built libraries, museums, and universities as well as research laboratories. For example, in 1892, Rockefeller endowed the new University of Chicago with funds matched by the Baptist Education Society (%Guralnick, 1979). Henry Shaw, a wealthy St. Louis businessman, donated land for the Missouri Botanical Garden as well as funds for the endowment of the Shaw School of Botany at the University of Washington in the 1890s (%Rodgers, 1944a). Most cities had one or more local families who built and funded public institutions and monuments (%Petulla, 1977).

The Woods Hole Marine Biological Laboratory was probably the earliest private research institution established in the United States. Woods Hole began as a summer school and research center for the Boston academic community in the 1870s. Its funding arrangements were uncertain until 1888. Permanent buildings were not constructed until 1914. Woods Hole was modelled on the Naples Zoological Station, to which many young biologists travelled in the last decades of the 19th century (%Allen, 1978). The Scripps family, of San Diego, established the Scripps Institution for Biological Research (later changed to Oceanography) shortly after the turn of the century. This institution was somewhat unique in receiving funds from both private and public sources (%Young, 1922). A variety of smaller, less permanent and less generously endowed institutions were established throughout the 1890s and early 1900s, including the Trout Lake Laboratory in Wisconsin where early work in limnology was conducted by Birge, Juday, and their students and colleagues (%Frey, 1966).

The most prominent institution to support biological research after 1900 was the Carnegie Institution of Washington. The institution was endowed with $10 million from the United States Steel Corporation in 1901 to support a huge program of basic scientific research in both the physical and natural sciences. The directors took care to distinguish their institution from graduate, research-oriented universities. Although Carnegie Institution of Washington's first two presidents were university administrators (Gilman was the past president of Johns Hopkins while Woodward came from Columbia University), the trustees all came from long careers in federal agencies and they wished to distinguish the institution clearly from educational institutions. Few of these men considered the university the necessary site for conducting basic research and their experience inclined them more toward the federal research laboratory model than the German university model (%Reingold, 1975).

The trustees of the Carnegie Institution of Washington were interested in supporting individual scientists, building research facilities, and providing for the publication of research done under the aegis of the Institution. Disputes among the trustees and between trustees and administrators had consequences for those who received funding and how these funds were disbursed. The problems which the trustees and administrators experienced selecting "promising young men" in many disciplines led them to rely on established professionals in these fields for recommendations. The Institution soon limited its largesse to proven specialists in established disciplines (%Reingold, 1979). In 1902, the governing committee of the Carnegie Institution began a concerted program of laboratory construction. In addition to several geophysical installations, a number of biological labortories were established. The Institution's Department of Plant Biology began construction of the Desert Laboratory at Tucson in 1903, while the Station for Experimental Evolution was opened at Cold Spring Harbor in 1904. The Departments of Marine Biology and of Embryology shared the facilities at Cold Spring Harbor after they were established as did the Eugenics Record Office endowed by Mrs. Harriman in 1910 (%Reingold, 1979; %Ludmerer, 1972). In 1918, the Department of Plant Biology established permanent research facilities at Pike's Peak in Colorado and later at Stanford University in California (%Tobey, 1981; %Hagen, 1982). Carnegie shifted its policy from laboratory construction to the long-term support of investigators who remained at their academic posts as the expenses of constructing and equipping laboratories rose after 1910 (%Reingold, 1979).

The Carnegie Institution of Washington recruited its researchers largely from the ranks of university students and faculty. The research interests of these scientists were, not surprisingly, similar to those of academic researchers. By allowing investigators to remain at their academic posts, the Institution ensured a continuing flow of students through its research facilities, as faculty used Carnegie funds to support promising graduate students and as post-graduate positions were made available. The connections established between academic scientists and full-time researchers at the Carnegie laboratories were just as strong as those established between agricultural scientists in federal laboratories, state university departments, and agricultural experiment stations. For example, experimental work in plant genetics was done by G. H. Shull, who left Carnegie in 1914 to teach at Princeton (%Rodgers, 1949). T. H. Morgan received funds from the Carnegie Institution after 1915 to support his genetic work with fruit flies (Drosophila melanogaster) (%Allen, 1979b). Experimental work in taxonomy was done by H. M. Hall, who moved to Carnegie from the University of California at Berkeley in 1922 (%Hagen, 1982). In spite of their early resolve to keep the tasks of research and teaching separate, the Carnegie administrators played an important role in the development of graduate education in the United States through their sponsorship of "research assistantships" (%Reingold, 1979).

In a manner similar to university and scholarly presses, the Carnegie Institution of Washington established a journal and a series of research reports at the same time that work was begun on laboratory construction. Researchers who received Carnegie funding were also certain of an outlet for publication. The one historical essay on the development of the Carnegie Institution of Washington does not deal with the Institution's publishing activities, but it is apparent from the most casual search of the literature that the Institution's Publication Series included most of the well-known names in taxonomy, ecology, and genetics between 1910 and 1940. The importance of the Institution as both a sponsor of research and as an outlet for the publication of research results lies largely in basic research rather than in the more applied fields of agriculture, horticulture, or forestry.

While the Carnegie Institution of Washington was only one of several private research institutions which sponsored experimental work in the first decades of the 20th century, it was undoubtedly the most important. In spite of attempts to distinguish the Institution's activities from those of research oriented universities, the focus on individual support and laboratory construction served to establish close ties betwen Carnegie and several key academic institutions, including Columbia University and the Universities of California and Chicago. Although researchers receiving Carnegie support were relieved of much of their teaching load, they maintained access to new graduate students and were able to attract the most promising of these students to their own research areas by providing them with financial support as well an an outlet for publication.

In spite of the early resolve of administrators and trustees of the Carnegie Institution to remain separate from the academic research community, and despite the federal experience shared by these men, the Institution became more closely tied to other academic institutions than to government agencies. It was from the universities that Carnegie drew its established and new researchers and, later, where laboratory facilities were located. In the attempt to remain at the <u>forefront</u> of a number of scientific disciplines, the Institution became allied with scientists working in universities rather than with scientists working in federal research laboratories or at state agricultural experiment stations. By the early 1900s, graduate universities were well established as the predominant institutional support for experimental work. It made little sense for the trustees of the Carnegie Institution to provide support for the agricultural sciences, which were in any case already well provided for by the federal government. Thus, private research institutions formed a closer institutional link with research-oriented universities than with agricultural experiment stations and state agricultural universities. The Institution did make some early attempts to maintain connections with federal and state agricultural research, but the generosity of federal funding for this type of experimental work, as well as the narrowing focus of the Institution's pattern of support, led to closer relations with university researchers.

Conclusion

Different types of institutions supported biological research during the late 19th and early 20th centuries. These institutions supporting increasingly distinct types of work. The development of specialized research problems, the training of recruits, the publication of research results, the administration of these institutions, and the development of networks of scientists within and between types of institutions were supported in different ways as academic and agricultural research arenas segmented after 1900.

Institutions, and the people who work in them, are responsive to different audiences (or constituencies) and tend to emphasize different types of work. Early in the 19th century, biological research in America consisted of survey work by military and exploratory expeditions, classification work in museums and botanical gardens, and the beginnings of experimental work in medical schools and botanical gardens. By the middle of the century, growing numbers of liberal arts colleges in the United States offered courses in Natural History, partly as a response to popular demand and partly as a result of growing numbers of professional researchers engaged in classification and experimental work. By the 1880s, a new type of academic institution had emerged which specialized in graduate education and in the support of experimental work. This period also saw the development of federal support for agricultural research (including experimental and survey work) for political reasons. The demand for professional researchers in this period grew rapidly and opportunities were available for all of the students trained at private universities, state universities, and agricultural colleges. After the beginning of the 20th century, experimental work received another boost in prestige as private research institutions, line the Carnegie Institution of Washington, began to provide support for academic scientists.

Institutions are enterprises which "continue through time in environments to which they must adjust themselves"

(Hughes, 1971: 62). The institutional environment includes types of funding, types of constituencies or clientele, and types of personnel. The institutional environment also includes different types of work which form the core activities of different types of institutions in social worlds. Over time, institutions undergo segmentation as their activities, their personnel, and their sources of funding change. As the balance in types of biological work changed at the end of the 19th century, new types of institutions were established by "entrepreneurs" specializing in the new types of work. Experimental work was heavily supported after the 1880s in graduate universities and by the federal government. The federal government continued to support the survey work done by existing federal agencies (chiefly the Department of the Interior) and classification work continued to be done at museums and botanical gardens.

Support for these older styles of work waned after 1890 and the institutions and professions committed to these types of work gradually declined in importance. As long as these types of work continued to be important to a constituency, however, the institutions and professionals which supported such work continued to exist. The shifting balance of support for different types of work resulted in the dominance of graduate universities in biological research after 1900. Older institutions, and particularly museums and botanical gardens, declined from their pre-eminent position and gradually became the repositories of the results of experimental and survey work done in other institutions.

CHAPTER THREE

SEGMENTATION AND CAREERS IN BOTANY

Introduction

This chapter looks at the process of segmentation in botany at the level of scientific careers. This process was linked to the economic, political, and the institutional contexts discussed in previous chapters. The careers of scientists running through different types of institutions are the threads by which these organizations intersect and segment within a variety of economic and political arenas. However, scientific disciplines are organized around sets of problems as well as sets of institutions. Here, I am concerned with the manner in which scientists, working in increasingly specialized problem areas, established institutional niches which were then successfully expanded into ongoing institutional commitments.

Between 1880 and 1920, a number of new types of institutions developed through which botanists moved during their careers. By the turn of the century, two clear institutional networks can be distinguished: graduate, research-oriented universities and private research institutions, on the one hand, and state universities, agricultural experiment stations, and federal government agencies on the other. These two networks supported different types of scientists working on distinct types of problems. The former network supported academic research on problems of evolution while the latter network supported agricultural research on problems of productivity and disease. Between 1880 and 1920, all of the institutions supporting biological research placed their major emphasis on experimental work using relatively sophisticated laboratory equipment and/or statistical methods of analysis. The new, graduate universities were most successful in supporting experimental work. Museums and botanical gardens were least successful, in spite of attempts to incorporate physiological and experimental work in their organizational structure. Prior, long-standing commitments to classification work prevented these institutions from committing their resources to such innovations. Federal and state governments were able to devote respectable levels of funding to the new style of research but prior commitments to non-specialized audiences prevented these institutions, too, from moving as far as the universities and private research institutions toward support for experimental work.

By the 1920s, these patterns of institutional and intellectual segmentation were well-entrenched. Private research institutions and graduate universities supported both the new style of research as well as the networks of professional scientists engaged in this work. Federal and state agricultural institutions cooperated in a network distinct from the academic network. These institutions supported both experimental work and survey work, although these styles of work were quite similar in the two arenas. Museums and botanical gardens, which in the middle of the 19th century had formed the institutional basis of the scientific community, had been transformed into repositories for the new information generated by scientists working in other institutions. Lacking the funds commanded by academic and government institutions, museums and botanical gardens were dependent on universities for new personnel as well as for access to laboratory facilities. These older institutions were in the difficult position of catering to several distinct audiences. Classification remained important, if not central, to both academic and agricultural networks, a strain which contributed to the debates about classification which occurred between 1880 and 1920.

Experimental work was associated with the transformation of Natural History into modern biology. This transformation was based on both technical improvements and on intellectual segmentation. Questions of physiology (i.e.

development) did not at first clearly distinguish boundaries of individual organisms from organizational boundaries. As distinctions between individuals and populations, between heredity and environment came to be made reliably, the disciplines of genetics and ecology segmented. Ecology took longer to segment from taxonomy, which eventually allied itself with genetics during the debate over the criteria to be used in classification work. Genetics was the most successful line of work in biology. This area of research promised rapid economic returns as the principles of heredity underlying hybrid vigor came to be understood (%Crabb, 1947). This area of research also proved most amenable to experimental methods adopted by Americans from the German <u>Entwicklungsmechanik</u> school. In both academic and agricultural research, experimental methods were the most narrowly focused and the most generously funded.

In contrast to the success of genetics, "field-centered physiology," as ecology was known (%Rodgers, 1944b), was unable to establish a strong position in academic institutions. Problems of the relationship between organisms and their environment proved intractable using experimental methods. The position of ecology within state universities was strong but limited. Scientists specializing in ecological problems were absorbed by agricultural colleges, state universities, and state agricultural experiment stations. A large number of ecologists specialized in agrostology (i.e. study of grasses) and many found employment with the federal Department of Agriculture as problems in the Western rangelands were addressed. Ecology never successfully penetrated the academic institutions and, like taxonomy, remained on the periphery of biological research after 1920.

Taxonomy, which monopolized classification work after 1900, remained a small line of work within biology. Attempts by taxonomists to engage in experimental work were supported by the Carnegie Institution of Washington after 1920 but, in general, experimental work remained outside the province of taxonomy. During the 1930s, taxonomists adopted genetic criteria for defining "species," the fundamental unit of analysis in biology. This alliance with genetics was prompted at least in part by the taxonomists' concern with the growing popularity of a system of classification based on environmental criteria advocated by ecologists and their constituency, namely federal and state agencies supporting survey work.

This chapter outlines the ways in which institutional segmentation both supported and prompted intellectual segmentation. Segmentation processes include building organizational bases around core activities and technologies (or methods). As recruits are trained in new styles of work, they create organizations within which to pursue these activities. As these organizations acquire resources from narrowing constituencies, they attract further generations of recruits. Acquiring resources from a constituency depends on defining the products of the work within such organizations as useful to that constituency. Products are sold when they appear to solve problems and the line of work or organization whose product is seen as most useful along this dimension is usually most successful in acquiring both resources and recruits.

Institutionalization of Survey Work

The earliest naturalists in America, the American Indians, had their own highly developed system of classification of plants and animals. When the Eastern seaboard was first colonized by Europeans, the local inhabitants provided the settlers with information which proved vital to their survival (%Crabb, 1947; %Debo, 1970). As the colonies were settled in the 17th and 18th centuries, numerous European explorers collected plants, animals, and minerals and shipped these specimens back to museums and private collections in Europe.

By the early 18th century, these Europeans had been joined by a number of "white" American naturalists. The collecting activities of men such as the Bartrams, Collinson, Carlton, and Mitchell were only one part of their wide-ranging exploitation of the resources of this new environment. Most of these men were educated in England and they were maintained close ties to the European scientific community. During this period, intellectual interests of naturalists in both Europe and the United States were rather broad. Mitchell, for example, felt just as competent discussing fossil animals and smallpox epidemics as he did collecting and classifying plants (%Berkeley & Berkeley, 1974). Although transportation and communication were slow and unreliable, these Americans maintained extensive networks with English and European naturalists, including Linnaeus, Gronovius, and the elder de Candolle (%Brockway, 1979).

Following the Louisiana Purchase in 1803, the United States government sponsored a growing number of military and exploratory expeditions throughout the continent (%Harrington, 1949). Many of these expeditions were accompanied by one or more naturalists, whose tasks were to collect specimens and catalog the variety of plant, animal, and mineral resources found in the regions through which these expeditions passed. Beginning in the 1830s, numerous state governments also sponsored surveys of their natural resources (%Guralnick, 1979). Institutions of higher education, established as these new territories became settled, provided employment for naturalists who spent their summers afield and their winters teaching and cataloging their collections.

Accompanying military and exploratory expeditions into the territories provided opportunities for many naturalists build extensive collections of plant, animal, and fossil specimens. Specimens collected by naturalists on government expeditions were usually stored at the national museums and herbaria in Washington. Duplicate specimens remained in private collections or in collections maintained by state Natural History societies and were often exchanged among naturalists trying to gather "complete" collections of one or another type of organism. Classification work remained central in Natural History until the 1870s, when alternative institutions and intellectual problems offered new scope for new generations of scientists.

While the three major areas of Natural History (i.e. plant, animal, and mineral) were distinct by the middle of the 19th century, individual researchers often crossed the boundaries between these areas. By 1840, geology was distinct from plant and animal studies. Geologists were the first scientific group in the United States to organize a professional society with a specialized journal whose representational language restricted communication with other naturalists as well as with lay audiences (%Rudwick, 1976). Even after Natural History segmented into three distinct lines of work, individual scientists still crossed the boundaries of these disciplines. In the middle of the 19th century, such crossing over was particularly evident in the work on fossil materials. Zoologists such as Louis Agassiz, Dana, Cope, and Marsh often compared contemporary as well as fossil specimens (%Rainger, 1981). The botanist, Asa Gray, used plant fossils in his botanical research (%Stafleu, 1971). The flood of fossil specimens coming to the Eastern seaboard from explorers in the Western territories probably contributed to the crossing of botanists and zoologists into an area staked out by geologists. The dominant intellectual questions of the period, in particular the question of the transmutation of species, also contributed to violations of these boundaries.

Common-sense distinctions between plants and animals were central to the division of labor which emerged in Natural History. Different alliances between emerging scientific disciplines and institutions also contributed to the split between botany and zoology. Before the middle of the 19th century, medical schools dominated the field of higher education and many early American botanists and zoologists were initially trained as physicians. After 1850, however, growing numbers of naturalists were able to find fulltime employment at high schools, liberal arts colleges, and state universities in the United States. With growing resources for research on biological organisms as well as growing numbers of practitioners, segmentation of Natural History after 1860 proceeded analytically as well as substantively.

Early Entrepreneurs in American Botany

The institutions which supported biological research after 1850 gradually specialized in terms of the tasks which they sponsored. Museums and botanical gardens specialized in classification work. Colleges and universities specialized in several types of experimental work on many different organisms. Federal agencies and state experiment stations continued to support survey work although they also supported experimental work although their focus was on problems which had more or less immediate applicability. Private research institutions, like the universities, focused narrowly on experimental work. This process of segmentation was not confined to the institutional level, but also took place at the level of individual careers.

The earliest American naturalists collected and cataloged plants as well as pursuing fulltime careers in medicine, religion, and farming. Later naturalists, initially trained as physicians, were only able to find fulltime employment within academic institutions after some years spent pursuing dual careers. These 19th century naturalists increasingly restricted their intellectual interests. Torrey was as comfortable in the fields of chemistry, mineralogy, and geology as he was in botany. Asa Gray, who was trained only a few years later, was uncomfortable with debates which crossed disciplinary lines (%Dupree, 1959).

While many early American botanists were physicians, others worked as surveyors and several pursued military careers. John Torrey (1796-1873) was the first prominent American botanist of the 19th century. When Torrey graduated from the New York College of Physicians and Surgeons (later Columbia University) in 1818, there were few academic posts available in the United States. He spent 6 years in medical practice before becoming professor of chemistry, mineralogy, and geology at the U.S. Military Academy at West Point. Torrey frequently complained that he did not have enough time to attend to his botanical studies as "chemistry still kept pressing new duties on him" (%Rodgers, 1942: 244). His influence as a botanist was based on a wide network of collectors scattered throughout the Western territories and Southern states. These collectors funneled huge numbers of specimens to

Torrey in New York which he classified and distributed to museums along the Eastern seaboard.

By 1840, Torrey was teaching chemistry and botany at the College of Physicians and Surgeons as well as at the College of New Jersey (later Princeton University), acting as the State Botanist for New York, and writing his massive Flora of North America. Torrey complained that, unlike his colleagues in England such as Sir William Hooker, he lacked essential equipment (such as microscopes) as well as an extensive library. After 1853, when he assumed the directorship of the New York branch of the United States Assay Office, Torrey was able to devote his time exclusively to botany as increasing numbers of collectors working in the West and South sent their specimens to him for classification.

Asa Gray (1810-1888) was one of the first professional botanists in the United States, since he made his living as a professor of Natural History at Harvard after 1842. His early training, not surprisingly, was as a physician and he practiced medicine in New York State for some years before accompanying the Wilkes Expedition to the Western territories between 1836 and 1838. Gray was appointed to a professorship at Harvard University in 1842 where he remained until his death in 1888. Over these four decades, Gray trained an entire generation of botanists. The growing numbers of their students formed the basis for a distinctively American botany after the turn of the century.

