EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

January 9, 1991

MEMORANDUM FOR DISTRIBUTION

FROM: **TOM WELCH** Tom

SUBJECT: **JANUARY PCAST MEETING**

Enclosed is the draft agenda for this week's PCAST meeting.

Please note the hour set aside by Dr. Bromley for OSTP presentations, Thursday morning.

Dr. Bromley has approved the following order, subjects, and times for presentations:

1. **Maryanne Bach - FCCSET (10 min)**
2. **Tom Ratchford - Education (10 min)**
3. **Rachel Levinson - Life Sciences (10 min)**
4. **Nancy Maynard - Earth and Environmental Sciences (10 min)**
5. **Michelle Van Cleave - National Security (10 min)**

Please note the times allotted are <u>maximums</u> and should allow for questions and remarks.

Talking points for Dr. Bromley's use have been drafted and are attached for your amendments. Please return (fax of pen changes is fine) no later than Wednesday, 3:00 PM.

Thank you.

Enclosures:
PCAST Agenda
Draft Talking Points

Distribution:
Tom Ratchford
Nancy Maynard
Michelle Van Cleave
Rachel Levinson
Maryanne Bach

CC: **Ken Yale**
Sally Sherman

DRAFT

As of 4:00 PM
January 8, 1991

PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY

JANUARY 10-11, 1991

AGENDA

5750 - CEQ Conference Room

THURSDAY, JANUARY 10, 1991

OPEN SESSION 9:00 AM - 12:00 NOON
CONFERENCE ROOM
COUNCIL ON ENVIRONMENTAL QUALITY
722 JACKSON PLACE, NW

8:30 - 9:00	ARRIVAL -- COFFEE AND PASTRIES	
9:00 - 9:30	OPENING REMARKS	DR. BROMLEY
9:30 - 10:30	BIODIVERSITY - AN INFORMATION BRIEFING	DR. WILSON
10:30 - 10:45	DISCUSSION	
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11:45 - 12:00	CLOSING REMARKS	DR. BROMLEY

DRAFT

THURSDAY, JANUARY 10, 1991 Continued ...

CLOSED SESSION, 12:00 NOON - 5:00 PM
ROOM 248
OMB DIRECTOR'S CONFERENCE ROOM
OLD EXECUTIVE OFFICE BUILDING

12:00 - 12:45	LUNCH	
12:45 - 1:00	BREAK	
1:00 - 4:30	ISSUES FOR PCAST CONSIDERATION	DR. BROMLEY
	1:00 - 2:00 TO BE DETERMINED	
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- 4:30	OTHER BUSINESS	DR. BROMLEY
- 6:30	COCKTAILS AND DINNER MAYFLOWER HOTEL	

DRAFT

FRIDAY, JANUARY 11, 1991

CLOSED SESSION 9:00 AM - 12:00 NOON
ROOM 180
OLD EXECUTIVE OFFICE BUILDING

8:30 - 9:00	ARRIVAL -- COFFEE AND PASTRIES (Dr. Bromley's Office, Room 360, OEOB)	
9:00 - 10:00	DISCUSSION OF FEBRUARY AGENDA AND OTHER ISSUES	DR. BROMLEY
10:00 - 12:00	ISSUES FOR PCAST CONSIDERATION	DR. BROMLEY
	10:00 - 11:00 GOVERNOR SUNUNU 11:00 - 12:00 CHAIRMAN BOSKIN	
- 12:00	CLOSING REMARKS	DR. BROMLEY

TALKING POINTS
FOR
THURSDAY'S OPEN SESSION

I. Welcome and Introductory Remarks

- oo Introduce D. A. Henderson
- oo Congressional Oversight Hearings on OSTP
- oo Budget Submission to Congress (OSTP Press Conference)
- oo State of the Union Address
- oo Optional - Leon Lederman Talking Points (attached)

II. Introduce E. O. Wilson

- oo It is important for PCAST to maintain its familiarity with the important aspects of global change. At earlier meetings we received a briefing on a White House conference related to this.
- oo The purpose of the White House Conference was to focus international thought by introducing the integrating concept of "Global Stewardship." It also emphasized a new dimension of the international dialogue on Global Change: that economic analysis and research on broad global change policies and on the consequences of such policies must be coordinated with the science of global change.
- oo Without doubt, an important dimension of global change research is the issue of biodiversity.
- oo Among the preeminent investigators of biodiversity is Edward Osborne Wilson, Mellon Professor of the Sciences, Harvard University.
- oo Professor Wilson's contributions include the very well received article in the Scientific American, "Threats to Biodiversity", September, 1989. Copies of the article as well as recent OSTP presentations are available on the wall shelf.
- oo We are most pleased that Professor Wilson is with us today. We look forward with great interest to his presentation.

III. Introduce OSTP Staff for 1990 Accomplishments

- oo The Bush Administration's policies are designed to increase the contribution of science and technology to the national goals of improved quality of life for all Americans, continued economic growth, and a strong national defense. This has been and will continue to be reflected in annual Federal budgets.

- oo The activities of the Office of Science and Technology Policy in support of these and other Administration policies and goals include: 1) providing access to authoritative science and technology information and expert scientific and engineering advice for the President, Federal officials, and Congress as input to the policy-making process; 2) participating in the formulation, coordination and implementation of national, domestic, economic, defense and foreign policy issues that involve science and technology; 3) maintaining and fostering the health and vitality of the U.S. science and technology base; and 4) coordinating research and development efforts by agencies of the Federal Government, to maximize the return on the nation's investment in R&D and to insure that the resources involved are used efficiently and appropriately.

- oo For PCAST to adequately advise the President, it is important that we understand the activities and accomplishments of OSTP for 1990. I have, therefore, asked members of the OSTP staff to provide us this morning with a series of short information briefings. Because of time limitations, only a portion of OSTP's accomplishments can be presented this morning.

FCCSET - Maryanne Bach

- oo I would like to begin these briefings with an overview of the 1990 accomplishments of the Federal Coordinating Council for Science, Engineering, and Technology.

- oo The Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) was established in 1976 by P. L. 94-282 to address high priority science and technology policy issues affecting more than one Federal agency. It is chaired me in my capacity as the Director of the Office of Science and Technology Policy. During FY 1990, FCCSET was restructured and revitalized. The full FCCSET was appointed for the first time; the membership now includes the relevant Cabinet Secretaries or Deputy Secretaries, and the Directors of the relevant science-and-technology-related departments and independent agencies.

- oo The FCCSET presentation will be given by Maryanne Bach, Executive Director, FCCSET.

Educational and International - Tom Ratchford

- oo The Education Summit led in FY 1990 to a set of national education goals and objectives to be reached by the year 2000.

- oo These goals form a national framework for Federal policy and strategic investments in science, mathematics, technology, and engineering education at all levels. OSTP worked closely with other EOP offices and Federal agencies in support of achievement of the three national education goals relating to science, mathematics, engineering and technology education.

- oo Let me now ask Dr. Tom Ratchford, my Associate Director for Policy and International Affairs to speak to the 1990 OSTP accomplishments in mathematics and science education.

Life Sciences - Rachel Levinson

- oo During FY 1990 OSTP took the lead on a number of life science issues of importance to the Administration including biotechnology, technology transfer in the biomedical sciences, the need for guidelines for handling misconduct in science, and the use of animals in biomedical research. A central focus was the operation of the Biotechnology Science Coordinating Committee, discussed under activities of the FCCSET Committee on Life Sciences and Health earlier.

- oo Dr. Rachel Levinson will describe our accomplishments in life sciences.

Earth and Environmental Science - Nancy Maynard

- oo In FY 1990, the Global Change Working Group was established under the Domestic Policy Council with me as its chairman. OSTP staff were actively involved in the Working Group, in analyses of the Intergovernmental Panel on Climate Change report, in preparations for upcoming negotiations for a Framework Convention on climate change, in preparations for the Second World Climate Conference, and in planning for the White House Conference on Science and Economics Research Related to Global Change.

- oo To expand upon these and other accomplishments, let me call upon Dr. Nancy Maynard, Assistant Director for the Environment.

National Security - Michelle Van Cleave

- oo The OSTP participates in interagency efforts aimed at resolving critical scientific and technical issues associated with national security and supports the National Security Council in matters concerning science and technology that are related to national security.

- oo To describe our 1990 accomplishments in this area, let me call upon Michelle Van Cleave, OSTP's Assistant Director for National Security.

January 10, 1991

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JANUARY 10-11, 1991

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Substantial progress made in recent months to develop a coherent, integrated program in M+S Ed.

~~Your first~~

1 ~~Interagency~~ These efforts ^ summarized 1/3 report Because of very limited time, call attn. to highlights, invite you to

2 Encouraged by President PL 101-589 signed stmt

3 CEHR - Watkins, Sanders, Williams
16 agencies participated; 12 on WG

4 Scope of activities K - Grad
Order of priority

5 Strategic Objectives

6 Implementation priorities

7 Baseline
Categories
FY 90
FY 91
FY 92 - Feb 4

8 Year ahead - Review - Chris Cross

9 FY 93 under discussion

1/10/91
PCAST
Presentation

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

January 3, 1991

Dear Madam Chair:

I am pleased to send you this progress report describing efforts underway by the interagency Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) to address issues of mathematics and science education. These efforts to develop a strategic plan for the Federal program on mathematics and science education for FY 1992 are in support of the National Education Goals related to these fields. Three of the six Goals address, directly or indirectly, science and mathematics education. They are:

> By the year 2000, American students will leave grades four, eight, and twelve having demonstrated competency in challenging subject matter including English, mathematics, science, history, and geography . . . [Goal 3]
>
> By the year 2000, U.S. students will be first in the world in science and mathematics achievement. [Goal 4]
>
> By the year 2000, every adult American will be literate and will possess the knowledge and skills necessary to compete in a global economy and exercise the rights and responsibilities of citizenship. [Goal 5]

The President noted the importance of the interagency process recently when he signed Public Law 101-589, the "Excellence in Mathematics, Science and Engineering Education Act of 1990." The President stated:

> "In developing the FY 1991 budget immediately following the Education Summit, the Administration took important steps to strengthen programs of Federal agencies and to increase funding for science and mathematics education. We intend to further develop that initiative through the work of a new interagency committee which is developing a strategic plan and priorities for the Administration's program in science and mathematics education."

Senate Request

This progress report is submitted in response to the Senate Appropriation Committee's request, as set forth in its Report No. 101-474 to accompany H.R. 5158. The formal, complete report requested by the Committee will be submitted with the President's FY 1992 budget. This progress report incorporates the multilevel priority-setting framework, also called for in the Committee report.

FCCSET Committee on Education and Human Resources

The White House Office of Science and Technology Policy (OSTP), through the Federal Coordinating Council for Science, Engineering, and Technology, established the Committee on Education and Human Resources (CEHR). This Committee is charged with addressing issues critical to:

> Improving science, mathematics, and engineering education, and technical training;
>
> Ensuring an adequate supply of well-educated and trained scientific and technical personnel;
>
> Enabling the Nation to retain world leadership in science and technology; and,
>
> Ensuring a well-informed, scientifically literate citizenry.

To accomplish this, the Committee plays a central role in coordinating activities of the Federal agencies related to science, mathematics, engineering, and technological education and training.

3.

The CEHR is chaired by Secretary of Energy James Watkins, with the Deputy Secretary and Acting Secretary of Education, Ted Sanders, and the Assistant Director for Education and Human Resources of the National Science Foundation (NSF), Luther Williams, serving as vice chairmen. The Committee includes senior policy-level officials from all Federal agencies with significant responsibilities in the area of science, mathematics, engineering, and technological education, including those with jurisdiction over the education of scientists, mathematicians, and engineers, as well as those with responsibilities for technician training and science literacy for the general public. The Committee also includes those agencies that are major users of scientific and engineering personnel.

The Committee established a Working Group on the FY 1992 Federal Program Plan for Education and Human Resources (EHR) to develop the first comprehensive inventory of Federal EHR programs and to begin the process of developing options for an FY 1992 multi-agency program for EHR activities. The members of the Working Group include representatives from the:

16 agencies
12 WG mbrs

Department of Energy
Department of Education
National Science Foundation
Department of Health and Human Services
Department of Defense
Department of Commerce
Department of the Interior

Department of Agriculture
Department of Labor
National Aeronautics and
Space Administration
Environmental Protection Agency

The focus of the Committee's effort is to develop recommendations for moving the Nation toward achieving the three National Education Goals related to mathematics and science education. Since the Goals relate primarily to precollege education, the CEHR focused on those programs relating predominantly to grades K-12. The Committee did, however, take into consideration all components of the educational system, including both "formal" (in-the-classroom) and "informal" (out-of-classroom or experiential) programs. The scope of activities includes (in descending order of priority):

4.

Precollege, formal

Precollege, informal

Undergraduate, formal

Undergraduate, informal

Graduate.

up food chain

U.S. graduate education programs are in a clear and undisputed position of world leadership. The priority placement of graduate education reflects an emphasis by the CEHR on those elements of our educational system most in need of attention.

Priority Framework

The Committee developed a National Mathematics and Science Education Priority Framework which lists both strategic objectives and implementation priorities. The implementation priorities vary, depending on the particular educational level.

Strategic Objectives

5.

The CEHR program's four strategic objectives, listed in descending order of priority, reflect the National Education Goals. These objectives relate to:

1 Improved student performance in science and mathematics;

2 Better prepared precollege teacher workforce;

3 Provision of an adequate workforce supply to all fields of science and technology, including increased participation of underrepresented groups; and,

4 Improved public science literacy.

6. Implementation Priorities

The CEHR implementation priorities specify program areas that require emphasis to accomplish the strategic objectives. Each implementation priority is dependent, to some degree, on the others, and the mix of programs will be important to enhancing the overall Federal effort. Emphasis in one area will necessarily influence the level of accomplishment of the others. Likewise, neglect of an area associated with a particular priority may affect overall success in meeting the Nation's education goals. In descending order of importance, the implementation priorities recommended for use in establishing the programmatic content of the Federal effort are:

1 Teacher preparation and retraining;

2 Curriculum reform, research and development in teaching and learning, dissemination, and technical assistance;

3 Organizational and operational reform of the education delivery system;

4 Student incentives (support) and opportunities; and,

5 Scientific literacy activities directed toward the general public.

7. FY 1990 and FY 1991 EHR Baseline

The Working Group developed a comprehensive inventory of Federal mathematics and science education programs. As a tool for planning, while at the same time recognizing differences in the character of EHR program activity across agencies, the Federal inventory was divided into three categories to reflect the source of funding and agency administrative control over EHR activities:

Category 1 programs are those whose budgets are directly appropriated for mathematics, science, and technology education, or are funded from research (or other) accounts and expressly managed as education programs.

Category 2 programs are funded under research or other accounts that do not fall under Category 1 (e.g., graduate research assistantships).

Category 3 programs are those whose purpose is general education (not specifically mathematics and science education) but under which science and technology education activities are supported (e.g., formula-driven programs of which mathematics and science are an integral part).

In its initial work, the Working Group concentrated on Category 1 programs. The FY 1991 EHR Category 1 budget, which serves as the baseline for subsequent fiscal years, is $1.72 billion, a 16% increase over FY 1990. Although graduate programs account for the majority of the budget, precollege programs received by far the largest absolute and percentage increases.

Although graduate education received the lowest priority, this ranking is not, in any way, meant to diminish its importance or downplay the critical role played by the Federal government in this area. Support of U.S. graduate education is essential to maintaining the quality of U.S. scientific research and economic competitiveness. In that graduate education also ensures adequate numbers of quality faculty to teach future generations of college students, it has a long-term impact on both the undergraduate and precollege education levels. The Federal government spends the largest share of its Category 1 mathematics and science resources on graduate education.

FEDERAL MATHEMATICS AND SCIENCE EDUCATION PROGRAMS

CATEGORY 1

	FY 1990	FY 1991	% Increase
Precollege	$333 million	$526 million	58%
Undergraduate	$412 million	$422 million	3%
Graduate	$741 million	$769 million	4%
TOTAL	$1.49 billion	$1.72 billion	16%

NOTE: Percentage increases are based on unrounded figures.

FY 92 – Feb 4 Bush – STRATEGIC PLANS AND PRIORITIES

The above figures are those appropriated for FY 1990 and FY 1991. Although the agencies have their appropriations at this time, minor modifications within budget amounts can be expected as agencies complete their current plans. The figures in the formal report may, therefore, vary slightly from those above.

Different agencies dominate program activities at each education level. For five agencies, mathematics and science education programs comprise relatively small

portions of the budget yet fill important programmatic roles related to their missions. Many of these activities support training of specialists; expand and support traditional curricula; provide informal teacher enhancement programs; and make students aware of important issues such as energy conservation, nutrition, health education, aeronautics and space, and the environment. The list below includes only those agencies that contribute significant percentages of the total Federal expenditure by educational level.

MATHEMATICS AND SCIENCE EDUCATION
PATTERN OF AGENCY RESPONSIBILITIES
FY 1991 CATEGORY 1 BUDGET

A. By educational level

	Total $	Agency (% of total Federal support)
K-12	$526 million	ED (46%); NSF (40%)
Undergraduate	$422 million	DOD (42%); NSF (25%); HHS (14%)
Graduate	$769 million	HHS (52%); DOD (30%)

B. Formal and Informal

Precollege formal	ED (57%); NSF (39%)
Precollege informal	NSF (41%); DOI (22%); DOE (20%)
Undergraduate formal	NSF (37%); DOD (34%); HHS (19%)
Undergraduate informal	DOD (57%); NASA (15%); DOE (12%)

FCCSET/CEHR Activities in the Year Ahead

8. With the CEHR program inventory and priority framework in place, the FCCSET Committee on Education and Human Resources shortly will begin a more intensive review of the effectiveness of current Federal programs. This review will look at evaluations and other information on program outcomes, and will analyze program designs to determine which strategies are most likely to be successful. The results of this review will guide development of a coordinated strategy for reallocating resources, as appropriate, to programs that will be the most effective in addressing priority needs.

Chris Cross

FY 93 plans under discussion in FCCSET, OSTP + OMB

The Future

The FY 1992 Budget which the President sends to Congress will be developed with the FCCSET recommendations in mind and will be consistent with the overall requirements of the Omnibus Budget Reconciliation Act of 1990 (P.L. 101-508)

OSTP is committed to working with all elements of our society and all parts of Federal, State, and local governments to achieve our National Education Goals. As you are well aware, a coordinated, national effort is necessary to make American students first in the world in science and mathematics achievement. The Administration, the Congress, the States, local governments, teachers and other educators, as well as parents, will all have to work together to attain the National Education Goals. With your help and cooperation, we are convinced that these Goals can be met.

Sincerely,

D. Allan Bromley
Director

The Honorable Barbara A. Mikulski
Chair
Subcommittee on Veterans Affairs,
Housing and Urban Development,
and Independent Agencies
Committee on Appropriations
U.S. Senate
Washington, DC 20510

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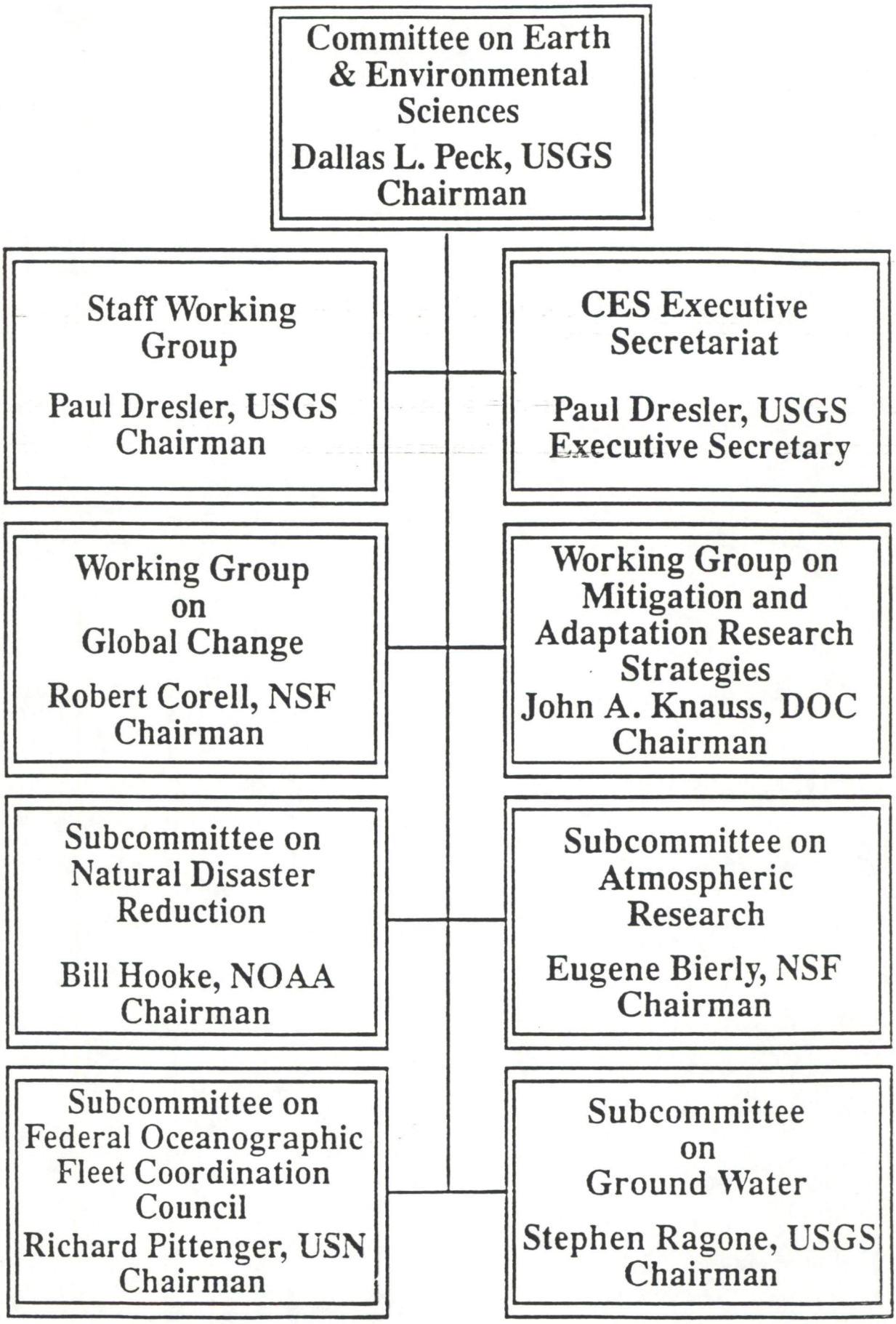
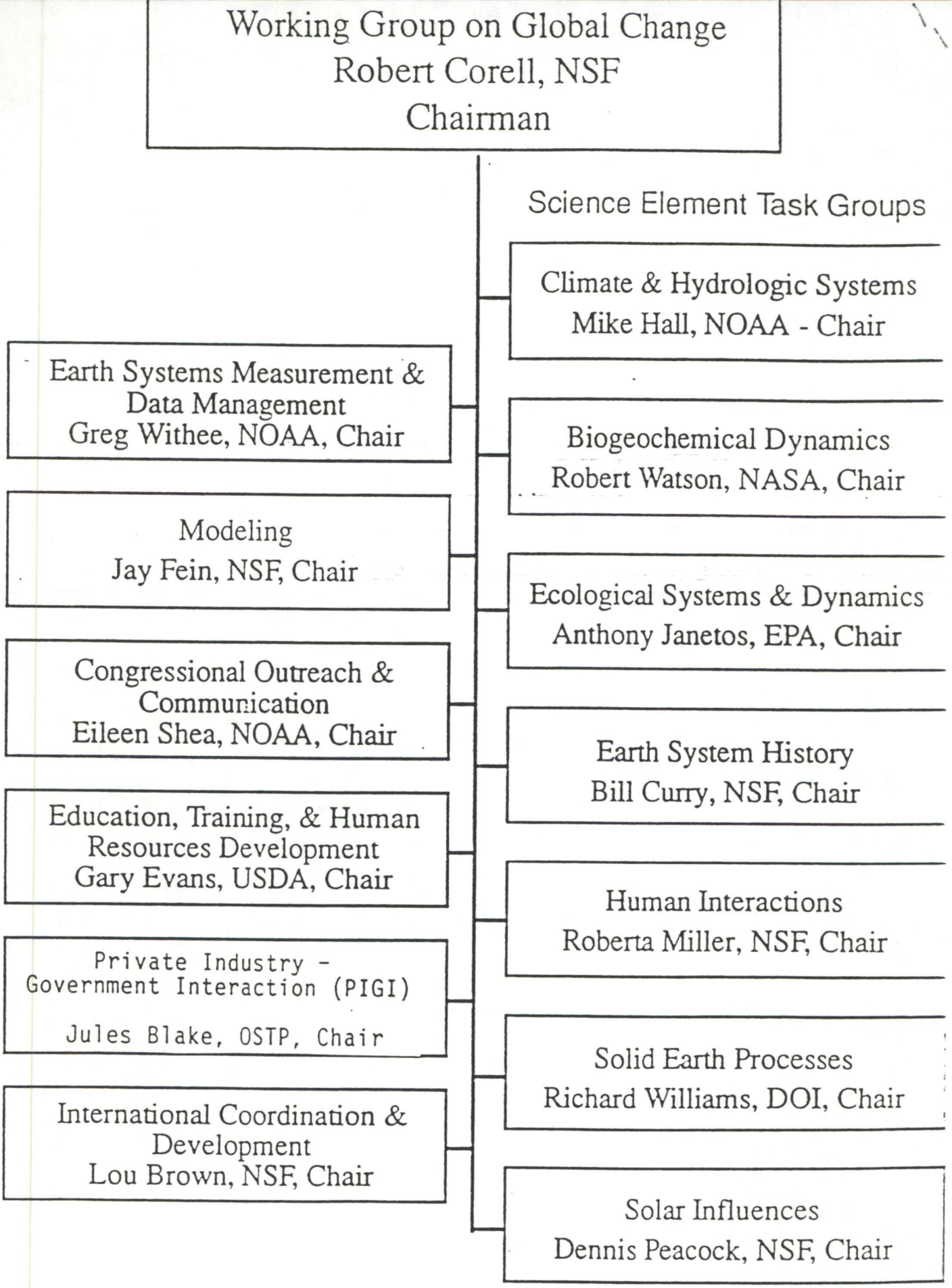
CEES ORGANIZATIONAL CHART
June 1, 1990

