Critical Needs for Research in Veterinary Science

Committee on the National Needs for Research in Veterinary Science, National Research Council

ISBN: 0-309-55051-3, 238 pages, 6 x 9, (2005)

CRITICAL NEEDS FOR RESEARCH IN VETERINARY SCIENCE

Committee on the National Needs for
Research in Veterinary Science

Board on Agriculture and Natural Resources

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS • 500 Fifth Street, N.W. • Washington, D.C. 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This study was supported by the American Animal Hospital Association, the Association of American Veterinary Medical Colleges, the American Veterinary Medical Association, the Centers for Disease Control and Prevention under Contract No. 200-2000-00629 (Task Order No. 28), the National Association of Federal Veterinarians, and the National Center for Research Resources and the National Institute of Environmental Health Sciences of the National Institutes of Health under Contract No. N01-OD-4-2139 (Task Order No. 140). Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number 0-309-09660-X (Book)
International Standard Book Number 0-309-55051-3 (PDF)
Library of Congress Catalog Card Number 2005931857

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, NW, Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu.

Printed in the United States of America.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Wm. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Wm. Wulf are chairman and vice chairman, respectively, of the National Research Council.

www.national-academies.org

COMMITTEE ON THE NATIONAL NEEDS FOR RESEARCH IN VETERINARY SCIENCE

JAMES E. WOMACK, *Chair*, Texas A&M University, College Station
LYNN C. ANDERSON, Charles River Laboratories, Wilmington, Massachusetts
LEONARD S. BULL, North Carolina State University, Raleigh
CHARLES C. CAPEN, Ohio State University, Columbus
NORMAN F. CHEVILLE (retired), Iowa State University, Ames
PETER DASZAK, Consortium for Conservation Medicine, Palisades, New York
W. JEAN DODDS, Hemopet, Santa Monica, California
MICHAEL P. DOYLE, University of Georgia, Griffin
DAVID R. FRANZ, Midwest Research Institute, Frederick, Maryland
JOHN A. SHADDUCK, Shadduck Consulting LLC, Fort Collins, Colorado
DARCY H. SHAW, University of Prince Edward Island, Charlottetown, Canada
DAVID E. SWAYNE, U.S. Department of Agriculture, Agricultural Research Service, College Station, Athens, Georgia
RAVI J. TOLWANI, Stanford University, California

National Research Council Staff

EVONNE TANG, Study Director
NORMAN GROSSBLATT, Senior Editor
JOHNNY HERNANDEZ, Anderson Intern
KAREN IMHOF, Administrative Assistant
PEGGY TSAI, Research Associate

BOARD ON AGRICULTURE AND NATURAL RESOURCES

MAY BERENBAUM, *Chair*, University of Illinois, Urbana-Champaign
SANDRA BARTHOLMEY, University of Illinois, Chicago
ROGER N. BEACHY, Donald Danforth Plant Science Center, St. Louis, Missouri
H.H. CHENG, University of Minnesota, St. Paul
W.R. GOMES, University of California, Oakland
ARTURO GOMEZ-POMPA, University of California, Riverside
PERRY R. HAGENSTEIN, Institute for Forest Analysis, Planning, and Policy, Wayland, Massachusetts
JEAN HALLORAN, Consumer Policy Institute/Consumers Union, Yonkers, New York
HANS R. HERREN, Millennium Institute, Arlington, Virginia
DANIEL P. LOUCKS, Cornell University, Ithaca, New York
WHITNEY MACMILLAN (Emeritus), Cargill, Incorporated, Minneapolis, Minnesota
BRIAN W. MCBRIDE, University of Guelph, Ontario, Canada
TERRY MEDLEY, E.I. duPont de Nemours and Company, Wilmington, Delaware
OLE NIELSEN (Emeritus), Ontario Veterinary College, Guelph, Canada
ROBERT PAARLBERG, Wellesley College, Watertown, Massachusetts
ALICE N. PELL, Cornell University, Ithaca, New York
BOBBY PHILLS, Florida A&M University, Tallahassee
PEDRO A. SANCHEZ, The Earth Institute at Columbia University, Palisades, New York
SONYA SALAMON, University of Illinois, Urbana-Champaign
B.L. TURNER II, Clark University, Worcester, Massachusetts
TILAHUN D. YILMA, University of California, Davis
JAW-KAI WANG, University of Hawaii, Manoa