Torrey and Gray were closely connected with the establishment of the U.S. National Herbarium (%Rodgers, 1942). The National Herbarium, Torrey's private collection housed at Columbia, and the Gray Herbarium at Harvard University were the major institutions where plant collectors, many working as surveyors for government agencies such as the Pacific Railroad Survey or the Coast and Geodetic Survey, sent their specimens for cataloging. These three collections were arranged by Torrey and Gray on the basis of the new natural system of classification developed in Europe. The natural system of classification included several more characters than the Linnaean system based simply on sexual characters of organisms (%Farley, 1982). Gray was more theoretically inclined than his teacher and colleague. He was convinced before Torrey that the new system of classification should be adopted by American botanists and he was an important influence in Torrey's adoption of this system. After these major institutions arranged their collections along new lines, many smaller botanical gardens and herbaria adopted the new system of classification (%Rodgers, 1942).

The careers of Torrey and Gray exemplify several important aspects of work in Natural History after the beginning of the 19th century. Their adoption of the natural system of classification in their own herbaria as well as at the federal government's herbarium set the stage for the widespread adoption of this classification system in the United States. Like Torrey, Asa Gray had an extensive network of European correspondents with whom he exchanged both information and specimens. Gray sent students from his own and other institutions to Europe for training. Upon their return to the United States, many of these students found employment at the land-grant universities of the West and Midwest where they were able to spend significant amounts of time conducting research far beyond the taxonomic interests of their mentors.

Experimental Work and the Professionalization of Botany

The "decades of transition" in botany (%Rodgers, 1944a) and the "revolt against morphology" in zoology (%Allen,1978) (1) encompassed a broad swathe of changes throughout biology between 1875 and 1900. The historical evidence points to changes in both intellectual content and technical approaches to biological problems by 1900. Intellectually, problems shifted from a focus on types of organisms to a focus on types of analytic issues, such as the nature of speciation, adaptation, and heredity (%Gerson, in prep.). Technically, although naturalists continued to go into the field, an increasing amount of research was conducted in laboratories, aquaria, greenhouses, and experimental plots using microscopes, microtomes, incubators, centrifuges, photographic equipment, and new chemicals (%Young, 1922).

In terms of individual careers, researchers trained in the 1860s remained concerned with questions of morphology and evolution. Those trained in the 1870s and 1880s took up more specialized problems using more sophisticated instruments. By the 1880s, taxonomy had been or was being superseded by physiological investigations based in laboratories, located, for the most part, at graduate universities and agricultural experiment stations. Botanical gardens and museums continued to support taxonomic work, although here too, styles of work changed as these institutions established laboratories and made attempts to support experimental work. The prestige of both the Missouri Botanical Garden, established in 1885, and the New York Botanical Garden, established in 1896, was based largely on their generous laboratory facilities (%Gleason, 1960; %Wyman, 1947).

A number of factors help explain these changes in the style of biological work at the beginning of the 20th century. Perhaps most important were the large numbers of American students who travelled to Europe for graduate education in the 1870s. Opportunities for higher education were still limited in the United States and travel to Europe at this time was relatively cheap (%Shils, 1979). The new style of research in Europe, and of Germany in particular, was an important exemplar for young Americans abroad. While the influence of German physiological research was particularly strong among zoologists (%Allen, 1978), the German influence is also discernible among American botanists after 1885 (%Rodgers, 1944a; Tobey, 1981).

Another important factor was the growing size of the botanical research community. The numbers of biological researchers contributing to a narrowing range of the problems more than doubled between 1880 and 1900 (%Rodgers, 1944a). As more and more young scientists found employment in institutions supporting research, individuals restricted their investigations to narrowing analytic and substantive problems. Growing opportunities for employment and expanding institutional resources supported both restriction of the scope of research questions and the development of increasingly sophisticated instruments. Technological improvements provided, in turn, new types of evidence which scientists could use in making sense of the natural world. All of these factors, as well as rising popular interest in the biological sciences, played some part in the emergence of the "new biology" after the beginning of the 20th century.

By the 1880s, botany in America was dominated by Asa Gray and his students. Over the 46 years he spent at Harvard University, Gray supervised a large number of graduate and undergraduate students. Many of these students were later employed at the land-grant universities that opened in the 1870s in the West and Midwest.

> Although Gray continued to tell young men to study medicine to assure themselves a livelihood and take up botany only later, the changes in American institutions after 1873 opened up new opportunities. The new universities ... many of them direct responses to the federal land subsidy for agricultural and mechanical colleges ... gradually worked toward more advanced training in botany and horticulture ... The Middle West became the land of opportunity for professional botanists (%Dupree, 1959: 387-88).

Other botanists found work in the agencies of the federal government, initially with the federal and state survey agencies, and later with divisions of the Department of Agriculture and the state agricultural experiment stations.

While Gray's earliest students were, like himself, chiefly interested concerned with the classification of flowering plants, his later students had wider ranging interests. These included the application of botanical principles in forestry, horticulture, and agriculture. The men who studied with Gray between 1860 and 1880 not only taught in colleges and universities, but also took on administrative duties at these institutions as well as running experiment stations and acting as state botanists. As this first generation of "professional" botanists began to train students in their turn, the field of botany underwent increasing segmentation. Investigations focused more narrowly on problems of plant heredity, adaptation, and speciation, as well as plant disease and development. After 1880, the boundaries between botany, forestry, horticulture, and agriculture became more distinct as specialized societies and journals were established to support these increasingly narrow disciplines (%Rodgers, 1944a; %Rossiter, 1979).

A striking illustration of the process of segmentation in botany is the division of the position which Gray held at Harvard University after his retirement. Gray himself was primarily interested in classification, but his close contact with the European botanical community kept him abreast of the latest developments in morphological and physiological investigations. Rather than undertaking investigation of these new problems himself, Gray's many students and colleagues worked on these new problems. After his death in 1888, the position which Gray held alone during his years at Harvard was divided among four of his former students and colleagues. These four botanists specialized in taxonomic and physiological studies of flowering plants, non-flowering plants, and trees.

The herbarium which Gray built during his years at

Harvard was taken over after his retirement in 1873 by Sereno Watson. Watson was only a few years younger than Gray and the directorship of the herbarium was taken over by B. L. Robinson (1864-1935) when Watson died shortly after Gray. After graduating from Harvard in 1887, Robinson spent several years studying in Strassberg before becoming curator of the Gray Herbarium in 1892. Robinson remained loyal to the principles of "natural" classification adopted by Gray in the 1850s even after new rules of nomenclature were adopted by American botanists in 1896 (%Gleason, 1960). All of the students who studied botany at Harvard, both during and after Gray's tenure, perforce learned this system of classification.

Gray carried a heavy teaching load while active at Harvard. After his retirement, these teaching duties were taken over by two of his former students whose areas of specialization reflected one of the major new divisions in the study of plants after 1860. G. L. Goodale (1839-1923) specialized in the study of phanerogams, or flowering plants. His colleague, W. G. Farlow (1844-1919), concentrated on studies of cryptogams, or non-flowering plants. It is interesting to note that, in contrast to Goodale, Farlow spent several years teaching at the Bussey Institution, Harvard's school of agriculture and later applied biology, before his appointment as the first professor of cryptogamic botany at Harvard in 1879 (%Cravens, 1978).

Like Goodale and Farlow, C. S. Sargent (1841-1927) graduated from Harvard Medical School; like Farlow and Robinson, he also spent several years studying botany in Germany. Upon his return to the United States, Sargent became one of the first professors of horticulture in the United States. In 1873, Sargent became the first director of the Arnold Arboretum (a botanical garden for trees) although it took him several years to obtain sufficient funds, land, and staff to establish permanent facilities. Sargent's career is indicative of the growing distinction made by plant scientists between botany, horticulture, and agriculture after 1870.

The growing division of labor in botany took place along both substantive and analytic lines. The definition of cryptogams as plants depended on the identification of these organisms, in the first place, and on information about their life-histories, in the second place. Gathering such information depended heavily on the development of microscopes and related tools. Most fungi, bacteria, and viruses are not detectable except with such instruments. This new substantive area in botany rested on the development of laboratory and experimental techniques. The study of microscopic organisms was initially tied to agriculture and horticulture and to concerns with plant diseases. It took more than a decade for cryptogamic studies to be widely accepted as part of botany (%Rodgers, 1944a).

The period between 1873 and 1892 saw several important changes in botany. These "decades of transition" (%Rodgers, 1944a) saw the transformation of botany from a largely descriptive and classificatory line of work to one that was more analytically oriented. The institutional context within which the students of Asa Gray received their botanical training was very different than that of their mentor. New institutional opportunities, new types of tools, and new intellectual problems offered wider scope for young scientists. By the mid-1870s, large numbers of engineering and vocational schools had been established, both in the Western territories and in the East. In the decade which followed, the graduate university emerged as the premier institution devoted to research. By 1890, young botanists could find work in a wide variety of institutions, including undergraduate colleges, state universities, graduate universities, and federal and state agencies.

Just as the scope of institutional opportunities expanded after 1875, so did the style of work. Before this period, most work investigating living organisms was done either in natural settings (usually remote geograhic areas) or in medical schools and hospitals. Description and classification of the "diversity of Nature" done largely by amateur naturalists gave way after the middle of the 19th century to the study of form (i.e. morphology). This was at least partly due to the rapid growth of Natural History collections and to the establishment of permanent facilities for research (%Farber, 1982).

Between the 1860s and 1880s, morphological investigations formed the largest and most important part of the research done by naturalists. Botanists and zoologists studied cells, organs, and organisms. They tried to discover an underlying plan to the diversity of the natural world. Phylogenies (or family trees) of different species of organisms were constructed using morphological evidence from fossils, mature organisms, and developing organisms (%Allen, 1978; %Farley, 1982). Morphological research was heavily dependent on microscopes and related tools for comparing anatomy, developmental patterns, and paleontological evidence. Gradually, increasing amounts of evidence were incorporated into the classification schemes used by naturalists. As this work became more specialized, requiring more elaborate tools, professional naturalists established institutional niches in museums and botanical gardens and later in colleges and universities.

By the 1880s, morphological work had reached a dead end. The intellectual focus of those engaged in this type of work was the question of evolution, and in particular, the problem of speciation. The field was characterized by speculation about evolutionary questions, none of which appeared answerable within the context of the available evidence. In what Allen (1978) calls the "revolt against morphology" (2), younger scientists educated after 1875 took up both new problems and new tools in investigating the "natural" world. Specialized studies in processes of differentiation and development became important as the techniques and tools of physiology, which until that time had largely been pursued in medical settings, were adopted by naturalists (%Farber, 1982). New methods of experimentation (closely tied to although distinct from statistical and quantitative analysis) were adopted by researchers. Questions of classification declined in importance. By the early 1900s, this line of work formed one small part of the entire arena of biological research.

Botany, Zoology and the Development of Biology

With the changing emphasis from classification to experimental work in botany and zoology came a new focus on questions of physiology (i.e. developmental processes). Embryology became popular among zoologists, while questions about the development of plants were given attention by botanists in this period. The "organismic metaphor," first outlined by Herbert Spencer in 1860 provided an intellectual device which many naturalists used to adopt physiological terms and approaches in their investigations of a wide variety of biological problems. This metaphor was quickly adopted by researchers studying such diverse phenomena as plant communities (%Clements, 1904), lakes (%Frey, 1966), ant-colonies (%Wheeler, 1911), and the atmosphere (%Henderson, 1913).

A number of botanists expressed misgivings about the emerging transformation of Natural History. Their chief concern was with the perceived subordination of botany to biological and, especially, zoological research. Development of the theory of the cell in the 1850s, which indicated greater continuity between plants and animals than researchers had previously suspected, provided a new perspective on biological research. However, while botanists accepted that plants were composed of cells, they had difficulties performing the kinds of experiments conducted by other biologists (%Farley, 1982). In 1874, Farlow referred to a "'biological epidemic' which ... threatened many botanical appointments" (%Cittadino, 1980: 177). Almost twenty years later, Coulter complained that the chair of botany at the new University of Chicago (a position he would soon occupy) had been filled by a zoologist: "It would be a difficult feat for one man to teach zoology alone or botany alone, as it should be taught; to ask him to teach both savors too much of the time when a man could be 'professor of natural science'" (%Coulter, 1892: 94).

By 1880, new experimental techniques had blurred many of the distinctions once widely accepted by naturalists. It was difficult, for example, for botanists and zoologists to distinguish between plants and animals when they studied microorganisms. Arbitrary distinctions separated "phytoplankton" and "zooplankton" before oceanography and limnology emerged as distinct lines of work within biology (%Frey, 1966). Experimental work with fungi, bacteria, and viruses also blurred the distinction between plants and animals made by most naturalists (%Farley, 1982). Another important distinction made by naturalists before 1860 was between cultivated and "natural" types of organisms. As evidence of the wide extent of variation within natural populations of organisms emerged in the course of survey and collecting work, this distinction also began to disintegrate (%Rodgers, 1949).

Physiological work in botany was not taken up by academic researchers as quickly as it was in zoology. This was due in part to the close relationship between physiological work in botany and agricultural research. The focus of many botanists on disease-causing organisms, encouraged by generous federal funding for this type of research, constrained their investigations in a way that zoologists investigating marine organisms, for example, did not experience. This contention is graphically illustrated in the adoption of the new research techniques in the Botany Department at Harvard University. Farlow was able to secure laboratory facilities as early as 1872 while working at the Bussey Institute, Harvard's school of applied biology. Goodale, on the other hand, was unable to secure such facilities within the university's Botany Department until 1883 (%Rodgers, 1944a).

Entrepreneurs and Enterprises in Botany

As the premier botanist in the United States, Asa Gray wielded enormous power within that social world. Although his students took many intellectual directions, they were extremely successful in bargaining their training with Gray into institutional resources. Even after his retirement from teaching, Gray continued to train and advise students who came to visit and study with him. One of the earliest of Gray's students was W. J. Beal (1833-1924), a morphologist who sent several of his own students to Gray for training. Beal spent most of his career at the Michigan State Agricultural College, teaching botany, forestry, and horticulture. He was one of the first botanists to establish a laboratory where a number of young botanists were first exposed to microscopes and microtomes (%Rodgers, 1944a).

One of Beal's most prodigious students was C. E.

Bessey (1845-1915), who maintained a regular correspondence with Gray although he spent only a short time actually studying at Harvard. Bessey spent his entire 45-year career teaching botany and horticulture in the Middle Western states. Bessey was influential in both botanical and agricultural circles. In addition to his friendly relations with fellow botanists such as Beal, Farlow, and Goodale, he was close to Fernow, Pinchot, and Woods of the USDA. Bessey was also botany editor for the American Naturalist from 1880 to 1897; he was influential in the drafting of the 1887 Hatch Act; and he directed the Nebraska State Botanical Survey (%Cittadino, 1980; %Tobey, 1981).

Bessey has been the subject of a great deal of attention from historians, due in part to his highly visible role in a number of economic and political arenas (%Cittadino, 1980; %Overfield, 1975; %Tobey, 1981). While the scope of Bessey's activities was not unusual, his influence outweighed that of many other scientists because of strategic relationships he was able to build over many years with state and federal government agencies, other scientists, and a variety of lay audiences. A look at Bessey's publications gives us a sense of the wide variety of audiences which he addressed. He published in scientific journals such as the Proceedings of the American Association for the Advancement of Science, Science, the annual Reports of the Missouri Botanical Garden, the American Naturalist, and the Botanical Gazette. He also addressed agricultural audiences, in the Proceedings of the Society for the Promotion of Agricultural Science, the annual Reports of the Nebraska State Board of Agriculture, the Proceedings of the American Pomological Society, the Bulletins of the Nebraska Agricultural Experiment Station, and the Reports of the Nebraska State Horticultural Society. Finally, he wrote for lay audiences in the Nebraska Farmer, American Agriculturist, the Breeders' Gazette, and Twentieth Century Farmer (%Overfield, 1975; %Tobey, 1981).

The other student sent by Beal to Gray for training was Liberty Hyde Bailey (1858-1954). Bailey worked for several years under Gray before accepting a position teaching horticulture at Michigan State Agricultural College. In 1888, Bailey became chairman of the department of horticulture at Cornell University. Like Bessey, Bailey was extremely influential in both scientific circles as well as in political and economic arenas. He spent much time promoting scientific methods of agriculture and horticulture to lay audiences of farmers. Bailey served as director of the Cornell College of Agriculture, dean of the New York State College of Agriculture, and director of the New York State Agricultural Experiment Station. In 1908, he was appointed head of the Country Life Commission which made recommendations on improvements of rural conditions throughout the United States. He lectured widely to scientific and amateur natural history societies as well as to farmers' organizations. Bailey was active in urging the broadening of taxonomic botany to include cultivated plants as well as those found in the wild, in which efforts he was strongly aided by Bessey (%Rodgers, 1944b, 1949).

The third student of Gray who established an important institutional base for botany in the Western states was John Merle Coulter (1851-1928). Together with Farlow and Bessey, Coulter completed the "eminent trio in the history of American botany" (%Rodgers, 1944b: 247). Coulter differed from Bailey and Bessey in his narrow focus on academic botany. In contrast to Gray's other students, Coulter did not evince an interest in agriculture or horticulture. Coulter also differed from other Gray students in his early experience working as a geologist for the Hayden Survey. After working at a number of administrative posts in small liberal arts colleges in the Midwest, Coulter accepted the position of dean of the new Botany Department of the University of Chicago, founded in 1892.

In his 30 years at the University of Chicago, Coulter supervised almost 200 doctoral students (%Drouet, in Coulter, 1914). Like Beal, Bessey, Bailey, Farlow, and

Goodale, Coulter was influential in the introduction of experimental methods into botanical research. He stressed the study of plant morphology and physiology in the department's program, and left taxonomic study to the botanists working at the Field Museum (%Rodgers, 1944b). Coulter's interests in morphological and physiological investigations were furthered by his control of the Botanical Gazette, a journal which he founded in 1875. Between 1875 and 1895, these students of Asa Gray controlled two of the three most important botanical journals in the United States (%Overfield, 1975; %Rodgers, 1944b).

Pre-eminence of the students of Gray in professional circles, in educational institutions, and in broader political arenas was undoubtedly due to the prominence of their mentor. However, the changing institutional and political context provided these men with opportunities to establish "footholds" within changing institutions and to gather resources, recruits, and audiences for their ideas. The segmentation of botany after the beginning of the 20th century rested on the "going concerns" established by these scientists, first at Harvard and, later, at the University of Chicago, the University of Nebraska, and at Cornell.

The Segmentation of Botanical Disciplines

Rapid growth in the numbers of biological researchers after 1880 was the result of a number of broad economic and political forces, including federal support for development in the Western states and growing popular support for science and resource conservation. The growth of biology after 1880 was also tied to the development of an increasing number of institutions which supported this type of work. The networks formed by scientists working on related problems initially crosscut their institutional affiliations. As different types of problems came to be supported within different institutional networks after 1900, these professional networks gradually segmented and their memberships ceased to have much overlap.

Taxonomic (or classification) problems were addressed by researchers working in museums and botanical gardens. Ecological problems were initially the province of both academic and agricultural researchers. As these problems proved intractable, however, they were pushed out of academic institutions and addressed, for the most part, by agricultural scientists. Genetic problems, which proved most amenable to experimental methods, were generously supported by both academic and agricultural institutions after 1900. As breeding work, done largely by seedsmen and farmers (%Crabb, 1947) became distinct from genetics, done by professionally trained scientists, genetic problems became more popular among young researchers. It is hardly surprising that these scientists chose to work on problems that offered institutional and intellectual rewards. Older researchers, in contrast, often returned to problems of classification at the end of their careers. Both Liberty Hyde Bailey, who worked in horticulture and applied botany, and John Merle Coulter, whose interests were exclusively academic, took up classification work after retiring from teaching.