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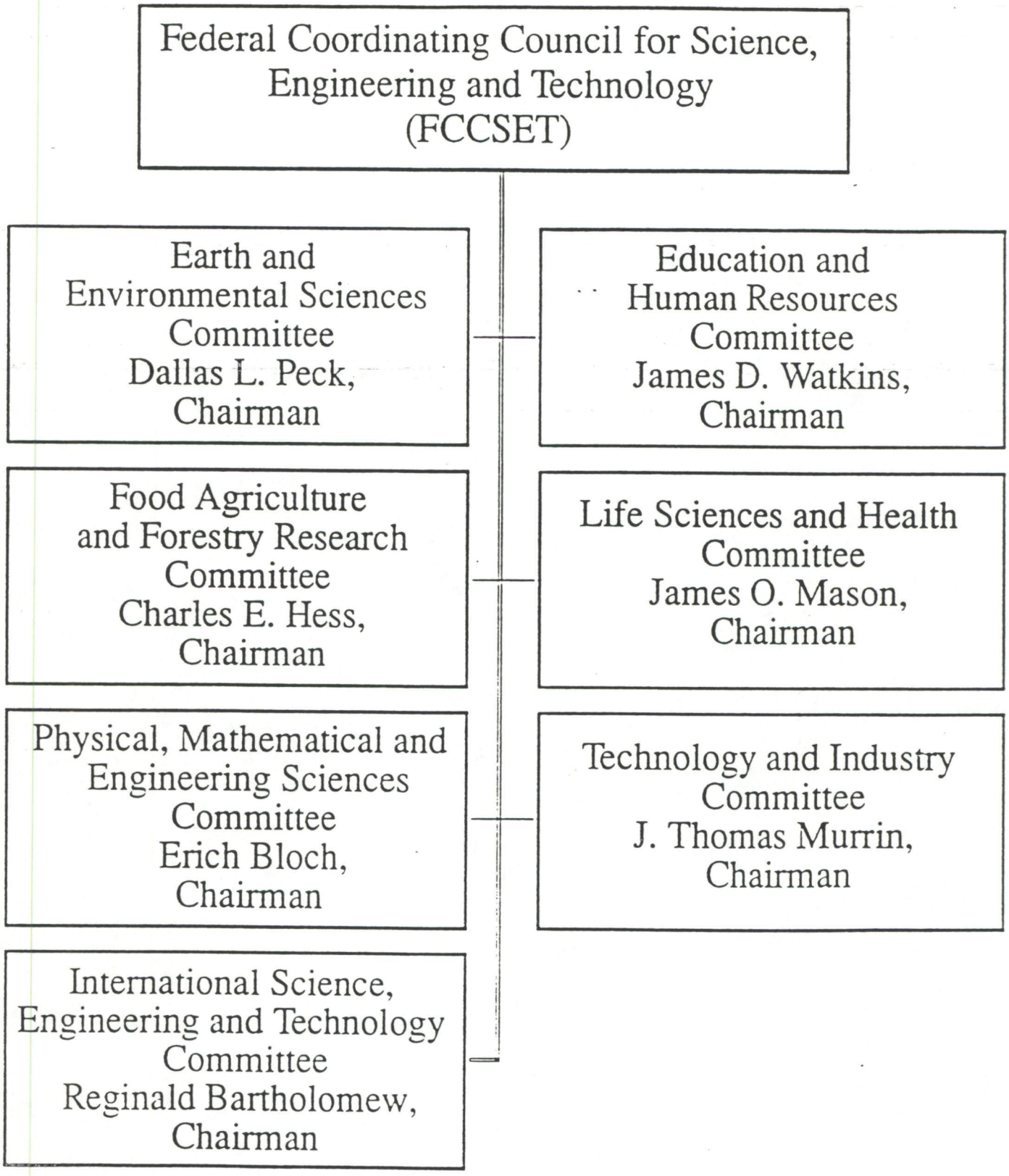
FCCSET Organizational Chart

July 10, 1990



ENVIRONMENT AND GLOBAL CHANGE

I. Formulation and Coordination of National Policy - Policy on Global Change

To insure development of a comprehensive and forward-looking U.S. policy on global change based upon sound science and economic growth, President Bush established the Domestic Policy Council Working Group on Global Change

Chairman = D. Allan Bromley

- . Provides Cabinet-level coordination on global change issues
- . Important source of information and advice to President

a. Studies by DPC GCWG:

- . Economic costs of global change and responses to it
- . Private sector activities and issues
- . Legal precedents for international agreements and conventions

b. Provided briefings for DPC GCWG Members by experts on scientific and economic aspects of global change

c. Activities

1. White House Conference on Science and Economics Research Related to Global Change

co-chairs: D. Allan Bromley, Michael Deland, Michael Boskin

- . concept for conference developed by DPC GCWG
- . Conference resulted in:
  - . concept of "Global Stewardship" (US approach)
  - . development of concept of integrated economic analysis on consequences of global change policies with science of global change - - useful to policy-makers
- . Specific Outcomes:
  - . Regional Research Institutes
  - . Coordination of research among nations funding global change research
  - . Communications network

2. Preparation for U.S. Participation and Negotiation at International Meetings

For example:

- . Noordwijk
- . Bergen
- . Intergovernmental Panel on Climate Change (3 Working Groups)
- . Second World Climate Conference
- . First Negotiating Session of the Framework Convention on Climate Change

3. Review of IPCC Working Group Reports

- . Working Group I - Scientific Assessment
  OSTP Coordinated Review
- . Working Group II - Impacts
- . Working Group III - Response Strategies U.S. Chair (Bernthal)

4. Preparations for the First Negotiating Session of the Framework Convention on Climate Change

- . President Bush offered to host the First Session
- . Preparations presently underway
- . Meeting: February 4 - 14, 1991
  Westfields Conference Center
- . UN-sponsored
- . Prior international meetings are backdrop for negotiations

5. Subgroup of DPC GCWG = Comprehensive/Incentives Task Force

- . Comprehensive approach addresses all greenhouse gases, their sources and sinks.
- . In contrast to current "piecemeal" approach which focuses narrowly on emissions of one gas, carbon dioxide, primarily from the energy and transportation sector
- . Employs a measure, such as an index, of the comparative enviromental impacts of the gases (e.g., global warming potential)
- . limitations measures should be market-based incentives
- . trading of emissions

II. Coordinating R & D Efforts by Agencies

1. Committee on Earth and Environmental Sciences (CEES)

Committee = successful template for other FCCSET Committees

Reports:

1. "Our Changing Planet: The FY91 U.S. Global Change Research Program"
   To accompany the President's FY91 Budget

2. "Our Changing Planet: The FY 91 Research Plan"
   . provides budget information by agency for FY91
   . outlines an accelerated, focussed research strategy to reduce key uncertainties
   . research strategy encompasses ground and space-based efforts in:
   research - data gathering - modelling

3. "Our Changing Planet: The FY 1992 U.S. Global Change Research Program"
   To accompany the President's FY 92 Budget
   Due out February 4, 1991

4. Working Groups

   (see diagrams)

5. Other CEES Activities:

   a. Response to National Academy Review of USGCRP/EOS
   b. S. 169
   c. Ad Hoc Economics Subgroup

   OMB request for recommendations for an agenda for resource levels and organizational changes required to support expanded research on the economics of global change

III. Other Activities

1. Bilateral and Multilateral S & T activities
2. NES - Environmental aspects
3. Panelists/speaker:
    - . Presidential Awards for Excellence in Science and Math Teaching
    - . AGU
    - . Global Climate Coalition
    - . EPC - EPRG
    - . Brookings
    - . Department of Education
    - . Chemical Manufacturers ASsoc.
    - . Congressional Forum
    - . Industrial Energy Users Forum
4. Arctic Ocean Program Review
5. Forestry
6. EMF
7. Oil Pollution R & D
8. Budget
9. Ocean Principals

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December 11, 1990

Dr. Thomas Ratchford
Office of Science and Technology Policy
Executive Office of the President
OEOB 431
Washington, DC 20506

Attention: Virginia Rosell

Dear Dr. Ratchford:

In accord with your request, I am enclosing a copy of the proofs of my forthcoming paper on "Academic Research and Industrial Innovation." It is important to recognize that estimates of the social rate of return in Table 4 are not meant to be more than highly tentative and incomplete explorations. As stated on page 11, they are "at best a crude beginning," and should be treated as such. The material in Tables 1, 2, and 3 is the heart of the paper. It constitutes some of the first evidence of a detailed and comprehensive sort regarding the role of academic research in industrial innovation. The results indicate that, particularly in drugs, instruments, and information processing, the contribution of academic research to industrial innovation has been considerable. This is the major finding of the paper, and I hope that you find it of interest.

Sincerely,

Edwin Mansfield
Director, Center for
Economics and Technology,
and Professor of Economics

Elsevier Science Publishers B.V., P.O. Box 1991, Amsterdam

Northprint: RPY00575

Page: 12 1st proof:

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Academic research and industrial innovation *

Edwin MANSFIELD

Department of Economics, University of Pennsylvania, Philadelphia, PA 19104-6297, U.S.A.

Final version received January 1990

1. Introduction

The purpose of this study is to estimate the extent to which technological innovations in various industries have been based on recent academic research, and the time lags between the investment in recent academic research projects and the industrial utilization of their findings. Because no attempt (to my knowledge) has been made to estimate the social rate of return from academic research, [1] we also make some rough and tentative estimates of this sort. While the results are subject to many limitations discussed below, they should be of interest to public policy-makers concerned with science and technology, as well as to economists and others that study the process of technological change.

At the outset, it should be noted that I am concerned primarily with recent academic research—that is, academic research occurring within fifteen years of the commercialization of whatever innovation is being considered. [2] A great many new products and processes are based on relatively old science that to some extent was due to academic research. In estimating the social rate of return from academic research, I ignore such long-term effects of academic research because they are very difficult to measure, because benefits occurring many years after the relevant investment in research are so heavily discounted, [3] and because the effects of relatively old science may not be a reliable guide to the present situation. This, like many other features of my estimation procedure, tends to impart a downward bias to the estimated rate of return.

2. New products and processes based on recent academic research

A random sample of 76 major American firms in seven manufacturing industries—information processing, electrical equipment, chemicals, instru-

[1] Relatively few detailed studies of the contribution of academic research to industrial innovation have been carried out. Most seem to have focused on the drug industry. For example, see Mansfield et al. [15, ch. 8] and Schwartzman [24]. Also, Mushkin [26] estimated social rates of return for biomedical research, much of which is carried out at universities and colleges. In addition, Project Hindsight and the Traces study dealt with about 20 weapons systems and five major innovations, and Gellman [7] provided relevant data bearing on this topic.

* The research on which this paper is based was supported by a grant from the Division of Policy Research and Analysis of the National Science Foundation, which of course is not responsible for the views expressed here. My thanks to Leonard Lederman, who was the first to encourage me to work on this project, and to Edward Denison, Rolf Piekarz, and Eleanor Thomas for helpful comments, and to the 76 firms that provided the basic data used in this paper. A preliminary version of this paper was presented at the National Science Foundation at Economics Day at the University of Pennsylvania, and at the 1988 annual meetings of the American Economic Association.

[2] By "recent", we mean recent in relation to the time when the innovation occurs. Some observers, particularly in the drug industry, have argued that 15 years is too short, because it often takes longer than this for academic research to be applied. Our reason for using 15 years is to be very conservative. Results based on other time intervals would, of course, be interesting and valuable.

[3] For example, a dollar of benefits occurring 20 years hence is worth now only about 3 cents if the interest rate equals 0.20.

Research Policy 20 (1991) RPY00575
North-Holland

Table 1
Percentage of new products and processes based on recent academic research, seven industries, United States, 1975–85

Industry	Percentage that could not have been developed (without substantial delay) in the absence of recent academic research		Percentage that were developed with very substantial aid from recent academic research	
	Products	Processes	Products	Processes
Information processing	11	11	17	16
Electrical	6	3	3	4
Chemical	4	2	4	4
Instruments	16	2	5	1
Drugs	27	29	17	8
Metals	13	12	9	9
Oil	1	1	1	1
Industry mean [a]	11	9	8	6

Source: See section 2.
[a] Unweighted mean of industry figures.

ments, drugs, metals, and oil—was chosen. [4] This sample accounts for about one-third of these industries' total sales in 1985. Data were obtained from each firm's top R&D executives concerning the proportion of the firm's new products and processes commercialized in 1975–85 that, according to these executives (and their staffs) could not have been developed (without substantial delay) in the absence of academic research carried out within 15 years of the first introduction of the innovation. [5] As indicated in table 1, about 11 percent of these firms' new products and about 9 percent of their new processes could not have been developed (without substantial delay) in the absence of recent academic research. [6]

The percentage of new products and processes based in this way on recent academic research seems to be highest in the drug industry (which has an obvious interest in the large amounts of medical, biological, and pharmaceutical research carried out at universities) and lowest in the oil industry. To a considerable extent, these interindustry differences with respect to new products can be explained by differences among firms in R&D intensity. A firm's percentage of new products based in this way on recent academic research seems to be directly related to the percentage of its sales devoted to R&D. Holding R&D intensity constant, interindustry differences are not statisti-

[4] The frame for this survey was the list of major firms in these industries in *Business Week*, 23 June, 1986. This list includes all firms spending over $1 million (or 1 percent of sales, if sales were at least $35 million) on R&D in 1985. A random sample of 76 of these firms was chosen, and data were obtained from all of them (sometimes after considerable discussion and negotiation) through questionnaires and interviews. The number of firms included in each industry is: information processing, 25; electrical equipment, 14; chemicals, 15; metals, 6; instruments, 7; drugs, 6; oil, 3. An attempt was made to allocate the sample optimally among industries (that is, with sample size being proportional to the total number in each industry times the relevant standard deviation). The sample size of 76 was chosen because it seemed large enough to result in the desired precision. See Cochran [4, ch. 5]. The firms in our sample accounted for about one-third of the sales in the population of firms in these industries in 1985.

[5] While our initial requests for information and cooperation were made to the firms' chairmen, the respondents were often the top R&D executives who based their responses in part on detailed data obtained from people at lower levels of their organizations. (For further comments on the data, see footnote 11.)

By "substantial delay", we mean a delay of a year or more. Of course, it is always hard to rule out completely the possibility that, in the absence of the relevant academic research, industrial or government researchers might have provided the necessary information; but according to the firms, this would have been extremely unlikely for the innovations they included in this category. As pointed out in section 5 below, they believe that, without the completion of the academic research, it would have taken at least 9 years longer, on the average, for these new products and processes to have been introduced.

[6] The figures in table 1 for each industry are weighted means of the firm percentages, the weights being the 1985 sales of the firms. The unweighted means of the firm percentages tend to be higher than the weighted means in table 1. The standard errors of the unweighted means are about 2 percentage points.

cally significant. [7] One of the most important reasons why relatively R & D-intensive firms are more likely than others to carry out innovations based on recent academic research is that they tend to be more closely abreast of such research.

In some cases, new products and processes could have been developed without the findings of recent academic research, but it would have been much more expensive and time-consuming to do so. [8] In table 1, such cases are designated as ones where development occurred with "very substantial aid from recent academic research". About 8 percent of these firms' new products and about 6 percent of their new processes during 1975–85 fell into this category. Frequently, while it was technically possible for the firm to have developed them without the findings of recent academic research, it seemed economically undesirable to have attempted it. Thus, in a practical sense, many of these innovations could not have been developed (without substantial delay) in the absence of recent academic research.

The percentages in table 1 are somewhat higher than those based on Gellman's study [7] of 121 innovations occurring in these industries during 1953–73 in the United States, which indicated that about 7 percent were based on inventions conceived at universities. (Among innovations designated as "radical breakthroughs", the percentage was 14 percent.) This would be expected since many innovations that are not based on inventions conceived at universities could not be developed (without substantial delay) in the absence of academic research. [9] For example, academic research often provides new theoretical and empirical findings and new types of instrumentation that are essential for the development of a new product, but does not provide the specific invention itself. Thus, academic studies by Professors Kipping and Staudinger provided basic information concerning organo-silicon chemistry which laid the groundwork for industrial silicones. [10]

3. Academic-research-based products and processes: Sales and savings

While the previous section indicates that about 11 percent of the new products introduced in these industries in 1975–85 could not have been developed (without substantial delay) in the absence of recent academic research, it tells us nothing about the economic importance of these new products. To help fill this gap, data were obtained from each firm concerning the 1985 sales of its new products first commercialized in 1982–85 that could not have been developed (without substantial delay) in the absence of recent academic research. From these data, estimates were made of the total 1985 sales for all such new products first commercialized in 1982–85 by all major firms in each of these industries, the results being shown in table 2. [11]

The total sales of such new products in 1985 in these seven industries seems to have been about $24 billion. Because there are large differences among firms in the sample with regard to the 1985 sales of such new products, the estimated total sales figures for individual industries contain large sampling errors. Thus, although the drug, infor-

[7] Letting P_i be the percentage of the ith firm's new products that could not have been developed (without substantial delay) in the absence of academic research, and R_i be the ith firm's percentage of sales devoted to R&D in 1985, the regression equation is

$$P_i = 7.11 + 2.18R_i \quad (R^2 = 0.10).$$
$$(2.73)$$

where the t-statistic is shown in parentheses below the regression coefficient. Holding R_i constant, both industry dummy variables and firm size (as measured by 1985 sales) are statistically non-significant.

[8] Frequently, academic research results in new techniques that enable scientists and engineers in firms and elsewhere to carry out R&D in particular areas more cheaply, quickly, or accurately. For example, high resolution nuclear magnetic resolution spectroscopy, which was based on research at Stanford and Harvard Universities, has become indispensable in many chemical laboratories.

[9] In the drug industry, table 1 shows that about 27 percent of the new products could not have been developed (without substantial delay) in the absence of recent academic research. This percentage is considerably higher than the percentage of drug discoveries made by the universities. According to [redacted] et al. [15] and Schwartzman [24], the latter figure may have been 10 or 15 percent. As noted in the text, the reason why the figure in table 1 is higher than the latter figure is that academic research often results in findings that are necessary but not sufficient for the discovery or improvement of a drug. Industrial R&D must be carried out to extend, supplement, and focus the findings of the academic R&D. (In addition, of course, some of the differences may be due to sampling errors, which are discussed in footnote 34.)

[10] Jewkes, Sawers and Stillerman [8, pp. 296–299].

mation processing, and electrical equipment industries seem to have the largest sales of new products of this sort, these differences could be due in substantial measure to sampling errors. Given our objectives, the important figures are the seven-industry totals ($24 billion and $17.1 billion) which, although they have substantial sampling errors, are sufficiently precise to be useful. (Note too that these totals are quite consistent with McGraw-Hill [10] data. [12])

[11] To make this estimate, we multiplied the number of major firms in each industry by the mean 1985 sales of such products of the firms in the sample. A major firm is defined here as one that is big enough to be included in the *Business Week* list cited in footnote 4. Many of the firms went to a considerable amount of trouble to provide reasonably accurate data. For other firms, the data are rough, but we tried in a variety of ways to make sure that the executives had what seemed to be a solid basis for their estimates. Nonetheless, data of this sort have obvious limitations, and should be treated with appropriate caution.

[12] The results in tables 1 and 2 seem to be quite consistent with McGraw-Hill's survey of business plans for research and development expenditures [10], which provides data for five of our seven industries. In its 1982 survey, McGraw-Hill asked the respondents what percentage of their 1985 sales would be in new products introduced for the first time in 1982–85. If this percentage for the kth industry is L_k, if the kth industry's 1985 sales equal M_k, if the percentage of new products in the kth industry that could not have been developed (without substantial delay) in the absence of recent academic research is N_k, and if the total sales during 1985 of new products commercialized in 1982–85 that could not have been developed (without substantial delay) in the absence of recent academic research is Y_k:

$$Y_k = L_k M_k N_k.$$

Inserting our estimates of N_k into table 1 for this equation, together with [illegible] estimates of L_k and the actual values of M_k, we find that the resulting estimates of Y_k for these five industries are close to our estimates of Y_k. The differences generally can be attributed to sampling errors.

The McGraw-Hill data cannot be used to check our results for the drug and information processing industries, because these data are not available for them. To obtain data concerning L_k for these two industries, we contacted leading firms in each industry, which provided us with rough estimates. For the information processing industry, the resulting estimate of Y_k is reasonably similar to our estimate of Y_k. But in the drug industry, it is much lower than our estimate of Y_k. According to some leading R&D executives in the drug industry, this is because our estimate of L_k for this industry is too low. But if this is not the case, and if our estimate of Y_k for this industry is too high, our final results will not be affected very much. For example, even if this estimate were double what it should be, the social rate of return in table 4 would be 26 percent, which is not very different from the figure of 28 percent given now.

Turning to new processes, data were obtained from each firm in our sample concerning the savings during 1985 from new processes first commercialized in 1982–85 that could not have been developed (without substantial delay) in the absence of recent academic research. From these data, estimates were made of the total savings during 1985 from such new processes for all major firms in each industry. [13] The seven-industry total was about $7.2 billion, as shown in Table 2. The information processing industry seemed to have greater savings than the other industries, but the sampling errors in the figures for individual industries are very large. The important figures are the seven-industry totals ($7.2 billion and $11.3 billion) which, while they contain substantial sampling errors, are accurate enough to be useful.

4. Time lags between academic research and industrial innovation

To understand the relationship between academic research and industrial innovation, we need data regarding the length of the time lags between academic research findings and the commercialization of the innovations based on these findings. Information concerning these time lags was obtained from the firms in our sample. For each firm's new products and processes introduced in 1975–85 that could not have been developed (without substantial delay) in the absence of recent academic research, data were obtained concerning the mean time interval between the relevant academic research finding and the first commercial introduction of the product or process. If more than one such research finding was required for the development of the innovation, this time interval was measured from the year when the last of these findings was obtained. [14]

[13] To make this estimate, we multiplied the number of major firms in each industry by the mean 1985 savings from such processes of the firms in the sample. For some firms, these savings data, like the sales data discussed in footnote 11, are rough. Our comments at the end of footnote 11 apply to these data as well.

[14] Because not all of the firms could provide data of this sort, and because others sometimes could only approximate these dates, the results contain errors, but the averages in table 3 should be reasonably accurate.

into

in

McGraw-Hill's

Table 2
Estimated sales of new products based on recent academic research and estimated savings from new processes based on recent academic research, seven industries, United States, 1985 [a]

Sales or savings	Innovations that could not have been developed (without substantial delay) in the absence of recent academic research	Innovations that were developed with very substantial aid from recent academic research
Total 1985 sales by major firms of new products first commercialized in 1982-85 and based on recent academic research:		
Billions of dollars	24.0	17.1
Percent of total sales of major firms	3.0%	2.1%
Total 1985 savings by major firms due to new processes first commercialized in 1982-85 and based on recent academic research:		
Billions of dollars	7.2	11.3
Percent of total costs of major firms	1.0%	1.6%

Source: See section 3.
[a] The seven industries that are included are listed in table 1.

As shown in table 3, the mean time lag in these industries was about 7 years. [15] In general, it appears that the time lag tends to be longer in larger firms, which is consistent with the view that development often takes longer in larger firms. Also, some small firms are formed to commercialize the results of academic research. When size of firm is held constant, the average lag tends to be greater in the metals industry than in the others, but the sample size in this industry is rather small, so this finding should be viewed with considerable caution. Letting D_i be the mean time lag (in years) for the ith firm,

$$D_i = 5.72 + 0.38S_i + 5.68Y_i \quad (R^2 = 0.30), \qquad (1)$$
$$\qquad\quad (2.25) \quad (2.95)$$

where S_i is the 1985 sales (in billions of dollars) of the ith firm and Y_i is a dummy variable that equals 1 if the ith firm is a metals firm and zero otherwise. [16]

For each firm's new products and processes introduced in 1975–85 that were developed with very substantial aid from recent academic research, similar sorts of data were obtained. As shown in table 3, the average lag for these innovations was 6.4 years, which is close to our result for innovations that could not have been developed (without substantial delay) in the absence of recent academic research.

It is interesting to note that Gellman [7] found almost precisely the same average lag for academic-research-based innovations in 1953–73 (his average was 7.2 years). Also, an analysis of Gellman's data indicates that academic-research-based innovations tend to be carried out by much smaller firms than other innovations. Whereas about 20 percent of other innovations were carried out by firms with under 100 employees, almost 60 percent of these innovations were carried out by such small firms, some of which were probably established to exploit the relevant academic research. [17]

[15] The standard error of each of the overall means in table 3 is about 0.6 years.

[16] In equation (1), the t-statistics are shown in parentheses below the regression coefficients.

[17] Of course, one should bear in mind that Gellman's data are in many regards not comparable with ours. Besides the differences pointed out in the last paragraph of section 2, it is worth noting that, whereas the lag can be longer than 15 years for innovations in Gellman's sample, this cannot be the case in ours, because we are concerned entirely with innovations based on recent academic research. Also, in this comparison (but not in that in the last paragraph of section 2), his data pertain to all industries, not just to those included here. Nonetheless, it is reassuring to find that his results are so close to ours.

Note too that there is no contradiction between our finding here that academic-research-based innovations tend to be carried out by small firms and our findings in footnote 7. The latter are based entirely on data for major firms.

Delete

5. The social rate of return from academic research: The basic model

To calculate the social rate of return from the investment in academic research, we must compare the stream of social benefits if this investment takes place with what it would have been without this investment, holding constant the amount invested in non-academic research. In other words, we are interested in what would happen if the resources devoted to academic research were withdrawn—and not allowed to do the same or similar work elsewhere. [18] Specifically, suppose that all academic research were to be terminated permanently at the end of year $t-1$.

Without the investment in academic research in year t, the findings of this research (on which new products and processes are based) would not be available, thus preventing or delaying the development and introduction of the new products and processes based on these findings. According to the firms in our sample, it would have taken at least 9 years longer, on the average, for the new products and processes in tables 1–3 (that were based on academic research) to have been introduced. But since estimates of this sort obviously are subject to large errors, we make the more conservative assumption that it would have taken 8 years for this to occur. As we shall see, our findings change relatively little, even if we assume that this average delay is much less (for example, 3 years).

The social rate of return from the investment in academic research in year t is the interest rate that makes the present value in year t of the extra social benefits due to the earlier introduction of these new products and processes equal to the investment in academic research in year t. This is an incremental rate of return, since it is the rate of return from only the final installment of the total investment required to bring forth the relevant academic research findings. Absent the investment in year t, the findings of this research would not have been produced (without considerable delays), but this investment is not the total investment required to elicit these findings. Because of the cumulative nature of science, this total investment may have extended over decades or centuries. Nonetheless, for policy-makers who must decide how much to invest next year in academic research, this incremental rate of return is of primary significance. Past investments in academic research are sunk costs, and the social rate of return from next year's investment is what counts.

To calculate this rate of return, we assume, based on the average time interval in table 3, that the new products and processes made possible by the investment in academic research in year t are introduced 7 years later (that is, in year t', where $t' = t + 7$). The social benefits from the innovations commercialized in year t' that are based on academic research in year t are assumed to con-

Table 3
Average time lag between a recent academic research finding and the first commercial introduction of a new product or process based on this finding, seven industries, 1975–85

Industry	Innovations that could not have been developed (without substantial delay) in the absence of recent academic research (mean number of years)	Innovations that were developed with very substantial aid from recent academic research (mean number of years)
Information processing	7.0	6.2
Electrical	5.3	4.9
Chemical	6.8	7.3
Instruments	4.2	4.2
Drugs	8.8	10.3
Metals	9.8	5.7
Oil [a]	N.A.	N.A.
Industry mean [b]	7.0	6.4

Source: See section 4.