National Research Council Staff

CHARLOTTE KIRK BAER, Director (until October 2004)
ROBIN SCHOEN, Director (from November 2004)
KAREN IMHOF, Administrative Assistant
DONNA LEE JAMEISON, Senior Program Assistant
AUSTIN LEWIS, Program Officer
PEGGY TSAI, Research Associate

Preface

Veterinary research has historically played an important role in the improvement of health and welfare of all animals, including humans. Veterinary scientists are often at the forefront of research in human diseases because many human pathogens have their origins in animal hosts. Moreover, animal models of disease have been used to elucidate the underlying mechanisms of many diseases in humans and other animals. In addition to its many contributions to human health, veterinary research—by targeting the prevention and control of agricultural, domestic, wild and aquatic animal diseases—contributes to the quality of human life. Food-animal health, for example, secures a safe and economic food supply for the human population. Veterinary research is also essential to the health and increased longevity of service and companion animals and thereby reduces stress in both animals and owners. The events of September 11, 2001, have changed our lives in many ways and have greatly increased the need for research in human and animal health as bioterrorism threatens human health directly and indirectly through disruption of our food supply. Despite the increasing demands on veterinary research, however, its workforce has not increased. The types and priorities of resources dedicated to human and animal health must be reevaluated to address the greatly increased demands on research in the veterinary community.

The National Research Council's Committee on the National Needs for Research in Veterinary Science—composed of specialists in pathology, laboratory animal medicine, infectious diseases, genomics, nutrition, food safety, biosecurity, and other subdisciplines of animal research—was charged to identify current needs and project future needs for research in three fields of veterinary science: public health and food safety; animal health; and comparative medicine. (The committee defines comparative medicine as the field of medicine that compares medical and scientific discoveries and knowledge of one or more animal species, including humans.) The committee was also asked to assess resources, infrastructure, and manpower available to meet those needs without making specific budgetary or organizational recommendations.

The committee met five times over a 10-month period, beginning in May 2004. To gather information, the committee hosted a workshop in which stakeholders and experts met to share data and opinions on current and future needs in veterinary research, on a vision for veterinary research from a government perspective, and on the integration of veterinary science into tomorrow's research. Workshop speakers were selected in part to fill perceived gaps in the background and expertise of the committee.

We have organized our report into five chapters. We attempted to define the role of veterinary research in human society in Chapter 1, and to highlight historic achievements and identify trends and frontiers in veterinary research in Chapter 2. On the basis of the research needs described in Chapter 2, we suggest in Chapter 3 an implementation plan for each area of research with short-term, intermediate-term, and long-term goals. We describe the resources available for veterinary research in Chapter 4. In crafting Chapter 4, the committee encountered several instances in which desired information was not available for two reasons. First, veterinary research crosses disciplinary boundaries, so it is difficult to define resources and personnel that are dedicated strictly to veterinary research. Second, some desired information is available but cannot be extracted from databases. For example, the U.S. Department of Agriculture has a good database on individual grants, but it is difficult to determine whether some relevant awards are credited to veterinary research. The Association of American Veterinary Medical Colleges provided many of the needed data, but we were also seeking data on the time that faculty devote to research in colleges of veterinary medicine. Most important, there is no central source of data on infrastructure, human, and financial resources for other academic and research units relevant to veterinary science, such as departments of veterinary science, wildlife and fisheries, and comparative medicine; colleges of agriculture; and zoological institutions. In Chapter 5, we assess the adequacies of available resources to meet the challenges posed to veterinary research.