During the years from 1890 to 1920, the discipline of botany segmented in several different ways. The intellectual dominance of Harvard declined after the death of Gray in 1888. Regional centers of botany developed in Chicago, where Coulter taught, and in California, where a large number of botanists worked at the University of California at Berkeley. There was also segmentation between botany *per se* and disciplines such as forestry, horticulture, and bacteriology. This substantive segmentation was crosscut by analytic segmentation among these disciplines, into genetics, ecology, and taxonomy. While this list is not complete, it provides a sense of the complexity of the arena of botanical research between 1900 and 1920.

The Botany Department at Harvard University continued to specialize in morphological research longer than most other academic institutions. Robinson, Goodale, and Farlow all taught at Harvard throughout this period and their students found employment in both academic and governmental institutions. However, the prestige of the Harvard botanists rested largely on the achievements of Gray. His successors never had to fight for resources as botanists at other institutions did. During the 1910s, the Bussey Institution (Harvard's school of applied biology) sponsored a program in plant genetics, but the prestige of Bussey never matched the prestige which Harvard achieved during Gray's lifetime.

The initiative in botany moved, after Gray's death, to a number of other, newer institutions. In the West and Midwest, Coulter and Bessey trained many students at the Universities of Chicago and Nebraska. These students specialized in a number of analytic areas, including genetics and ecology. The impetus of training in taxonomy remained at Harvard, where Gray's students taught, and at Columbia, where Nathaniel Lord Britton took over Torrey's collection as well as his institutional position. Britton was successful in establishing a new botanical garden in the 1890s and in promulgating the American Code of Nomenclature. His success rested, however, on his alliances with Coulter, Bailey, and Bessey in opposition to Robinson at the Gray Herbarium.

Graduates from the Botany Department at the University of Chicago worked in almost every prestigious academic institution across the continent after 1900. Coulter's students specialized in a wide array of research problems, including taxonomy, morphology, physiology, pathology, genetics, ecology, and forestry. Along with his closest associates, Arthur and Barnes, Coulter was responsible for the extension of botanical research to mosses, lichens, algae, and fungi.

J. C. Arthur (1850-1942) was a former student of Bessey who also studied with Farlow at Harvard. He had worked for a short time at the New York State Agricultural Experiment Station but most most of his career was spent teaching botany and plant pathology at Purdue University. His interest in plant diseases led him to conduct a series of studies of fungi and he was responsible, along with T. J. Burrill, for the incorporation of fungi into the botanical system of classification. C. R. Barnes (1858-1910) was a former student of Coulter although he spent two summers studying with Gray at Harvard. Barnes spent his entire career in academic institutions, where he pursued a research program in bryology (i.e. study of mosses) as well as establishing an experimental laboratory for physiological research at the University of Wisconsin. Together, Arthur, Barnes, and Coulter published the Handbook of Plant Dissection in 1886 which with Bessey's Botany for High Schools and Colleges (published in 1880) remained the most widely used textbook in botany for many years (%Rodgers, 1944b).

Genetics

The major focus in biological research after 1890 was in genetics. The Harvard botanists were not disposed to move into this intellectual area nor were they able to dominate the field. The lead in plant genetics was taken, instead, by a number of botanists who studied with Coulter, Bessey, and Eugene Davenport of the University of Illinois. These botanists, dominated by East and Shull, found positions at Harvard's Bussey Institution, with the Carnegie Institution of Washington, and at federal laboratories and state agricultural experiment stations. Genetics was heavily supported by agricultural colleges and by federal and state government agencies interested in improving crop productivity (%Crabb, 1947; %Rodgers, 1949).

While federal laboratories and state agricultural experiment stations provided important support for work in plant breeding and genetics, theoretical work in plant genetics was done for the most part in university agriculture departments. Before 1920,

> ... the only genetics program that could rival Columbia's was that of Harvard's Bussey Institution. The Columbia genetics program was highly focused on Drosophila; the Bussey's was far more diverse. The Bussey sponsored genetics research before becoming a graduate school of applied biology in 1909, but most of its major work in the field occurred between 1909 and 1936 ... William E. Castle supervised research in mammalian genetics for most of his career, as did

> Edward M. East in botanical genetics ... each directed twenty successful doctoral students, a number of whom ... became nationally recognized geneticists in their own right (%Cravens, 1978: 167-68).

E. M. East (1879-1938) graduated from the University of Illinois in 1904, where he studied chemistry and botany. East spent several years working in the Illinois Agricultural Experiment Station on a series of experiments to improve the nutritional content of feed-corn. In 1905, he moved to the Connecticut Agricultural Experiment Station, where he conducted breeding experiments with corn, potatoes, and tobacco. In 1909, he was appointed professor at the Bussey Institute where he remained until his death in 1938 (%Provine, 1971). In contrast to the distinction which emerged soon after the turn of the century between breeders and geneticists in animal genetics (%Lush, 1951), the ties between plant geneticists, plant breeders, and seedsmen remained strong well into this century (%Crabb, 1947).

One of the best-known American geneticists graduated from Coulter's department at the University of Chicago. During his years at Chicago, G. H. Shull (1874-1954) came under the influence of C. B. Davenport, a mammalian geneticist who had come to Chicago from Harvard in 1899. Shull had already spent several years working at federal Bureau of Plant Industry, dominated in this period by a group of Bessey's students from the University of Nebraska. Shull moved to Cold Spring Harbor in 1904, at Davenport's invitation, to work at the Carnegie Institution of Washington's Station for Experimental Evolution. While at Cold Spring Harbor, Shull conducted breeding experiments with evening primrose, foxglove, poppy, tobacco, sunflower, tomato, bean, and potato plants. He also worked with corn, and after 1908, Shull and East communicated frequently, although they soon came to disagree about principles of genetics (%Rodgers, 1949; %Crabb, 1947). In 1915, Shull moved to Princeton University as a professor of botanical genetics. Together with R. A. Emerson at Cornell University, and D. T. MacDougal at the Carnegie Institution's Tucson Botanical Laboratory, Shull and East formed the core of botanists engaged in research on plant genetics in the first decades of the 20th century.

Among Bessey's students, there were a number who specialized in genetic research. In contrast to Chicago botanists, Nebraska botanists remained for the most part in institutions which sponsored agricultural research. H. J. Webber (1865-1946) is a good example of the career path followed by many of Bessey's students. After graduating from the University of Nebraska, Webber went to work at the USDA in 1892 as an assistant pathologist. In 1897, he became director of the federal Laboratory of Plant Breeding where he was in charge of research projects on cotton, corn, pineapples, potatoes, and timothy clover for 10 years. After five years at Cornell University, where he headed the new department of experimental plant biology under the direction of Liberty Hyde Bailey, Webber moved to California to become director of the Citrus Experiment Station and dean of the Graduate School in Tropical Agriculture at the University of California at Riverside (%Rodgers, 1949).

Another of Bessey's students who went into plant genetics was D. T. MacDougal (1865-1958). Trained by two former Bessey students, Macmillan and Arthur, MacDougal worked closely with a group of Bessey students at the federal Bureau of Plant Industry, including Webber, Emerson, A. S. Hitchcock, and Bessey's son, Ernest (%Harding, 1947). In 1902, MacDougal went to work at the New York Botanical Garden as manager of the experimental gardens and director of the botanical laboratory. During this period, he worked with G. H. Shull on a breeding program using plant material donated to the institution by de Vries himself (%Rodgers, 1949). In 1904, MacDougal went to work for the Carnegie Institution of Washington as director of the Desert Botanical Laboratory in Tucson (%Cittadino, 1980).

While Bessey himself was primarily interested in classification and morphology, he encouraged his students to branch out into other fields, including plant genetics, plant ecology, phytopathology, and systematics. In contrast to Coulter, Bessey trained his students in agriculture and horticulture, as well as plant pathology, physiology, and morphology. Most of Bessey's students went into agricultural sciences; indeed, by the 1890s,

> Bessey trained his botanical students with federal service in mind ... His students received a broad botanical training with an emphasis on physiology and pathology, were strong in laboratory techniques, and had a good foundation in bibliography. As a result of this training, Bessey's students could adjust to research problems whether they involved cotton diseases in Texas, farming in Hawaii, lumbering in Pennsylvania, or rice diseases in South Carolina (%Overfield, 1975: 175).

<u>Ecology</u>

Like Coulter, Bessey had students who specialized in ecology as well as in genetics. Far more of Bessey's students went into genetics than into ecology. However, student F. C. Clements (1874-1945) was probably the best-known plant ecologist in the United States in the first half of the 20th century. Indeed, he is often called the "father" of American plant ecology (%Tobey, 1981). Before graduating in 1898, Clements spent several years at the University of Nebraska working with Bessey on the state Botanical Survey. In 1907, he went to the University of Minnesota where he remained for 10 years. While at Minnesota, Clements developed his ideas about plant succession. Clements's ecological theories were adopted by agricultural scientists working in government agencies on the problems of rangeland management in the Western states. Clements left the University in 1917 to work for the Carnegie Institution of Washington, setting up the Pike's Peak Laboratory in Colorado. Although Clements himself had few students, his collaborator J. E. Weaver (1884-) "trained more of the academic scientists engaged in the drought (of the 1930s) than any other individual" (%Tobey, 1981: 192).

Like Bessey, Coulter had only one well-known student who specialized in ecology. H. C. Cowles (1869-1939) is regarded, along with Clements, as one of the founders of the discipline of plant ecology. He began his academic training in geology at the University of Chicago, after spending a year as an assistant with the United States Geological Survey. Cowles published very little and his reputation lay largely in his teaching. He trained almost as many students in ecology as Coulter trained in all of botany. Among these students were V. E. Shelford, C. C. Adams, P. B. Sears, and W. S. Cooper, as well as Transeau, Braun, Chaney, Cottam, Nichols, Cain, Fuller, Vestal, Shreve, and Livingston (%Sprugel, 1980). While Cowles himself never publicly disagreed with Clements's ideas, his students were vehement in their criticisms of the Nebraska-trained ecologists (%McIntosh, 1977; %Tobey, 1981).

Taxonomy

In contrast to genetics, and even ecology, which were pursued in both academic and agricultural research institutions, taxonomy remained the province of scientists working in museums and botanical gardens. Most universities had small herbaria but the experts in this field were associated for the most part with the large botanical gardens, such as the New York Botanical Garden, the Missouri Botanical Garden, the Gray Herbarium at Harvard University and the National Herbarium. The scientists who ran these institutions all represented very different schools of thought in classification work.

Although a number of the botanical gardens created at the end of the 19th century had laboratory facilities, this type of institution could not provide the generous support for experimental work available at universities, in the federal and state agricultural laboratories, and in the private research institutions. Recruitment was difficult in a line of work with declining prestige. Most botanical gardens maintained close relations with one or more universities in order to obtain needed staff for taxonomic work. The Field Museum in Chicago recruited among the botanical students of the University of Chicago, while the New York Botanical Garden obtained staff from Columbia and Princeton Universities (%Gleason, 1960; %Rodgers, 1944b). As at the Kew Gardens in England, the opportunities for training were limited and most taxonomists shuttled back and forth between an academic institution and a museum or botanical garden (%Brockway, 1979; %Rodgers, 1944a).

Per Axel Rydberg (1860-1931) was "probably the ablest student in systematic botany whom Bessey produced" (%Rodgers, 1944b: 217). Rydberg spent 4 years working for Bessey as an assistant with the Nebraska Botanical Survey before moving to Columbia University to work with Britton (%Gleason, 1960). Although associated with the New York Botanical Garden, Rydberg spent much of his time collecting in the Rocky Mountains and the Western states. In contrast to Bessey, Coulter did not train his students in taxonomy. He sent students interested in classification problems to the Field Museum, which had a large herbarium. The Botany Department at the University of Chicago focused exclusively on experimental work in genetics, ecology, and physiology (%Rodgers, 1944b).

Conclusion

The numbers of scientists doing taxonomy remained much smaller than the number of scientists working in genetics, ecology, physiology, pathology, and other areas of plant science. This was partly because of the limited opportunities for training in this field, as well as limited employment opportunities. There were relatively few openings for taxonomists outside of the museums and botanical gardens which supported this type of research. By the beginning of the 20th century, there were no more than 10 major institutions supporting work in plant classification although scientists working in other areas often argued about the significance of their work for classification.

By 1900, taxonomists formed a small and not very prestigious line of work within botany as a whole. Intellectual and institutional commitments were increasingly made in other directions within botany as well as within zoology. Genetics, in particular, exemplified the new experimental and statistical approach to biological problems and scientists involved in genetics research obtained the greatest institutional support in both academic and agricultural arenas. In the latter arena, ecological research also received support. The use of quantitative methods of analysis provided ecology with a better foothold in academic institutions than taxonomy was able to gain.

The scientists engaged in botanical research between 1880 and 1920 both created and followed the institutional and intellectual opportunities within the discipline. Abundant resources meant that many botanists moved into agricultural research after 1890. The "force-fed specialization" (%Rossiter, 1979) of economic entomology, plant and animal breeding, as well as plant and animal pathology were the result of skillful political maneuvering by scientists hoping to protect themselves from routine teaching duties in the liberal arts colleges, and from routine tasks in the agricultural experiment stations. Many lines of work adopted the language of experimental research in order to gain access to funding and to protect their practitioners from the pressing demands of a variety of clientele.

Establishing the priority of research was the major ideological commitment uniting professional scientists at the end of the 19th century. The new institutions which were were established, including universities, federal and state experiment stations, and private research institutions, all accorded experimental work the prestige which scientists sought. Older institutions, such as liberal arts colleges, museums, and botanical gardens, were rarely successful in sponsoring research programs. These older institutions found it difficult to transform their commitments to the older style of work. This contributed to their declining prestige within the professional scientific community.

As museums and botanical gardens declined in importance, so did the types of work and the types of researchers associated with these institutions. Just as museums and botanical gardens became the repositories for the results of work done in other institutions, so taxonomy and classification work became the respository for the problems of other lines of work. The jettisoning of intractable problems by successful lines of work simply contributed to the declining prestige of taxonomy after the beginning of the 20th century.

Footnotes

(1) These are terms used by historians to describe the change from Natural History to biology at the beginning of the 20th century. My contention is that these changes included technical and organizational shifts as well as changes in the conceptual framework of biology.

(2) This term has recently become the subject of debate amongst historians concerned with the development of biology in the late 19th and early 20th centuries. While the issue of whether biology underwent "evolution" or "revolution" in this period is an important one, I wish for the purposes of this discussion to simply point out that the fact of such change is not under dispute. See %Allen (1981), %Benson (1981), %Churchill (1981), %Maineschein (1981), and %Rainger (1981) for details of this debate.

CHAPTER FOUR

DAILY WORK IN BOTANICAL RESEARCH

Introduction

The structure of economic and political arenas, the development of institutionalized support for scientific work, and the emergence of specialized networks of scientists formed the context within which botanical research was conducted at the end of the 19th and beginning of the 20th centuries. These intellectual and institutional developments rested, in large part, on the daily work of researchers in a variety of contexts. My focus here is on the problems which botanists faced in pursuing their work, on the various technical staff upon whom they depended, and on other lines of work concerned with the manner in which botanical research was conducted. The purpose of this chapter is to outline the contingencies of the daily work in which botanists engaged. The underlying assumption is that these contingencies had an important impact on both the intellectual content and the institutional context of botany between 1880 and 1920.

Work in botany can be divided into three major types:

(1) surveying and collecting, (2) experimental, and (3) classification work. These can be placed on a continuum on the basis of the level of uncertainty entailed in each type of work. Surveying and collecting work, where botanists map geographic areas and collect preserved specimens, involves uncertainties of sampling and representation. Experimental work is done with living plants and botanists are faced with a wide variety of uncertainties generated by the characters of these organisms as well as by attempts to control these characters. Classification work relies heavily on both collecting and experimental work and the uncertainties of both are incorporated into the classification system.

The uncertainties of work with plants were packaged differently by different botanists. Experimental approaches promised control over the uncertainties of work with living plants. Control over aspects of the environment differed in working with different types of plants. These differences led researchers to draw a variety of boundaries, between types of plants, between plants and animals, between plants and the environment, and between individuals and populations, in different ways. Since variations in the control over uncertainty were not always clear to users, the results of such work were often interpreted in different ways.

Survey Work

Surveys can be divided into several different types on the basis of their emphasis on different types of information. Military surveys are conducted in order to map terrain which will be subject to some type of military action. Exploratory surveys are conducted in order to determine the location of important resources for exploitation. Topographical surveys are concerned with locating areas of land suitable for different uses. These different types of surveys rely on the same tools and techniques and are often part of the work of a single expedition. Exploratory and topographical surveys focus on much the same type of information, including landmarks, transportation routes, and existing resources, while military surveys are more oriented to defense strategies and uses (%Mukerji, 1982; %Wilford, 1981).

Early surveyors operated under a specific set of contingencies shaped by the conditions of the territory into which they travelled and by the purposes of the surveys which they conducted. Surveys conducted for military purposes focus on prominent landmarks, defensible positions, and available water and food resources. Exploratory surveys focus on other types of resources, including navigable rivers, existing plateaus, mountainous areas, and so forth. The purposes of these surveys were not necessarily antithetical, but the information gathered during the course of a survey was biased by the overall emphasis of the survey.

The possibilities for collecting on an expedition vary with the overall purpose of the expedition. On military expeditions, collecting was limited since the naturalist was unable to systematically sample an area. Collecting was done along the narrow route followed by the expedition. On this type of expedition, leaving the party to botanize on one's own could be extremely dangerous. On an exploratory expedition, there was less of a tendency to follow a narrow route and naturalists were able to collect more systematically and with a view to theoretical concerns. On a topographical expedition, opportunities for collecting on a theoretical basis were extremely good and it is hardly surprising that collecting activities took a sudden jump after the Civil War when this type of survey work began to predominate.

In the early 1800s, the United States government laid claim to a huge territory west of the 100th meridian. From the Mississippi River to the Pacific Ocean stretched a vast, largely unmapped area whose resources were unknown. The first surveys of the new territories were both military and exploratory in nature (%Wilford, 1981). During the first half of the century, agencies of the federal and state governments were busy mapping this area, determining the resources available for exploitation, and eliminating the Indians then occupying these territories. Military surveys also had an exploratory aim: surveyors on these expeditions took astronomical and barometric readings to fix the location of prominent landmarks in order to insure that later travellers could follow the same route.

After the Civil War, a number of expeditions were jointly sponsored by government and private institutions. Universities began to provide their faculty with opportunities to travel to the West for purposes of collecting fossils, plants, and animals. For example, Harvard University and a group of private supporters provided funds to Asa Gray and F. V. Hayden for a collecting trip and survey of the Western states in 1877 (%Dupree, 1959). The same year, Yale University and the United States Geological Survey jointly sponsored several expeditions by Marsh and Powell to the Western states after 1879. Collections of fossils from these expeditions were housed at both the U.S. National Museum and at Yale (%Stegner, 1954).

By the 1890s, state governments were sponsoring surveys jointly with agricultural and land-grant colleges. Perhaps the most prominent example in botany is the joint sponsorship of the Nebraska State Botanical Survey coordinated by C. E. Bessey between 1892 and 1905. Initially conceived as a service to agricultural interests in the state, the Nebraska Botanical Survey eventually yielded much information on which early theoretical plant ecology was based (%Tobey, 1981). Other states that sponsored natural resource and agricultural surveys jointly with agricultural colleges or universities in this period included Illinois, Wisconsin, Colorado, and Minnesota (%Hays, 1980; %Rodgers, 1944a).

The overall purpose of an expedition affected the information that it was possible to gather. Different types of expeditions travelled through a territory in distinct ways. In the case of a military expedition, as much ground as possible was covered in the shortest period of time. Travel was generally unimpeded by large amounts of equipment and defense was a matter of great concern. The surveyor had a limited set of tools, including chronometers, sextants, barometers, and compasses, which were small and could be easily transported (%Wilford, 1981). Opportunities for collecting were extremely limited on a military expedition and transportation for specimens was also uncertain. In the case of exploratory expeditions, travel through an area was likely to be slower. Rather than moving rapidly along the most easily navigable route, explorers were more likely to traverse back and forth across a region and to settle for days or weeks in a single spot so that an area could be thoroughly mapped (%Stegner, 1954). Chances of collecting plant, animal, and fossil specimens on this type of expedition were very good, and in fact, this was often an explicit part of the work.