[a] Reliable data could not be obtained for a sufficiently large number of innovations to allow us to present figures for this industry.

[b] Unweighted mean of industry figures.

[18] Note that we focus on the rate of return from the entire investment in academic research, not the rate of return from an extra dollar spent on academic research. While the latter rate of return is of great significance, we cannot estimate it with the existing data. Our objective is not to allocate the growth in output among various contributing factors, as in Edward Denison's pioneering work (for example, Denison [5]). Instead, it is to estimate the extent of the social benefits which would have been forgone in the absence of recent academic research, which obviously is a polar extreme. In interpreting the results, it is important that this be borne in mind (see section 7). For interesting discussions of other relevant considerations, see Kendrick [9]) and Nelson [21].

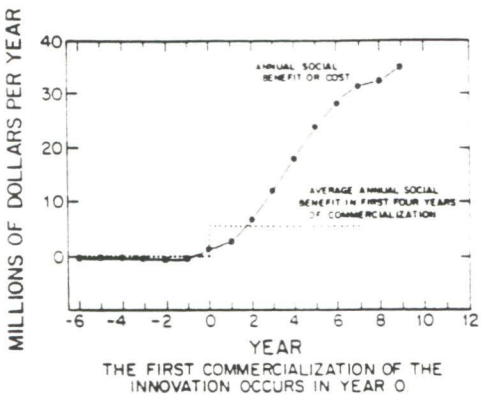

Fig. 1. Annual social benefit or cost, by year, from first commercialization of innovation, mean for 53 industrial innovations. *Source:* Foster Associates [6], Mansfield et al. [13], and Nathan Associates [17].

tinue up to year $t' + 7$ (and no longer) at their average annual level in the first four years after commercialization, and to be zero before year t'. This, as explained in the following paragraphs, is a very conservative assumption.

Figure 1 shows the average annual stream of social benefits and costs for the 53 industrial innovations studied in Mansfield et al. [14], Foster Associates [6], and Nathan Associates [17], the three principal sources of data on this topic. [19] For the innovations based on academic research in year t, we are replacing the time form of social benefits and costs in fig. 1 with the dotted line shown there. This dotted line underestimates the average social benefits in the years after the commercialization of the innovation, as well as the social costs (due to investment in applied R&D, plant and equipment, and startup activities) prior to year t'. On balance, this a very conservative assumption, if the time form of social benefits (savings from new processes, profits from new products, and benefits to those other than the innovator) and costs is at all similar to that of the 53 innovations included in fig. 1. If the interest rate is 0.25, the discounted net social benefits based on this assumption are about half of their actual value. If the interest rate is lower, this assumption is even more conservative.

The reason why the social benefits stop in year $t' + 7$ is that we make the conservative assumption that, in the absence of academic research, the relevant research findings would have been obtained (through industrial, government, or other research) in time to permit the introduction of the new products and processes based on these findings in year $t' + 8$—that is, 8 years after they would have been introduced if the investment in academic research in year t had been made.Hence, after year $t' + 7$, there are no social benefits in excess of those that would have accrued without academic research in year t. [20] Note once again that the firms in our sample regard this assumption of a 8-year delay as being conservative (that is, on the low side). [21]

Thus, based on the very conservative assumptions described in this section, if we want to estimate the social rate of return from the annual investment in academic research during 1975–78, we must find the value of i which satisfies the following equation:

$$X\left[\frac{1}{(1+i)^7} + \frac{1}{(1+i)^8} + \cdots + \frac{1}{(1+i)^{14}}\right] = C, \tag{2}$$

where C is the annual investment in academic research during 1975–78, and X is the annual social benefit from this investment.

[19] Three of Nathan's innovations had to be omitted because of incomplete data. A fourth was excluded because the timing of the social benefits from this innovation was affected dramatically—and very atypically—by the outbreak of an epidemic. The costs and benefits in fig. 1 are in constant dollars.

[20] This assumes that the average social benefit during the first four years after commercialization is about the same if the innovation is delayed 8 years as if it is not delayed. Whether or not this is true will vary from case to case, but since benefits 8 years or more after commercialization are so heavily discounted, the results are not influenced much by this assumption. Moreover, it is a conservative assumption so long as the delay does not increase the annual social benefit from the innovation, which seems unlikely in most cases.

[21] In considerable part, this long delay occurred because industrial researchers often had little or no incentive to do the kinds of work that academic researchers carried out. Whereas the academic research underlying the innovations in tables 1–3 was of interest to academic researchers (and to the federal agencies that financed much of it), it often seemed to be of little or no direct use to firms; and even when it did seem to be of use, there often was no effective means for the firms to appropriate the benefits.

6. Academic research during 1975–78: Estimated rate of return

To solve equation (2) for r, we need the values of C and X. With regard to C, we use the worldwide investment in academic research, since academic science is in many respects an international enterprise, and firms in all countries draw on the findings of foreign as well as domestic academic research. OECD data and Campbell [2,3] are used to estimate the annual investment during 1975–78 in academic research (other than the social sciences and psychology) in the OECD countries and the Soviet Union (which, according to the National Science Foundation, [22] carry out almost all of the world's scientific and technological activities). Because of the difficulties in distinguishing R&D from teaching (and for other reasons), the resulting estimate of C (which is expressed in 1985 dollars [23]) is rough. [24] Fortunately, our results are not very sensitive to reasonable variations in this estimate.

To estimate X, the first thing to note is that, since there is a 7-year lag, the investment in academic research during 1975–78 results in new products and processes commercialized in 1982–85. Let b_{ij} be the social benefit during year $t'+j$ (where $j = 0, \ldots, 3$) from the ith new product or process (based on academic research) commercialized in year t'. If we define $B(t')$ as $\sum_i \sum_{j=0}^{3} b_{ij}/4$, where the first summation is over all of the new products and processes commercialized in year t' that were based on academic research, it follows that $B(t')$ is the sum of the social benefits accruing annually from the new products and processes commercialized in year t' that were based on recent academic research, if one accepts the very conservative assumption in section 5—that is, if we assume that the annual social benefits equal their average annual level in the first four years after commercialization.

Under this very conservative assumption, X equals the mean value of $B(t')$ during 1982–85.

[22] National Science Foundation [18, p. 4]. According to the National Science Foundation [18, p. 278] about 11 percent of academic R&D in the United States in 1975–78 went for the social sciences, psychology, and other research not concerned with engineering or the physical, environmental, mathematical, or life sciences. In other countries like Japan, this percentage may be higher [18, p. 206], but to be conservative, we assume that the U.S. percentage is true in all countries. This may tend to bias the estimated rate of return downward.

[23] Like the National Science Foundation, we use the GNP deflator to convert to 1985 dollars. As pointed out in Mansfield [11], this deflator has important weaknesses, but for present purposes it should be good enough. While it may result in some downward bias in C, this bias will be too small to affect the results materially.

[24] For a description of the OECD data, see OECD [22]. Data for 1975–78 were provided by Allison Young of OECD. For the United States, the OECD figures exceed the NSF figures, because they include capital spending and federally funded research and development centers administered by universities. Since work by the centers is not included in our definition of academic research, the R&D performance of these centers is deducted from the OECD figures.

To estimate academic research expenditures in the Soviet Union, we use Campbell's figures [3] for 1975–78 and his dollar-ruble conversion ratio for 1976 and 1977. See Campbell [2].

There are several important problems in these data. For one thing, unsponsored research by U.S. faculty members is omitted. According to the National Science Foundation [19], about 16 percent of engineering research in universities was unsponsored in 1978, as well as about 22 percent of research in the physical sciences, 13 percent in the life sciences, and 16 percent in the environmental sciences. Thus, to take account of unsponsored research, the American figure should be increased. Also, some spending by states on research at state universities, if it is not designated as research, is omitted. On the other hand, Japan counts all of its university teaching budget as academic research, which means that its figure for university R&D is too high. See *Science*, 2 October 1987. According to experts in the field, there is no reason to believe that the OECD figures for all member countries as a whole are biased downward.

Martin and Irvine [16] have made a careful study of academic research financed by government in France, Germany, Japan, the Netherlands, the United Kingdom, and the United States. Including estimates of unsponsored research by faculty members, they estimate the amount that was spent on academic research financed by general university funds and academic, separately budgeted, research in these six countries in 1975. Since these countries account for about 86 percent of all OECD academic research, according to the OECD data, a reasonable estimate of the OECD total academic research supported by government in 1975 is their figure divided by 0.86. Including the Soviet Union, the total (excluding psychology, social sciences, vocational studies, and humanities) provides no indication that our estimate of C is on the low side.

Nonetheless, even if our estimate of C were 25 percent too low, our results would not be changed, except in detail. The social rate of return is 25 percent (rather than 28 percent, as shown in table 4). Neglecting the benefits to users from new products, the social rate of return is 8 percent (rather than 10 percent, as shown in table 4).

That is,

$$X = \sum_{t'=1982}^{1985} B(t')/4 = \sum_{t'=1982}^{1985} \sum_{j=0}^{3} B(t', j)/16, \tag{3}$$

where $B(t', j) = \sum_i b_{ij}$. (That is, $B(t', j)$ is the sum of the social benefits in year $t' + j$ accruing from the new products and processes commercialized in year t' that were based on recent academic research.) Under this conservative assumption, the sum of the social benefits during 1985 of all of the new products and processes first commercialized in 1982–85 that were based on recent academic research is:

$$B_{85} = \sum_{t'=1982}^{1985} B(t', 1985 - t'). \tag{4}$$

Assuming for simplicity that the effects of j on $B(t', j)$ are independent of those of t' on $B(t', j)$,[25] we can approximate X by $B_{85}/4$. (Note that X, like C, is in 1985 dollars.)

As is well known, the social benefits from a new process consist of the savings to the innovator plus whatever net benefits accrue to others, and the social benefits from a new product consist of the increased gross profits (cash flow adjusted for effects on displaced products) of the innovator plus the net benefits to users.[26] To make a conservative estimate of B_{85}, we begin by adding the savings from the new processes in the left-hand column of table 2 to the gross profits (cash flow adjusted for effects on the profits of displaced products) from the new products in the left-hand column of table 2.[27] However, this figure must be adjusted for three reasons. First, we have assumed that the investment in academic research resulted in no social benefits from the new products and processes developed "with substantial aid" from recent academic research. In fact, it seems reasonable to assume that at least half of these new products and processes would not have been developed (without substantial delay) in the absence of academic research. Thus, half of the savings from the processes and gross profits from the products in the right-hand column of table 2 are added to the above figure.[28]

Second, we have assumed that only American firms enjoy savings and profits from innovations based on academic research. Even in the 1960s, when America was far more dominant technologically than in 1982–85, the National Science

[25] Put differently, we assume that the changes over time (during the first 4 years) in the sum of the social benefits accruing from the new products and processes commercialized in year t' (that were based on recent academic research) are the same, regardless of whether $t' = 1982$, 1983, 1984, or 1985. In other words, if we constructed an annual social benefits curve (like that in fig. 1) for the sum of all innovations commercialized in 1982, its slope (for number of years = 0,...,3) is assumed to be the same as for innovations commercialized in 1983, 1984, or 1985. This assumption seems to be a reasonable first approximation. Without much more detailed data (which do not presently exist), some assumption of this sort must be made.

For a simple case where the effects of j are independent of those of t', take the situation where $B(t', j) = f(t') + g(j)$. Under these circumstances, it follows from equations (3) and (4) that

$$X = \bar{f} + \bar{g}, \tag{5}$$

and

$$B_{85} = 4(\bar{f} + \bar{g}), \tag{6}$$

where

$$\bar{f} = \sum_{t'=1982}^{1985} f(t')/4$$

and

$$\bar{g} = \sum_{j=0}^{3} g(j)/4.$$

Obviously, $X = B_{85}/4$, which is the point made in the text.

[26] For a much more detailed and complete discussion of the measurement of the social benefits from a new process or product, see Mansfield et al. [13].

[27] As explained in Mansfield et al. [13], gross profit—that is, profit without depreciation being deducted—is the relevant concept here. To estimate gross profit, we multiplied the estimated 1985 sales of the products that could not have been developed without recent academic research by the average ratio of gross profit (net profit plus depreciation) to sales in 1985 in the relevant firms, the latter ratio being obtained from the firms' accounting records. Next, a rough adjustment was made to allow for the fact that the new products' profits were partly at the expense of older products (sold by other firms as well as by the innovators) they partially or entirely displaced [13]. Based on interviews with company executives, the resulting gross profit figures are reasonable, but rough.

[28] Here too we assume that there would be an 8-year delay in the absence of academic research. To see what the effects would be if we made the even more extreme assumption that academic research resulted in no social benefits from the new products and processes developed "with substantial aid" from recent academic research, see table 4.

Foundation [20] estimated that American firms carried out only slightly more than half of the major innovations in the leading OECD countries. Based on this and more recent evidence, [29] it appears that a conservative estimate of the worldwide savings and gross profits in 1985 from new products and processes first commercialized in 1982–85 that were based on recent academic research would be double the American figure obtained in the previous paragraph. (Note that, even if we were to assume that they were only 1.5 times the American figure, our results would change relatively little.)

Third, we have assumed that new products and processes based on recent academic research result in no social benefits other than to the innovator, which is ridiculously conservative. [30] For the product innovations in Mansfield et al. [13], the benefit to users during the first four years after their introduction was about eight times as great as the gross profit from these products, even though in some cases we must ignore the effects on the profits of displaced products, thus reducing the ratio of benefits to users to gross profit. [31] (For the product innovations in Foster Associates [6]) and Nathan Associates [17], the ratio was even higher.) Based on a small random sample of academic-research-based innovations, this 8-to-1 ratio seems to be too low. [32] Nonetheless, we make the seemingly conservative assumption that this ratio prevails for new products. [33] For new processes, we ignore social benefits other than to the innovator.

The resulting estimate of X, together with our estimate of C, implies that the estimated social rate of return—that is, the value of i in equation (2)—is 28 percent. Of course, the roughness of this figure should be emphasized, but it is noteworthy that the estimated rate of return is so high, given the many ways in which it has been biased downward. Among other things, we have ignored: (1) the social benefits from innovations based on academic research in all industries other than the seven in table 1; (2) the increases in annual social benefits from innovations based on academic research after their first four years of commercialization; and (3) the social benefits from innovations based on academic research findings that are commercialized more than 15 years after the findings or that are introduced by non-major firms.

Moreover, as shown in table 4, the estimated rate of return is 23 percent, even if we exclude all social benefits from innovations developed with substantial aid from academic research. Going to an even more conservative extreme, the figure is

[29] According to the National Science Foundation [18, p. 203] the United States carried out 39 percent of the industrial R&D in these industries in seven countries (Japan, Germany, the United Kingdom, France, Canada, Italy, and the United States). Since many countries, including the Soviet Union, are omitted, the percent of world R&D must be well below 39 percent. According to Gellman's data [7], the proportion of innovations based on academic research in other countries (Canada, France, Germany, Japan, and the United Kingdom) was an high as in the United States, and the average time lag was not significantly different.

[30] For a description of methods to estimate the benefits to users, see Mansfield et al. [13]. Even without the work of the past decade or so, it is obvious that the exclusion of the benefits to industrial and individual users results in a gross under-estimate of the social benefits, since the benefits of new products are passed on (in substantial measure) to users (including consumers).

[31] This pertains to the first 4 years after commercialization, which is the period used here to estimate benefits. One reason why the ratio is relatively high is that profits often are lower than in later years.

[32] Because the direct estimation of the benefits of an innovation to users is a very laborious and expensive process, we have had to limit this part of our study to ten new products in these industries that were based on recent academic research. These products were randomly chosen. In every case, the ratio of the benefits to users to the innovator's gross profit (in the first four years after the product's introduction) exceeded 8. These results, taken in combination with the findings of Mansfield et al. [13], Foster Associates [6], and Nathan Associates [17], which provide detailed estimates for about 40 new products, seem to provide substantial evidence that the 8-to-1 ratio is conservative.

[33] It would be preferable, of course, to make direct estimates of the benefits to users, rather than to make crude estimates based on this ratio, but existing resources do not permit such an ambitious undertaking. In table 4, it is shown that the estimated social rate of return is 10 percent even if the benefits to users are assumed to be zero. Thus, even if this ratio were too high, the rate of return would still be substantial.

Note too that we ignore the benefits to imitators of new products based on recent academic research, as well as the benefits to customers of firms that carried out process innovations based on recent academic research. These benefits can, of course, be considerable.

Table 4
Estimated rate of return from worldwide investment in academic research in 1975–78, based on alternative assumptions

Assumption	Rate of return (%)
Including half of innovations developed with substantial aid from academic research	
Including estimated benefits to users from new products	28
Excluding benefits to users from new products	10
Excluding all innovations developed with substantial aid from academic research	
Including estimated benefits to users from new products	23
Excluding benefits to users from new products	5

Source: See section 6.

10 percent (not excluding all social benefits from innovations developed with substantial aid from academic research) or 5 percent (excluding all social benefits from innovations developed with substantial aid from academic research), even if we ignore all social benefits to users from new products based on recent academic research. [34]

7. Conclusions

Because the results of academic research are so widely disseminated and their effects are so fundamental, subtle, and widespread, it is difficult to identify and measure the links between academic research and industrial innovation. This paper presents, apparently for the first time, data concerning the percentage of new products and processes that, according to the innovating firms, could not have been developed (without substantial delay) in the absence of recent academic research. Since these data were obtained from key technical and managerial personnel of the innovating firms, they merit attention, although they, like other such survey data, are rough and contain sampling errors.

Our findings suggest that about one-tenth of the new products and processes commercialized during 1975–85 in the information processing, electrical equipment, chemicals, instruments, drugs, metals, and oil industries could not have been developed (without substantial delay) without recent academic research. The average time lag between the conclusion of the relevant academic research and the first commercial introduction of the innovations based on this research was about 7 years (and tended to be longer for large firms than for small ones). A very tentative estimate of the social rate of return from academic research during 1975–78 is 28 percent, a figure that is based on crude (but seemingly conservative) calculations and that is presented only for exploratory and discussion purposes. It is important that this figure be treated with proper caution and that the many assumptions and simplifications on which it is based (as well as the definition of a social rate of return used here) be borne in mind. While interesting, it is by no means a full or satisfactory solution to the long-standing—and extraordinarily difficult—problem of evaluating the payoff to society from academic research. It is at best a very crude beginning.

Nonetheless, our results provide convincing evidence that, particularly in industries like drugs, instruments, and information processing, the contribution of academic research to industrial innovation has been considerable. Needless to say, this does not mean that other inputs like industrial research, plant and equipment, labor and management have not been important as well. But whereas the contribution of these other inputs generally is taken for granted, the role of academic research sometimes has been regarded as far more questionable. Our results, while they do not address the very difficult question of how to allocate the social returns between academic and industrial research, indicate that, without recent academic

[34] There are sampling errors in the estimated rates of return in table 4. Since our sample was randomly chosen, rough estimates can be made of these sampling errors. Because there is considerable variation among firms and because the sample size in some industries is quite small, the figures for individual industries in table 2 contain very large sampling errors. However, what is important here is the sum of the industry figures for savings from new processes plus gross profits from new products. If we include half of the innovations developed with substantial aid from academic research, as well as the benefits to users from new products, the probability is 0.975 that the rate of return exceeds 15 percent, based on the assumptions in the previous section. Note too that the estimates by Mushkin [26] of the social rate of return from biomedical research are about 50 percent, which exceed those in table 4.

research, there would have been a substantial reduction in social benefits. This really is what the estimated social rate of return, as defined above, is saying.

To prevent misunderstanding, it may be worthwhile to conclude by recognizing that the rationale for academic research extends far beyond the sorts of narrowly defined economic benefits considered here. Obviously, knowledge concerning the universe is important for its own sake, and the education of students, which occurs in many academic research projects, is socially important as well. Nonetheless, it is interesting to find that, even if academic research is judged in these relatively restricted terms, its role seems to be substantial. [35]

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[35] It should also be emphasized that our results do not rest on the so-called linear model of innovation, which assumes that universities first perform basic research, the results of which are transferred to industry, which in turn does the development leading to the innovation. As is well known, this linear model is often violated. For example, academic research frequently occurs in response to R&D carried out, and problems encountered, in industry. Our analysis in no way assumes that the linear model is true. It is just as valid if the relevant academic research is in response to industrial research.

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STATEMENT FROM D. ALLAN BROMLEY, ASSISTANT TO THE PRESIDENT FOR SCIENCE AND TECHNOLOGY

Leon Lederman's report Science: End of the Frontier? raises important issues that deserve, and are receiving, serious consideration. The view that activities of individual scientists and engineers throughout the nation represent the backbone of U.S. strength in science and technology is one that I have long shared. The anecdotal evidence that Lederman has compiled emphasizes the fact that the number of such investigators and the total of their requests for federal support of their research have both grown more rapidly during the past decade than has the available funding. The pain and concern expressed by the research community are very real.

However, it is important to note that overall support for academic research and development has grown substantially -- from about $7 billion in 1968 (in 1988 dollars) to $13 billion in 1988, according to the Government-University-Industry Research Roundtable. Within this total, federal support rose from $5 billion in 1968 (in 1988 dollars) to $8 billion in 1988. Funding for research and development at America's colleges and universities has now reached 0.27 percent of the gross national product, an all-time high.

The Bush Administration recognizes the vital contributions that individual and small-group research makes to fundamental scientific understanding, economic growth, an improved quality of life, enhanced national security, and the training of young scientists and engineers for industry, government, and academia. The Administration has therefore endorsed doubling the budget for the National Science Foundation within five years and has increased funding for research and development at the many other federal agencies that support individual investigators.

The Administration is also taking other steps in this area. It is premature for me to discuss the fiscal year 1992 budget, but support for individual investigators will receive special attention in that budget.

At the same time, it is important to recognize that the recently concluded budget agreement imposes spending caps on domestic discretionary funding that limit spending growth. Nevertheless, there is widespread agreement in the Administration and in the Congress that we, as a nation, are underinvesting in research and development, and we will continue to strive for adequate support for individual and small-group research.

ESSAY

Technology and competitiveness

by B. R. Inman
and Daniel F. Burton

The once commanding U.S. advantage in technology has slipped away. The culprit? International competition. The consequence? U.S. government and business relationships have been fundamentally altered, with major implications for U.S. science and technology policy. Although the repercussions are still being sorted out, the basic message is clear: when it comes to technology, U.S. public policy can no longer afford to be preoccupied with basic research and military issues; economic security and industrial competitiveness are also vital considerations.

Five technology stories illustrate the changing public policy debate: consumer electronics, semiconductors, superconductors, the FSX fighter airplane and high-definition television. Taken together, they hold important lessons for U.S policymakers.

The decline of U.S. consumer electronics was the first shot across industry's bow. American inventors pioneered this field with such innovations as the phonograph, radio broadcasting, television receivers, the transistor, color television, portable radios and videocassette recorders. Until 1970, American industry dominated the consumer electronics business. Since then, it has lost virtually the entire market. The industry learned too late that technical breakthroughs must be relentlessly followed up with manufacturing systems capable of high-quality, low-cost, volume production. The federal government contributed to the demise of the industry by allowing imports to be dumped in the U.S. market while foreign markets remained essentially closed to American producers.

If the collapse of consumer electronics could be dismissed in some circles as a low-wage, commodity industry without real importance to the U.S. economy, semiconductors could not. Semiconductors personified Silicon Valley high tech to many Americans, and the trials of this industry captured the public imagination. Following on the heels of consumer electronics, the sequence of events seemed all too familiar. Invented in the U.S., semiconductors spawned a vital American industry that captured a worldwide market. In 1976, however, Japan launched the Very Large Scale Integration (VLSI) program. Ten years later the Japanese had captured 65 percent of the world market for computer memory products. The lesson learned was a hard one: even high-tech U.S. industry could be devastated in short order by foreign competition. The decline of the U.S. semiconductor industry reaffirmed the fact that leading-edge product technology by itself is not enough; process technology, world-class manufacturing capability and government-industry cooperation are also essential.

Close on the tracks of the semiconductor fiasco came the superconductor breakthrough. The series of events that followed highlighted two key issues. First, these events demonstrated just how quickly technical knowledge is diffused around the world. The finding at the IBM laboratory in Switzerland set off an international chain reaction of intense verification efforts and new research advances throughout Japan, the U.S., Europe and China. Second, superconductors riveted U.S. government attention on one overriding issue: how to translate basic research into products and processes that yield the sought-after military and economic benefits. The demise of the U.S. consumer electronics and semiconductor industries was not lost on public officials.

In the spring of 1989 another technological issue made headlines—the FSX fighter. The debate revolved around a proposed joint venture between the U.S. and Japan to produce a new tactical fighter based on General Dynamics' F-16 aircraft. Critics feared it would be a giveaway of American technology and would help Japan achieve its long-standing goal of creating a civilian aerospace industry. Proponents argued that it would actually keep Japan from building its own plane and that the U.S. would gain access to Japanese technology. Although a modified version of the agreement was eventually signed, the debate brought out a deeper policy question: Should American economic interests be given as much weight as traditional security concerns in the formulation of U.S. foreign policy?

For the past two years, Washington has been embroiled in a policy dispute over high-definition television. Backers of HDTV hail it as the most significant development since color television and think it will drive several related technologies. Critics have downplayed it as a technical advance that is limited to a narrow market. For many, the controversy has come to symbolize the government's difficulty in developing a coherent technology policy. Technical feasibility, standards, market demand, military implications and the role of foreign industry are all hotly debated issues. In addition, the HDTV controversy has drawn attention to the fact that a solid manufacturing base is essential to technological leadership. It has also emphasized the close linkages among several related technologies. As one government official stated, "The next generation of televisions is the next generation of computers."

Taken together, these developments have prompted recognition of the need for a workable U.S. public policy framework for technology. Although the debate is still unfolding, there is growing awareness that action is essential in four areas: strengthening the U.S. manufacturing base, upgrading the policymaking machinery for technology, rebuilding the technological infrastructure and widening federal R&D efforts to include more commercially relevant technology. In each area, the need is clear; the means are less apparent.

The debate about technology and competitiveness has enormous implications for U.S. national security and economic growth. As such, it promises to have a far-reaching impact not only on the strategic objectives the nation pursues but also on the institutions that shape our policies. In the past, U.S. policies have tended to impede rather than to assist efforts of the private sector to bring new technology rapidly to market, because the U.S. government has not addressed the commercialization of technology as a public policy issue. We can no longer afford to ignore this issue. Arcane topics, such as technical standards, patent law, R&D funding and intellectual property, that once were viewed as the responsibility of obscure bureaucrats will increasingly engage public officials at the highest levels. And government agencies will have to be refocused to address the new priority of technology and competitiveness.