I am grateful to the committee of experts who gave their time and energy generously to a report they perceived to be timely and important. Each committee member participated in the writing, review, discussion, and revision of this report and eventually accepted it as a consensus interpretation of the status of and needs for research in veterinary science. I was impressed from beginning to end with the ability of this diverse collection of professionals to speak and listen, instruct and learn, agree and disagree, and ultimately reach an objective consensus on the issues posed in our charge. On behalf of the committee, I thank our study director, Dr. Evonne Tang, for providing direction, marshaling resources, and keeping this committee focused on its charge. The sometimes appropriate metaphor of herding cats is probably not lost on an audience drawn to veterinary research. We are also indebted to our administrative assistant, Karen Imhof, who, with Evonne made our work both productive and enjoyable.

James E. Womack, *Chair*
Committee on the National Needs for
Research in Veterinary Science

Acknowledgments

This report is a product of the cooperation and contributions of many people. The committee would like to thank all the participants of the Workshop on National Needs for Research in Veterinary Science on July 19-20, 2004, and others who provided information and input.

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following for their review of this report:

Ed Breitschwerdt, North Carolina State University
James Estep, Battelle Medical Research and Evaluation Facility
John M. Gay, University of Washington
Scott McEwen, University of Guelph, Canada
Michael Miller, Colorado Division of Wildlife
George Seidel, Colorado State University
Gary Sherman, USDA Cooperative State Research, Education, and Extension Service
John Sundberg, The Jackson Laboratory
Linda Toth, Southern Illinois University School of Medicine

Although the reviewers listed above have provided constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Dr. John G. Vandenbergh of the North Carolina State University. Appointed by the National Research Council, Dr. Vandenbergh was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the author committee and the institution.

Contents

TABLES, FIGURES, AND BOXES

Tables

Figures

Boxes

Summary

Research in veterinary science is critical to the protection of public health and the advancement of science that benefits both humans and animals as individuals and populations. Veterinary research includes studies on prevention, control, diagnosis, and treatment of diseases and on the basic biology and welfare of animals. It transcends species boundaries to include the study of spontaneous and experimental models of both human and animal disease and research at important human-animal interfaces, such as food safety, wildlife and ecosystem health, zoonotic diseases, and public policy.

The rich history of veterinary research, which includes studies on infectious disease and in other biomedical sciences, is replete with seminal contributions to the improvement of animal and human well-being. The many contributions of veterinary research were the results of society's recognition of its important role and society's subsequent support in the form of human, fiscal, and infrastructural resources. The current level of support for veterinary research, however, has not kept pace with the challenges posed by new and emerging threats and the nation's growing demands for knowledge in biomedicine and animal health. That society's needs are outgrowing our knowledge base is seen in examples of missed opportunities to safeguard and improve human and animal health and welfare (Box S-1).

The capacity of veterinary research depends on the availability of human and financial resources, research facilities, and infrastructure. This report identifies some of the most critical research needs and outlines recommendations and strategies for meeting them. Failure to provide the necessary resources could have devastating effects on both human and animal welfare, impede biomedical advances, and harm the economy and society as a whole.

BOX S-1
Examples of Opportunities for Veterinary Research to Safeguard and Improve Human and Animal Health

In June 1999, an unusual number of dead birds were reported in the borough of Queens, New York City. Some 6-8 weeks later, an unusual number of human cases of encephalitis were noted in a local hospital. The human disease was diagnosed as St. Louis encephalitis, which is a mosquito-borne viral encephalitis that does not produce disease in birds. The misdiagnosis was not recognized until 2-3 weeks later when the animal and human disease data were integrated. West Nile virus was then identified as the causative agent of both bird and human deaths. The lives and dollars that might have been saved by knowing 6 weeks earlier that a new deadly arbovirus had been introduced to North America cannot be estimated. An early awareness of this now costly emergent disease might have increased the likelihood of its eradication because its geographic footprint was much smaller before it spread to humans. Even if it could not be eradicated, the impact of West Nile virus could have been lessened if veterinary research had been better integrated with human medicine.

The Asian H5N1 avian influenza epizootic began in Hong Kong in 1997 with cases on poultry farms in March, April, and May. The first human case occurred in May, but the diagnosis of avian influenza was delayed by 3 months because of inadequate interaction between veterinary and public-health officials. Since late 2003, Asian H5N1 avian influenza has emerged as the largest exotic poultry health crisis of the last 50 years; so far, it has involved the death or preemptive culling of over 200 million poultry. The virus has also caused severe disease and death in humans. Veterinary medical research in epidemiology, vaccinology, diagnostics, and pathogenesis is recognized as critical for the control of the virus, its eradication from birds, and prevention of human infections. Additional research is needed to improve protection against the next major zoonotic outbreak and a potential pandemic of influenza.