With the gradual settling of the West, military activity declined. The threat of hostilities between Indians and white settlers declined rapidly after the Civil War, as the Indians were confined to reservations and as their population was weakened and exterminated through war, disease, and malnutrition (%Debo, 1970; %De Voto, 1952). Surveying done after the Civil War was primarily exploratory and for purposes of locating resources of potential value, including timber, metals, and minerals, as well as arable land and navigable rivers. Such survey expeditions often included one or more naturalists "whose duty it was to investigate and report upon the wild life, both plant and animal, of the region visited" (%Young, 1922: 38). While these naturalists had little to say in the overall direction and pacing of the expedition, as members of a relatively small party, they were influential in the day-to-day surveying work. Naturalists often helped take readings and draw maps of the territory through which they passed (%Wilford, 1981). Surveyors, in turn, assisted naturalists in their collecting activities by bringing interesting specimens back to camp, helping to preserve animal skins, and to dry plants for later transportation (%Dupree, 1959).

Prior to the 1800s, most naturalists did their own collecting work as well as their own classification work (%Berkeley & Berkeley, 1974). They had a comprehensive picture of the location in which a specimen was found, the other plants with which it grew, and the extent of variation within the population of that type of organism. By the middle of the 19th century, well-known botanists such as John Torrey and Asa Gray had large networks of collectors in different regions of the continent. The specimens which these collectors sent to Torrey and Gray were stored in their personal collections, cataloged, classified, and duplicates exchanged with colleagues at other institutions in Europe and the United States (%Dupree, 1959; %Rodgers, 1942).

While most botanists continued to do at least some of their own collecting, collecting and classification work gradually became distinct. Collecting was generally done in conjunction with survey work, whether this was in a remote area or to the area where the botanist lived. Classification work, on the other hand, was generally done in the herbarium or museum and was characterized by very different resources and materials. Classification work remained dependent on both survey and collecting work for mapping the location of organisms and collecting samples.

By the end of the century, then, many surveys had been done in the United States for several different purposes.

In terms of botanical work, the importance of these surveys varied. Military surveys were of limited use to naturalists since the information collected on such expeditions consisted primarily of strategic locations and routes across a narrow band of territory. Exploratory surveys, on the other hand, were useful to naturalists in terms of specimens collected as well as the geographic information gathered by naturalists and surveyors.

With the shift in the primary style of survey expedition, from military to topographic and exploratory, came a shift in the participation of naturalists in this type of work. As more and more expeditions were undertaken, with an increasing variety of sponsors, naturalists came to be an accepted part of any such expedition. While the opportunities for collecting varied according to the overall purpose of the expedition, most naturalists were able to find time to collect specimens. For example, although John Bigelow worked primarily as a surveyor for the Pacific Railroad Survey during the 1850s, he was able to find time each year to botanize, collecting specimens of a large number of California plants which he sent to John Torrey in New York for classification (%Ferris, 1970).

During the last half of the 19th century, another shift in this type of work occurred. Most early exploratory and topographic surveys left a settled and civilized area to travel into an unsettled area with few amenities.

Travel was most often by horse, mule, or on foot and this placed important constraints on the types of equipment which naturalists could carry with them and on the amount of collecting they could do. By the beginning of the 20th century, most surveys in the United States were conducted in settled areas while their overall emphasis gradually shifted from exploration to land-use orientation. Exploration continued but increasingly moved outside of the continental United States to Alaska, Hawaii, the Philippines, South and Central America, and Asia. Liberty Hyde Bailey, for example, traveled to China as well as making numerous trips to South America in the early 1900s (%Rodgers, 1949). Nathaniel Lord Britton made more than 20 trips to the West Indies between 1898 and 1916 for collecting purposes (%Gleason, 1960).

Many of the state natural resource and botanical surveys employed scientists already working in state colleges and universities (%Rodgers, 1944a). The constraints of travel to and from a geographic area were much reduced in these cases. More equipment could be taken to a site for purposes of gathering information and more specimens could be removed for later examination. The possibility of returning regularly to an area meant that information could be gathered at different times of year about the life-cycle of the organisms in that area (%Tobey, 1981). All of these changes contributed to the body of information on which botanical theories were based and provided opportunities for alternative interpretations of existing evidence.

Survey work formed the basis of early biogeographical work by European as well as American naturalists. Early thematic maps were attempts to represent the relationships between geographic regions and their indigenous flora and fauna (%Thrower, 1972) (1). Early 19th century work in topography as well as the development of natural resource surveys provided naturalists with materials for mapping the distribution of plants in relation to climatic variables. By the 1890s, plant geography was an important part of European botany and was gaining popularity among American botanists in the Western states (%Shimwell, 1971; %Tobey, 1981).

Survey and collecting work formed an important foundation for botanical research during the 19th century. Surveying and collecting were distinct types of work, although in many cases they were done together. The mapping and collecting work of naturalists was constrained in several ways by the nature of the expeditions which they accompanied. With the gradual change from military to exploratory and topographical surveying, collecting changed from an incidental part of the work of an expedition to one of the major tasks. While exploration continued in remote areas of the world, surveying in the United States became increasingly local and made use of scientists within the immediate area, with concomitant changes in the sampling done by botanists. The results of surveying and collecting work were also used in different ways by the institutions which sponsored this work as well as by other lines of work.

Biogeographic work, mapping the location of types of plants and animals in terms of environmental variables, began early in the 19th century in conjunction with surveying and exploratory work in remote areas visited by European and later American naturalists. By the end of the 19th century, this type of work was done by botanists working at agricultural colleges and experiment stations. The survey work done by these later botanists was on a much smaller scale than the work that had been done early in the century and was theoretically more elaborate, although the tasks which made up the work remained much the same.

Experimental Work

While survey and collecting work continued to be done throughout the late 19th and early 20th centuries, the emphasis gradually changed to experimental work. This change was tied to shifting institutional commitments as well as to changes in the techniques and problems of botany. As materials in experimental work, plants presented a number of problems. The control which experimental methods offered over these organisms differed from the control which other scientists exerted over other types of experimental material. The changing institutional sponsorship of botanical research supported the ascendancy of experimental work in spite of continuing problems applying experimental methods to plants while the increasing dependence of botanical researchers on technical support staff played an important part in the style of experimental work which did develop.

Plants as Experimental Material

Different types of organisms vary in the ease with which they can be used in experimental work. Work with plants was subject to different kinds of uncertainty than work with animals or insects. Most plants are capable of reproducing asexually as well as sexually and vegetatively. Plants are also capable of doubling or tripling their chromosomes when they reproduce and they frequently produce fertile offspring from hybrid matings. Some plants are very difficult to propagate while other plants reproduce abundantly with minimal human interference. Different plants require different environmental conditions for healthy growth. Most plants are far more plastic than animals or insects in response to environmental differences. Botanists must deal with different sets of contingencies depending on the conditions required by the plants they are working with, on the technology available (and necessary) to sustain such conditions, and on the willingness of sponsors to fund the purchase of equipment necessary to provide such conditions.

From the time seeds are first planted, through their first growth spurt, and especially during flowering and fruiting periods, most plants are vulnerable to environmental fluctuations. A severe frost or drought can retard the full growth of experimental plants or destroy them completely. Young plants are also susceptible to insect and fungal pests. Many plants depend on insects for pollination and the application of pesticides can affect the ability of the plant to reproduce. Once plants are pollinated and seed is set, there are further dangers of bird and insect depredations. Finally, fungal infestations, drought, and temperature fluctuation can affect the abundance of seed available for subsequent plantings (2).

The same plant may be chosen for experimental work by different groups of scientists for different reasons (3). The reasons for choosing corn as experimental material were different for botanists working in agricultural experiment stations and those working in universities. Station scientists worked with corn after 1900 because it was an easily grown, hardy plant much in demand on domestic and foreign markets. University scientists worked with corn because of its rapid developmental cycle and because it was easily available through commercial outlets (%Crabb, 1947). The speed with which different plants reproduce is also important for scientists and sponsors. Some plants, such as trees, are very difficult to grow from seed and reproduce infrequently. Other organisms grow easily from seed and reproduce one or more times a year. The rapidity of the reproductive and developmental cycles of any type of organism is an important consideration for scientists since sponsors are interested in work which produces results quickly and regularly. Such a consideration was probably behind the choice of Drosophila melanogaster for the genetics program at Columbia University since each generation of these insects develops and reproduces within 14 days (%Allen, 1978).

The use of plants as experimental material made work on the problems posed in 20th century biology more difficult to solve. The ability of plants to reproduce asexually as well as sexually and vegetatively, made problems for botanists in the application of Mendelian theories of heredity in many cases. Asexual reproduction obscures the crucial distinction between individual organisms and populations of organisms, since a population may be the genetically identical offspring of a single individual. Another feature of plants is that the offspring of one plant may have double or triple the number of chromosomes of the parent plants. Such changes in the number of chromosomes were interpreted by biologists working with animals or insects as <u>speciation</u> in a single generation. Most important, plants are capable of far more plastic responses to changing environmental conditions than animals or insects. These characters of plants made sorting out the problems of evolutionary biology difficult. This confusion was compounded by the widespread view that plants were <u>simpler</u> than animals since they lacked mobility and sentience.

<u>Experimental Work and Levels of Control</u>

Experimental work varies along a number of different dimensions. Control over the <u>organisms</u> under investigation is one important factor. Lack of information about the characters of an organism, its development, and reproductive features can cause problems for researchers working with different types of organisms. Control over the <u>environment</u> is another important factor in the pursuit and in the interpretation of the results of experimental work. Some experimental work is done outdoors where environmental conditions are difficult to regulate. Other experimental work is conducted indoors, where environmental conditions are more easily controlled. Experimental work also varies in terms of the difficulties with which organisms can be maintained. Some organisms thrive under conditions that are easy to provide. Other organisms require special nutrients or environmental conditions which are difficult to provide. In some cases, the economic importance of such organisms justifies continued work with them, but in most cases, experimental work is done with organisms which do not have rigorous requirements for basic survival.

Early experimental work in botany suffered from problems with control of environmental variables. Several botanists, for example, experienced "various accidents, frosts, droughts, and pests (which) prevented important plants from maturing or destroyed their fruit" (%Stubbe, 1972: 122). The French botanist Bonnier did not fence his experimental plants and was unable to find them when he returned to check their responses to alpine conditions (%Hagen, 1981). Widespread and frequent droughts, storms, and temperature fluctuations in the Midwest discouraged hybridization work with corn until well into the 20th century (%Crabb, 1947).

Experimental work appeared to give scientists a greater degree of control over the organisms with which they worked. Survey and collecting work involves a minimal degree of control over organisms which are collected and transported to distant institutions. Experimental work in outdoor plots involves a somewhat greater degree of control. Fencing such plots protects the plants from depredations by herbivores as well as from trampling. There is little control in outdoor plots, however, over environmental conditions such as rainfall and temperature although botanists may (and do) water experimental plots during droughts as well as weed out competing plants (%Clausen, Keck & Hiesey, 1940; %Mason, 1981).

Moving into greenhouses provided botanists with a greater degree of control over environmental conditions. Although many early greenhouses had major problems with temperature maintenance and ventilation, these problems were ameliorated by the 1880s. By providing a protected environment for the earliest stages of development, greenhouses served to ensure that a large number of seedlings could be grown out for later transplanting outdoors (%Hix, 1974). Greenhouses were also important in regulating temperature fluctuations in order to grow out tropical plants. England, Europe, and the United States all have colder climates than many of the regions in which new plants and seeds were collected and greenhouses provided the temperature and humidity levels required by such plants (%Brockway, 1979).

Further control over environmental conditions was possible with the development of laboratory facilities. Temperature, humidity, ventilation, and nutrition could all be adjusted to promote or retard the development of different types of plants. While control over temperature and humidity was easier and contamination of experimental plants was also less likely, laboratory work limited scientists in terms of the types of organisms they could study. Most plants require a significant amount of space as well as light, moisture and ventilation. While small numbers of plants can be grown inside a laboratory, it is difficult to grow out enough plants to establish a statistically significant sample indoors. Laboratory work in botany, therefore, has been largely limited to examination and analysis of specimens brought in from the field, experimental plot, or greenhouse and to microorganisms such as fungi and bacteria.

Sponsors of Experimental Work

Practical breeding of domestic plants and animals began very early in the history of human evolution. Early attempts to select individual organisms for desirable traits formed the basis for later, more rigorous experimentation with biological organisms (%Olby, 1966; %Stubbe, 1972). A wide variety of plants and animals have been altered by human selection and cultivation, including dogs, cattle, sheep, chickens, and pigs as well as grains, vegetables, flowers, and fruits (%Baker, 1970; %Dunn, 1951). The Greeks, Romans, Mayans, Incas, Aztecs, and other ancient civilizations all made use of selection to improve their domesticated sources of food (%Crabb, 1947).

By the beginning of the 19th century, there were large numbers of plant breeders working in England, Europe, and America (%Farley, 1982). Cross-breeding had long been known to increase the vigor of individual plants and horticulturists pursued work with a wide variety of crops, including corn, wheat, rye, barley, grapes, apples, pears, plums, peas, potatoes, and many others (%Harding, 1947; %Stubbe, 1972). While most of the plants chosen for experimental work had economic importance, many breeders also chose plants with features that could be easily classified. Work with these plants was concerned as much with debates about the nature of species as with increasing the productivity of important food crops (%Olby, 1966).

Early experimental work in Europe was conducted on private estates or botanical gardens in Germany, England, France, and Russia. Private land-owners in these countries engaged in practical experiments in hybridization in order to increase the productivity of their crops. They were also interested in questions about the nature of species. While many of these wealthy individuals conducted their own experiments, others employed botanists to do experimental work. For example, John Mitchell, an American physician, was employed by the Duke of Argyll to conduct experiments and discuss botanical questions in the late 1700s (%Berkeley & Berkeley, 1974).

By the mid-19th century, there were several different types of sponsors for experimental work in botany. The great private estates were breaking up, but there were growing numbers of public institutions willing to sponsor this type of research. Museums, botanical gardens, and universities all provided support for experimental work in breeding. Such work was also encouraged by the open competitions staged by scientific academies after the beginning of the 19th century. This early experimental work was largely concerned with questions of hybridization, the fixity of species, and the relationship between species and varieties (%Farber, 1982; %Stubbe, 1972).

Work in hybridization was sponsored by federal and state agencies as well as by private commodity interests. The work done by C. G. Hopkins between 1896 and 1905 at the University of Illinois Experiment Station, for example, was supported by the federal Department of Agriculture's Office of Experiment Stations, by the university itself, and by Funk Farms, a private Midwestern seed company (%Crabb, 1947). Later work in genetics, which was less closely tied to breeding work, was sponsored by universities, federal and state agricultural agencies, and by private research institutions. G. H. Shull's work on plant genetics was begun at the Carnegie Institution of Washington's Station for Experimental Evolution at Cold Spring Harbor, and continued after Shull moved to Princeton University (%Provine, 1971). The federal Department of Agriculture sponsored its own program of plant genetics in the Bureau of Plant Industry where work to improve yields and heighten disease resistance was done with a wide variety of crop plants (%Harding, 1947).

<u>Experimental Work and Technical Staff</u>

In the shift from survey work to experimental work, there was an increase in both the technology and the staff necessary to maintain the flow of work. Survey and collecting work requires equipment which is technically straightforward and easily transported. Compasses, theodolites, and drafting materials are needed for survey work (%Wilford, 1981). Drying boxes, presses, and large sheets of paper are needed by plant collectors as well as careful records of the conditions under which individual plant specimens were collected (%Rodgers, 1949). After 1900 or so, plant collectors included cameras as part of the standard equipment of a collecting expedition as well as clothing, medicines, and money or items for trading with local inhabitants (%Gleason, 1960).

Early experimental work, done by naturalists in their own or nearby gardens, entailed the support of gardeners and horticulturists. The cooperation of such staff was vital in many cases since the success of a project rested on survival of the plants to reproduce. Gardening staff could sabotage years of experimental work by neglecting to cover plants before a threatened frost or by neglecting to water plants during a period of dry weather. For example, Koelreuter, a German botanist, left the tasks of tending his hybridized plants to the gardeners and "by simply ignoring his instructions they succeeded in ruining most of the experiments" (%Olby, 1966: 24).

Over the course of the 19th century, experimental work came to require even more specialized support by other scientific lines of work. Analyses of many environmental variables as well as oil and protein contents of different plants was done more and more by chemists rather than by botanists themselves (%Crabb, 1947). Collecting plant specimens was often done by college students after 1870, but collecting more exotic types of plants was done by specialized plant collectors such as David Fairchild of the United States Department of Agriculture (%Fairchild, 1938).

With the development of greenhouses, trained gardeners were needed to maintain the equipment and the plants inside these buildings. Gardening and clerical staff at botanical gardens, herbaria, and museums were responsible, by the last quarter of the 19th century, for much of the routine work associated with experimental programs in plant breeding. This included plant care on the grounds, maintaining public displays, work in the greenhouses, and careful record keeping.

As laboratories were established at many types of institutions, needs for even more specialized support staff developed. Technicians who understood and could repair the machines which maintained the humidity and temperature levels in greenhouses and laboratories were needed (%Hix, 1974). In work on experimental plots, the important but boring tasks of hand-pollinating experimental plants, recording their rates of growth, harvesting seeds, and storing these away from pests were given over to support staff. At the Illinois Experiment Station, for example, an untrained field technician, was given complete responsibility for pollinating selected plants by the botanist E. M. East (%Crabb, 1947).

Experimental Work and Experimental Methods

In the first half of the 19th century, botanical research began to focus on a different set of questions. From a dominant focus on describing and classifying the diversity of nature, naturalists began to ask questions about the distribution of species (%Farber, 1982). During the second half of the 19th century, distributional questions began to lose ground in the face of growing interest in the questions of evolution. Between 1860 and 1880, the problem of the mutability of species rose to pre-eminence in botanical research. Classification and description declined in importance and the emphasis of research shifted towards explaining the precise mechanisms by which evolution occurred (%Gerson, in prep.).

There were a number of difficulties investigating the mechanisms of evolution. Biologists working with different types of organisms conceptualized these problems in distinct ways which were related partly to characteristics of the organisms and partly to the methods which researchers used. Distinctions between individual organisms and populations of organisms were not always clear. The distinction between hereditary and environmental factors in the development of organisms and species was difficult to pinpoint. The relationship between structural and functional characters of organisms was also a matter of debate among researchers.

There were several developments in research methods during this same period. One important development was the shifting focus from anatomical and morphological research to cytological work, on the one hand, and statistical work, on the other. Interest in cytology grew as the resolving power of microscopes increased and as theories of the cell were elaborated (%Farley, 1982). By the 1890s, quantitative and statistical methods of analysis, which grew out of early demographic research, were being applied in biology (%Provine, 1971).

There were a number of methodological innovations made in botany at the beginning of the 20th century. These innovations were based on the growing popularity of experimental methods in biology. Experimental methods were proving successful in the investigation of heredity as the work of T. H. Morgan proceeded between 1910 and 1925 (%Allen, 1978). In botany, the <u>ear-to-row method</u>, the <u>quadrat method</u>, and <u>transplant garden experiments</u> were all attempts to incorporate experimental methods within botany. The results were not as spectacular in botany as they were in embryology and zoology. Nevertheless, botanists believed that these methods were most suitable to the problems with which they were concerned as well as offering greater control over the uncertainties of working with plants. These experimental methods did provide <u>conventions</u> by which some of the uncertainties of working with plants were packaged. These three methods are interesting because they indicate the different ways in which botanists packaged the uncertainties of working with plants, depending on the questions asked and the problems raised in very different contexts.