The broad contours of a responsive technology policy are beginning to take shape. The challenge ahead is to implement specific policies and programs that produce concrete results.

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R_x: A Technology Policy

By B. R. INMAN, president of Inman Associates and member of the Executive Committee of the Council on Competitiveness, and DANIEL F. BURTON, executive vice president of the Council on Competitiveness.

The once commanding U.S. advantage in technology has slipped away. The culprit? International competition. The consequence? U.S. government and business relationships have been fundamentally altered, with major implications for U.S. science and technology policy. Although the repercussions are still being sorted out, the basic message is clear: when it comes to technology, U.S. public policy can no longer afford to be preoccupied with basic research and military issues; economic security and industrial competitiveness are also vital considerations.

The decline of U.S. consumer electronics was the first shot across the bow. American inventors pioneered this field with such innovations as the phonograph, radio broadcasting, television receivers, the transistor, color television, portable radios and videocassette recorders. Until 1970, American industry dominated the business. Since then, it has lost virtually the entire market. The industry learned too late that technical breakthroughs must be followed up with manufacturing systems capable of high-quality, low-cost, volume production.

If the collapse of consumer electronics could be dismissed as a low-wage, commodity industry without real importance to the U.S. economy, semiconductors could not. Semiconductors personified Silicon Valley high tech to many Americans, and the trials of this industry captured the public imagination. Following on the heels of consumer electronics, the sequence of events seemed all too familiar. Invented in the U.S., semiconductors spawned a vital American industry that captured a worldwide market. In 1976, however, Japan launched the Very Large Scale Integration (VLSI) program. Ten years later the Japanese had captured 65 percent of the world market for computer memory products. The decline of the U.S. semiconductor industry reaffirmed the fact that leading-edge product technology by itself is not enough; process technology, world-class manufacturing capability and government-industry cooperation are also essential.

Close on the heels of the semiconductor fiasco came the superconductor breakthrough. The series of events that followed highlighted two key issues. First, the incident demonstrated just how quickly technical knowledge diffuses around the world. The finding at the IBM laboratory in Switzerland set off an international chain reaction of intense verification efforts and new research advances throughout Japan, the U.S., Europe and China. Second, the discovery riveted U.S. government attention on one overriding issue: how to translate basic research into products and processes that yield the sought-after military and economic benefits.

In the spring of 1989 another technological issue made headlines—the FSX fighter. The debate revolved around a proposed joint venture between the U.S. and Japan to produce a new tactical fighter based on General Dynamics' F-16 aircraft. Critics feared it would be a giveaway of American technology and would help Japan achieve its long-standing goal of creating a civilian aerospace industry. Proponents argued that it would actually keep Japan from building its own plane and that the U.S. would gain access to Japanese technology. The debate brought out a deep policy question: Should American economic interests be given as much weight as traditional security concerns in the formulation of U.S. foreign policy?

Finally, for the past two years, Washington has been embroiled in a dispute over high-definition television. The controversy symbolizes the government's difficulty in developing a coherent technology policy. The HDTV controversy also underscores the fact that a solid manufacturing base is essential to technological leadership.

Taken together, these developments have prompted recognition of the need for a workable U.S. public policy framework for technology. Action is essential in four areas: strengthening the U.S. manufacturing base, upgrading the policy-making machinery for technology, rebuilding the technological infrastructure and widening federal R&D efforts to include more commercially relevant technology.

The debate about technology and competitiveness has enormous implications for U.S. national security and economic growth. U.S. policies have tended to impede rather than to assist efforts of the private sector to bring new technology rapidly to market, because the U.S. government has not addressed the commercialization of technology as a public policy issue. We can no longer afford to ignore this challenge. Arcane topics, such as technical standards, patent law, R&D funding and intellectual property, that once were viewed as the responsibility of obscure bureaucrats will increasingly engage public officials at the highest levels. And government agencies will have to be refocused to address the new priority of technology and competitiveness.

Biodiversity

- **Biodiversity**, as a topical concern, poses many problems that hinder efforts to bring order, leadership and effective action toward solutions.

  - Interpretation of meaning differs widely.

  - Because it pervades the programs/missions of many agencies, the activities conducted are diffuse and not coordinated.

  - Because of disparate interpretations of definitions, there is neither a common 1) understanding of substance, nor 2) agreement on technical/societal/economic importance.

- **Biodiversity** has both scientific and economic components acting interdependently. Scientifically, it spans the gamut from molecular biology to ecology and systematic biology. In an economic context, biodiversity is integral to biotechnology, materials science, pharmaceuticals, and a sustainable biosphere. This degree of complexity necessitates treatment of biodiversity on its own as a science policy issue.

- Writ large, **biodiversity** involves the following.

  Direct Activities: -surveying/monitoring, -species/ecosystem management, -research, -training, -protected areas (conservation), -germplasm banks.
  Indirect Activities: -regulatory programs, -public education, -institution building, -enforcement, -multi-purpose management (forestry, Bureau of Land Management, etc.), and -museums

- Based on the categories above, the reported federal expenditure on activities relevant to biodiversity is very large (>$1.0 billion). Even with a 50% uncertainty, this would be a major investment.

- A significant problem is the inability to track exactly what is being accomplished, much less to identify underfunded activities and specific needs.

- Cooperative activities can be developed, with exciting results. For example NSF and US AID are jointly supporting projects on biodiversity: NSF supports the participation of U.S. scientists, while AID supports the participation of host country scientists. (Projects include: ethnobotany/ethnopharmacology, biology of rare tropical species, etc.)

- Current events

  - NSF/AID/NCI(Fogarty International Center) workshop on "Drug Development, **Biodiversity** and Economic Development" with industry, developing countries and agencies in mid-March. One product is to be an action plan for further interagency cooperation. This plan could be taken to a **Biodiversity** subcommittee or working group of FCCSET.

- Finally, UNEP has tentatively scheduled the first round of negotiations of a **biodiversity** convention (3/91). A difficult process and complex set of issues: funding, especially the concept of "additionality" (funds above current foreign aid expenditures), and central funding; politically linking preserving biodiversity, access to biotechnology, and rights to germplasm.

National Science Board

Loss of Biological Diversity: A Global Crisis Requiring International Solutions

A Report to the National Science Board

Committee on International Science's
Task Force on Global Biodiversity

NATIONAL SCIENCE BOARD

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Craig C. Black
Chair
NSB Task Force on Global Biodiversity

PREFACE

The Committee began work on this report in October 1987. Over the course of two years' deliberations, we heard from numerous individuals—practitioners of systematic biology and ecology, resource economists, and information scientists to mention a few. We heard from researchers from the Smithsonian, several universities, USDA, USAID, and the National Library of Medicine. We heard about issues in the tropics, the temperate zone, the marine environment, in the lakes and rivers and in the soils—literally every corner of the Earth. The overriding theme that has come through to us, and which we sought to convey in our recommendations, is that to investigate biological diversity and to understand biological diversity we must realize that we are dealing with a transdisciplinary problem.

When considering biological diversity—the loss of species, and the environmental degradation and changes taking place on the planet—we have been too quick to settle on the biological and environmental sciences as sole sources for answers. However, the economics of development, as well as sociological and cultural factors are central to understanding both the basis of the biodiversity crisis and its eventual solutions. Information science and computational science will play a significant role in any program designed to understand and to track environmental and biological changes. The amounts of data to be collected, analyzed and archived are staggering. In fact, the eventual solutions to many of the data issues are likely dependent on technologies yet to be developed in the computational sciences.

Overarching all of this is the undeniable fact that any approach to an understanding of biological diversity—what it is now, how it is being affected through human activities as well as natural changes in the environment—has to be done on an international basis. Biological diversity is not a research project that is limited to a laboratory or a university campus in this country. It is a research program that has to be carried out on an international scale with the full cooperation and participation of scientists from a variety of countries around the world.

When discussing the international dimensions of biological diversity, we are speaking of the need to develop structures and cooperative agreements, and cooperative research programs with individuals in the developing countries of the world. When we speak of the European Common Market and Japan, we are seeking a partnership with our developed world counterparts. Because to understand biological diversity and develop workable means to manage, preserve and restore biological diversity, we are going to have to invest cooperatively with countries in Central America, South America, Southeast Asia and in Africa to develop within their own boundaries the research capabilities to understand and to continue to pursue research programs in areas related to ecological change, species loss, ecological restoration, and eventually sustainable natural resource development.

The biological diversity crisis is indeed that; there is but one Earth, one biota, and our actions in the developed and developing world alike are destroying that which is irreplaceable. There are no quick solutions—even the full dimensions of the resource are elusive—nor is there a second chance. The actions needed are clear to us and are set forth in the report recommendations. Biological diversity has been recognized for at least the past 15 years. Yet progress to mount a reasonable research program to get not only the information that is being lost but to develop the basis with which to counteract that loss has been slow to develop. Our choice of the word "crisis" is a very deliberate one because we are rapidly running out of time where we can hope to understand and preserve the diversity of life on this planet. It is with this motivation and conviction that we submit our findings.

Craig C. Black, Chair
September 1989

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I. PROLOGUE: GLOBAL BIODIVERSITY—A VANISHING RESOURCE

We are at a critical juncture for the conservation and study of biological diversity: such an opportunity will never occur again. Understanding and maintaining that diversity is the key to humanity's continued prosperous and stable existence on Earth.

The extinction event that we are witnessing is the most catastrophic loss of species in the last 65 million years. Most importantly, it is the first major extinction event that has been caused by a single species, one that we hope will act in its own self interest to stem the tide.

Unless the international community can, indeed, reverse the trend, the rate of extinction over the next few decades is likely to rise to at least 1000 times the normal background rate of extinction, and will ultimately result in the loss of a quarter or more of the species on earth.

II. EXECUTIVE SUMMARY

Biological diversity refers to the variety and variability among living organisms and the ecological complexes in which they occur. Diversity can be defined as the number of different items and their relative frequency. For biological diversity, these items are organized at many levels, ranging from complete ecosystems to the chemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species, genes, and their relative abundance (OTA, 1987).

There is an ongoing, unprecedented loss of the variety as well as absolute numbers of organisms—from the smallest microorganism to the largest and most spectacular of mammals. Loss of tropical moist forests, which contain over half the total species of organisms, has been well documented by scientists and is now widely reported in the media. Many other ecosystems are also threatened; as human populations and their support systems expand, natural ecosystems at all latitudes are altered or converted.

At its meeting on October 15, 1987, the National Science Board concluded that the world's decreasing biological diversity is a critical scientific issue requiring immediate attention. The National Science Board's Committee on International Science was asked to study the scientific and international aspects of the decline of biological diversity and to recommend a course of action. This report describes what the National Science Foundation (NSF) can do to influence the U.S. science and education base, articulates where international scientific cooperation is needed, and suggests roles for other agencies and organizations (both national and international) which have scientific, educational, and management responsibilities.

The current disappearance of biota has several causes: the destruction or degradation of entire ecosystems; the accelerating loss of individual species from communities or ecosystems as a result of human disturbance; and the loss of genetically distinct parts of populations due to human-induced selective pressures. Although not all parts of the planet are equally affected, the problem is global, and human activities are the primary cause.

The loss of biological diversity is important because human existence depends on the biological resources of the earth. Human prosperity is based very largely on the ability to utilize biological diversity: to take advantage of the properties of plants, animals, fungi, and microorganisms for food, clothing, medicine, and shelter.

Scientific knowledge about the earth's biological diversity has huge gaps. This lack of information hampers society's ability either to estimate the magnitude of the problem or to prevent further losses. It is impossible to identify all the biological resources at risk, since there is no complete inventory of all the life forms on earth. Approximately 1.4 million species have been given scientific names, but estimates of actual numbers range from 5 million to 80 million species. Although knowledge of some taxa is extensive, the vast majority of groups are largely unknown. The current wave of extinction is destroying both known biotic resources and those still undiscovered.

As is proving to be the case with most environmental problems, neither the loss of biological diversity nor its solution is the exclusive province of any one nation. International cooperation is necessary to develop both scientific knowledge and successful mitigation and management strategies. The root causes of the problem include sociological and economic processes which operate on an global scale; a thorough understanding will require investigation and elucidation of both biological and non-biological components.

There are several reasons for increasing National Science Foundation (NSF) involvement in biodiversity studies: the economic and social importance of biodiversity (and the risk of opportunity lost due to accelerating extinction); the contributions such leadership can make toward to conservation of biological diversity; the important role of such studies in the international growth of science, especially in tropical countries; the potential impact of such studies on the future course of biology as a whole; and enhancing public awareness of the issues.

NSF should assume a scientific leadership position with respect to agencies in the U.S. and throughout the world. By insisting on the central importance of biodiversity, the NSF could encourage collaborative support for the actions recommended below.

The Committee's five recommendations are outlined below.

1. **The Committee believes that the role of the NSF is clear—NSF should, as a matter of National Science Board Policy, provide leadership to undertake the inventory of the world's biodiversity.**

   We recommend that support of biotic inventories be significantly expanded within the Division of Biotic Systems and Resources, with initial funding of $5 million annually, climbing to about $20 million.

   We specifically recommend significant expansion of support of microbial systematics and ecology, with an initial funding of $8 million and a growth to approximately $20 million annually. Although microorganisms are the basis for numerous advances in molecular biology and genetics and are one of the bases for the rapidly emerging field of biotechnology, microbiology is poorly known from the standpoint of ecology, species diversity, and systematics. The study and classification of these organisms is both difficult and costly, because the methods used are primarily molecular and require expensive technologies.

   We additionally propose that the Biological Research Resources Program be enhanced. Support for those institutions most active in the inventory should be funded at the rate of $5 million annually. This will supply funding necessary to handle the increased numbers of specimens generated by the inventory. A comparable sum will be needed for information management, e.g. data banks, Geographic Information Systems (GIS), to handle and disseminate the data generated by the inventory.

2. **The scientific basis for conservation biology, restoration ecology, and environmental management must be strengthened.**

   We recommend increased support across the Federal government to develop the scientific base underlying the emerging fields of conservation biology, restoration ecology, and environmental management. Effective preservation and restoration must include social and economic considerations. This will involve multidisciplinary research in ecosystem restoration, creation and enhancement, in development of environmental planning and management methods, and in development of environmentally compatible technology. These programs should be funded at a level of $3.5 million the first year, building to a level of $10 million per year.

3. **Educational and public awareness programs related to biodiversity need increased support.**

   We recommend special emphasis on biological diversity education, including K-12 and informal science education.

   Specifically needed are opportunities for predoctoral and postdoctoral training in the fields such as systematics, ecology, conservation biology, and environmental management. Support of international students studying these disciplines in U.S. institutions should be included. NSF has virtually the full responsibility for the health of these fields of biology in the U.S.

   Although predoctoral and postdoctoral opportunities are vital at this time, primary and secondary education should not be ignored. The present mode of primary support for the K-12 level should include the development of materials pertinent to systematics and ecology. These subjects are of interest to most students, and it is increasingly important that all citizens be educated about the global biodiversity crisis. Early education in these subjects is now as important to the national interest as early education in mathematics and other sciences.

4. **The economic and social aspects of the biodiversity crisis need additional study.**

   We recommend additional funding, initially at the level of $1 million annually, for theoretical and empirical studies of the economic and social causes, consequences, and remedies of the biodiversity crisis. These funds would be added to the budgets of the appropriate programs in the Division of Social and Economic Sciences.

5. **Enhance support for developing country scientists and institutions for biodiversity research and conservation.**

   We recommend that NSF, in concert with bilateral and multilateral development assistance agencies, devise new mechanisms to fund scientists and institutions in developing countries working on biodiversity. NSF leadership is critical, because NSF is in a key position to mobilize the resources of the scientific community. These activities will involve U.S. scientific collaboration, but their primary focus must be directed to improving institutional infrastructure, educational opportunities, and employment of systematists, ecologists, and environmental management specialists in the developing countries. Initial funding should be at the level of approximately $2 million.

   This recommendation recognizes that the planet's biodiversity is heavily concentrated in the humid tropics; that new forms of international funding partnerships are essential to the advance of science; and that NSF's future leadership role in biodiversity depends upon its securing an expanded international operating mandate. In the absence of this mandate and increased funding, NSF's capacity to provide international scientific leadership (especially collaborative initiatives) is likely to remain unrealized.

III. PURPOSE OF THE REPORT

Biological diversity is a multi-disciplinary, multi-agency, multi-government issue. At its meeting on October 15, 1987, the National Science Board (NSB) concluded that the world's decreasing biological diversity is a critical scientific issue which requires immediate attention. National and international cooperation are needed to develop both knowledge about and solutions to the problem. The knowledge generated and the solutions undertaken will, in turn, lead to important new opportunities in economic development.

Because of the global scope of the issue, the NSB's Committee on International Science, augmented by other NSB members and scientists at-large, was asked to undertake a study of the scientific and international aspects of the decline of biological diversity. To respond to that charge, this report assesses the issues and sets forth a course of action. The report describes what the National Science Foundation (NSF) can do to influence the U.S. science and education base, articulates where international scientific cooperation is needed, and suggests roles for other agencies and organizations (both national and international) which have scientific, educational, and management responsibilities.

IV. SCOPE OF THE ISSUE

Biological diversity refers to the variety and variability among living organisms and the ecological complexes in which they occur. Diversity can be defined as the number of different items and their relative frequency. For biological diversity, these items are organized at many levels, ranging from complete ecosystems to the chemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species, genes, and their relative abundance (OTA, 1987).

The destruction of ecosystems throughout the world, but especially in the warmer regions, has been well documented by scientists and is now widely reported in print and on television. For example, tropical moist lowland forests, the biologically richest, most poorly known, and, until recently, least disturbed of tropical communities, are being decimated at a rapidly accelerating rate. Large areas of the tropics potentially are affected. Left unchecked, most of the forests will be entirely lost or reduced to small fragments by early in the next century.

Brazil has recently taken a positive step to combat the problem by issuing a management plan for Amazonian tropical moist forest and establishing a new institute to study the issue (Secretaria de Assessoramento da Defesa Nacional, 1989).

The loss of tropical moist forests can have profound and far-reaching effects, including: changes in climate, especially rainfall patterns; changes in biological productivity; soil erosion; and an increase in emissions of "greenhouse" gases, which further affects global climate. Destruction of such biologically rich ecosystems also causes extinctions of vast numbers of species. Most of the lost species are unknown; their potential agricultural, pharmaceutical, or silvicultural values vanish with them.

Although habitat loss in tropical regions has drawn the most attention and are the most immediately threatened, losses of natural ecosystems are occurring in nearly every part of the globe as human populations and their support systems expand.

CURRENT KNOWLEDGE ABOUT THE BIODIVERSITY CRISIS

There is an ongoing, unprecedented loss of variety as well as absolute numbers of organisms—from the smallest microorganism to the largest mammal. Loss of tropical moist forest is only one example. Other ecosystems are also threatened, including coral reefs, inland and coastal wetlands, and other tropical forest types. Although not all regions of the planet are equally affected, the problem is global, and human activities are the primary cause.

The decline in biological diversity is important not only for reasons of aesthetics or scientific curiosity, but because human existence depends on the biological resources of the earth. The current wave of extinction is destroying both known biotic resources and those still undiscovered.

The current loss of biota has several causes. One is the destruction, conversion, or degradation of entire ecosystems, with the consequent loss of entire assemblages of species. Another is the accelerating loss of individual species within communities or ecosystems as a result of habitat disturbance, pollution, and over-exploitation. Third, and more subtle, is the loss of genetic variability. Selective pressures such as habitat alteration, presence of chemical toxins, or regional climate change may eliminate some genetically distinct parts of the population, yet not cause extinction of the entire species.

Estimates of species loss rates suggest that, unless current trends are reversed, from one quarter to one half of the earth's species will become extinct in the next 30 years (Lovejoy, 1980; Ehrlich and Ehrlich, 1981; Norton, 1986).

GAPS IN SCIENTIFIC UNDERSTANDING OF BIODIVERSITY

Our knowledge about the earth's biological diversity has significant gaps. The lack of information hampers society's ability either to understand the magnitude of the problem or to prevent further losses.

It is impossible to even identify all the biological resources at risk, since there is no complete inventory of all the life forms on earth. Current estimates range from 5 million to 80 million species (Erwin, 1983; Stork, 1988; Wilson, 1988). Thus, incredibly, the amount of diversity on the planet is not known even to within the nearest order of magnitude.

Scientists have collected and named only 1.4 million species so far (Wilson, 1988). Although knowledge of some taxa is extensive, the identity and natural history of other groups are largely unknown. A more adequate knowledge base is needed to support the relatively new sciences of conservation biology, restoration ecology, and environmental management. Better information will help develop the means to slow or reverse the losses.

THE PROBLEM IS GLOBAL AND THE SOLUTION INTERNATIONAL

As is proving to be the case with most environmental problems, neither the loss of biological diversity nor its solution is the exclusive province of any one nation. Loss of species is taking place in both the North and the South, primarily as a result of the economic exploitation of species' habitats. Natural resource exploitation is in part a function of international markets and financial practices. Trade in elephant ivory (mostly illegal) and tropical timber (legal) has important consequences for biodiversity maintenance. Similarly, development agency policies to fund (for example) dams, frontier roads, even agriculture, lead directly to the demise of species. Moreover, developing country debt undoubtedly drives these countries to higher levels of natural resource exploitation (and consumption) than would otherwise be the case.

If the causes of biodiversity loss are a part of the international financial fabric, so, too, are the solutions. International cooperation and funding are necessary to develop both scientific knowledge and successful mitigation and management strategies. At the most elementary level, biodiversity funding needs are greatest—both in terms of scientific inquiry and in terms of conservation—in poorer, developing countries. If global and scientific objectives are to be served, more effective mechanisms for North-South transfers of funding must be found; more productive mechanisms for scientific collaboration must be invented.

V. GLOBAL PRESSURES ON BIODIVERSITY

This is a time of unprecedented extinction—the permanent loss of many of the kinds of organisms that inhabit Earth. Several factors contribute to this crisis. They include the explosive growth of a record human population; the existence of widespread and extreme poverty and malnutrition; and a notable lack of sustainable, productive agricultural and forestry systems in many regions where such systems are needed. The resulting economic pressures force many people in developing countries to overexploit natural resources, leading to ecosystem degradation and destruction. This is exacerbated by written and unwritten policies, both of developed and developing countries, which encourage such exploitation.

GLOBAL POPULATION AND ECONOMIC PRESSURES

The global human population, now 5.2 billion, has doubled in size since the early 1950's. This record number of people puts increasing pressure on the earth's biological resources.

The global distribution of people has been changing drastically. For every person who lived in an industrial country like the U.S. in 1950, there were two people living elsewhere; by 2020 (just 70 years later), there will be five. At that time, approximately four times as many people will live in countries that are partly tropical (excluding China[1]) as did in 1950 (World Resources Institute et al., 1988).

In addition, the world population will not stabilize for at least two or three more generations. A high proportion of the people in developing countries have yet to reach childbearing age (typically, 38% to 45% are less than fifteen years old) (World Resources Institute et al., 1988). United Nations' projections from the early 1980's suggested that, even if countries' current family-planning objectives were continued, a stable world population of 9 to 12 billion people would be achieved only in the latter portion of the next century (World Resources Institute et al., 1988). However, that projection assumed a greater increase in worldwide family planning than has occurred. The most recent projections from the United Nations Population Fund (UNFPA), based on the current rate of birth control use, indicate that the world's human population will reach 14 billion by the year 2100. Unless birth control use increases significantly, the world population will reach 10 billion by the year 2025 (UNFPA, 1989).

Although a smaller and smaller percentage (currently about 25%) of the world's population lives in industrialized countries, they control most of the world's wealth. The people in developing nations base their standard of living on no more than 15% of the world's total resources, although they represent 75% of the global population. This unequal distribution of resources is true regardless of what statistic is measured: money, industrial energy, metals, or industrial production (World Resources Institute, 1988).

Developing countries have more agrarian economies and are more directly dependent on natural resources. At present, humans are using between 20% and 40% of the

[1]Because of the unavailability or unreliability of data for China (PRC), these data are not included.

net terrestrial primary productivity (Vitousek et al., 1986; Wright, 1987). Larger populations will require even greater use of natural resources.

More than one billion of the roughly 2.8 billion people now living in the developing world, exclusive of China, are living in a substandard condition that the World Bank defines as absolute poverty. This widespread poverty drives the overexploitation of natural resources, such as clearing tropical forest for agricultural uses.

For these reasons, political and economic instability are widespread, and the scientific and technological infrastructure of developing countries is tragically inadequate. Unless changes are made, prospects for stable development in the tropics in the near future are poor.

HABITAT DEGRADATION CAUSES LOSS OF BIODIVERSITY

Habitat destruction throughout the world, especially tropical regions, is directly related to the population and economic factors described above. Humans have always altered their habitat. However, as human numbers and human technological abilities increase, anthropogenic changes in ecosystems cause environmental degradation and species extinctions.

Much discussion has centered on tropical terrestrial habitats because of the immediate threat and direct connection to human causative factors. Over half the world's species are associated with tropical forests. These forests are being cut at an increasing rate. Ten years ago, the United Nation's Food and Agriculture Organization (FAO) estimated that 70,000 square kilometers of tropical moist forest were destroyed per year: a loss rate of 100 acres every three minutes. The current rate of loss is estimated at 100 acres of forest per minute—the equivalent of losing an area the size of a football field every second. In addition to outright destruction, estimates are that at least another 100,000 square kilometers are significantly disturbed annually (Myers, 1988).

The theory of island biogeography states that when natural communities have been reduced to less than 10% of their original area, half of the original species are at risk (MacArthur and Wilson, 1967). For example, when forests in Central and South America are reduced to patches of twenty square miles or less—a common occurrence—10% or more of the bird species are lost within 10 years (Terborgh, 1974; Willis, 1979; Simberloff, 1984; Wilson, 1988)

A 90% reduction in habitat area has already occurred in several regions of the world, including western Ecuador, Madagascar, and the Atlantic forests of Brazil. In these regions, the surviving biota clings to life in islands of vegetation. These small populations are subject to climatic change associated with edge effects; frequent human-induced disturbance; and inbreeding effects. In these cases, local environmental disasters can easily extinguish entire species.

Such species extinctions may not have immediate effects on human well-being. However, as forests are removed, profound effects on regional and global climates result. For example, at least half of the rainfall in the Amazon is associated with the forest cover (Salati et al., 1983; Salati and Vose, 1984). By stripping the Amazon Forest (an action that, until very recently, was heavily subsidized by the Brazilian government) Brazil may be ruining its own productive agriculture. Clear-cutting the Amazon may cause regional temperatures to rise more than 5°C in the agricultural lands of southern Brazil (Salati et al., 1983; Salati and Vose, 1984).

Destruction of tropical moist forest is a dramatic example of how human activities are causing species loss and other undesirable environmental effects. However, such habitat degradation and concommitant species loss is not limited to the tropics or to terrestrial environments.