The pharmaceutical enterprise screens millions of molecules per year in the process of developing candidate drugs. Only a few candidate drugs prove to be safe and effective; only 350 new drugs, biologics, and vaccines were approved in the last decade. A major bottleneck in the process is the lack of satisfactory test systems for preclinical trials. Veterinary science could offer powerful solutions to development of pharmaceutical products through sound basic and translational research on animal biology, genomics, proteomics, genetically modified animal models, integrative physiology, and spontaneous diseases of animals if adequate resources were available.

To prepare this report, the Committee on National Needs for Research in Veterinary Science analyzed national research needs in three fields of veterinary science—public health and food safety, animal health and welfare, and comparative medicine—and looked at a number of emerging issues that fit in two or more those fields. The research needs include scientific investigation in domestic, wild, companion, service, and laboratory animals. The committee's analysis was based on a comprehensive review of published literature; information obtained from stakeholders, including the Association of American Veterinary Medical Colleges (AAVMC) and several veterinary specialty colleges; and comments provided by national experts at the committee-hosted Workshop on National Needs for Research in Veterinary Science. Current funding levels and sources also were analyzed. On the basis of workshop input and analyses of available data, the committee identified past and future research trends and gaps and the scientific expertise and infrastructure required to meet the most critical research needs. In accordance with its stated charge, the committee did not make specific budgetary or organizational recommendations. (See Appendixes A and B for complete statement of task and biographical information on committee members.)

CHALLENGES FOR VETERINARY RESEARCH

Veterinary research offers numerous opportunities for improving animal and human health, and unforeseeable challenges can be met best with a competent and properly equipped veterinary research community. Specific findings and critical research needs are detailed in Chapter 2 and summarized below.

Public Health and Food Safety

Foodborne disease is a major cause of morbidity and mortality in the United States. Animals—both domesticated and wild—are frequent reservoirs of foodborne pathogens that can cause human illness. Human public health is affected not only by foodborne pathogens but also by the security of our food animals. A new awareness of the need for research on food and agricultural biosecurity arose after September 11 and the "anthrax letter" attacks later in 2001 because biosecurity research is closely related to maintaining safe agriculture and the food supply. Veterinary research on public health and food safety can contribute to:

- Improving detection and surveillance of foodborne pathogens associated with livestock and poultry production.
- Developing interventions to reduce their dissemination.
- Understanding the development and mechanisms of antibiotic resistance among foodborne pathogens associated with animals in the food chain.
- Developing preharvest and postharvest surveillance systems, diagnostic and detection systems, vaccines, immunomodulating drugs, animal and product tracking systems, and ecologically sound means of disposal of animal carcasses.
- Improving our ability to detect and identify disease and pathogens in animal populations and our understanding of interactions between pathogens and hosts so that effective preventive measures and countermeasures can be developed.

A concerted research effort can reduce the recurrence of food pathogens associated with livestock and poultry and ensure the security of our food supply.

Animal Health and Welfare

The increasing demand for veterinary research in animal health and welfare has several underlying causes:

- The perspective of the role of animals in human society and in the ecosystem has changed.
- A secure supply of food animals—such as poultry, cows, and fish—depends on their health.
- Some food-animal diseases affect human health directly (for example, some strains of high-pathogenicity avian influenza virus).
- Companion and service animals have an important role in human welfare.
- Laboratory animals are integral to our understanding of basic biology and physiology and are crucial for biological and medical advances.
- Wildlife health is important for the maintenance of the ecosystem and for the economy.
- Some emerging infectious diseases are associated with zoonoses (animal diseases that can be transmitted to humans).

Veterinary research is poised to improve human and animal health further through advances in preventive medicine, enhanced treatment for animal diseases, and a better understanding of transmission of zoonotic and other emerging diseases between wild and domestic animals and humans.