Early work in breeding involved the selection and breeding of individual plants for specific traits. The ear-to-row method was developed by geneticists in an attempt to gain control over the uncertainties of determining heredity in plants. This method utilized a black-world perspective (%Wimsatt, 1980) which entirely ignored variations among plants which might be due to environmental factors. This experimental method was developed between 1896 and 1904 by agricultural scientists working with corn at the University of Illinois Experiment Station. Seeds were taken from individual plants and grown out in single rows. Once grown out, each row was harvested and studied separately. For the first time, it was possible to make comparisons between offspring of the same plant as well as between offspring of different plants (%Crabb, 1947). This method provided a way for botanists to compare characters between generations of plants as well as to trace the heredity of specific traits from an individual plant to a population of offspring.

Although initially developed by European cartographers engaged in survey work, the quadrat method was elaborated by American ecologists trying to control the uncertainties of determining environmental boundaries in the field. This method utilized a black-box perspective (%Wimsatt, 1980) which ignored hereditary variations among the plants which ecologists examined. The quadrat method consists of laying down an arbitrary grid with sections, or quadrats, of equal size. Early quadrats were large areas which could be qualitatively compared in terms of the abundance of different plants in each area. Between 1896 and 1905, ecologists working at the University of Nebraska used the quadrat method to attempt to locate the boundary between two types of prairie, each dominated by a distinct type of grass. A series of quadrats were established across Nebraska in a straight line. Each quadrat was small enough for researchers to count the plants within the quadrat in a single day. Boundaries between two different environments could be identified when the numbers and types of plants within each quadrat were compared (%Tobey, 1981). The quadrat method provided plant ecologists with a quantitative approach to the problem of the relationship between plants and the environment.

Transplant garden experiments were developed by taxonomists in order to distinguish hereditary factors from the effects of the environment on plant development. Standard garden experiments involved collecting specimens from different geographic populations of the same species and cultivating them in a single garden. Variations observed among these plants was assumed to be genetically based, since all were subject to identical environmental conditions. Reciprocal transplant experiments involved collecting specimens from populations of the same species and establishing ramets (sections from the same plant) in standard gardens at different locations. Variations observed among ramets from the same plant in different gardens was assumed to be the result of different environmental influences on identical genetic material.

Standard garden experiments utilized a black-world perspective in which the environment was assumed to have an equal effect on different hereditary types. Reciprocal transplant experiments utilized a black-box perspective in which only those variables resulting in observable changes in the plants were considered important. The result of this flexible packaging of experiments was that the interaction between plants and their environment was never the subject of investigation. This type of packaging is particularly characteristic of work related to classification in which results from other lines of work are brought together.

Experimental work in botanical laboratories was restricted, for the most part, to anatomical and physiological comparisons of different types of plants (%Rodgers, 1944a). Studies of fungi and bacteria entailed the use of microscopes as well as incubators and other equipment for growing out colonies of these organisms. Early work on fungi attempted to determine the relationship between these organisms and various diseases (%Harding, 1947). Chemical and cytological comparisons of different plants were frequently done after 1900. However, the problems of modern biology were not easily distinguished in experimental work with plants. Botanists had greater difficulties applying the reductionist research strategies used in experimental work than did biologists working with other types of organisms (%Gerson, in prep.; Volberg, 1982). Attempts to control different aspects of organisms and environments led botanists to develop methods which packaged these variables differently.

Classification Work

Classification involves the arrangement of a body of knowledge in such a way that it can be easily retrieved by others. Most fields of human endeavor include some system of classification to which novices are introduced, usually quite early in their training. Scientific disciplines, artistic and craft worlds, and professions have taxonomies of the knowledge which they both generate and use. The system of classification associated with any such arena will usually contain within it the strains and contradictions of the work and world with which it is associated. The system of classification used in botany underwent changes as changes occurred in collecting and experimental work.

Classification in botany, and in biology more generally, is characterized by a fundamental paradox. On the one hand, the system of classification is supposed to be stable and preserve information which has already been produced. For this reason, taxonomists are concerned with maintaining control over how the fundamental units of the classification system are defined. On the other hand, the system of classification is supposed to be flexible in order to absorb new information as it is created. This means that taxonomists must also worry about the uncertainties inherent in work with different types of organisms.

The botanical system of classification was initially based on materials obtained through survey and collecting work. By the end of the 19th century, a tremendous amount of new information about biological organisms had been generated by researchers engaged in experimental work. The fundamental categories of the classification system were challenged by this new information and debates raged throughout the professional community about the criteria by which such categories were to be defined. The paradox contained within the botanical system of classification was further compounded by the multiplicity of audiences making use of this information. These audiences included botanists working in the field as well as in laboratories, plant breeders and distributors, and hobbyists. These groups of users were interested in different characters of the organisms with which they worked and each class of users wished the system of classification to reflect the importance of the particular set of characters with which they were concerned.

The classification of organisms is important for a number of reasons. The system of classification arranges information about different organisms, their structure, development, and the conditions under which they are usually found. Botanists, breeders, and hobbyists all require these types of information in order to successfully raise and reproduce the organisms with which they are concerned. Classification also provides a way to talk about the relationships among different types of organisms and between organisms and the environment. The spatial and historical relationships among species and varieties of organisms form the intellectual core of biology and the research activities of professional botanists are directed toward explaining such relationships. The manner in which a classification system is arranged depends on commitments to different types of work in different institutions.

Classification work in botany requires a permanent physical facility where specimens can be stored, retrieved, and examined. This type of work has complex relationships with other lines of work, since it both depends on and is required for these other going concerns (%Hughes, 1971). Doing classification work does not require elaborate and sophisticated equipment. Information produced by workers in other institutions and lines of work can be used. Classification work tends to be done in long-established institutions whose resources are committed to providing space for storage and adequate clerical support for this type of work.

Classification work is not, in itself, technically complex. The tasks involved in this type of work include preserving specimens collected in the field, describing, cataloging, and comparing these specimens, and publishing the results of this work in journals devoted to publishing lists and descriptions of new and revised species (%Gleason, 1960). There are uncertainties and constraints attached to each of these tasks. Collecting specimens, as we have seen, is subject to a set of contingencies which affect later classification work. Specimens may not accurately reflect the extent of variation in the population from which they were taken. Specimens may be damaged during transportation to the institution where they will be stored. The process of drying and preserving specimens often changes the texture and color of different parts of the specimen. Processes of preservation often include the application of chemicals to specimens which may induce additional physical changes.

The description and cataloging of specimens is also subject to uncertainties. Description of a specimen rests, in large part, on the state of preservation of the specimen. The cataloger may not take note of damage to the specimen or of changes in coloration due to preservation. The measurements taken of a specimen may not include all of the characters that are wanted by the cataloger. Once specimens are preserved, measured, and described, they are arranged in series and compared with one another. If collectors have not found enough specimens, or if specimens have been damaged, the cataloger may have difficulties constructing a complete series of specimens of a particular species. This has consequences later for the boundaries that are drawn between species, since an incomplete series of a single species may be classified as two separate species (%Gould, 1977).

The staff needed to support classification work do not require highly technical skills to do what are, for the most part, routine clerical tasks. Pressing and preserving specimens, illustrating or photographing specimens, filling out and filing cards describing each specimen are all part of the work which supports classification work. After the beginning of the 20th century, when institutional support for classification work declined and funds for clerical support became difficult to obtain, taxonomists often did these clerical tasks themselves.

Classification work differs from both survey and experimental work in its dependence on other types of work for information. Without the contributions of other lines of work, there would be no classification work in botany. These other lines of work are, in turn, dependent on classification work for filing and retrieving the information which they generate. This mutually dependent relationship has contributed to debates about classification since the 18th century. Most of the institutions which sponsor botanical research support herbaria as well, along with a resident systematist. Although classification work is done in many different kinds of institution, museums and botanical gardens dominate this type of work. It is in these institutions that classification work was first done and it is these institutions which provide the space to store large numbers of specimens, the expertise to preserve them, and the clerical staff to retrieve them when needed.

The mutual dependence of classification work and other lines of work in botany also means that changes in other types of work have an impact on classification work. Botanists working in the laboratory "discovered" new types of organisms to be classified as well as new types of information about organisms already classified. Improvements in the instruments used in the laboratory provided botanists with information about cytological, chromosomal, and biochemical characters of organisms. This array of new criteria were used in adjusting the system of classification. Botanists doing experimental work in gardens and greenhouses added to knowledge about the relationship between organisms and their environments. This information was used to challenge, in turn, the existing system of classification.

The Linnaean system of classification in botany was developed in the early 18th century. It was based on comparisons of sexual (and more specifically male) characters of plants (%Farley, 1982). Careful records of specimens examined in this way were kept and species were classified on the basis of these characters. By the beginning of the 19th century, deciding where an organism belonged within the classification system had become extremely difficult. Retrieving information about an already classified organism was equally hard. Botanists engaged in classification work sometimes gave different plants identical names; in other cases, similar or related plants were given two or more names (%Gleason, 1960).

In the mid-1800s, a number of young botanists in France and America urged a reform of the existing system of classification in botany. The new system of classification adopted by de Candolle in France, by the Hookers in England, and by Torrey and Gray in the United States was based on several new criteria. Leaf shape, stem patterns, and characters of flowers such as number of petals, in addition to sexual characters, formed the basis of this augmented system of classification. Reform of the classification system in botany was tied to the development of public Natural History collections, to the expansion of survey and collecting work, and to developments in cytological research, all of which occurred in this period.

With the development of experimental work, and growing institutional support for such work after 1880 in the United States, came further changes in classification work. Advances in microscopical power provided taxonomists with new types of characters to compare. The development of experimental work led some taxonomists to incorporate developmental characters into the classification system rather than relying solely on characters of mature plants (%Constance, 1958). This movement was particularly strong in cryptogamic botany, where work with fungi and bacteria challenged the established notions of plant classification.

As survey, experimental, and classification work continued in the last decades of the 19th century, existing categories of the classification system were stretched almost beyond recognition. Common-sense categories based on widespread agreements about how the natural world was organized and operated no longer seemed useful. Cytological research provided evidence for much greater continuity between plants and animals than had been suspected (%Farley, 1982). Another important distinction made by botanists before the 20th century, between wild and cultivated organisms, was also challenged in this period. Most botanists, breeders, and hobbyists accepted the notion that domesticated species of plants exhibited far more variability than similar, often related, species found in uncultivated areas. Survey work revealed a great deal of variability among populations of plants found in the wild. This led some botanists to argue that cultivated plants should be included in the classification system (%Overfield, 1975; %Rodgers, 1949).

Perhaps the major challenge to the existing system of classification in botany came from survey work. For almost two hundred years, the system of classification in botany had rested on distinctions between _types of organism_ (whether these were anatomical or physiological). Survey work provided a new emphasis on distinctions between _types of environment_. The massive program of plant introduction, launched by the American government in the 1890s, provided further support for this change. The successful introduction of a plant to a new environment depended on similarities and differences between the environment to which the plant was adapted and that to which it was introduced (%Crabb, 1947, %Rodgers, 1949).

Classification work was done by many different botanists although specialists in different types of organisms were well-known. Students were introduced to principles of classification early in their training and teachers, of necessity, knew something of this subject. Collectors and experimenters in botany all made use of, as well as caused changes in, the system of classification. Perhaps because of its widespread applications, many botanists applied the results of their experimental or survey work to existing categories. When these results challenged the existing system of classification, botanists urged changes in the system to reflect the new information (%American Naturalist, 1908).

Institutions, Disciplines, and Types of Work

Each of the types of work done in botany (as well as in forestry, agriculture, and horticulture) entails different kinds of uncertainty. The methods developed by botanists to investigate evolutionary problems were designed to increase their control over the uncertainties of their work. Different kinds of work involve different varieties of uncertainty. Survey and collecting work entails uncertainty about whether an area has been mapped adequately. Distances between landmarks and sampling procedures are open to alternative interpretations, since surveyors and collectors rely on on different instruments for measurements and since sampling is so subject to bias (%Robinson, 1950).

Experimental work also entails various types of uncertainty. Experimentalists cannot be certain that their control over all the parameters in an experiment is complete. Correlations between two variables may, in fact, be related to a third or fourth variable which has not been taken into account. The organisms used in experimental work also have an effect on the results of such work. Uncertainty about the location and permeability of the boundary between organisms and their environments contributes to uncertainty about the results of experimental work.

Classification work involves other types of uncertainty, including the packaged uncertainties of other lines of work. Taxonomists cannot be uncertain that the sample of specimens they have collected or obtained reflects the full extent of variation within a population. They are rarely sure about whether these specimens will produce offspring with similar characters since these specimens may not be living or may be difficult to reproduce.

After the mid-1800s, classification work was done largely in museums and at botanical gardens. Large numbers of naturalists and collectors returned with or sent back specimens of flora from many parts of the world. As survey work in the Western territories of the United States continued, museums and botanical gardens provided facilities for storing and preserving these records of the resources of the continent (%Rodgers, 1942). The institutions where these collections were maintained also supported breeding work with new types of plants (%Farber, 1982). Definitions of the species concept were subject to intense debate as new types of organisms stretched the existing categories of the system of classification (%Farley, 1982; %Volberg, 1982).

Experimental work requires more elaborate physical facilities than collecting and classification work. Experimental work developed at academic institutions where resources were not committed to housing and preserving large collections of specimens. The physical and technical requirements for experimental work gradually became more elaborate and required greater investments on the part of institutions supporting this type of work. Increased control over environmental variables required more sophisticated machinery as well as more highly trained staff to maintain the equipment. Universities and private research institutions commanded such funds, while museums and botanical gardens had committed their resources to support collecting and classification work. These institutions were unable to follow the entrepreneurial direction taken by newer types of institutions. Surveying and collecting work continued to be supported by federal and state agencies interested in gathering information about natural resources. Specimens collected in the course of such work continued to be stored at museums and botanical gardens. Some federal agencies, such as the Department of Agriculture, were successful in supporting experimental work after gaining access to resources not yet committed to other types of work. Other federal agencies, such as the Department of the Interior, were unable to support experimental work because of prior commitments to survey and collecting work as well as changing alliances in existing political arenas.

The boundaries between types of work and types of institutions were rarely clear-cut. Classification work, for example, continued to be done at universities and colleges. Many universities supported important herbaria and botanical gardens, including Washington University in St. Louis, Harvard University, and the University of California. Experimental work, too, was not confined to the universities; both the Missouri Botanical Garden and the New York Botanical Garden supported laboratory facilities for botanical research. Survey and collecting work was sponsored by botanical gardens and universities as well as by federal and state government agencies.

Survey and collecting, experimental, and classification required rather different institutional commitments in terms of technology, training, and funding. Between 1880 and 1920, these different types of work gradually came to be done in different institutions. Before the 1880s, survey and collecting work, classification work, and experimental work were all done in a variety of institutions. In this period, individual scientists also engaged in these different types of work. By the 1920s, however, surveying work was done largely by federal and state agencies, classification work was done for the most part in museums and botanical gardens, and experimental work was done at universities, agricultural experiment stations, and in private research institutions. Individual scientists were also constrained by commitments to dominant styles of work and narrow intellectual problems within disciplines.

The gradual segmentation of intellectual disciplines reflects different mixtures of these types of work. Ecology grew out of the tradition of survey work. Genetics was largely an experimental line of work, although population genetics rested heavily on survey work. Taxonomy consisted of classification work and depended heavily on other lines of work in botany for new information. A variety of specialized lines of work were based on classification by <u>types of organisms</u>, such as mycology (i.e. study of fungi) and bryology (i.e. study of mosses). Another set of disciplines were based on classification by _types of environments_, including forestry, limnology, and agrostology. These different lines of work reflected commitments to different methods of classification and to different problems within different types of institutions.

Botanists often made use of the research results of other scientists. The uncertainties of different types of work did not carry over into the adopting line of work. For example, the uncertainties of classification work were ignored by botanists doing experimental work with different types of plants. The uncertainties of survey work, and particularly the problems of sampling, were ignored by experimentalists using the results of this work. The uncertainties of survey work and experimental work were downplayed by botanists doing classification work. The possibilities for "packaging" anomalies (%Gerson & Star, 1983) were increased by the institutional and intellectual segmentation which took place in botany after 1900. Packaging was done both by producer and consumer lines of work. With producers and users no longer located within the same institutions, the possibilities for packaging anomalies increased. Challenges to the packaged results of botanical research increasingly took place _across_ institutional and intellectual boundaries rather than within such boundaries.

Conclusion

Between 1850 and 1950, there were at least three basic types of work in botany, including survey and collecting work, experimental work, and classification work. Classification work was particularly interesting because of its dependence on survey, collecting, and experimental work. These types of work were, in turn, dependent on classification work for cataloging and retrieving information about types of organisms and types of environments. The types of work which made up botanical research can be arranged on a continuum stretching from remote areas surveyed, mapped, and sampled by collectors to sophisticated laboratories housing many types of equipment with which to control the conditions under which organisms could be grown out and observed. The level of control over environmental conditions as well as the level of sponsorship for such types of work varied during this period. Survey and collecting work was less expensive than most types of laboratory work and required less in the way of equipment. Laboratory work provided researchers with greater control over some of the conditions of their work, although such control was seldom complete. Survey and collecting work requires little in the way of supporting staff, in contrast to laboratory work where scientists must rely heavily on technicians.

There were many varieties of survey and collecting work, and even more types of experimental work. All of these types of work, however, were characterized by environmental constraints, constraints imposed by sponsors of the work, and by different levels of technical and mechanical assistance. Uncertainty about the results of scientific work was generally packaged in such a way that audiences did not see the anomalies with which researchers were faced. As different types of institutions specialized in the support of types of work, and as intellectual disciplines, each based on a different mix of survey, experimental, and classification work, segmented out of botany, the opportunities for ignoring or discounting the uncertainties of other types of work increased. The uncertainties of packages taken from other lines of work were neither presented by the producers nor raised by the consumers.

After 1900 classification work declined rapidly in importance. At the same time, taxonomists were engaged in extremely bitter debates about their work. Both of these developments were the consequence of growing intellectual and institutional emphases on experimental work. Both were also the result of the strains associated with packaging the results of other types of work. The criteria developed and used by botanists doing different types of work led institutions to adopt different systems of classification. Botanists doing classification work were involved in sorting out the contradictions and uncertainties of the results of survey and experimental work. In spite of the fact that most botanists regarded classification as a fundamental aspect of their work, there was widespread disagreement about the fundamental unit of analysis to be used in the system of classification as well as about the criteria by which this unit should be defined. After 1920, however, taxonomists agreed to give the criteria used by experimental researchers the greatest weight in doing classification work. This gave the prestige of genetics a further boost, while simultaneously contributing to the jettisoning of ecological problems from botany.

Footnotes

(1) Maps are an important device for representing information which others can use. The development of thematic mapping depended on methods of topographic mapping developed by European cartographers in the 17th and 18th centuries (%Thrower, 1972; Wilford, 1981). Maps form an interesting contrast to statistics as a form of representation, particularly when we consider that both played a role in the development of the disciplines of geology and ecology (%Rudwick, 1976; %Tobey, 1981).

(2) The discussion of characters of plants and the uncertainty which work with these organisms generates for botanists rests on reading of a variety of technical sources. These are included in the Bibliography.

(3) The fact that biologists and naturalists work with different types of organisms has consequences for those who study their activities. Historians who study embryologists, for example, may develop different interpretations of historical events than those who study botanists (%Allen, 1978; %Rodgers, 1944a).

CHAPTER FIVE

DEBATES ABOUT CLASSIFICATION IN BOTANY

Introduction

Every scientific world develops an associated system of classification which codifies and categorizes the knowledge produced by the participants of that world. The classification system contains the strains and contradictions of the world with which it is associated. Most classification systems contain a fundamental paradox: they must be stable enough to be useful to more than one generation of users and at the same time they must be flexible enough to accomodate new information generated by those users. The strains of encompassing this paradox are reflected in the debates and arguments among the users of a system of classification.