Terrestrial ecosystems in every latitude are being destroyed, degraded or converted. In addition, virtually any perturbation of the terrestrial environment has a corresponding effect on aquatic habitats, though the effect may be separated in time and space. Destruction or degradation of aquatic habitat causes both changes in species abundances and outright extinctions. Consider the following examples.

—Emissions from power plants in the midwestern United States cause acid rain in Canada and in the northern United States. Acid rain has been linked to forest dieback and to the reduction or loss of many aquatic species in northern lakes and ponds. Similar observations have been made in Europe.

—Almost 35% of all rare and endangered species in the United States are either located in or dependent on wetlands, although wetlands constitute only about 5% of the nation's lands (Kusler, 1983). However, wetlands are often converted to other uses. The current rate of wetlands loss in the United States is probably greater than 275,000 acres per year (Conservation Foundation, 1988).

—In the United States' Pacific Northwest, logging practices have been linked to reductions in the salmon runs. Logjams have blocked streams, preventing salmon from traveling upstream to spawning grounds. In addition, soil erosion from clear-cutting forests has caused siltation of salmon spawning grounds, either preventing salmon from spawning or killing eggs already laid.

—Catastrophic flooding in Thailand has been linked to the logging and conversion of forests.

Freshwater ecosystems are not the only aquatic habitats affected by alteration of terrestrial habitat. Marine and coastal environments are also affected by changes made on land.

A large proportion of the world's people live in coastal regions. In many areas, the ocean biological resources are

a significant economic resource for the region's inhabitants. Therefore, reduction or destruction of the marine coastal habitat may have severe economic impact on local people.

Coastal bays and estuaries serve many important functions. For example, estuarine systems are sites of high denitrification and are important in reducing eutrophication. In addition, these regions are nursery areas for many marine species. Such "ecosystem services" may be lost as the system is overstressed. Degradation of coastal areas may reduce populations or even eliminate some species of fish, crustaceans, and mollusks.

Human-induced eutrophication can reduce species diversity in coastal regions. For example, eutrophication of Chesapeake Bay from agricultural runoff and sewage has probably increased the production of algal biomass and altered algal species abundances. Increased algal blooms may cause the increased frequency and duration of the seasonal anoxia in the Bay. These changes probably have reduced numbers of benthic organisms and thereby contributed to reducing the productivity of the Bay (Officer et al., 1984).

Biological diversity in other marine systems can also be affected by human activity. For example, coral reefs are among the most diverse, biologically, of any assemblage of organisms and are often a significant source of protein for the people of the region. However, coral reef ecosystems are fragile and extremely vulnerable to disturbance. Eutrophication and sedimentation affect coral reefs. In Hawaii's Kaneohe Bay, sewage effluent and siltation from terrestrial runoff had devastating effects on the coral reefs (Smith et al., 1981).

VI. THE SCIENCE OF BIODIVERSITY

Scientists who collect, describe, and classify organisms and evaluate their phylogenetic relationships are traditionally called taxonomists or systematists. Such scientists study a group, or groups, of related species, often on a regional basis, and may attempt to determine the phylogeny (pattern of evolutionary descent) of the members of that group. To determine phylogenetic relationships, systematists use characteristics ranging from gross morphology to gene sequences. Systematists also study other aspects of the group's natural history (for example, the pollination and dispersal biology of plants).

Systematists prepare monographs of particular groups of organisms, e.g., the palms of the world or the mammals of North America. In a complementary fashion, they also conduct biotic surveys of a variety of organisms in a particular area, for example, the flora of Puerto Rico. Studies of both kinds—monographic treatments of particular groups of organisms and the faunistic or floristic accounts of the organisms that occur in a particular region—are important elements in building up a more complete account of the world's biodiversity.

Systematic studies provide the necessary underpinnings for further biological research. Such basic biological knowledge is essential for productive investigation into the organisms' natural history, ecology, and genetics: the scientific information needed to formulate scientifically-based policies for environmental management.

Biologists are still very far from a complete inventory of all the species of animals, plants, and microorganisms, although Swedish naturalist Carolus Linnaeus founded the science of plant and animal taxonomy over two hundred years ago. In most cases, answers are unavailable for the seemingly simple but important questions, such as: How many species are there? Where do they occur? What is their ecological role? What is their status: common, rare, endangered, extinct?

Of the estimated 1.4 million kinds of organisms which have been assigned names, only about 400,000 occur in the tropics and subtropics; yet scientists agree that no fewer than three million species actually occur in these regions, and the eventual total may be as much as ten times greater (Erwin, 1983). Even for the named species, detailed descriptions of their biology is known for very few species. In other words, current scientific knowledge is inadequate for estimating even the most general characteristics of the abundance and distribution of the plants, animals, and microorganisms.

An NSF-sponsored study on research priorities in tropical biology, completed a decade ago and published in 1980, advocated a worldwide survey of plants, vertebrates, butterflies, mosquitoes, and a few other relatively well-known groups of organisms (NRC, 1980). The report argued that such information would provide an index to patterns of distribution and the nature of communities throughout the tropics. To identify valuable biological resources before they are irretrievably lost, such a survey should be conducted soon; the population, economic, and political factors outlined previously are generating increasing pressures on the world's remaining biodiversity.

In addition, there are other groups of organisms which deserve special attention—ecologically significant groups such as free-living nematodes, ciliates, mites, filamentous fungi, and bacteria. Present knowledge of these groups is very limited, both from a systematic and from an ecological point of view. Current specialists, younger scientists, and students must be encouraged to pursue this area of science.

BIODIVERSITY OF SIGNIFICANT TARGET GROUPS

Biologists have targeted certain major groups of organisms—microorganisms, plants, terrestrial and aquatic

invertebrates, and marine biota—as ecologically significant and consequently deserving special attention. In some cases, even the most basic natural history of these organisms is poorly known.

Microorganisms

Although the basis for numerous scientific advances in molecular biology and genetics, microbiology is poorly known from the standpoint of species diversity and systematics, because of the inherent difficulties in classification. This lack of knowledge about the types and abundance of microorganisms is a major limitation for microbial ecology.

Microorganisms constitute "biological bridges" between trophic levels, between abiotic and biotic factors, and between the biogeosphere and the level of gaseous atmospheric constituents. These linkages assume importance far beyond the microscopic realm in which they operate. For example, mycorrhizal hyphae mediate interactions in plant communities by transferring nutrients between plant species (Chiariello et al., 1982). Other microorganisms are an important source of the greenhouse gases which have a crucial effect on earth's climate—but little is known about that aspect of their ecology.

Many types of microorganisms cause disease in plants and animals. Although diseases are usually considered in light of their economic and medical consequences for humans, microbial and parasitic diseases may play a significant role in population regulation within natural communities. Human-induced changes in ecosystems and the resulting alteration in host species abundances may have unforeseen and undesirable effects on the epidemiology of those diseases.

The current tendency in microbial ecology is to focus on function, rather than on specific species. Because chemical methods for studying microorganisms are more advanced than taxonomic methods, it is easier to study the reactions that microorganisms catalyze, rather than a specific species of microorganism. For example, sulfur deposition in rainfall enhances microorganisms which can reduce inorganic sulfur. This, in turn, stimulates the methylation of inorganic mercury and results in toxicity in aquatic food chains. Yet, surprisingly, the precise taxonomy and community ecology of these microorganisms is unknown. Improving scientific understanding of microbial ecology will require increased knowledge of microbial systematics.

Humans have derived many benefits from scientific knowledge about microorganisms. Actinomycetes alone have been the source of 3000 antibiotics since 1950 (Demain and Solomon, 1981). Biotechnology promises to increase the utilization of microorganisms in solving medical, agricultural, and environmental problems. The two foundations for this "biological revolution" are the techniques and fundamental understanding of molecular biology and genetics, and the diversity of naturally occurring organisms. For biotechnology to fulfill its promise, more knowledge is needed about the microorganisms which will form one of the bases for this new technology.

In the past, there has been little funding for microbial systematics and microbial ecology. However, money alone is not the answer. Like other areas of systematic biology, the human resource base is thin. Rectifying this situation will require education at all levels and attention to training and retraining opportunities.

Plants

In this report, "plants" refers to vascular plants (ferns, conifers, and flowering plants) plus bryophytes (mosses, liverworts, and hornworts). Because of their capacity to convert radiant energy into chemical energy through the process of photosynthesis, plants, along with algae and photosynthetic bacteria, are the basis for all food chains.

There may be as many as 250,000 species of vascular plants, approximately two-thirds of which are found in the tropics. The New World tropics are particularly species-rich; for example, one-sixth of the global diversity of plants, 45,000 species, is found in just three Latin American countries: Ecuador, Peru, and Colombia. Although estimates of the number of plant species are available, more specific biological knowledge is lacking.

Much of the diversity of life is threatened by the destruction of plant diversity, because plants provide both food and habitat for other organisms. One-half of the biological diversity of the earth is associated with tropical forests and is, therefore, threatened by their degradation or destruction. Many as yet unknown plant species will probably become extinct by the year 2000, since all forests will be severely damaged or entirely removed within the next 25 years (Raven, 1988).

Plants provide food, clothing, medicine, and shelter for humans. Tropical regions of the world probably harbor many as yet undiscovered plant species which have beneficial uses for humans. For example, the legume family, a plant family with about 18,000 species, contains many well known foods, forage plants, and a large number of important tropical timber trees. Both the winged bean (*Psophocarpus tetragonolobus*), a new food plant whose use has spread widely through the moist tropics over the past 15 years, and the "wonder tree" (*Leucana leucocephala*), hailed as the solution to problems of soil erosion and firewood shortages, are legumes (NRC 1975, 1979). Legumes are, obviously, of great economic importance and have significant potential as genetic raw material for agricultural biotechnology. However, most of the legumes now utilized in productive human systems were discovered quite by chance. Little is being done to investigate the enormous numbers of legume species that exist in the tropics. Six thousand legume species are found in Latin America alone—and 3,000 to 4,000 of those are in danger of extinction.

Although there are ongoing efforts, at this time there is no comprehensive survey of plant distribution. The dearth of scientists trained for systematic studies in tropical countries and the lack of financing means progress is slow. As is the case with microorganisms, insufficient numbers of

adequately trained scientists makes the preparation of even simple inventories very difficult.

Terrestrial/Aquatic Invertebrates

After microorganisms, invertebrates are, numerically and functionally, the dominant group of organisms on earth. They are slso by far the most diverse in numbers of species. However, again like microorganisms, most invertebrate groups in most parts of the world are poorly known; overall, far fewer than 50% are actually described. The same processes which cause extinction of higher plants and vertebrates also operate on invertebrates. Many species are highly specialized with respect to food, habitat, or other environmental requirements.

The statistics about invertebrates are impressive. For example, ants comprise 5% to 15% of the biomass of the entire fauna of most terrestrial ecosystems. Approximately two-thirds of the 1.4 million described species are invertebrates (Wilson, 1988). Estimates of the total number of species on earth have been revised sharply upward based largely on recent collections of arthropods from tropical forest canopies (Erwin 1982, 1983).

Invertebrates have key functions in ecosystems, including pollination, decomposition, disease tranmission, and population regulation of other species. For example, the interactions of soil mesofauna (e.g. nematodes, collembola, and mites) and soil microorganisms are crucial in maintaining the plant-soil system. Nematodes both feed on and act as dispersal agents for soil bacteria. In turn, predaceous fungi capture live nematodes for use as energy sources.

The activities of invertebrates can have major economic impacts on humans. For example, agriculture depends on crop pollination by bees, yet can suffer greatly from herbivory by other insects. As another example, consider some of the major human diseases mediated by invertebrates: malaria, schistosomiasis, bubonic plague, encephalitis. The recent spread of Lyme disease in the United States has been linked to ticks of deer and mice.

However, invertebrates are not studied in proportion to their number or importance in ecosystems. For example, there are perhaps 20 ant taxonomists worldwide, and fewer who can identify tropical species. For animals like nematodes, collembola, and mites, the number of specialists is even smaller (Wilson, 1985). Knowledge of invertebrate systematics is crucial for productive scientific investigation into other aspects of invertebrate biology.

Marine Biota

Over two-thirds of the Earth's surface is ocean. The biota of Earth's oceans are essential to the structure and function of the global ecosystem. For example, marine phytoplankton play an important role in the maintenance of the atmosphere. Much of the Earth's human population depends on the oceans, especially marine coastal systems, for food. Approximately 80% of the marine species of commercial importance occur within 200 miles of a coast.

Very little is actually known about the marine biota. Fish, molluscs, and corals are the best-known groups. However, major groups of organisms and new habitats are still being discovered. The phylum Loricifera was described only in 1983 (Kristensen, 1983), and an entirely new habitat was revealed by the discovery of ocean vent systems. The bottom of the ocean is still largely unexplored; assaying and understanding its biological diversity requires a commitment of resources like that committed for exploring the Moon. Funding for ships and associated sampling tools is the limiting factor; such research requires costly and specialized equipment.

Current estimates of the total number of species on the planet assume that approximately 80% of species are terrestrial. However, some research suggests that deep sea fauna may rival tropical forests in species diversity (Grassle, pers. comm. in Ray, 1988). The processes maintaining biological diversity in oceans are similar to those seen in terrestrial ecosystems: gap formation and patch dynamics. However, exactly how these processes operate in marine ecosystems remains largely unknown, because few long-term studies have been undertaken.

Inventories and ecological studies are needed in all oceans, with special emphasis on those habitats most immediately threatened. So little is known about the marine biota that rates of extinction are difficult to estimate; however, Ray (1988) suggests that disturbance and degradation of coastal zones is occurring as rapidly as tropical forest destruction. Just as with terrestrial systems, marine biological diversity is highest in the tropics—and those are also the regions at risk. For example, coral reefs are both highly diverse and extremely fragile.

FUTURE BIODIVERSITY STUDIES

For all groups of organisms, sampling those that occur in threatened regions is of special importance now, because natural communities are being destroyed so rapidly. Large numbers of endemic species are being lost in specific areas that Norman Myers has called "hot spots" (NRC, 1980; Myers, 1988). Particularly in these areas, but increasingly throughout the tropics, inventory work and preservation are crucial. The fine details of classification can be left until later.

Nonetheless, in practice it is often impossible even to recognize the numbers of species present in a given sample without having a specialist's knowledge of that particular group. For that reason, both monographic studies, which constitute the principal activity of many systematic biologists, and regional inventories are of primary importance.

To achieve an acceptable standard of knowledge about the world's biota, the following actions are needed:

(1) Complete a global biological inventory. This is urgent; without a reversal in current rates of habitat destruction and species extinction, a comprehensive

systematic survey will be possible only for the next 10 to 20 years. To ensure the protection of natural resources before they are irretrievably lost, creation and maintenance of protected natural areas is essential.

Whereas some environmental problems are on the horizon, species extinction is here and now. It is not reversible. In systematics research, there must be a balance between hypothesis testing, description, and stewardship.

(2) Obtain comprehensive knowledge of representative and threatened regions. For example, study 200 locations in great depth; concentrate resources of time and of expertise, to avoid dilution of effort. Study locations need to be chosen carefully, in order to devote sufficient effort to poorly known areas, those which are being rapidly destroyed, and those with a high level of endemism, e.g. Madagascar (see NRC, 1980; Myers, 1988). Even 200 sites reflects only a portion of the locations currently under some type of protection. The number of locations at risk is much higher.

(3) Conservation is extremely important. Providing an improved scientific basis for conservation of species and habitats requires nvestigations into organisms' natural history, ecology, and genetics. In addition, there should be more emphasis on the application of technology to seed banks and other types of genetic reservoirs.

(4) Develop comprehensive databases on biological diversity. Computerized data banks are the most effective means of disseminating the data collected and making it available for scientific and societal purposes.

(5) Human resource development is critical. Several factors have contributed to the paucity of trained personnel, including the lack of research and/or teaching positions for systematists, lack of training grants, and competition from other areas of biology.

The forthcoming Higher Education Survey on Systematic Biology Training and Personnel reports that, although the surveyed institutions listed 55 faculty vacancies in systematics, only 20 new hires were likely to be in systematics (Higher Education Panel, 1989). If systematics faculty are not replaced, how will new systematists be trained?

In 1987-88, only 3% of the biology PhD's granted were in systematic biology (Edwards et al., 1985; NSF, 1989). The number of systematics graduate students has declined substantially within the past 10 years. An NSF-commissioned survey done in 1985 reported 1298 doctoral students in systematics (Edwards et al., 1985). In contrast, the forthcoming Higher Education Survey on Systematic Biology Training and Personnel reports that, doctoral and master's students combined, there were only 1,154 systematics graduate students in 1987-88 (Higher Education Panel, 1989). Anectodal evidence suggests that although college students are interested in natural history studies, lack of professional opportunities discourage students from pursuing systematics in graduate school.

A "climate of opportunity," consisting of training funds for aspiring systematists, tenure track slots in colleges and universities and support for research grants, is needed to attract scientists to these fields.

(6) International programs of research cooperation need more attention. The focus should be the rejuvenation of cooperation with developing countries.

Ten years ago, it was estimated that as few as 1,500 (NRC, 1980) systematists worldwide were competent to deal with even one group of tropical organisms. The situation has scarcely improved in the 1980's. The lack of scientists in developing countries makes the overall personnel problem particularly acute, since the vast majority of species inhabit precisely these regions, and they are by far the most poorly known on earth.

Systematists are indispensible for advances in all fields of biology, including ecology, agriculture, and conservation biology. These areas of research are especially important for developing countries.

VII. WHY SHOULD NSF BE INVOLVED IN THE BIODIVERSITY CRISIS?

There are several reasons for increasing National Science Foundation (NSF) involvement in biodiversity studies: the economic and social importance of biodiversity (and the risk of opportunity lost due to accelerating extinction); the important role of such studies in the international growth of science, especially in tropical countries; and the potential impact of such studies on the future course of biology as a whole. NSF leadership in this area can make significant contributions by providing the scientific bases for conservation and enhancing public awareness of the issues.

THE ECONOMIC AND SOCIAL IMPORTANCE OF BIODIVERSITY

Human prosperity is based very largely on the ability to utilize biological diversity: to take advantage of the properties of plants, animals, fungi, and

microorganisms as sources of food, clothing, medicine, and shelter.

Human beings are placing increasing demands on global natural resources. Therefore, it is especially important to understand how to build sustainable systems, and ecologically sound sustainable development requires knowledge. Surprisingly few kinds of organisms are either domesticated or harvested from the wild.

For example, forestry and agriculture are two productive systems based on individual kinds of plants and animals. Undisturbed tropical moist lowland forest is characterized by a moderately high primary productivity. Yet the agricultural and forestry systems with which people have replaced it often fail after only a few years of productivity. Understanding the forest depends directly on both ecological and systematic knowledge: how many kinds of organisms are there, what are their characteristics, and how do they interact?

The changes correlated with forest clearing have generated a collective interest in re-vegetating major portions of the world. Restoration ecologists attempt to return degraded or destroyed ecosystems to many of the economic and aesthetic purposes originally served. Replanting and reforesting tropical areas would slow global warming. It would also supply food and fuel for many people who live in the tropics, thus reducing the economic pressures to cut intact forests. Conservation of the uncut areas will lead to watershed and soil protection, a slowdown in regional climate change, and the preservation of a substantial amount of biodiversity. Detailed knowledge of the plants and the ecological systems of those regions is needed to successfully accomplish the goals of restoration and reforestation.

Scientists estimate that there may be tens of thousands (Meyers, 1983; Plotkin, 1988) of plant species that could be used as food, yet little effort is being made to identify and cultivate them. The few plants now used for agriculture were selected by our Stone Age ancestors as particularly easy to gather and to harvest by hand; nearly all of them have been in cultivation for 2,000 years or more. Methods of selecting new crops have not evolved as human needs and capabilities have changed.

Many of the world's important crop species originated in the tropics. As much as 98% of U.S. crop production is based on species which originated elsewhere (Caufield, 1982). Therefore, wild relatives and regional varieties of current crops are important sources of genetic diversity. Such genetic resources are being lost as wild relatives become extinct and as the use of regional varieties is discontinued. For example, maize is the world's third most important crop. The recent discovery of *Zea diploperennis*, a perennial, virus-resistant, wild relative of maize, has significant agricultural implications. However, this new species of *Zea* could easily have been one of the many plant species lost to extinction; it is known only from a single six hectare site in the Mexican state of Jalisco (Iltis et al., 1979; Vietmeyer, 1979).

Basic biological information is needed to protect current systems against destructive organisms and to develop sustainable systems based on wise use of natural resources. Often, very little is known about pest species. For instance, despite the economic threat posed by leafhoppers as plant pests, there are no more than a handful of specialists worldwide capable of identifying them or describing them scientifically. As a result, when the brown rice leafhopper (*Niloparvata lugens*) suddenly became an agricultural pest and ravaged rice crops throughout the warmer parts of Asia in the late 1970's, it was virtually unknown. Although its biology became the subject of crash programs, almost nothing was known initially. Lack of basic biological knowledge about the brown rice leafhopper impeded the development of methods to combat the new pest (Yanchinski, 1978).

Nearly half of the drugs now in use were developed from substances initially found in nature; these substances were the products of plants, fungi, and microoganisms. At present, no more than 1% of all plant species have been examined in laboratories for their chemical properties; even less is known about bacteria and fungi, especially those found in the world's oceans. These organisms, often natural biocontrol factories, have untapped pharmacological potential. For example, vincristine and vinblastine, drugs used in treating childhood leukemia and Hodgkin's disease, were derived from the Madagascan periwinkle plant (*Catharanthus roseus*). The tropical regions of the earth harbor tens of thousands of unnamed plants and microorganisms. When surveyed, such plants and microorganisms are likely to be sources of new products useful for industry, such as gums, latex, resins, dyes, waxes, oils, sweeteners, and new sources of energy.

Modern methods of genetic technology offer bright possibilities for agriculture, pharmacology, and medicine. These methods depend on the discovery and utilization of particular genes. Each organism represents a collection of tens or even hundreds of thousands of genes, some of them unique; extinction is not only the loss of an unique kind of organism, but also the permanent loss of a collection of genes.

Finally, and of fundamental importance in a world of depleted energy potential, many products can be produced in low-energy-input systems simply by allowing organisms to grow: yet little effort is being made to improve knowledge of these systems or to encourage the studies on which such an improvement could be based.

BIODIVERSITY STUDIES IN INTERNATIONAL SCIENCE

Current international cooperation in science is heavily directed toward the European Community and Japan, and to a lesser extent other developed countries such as the Soviet Union. This current emphasis neglects the decisive future role of developing countries in the economy and environmental health of the world as a whole. The effects

of destroying tropical forests in enhancing the greenhouse effect have begun to make the interconnections between environment and economics clear, as have ill-advised efforts to dispose of toxic and radioactive waste products in countries that desperately need foreign currency. The sustainable management of the global ecosystem for common benefit must involve the people of all nations.

Because the great bulk of biodiversity occurs in tropical countries, especially those with forests and fringing reefs, tropical regions are the highest priority for both protection and research. Studies of diversity are labor-intensive and require less expensive apparatus and materials than most other scientific research. It follows that such research can and should be a major part of the scientific agenda in developing countries. Tropical countries will gain increasing benefit from their biological resources in the improvement of agriculture, the development of new pharmaceuticals and industrial products, and the promotion of tourism.

Working in isolation, scientists in industrial countries will not be able to adequately address the problems of biological diversity in the tropics and subtropics: these goals can be achieved only with major participation from scientists living in those countries.

Therefore, the Committee holds the preoccupation with scientific and technical interchange between advanced, industrial countries to be ill advised. We strongly recommend that the National Science Foundation, for reasons of national and international interest, embark on a reinvigorated program of scientific and technical interchange with developing countries throughout the world. To be successful in such a leadership role, the National Science Board must recognize this essential international role and assume its broader responsibilities.

BIODIVERSITY AND FUTURE TRENDS IN BIOLOGICAL RESEARCH

Classical biology contained a large component of systematics: biologists named species, tried to establish the relationships between them, and described their natural history. During the 1950's, the revolution of molecular and cellular biology forced a thematic shift in the study of biology—with enormous benefit. At present, the principal disciplinary orientation stresses levels of organization, such as cellular and molecular, rather than taxonomic groups of organisms.

However, investigations in cellular, developmental, and even molecular biology reveal phenomena which often concern only particular species or, at most, limited groups of species. To determine degrees of generality, investigators map these phenomena onto phylogenetic groups. There is an informal rule in the conduct of biological research that, for every problem, there exists a species ideal for its solution. Enteric bacteria are valuable for genetic mapping, but inappropriate for studies of meiosis. Langurs and lions were the key to understanding infanticide, but would have been an unsatisfactory choice for genetic mapping.

Extinction of species will thus constrain the discovery of unifying biological principles. Furthermore, new emphasis is being placed on the uniqueness of each species. While biologists will continue to think in terms of levels of organization and chains of causation, more and more will commit themselves to studying a particular group of organisms across all the levels of organization. This trend promises a new and productive pluralization of biology, with systematics returning to prominence in biological research. The current biological revolution has helped unite the two approaches: systematists now routinely compare proteins, while molecular biologists construct phylogenetic trees.

The future of basic biological research lies substantially in the exploration of diversity. The surest path to discovery will be systematics of a new kind, in which expanded knowledge of organisms is promoted by research which shuttles between all levels of organization, with an emphasis on diversity and its uses.

VIII. THE ROLE OF THE NATIONAL SCIENCE FOUNDATION

NSF is the dominant Federal agency responsible for research and training in organismal biology. For example, the Foundation currently provides 90% of the Federal support for systematics work at colleges and universities and 75% of the support for ecolgical sciences. Research and education are the "stock in trade" of the Foundation. Given NSF's prominent role nationally and globally in support of organismal biology, it is now entirely appropriate that the Foundation, in its leadership position, stimulate the study of biodiversity.

NSF should take the initiative with respect to similar agencies throughout the world. By insisting on the central importance of biodiversity in meetings with corresponding bodies in such industrialized countries as West Germany, Japan, and Switzerland, the NSF could develop partnerships to support the actions recommended here.

The National Science Foundation can, indeed, must act in three interconnected spheres to address the scientific and educational issues at stake in the biodiversity crisis: within NSF; among Federal agencies; and in the international community of scientific and educational organizations.

WITHIN NSF

NSF must increase funding to support research and training in systematics and ecology, focusing specifically on: biotic inventory; phylogenetic analysis; physiological

and genetic mechanisms; and ecological structure and function. Biological inventories and systematic studies are necessary underpinnings for investigations into more complex aspects of organisms' natural history, physiology, ecology, and genetics. Support for natural history museum operations and for education and training are necessary components of this activity.

Conservation biology, restoration ecology and environmental management, although applied disciplines, depend on basic biological knowledge. By funding more research in systematics, ecology, and other disciplines that contribute to the underlying scientific base, NSF can broaden the knowledge base for these applied fields.

In addition, some recent research by resource economists highlight the imperative of increasing interaction between and among economists and biologists. Prices for non-timber tropical forest products have only recently been compared (favorably, it turns out) to timber harvest prices. National tax and credit policies have, in the recent past, contributed directly to and extraordinary amount of rainforest conversion in Brazilian Amazonia and to forest conversion in the United States (Repetto, 1988). United Nation economic growth indicators such as Gross Domestic Product (GDP)—indicators used by planners, bankers, and economists throughout the world—do not include information on reductions in stocks (e.g., timber, soil, fisheries, etc.). Natural resource balance sheets do not exist, nor are there other clear indicators to encourage policymakers to invest in a country's natural resource base through (e.g.) reforestation. Further, there are troubling questions as to whether neoclassical economic theory, as understood and practiced at the close of the 20th Century, adequately addresses natural resource depletion (hence biodiversity loss) issues.

Because public policy land-use decisions which directly affect biodiversity conservation are often made in the idiom of economics (based on the evaluation of costs and benefits), the Committee urges that NSF initiate the development of research agendas which necessitate increased collaboration among economists and biologists.

AMONG FEDERAL AGENCIES

The NSF should promote awareness of biological resource issues in the policy deliberations of Federal organizations. The mission of all natural resource agencies touches on the preservation of biological diversity, both nationally and internationally. The Department of Agriculture, for example, currently concerns itself with crops and their improvement. All productivity in agriculture and forestry is ultimately based on biodiversity. The Department of Interior's land management agencies are charged with managing land for multiple use, which includes harvesting both mineral and biotic resources, all the while maintaining those natural resources for future generations.

In this environment of multiple needs and demands, there is a clear need for leadership to provide a forum and to coordinate scientific consensus on the issue of biodiversity. The Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) could provide such a forum for the various federal agencies by establishing a committee, similar to the Committee on Earth Sciences, on the global loss of biodiversity.

Among development-oriented agencies in particular, concern over biotic impoverishment must be transformed into active stewardship of species and community resources. Better knowledge of those resources would enhance the effectiveness of such stewardship. For example, the U.S. Agency for International Development (AID) mission should enable NSF to forge partnerships with AID to develop the scientific and technical infrastructure in many countries. AID, with now very limited resources, is now devoting considerable attention to the preservation of biodiversity and to other environmental problems in its client countries. Establishment of protected areas is increasingly an integral part of regional development schemes. AID and similar development agencies could assist materially in supporting national museums and similar institutions, in the establishment of regional and national data banks, in education, and in the development of more effective environmental planning and management.

Science must form the basis for identifying policies and actions which will most effectively preserve biodiversity. The single most effective step would be the creation and international funding of an extensive system of international parks and reserves. However, in many parts of the world, natural systems are becomingly increasingly fragmented, simplified, and perturbed; the preservation of pristine ecosystems is becoming less and less possible. In addition, park boundaries are insufficient barriers to many sources of environmental degradation, e.g. acid rain, greenhouse warming, and air and water pollution. Therefore, developing methods to maintain biodiversity in "altered" habitats is critically important; it will not be sufficient only to maintain biodiversity in "untouched" reserves. More research is needed to develop effective methods to restore and enhance damaged ecosystems.

Creation of global networks of seed banks, botanical gardens, zoos, and microorganism culture collections would preserve biotic resources on another level. An additional part of the solution is development of an international convention (similar to that on the protection of the ozone layer) which treats biodiversity as a common property resource and funds its preservation internationally. In response to the World Commission on Environment and Development (the Brundtland Commission), the United Nations Environment Programme (UNEP) is taking the lead in the development of such a convention, with substantial assistance from non-governmental organizations such as the International Union for the Conservation of Nature (IUCN) and World Resources Institute (WRI) (World Commission on Environment and Development, 1987).

In all cases, the NSF, by demonstrating the importance of biodiversity for science and for economic development, could help strengthen the positions of its sister agencies. The cooperation of other agencies would greatly increase the available funding for the solutions proposed here.

WITH INTERNATIONAL SCIENTIFIC AND EDUCATIONAL ORGANIZATIONS

International collaboration is required to solve the problems of biotic degradation and loss. NSF, by expanding the activities of its International Programs (INT), can assume a leadership role in promoting bilateral and multilateral research in systematics and ecology, environmental planning and management, museum development, and educational training.

What can the NSF do to lead the U.S. scientific community into productive interactions with institutions and individuals in developing countries? Resources in these countries are usually inadequate for the kinds of partnership agreements envisioned in NSF-INT for Japan and the European Community countries. Consider that the budget of the University of California is larger than the national budgets of many Latin American and most tropical African countries. No amount of discussion about the necessity of full financial participation in binational research schemes will alter that.

Therefore, new formulas must be found for NSF to help maintain the developing countries' museums and universities which provide education in the ecological sciences and systematic biology. These sciences form the basis for sound conservation and environmental management. For these reasons, such institutions are clearly a resource for American science and are bound to become increasingly important to international science and developing countries' economic well-being in the years to come.

NSF should collaborate with AID, the World Bank and their international counterparts to support these key institutions. The Committee emphasizes the need to stabilize the financial and physical condition of museums and other institutions which house collections. In addition, education in systematic biology, ecology, and environmental planning and management in developing countries, and the provision of adequate, permanent positions for those educated, are essential. Sustainable development requires sound natural resource planning and utilization. Development agencies can make contributions to biodiversity maintenance in many ways: through training programs, support for research, projects to establish and maintain biological reserves, funding for policy analysis, and through their own conditions for economic assistance.

IX. DISCUSSION AND RECOMMENDATIONS

The Committee's recommendations fall into five categories:

(1) the global inventory of biodiversity, including the management of related information and specimens;

(2) the scientific basis for conservation biology, restoration ecology, and environmental planning and management;

(3) support for related educational programs;

(4) support for selected socio-economic research;

(5) enhanced support for foreign institutions active in this area.

These recommendations are discussed in detail below.

1. The Committee believes that the role of the NSF is clear—NSF should, as a matter of National Science Board Policy, provide leadership to undertake the inventory of the world's biodiversity.

Traditionally, support has been focused on a limited number of groups and on the development of whatever hypotheses were fashionable at a given time. Implicit in this strategy is the notion that all species will be around indefinitely. Given the current staggering loss of species, there is pressing need to chart the contours of biological diversity, both as a matter of scientific importance and one of human necessity. NSF has been the prime source of funding for systematic and ecological research in the U.S., and even on a world scale. The dimensions of the problem demand a new kind of thinking about funding patterns for the Foundation.

The biotic inventory program recommended would conduct surveys of the plants, animals, and microorganisms of the world. The criteria for funding should go beyond the scholarship and productivity of the principal investigator(s) (which are already operational criteria for NSF), but also consider: the importance of the region or group proposed for study; the degree of threat to that particular region; and the potential of the project to contribute to meaningful international interactions and to education.

For many groups of organisms, and especially groups (such as microorganisms and many invertebrate groups) which are very rich in species but the object of few studies, the training and recruitment of additional specialists will be necessary. Much of this recruitment can and should occur in developing countries. A new partnership is needed between NSF and the international development donor agencies; scientific leadership, support of specialized training and research, and long-term funding commitment to continued employment are critical to both early success and sustained progress.

We recommend that support of biotic inventories be significantly expanded within the Division of

Biological Systems and Resources, with initial funding of $5 million annually, climbing to about $20 million.

The total cost of a global survey of biodiversity conducted over a ten year period (presuming the availability of a sufficient number of trained people) can be estimated, very approximately, as follows.

—Detailed investigation, over several years, of perhaps 100 major sites in Latin America (which is more poorly known biologically and richer in species) and at least another 100 in Africa and Asia together, would be necessary to gain a sufficiently detailed picture of the distribution of plants, vertebrates, and major invertebrate groups throughout the tropics.

—The cost of investigating each of these sites, including only the field work and processing the resulting data, has been estimated as between $300,000 and $750,000. The total cost for the project is estimated at between $60 million and $200 million over a ten year period.

—Studies of additional groups of organisms would add to the expense, partly because extensive primary monographic studies would be required to characterize the organisms sufficiently.

These figures are consistent with the recommended level of expenditure. On the one hand, by no means would all the work be funded by NSF, and on the other, various kinds of additional studies would be funded in the program proposed above.

The comparable costs for the inventory of freshwater and marine biota need to be added. That might, owing to the high cost of ship time, double these figures.

We recommend significant expansion of support of microbial systematics and ecology, with an initial funding of $8 million and growth to approximately $20 million annually.

It is tempting to focus solely on larger organisms. It is critical to understand that little information is available about microbial communities in most tropical, subtropical, or marine habitats. Microbial systematics and ecology have been so seriously underfunded that scientific understanding of the organisms is simply inadequate. As terrestrial habitats, especially in the tropics, are destroyed and marine and freshwater habitats polluted, the bacteria, fungi, and protoctists in these habitats are also destroyed.

Microorganisms are one of the bases of food webs and are crucial links in the transfer of energy and nutrients in all communities on land, in fresh waters, and in the seas. More complete scientific knowledge of microbial ecology will be necessary for effective restoration ecology. For example, microbially-mediated rhizosphere processes are crucial in maintaining the plant-soil system, both for individual plants and on an ecosystem level. In addition, mesofauna (e.g., collembola, mites, and nematodes) are an integral part of the soil biota. Ecological studies of the interactions between microorganisms and other soil biota must not be neglected. Successful reforestation and revegetation apparently requires re-establishing the belowground mutualists, not just restoring the aboveground plant community (Perry et al., 1989).

The classification of bacteria and fungi has not yet been established clearly. Current methods for studying these organisms require expensive molecular technologies to complement traditional means of identification. No less than a sustained effort in the systematics and ecology of bacteria and fungi will result in anything approaching an adequate knowledge base in this field.

The problems of understanding many of the groups of the kingdom Protoctista (Protista) parallel those for bacteria and fungi. Specimens are difficult to preserve, and previous methods were inadequate. Consequently, efforts to develop modern systematics for these organisms must go far beyond re-interpretations of old illustrations. Only a dedication to developing a modern systematics of these organisms will yield a comprehensive outline of their taxonomy and basic morphology.

Understanding the ecological interactions of microorganisms is crucial, because the activities of microorganisms have substantial economic impact on humans. For example, bacteria, fungi, and protoctists all cause plant and animal diseases, including those of humans. Systematics studies provide the basis for future biological research. Better knowledge of microbial systematics will allow more productive investigation of microbial ecology.

We additionally propose that the Biological Research Resources Program be enhanced. Support for those institutions most active in the inventory should be funded at the rate of $5 million annually. This will supply funding necessary to handle the increased numbers of specimens generated by the inventory. A comparable sum will be needed for information management, e.g. data banks, Geographic Information Systems (GIS), to handle and disseminate the data generated by the inventory.

Surveying the world's biota will send a flood of specimens to the museums of the world. The NSF Biological Research Resources (BRR) Program, established about 17 years ago to address the needs of systematics collections, has not been able to keep pace with current growth in the numbers of specimens.

For the proposed inventory to be effective, new specimens must be incorporated into existing collections rapidly and efficiently. This, plus incorporating the information into data banks, will allow further exploratory and monographic studies to proceed more rapidly. Having the information easily accessible will be an aid in conservation. Additional funding should be provided for facilities and

collections in the major museums of the U.S., in addition to strengthening museums in developing countries.

The construction of adequate data banks is imperative. Since data banking *per se* is costly and not often funded adequately, we recommend the special provision of funds to enlarge and improve the existing operations and develop new ones. Supplementary funding should be provided for some existing grants to allow the incorporation of these surveys or monographic studies into data banks that are generally accessible. For example, the *Flora of North America* program, which is operated by a network of more than 20 institutions in the U.S. and Canada, is generating a data bank on the plants of the region. The Missouri Botanical Garden, in conjunction with the California Academy of Sciences and Harvard University, is starting to add data on the plants of China by means of a comparable joint Sino-American project. A data bank containing the characteristics of some 30% of the plants of the world may not be not far off. Can this be used as a model for other groups and extended to the tropics?

Data-processing strategies that make the data available in machine-readable form should be emphasized. This would make information about previously studied organisms easily available. Such easy access will help determine which groups or areas are the least known or are the most promising for further investigations. Faster inventories of biota may be possible by using automated taxonomic methodologies.

On the other hand, we do not envision the program we have outlined here as a substitute for the Smithsonian Institution's BIOLAT program, which deals with small areas in great depth and stresses ecology as well as systematics. Ecology, ecosystem, and related programs within the NSF Directorate of Biological, Behavioral, and Social Sciences should continue to emphasize tropical ecology to the extent possible.

2. The inventories for which we are calling, and the enhanced training activities in developing countries, will help provide the underpinning for the newly emerging fields of restoration ecology, conservation biology, and environmental planning and management.

There are many important reasons for learning about organisms, but one of the most obvious is saving them. Effective conservation, ecosystem restoration, and environmental management require specific knowledge of species and ecosystems.

Restoring damaged ecosystems and enhancing existing ones can reverse the losses of natural ecosystems and associated biota. Many wetlands restoration projects are currently underway. Some projects have successfully restored natural forest habitats. Experiments have been conducted on building artificial reefs to enhance marine ecosystems.

We recommend increased support across the Federal government to develop the scientific base underlying the emerging fields of restoration ecology, conservation biology, and environmental management. Effective preservation and restoration must include social and economic considerations. This will involve multidisciplinary research in ecosystem restoration, creation and enhancement, in development of environmental planning and management methods, and in development of environmentally compatible technology. More research is needed in population biology and genetics, agro-ecology, wildlife biology and fisheries ecology as well as on preservation of genetic material and captive propagation.

Federal agencies involved in resource management decisions, such as the Forest Service, the Park Service, the Bureau of Land Management, and the Environmental Protection Agency, could make a strong contribution. AID might participate in the international efforts. These programs should be funded at a level of $3.5 million the first year, building to a level of $10 million per year.

3. We recommend special emphasis on biological diversity education, including K-12 and informal science education. Specifically needed are opportunities for predoctoral and postdoctoral training in the fields such as systematics, ecology, conservation biology, and environmental management. Support of international students studying these disciplines in U.S. institutions should be included. NSF has virtually the full responsibility for the health of these fields of biology in the U.S.

Historically, the biological fields considered important to human health were the best funded. For example, most predoctoral and postdoctoral fellowships in the biological sciences are provided by NIH. This pattern made possible an impressive acceleration of knowledge about molecular biology, genetics, metabolism and structural details of cells, tissues, and organs and the ways their actions are integrated.

On the other hand, knowledge about organismal biology has not increased proportionately. Within biology departments, the lack of fellowship or training grant support for evolutionary and systematic biology has exacerbated the sometimes low regard for these traditional and now critically important fields. To increase training opportunities, systematics and organismal biology must also be given more importance in university curricula.

For these reasons, we recommend that the NSF, which has virtually the full responsibility for the health of these areas of biology, emphasize educational and training support. The enhanced levels of research support we have recommended will lead directly to additional educational opportunities. Students are often, and should be, supported on research projects. Recruitment of additional students will depend, in part, on the availability of funding.

Primary research support in the U.S. goes to universities, and, for obvious reasons, educational funding is almost exclusively centered there. However, many leading systematics institutions—the Field Museum, Bishop Museum, California Academy of Sciences, and New York Botanical Gar-

den are examples—are not operated by universities. These free-standing museums actually carry out much of the research in these fields and contain the majority of the national collections of organisms. Creation of adequate educational support programs for systematic and evolutionary biology may require viewing these museums and collections as educational institutions. At the very least, it will be desirable to support linkages between them and universities and to consider modest new funding in this area.

Although predoctoral and postdoctoral opportunities are vital at this time, primary and secondary education should not be ignored. The present mode of primary support for the K-12 level should include the development of materials pertinent to systematics and ecology. These subjects are of interest to most students, and it is increasingly important that all citizens be educated about the global biodiversity crisis. Early education in these subjects is now as important to the national interest as early education in mathematics and other sciences.

Educational collaboration with developing countries is crucial to the success of the program outlined here. Building an adequate research base in developing countries is of fundamental importance. Special efforts should be made to encourage the enrollment of foreign students, especially those from developing countries, in U.S. institutions. It is also important to encourage researchers from developing countries to use the extensive facilities and research groups that are available in the U.S. Collaboration of all kinds should be sought aggressively; for example, participation of foreign scientists in NSF-supported research projects should be strongly encouraged.

4. We recommend additional funding, initially at the level of $1 million annually, for theoretical and empirical studies of the economic and social causes, consequences, and remedies of the biodiversity crisis. These funds would be added to the budgets of the appropriate programs in the Division of Social and Economic Sciences.

One of the key questions is, "Who pays for the conservation of biological diversity?" Most of the threatened species are located in low-income countries of the humid tropics; most arguments for preserving genetic diversity are framed in terms of global benefits for humanity. Current economic policies, methods of analysis, and practices contribute to the biodiversity crisis; they are not neutral. Until connections between methods of economic analysis and the depletion of natural resources are better recognized and understood, rates of biological extinction will probably not be reduced significantly.

National income accounting is the framework normally used for analyzing a country's economic performance and providing policy signals to national decision-makers. These accounts completely ignore the depletion of natural resource assets; they recognize only the income which such resources generate. Counting natural resource extraction only as income results in the overstatement of consumption benefits and erroneous incentives for overexploitation.

Many national economic policies contribute directly to environmental degradation and the loss of biodiversity. These policies create perverse incentives to deforest lands, drain wetlands, reduce fishery species (in national and international waters) to alarmingly low levels, erode soils, pollute water and air, and dangerously overharvest wild animals. Subsidies, investment credits, taxes, trade regulations and governmental foreign exchange rates comprise a set of instruments which often cause destruction and/or depletion of natural resources. Two examples are the tax and investment incentives for converting tropical forests to cattle ranches in parts of Latin America, and pesticide subsidies for rice production in Asia.

The debts of developing countries are also associated with the loss of biodiversity. Debtor countries must generate foreign exchange earnings to service their debts; debt-servicing pressures stimulate (and may even require) higher levels of natural resource exploitation.

In addition, social and cultural customs heavily influence natural resource stewardship practices. Local conventions governing the management of common property resources often lead to immediate over-exploitation. For example, ownership of timberland is obtained by demonstrating a willingness to "develop," which often is most effectively achieved by burning off the primary forest.

The challenge is designing monetary incentive schemes that enhance the probability of preserving habitats through time, particularly in nations with unstable political regions. "Debt-for-nature" swaps (purchasing a portion of country's debt in exchange for habitat preservation) is only one of many imaginative financial instruments. Long-term purchase of habitat preservation rights is another. There are alternative payment policies. Examples include lump-sum payments in the beginning; balloon payments at the end of a specific period; or annual payments. These different strategies have not been evaluated to determine which best insures habitat preservation through time.

NSF should create a research program that would:

—Identify and assess governmental decisions that create perverse policy incentives to extinguish species. These decisions are imbedded in institutional and policy flaws and omissions.

—Develop alternative socio-economic policies and institutional mechanisms to substitute for the flawed ones.

—Study mechanisms that effectively transmit information about preferred policies, institutions, and market forms to nations with habitat needing preservation.

—Identify institutional mechanisms for maintaining the quantity and quality of the preserved habitats.

—Identify institutional arrangements that enable habitat preservation to contribute to the local economy.

—Encourage synthetic analysis of case studies to identify specific policies, as well as common ingredients, which have played a major role in successful individual preservation schemes.

5. We recommend that NSF, in concert with bilateral and multilateral development assistance agencies, devise new mechanisms to fund biodiversity scientists and institutions in developing countries. NSF leadership is critical, in part because of a vacuum. These activities will involve U.S. scientific collaboration, but their primary focus must be directed to improving institutional infrastructure, educational opportunities, and employment of systematists, ecologists, and environmental management specialists in the developing countries. Initial funding should be at the level of approximately $2 million.

We recommend expansion of support for cooperative research and related development of capabilities in other countries (under the existing Science in Developing Countries guidelines). Further, we recommend that the NSF take the initiative in fostering a consortium of U.S. and foreign sources of support for related scientific infrastructure. Unless NSF, with an authorized expanded international biodiversity mandate, is able to provide *funding* leadership for such a consortium, its *scientific* leadership role will likely be weakened.

The museums located in tropical countries are key institutions for promoting biological inventories on a worldwide basis. Although operating within the limited national budgets of their individual countries, the museums have often done an outstanding job of preserving representative samples of their biological diversity. They are frequently the primary agencies for granting permits of all kinds to foreign scientists, and often receive, by law or custom, large and sometimes unique samples of collections made within their borders. For these reasons, international mechanisms for funding these institutions are urgently required.

Educational institutions in developing countries that have programs in biodiversity studies need support. They are essential components for producing personnel. Regional groupings of institutions, such as the Latin American Botanical Network, which attempt to build on several centers and thereby provide opportunities for students on a regional basis, have an important role to play.

Training local people as technicians both educates more local people and provides personnel for inventory work. Many individuals can effectively participate in biodiversity projects with only a limited amount of training. Such technicians should often be trained and supported with grant funds. The possibility of major programs, involving extensive biodiversity surveys and many people, should be investigated thoroughly.

Not every country has the resources to have a major university program in biodiversity studies; only about 6% of the world's scientists live in developing countries. Sharing the available opportunities and strengths can be an ingredient in building regional consciousness. As in the case of museums, even if NSF is unable to provide a major portion of the support, it can certainly emphasize what is possible and play a lead role in encouraging other kinds of institutions to fund university-based programs.

X. CONCLUSION

The loss of biological diversity threatens both scientific understanding and human prosperity. The diversity of species is the heart of biological research. Human existence requires natural resources: humans use the earth's biological resources for food, clothing, medicine, and shelter. Counteracting the current wave of extinctions will require increased knowledge and concerted action by all the nations of the world.

The National Science Foundation has three guiding themes: scientific opportunity, education and human resources, and science infrastructure. Of all the Federal agencies, the Foundation is in a key position to mobilize the resources of the scientific community to focus on the task before us. The National Science Foundation must take a leadership role to establish cooperative international efforts in conservation and in biodiversity studies and to bring new energy, determination and funding to strengthen U.S. domestic scientific capability and explorations.

XI. REFERENCES

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NATIONAL SCIENCE FOUNDATION
WASHINGTON, D.C. 20550

January 10, 1991

PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY

JANUARY 10-11, 1991

AGENDA

THURSDAY, JANUARY 10, 1991

OPEN SESSION 9:00 AM - 12:00 NOON
CONFERENCE ROOM
COUNCIL ON ENVIRONMENTAL QUALITY
722 JACKSON PLACE, NW

8:30 - 9:00	ARRIVAL -- COFFEE AND PASTRIES	
9:00 - 9:30	OPENING REMARKS	DR. BROMLEY
9:30 - 10:30	BIODIVERSITY - AN INFORMATION BRIEFING	DR. WILSON
10:30 - 10:45	DISCUSSION	
10:45 - 11:45	OFFICE OF SCIENCE AND TECHNOLOGY POLICY - 1990 ACCOMPLISHMENTS	OSTP STAFF
11:45 - 12:00	CLOSING REMARKS	DR. BROMLEY

THURSDAY, JANUARY 10, 1991 Continued ...

CLOSED SESSION, 12:00 NOON - 5:00 PM
ROOM 248
OMB DIRECTOR'S CONFERENCE ROOM
OLD EXECUTIVE OFFICE BUILDING

12:00 - 12:45	LUNCH		
12:45 - 1:00	BREAK		
1:00 - 5:00	ISSUES FOR PCAST CONSIDERATION		DR. BROMLEY
	1:00 - 2:00	MR. GATES	
	2:00 - 3:00	DR. BERNTHAL	
	3:00 - 4:00	DISCUSSION	
	4:00 - 4:30	DEPUTY SECRETARY ATWOOD	
	4:00 - 5:00	ADMIRAL TRULY	
- 6:30	COCKTAILS AND DINNER MAYFLOWER HOTEL		

FRIDAY, JANUARY 11, 1991

CLOSED SESSION 9:00 AM - 12:00 NOON
ROOM 180
OLD EXECUTIVE OFFICE BUILDING

8:30 - 9:00	ARRIVAL -- COFFEE AND PASTRIES (Dr. Bromley's Office, Room 360, OEOB)	
9:00 - 10:00	DISCUSSION OF FEBRUARY AGENDA AND OTHER ISSUES	DR. BROMLEY
10:00 - 12:00	ISSUES FOR PCAST CONSIDERATION	DR. BROMLEY
	10:00 - 11:00 GOVERNOR SUNUNU 11:00 - 12:00 CHAIRMAN BOSKIN	
- 12:00	CLOSING REMARKS	DR. BROMLEY

PRESS PEOPLE INVITED

Wil Lepkowski	Chemical and Engineering News
Colleen Cordes	Chronicle of Higer Education
Bruce Agnew	Journal of NIH Research
Ed Chen	Los Angeles Times
Chris Anderson	Nature
Chris Joyce	New Scientist
Richard McCormack	New Technology Week
Warren Leary	New York Times
Michael Miller	Performance Materials Magazine
Irwin Goodwin	Physics Today
Dan Greenberg	Science and Government Report
Barbara Culliton	Science Magazine
Arthur Kranish	Science Times
Tim Beardsley	Scientific American
Jeffrey Mervis	The Scientist
Dick Thompson	Time
Georgia Persinos	Washington Insight
William Booth	Washington Post

PCAST MEMBERS EXPECTED

Name	Thursday	Thursday Dinner	Friday
Borlaug	Yes	Yes	Yes
Buchsbaum	No	No	No
Drake	Yes	Yes	Yes
Gomory	Yes	Yes	Yes
Healy	Yes	Yes	Yes
Likins	Yes	Yes	Yes
Lovejoy	Yes	Yes	Yes
Massey	No	No	No
McTague	Yes	Yes	Yes
Nathans	Yes	Yes	Yes
Packard	Yes	Yes	Yes
Shapiro	Yes	Yes	Yes

DRAFT January 10, 1991

PCAST AGENDA UNDER CONSIDERATION

A. SHORT TERM ISSUE PAPERS (Completed papers may be updated)

1. Mathematics and Science Education -- Peter Likins
   (Sent to EOP and briefed to President, December 1990)

2. Technology and the U.S. Standard of Living -- Ralph Gomory
   (Sent to EOP and briefed to President, December 1990)

3. Priorities in Federal S&T Funding -- Charles Drake
   (Drafted, Edited, December 1990)

4. OSTP's Technology Policy -- Ralph Gomory & Sol Buchsbaum

5. S&T Gaps in National Security -- Sol Buchsbaum

6. College and University Infrastructure -- Dan Nathans

B. OTHER ISSUES THAT MAY BE ADDRESSED IN SHORT TERM

1. Nuclear Energy (Fission and Fusion)

2. Biodiversity

3. Trust/Anti-Trust

4. Conservation (Broad Interpretation)

5. Human Genome

C. PCAST PANELS UNDER CONSIDERATION

High Performance Computing and Communications

Chairman:	Sol Buchsbaum
Vice Chairman:	Ralph Gomory

Education and Human Resources

Chairman:	Peter Likins
Vice Chairman:	Charles Drake

Technology and National Security

Co-Chairman:	Sol Buchsbaum
	Johnny Foster

International Economic Competitiveness

Including Subset Issue: Materials Science and Engineering

Chairman: Ralph Gomory/John McTague
Vice Chairman: Harold Shapiro/Peter Likins

PROPOSED PANELS 1991-1992

Bioscience and Biotechnology

Chairman: Dan Nathans
Vice Chairman: Bernadine Healy

Global Enivironment and Natural Resources

Chairman: Tom Lovejoy
Vice Chairmen: David Packard
Norman Borlaug

DRAFT As of January 8, 1991

PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY

FEBRUARY 7-8, 1991 AGENDA

THURSDAY, FEBRUARY 7, 1991

OPEN SESSION 9:00 AM - 12:00 NOON
CONFERENCE ROOM
COUNCIL ON ENVIRONMENTAL QUALITY
722 JACKSON PLACE, NW

8:30 - 9:00	ARRIVAL -- COFFEE AND PASTRIES	
9:00 - 9:30	OPENING REMARKS	DR. BROMLEY
9:30 - 10:30	U.S. GLOBAL CHANGE RESEARCH PROGRAM Hal Mooney - NAS GC	DR. PECK
10:30 - 10:45	DISCUSSION	
10:45 - 11:45	OFFICE OF SCIENCE AND TECHNOLOGY POLICY - 1990 ACCOMPLISHMENTS	OSTP STAFF
11:45 - 12:00	DISCUSSION CTI HPCC	

DRAFT

THURSDAY, FEBRUARY 7, 1991 Continued ...