There were enormous changes in the context within which botany developed between 1880 and 1920. During this period, the definition of the species became a major subject of debate within botany (and biology) as researchers attempted to use it in a growing number of ways. New varieties of technology provided information about organisms which challenged the existing classification system as well as generating new criteria by which the fundamental unit of analysis could be defined. Continuing research challenged the categories which botanists had taken for granted. Uncertainties about the boundaries drawn between plants and animals, between cultivated and wild organisms, and between internal and external forces of change in organisms grew out of institutional and intellectual changes in biology as a whole. These uncertainties led researchers to attempt to control as many of the variables in their work as possible. The boundaries which researchers established in their work with organisms in the laboratory supported the categories already established in the system of classification. Researchers whose work did not support these categories had growing problems obtaining resources to continue their work.

Robustness and the Species Concept

The species concept is the fundamental unit of analysis in the biological system of classification. This concept provides boundaries around the many types of organisms which biologists study. These boundaries help researchers to organize the information which they generate about the empirical world. Over a period of two centuries, this concept changed a great deal. Different researchers, working at different times and in different institutions, used many different criteria to define this unit of analysis. However, in order to control some of the uncertainties associated with their work, biologists treated the species concept as robust.

Robustness can be defined as a coincidence of boundaries which creates a discontinuous change in several measurements of an entity and its environment (%Wimsatt, 1976, 1981). The quality of robustness is not inherent in the empirical world. Instead, robustness represents the result of negotiations among those investigating a given phenomenon. Coincidence of boundaries is usually the primary reason for accepting an object or entity as real. However, different tests of a boundary may provide researchers with different answers to the question of where the boundary is located. Debates develop when researchers, assuming that they are referring to the same entity, in fact locate the boundaries of organisms differently.

The central problem for biologists was (and is) that the species concept is not robust. The use of different criteria (i.e. morphological, physiological, and genetic) sometimes provided researchers with different boundaries for the entity under investigation (1). Individual organisms were considered robust because the coincidence of a number of boundaries created a discontinuous change at what researchers took to be the boundary between the organism and its environment. The robustness of the individual organism provided researchers with a powerful analogy by which they treated the species as a robust entity. Debates about the species concept have persisted precisely because this entity is not robust.

Boundaries can be thought of (and are generally treated as) lines between things. There are several different types of boundaries that researchers draw, each of which reduces the complexity of a phenomenon in different ways. First, boundaries divide continuous series into two or more parts which may then be treated as discrete. Second, establishing boundaries means that an inside and an outside (or a system and its environment) can be distinguished. Changes on one side can then be correlated with changes on the other side of the boundary. Third, boundaries divide temporal processes into sequences which can then be compared to other temporal processes or to spatial distributions. Dividing a continuous series into parts, establishing an inside and outside, and sequencing all allow the researcher to focus attention selectively on particular aspects or features of the phenomenon. Establishing boundaries is a particularly useful way of converting ill-understood or difficult-to-study processes or continua into more easily studied parts (2).

The fact that the species was not a robust representation meant that researchers could use different criteria to locate the boundaries of this entity. Different definitions of species were constructed from a number of criteria. The use of different criteria yielded evidence about the boundaries of the same organism which did not always coincide. The development of new methods and tools provided researchers with new criteria for distinguishing boundaries and sequences in the empirical world. These new criteria varied in their fit with criteria already in use. Different criteria also varied in their usefulness to researchers attempting to define species and study speciation among different types of organisms.

Arguments about the nature of species were often based on the use of multiple criteria from different lines of work with distinct types of organisms. Participants in debates carefully blended different types of evidence in their arguments. Where one type of evidence was unavailable, an alternative type of evidence was often substituted (3). Shifting among types of evidence concealed the lack of robustness of the boundaries set by researchers.

When the boundaries established by researchers using different criteria and working with different types of organisms did not coincide, and sometimes even when they did, researchers negotiated about how and where boundaries were to be located. Debates developed as a consequence of disagreements over where the boundaries of a phenomenon were located. Debates also developed as a consequence of disagreements over how boundaries were to be identified (i.e. the criteria to be used). While these types of debate can be distinguished analytically, they were not always clearly distinguished by researchers attempting to reach an agreement over procedure.

The Species Concept and Reductionist Research Strategies

Reductionist research strategies, like other recipes for action, rely on the use of heuristics. Heuristics are cost-effective, theoretical devices for solving problems in an approximate way (%Wimsatt, 1980). Researchers adopt heuristics when faced with problems of enormous computational complexity or when the dimensions of an object offer convenient boundaries. Establishing boundaries acts as a heuristic in breaking problems into smaller component parts by laying a grid of discrete categories over phenomena which otherwise appear continuous. Existing discontinuities create de facto boundaries which often are not questioned until evidence emerges to contradict this working assumption. For example, the existing boundary of the skull served as the de facto boundary of the mind for researchers and physicians working on neurological problems at the end of the 19th century (%Star, 1983a).

Whether a heuristic is adopted for reasons of computational complexity or for reasons of assumed robustness, the value of this problem-solving technique is two-fold. First, decomposing a problem via the use of one or more heuristics allows the dimensions of the problem to be treated as distinct and independent variables. This not only simplifies the problem but allows (often tacit) mapping back and forth between dimensions. Second, as sub-problems are distinguished and decoupled, these parts of the problem can be solved sequentially as unconnected problems. The computational advantage here is that the researcher does not have to pay attention to all of the sub-problems at once.

The use of heuristics permits the complexity of empirical relationships to be hidden and simplified. Treating variables as distinct and independent requires the use of abstractions which may not all be identical. This method depends on a "fiction" in which "a knife-edge present is ... set up for the purposes of the most exact measurement possible" (%Mead, 1938: 220). The differences among these abstractions remain obscured from researchers and their audiences, however, by selectively focusing on one or another variable while treating the others as unchanging for the moment.

As a result of the control which reductionist research strategies appeared to promise, they were widely adopted in biology after 1880. The intellectual consequences of the success of reductionist approaches in biology included: (1) the separation of the problems of species and speciation (i.e. structure and process); (2) the distinction between heredity and environment in the analysis of evolutionary processes (i.e. inside and outside); and (3) the separation of sequences at the individual level and at the population level (i.e. ontogeny and phylogeny). The boundaries between these problems were not well-established until after 1920. Even after the 1920s, debates over the boundaries of the species continued between researchers engaged in classification work and those engaged in experimental work, between genetic and ecological researchers, and between researchers interested in individual organisms and those interested in populations.

Species and Speciation

Distinguishing species from processes of speciation depends on the distinction between space and time. The species is usually conceived of as an entity with boundaries in space while speciation is thought of as the process by which that object comes into and passes out of existence. The interactive relationship between these dimensions is lost, however, when they are treated as distinct. For biologists in the 1880s, severing the connection between the spatial and temporal aspects of the species reduced the complexity of the problem to be investigated. Researchers continued to have difficulties, however, with the definition of the species.

Within any given work context, the species can alternate between a representation of a spatial distribution and a temporal process. In doing classification work, the species was generally treated as a spatial phenomenon although acknowledgement was made of the historical process by which such spatial distribution was achieved. In doing experimental work, the focus of attention was on mechanisms of speciation rather than on the distribution of species. These two problems were not consistently treated as independent until after the beginning of the 20th century. Even today researchers continue to substitute distributional or spatial evidence for historical evidence in arguments about speciation (%Volberg, 1982).

Heredity and Environment

As experimental investigation of mechanisms of speciation (or evolution) continued, heredity and environment came to be treated as distinct and independent variables (%Cravens, 1978). Distinguishing these variables required the researcher to locate a boundary between the inside and the outside of the individual organism. The robustness of this boundary varied depending on the type of organism under investigation. Organisms which changed rapidly and radically in response to changes in the environment were more difficult to determine than organisms which changed little. As experimental work continued during the 1880s and 1890s with microorganisms and plants, researchers had increasing difficulty pinpointing the boundary between organisms and environments. These types of organisms were extremely plastic in their responses to environmental changes. In addition, the environment at one level of organization could be the system at another level of organization.

Over the first few decades of the 20th century, focus turned increasingly to the role of heredity (i.e. the inside) in the process of speciation. Reductionist research strategies appeared to offer a substantial degree of control over the environment provided for experimental organisms. Researchers working with organisms which could not be raised and reproduced in the laboratory had greater difficulties adopting reductionist research strategies. Researchers working in greenhouses, experimental plots, and in the field were unable to control and simplify the environment easily. Nor were their attempts to control hereditary variables very successful, although research early in the century work on did indicate that there were limits to hereditary variability (%Provine, 1971).

Simplifying organisms instead of the environment led researchers to emphasize a different set of boundaries. Rather than emphasizing the boundaries of individual organisms as robust, researchers treated the boundaries of geographic regions as robust. These different perspectives gave rise to arguments about both types of boundaries. Different perspectives also led researchers to disagree about the criteria to be used in the biological system of classification. Researchers argued about whether the classification system should be based on distinctions among types of organisms or among types of environments.

<u>Sequencing</u>

In the same way that spatially continuous phenomena can be separated into discontinuous parts, developmental processes may be separated into bounded steps or sequences. The value of establishing this type of boundary is that development at a lower level can be <u>mapped up</u> to the development of the system, or conversely, the development of the system can be <u>mapped down</u> to the sub-systems. Sequencing acts to tie together two levels of phenomena by interlocking two distinct developmental processes (4). The relationship established between sequences at different levels of organization varies with the robustness of the boundaries of the entities under investigation.

Sequencing depends on the abstractions of space from time and of organism from environment. If these dimensions are treated as distinct, the complexity of mapping from a single individual to an aggregate or _vice versa_ becomes greatly simplified (%Robinson, 1950). Abstracting objects from the processes by which they come into and pass out of existence permits further abstraction of the process into a series of steps which may then be mapped onto development at another level. When a developmental process is extremely long, as is the case with evolution, this heuristic device reduces the analytic complexity of this problem dramatically.

Researchers doing different types of work made use of these different heuristics to reduce the complexity of the problems with which they were concerned. The abstractions which worked with one problem, however, did not always fit easily with abstractions which worked with other problems. Simplifications of the environment worked in the laboratory because the complexities of the relationships between space and time, between organisms and the environment could be systematically screened out. The environmental boundaries established by fieldworkers were less robust than those of individual organisms. Simplifications of the environment were made more difficult because researchers disagreed about how and where such boundaries should be located. In particular, researchers doing classification work were obliged to wrestle with the contradictions created by the use of different heuristics in other lines of work.

<u>Botanical Research and Botanical Classification</u>

Classification systems tend to reflect common-sense understandings of the world. Like the distinctions between plants and animals, and between cultivated and wild organisms used by naturalists in the 19th century, distinctions between space and time and between individuals and populations were incorporated into the biological system of classification after the beginning of the 20th century. The crucial change in the species concept was the transformation of this unit of analysis from a <u>spatial entity</u> to a <u>temporal process</u>. This transformation was never complete; rather, for different purposes, the species was treated as more or less spatial or processual. In classification work, the species was usually treated as a spatially-distributed phenomenon while in experimental work, temporal processes were the focus of attention. Researchers could move back and forth between these perspectives without realizing the substitutions that were made.

As new biological lines of work developed at the end of the 19th century, new criteria for the definition of species also developed. Between 1890 and 1920, arguments raged among biologists about how different criteria should be weighed in relation to one another and about how to standardize the system of classification. Researchers and institutions with lengthy commitments to morphological work resisted the incorporation of new criteria while experimental researchers argued that physiological criteria should carry the same weight as morphological criteria.

Until the early 1800s, botanical classification was a relatively straightforward matter. The Linnaean system was based on an Aristotelian view of species as "ideal types" which could never be realized in nature (%Hull, 1965; %Ruse, 1969). This system was based on comparisons of sexual characters of plants and was largely limited to the classification of flowering plants (%Farley, 1982). By the 1850s, deciding where an organism belonged within the classification system had become more difficult. Explorers and collectors provided naturalists with thousands of new organisms which were difficult to classify according to the Linnaean system. Fungi, mosses, and ferns lacked the clear sexual characters found among flowering plants. Communication among centers for classification work was limited and botanists sometimes gave different plants identical names; in other cases, similar or related plants were given two or more names (%Gleason, 1960).

In the mid-1800s, a number of botanists in France, England, and America urged reform of the existing system of classification in botany. Reform of the system of classification in botany was tied to the development of public Natural History collections, to the expansion of survey and collecting work, and to developments in cytological research. The new system of botanical classification reflected changes in the tools used by botanists as well as changes in the amount and type of material to be classified. This system of classification came into widespread use outside of France after the Kew Gardens in England and the U.S. National Herbarium adopted its principles in organizing their collections (%Brockway, 1979; %Rodgers, 1949).

The new system of classification was based on several new morphological criteria. Characteristics of root, stem, leaf, and fruit as well as added features of flowers such as the number of petals, formed the basis of this augmented system of classification. Non-flowering plants were expanded from one of 24 classes in the Linnaean system to one of three major categories in the Candollean system (%Farley, 1982). The Linnaean system of classification was oriented to the needs of practical horticulturists, plant breeders, and naturalists working at institutions which housed large collections of specimens (%Allen, 1976; %Farber, 1982). This system of classification was primarily designed to help identify individual plants. Users also had access to information about the conditions under which an organism was known to thrive. This was important to breeders, who were beginning in this period to raise new (often tropical) organisms for profit, and to naturalists trying to propagate new types of organisms in zoological and botanical gardens.

By the 1850s, evidence from overseas, from paleontological research, and from work on plant and animal reproduction pointed increasingly to the notion that species changed over time. The extent of variation within species reduced the usefulness of the "ideal type" for purposes of identification. The theory of evolution made variation within species the basis for their transformation (%Gerson, in prep.). Evolutionary questions added a temporal dimension to the fundamental unit of the classification system. If species changed over time, what were the criteria by which an individual organism could be identified? Differences between individual specimens might be the result of variations within species or between species. At what point did variation become the basis for a new species? If species changed over time, how were the relationships among existing and extinct species to be categorized?

The problem of reconstructing the relationships among species became an important part of classification work during the 1860s. Adding a temporal dimension to the system of classification meant that the boundaries drawn between species could be either temporal or spatial or both. Drawing spatial boundaries made use of morphological and geographic criteria. Drawing temporal boundaries made use of fossil evidence and physiological criteria. Adding a temporal dimension to the system of classification increased the importance of the question of how evolution proceeded (i.e. gradually or in discrete jumps). If evolution proceeded in jumps, then the boundaries between species were easy to define. If evolution proceeded gradually then the boundaries between species were more difficult to draw.

Emergence of New Criteria

Until the 1880s, classification work in biology continued to be based almost exclusively on morphological comparisons of organisms. While physiological research began early in the 19th century in Europe (%Farber, 1982), this new set of criteria was not immediately incorporated into the system of classification. Morphological features were most useful to researchers working in museums and herbaria. Physiological criteria were more useful to researchers doing experimental work at universities, agricultural experiment stations, and later private research institutions. Classifying physiological features meant expanding the boundaries of the species to include sequences of development (%Arthur, 1908).

By 1900, the botanical system of classification had several different types of users with quite distinct purposes. Botanists engaged in experimental and physiological work were concerned with the analytic problems of speciation and heredity. Botanists engaged in classification work were concerned with both the reconstruction of phylogenies and with identification of specimens. Breeders, horticulturists, and agriculturists were concerned, for the most part, with identification of the organisms with which they worked. The system of classification thus served a variety of purposes although only a limited number of criteria were used in the definition of species.

Discovery of New Types of Organisms

A corollary to the expanding number of users of the system of classification was the expanding number of organisms revealed by ongoing exploration and experimental work. Chemical and cytological investigations added different information to the system of classification than the activities of explorers and collectors (%Rodgers, 1949). The information generated by researchers about a variety of new types of organisms at the end of the 19th century led them to challenge long-standing notions about the boundaries found in nature.

Throughout the 18th century, botanists, breeders, and horticulturists generally agreed that domesticated species of plants exhibited far more variability than similar, often related, species found in the wild. During the 19th century, through the efforts of explorers and collectors, evidence of the extent of variability found in the wild poured into museums and herbaria. Botanists doing survey and collecting work found that variation was as common among natural populations as it was among domesticated species. By 1900, several botanists, including Liberty Hyde Bailey and C. E. Bessey, were arguing that cultivated plants should be included in the botanical system of classification (%Rodgers, 1949; %Overfield, 1975).

Another boundary widely accepted by naturalists and biologists was the distinction between plants and animals. This distinction was originally based on common-sense understandings of the organic world. In fact, classification work had for many years segmented along lines which reflected these common-sense understandings. Botany and zoology were devoted, respectively, to the investigation of plants and animals. These disciplines were specialized, in turn, according to types of plants and animals --- vertebrates and invertebrates in zoology, flowering and non-flowering plants in botany (%Gerson, in prep.). Cytological work in many laboratories during the mid-1800s challenged the long-standing distinction between plants and animals. The discovery that all organisms were made up of cells prompted researchers to speculate about parallels in the development of plants and animals (%Farley, 1982). Microorganisms were particularly difficult to classify since they exhibited greater continuity than did higher orders of plants and animals (%Frey, 1966; %Lussenhop, 1974).

A third boundary that had been taken for granted by naturalists was that between organisms and their environments. The extent of variation in nature discovered by explorers and collectors during the 19th century challenged long-standing agreements about the boundary between organisms and their environments. Cytological work also challenged this agreement. Cells had boundaries although they were parts of a larger whole. The notion that boundaries existed at different levels of organization suggested to many researchers that the relationship between organisms and the environment was more complex than had been supposed. This issue was especially pertinent for naturalists and biologists in the early 20th century because of its ties to broader debates about the role of heredity and environment in human evolution (5).

After 1900, a distinction which had not been made in a reliable way before the end of the 19th century began to emerge. This was the distinction between individual organisms and populations of organisms. Until this time, researchers had not been very concerned with the boundary between individuals and populations. This was partly due to problems of reliably distinguishing between levels of organization. Debates in biology after the turn of the century focused precisely on the relationship between levels of organization. A series of critical innovations made in the study of heredity after 1900 all pointed to the distinction between individuals and populations and, together, provided the rationale for focusing on one level or the other (%Gerson, in prep.). Problems remained for biologists studying microorganisms where the boundary between individuals and populations was difficult to draw (%Lussenhop, 1974). Botanists, in particular, had problems with this distinction since plants are capable of asexual reproduction and a population can be the genetically identical offspring of a single individual.

Uncertainties about the fundamental categories of the system of classification were raised by experimental work with old and new types of organisms. The taken-for-granted boundaries incorporated into the classification system were no longer as robust as they had once seemed. At the same time, new boundaries between organisms and the environment and between levels of organization appeared increasingly robust. Between 1890 and 1920, the system of classification in biology underwent several profound changes as new criteria and boundaries were incorporated and old ones were discarded. Just as the older types of work never completely disappeared, however, the older categories of the classification system were never completely discarded.

Classification and the Emergence of Modern Biology

Until the middle of the 19th century, the biological system of classification was oriented primarily to the needs of breeders and horticulturists for identification. By the 1850s, naturalists had become more concerned with evolutionary questions. The theory of evolution added a new developmental dimension to classification work. Problems of identification were augmented by problems of genealogy. Throughout the second half of the 19th century, naturalists were occupied with problems of constructing "family trees" for a variety of species, with concomitant problems of delineating the boundaries between extant and extinct species (%Coleman, 1977).

By the 1880s, naturalists were becoming more concerned with the precise mechanisms by which evolution occurred. Questions about the definition of species waned at the same time that interest in the mechanisms of evolution grew. Biologists interested in problems of evolution adopted experimental approaches to answer these questions. There was little recognition among biologists that the species, their fundamental unit of analysis, was not a robust object. In contrast to most individual organisms, species did not always have the same boundaries nor were all of the boundaries of a given species coincident. Depending on the type of organism under investigation and on the type of measurements made, there was more or less evidence of discontinuous change between two species or between species and the environment.

Nor did biologists uniformly adopt a developmental dimension in their research. Adopting a developmental dimension pushed biologists in the direction of reductionist research strategies, since the complexities of analyzing biological processes would otherwise have been overwhelming. Reductionist research strategies appeared to offer biologists a measure of control over the phenomena which they investigated. These strategies allowed researchers to focus selectively on particular aspects of the phenomenon under investigation. Selective focus on one aspect of a given problem screens out many of the uncertainties of biological research.