CLOSED SESSION 12:00 NOON - 5:00 PM
ROOM 208
CORDELL HULL CONFERENCE ROOM
OLD EXECUTIVE OFFICE BUILDING

12:00 - 12:45	LUNCH	
1:00 - 2:00	U.S. SECURITY POLICY	HON. PAUL WOLFOWITZ UNDERSECRETARY OF DEFENSE FOR POLICY
2:00 - 2:15	DISCUSSION	
2:15 - 3:15	NATIONAL MILITARY STRATEGY	DIRECTOR STRATEGIC PLANS JOINT CHIEFS OF STAFF
3:15 - 3:30	DISCUSSION	
3:30 - 4:30	DOD TECHNOLOGY STRATEGY	DR. HERZFELD
4:30 - 4:45	DISCUSSION	
4:45 - 5:00	CLOSING REMARKS	DR. BROMLEY

DRAFT

FRIDAY, FEBRUARY 8, 1991

CLOSED SESSION 9:00 AM - 12:00 NOON
ROOSEVELT ROOM
WEST WING
THE WHITE HOUSE

8:30 - 8:50	ARRIVAL -- COFFEE AND PASTRIES (DR. BROMLEY'S OFFICE, ROOM 360, OEOB)	
8:50 -	MOVE TO ROOSEVELT ROOM	
9:00 - 10:00	CRITIQUE OF FCCSET REPORT ON MATHEMATICS AND SCIENCE EDUCATION	DR. LIKINS
10:00 - 11:00	CRITIQUE OF FCCSET REPORT ON U.S. GLOBAL CHANGE RESEARCH PROGRAM	DR. LOVEJOY
:00 - 12:00	OTHER BUSINESS	DR. BROMLEY

THE WHITE HOUSE

WASHINGTON

January 9, 1991

Dear Brent,

As I mentioned in my letter of January 4, the President's Council of Advisors on Science and Technology (PCAST) looks forward to meeting with you on Thursday, January 10, 1991. The PCAST members are interested in learning about activities of your office and can give advice and assistance on science and technology issues. An updated meeting agenda is attached.

You will recall that the PCAST is a group of 12 prestigious individuals from academia and industry who report directly to the President and, at his request, examine a broad range of science and technology issues. In addition, PCAST forms smaller ad hoc panels of private sector executives, researchers, and academics to address issues in depth.

The PCAST serves two major functions. The first is to provide the President with accurate, objective information on science and technology as it affects public policy -- in short, science and technology for policy. Of particular importance here is providing not only science and technology input but also some realistic feel for the reliability and accuracy of that input. To fulfill this function, the PCAST meets regularly with the President, Cabinet members and Executive Office of the President Staff.

A second major task is to help ensure the health and productivity of science and technology in this country -- in short, to advise on policy for science and technology. To do this the PCAST provides their opinion of science and technology plans and programs within the federal government.

When we meet later this week, the PCAST would be interested in hearing your top objectives for 1991 and how PCAST can be of assistance. We would also be pleased to hear other issues that are of importance to you and your office and those issues for which you believe the PCAST can offer advice.

Finally, the PCAST is interested in hearing your ideas on private sector initiatives that might be supportive of your objectives and the needs of the President.

Sincerely,

D. Allan Bromley
Assistant to the President
for
Science and Technology

The Honorable Brent Scowcroft
Assistant to the President
for National Security Affairs
West Wing
The White House

Enclosure

MARYANNE C. BACH
Executive Director
Federal Coordinating Council for Science Engineering and Technology (FCCSET)

Maryanne Bach recently joined FCCSET to serve as Executive Director working directly for Dr. D. Allan Bromley, Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology Policy (OSTP). Ms. Bach came to FCCSET from the Department of the Interior where she most currently was appointed by Secretary Manuel Lujan, Jr. to serve as the Department's Director of the Office of Program Analysis. Reporting to the Assistant Secretary for Policy, Management and Budget, the Office oversees and coordinates major program and policy development for Interior, including wetlands, global change, energy strategy, and initiatives to enhance stewardship of our natural resources.

Prior to October 1988, Bach served as Special Assistant to the Secretary and the Deputy Assistant Secretary for Fish and Wildlife and Parks where she was key to the Department's endorsement of major steps to enhance and protect prime wildlife and wetland habitat, including legislation to expand the Everglades National Park and an international wetlands agreement, the North American Waterfowl Management Plan. She has also chaired the Department's Wetlands Working Group. In addition, Ms. Bach serves as the Secretary's representative to the National Park Systems Advisory Board, a sixteen member group that gives independent advise on Park matters.

Prior to her arrival at the Interior Department, Bach served eight years on the Republican staff of the Committee on Science, Space and Technology of the U.S. House of Representatives. As the Republican Science Coordinator, Ms. Bach oversaw major policy development in the field on non-military federal research and development. This included the coordination of the legislative and oversight activities for: the National Oceanic and Atmospheric Administration (NOAA), the research and development programs of the Environmental Protection Agency (EPA), the environmental program in the DOE, the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the National Technical Information Service (NTIS) within the Department of Commerce (DOC), all international R&D activities, as well as technology transfer and biotechnology issues under the jurisdiction of the Committee. Formerly, she coordinated the work of the Investigations and Oversight Subcommittee, as well as served as the principal Minority representative on the Committee's Supercomputer and Biotechnology Task Forces during their existence in 1985-87.

A native of New York, Bach received her B.S. degree (cum laude) in biology from Providence College, Rhode Island and a M.S. in Botany and Plant Ecology (magna cum laude) from Iowa State University. While at Iowa State, she worked for the Science and Humanities Research Institute and The Nature Conservancy.

Bach is a member of the American Association for the Advancement of Science (AAAS), Phi Sigma Tau, Phi Kappa Phi, the Iowa Academy of Science and The Nature Conservancy.

FREDERICK M. BERNTHAL
DEPUTY DIRECTOR
NATIONAL SCIENCE FOUNDATION
WASHINGTON, D.C.

President Bush's appointment of Dr. Frederick M. Bernthal as Deputy Director of the National Science Foundation was confirmed by the Senate on March 1, 1990. The Foundation is charged with promoting and strengthening U.S. scientific and engineering research and education. Its budget of $2.4 billion supports 12,000 to 14,000 grants annually in the natural and social sciences, engineering, and education.

Prior to his appointment to the Foundation, Dr. Bernthal served for two years as Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs. He negotiated the U.S.-USSR Agreement for Cooperation in Basic Sciences and led numerous U.S. delegations to international meetings on environmental and science and technology issues, including the first meeting of the parties to the Montreal Protocol on Depletion of Stratospheric Ozone, and the UN-sponsored Intergovernmental Panel on Global Climate Change. He chairs the 50-nation Response Strategies Working Group of that Panel.

Dr. Bernthal served as a member of the U.S. Nuclear Regulatory Commission from 1983 to 1988. In the wake of the Chernobyl disaster, he led a 12-member interagency U.S. Nuclear Safety Delegation to the Soviet Union and negotiated and signed the first U.S.-USSR nuclear safety protocol.

In 1978, Dr. Bernthal was a Congressional Science Fellow of the American Physical Society, and joined the staff of U.S. Senator Howard Baker. In April of 1980 he was appointed Chief Legislative Assistant to then Senate Majority Leader Baker, on whose staff he continued to serve until 1983.

From 1970 to 1978, he was a professor of Chemistry and Physics at Michigan State University. He spent a year in research at the Niels Bohr Institute of the University of Copenhagen, and in 1977 was a NATO Senior Scientist Fellow.

Dr. Bernthal earned the B.S. degree in chemistry with distinction from Valparaiso University in 1964, and a Ph.D. in nuclear chemistry in 1969 from the University of California at Berkeley. He was a postdoctoral research staff scientist at Yale University from 1969 to 1970.

The author of over 45 publications in professional scientific journals, Dr. Bernthal is a member of the Scientific Research Society of Sigma Xi, the American Physical Society, the American Chemical Society, and the American Association for the Advancement of Science.

THE CHAIRMAN OF THE
COUNCIL OF ECONOMIC ADVISERS
WASHINGTON

Michael J. Boskin
Chairman
The President's Council of Economic Advisers

Michael J. Boskin is the Chairman of the President's Council of Economic Advisers. He was appointed to this post by the President on February 2, 1989, following unanimous confirmation by the Senate. As Chairman, he provides economic analysis and advice directly to the President and assists in formulating national economic policies. Dr. Boskin is on leave from Stanford University where he is the Burnet C. and Mildred Finley Wohlford Professor of Economics. He is also on leave as a Research Associate of the National Bureau of Economic Research.

Dr. Boskin is the recipient of numerous professional awards and citations, ranging from the Chancellor's Award and Department Citation as outstanding undergraduate at the University of California in 1967 and the first National Tax Association Outstanding Doctoral Dissertation Award in 1971 to the Abramson Award for Outstanding Research from the National Association of Business Economists in 1987, and Stanford University's Distinguished Teaching Award in 1988. He is the author of more than 80 books and articles in the areas of government spending, tax theory and policy, public debt, Social Security, retirement patters and behavior, U.S. saving behavior, capital formation, U.S. economic growth, and the economic status of the elderly.

Dr. Boskin received his B.A. degree with highest honors in 1967 from the University of California at Berkeley, where he also received his M.A. in 1968 and his Ph.D in 1971.

Previously, Dr. Boskin had served as a consultant and advisor to the White House, Department of Health and Human Services, Treasury Department, National Science Foundation, and other government agencies, and various Congressional Committees.

Dr. Boskin is a member of the Economic Education Committee of the American Economic Association. He and his wife, Chris, moved to Washington, D.C. from California. They both enjoy tennis and skiing.

September 1989

Mr. Robert M. Gates

Assistant to the President and Deputy for National Security Affairs

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Robert M. Gates was appointed Assistant to the President and Deputy for National Security Affairs by President Bush on August 3, 1989.

Mr. Gates served as Deputy Assistant to the President for National Security Affairs from January 20 to August 3, 1989. Prior to that, he served as Deputy Director of Central Intelligence from April 1986 to January 1989. In this position he was principal deputy to the Director, who heads the Intelligence Community (all of the foreign intelligence agencies of the United States) and directs the Central Intelligence Agency.

Mr. Gates, a native of Kansas, received his BA Degree from the College of William and Mary in 1965, his Masters Degree in history from Indiana University in 1966, and his Doctorate in Russian and Soviet history from Georgetown University in 1974.

Mr. Gates joined the Central Intelligence Agency in 1966, serving as an intelligence analyst and as one of two Assistant National Intelligence Officers for Strategic Programs. In 1974 he was assigned to the National Security Council Staff.

After more than five years at the National Security council, serving three Presidents, Mr. Gates returned to the Central Intelligence Agency in late 1979. He subsequently was appointed to a series of administrative positions and served as National Intelligence Officer of the Soviet Union prior to his appointment as Deputy Director for Intelligence in January 1982.

As DDI for nearly four and one half years, Mr. Gates directed the Central Intelligence Agency's component responsible for all analysis and production of finished intelligence. In September 1983, the Director appointed Mr. Gates Chairman of the National Intelligence Council concurrent with his position as Deputy Director for Intelligence. As Chairman of the National Intelligence Council, Mr. Gates directed the preparation of all national intelligence estimates prepared by the Intelligence Community.

Mr. Gates served as Acting Director of Central Intelligence from December 18, 1986, until May 26, 1987.

Mr. Gates has been awarded the National Intelligence Distinguished Service Medal and has twice received CIA's highest award, the Distinguished Intelligence Medal. He also is a recipient of the Intelligence Medal of Merit and the Arthur S. Fleming Award, which is presented annually to the ten most outstanding young men and women in the Federal Service.

Mr. Gates and his wife Becky have two children.

APRIL 1990

CURRICULUM VITAE

DONALD AINSLIE HENDERSON

BORN: September 7, 1928
Lakewood, Ohio

OFFICE ADDRESS: 615 N. Wolfe Street
Baltimore, MD 21205
301-955-3540

MARRIED: Nara Irene Bragg
Rochester, New York
September 1, 1951

HOME ADDRESS: 3802 Greenway
Baltimore, MD 21218
301-889-2880

CHILDREN: Leigh Ainslie, 1954
David Alexander, 1956
Douglas Bruce, 1960

EDUCATION:

A.B., Oberlin College, 1950
M.D., University of Rochester School of Medicine, 1954
M.P.H., Johns Hopkins University School of Hygiene and Public Health, 1960

Honoris causa:
M.D., Universite de Geneve (1980)
LL.D., Marietta College (1978)
L.H.D., State University of New York (1981)
Sc.D., University of Rochester (1977);
Oberlin College (1978);
University of Illinois (1979);
University of Maryland (1980);
Yale University (1986)
Albany Medical College (1989)

APRIL 1990

POSITIONS HELD:

Mary Imogene Bassett Hospital, Cooperstown, New York, Intern in Medicine, 1954-1955; Resident in Medicine, 1957-1959
Communicable Diseases Center, Department of Health, Education, and Welfare, Assistant Chief, Epidemic Intelligence Service, 1953-1956; Chief, Epidemic Intelligence Service and Assistant to Chief, Epidemiology Branch, 1956-1957; Assistant Chief, Epidemiology Branch and Chief, Epidemic Intelligence Service, 1960-1961; Chief, Surveillance Section, Epidemiology Branch, 1961-1965; Chief, Smallpox Eradication Program, 1965-1966
World Health Organization, Chief Medical Officer, Smallpox Eradication, 1966-1977
Johns Hopkins University School of Hygiene and Public Health, Dean and Professor of Epidemiology and International Health, 1977-

PROFESSIONAL SOCIETIES:

American Board of Preventive Medicine, 1969-
American College of Epidemiology, Fellow, 1990-
American College of Preventive Medicine, Fellow, 1978-
American Epidemiological Society, 1963-
American Public Health Association, 1956; Fellow, 1961-
American Society of Tropical Medicine and Hygiene, 1981-
Association of Schools of Public Health, Treasurer, 1978; Vice-President, 1981-1982; 1987-1988; President, 1988-
Indian Society for Malaria and Other Communicable Diseases, Fellow, 1975-
International Epidemiological Association, 1965-
Royal College of Physicians (Edinburgh), Fellow, 1986-
Royal Society of Tropical Medicine and Hygiene, Fellow, 1976-

APRIL 1990

SCIENTIFIC AWARDS AND RECOGNITIONS: *(United States)*

National Medal of Science, 1986
National Academy of Sciences - Public Welfare Medal, 1978
Charles S. Dana Foundation Award for Pioneering Achievement in Health, 1986
American Academy of Arts and Sciences, Fellow, 1986-
Institute of Medicine, National Academy of Sciences, Member, 1978-
Albert Schweitzer International Prize for Medicine, 1985
American College of Physicians - James D. Bruce Memorial Award, 1978
American Public Health Association - Rosenhaus International Award for Excellence, 1975
American Academy of Pediatrics - Honorary Fellow, 1980
Johns Hopkins University - Distinguished Alumnus Award, 1982
Michigan State University - Walter P. Paterge Medal of Public Service, 1984
Vanderbilt University School of Medicine Medal, 1990
Ohio Foundation of Independent Colleges, Hall of Fame, 1990
Blue Cross-Blue Shield - 50th Anniversary Distinguished Service Award, 1979
U.S. Association for the United Nations - Joseph C. Wilsen Award in International Affairs, 1978
U.S. General Accounting Office - Comptroller General's Special Recognition, 1986
U.S. Department of Health and Human Services
- Superior Service Award, 1964
- Sustained Superior Performance Award, 1966

U.S. Public Health Service - Distinguished Service Medal, 1976
- Commendation Medal, 1962

Delta Omega Honorary Public Health Society - Member, 1979
- Outstanding Alumnus Award, 1980

Sigma Xi - Member, 1956

SCIENTIFIC AWARDS AND RECOGNITIONS: *(Other Countries)*

The Japan Prize, 1988
Republic of China - Health Medal of the First Grade, 1988
Government of Uruguay - Medal of Abnegation, 1988
Universidad Peruana Cayetano Heredia, Honorary Professor, 1988
Commemorative Award of Seventh World Congress of the International Physicians for the Prevention of Nuclear War, 1987
Gairdner Foundation (Canada) - International Award of Merit, 1983
Royal Colleges of Physicians of the United Kingdom - Faculty of Community Medicine - Honorary Fellow, 1981
Royal Society of Medicine
Richard T. Hewitt Award, 1986
Honorary Member, 1980

London School of Hygiene and Tropical Medicine and Royal Society of Tropical Medicine and Hygiene - George McDonald Prize and Medal, 1976
Government of Ethiopia - Medal for Contributions to Health, 1979
Government of Afghanistan - *Roghtya Nashan* (Health Medal), 1976
Ernst-Jung Foundation, (Germany) - *Ernst-Jung Preis fur Medizin*, 1976
Government of India - Special Award, 1978
Indian Society for Malaria and Other Communicable Diseases - Special Award, 1975
Lahore, Pakistan - Certificate of Merit, 1977

AWARD TO WHO FOR SMALLPOX ERADICATION:

Special Albert Lasker Public Health Service Award, 1976

SPECIAL LECTURESHIPS:

Alumni Reunion Lecture, Oberlin College, 1990
Cleveland City Club Forum Speaker, 1990
Vanderbilt University World Health Week, Keynote Speaker, 1990
Kathryn Boucot Sturgis Lecture, 1990
Alumni Reunion Lecture, University of Rochester, 1989
John P. McGovern Lecturer, Baylor College of Medicine, 1989
Annual Banquet Address, Clinico-Pathological Society of Washington, 1989
Phyllis Lewander Memorial Lecture - Children's Hospital National Medical Center, Washington, D.C., 1989
American Pediatric Society - Washington, DC, 1988
Bloomfield Lecture - Case-Western Reserve University, 1987
Joseph Mountin Lecture- Centers for Disease Control, 1987
Agnard Lecture - University of Washington, 1987
Frontiers of Science Lecture - University of Florida, 1987
Eighteenth International Pediatric Congress - Keynote Speaker, 1986
Chief Guest and Keynote Speaker, 30th Aniversary of Indian Public Health Association - Calcutta, India, 1985
National Convention on the Management of Health Systems - Convention Orator; Jaipur, India, 1985
P.D. Agarwal Memorial Oration - Calcutta, India, 1985
Oberlin College Sesquicentennial Speaker - 1983
Harvard Medical School Bicentennial Speaker - 1982
Rameshwar Sharma Oration - School of Medicine, Jaipur, India, 1981
Harben Lecture - Royal Institute of Public Health and Hygiene, London, 1980
Stephens Lecture - Oberlin, Ohio, 1980.
V.W. Scully Distinguished Lecture - Hamilton, Ontario, Canada, 1979
Joseph C. Wilson Lecture - Rochester, New York, 1979
Julia M. Jones Memorial Lecture - American Lung Association and American Thoracic Society, 1979
Merck Sharpe and Dohme Lecture - Canadian Public Health Association, Ottawa, Canada, 1977
James Bordley III Lecture - Mary Imogene Bassett Hospital, Cooperstown, New York, 1977
Jenner Memorial Lecture - Bristol (UK) Royal Infirmary, 1975
Commencement and Convocation Addresses:
San Diego State University School of Public Health - 1988
University of California (San Diego) School of Medicine - 1984
Michigan State University School of Medicine - 1984
University of Southern California School of Medicine - 1978

APRIL 1990

PROFESSIONAL COMMITTEES: (Present)

World Health Organization
Expert Advisory Panel on Virus Diseases, 1976-
Committee on Orthopoxvirus Infections, 1981-
Consultant Group on Poliomyelitis Eradication, Chairman, 1988-
Pan American Health Organization
Technical Advisory Group on Immunization, Chairman, 1985-
American Journal of Epidemiology,
Board of Overseers, Associate Editor, 1969-1977; Chairman, 1984-
Editorial Advisory Board - Bibliography of Bioethics, 1979-
International Association for Maternal and Neonatal Health, Scientific Council, 1981-
Rotary Foundation of Rotary International, Polio Plus Advisory Committee, 1985-
Government Accounting Office
Advisory Board, Program Evaluation and Methodology Division, 1988-
U.S. Department of State
Advisory Committee on Oceans, Environmental and Scientific Affairs, 1988-
Department of Health and Human Services
National Vaccine Advisory Committee, 1988-1989; Chairman, 1990-
Secretary's Council on Health Promotion and Disease Prevention, 1989-
Association of Academic Health Centers
Task Force on Health Promotion /Disease Prevention, 1989-
"AIDS Patient Care" magazine - Editorial Advisory Panel, 1987-
United Fresh Fruit and Vegetable Association, Scientific Advisory Panel, 1988-
Institute of Medicine, Board on International Health, 1988-
Charles A. Dana Foundation Awards Jury, 1990-
Foundation for Development of International Health (Japan), Scientific Consultant, 1990-

BOARD OF DIRECTORS/TRUSTEES:

Indian Institute of Health Management Research, 1985-
Maryland Society for Medical Research, Inc., 1978-
Population Crisis Committee, 1981-
International Center for Diarrheal Disease Research (Dhaka), 1988-
Medical Alumni Association, Mary Imogene Bassett Hospital, 1989-

BIOGRAPHICAL LISTINGS:

Who's Who in the World
The International Who's Who
Who's Who in America
Who's Who in Frontiers of Science and Technology
American Men and Women in Science: Medical and Health Sciences
Dictionary of International Biography

APRIL 1990

PROFESSIONAL COMMITTEES: *(Past)*

American Public Health Association
- Committee on Hepatitis, Chairman, 1961-1965
- Multiple Antigen Committee, 1964-1966
- Epidemiology Section Council, 1965-1967

Surgeon General's Advisory Committees on:
- Influenza, Secretary, 1961-1963
- Measles Vaccines, Secretary, 1963
- Immunization Practice, Secretary, 1964-1966

World Health Organization
- Special Committee on Measles Vaccine, Consultant, 1963
- Scientific Group on Human Virus Vaccines, Member, 1965
- Global Commission for the Certification of Smallpox Eradication, 1978-1980
- Program Advisory Group for the Prevention of Blindness, 1978-1982
- Programme for Research and Training in Tropical Diseases - Scientific and Technological Advisory Committee, 1982-1984
- Caribbean Epidemiology Center - Scientific Advisory Committee, 1980-1983

National Research Council, National Academy of Sciences
- Board on Science and Technology in International Development, 1981-1983
- Committee on Research Grants, 1982-85

National Academy of Sciences, Institute of Medicine,
- AID Health Strategy Study, Steering Committee, 1978
- Steering Committee for the Study on Clinical Investigations in Developing Countries, 1978-1980
- Advisory Committee on Health, Biomedical Research and Development, Chairman, 1981-1983
- Steering Committee, Study of Tropical Diseases, 1984-1987

Government Accounting Office
- Research and Education Advisory Panel to the Comptroller-General, 1977-1986

Department of Health and Human Services
- PHS Hospitals *ad hoc* Advisory Committee, 1978
- Secretary's Committee on Influenza, Vice-Chairman, 1979
- National Ethics Advisory Board, 1977-1980
- CDC Programs and Policy Advisory Committee, 1978-1980
- Immunization Practices Advisory Committee, Centers for Disease Control, 1982-1986

Chairman, Mayor's Task Force on Environmental Carcinogens (Baltimore), 1977-1978

NASA - Planetary Protection Study Group, 1978

Executive Office of the President, Office of Science and Technology
- Task Force for Science and Technology in Foreign Assistance, Chairman, 1980
- Advisory Committee on Science, Technology and Development, 1978-1979
- Consultant, 1978-1982

Harvard University,
- Visiting Committee, University Health Services, 1981-1985

Burroughs-Wellcome Fund - Pharmacoepidemiology Awards Committee, 1985-1987

City University of New York Medical School, National Visiting Council, 1986-1989

Institute of Medicine, National Academy of Sciences,
- Committee on the Evaluation of Poliomyelitis Vaccine, 1987-88

U.S. Agency for International Development
- Research Advisory Committee, 1985-1990

PUBLICATIONS:

More than 100 scientific publications dealing primarily with smallpox eradication, epidemiology and immunization.

RACHEL ELIZABETH LEVINSON

Office of Science and Technology Policy
Executive Office of the President
Washington, D.C. 20506
(202) 395-4850 (202) 395-3719 FAX

11700 Bunnell Ct., N.
Potomac, MD 20854
(301) 983-8670

PROFESSIONAL EXPERIENCE

POLICY

ASSISTANT DIRECTOR FOR LIFE SCIENCES: Division of Life Sciences, Office of Science and Technology Policy, Executive Office of the President,
September 1990 - present

The Office of Science and Technology Policy (OSTP) serves as a source of science and technology expertise for the President and other organizations within the Executive Office of the President and provides for coordination, reviews and policy analyses of research and development programs of the Federal Government. The Assistant Director for Life Sciences provides scientific and technological advice involved in areas of national concern, including the economy, health, foreign relations, and the environment; evaluates the scale, quality, and effectiveness of the Federal effort in the life sciences and technology; assists agencies throughout the Federal budget development process; and promotes coordination of the activities of the research agencies of the Federal Government. In addition, the Assistant Director retains the responsibilities described below.

SENIOR POLICY ANALYST FOR BIOTECHNOLOGY: Division of Life Sciences, OSTP
November 1989 - September 1990

The Senior Policy Analyst for Biotechnology is responsible for the following: analysis and policy formulation of the key issues involved in environmental, health and safety regulations, and analysis of Federal policies toward industrial innovation, particularly in the biotechnology field; support for the Associate Director, Life Sciences, in formulating and implementing major initiatives by the Director, OSTP, in the scientific arena; direction of major conceptual, analytical and evaluative studies of different aspects of biotechnology policy, designed to provide high-level advice and analysis to be used by the President; and liaison for OSTP with other Government agencies, Congressional committees, national laboratories, universities, the private sector, and embassies and foreign governments on the sciences programs, both in the U.S. and abroad, to continuously assess their status and to identify the greatest opportunities for beneficial cooperation.

Selected Special Projects: Serves as Vice Chairman of the Working Group on Biotechnology, Vice President's Council on Competitiveness. The Working Group has been charged to develop a set of recommendations for Federal policies designed to stimulate the domestic biotechnology industry and to identify and remove barriers to international competitiveness.

Serves as Executive Secretary to the Biotechnology Science Coordinating Committee (BSCC), a committee established in OSTP in 1985. The BSCC provides for interagency science policy coordination and guidance and the exchange of information regarding the scientific aspects of biotechnology research and regulation.

Serves as OSTP liaison member of the National Biotechnology Policy Board, a Congressionally mandated organization comprised of government, university, and industry representatives charged to assess and to recommend policies and programs pertaining to biotechnology. Topics for discussion include basic and applied sciences, training, competitiveness and technology transfer.

DEPUTY DIRECTOR: Office of Recombinant DNA Activities, Office of Science Policy and Legislation, Office of the Director, National Institutes of Health, August 1988-November 1989. **Acting Director:** August 1988-August 1989

The Office of Recombinant DNA Activities (ORDA) serves as a national focal point for maintaining and disseminating information on recombinant DNA research to NIH and other Federal agencies, research institutions, biosafety committees, Congress, state and local governments, and the private sector. The Deputy Director assisted the Director, ORDA, in providing briefings and staff support to the Director, NIH, concerning recombinant DNA and biotechnology policy; supervised staff in the administration of the Recombinant DNA Advisory Committee; served as Executive Secretary, Human Gene Therapy Subcommittee and other subcommittees; and oversaw daily operations.

Selected Special Projects: Represented NIH at interagency and international meetings concerning the development of consistent guidelines for biotechnology, coordinated and administered NIH approval of the first human gene transfer experiment, and assisted the NIH Legal Advisor and the Department of Justice in several legal actions.

PROGRAM ANALYST: Science Policy Analysis and Development Branch, Office of Science Policy and Legislation, Office of the Director, National Institutes of Health, 1983-1988

Analyzed current policy and assisted in the development of new policies in areas including: biotechnology, characterization of the human genome, government/industry/university relations, patents, technology transfer, biomedical ethics and research resources.

Developed and authored policy analyses, speeches, Congressional testimony, position papers, briefing materials, descriptive reports and critiqued documents submitted to the Office of the Director by other NIH components. Initiated and maintained liaison with knowledgeable persons in and outside of NIH in support of responsibility to inform appropriate officials of developments in assigned issue areas.

Selected Special Projects: Served as Executive Secretary to the NIH Ad Hoc Program Advisory Committee on Complex Genomes, the NIH Working Group on Complex Genomes, and the NIH Committee on Biotechnology Activities. In preparation for

February 1988 meeting of the Ad Hoc Program Advisory Committee, developed meeting agenda and roster of scientific experts from industry, academia, the NIH intramural research program, Congressional staff, and other organizations; discussed meeting objectives with participants; selected background material; responded to questions from the media; prepared introductory remarks and talking points on current NIH policies and related legislative activities for the NIH Director and the Associate Director for Science Policy and Legislation; and produced and published summary report.

RESEARCH

Laboratory of Pathology, National Cancer Institute, 1973-1983

Acquired extensive practical and theoretical background in a variety of areas of biomedical research including: immunology, endocrinology, carbohydrate chemistry and cancer biology. Activities included: isolation and characterization of carbohydrates, structural proteins and glycoprotein hormones from human tissue; production and identification of monoclonal antibodies through the development of hybridoma cell lines; immunofluorescence labeling and microscopy for in situ localization of specific antigens; mass spectroscopy; and induction and passage of tumors in animal model systems.

EDUCATION

Master of Arts; Science, Technology, and Public Policy, 1985
George Washington University, School of Public and International Affairs
Areas of Concentration: Science Policy, Public Administration and Ethics
Thesis Title: The Impact of Prospective Payment On Clinical Trials

Graduate Work; Biochemistry and Endocrinology, 1976-1981
American University and Foundation for Advanced Education in the Sciences

Bachelor of Science; Zoology, 1975
University of Maryland, College Park

PROFESSIONAL AFFILIATIONS

Washington Association for Science, Technology, Engineering, and Public Policy
Founding Member and Advisory Board Member
American Association for the Advancement of Science - Member
District of Columbia Science Writers Association - Member
The Hastings Center on Ethics and Society - Associate Member
Washington Area Ethics Society, Kennedy Institute for Bioethics - Member

BIOGRAPHICAL INFORMATION

J. THOMAS RATCHFORD

Dr. J. Thomas Ratchford is Associate Director for Policy and International Affairs of the Office of Science and Technology Policy (OSTP) in the Executive Office of the President. Prior to his appointment to this post by President Bush in November 1989, Dr. Ratchford was the Associate Executive Officer of the American Association for the Advancement of Science (AAAS). At AAAS he served as deputy to the chief executive officer and headed the Association's program directorates: Education and Human Resources, International Programs and Science and Policy Programs.

Educated and trained as a solid state physicist, Dr. Ratchford has taught at Washington and Lee University and served on research staffs of various private and governmental laboratories. From 1964 to 1970, he was responsible for formulating and administering a basic research program in the solid state sciences for the Office of Scientific Research of the Department of the Air Force. Dr. Ratchford was a member of the professional staff of the Committee on Science and Technology of the United States House of Representatives from 1970 to 1977, and was one of the first scientists to serve the Congress on a full-time basis. His responsibilities there dealt mainly with policy and funding for science and technology, and for energy research and development.

As a Congressional Fellow of the American Political Science Association in the late 1960's, Dr. Ratchford served in the offices of members of the House and Senate with particular interests in scientific and technological issues. In 1976, he was a Research Scholar at the International Institute for Applied Systems Analysis in Laxenburg, Austria, doing research on the economics and technologies of global energy systems.

Over the years he has chaired outside advisory panels for organizations such as the Gas Research Institute, the Congressional Office of Technology Assessment, and the National Science Foundation, and has served as a consultant and advisor to various governmental, university and industrial organizations.

Dr. Ratchford received his B.S. in mathematics and physics from Davidson College in 1957. The University of Virginia awarded him an M.A. in 1959 and a Ph.D. in 1961, both in physics. A member of Phi Beta Kappa and Sigma Xi, he is a fellow of the AAAS and a member of the American Physical Society and the Virginia Academy of Science. He is married to the former Joanne Walton Causey, and they have four children: Joseph Thomas Jr., Laura Leigh, James Raymond and David Andrew.

1/90

THE WHITE HOUSE

WASHINGTON

BIOGRAPHY OF JOHN H. SUNUNU

John Henry Sununu, 51, of Salem, New Hampshire, was commissioned Chief of Staff to the President of the United States on January 21, 1989. As Chief of Staff, Governor Sununu oversees the daily operations of the White House and its staff.

After playing an influential role in President Bush's New Hampshire primary victory, Governor Sununu served as National Co-Chairman of the Bush/Quayle campaign. During the general election, the Governor became one of the most active surrogate speakers on the campaign trail and travelled extensively across the country.

Governor Sununu became New Hampshire's 93rd Governor on January 6, 1983, and served three consecutive terms prior to joining the White House staff.

Governor Sununu assumed office with a background of nearly 20 years experience as an educator, engineer, small businessman and community leader.

The Governor gained both regional and national recognition through his chairmanship of the Coalition of Northeastern Governors, the chairmanship of the Republican Governors' Association, and his election in 1987, to the chairmanship of the National Governors' Association.

Within the National Governors' Association, Governor Sununu served as chairman of several committees. He was particularly active as chairman of the New Technology Education Task Force, which, two years ago, issued "Time for Results;The Governors' 1991 report on Education". Also through his efforts, the NGA, and later the New Hampshire Legislature, endorsed innovative acid rain legislation.

Governor Sununu is a member of the National Academy of Engineers' Committee on Public Engineering Policy and has served as a member of the President's Council on Environmental Quality Advisory Committee, the New England Regional Energy Advisory Council, the board of trustees of the Northeast Solar Energy Center, and as chairman of the board of directors of Consumer Alert.

July 1990

The Governor attended the Massachusetts Institute of Technology at both the graduate and undergraduate levels, and earned his Ph.D there in 1966 in mechanical engineering. From 1968 to 1973, he was associate dean of the College of Engineering at Tufts University where he had been an associate professor of mechanical engineering since 1966. He was invited to join the Advisory Board of the Technology and Policy Program at MIT in August, 1984.

From 1965 until his election as Governor, he served as President of JHS Engineering Company and Thermal Research Inc.; in addition, he helped found, and served, as chief engineer for Astro Dynamics Inc. from 1960 to 1965.

The Governor married the former Nancy Hayes in 1958. They have eight children.

National Aeronautics and
Space Administration

Washington, D.C.
20546

Biographical Data

RICHARD H. TRULY
NASA Administrator

Richard H. Truly became the eighth administrator of NASA on July 1, 1989. One day earlier, he concluded his naval career of more than 30 years, retiring as a Vice Admiral, United States Navy. He is the first astronaut to head the nation's civilian space agency.

Truly became NASA's associate administrator for space flight on February 20, 1986. In this position, he led the painstaking rebuilding of the Space Shuttle program. This was highlighted by NASA's celebrated "return to flight" on September 29, 1988, when **Discovery** lifted off from Kennedy Space Center, Florida, on the first Shuttle mission in almost 3 years.

Before returning to NASA, the former Shuttle astronaut served as the first commander of the Naval Space Command, Dahlgren, Virginia, established October 1, 1983. His career in the U.S. Navy began in 1959, when he was commissioned an ensign. This coincided with his graduation from Georgia Institute of Technology, which he attended as a Naval R.O.T.C. midshipman and earned a bachelor's degree in aeronautical engineering.

Following flight school, he was designated a naval aviator in 1960. His initial tour of duty, Fighter Squadron 33, was aboard USS Intrepid and USS Enterprise, and he made more than 300 carrier landings. From 1963 to 1965, he was a student and then instructor at the U.S. Air Force Aerospace Research Pilot School, Edwards Air Force Base, California.

In 1965, Truly became one of the first military astronauts selected to the Air Force's Manned Orbiting Laboratory program in Los Angeles, California, and transferred to NASA as an astronaut in August 1969. He served as capsule communicator for all three of the manned Skylab missions in 1973 and the Apollo-Soyuz mission in 1975. As a naval aviator, test pilot, and astronaut, Truly has logged over 7,500 hours in numerous military and civilian jet aircraft.

He was pilot for one of the two-man crews that flew the 747/Space Shuttle **Enterprise** approach and landing test flights during 1977. He then served as backup pilot for STS-1, the first orbital test of the Shuttle. His first flight in space was November 12-14, 1981, as pilot of Space Shuttle **Columbia** (STS-2), significant as the first manned spacecraft to be reflown in space. His second flight (STS-8, August 30-September 5, 1983) was as commander of Space Shuttle **Challenger**, the first night launch and landing in the Shuttle program.

On January 18, 1989, Truly was awarded the Presidential Citizen's Medal by President Reagan. His NASA awards include two NASA Distinguished Service Medals, the NASA Outstanding Leadership Medal, two NASA Exceptional Service Medals, and two NASA Space Flight Medals. His military decorations include the Defense Distinguished Service Medal, the Defense Superior Service Medal, two Legions of Merit, the Navy Distinguished Flying Cross, and the Meritorious Service Medal.

Truly also has received the Robert J. Collier Trophy (twice, 1982 and 1989), the Robert H. Goddard Memorial Trophy (twice, 1982 and 1989), the Society of Experimental Test Pilot's Ivan C. Kincheloe Award (1978) and James H. Doolittle Award (1988), the Federation Aeronautique Internationale Gold Space Medal (1984), the Harmon International Trophy (1982), the Thomas D. White Space Trophy (1982), the American Institute of Aeronautics and Astronautics Haley Space Flight Award (1980), the American Astronautical Society's Flight Achievement Award (1977) and John F. Kennedy Astronautics Award (1990), the Air Force Association's David C. Shilling Award (1978), the Boy Scouts of America Distinguished Eagle Scout Award, the Medal of Honor of the National Society of the Daughters of the American Revolution, and the Sons of the American Revolution Gold Good Citizenship Award.

Truly was born in Fayette, Mississippi, on November 12, 1937, and attended school in Fayette and Meridian, Mississippi. He is married to the former Colleen (Cody) Hanner of Milledgeville, Georgia. They have three children--Mike, Dan and Lee--and three grandchildren--Ashley, Courtney and Peter.

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

MICHELLE K. VAN CLEAVE

ASSISTANT DIRECTOR FOR NATIONAL SECURITY AFFAIRS
AND
COUNSEL

Michelle Kim Van Cleave was reappointed Assistant Director for National Security Affairs and Counsel, White House Office of Science and Technology Policy, on October 1, 1989--positions she had held from August 1987 through February 1989. Prior to rejoining OSTP, Ms. Van Cleave served as Republican Counsel to the Committee on Science, Space, and Technology, U.S. House of Representatives.

From 1981 through July 1987, Ms. Van Cleave was Assistant for Defense and Foreign Policy to Congressman Jack Kemp (R-NY), serving concurrently as National Security Assistant to the House Republican Conference and Associate Staff Member, House Appropriations Subcommittee on Foreign Operations, U.S. House of Representatives.

From 1979 through 1981, Ms. Van Cleave was an associate with the Los Angeles law firm of Horvitz and Greines, specializing in appellate advocacy.

Ms. Van Cleave was Coordinator and Staff Attorney in the Office of the General Counsel, 1981 Presidential Inaugural Committee, and assisted in the work of the Department of Defense Transition Team Office of President-elect Reagan 1980. At the Republican Convention in 1984, Ms. Van Cleave was a member of the Platform Committee staff, with responsibility for foreign policy.

Ms. Van Cleave has served as a member of the Board of Advisors, Center for Security Policy, and as consultant to the Heritage Foundation, the Fund for an American Renaissance, and the American Security Council. She has spoken before a variety of conferences and organizations including the Aspen Institute Berlin, the New York Institute of Technology, the National Defense University, Tufts University, Johns Hopkins School for Advanced International Studies, Republican National Committee regional meetings, the Military Operations Research Society and the American Chamber of Commerce (Manila). She also served as a Congressional Staff Advisor to the U.S. delegation to the United Nations Second Special Session on Disarmament.

Ms. Van Cleave holds M.A. and B.A. degrees in international relations from the University of Southern California and a J.D. from the U.S.C. School of Law. She is a member of the State Bar of California.

December 1989

Withdrawal/Redaction Sheet
(George Bush Library)

Document No. and Type	Subject/Title of Document	Date	Restriction	Class.
01. Resume	Resume of Edward Osborne Wilson [social security number redacted] (1 pp.)		(b)(6)	

Collection:

Record Group: Bush Presidential Records
Office: Science and Technology Policy, Office of (OSTP)
Series: Bromley, D. Allan, Files
Subseries: Organization Files - PCAST
WHORM Cat.:
File Location: President's Council of Advisors for Science and Technology: Meetings - 1/10/91-1/11/91

Date Closed:	5/17/2010	**OA/ID Number:**	62079-001
FOIA/SYS Case #:	2005-0336-F	**Appeal Case #:**	
Re-review Case #:		**Appeal Disposition:**	
P-2/P-5 Review Case #:		**Disposition Date:**	
AR Case #:		**MR Case #:**	
AR Disposition:		**MR Disposition:**	
AR Disposition Date:		**MR Disposition Date:**	

RESTRICTION CODES

Presidential Records Act - [44 U.S.C. 2204(a)]

P-1 National Security Classified Information [(a)(1) of the PRA]
P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]
P-3 Release would violate a Federal statute [(a)(3) of the PRA]
P-4 Release would disclose trade secrets or confidential commercial or financial information [(a)(4) of the PRA]
P-5 Release would disclose confidential advice between the President and his advisors, or between such advisors [a)(5) of the PRA]
P-6 Release would constitute a clearly unwarranted invasion of personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of gift.

PRM. Removed as a personal record misfile.

Freedom of Information Act - [5 U.S.C. 552(b)]

(b)(1) National security classified information [(b)(1) of the FOIA]
(b)(2) Release would disclose internal personnel rules and practices of an agency [(b)(2) of the FOIA]
(b)(3) Release would violate a Federal statute [(b)(3) of the FOIA]
(b)(4) Release would disclose trade secrets or confidential or financial information [(b)(4) of the FOIA]
(b)(6) Release would constitute a clearly unwarranted invasion of personal privacy [(b)(6) of the FOIA]
(b)(7) Release would disclose information compiled for law enforcement purposes [(b)(7) of the FOIA]
(b)(8) Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA]
(b)(9) Release would disclose geological or geophysical information

Curriculum Vitae
EDWARD OSBORNE WILSON

(Soc. Sec. No. [redacted] (b)(6))

BORN: Birmingham, Alabama, June 10, 1929; parents: Linnette Freeman Huddleston and Edward Osborne Wilson, Sr. (father deceased). Married: Irene Kelley, 1955. One daughter: Catherine, born 1963.

EDUCATION: Graduated Decatur Senior High School, Decatur, Alabama, 1946
B.S. (biol.), University of Alabama, 1949
M.S. (biol.), University of Alabama, 1950
Ph.D. (biol.), Harvard University, 1955

POSITIONS:
Alabama Department of Conservation: Entomologist, 1949
Harvard University: Junior Fellow, Society of Fellows, 1953-56; Assistant Professor of Biology, 1956-58; Associate Professor of Zoology, 1958-64; Professor of Zoology, 1964-1976; Curator in Entomology, Museum of Comparative Zoology, 1973-; Frank B. Baird Jr. Professor of Science, 1976-; Mellon Professor of the Sciences, 1990-1993
University of California, Berkeley: Hitchcock Visiting Professor, 1972
Society for the Study of Evolution: President, 1973
Marine Biological Laboratories: Board of Trustees, 1976-80
John Simon Guggenheim Foundation: Fellow, 1976; Advisory Board, 1977-81; Committee of Selection, 1982-89
World Wildlife Fund: Scientific Advisory Committee, 1978-; Board of Directors, 1984-90; Executive Committee, 1987-90
National Research Council: Board on Science and Technology in International Development, 1984-86; Committee on Research Opportunities in Biology, 1985-89; Chairman, Committee on Biodiversity, 1988-90
National Science Board Taskforce on Biodiversity, 1987-89
Xerces Society: President, 1989-90

Griswold Lecture, Cornell University (1968)
Bartram Lecture, Florida State University (1976)
Messenger Lectures, Cornell University (1976)
Distinguished Lecture, Eastern Psychological Association (1977)
Leon Lecture, University of Pennsylvania (1977)
Gilmour Lecture, Johns Hopkins University (1977)
Orr Lectures, Dartmouth College (1977)
Beatty Lectures, McGill University (1977)
Harris Lectures, Northwestern University (1978)
Tanner Lecture in Philosophy, University of Michigan (1979)
Patten Memorial Lectures, Indiana University (1979)
Annual Lecture, Carnegie Institution of Washington, D.C. (1979)
Tarner Lecturer, Trinity College, Cambridge University (1979-82)
Aharon Katzir-Katchalsky Lecture, Weizmann Institute, Israel (1980)
George Gay Lecture in Ethics, Harvard Medical School (1980)
Wilhemine Key Lecture, American Genetic Association (1980)
Adolf Meyer Lecture, American Psychiatric Association (1981)
Inaugural Corliss Lamont Lecture, American Humanist Association (1982)
Philip Denecke Lecture, Oxford University (1982)
Plenary Lecture, American Psychoanalytic Association (1982)
Robert Clinton Rhodes Lecture, Emory University (1983)
Loren Eisley Lecture, University of Pennsylvania (1983)
Man and Ideas Lecture, Carnegie Institute (1984)
Presidential Lecture, Rice University (1984)
Rosenstadt Visiting Professor of Medicine, University of Toronto (1984)
Lewis Clark Vanuxum Lecture, Princeton University (1985)
Mangelsdorf Lecture, University of North Carolina (1985)

Centennial Lecture, University of Arizona (1985)
Tansley Lecture, British Ecological Society (1985)
Felix Santschi Lecture, University of Zürich (1986)
Distinguished Lecture, Family Theory Symposium, Georgetown University (1986)
Joseph Leconte Lecture, Georgia Southern College (1986)
Keynote address, National BioDiversity Forum (1986)
Keynote address, Conservation 2100, New York Zoological Society (1986)
Keynote address, American Academy of Psychiatry and Law (1987)
Keynote address, Entomological Society of America (1987)
Address, National Geographic Society Centennial (1988)
Phi Beta Kappa Lecture, University of Miami (1988)
Lionel Trilling Lecture, Columbia University (1988)
Centennial Lecture, Marine Biological Laboratories, Woods Hole (1988)
Gannon Lecture, Fordham University (1988)
Bicentennial Lecture, Georgetown University (1989)
Mahoney Lecture, National Institutes of Health (1989)
Hilldale Lecture, University of Wisconsin (1989)
Centennial Lecture, Entomological Society of America (1989)
NSF Graduate Research Fellowship Commemorative Lecture, American Zoological Society (1989)
H. O. Lund Lecture, University of Georgia (1990)

MEMBERSHIPS AND AWARDS:

National Medal of Science (1977)
Crafoord Prize, Royal Swedish Academy of Sciences (1990)
Prix du Institut de la Vie, Paris (1990)
Gold Medal, Worldwide Fund for Nature (WWF-International) (1990)
Distinguished Scientific Humanist Award, Free Inquiry (1990)
Revelle Medal, San Diego Natural History Museum (1990)
University Medal, University of Helsinki (1989)
Ingersoll Prize in Scholarly Letters (1989)
Benjamin Dann Walsh Award, Illinois Academy of Sciences, Chicago (1989)
Founder's Award, Field Museum, Chicago (1989)
Golden Plate Award, American Academy of Achievement (1988)
Terrestrial Ecology Prize of the Ecology Institute, Germany (1987)
National Zoological Park Medal in Zoology and Conservation (1987)
Rector's Medal of the University of Bergen (1987)
L. O. Howard Distinguished Achievement Award, Entomological Society of America (1985)
Tyler Prize for Environmental Achievement (1984)
Laureate, Academy of Humanism (1983)
Distinguished Humanist Award, American Humanist Association (1982)
Book of the Year Award, Alabama Library Association (1979)
Pulitzer Prize, General Non-fiction (1979)
Leidy Medal, Academy of Natural Sciences (1979)
Carr Medal, University of Florida (1979)
Distinguished Service Award, American Institute of Biological Sciences (1976)
Founders Memorial Award, Entomological Society of America (1973)
Mercer Award, Ecological Society of America (1971)
Cleveland Research Prize, American Association for the Advancement of Science (1968)

Fellow:

American Academy of Arts and Sciences (1959)
American Philosophical Society (1976)
Animal Behavior Society (1976)
Deutsche Akademie der Naturforscher Leopoldina (German Academy of Sciences) (1977)
Royal Society of Sciences of Uppsala (1989)

E. O. Wilson, C.V.

Member:
National Academy of Sciences (1969)
Foreign Member:
Royal Society, England (1990)
Finnish Academy of Science and Letters (1990)

Honorary Life Member:
American Genetic Association (1981)
British Ecological Society (1983)
Entomological Society of America (1987)
Darwin Society, University of Bergen (1987)
American Humanist Association (1989)

Member of founding group of the following organizations:
International Centre of Insect Physiology and Ecology (ICIPE)
Organization for Tropical Studies (OTS)
Ecosystems Center of the Marine Biological Laboratory

D.Phil. (hon. caus.): Uppsala University, 1987
D.Sc. (hon. caus.): Duke University, 1978; Grinnell College, 1978; University of West Florida, 1979; Lawrence University, 1979; Fitchburg State College, 1989; Macalester College, 1990
L.H.D. (hon. caus.): University of Alabama, 1980; Hofstra University, 1986
LL.D. (hon. caus.): Simon Fraser University, 1982

RESEARCH INTERESTS:
Evolutionary biology; biology of social insects; classification of ants; sociobiology; biogeography; ethical philosophy

ARTICLES, MOSTLY TECHNICAL: about 320

CITATION CLASSICS (*Current Contents*, most cited articles and books):
Brown, W. L. and E. O. Wilson. 1956. Character displacement. *Systematic Zoology*, 5: 49-64.
MacArthur, R. H. and E. O. Wilson. 1967. *The Theory of Island Biogeography*. Princeton University Press, Princeton, NJ. 203 pp.
Simberloff, D. S. and E. O. Wilson. 1969. Experimental zoogeography of islands: the colonization of empty islands. *Ecology*, 50(2): 278-296.
Wilson, E. O. 1975. *Sociobiology: The New Synthesis*. Belknap Press of Harvard University Press, Cambridge, MA. 697 pp.

BOOKS:
The Theory of Island Biogeography, with Robert H. MacArthur (1967)
A Primer of Population Biology, with William H. Bossert (1971)
The Insect Societies (1971)
Life on Earth, with 6 co-authors (1973); second edition (1978)
Sociobiology: The New Synthesis (1975); the abridged edition (1980)
On Human Nature (1978)
Caste and Ecology in the Social Insects, with George F. Oster (1978)
Genes, Mind, and Culture, with Charles J. Lumsden (1981)
Promethean Fire, with Charles J. Lumsden (1983)
Biophilia (1984)
Scientific American Readings:
Ecology, Evolution, and Population Biology, editor (1974)
Animal Behavior, co-edited with Thomas Eisner (1975)
The Insects, co-edited with Thomas Eisner (1977)
Biodiversity, editor (1988)
The Ants, with Bert Hölldobler (1990)
Success and Dominance in Ecosystems: The Case of the Social Insects (1990)

Ph.D. STUDENTS:
Stuart A. Altmann, William H. Bossert, Donald J. Farish, Adrian B. Forsyth, Robert L. Jeanne, William B. Kerfoot, Nancy K. Lind, David R. Maddison, Robert A. Metcalf, Scott E. Miller, Mark W. Moffett, Herbert E. Nipson, Aniruddh Patel, Robert E. Silberglied, Alastair M. Stuart, Roger B. Swain, Robert W. Taylor, Leeanne Tennant, Margaret K. Thayer, Barbara L. Thorne, John E. Tobin, James D. Weinrich, Norman E. Woodley