As research continued, the consensus as to what constituted a species disintegrated further. The spatial and temporal dimensions of species and the process of speciation were not clearly separated. Nor were the internal and external dimensions of species always clearly decomposed. On some occasions, these dimensions were treated as separate while on other occasions, they were not distinguished. Different researchers used a variety of conceptual and methodological techniques in their work to generate a number of lines of evidence upon which alternative arguments could be built.

The problems and methods of lay audiences of the classification system changed relatively little during the 19th century. The problems and methods of the professional biologists using and contributing to the system of classification changed a great deal. Debates about classification between 1890 and 1920 reflect these increasingly specialized concerns. The system of classification continued to be used by breeders, horticulturists, and hobbyists and identification remained an important part of the system of classification. Professional biologists and naturalists, however, were more concerned with genealogical reconstruction and with questions about evolution.

Incorporating evolutionary theory into the biological system of classification created problems for researchers attempting to delimit the species which they studied. The question of the relationship between organisms and their environments was an issue of major concern. Biologists wondered whether the variation which they observed among organisms had an internal or an external source. Alternative answers to this question committed researchers to answers to the question of whether speciation was the result of internal or external forces. This question of the internal or external source of variation posed additional problems for researchers engaged in classification work. If speciation was the result of environmental forces, then the system of classification should be modified to reflect the importance of the environment in shaping organisms.

The success of genetic research after 1900 was based largely on the demonstration that heredity operated to produce a continuing source of variation. This work did not address the related question of how such variations were selected in terms of their fit with existing environments. Different answers to the problem of variation committed researchers to different answers to the problem of speciation. These problems were complicated by the lack of distinction between generations of organisms and between individual and population variation.

Researchers simplified environmental variables in different ways. Some researchers focused on climatic variables, such as temperature and humidity. Others focused on available moisture and food. These different perspectives led them, in turn, to emphasize very different boundaries between organisms and the environment. As research in genetics continued, the distinction between individuals and populations was made more reliably. The question of the definition of species, however, continued to be subject to routine confusions between heredity and environment as well as between individuals and populations.

The robustness of the boundaries between hereditary and environmental variables and between individual organisms and populations depended on the criteria used to locate these boundaries. The availability of any given criterion varied depending on the type of organism under investigation. Even in cases where a given criterion was available, uncertainties about how to interpret the results of a measurement could influence the decisions of researchers. Agreement on a definition of species was contingent upon negotiations among researchers doing different types of work with a variety of organisms. The distinctions that came to be made after 1915 differed among groups of researchers. These heuristic boundaries allowed researchers to treat these variables separately, controlling for one or the other in any given experiment. These boundaries were drawn differently depending on the uncertainties of work with different types of organisms and on the types of control which researchers attempted to establish.

Classification and Uncertainty

Researchers doing classification work often had problems applying morphological criteria in the definition of species. Variations in the structure of flower parts, for example, did not always match variations in the structure of stems, roots, and leaves. Survey and collecting work produced evidence that variation among organisms followed variations in climate (%Cowles, 1899). Climatic variables became an additional criterion in the system of classification and attempts were soon made to define species on this new basis. However, variations among organisms did not clearly follow climatic variations. Other geographic dimensions, including soil and topography, all became criteria in the classification of plants.

By the end of the 19th century, there were a large number of criteria used in defining species. In many cases, criteria did not exhibit clear discontinuities while in other cases, discontinuities in one criterion did not match discontinuities in other criteria. Researchers had to make relatively arbitrary decisions about where the boundaries of any given species were located. Such decisions left researchers open to challenges by others working with the same or related types of organism. The numbers of such arbitrary decisions made by the end of the 19th century had increased dramatically as a result of the development of new measurement techniques and the discovery of new types of organisms. The many arbitrary decisions made by researchers contributed to the debates about classification in biology in this period.

As research on heredity continued, new criteria were introduced into the system of classification. By 1915, geneticists were producing chromosomal maps (%Allen, 1978). These maps constituted another criterion for use in classification (%Hagen, 1982). While they worked well for certain types of organisms, they were not particularly useful for botanists or for paleontologists. These researchers found it very difficult to use the number of chromosomes as a stable feature for the purposes of classification. It was impossible to get chromosomal information from fossils, while many plants had doubled or tripled their chromosomes between generations.

Researchers working on problems of heredity also based their definition of species on the criterion of interbreeding. Thus, two organisms capable of producing fertile offspring were viewed as members of the same species. Organisms incapable of producing offspring were clearly not members of the same species (%Mayr, 1977). Much of the work in genetics was done with organisms capable of reproducing under laboratory conditions. Organisms unable to reproduce in the laboratory were of little use in this particular line of work and the difficulties of defining species on the basis of the possibility of interbreeding were not immediately apparent to researchers in genetics.

Botanists working in experimental plots and gardens experienced significant problems using genetic criteria in defining species. Plants which were classified as distinct species on the basis of morphological characters were often capable of producing fertile offspring. Other, morphologically similar plants were incapable of reproducing because their physiological and reproductive cycles were so different. Even for researchers in the laboratory, applying the criterion of interbreeding to the definition of species was problematic. Some organisms produced fertile offspring in the laboratory but not in the field. Some organisms which did not breed in the laboratory did so outside of this controlled environment (6).

The uncertainties of working with different types of organisms were important in terms of how researchers defined the species concept. Plants have greater plasticity as well as greater variability than animals, in many cases (%Dean, 1979). There were concomitantly greater problems applying these criteria in botany than in zoology, although the question of the definition of species constituted an important problem in both lines of work. With the growing commitment of biologists to reductionist research strategies and to an internalist explanation of both speciation and species, environmental concerns were gradually pushed to the edges of biological research.

Classification and Control

A broad spectrum of criteria by which species could be defined were available to biologists by the first decade of the 20th century. Morphological, physiological, climatic, spatial, ecological, and genetic characters were all used to classify different types of organisms. In drawing boundaries between species, some of these characters were more useful than others. The usefulness of these criteria depended on the type of organism being classified, the type of work being done with that organism, and the matching of boundaries produced by alternative criteria.

The appeal of experimental approaches in biological research was the promise of greater control over the uncertainties of research with biological organisms. Experimentalists attempted to achieve this control by screening out uncertainties through the use of reductionist research strategies. These strategies became agreed-upon conventions for carving up the natural world in different ways. The use of reductionist research strategies, which depended on selective focus and on establishing different types of boundaries, also enabled researchers to make use of substitutions. In cases where one type of evidence was unavailable (i.e. genetic criteria for fossils), another type of evidence could be used (i.e. morphological criteria). In cases where one type of evidence disagreed with other types of evidence (i.e. genetic criteria and physiological criteria), researchers tended to emphasize the type of evidence which supported their prior intellectual commitments and to downplay or ignore the evidence which did not.

Segmentation and Debates about Classification

A variety of new research techniques came out of both survey and experimental work in the 19th century. These new methods provided researchers with new criteria by which to categorize the phenomena they studied. Researchers also discovered a number of new types of phenomena. Adopting new methods had a major impact on how classification work was done after the middle of the 19th century. Researchers disagreed about how new criteria were to be weighed in relation to criteria already in use. Changes in the system of classification after 1890 rested on changes in botanical research after the middle of the 19th century.

Disagreements about the boundaries of the organic world were resolved by institutional and intellectual segmentation. The longstanding distinction between cultivated and natural populations formed the ideological basis for the institutional split between academic and agricultural botanists. The distinction between heredity and environment was maintained by turning research efforts towards heredity and systematically screening out problems of the environment out of biological research. In arenas where environmental problems could not be screened out, as in agriculture and resource conservation, variations among organisms were screened out instead. Researchers working with organisms which were not amenable to the distinctions made along these dimensions after 1900 had difficulties obtaining institutional support as well as professional recognition (%Hagen, 1982; %Tobey, 1981).

With the elaboration of problems of evolution, the older problem of defining species declined in importance. After 1900, a series of critical innovations served to fracture the problem-structure in biology in a new way. These innovations all pointed to the distinction between individual-level and population-level phenomena and together provided the rationale for focusing on one or the other type of phenomenon. After 1915, institutions, disciplines, and individual scientists still committed to older styles of research (including survey and classification work) had increasing difficulty gaining access to resources such as space, tools, staff, and students.

Intellectual focus and institutional commitments shifted rapidly after 1915 toward the study of individual organisms, on the one hand, and populations of organisms, on the other. A small number of researchers continued to be interested in the problem of defining species. A much larger group of researchers using new criteria to draw the boundaries of species remained marginally interested in problems of classification (%Anderson, 1937; %Dobzhansky, 1944). After 1915, the pattern of disciplinary re-organization became increasingly visible. Ideas and approaches which respected the individual/population split flourished after 1915 while those which did not floundered. This realignment in biology constituted an intellectual and institutional re-organization of the arena (%Gerson, in prep.).

In 1892, a number of young botanists, led by Nathaniel Lord Britton and including John Merle Coulter and Liberty Hyde Bailey, adopted a new code of nomenclature (or rules of classification). Research done by botanists between 1880 and 1900 constituted a series of challenges to the typological definition of species. The promulgation and adoption of the new code of nomenclature served several purposes. First, the new rules served notice of American independence from the European botanical community and its American representatives. Second, the new rules provided some uniformity to methods of naming new plants (%Over-field, 1975). Finally, the uncertainties of classifying organisms in the face of the disintegration of once well-recognized categories provided an opportunity for younger botanists to establish institutional footholds on the basis of innovations in classification.

Disputes within the botanical research community about the rules of classification pitted Britton and his supporters against botanists working in the Gray Herbarium at Harvard University. Work with different types of organisms as well as institutional and regional affiliations influenced the positions taken by botanists in these debates. Eastern botanists split in their support of Britton or the Harvard botanists. Botanists in the West and Midwest were also split; Coulter soon came to disagree with Britton while Bailey appears to have accepted the new rules (%Rodgers, 1944b, 1949). Botanists working in California disagreed with both schools of thought (%Rodgers, 1944a).

The dispute soon spread beyond the research community to involve other audiences such as breeders and horticulturists. Two books published in 1898, Britton's Illustrated Flora and the 6th edition of Gray's Manual (edited by B. L. Robinson) made use of these different sets of rules for classifying plants (%Gleason, 1960). When the U.S. Department of Agriculture committed its publications to the new rules of classification, these practical users, as well as botanists working in the federal laboratories and in agricultural experiment stations, were forced to adopt the new rules (%Rodgers, 1944b). By persuading the major federal institution supporting biological research to adopt the new rules of classification, these scientists effectively coerced other users to adopt the same system.

The problem of defining species did not disappear with the promulgation of new rules for classification. In 1908, the American Naturalist published the proceedings of a symposium on "Aspects of the Species Question," in which two taxonomists, two physiologists, and two ecologists attempted to define the fundamental unit of analysis in botany. It is apparent from these papers that there was as yet no consensus on how distinctions were to be made between heredity and environment or between individuals and populations (%Arthur, 1908; %Bessey, 1908; %Britton, 1908; %Clements, 1908; Cowles, 1908; %MacDougal, 1908). In 1938, the American Naturalist published another series of papers on "Supra-Specific Variation in Nature and in Classification." These papers indicate that arguments over the definition of the species continued among researchers concerned with issues of classification (%Anderson, 1938; Kinsey, 1938; %Simpson, 1938).

It was not until 1910 that the international botanical community adopted a revised set of rules which incorporated the changes in classification work of the previous 50 years (%Shimwell, 1971). The young botanists who had staged the American reform were, by that time, established leaders in American botany. Some of the intellectual furor over fundamental categories of classification had died down as the different distinctions between organisms and environments and between individuals and populations became standard.

Members of the botanical research community varied in their participation in the debates about the adoption of the Rochester Code. Geneticists were concerned with classification issues only to the extent of arguing that chromosomal characters should be incorporated into the system of classification. Ecologists were concerned with giving heavier weight to environmental variables which affected the development of different species. Taxonomists remained committed to a style of classification which emphasized morphological characters of mature organisms and arranged other types of information within these categories. Breeders and horticulturists had little interest in the finer points of classification work and remained with one or the other system on the basis of prior experience.

Debates about systems of classification tended to be both ideological and methodological. These debates were usually resolved through processes of segmentation, by which researchers acquired a stake in a new or revised system of classification and then parlayed this stake into commitments at the institutional level. Alternative systems of classification were resisted by institutions and scientists already committed to existing systems. New systems of classification, in their turn, were pushed by researchers trying to establish their reputations on the basis of innovations in methods and theory.

Genetics epitomized the experimental approach to biological research. Genetic criteria were easily obtained for many of the organisms with which these researchers worked. These criteria also fit well with the existing system of classification by types of organisms. Genetic criteria were useful to researchers working in laboratories with organisms characterized by fixed numbers of genes. After chromosomal maps were developed, taxonomists, or systematists as they were called after 1930 (7), also found genetic criteria useful. In map form, genetic criteria constituted another morphological character comparable across species (%Hagen, 1982).

Taxonomists were in a difficult institutional situation: their institutional resources were declining and the intellectual focus of biological research was rapidly shifting away from classification issues. Their alliance with geneticists over the issue of incorporating new criteria into the biological system of classification was due only in part to the usefulness of genetic criteria in classification work. This alliance also owed a great deal to the access which taxonomists gained in this way to institutional resources, including equipment, staff, and students as well as teaching and research positions.

By the 1930s, genetic criteria had been incorporated into the botanical classification system. The alliance between geneticists and taxonomists over the adoption of new criteria for purposes of classification was strong enough to resist challenges by ecologists pushing for a classification system based on environmental types. Questions about the influence of the environment on the development of organisms did not disappear. However, classification on the basis of environmental types was subject to more uncertainties than classification on the basis of types of organisms. Environments were more difficult to simplify than organisms and ecologists also had difficulties adopting the experimental methods used successfully in genetics (%McIntosh, 1980).

The alliance between genetics and taxonomy was never complete. Taxonomists had continuing problems defining the relationship between populations and taxonomic units. There was also disagreement among taxonomists over the general usefulness of a system of classification based primarily on phylogenetic distinctions (%Hagen, 1982). Ecological and physiological criteria were more useful in the classification of certain types of organisms (such as plants and microorganisms) than genetic or morphological criteria. In cases where genetic or morphological criteria were difficult to obtain, these alternative criteria were used by taxonomists. The system of classification in biology, then, continued (and continues) to be characterized by a fundamental unit of analysis defined on the basis of a multiple criteria.

Conclusion

New biological lines of work intersected and segmented during the 1880s and 1890s. Several different units of analysis also emerged, each associated with a new line of work. Within lines of work, the usefulness and robustness of these units of analysis varied. There were arguments within ecology, for example, over the usefulness of the community concept as a unit of analysis (%Tobey, 1981). Within taxonomy, there were arguments over how the species should be defined. The usefulness and robustness of these units of analysis also varied between lines of work. Ecologists and taxonomists argued about the relationship between species and communities and both argued with geneticists about the relationship of these units of analysis to populations (%Constance, 1952; %Hagen, 1982; %McIntosh, 1980).

Disagreements within and between lines of work in biology were rooted in the question of the <u>stability</u> of the biological system of classification. If the system of classification were based on too few criteria, its usefulness to numerous audiences would be limited. If the system of classification were based on too many criteria, its usefulness as an organizing system would be limited. Debates about classification revolved around the issue of whether and how new criteria would be brought into the system of classification. Where new criteria did not appear to fit with existing categories, researchers doing classification work resisted their incorporation. Where new criteria fit well with existing categories, researchers doing classification work tended to accept them more quickly.

Debates about classification in biology are extremely longstanding (%Hull, 1965). At times, these debates have been confined to the line of work concerned with classification. At other times, these debates have spread to include other lines of work. During periods when uncertainty about biological phenomena is low, debates about classification are confined to the line of work engaged in these tasks. During periods when uncertainty about these phenomena is high, debates about incorporating new criteria and new categories into the system of classification open up to include lines of work not directly concerned with classification work. This was the case in the 1850s as well as in the 1890s.

Debates about the system of classification in biology have continued precisely because the fundamental unit of analysis in this arena is a political rather than an empirical entity. Uncertainty about how species were to be defined was reduced through both intellectual and institutional segmentation as well as the application of reductionist research strategies. The way in which the fundamental unit of analysis in biology was defined depended on the shifting power and prestige of different lines of work in biology. Those lines of work which had or gained access to considerable academic resources dominated negotiations about the criteria to be used in defining species. Lines of work with access to few academic resources, or with alternative resource bases, developed their own system of classification which reflected their needs.

Footnotes

(1) Biologists continue to have problems defining the boundaries of a variety of phenomena, including social insects, slime molds, and eucaryotic cells (%Wimsatt, 1976).

(2) The transformation of fluid, processual problems into structural, anatomical problems involves the substitution of spatial referents for temporal processes. Spatial referents are more easily packaged and appear more certain than temporal processes. "When temporal events are made discrete, their connections become mysterious. This mystery comes from the spatialization of time and, more specifically, from the mechanical atomic model of temporal events" (%Schon, 1963: 151). The pragmatic philosophers had much to say about this type of transformation. Research into how, where, and when such transformations occur is underway.

(3) "By means of (instituting substitutions) ... a thing which is within grasp is used to stand for another thing which is not immediately had, or which is beyond control ... These become amenable to transformations in virtue of reciprocal substitutions" (%Dewey, 1958: 119).

(4) Establishing boundaries and sequencing are the foundation of substitutions used in scientific work. For example, the use of substitutions permits biological researchers to reconstruct the process of evolution on the basis of embryological and developmental evidence. The notion that "ontogeny recapitulates phylogeny" grew out of the use of substitutions in biological research in the 1880s and 1890s (%Gould, 1977; %Volberg, 1982).

(5) The heredity-environment controversy was based on the biological argument about whether hereditary or environmental factors were more important to individual and to species development. The controversy moved beyond biology into the social sciences in the 1910s and played an important role in public policy debates about eugenic sterilization and immigration restrictions in the 1920s and 1930s (%Cravens, 1978; %Ludmerer, 1972).

(6) For example, while salamanders breed freely in the wild, they are difficult to breed in the laboratory. Although the German herpetologist Kammerer was able to breed salamanders in the laboratory, his research results on the inheritance of acquired characteristics were discredited when other researchers were unable to breed these organisms under artificial conditions (%Koestler, 1972).

(7) "Attempts have been made to distinguish between the terms 'taxonomy' and 'systematics.' ... the terms, in practice, appear interchangeable ... " (%Hagen, 1982: 12-13).

CONCLUDING REMARKS

"The striving to make stability of meaning
prevail over the instability of events
is the main task of intelligent human effort"

(Dewey, 1958)

Introduction

This dissertation has examined the relationships between social, political, and economic arenas, institutions, professional networks and careers, types of work, and debates about scientific ideas. These relationships are interdependent: commitments made to different problems, different technologies, and different sites, operate as constraints on the institutions and individuals acting within these arenas. As arenas change, those parts of arenas committed to prior problems and styles of work are jettisoned. Thus, in the arenas which developed around biological research at the end of the 19th century, conservation issues, museums and botanical gardens, agricultural scientists, ecologists, and classification work were all jettisoned. These participants in the arenas of biological research did not disappear. Instead, they developed alternative institutional bases, technical procedures, and theoretical concerns.

These final remarks include a summary of the report presented here and a discussion of some of the possible directions for future research. The summary focuses on the analytic issues developed in this report, including social worlds, segmentation, and the development of conventions in scientific work between 1880 and 1920. Directions for future research include investigation of types of uncertainty, the relationship between uncertainty and conventions, as well as between classification work and jettisoning, and an analysis of processes of intersection.

Summary

Between 1880 and 1920, the development of economic activities prompted the emergence of a variety of scientific lines of work, as economic and political constituencies demanded resources and expertise to solve problems related to their activities. The development of natural resources in the United States included many economic activities. These activities were distributed regionally across the continent. The extraction and exploitation of various resources entailed different patterns of transportation, communication, and settlement. Numerous interest groups organized around different types of economic activity constituted cores around which social worlds coalesced.

Economic arenas varied in terms of the resources each devoted to political activities. Political arenas which developed on the basis of economic interest groups were crosscut by local, state, and national political arenas. Alliances were made among economic and political interest groups at different levels. The boundaries of economic activities, of political arenas, and of the interest groups associated with different social worlds were seldom clear-cut. Disputes typically arose in geographic regions where the boundaries between economic activities overlapped. As economic development of the West continued, those groups commanding the broadest constituencies and with the most narrowly defined problems were best able to gain access to resources distributed by the federal government. Those without narrowly defined problems, and without powerful constituencies, were less successful in obtaining resources from the federal government.

Economic and political interest groups exerted a powerful influence on the directions in which federal resources flowed. Broad-based social support for scientific expertise was an important factor in how economic problems of the late 19th and early 20th centuries were defined and addressed. Both agriculture and natural resource arenas lobbied for administrative agencies staffed by scientists after 1880. However, agriculture was far more successful in such efforts than were conservationists. The success of agriculture was due to the narrowly defined, technical problems which this economic arena presented to scientists. The agriculture arena was also characterized by a strong, centralized federal agency which was able to mobilize scientific and economic interest groups in support of its technical programs.

The decline of conservation issues, in contrast, was due to the loosely allied constituency of urban reformers and scientists which formed the political base of this social movement. Through administrative and political skill, conservation issues were addressed between 1895 and 1905 in a relatively concerted manner. However, the constituency on which these efforts rested had a broad, and sometimes conflicting, agenda. Conservation issues were not easily defined in technical terms and, as the alliance between urban reformers and conservationists disintegrated in the early 1900s, the resources which this arena had mobilized flowed in other directions. One important consequence of the rising popularity of science in the last quarter of the 19th century was the emergence of new institutional forms to support this type of activity. Gradually, levels of expertise developed among the many lay audiences interested in the natural world and this social world segmented into a variety of more specialized arenas.

Museums and botanical gardens were the oldest institutions supporting biological research. These institutions had long-standing alliances with government agencies involved in survey work, since they housed the collections made in the course of such work. Botanical gardens also supported experimental work as it developed early in the 19th century. However, commitments to classification work prevented these institutions from supporting experimental work in the way that academic institutions did after 1880.

Numerous colleges and universities were established in the United States after the middle of the 19th century. The German university model provided American scientists with an exemplar which they strove to recreate in their own institutions. Gradually, support for research became distinct from teaching and these activities were done in separate institutions or departments after 1900. During this period, academic and agricultural research also came to be done in separate institutions.

The federal government played an important part in the development of biological and agricultural research in the United States. The demands of economic and political interest groups for expertise in addressing the problems of development in the Western states led the government to establish many administrative agencies after the middle of the 19th century. In contrast to other resource problems, agriculture received the bulk of federal support after 1890. Agricultural problems were not subject, as other resource problems were, to jurisdictional battles among federal agencies. Agricultural problems were narrowly defined and the constituency served by federal support in this arena was large and powerful.

Part of the federal support for agriculture came in the form of financial support for educational and research institutions. Agricultural experiment stations were established in each state by the early 1890s. In contrast to academic scientists, however, agricultural scientists were subject to a variety of demands from administrators, local constituents, and academic colleagues. These conflicting demands had consequences for the type of research in which station scientists engaged. The shared interests of station scientists and scientists working for the federal government furthered the development of distinct agricultural science societies and journals after 1910.

Popular interest and philanthropic activities contributed to the development of private research institutions after 1900. These institutions were devoted exclusively to research, in contrast to the graduate, research-oriented universities which developed in the 1890s. Scientists working at private research institutions generally came from academic institutions and remained active in the professional networks supported by academic scientists.

The institutions which developed in the last quarter of the 19th century to support biological research gradually segmented in terms of the professional networks associated with different types of problems as well as in terms of the types of work which each supported. Museums and botanical gardens continued to specialize in the support of classification work. Federal and state government agencies supported survey work and experimental work in addition to training programs. Universities and private research institutions confined their support to a narrow range of research activities, and particularly experimental work, after 1900. Institutional segmentation took place around different core activities, technologies, and sites for survey and collecting, experimental, and classification work.

The success of many institutions in sponsoring experimental work rested on skillful research entrepreneurs who were able to establish niches within existing organizations and build these into going concerns committed to new types of work and intellectual problems. Early American naturalists took advantage of government survey work to establish large networks of collectors who funneled specimens to major museums and herbaria in the East. The first professional botanists were able to establish careers and institutions on the basis of their sponsorship of experimental work in the 1880s. Their students built careers on the basis of specialization in analytic disciplines, such as genetics, ecology, and taxonomy. The segmentation of these disciplines rested on the different experimental methods used in each line of work. While academic and agricultural research relied on very similar methods, the segmentation of these arenas crosscut disciplinary segmentation after 1900 as they came to be characterized by separate professional networks as well as intellectual problems.

The daily work of botanists was shaped by institutional arrangements and professional scientific networks. Work with new types of organisms and new tools was supported by different institutional sponsors. Growing numbers of technical staff were needed to conduct experimental work by characterized the end of the 19th century. The shifting balance among the three major types of work in botany contributed to segmentation in this discipline after 1900.

The emergence of botany was associated with survey and collecting work by European naturalists in the 18th and 19th centuries. Different types of expedition affected the types of mapping and survey work which were done. Growing numbers of government sponsored surveys in the United

States after 1860 gave naturalists opportunities to map regional flora and collect specimens on which to base more theoretical classification work. The development of greenhouse and laboratory technologies allowed botanists to develop more sophisticated experimental techniques. Working in the laboratory limited botanists in terms of the organisms they could use for research purposes. Commitments to improving experimental methods forced botanists to rely more heavily on technical staff. Differences in the methods which botanists adopted caused the greatest problems for the botanists engaged in classification work where the results of other types of research were triangulated.

Classification work consists of placing conceptual boundaries over the empirical world. Classification, experimental, and survey work in the last part of the 19th century challenged long-standing conventions in botany. Since classification work rested heavily on other botanical lines of work, changes in these types of work led to changes in the botanical system of classification.

Survey and collecting work, experimental work, and classification work entail different commitments of institutional resources as well as different intellectual commitments. Between 1880 and 1920, the shifting balance of commitments to these types of work both in institutions and individual careers led to the segmentation of several botanical sub-disciplines as well as to the segmentation of separate academic and agricultural arenas. Processes of segmentation rested on different types of work, the commitments and conventions which each of these entailed, and the shifting balance of these types of work within and among institutions and careers.

Debates about the system of classification in botany between 1880 and 1920 reflect shifting patterns of commitments and constraints. The growing importance of experimental work and the emergence of academic institutions to support this type of work challenged the dominance of classification work within botany. The fundamental unit of analysis in classification work, the species, was not a robust concept in the sense of being reliable across multiple contexts of use. Biologists doing different types of work with a wide variety of organisms used different criteria to define the boundaries of this fundamental unit of analysis.

Experimental work in biology entailed the adoption of reductionist research strategies. The success of experimental work led to bitter debates about the system of classification in botany between 1890 and 1920. Conventional distinctions between individual organisms and populations of organisms developed in this period, as did distinctions between organisms and their environments. While these distinctions worked well in some lines of work, they were less useful in other lines of work. The biological system of classification lost some of its usefulness to botany with the incorporation of these distinctions.

The uncertainties of working with biological organisms, and the control which experimental methods appeared to offer in this work, led to the increasing dominance of experimental work in biology after 1900. However, experimental methods created more problems than they solved in some lines of work. These lines of work gradually lost the institutional resources which they had previously commanded. Lines of work in which experimental methods proved useful were able to jettison the problems these methods could not solve to other lines of work. Lines of work in which experimental methods proved less useful were forced to develop alternative institutional bases, recruitment procedures, and professional societies.

Future Directions for Research

The report presented here has focused on the processes of segmentation which characterized the development of American botany between 1880 and 1920. One important aspect of processes of segmentation in social worlds is the jettisoning of those participants and problems which do not fit well with changing commitments. Such jettisoned participants carry with them the unsolvable problems of the parent social world. This process has consequences for the parent social world, for the jettisoned participants, and for the problems which are jettisoned.

The process of jettisoning also affects the scientific worlds which historians and social scientists study. Successful jettisoning focuses the attention of social scientists on the successful line of work, while less successful participants remain unexamined. This process has led social scientists and historians of the life sciences to focus their attention on genetics, to the exclusion of both ecology and taxonomy. While this situation has recently begun to change, historical and sociological analysis of these biological disciplines remains meager and follows the intellectual lead set by studies of genetics.

Types of Uncertainty

The pervasiveness of uncertainty in human lives has, perhaps, limited sociological analysis of this phenomenon. There has been some suggestive work done on uncertainty in medical settings and in large organizations. A recent study in the development of neurophysiology has also gone some way toward analyzing the effects of uncertainty on work in clinical and basic research settings (%Star, 1983a). The report presented here has looked at how uncertainty in botanical research affected the intellectual development of this scientific discipline. Attention to the notion of uncertainty is important if we are to further our analysis of social worlds.

In the sociology of medicine, the concept of uncertainty has received some attention over the years. Fox (1957) discusses the kinds of uncertainty faced by medical students and distinguishes between uncertainty arising out of students' perception of their own ignorance, out of the inadequacies of medical knowledge, and out of students' inability to distinguish between these. Davis (1960) points to uncertainty as a management technique in patient-family and medical professional interactions. Light (1979) analyzes five types of uncertainty in medicine, including the actions of medical instructors, the limits of medical knowledge, and the uncertainties of diagnosis, treatment, and client response. This discussion is particularly interesting because Light points to the ways in which medical students and professionals attempt to control for different types of uncertainty through a variety of accomodations.

In her study of large organizations, Kanter (1977) includes a discussion of uncertainty. She argues that uncertainty is greater for managers than for clerical workers. This generates pressures for conformity and homogeneity at the managerial level. Both Light and Kanter point to the role that uncertainty plays in the development of homogeneous social groups and hierarchical social structures. Both also point out that high levels of uncertainty generate an orientation toward procedure rather than toward outcome on the part of groups dealing with high levels of uncertainty.

In future research, it will be important to develop a general analysis of types of uncertainty which operate in different contexts. It will also be necessary to examine variations in the sources of uncertainty and how these affect the ways in which uncertainty is managed. In this report, we have seen that control over uncertainty is an important part of scientific research. It is reasonable to assume that different types of mechanisms for control are associated with different types of uncertainty. Questions for the future include: How is uncertainty recognized and defined? How are procedures for managing uncertainty instituted? What are the consequences of using different procedures for the various participants in work settings, organizations, and arenas?

Uncertainty and Conventions

One of the most common means for handling uncertainty is by establishing conventions. Conventions are agreements about how to deal with problems in a line of work or social world which become customary. Conventions dictate the types of materials and abstractions that are used as well as the forms for combining these. Conventions are parts of interdependent systems and become embodied in equipment, materials, training, available facilities, and systems of notation (%Becker, 1982). Establishing conventions is part of the process of establishing a social world, and is an especially important part of worlds which emerge from the intersection of segments of other worlds. How do the different conventions of participants in an intersection come to be shared? How do participants find out, and what do they do, when they discover that their conventions are not the same? What are the processes by which conventions are re-negotiated and standardized? And what are the consequences of such negotiations for relationships with parent social worlds?

Conventions are one means of lowering the level of uncertainty which must be faced within a work context. Simplifications (%Star, 1983b) and substitutions (%Volberg, 1982) are types of conventions used in scientific lines of work for handling uncertainty. The next research step will be to investigate <u>how</u> people develop and learn conventions for studying different problems? What are the relationships between types of conventions and types of uncertainty?

Intersections and Social Worlds

The focus of this report has been on processes of segmentation and how these operated to jettison some participants in a social world and not others. There are a number of themes which have remained in the background, for the sake of analytic and expositional clarity. Perhaps the most important of these is the issue of intersections and the part that these play in successful jettisoning of participants and problems from a social world. The analysis of social worlds is a recent line of work in sociology and there has, as yet, been little analysis of the sources and processes of intersections. This will be an important analytic direction to take in the future.

What can we say about intersections here? To begin with, the sources of intersection are likely to be similar to the sources of segmentation. Changing core activities bring social groups together as well as separating them. Intersections take place around newly defined core activities, around new technologies adopted simultaneously in several lines of work, and around new sites and organizations which bring together groups that were not previously aware of one another. Intersections are most likely to occur when a line of work or an institution is jettisoned by one social world and must make alliances with other social worlds in order to continue its activities. For example, when ecologists were jettisoned by institutions supporting academic research, they allied themselves with one segment of the world of physicists and mathematicians interested in modelling biological processes (%Scudo & Ziegler, 1978).

Just as there are processes of segmentation, so there are processes of intersection. Processes of segmentation include the formation of sub-worlds around different types of activities, their differentiation from parent worlds, their competition for resources within the larger social world, and debates about a variety of issues including the legitimacy of sub-world activities (%Strauss, 1979). Processes of intersection, presumably, will mirror these processes of segmentation. Close attention will have to be paid, however, to the <u>definitions</u> of core activities in intersecting worlds, since this is the point at which different (sometimes competing) understandings are tacitly adopted within a line of work. The intersection of sub-worlds often involves the joining of a new technology with a jettisoned problem from another social world. The problems and uncertainties which develop as a result of such intersections are often dealt with in ways hidden from larger audiences. Analysis of the sources and processes of intersection, and the relationship of intersections and segmentation, will be an important future direction for research.

Classification Work and Jettisoning

Another possibility for future research lies in the relationship between systems of classification and debates within and among social worlds. It has been noted that most social worlds possess a system of classification, or taxonomy, by which the knowledge of that social world is codified. A social world's system of classification can be thought of as a map to the hidden assumptions operative within that world. Debates about a world's system of classification are indicative of the fundamental problems with which that world is concerned.

In the final chapter of this report, we saw how a line of work predicated on an alternative classification system was jettisoned by its parent social world. There is little in the available literature, however, which points directly to the reasons for the jettisoning of ecology from the parent world of biological research. Was it simply on the basis of attempts by ecologists to incorporate environmental criteria into the biological system of classification? What part did alternative styles of work (and especially classification work) play in this process? What part did the intersection between genetics and taxonomy play? What is the relationship between the jettisoning of problems, the jettisoning of lines of work, and the jettisoning of different types of uncertainty?

Conclusion

One of the most interesting features of in the development of scientific research in our society has been the promise held out that the pursuit of science will reduce the uncertainties with which human beings are faced. As I have tried to show here, uncertainty is not reduced through scientific research but through processes of negotiation which are not, in themselves, peculiar to science. Rather, standardized ways for dealing with different types of uncertainty are worked out amongst the participants in many different types of social world.

Science operates in the same ways as other social worlds and is understandable in much the same terms. This report is one step in a process of research and writing about the role of science in society. My interest in this topic goes back at least ten years and will undoubtedly continue in the future. The questions I have raised here remain to be answered and will as assuredly be joined by further questions in the course of future research. As Dewey noted, it is the human predicament of "the inextricable mixture of stability and uncertainty (which) gives rise to philosophy" (1958: 41). It is this predicament and my struggles with it which gave rise to the research reported here.

APPENDIX I

METHODS

One of the "dictums" of grounded theory is to "study the unstudied," (%Glaser & Strauss, 1967) and this thesis reflects that perspective. Physics and chemistry have received the most attention from historians and sociologists while the life sciences have been relatively neglected until recently. Analysis of the life sciences has focused for the most part on genetics (e.g. %Allen, 1978, 1979, 1981; %Churchill, 1981; %Provine, 1971, 1979). Other disciplines such as ecology, for example, have received little attention from social scientists, although this is beginning to change (e.g. %Burgess, 1977; %McIntosh, 1977, 1980; %Tobey, 1981). Although scholars have pointed to the intimate relationship between the disciplines of genetics, ecology, and taxonomy (%Cravens, 1978; %Rodgers, 1944a), no attempt has been made to compare the development of these lines of work.

In researching the development of botany in the United States, I found that the relationships among these lines of work made little sense unless developments in the entire context of biological research were taken into account. This research project began by looking at the development of ecology in the 20th century. Only after a history of ecology had been reconstructed did I turn to taxonomy. The development of genetics was used as a comparison with these other lines of work, and then only after the development of these more obscure lines of work was clearly understood.

In this appendix, I outline the methods used in researching and writing this report. Rather than tediously reconstruct the order in which I did my research, I will present this methodological report in terms of the core activities involved in this research.

Data Collection Procedures

In the course of this research, I concentrated on three major lines of investigation. These included library research in several of the libraries at University of California, Berkeley; a series of interviews with scientists, historians, and sociologists; and fieldwork at conferences, seminars, and in botany classes offered through the University of California, Berkeley. These data collection procedures provided me with extensive materials on the history and development of both plant ecology and taxonomy after the turn of the 20th century.

In the libraries, I read and coded numerous articles from the journals *Ecology*, *Annual Review of Ecology and*

Systematics, and _Systematic Zoology_. I also looked at early issues of _American Naturalist_ and _Botanical Gazette_ from the 1890s and early 1900s. I read the available biographic articles on major ecologists, including F. E. Clements, H. C. Cowles, and H. A. Gleason. For biographical information on other botanists, I examined a number of biographical dictionaries, including the _Biographical Dictionary of American Science_, the _Dictionary of Scientific Biography_, and the _Dictionary of American Biography_. I examined many theoretical articles in ecology, taxonomy, and botany published between 1895 and 1950 as well as textbooks from this same period. Finally, I read a variety of historical articles and books dealing with the development of genetics, taxonomy, ecology, and botany between 1880 and 1950. Many of these historical and source materials are listed in the Bibliography.

Focused interviews were done with a variety of botanists, taxonomists, and ecologists at various stages in their careers. I was especially interested in finding out how contemporary ecologists conducted their work so that I could compare this information with what I found in my readings. I also interviewed historians and social scientists interested in this area of research. The purpose here was to compare my developing ideas with those of other analysts as well as to compare the current ideas of these researchers with those presented in their articles and books.

Throughout the three-year period of this research, I went to classes, seminars, and conferences in ecology and botany. In these settings, I learned about these disciplines in the same way as the students within these disciplines. These experiences were invaluable in providing information about how ecology and botany are done on a day-to-day basis. In the course of this research, I became interested in how novices are socialized into scientific disciplines. The questions raised by students and conference participants and the answers provided to these questions were indicative of the means by which social worlds are shaped and maintained. In conducting my fieldwork, I relied heavily on procedures outlined in Schatzman and Strauss (1973).

Analytic Procedures

The method used in analyzing the data collected through library work, interviews, and participation in the social worlds of ecology and botany is known as "grounded theory" (Glaser & Strauss, 1967; Glaser, 1978). This method permits conceptual categories and their interrelationships to emerge from the data, rather than imposing analytic categories on the data from the outside.

Grounded theory is based on the "constant comparative method of qualitative analysis" by which data is collected and analyzed in an ongoing and reflexive manner. Its authors note that

> constantly redesigning the analysis is a well-known normal tendency in qualitative research ... which occurs throughout the whole research experience from initial data collection through coding to final analysis ... in the approach presented here, (this) tendency is used purposefully as an analytic strategy (Glaser & Strauss, 1967: 101-102).

Although this report constitutes the final version of the dissertation, I have already recognized major revisions which will be made before submitting this work for publication. Rather than focus on the relationships between segmentation and <u>levels of organization</u>, I plan to rewrite this report to highlight the relationships between segmentation and <u>types of work</u>.

In addition to my debt to the authors of the methods books on which I relied, I must also acknowledge a debt to Howard S. Becker and, in particular, to his unpublished paper on "Sociologists' Writing Problems." The major point of this paper is that the best way to get something written is to sit down and start writing it, without waiting until you have it "all worked out." Had it not been for this advice, I might still be waiting for my dissertation to be written.

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