Comparative Medicine

Comparative medicine is the field that compares medical and scientific discoveries and knowledge of more than one animal species, including humans. Research in comparative medicine is invaluable for the overall medical research enterprise and for the improvement of animal health. Animal models used in biomedical research provide a whole-animal perspective that cannot be achieved at the molecular, cellular, or organ-system level. With technological advances, many new fields are emerging in comparative medicine, for example:

- Comparative genetics, which aims to develop reliable molecular markers of specific genetic traits to identify carrier and affected animals.
- Genome and phenome research that identifies specific genotypes associated with phenotypes.
- Stem-cell research and cloning.
- Genetically engineered animal models.
- Biomaterial developed to treat human and animal diseases.

Continuous progress in biomedical research will depend on our ability to develop and refine animal models to advance biomedical research, to preserve valuable models, and to improve methods for developing genetically engineered animal species other than the mouse to advance understanding of select diseases.

RESEARCH AGENDA AND STRATEGIES

The committee outlined a research agenda and recommended strategies for doing the research (Chapter 3) on the basis of the critical research needs described above. The especially compelling scientific opportunities to improve the quality of life of and minimize biological threats to animals and humans include the following:

- Implement the concepts of One Medicine and interdisciplinary and translational research in the broader biomedical research agenda.
  - Substantially improve the integration of molecular biology, genomics, immunology, whole-animal physiology, pathophysiology, and other disciplines in clinical disease research.
  - Encourage scientists, through grant-funding mechanisms and other means, to work collaboratively across disciplines, institutions, and agencies.
  - Encourage research institutions to foster research environments that nurture and reward successful team-oriented investigators and research.
  - Expand veterinary student involvement in ecosystem health and increase their opportunities to work collaboratively to study and understand complex systems and the intricate relationships between humans (individuals, cultures, and societies), animals (domestic and wild), and the environment.
- Set priorities for research to expand our knowledge, detection, and control of infectious diseases.
  - Emphasize classes of disease agents of the highest economic importance, including those most likely to cause massive epizootics or epidemics and new and emerging diseases and candidate bioterrorism agents.
  - Emphasize the study and eradication of laboratory animal diseases that adversely affect the quality of biomedical data.
  - Focus research on the molecular bases of virulence and on how pathogenic organisms replicate and survive in the environment, including studies of vector biology, wild-animal hosts and reservoirs, host defense factors, and host-pathogen interaction.
  - Develop and validate rapid, sensitive, reliable, and where possible quantitative systems for detecting and monitoring disease-causing organisms.
- Expand the study and use of bioinformatics and develop databases and other resources that are readily accessible to the scientific community to enable
  - A population-level view of disease and research on the interaction between wildlife, domestic animals, and humans.

–Tracking of pathogen prevalence in animals, including companion, food-producing, and laboratory animals.

–Tracking of foodborne diseases.

–Maximizing the sharing and efficiency of developing, preserving, and housing important rodent and other animal models.

- Quantify critical, scientifically based measures of animal health and welfare to optimize efficient, effective, sustainable, and socially responsible food-animal production and laboratory animal research.
- Expand research on the human-animal bond and the overall role of animals in society.

Although the different disciplines of veterinary research are grouped in three categories—public health and food safety, animal health and welfare, and comparative medicine—the disciplines are intertwined, and many of the committee's recommendations apply to two or all three fields. For example, research in comparative medicine contributes to animal health through development of preventive medicine and treatment. Study of wildlife diseases contributes not only to wildlife health and conservation but also to public health because many human diseases are zoonotic. In short, veterinary research has interfaces with human and animal health and is interdisciplinary; therefore, collaborative and interdisciplinary research is crucial in translating scientific advances from one traditional discipline to another. However, such research may be hampered by administrative barriers, cultural barriers, and lack of economic resources. Agencies that support veterinary research have their own missions. When proposed interdisciplinary research is relevant to the mission of several agencies but does not perfectly fit the mission of any one agency, it can be difficult to get funding to support it.

Recommendation 1: The veterinary research community should facilitate and encourage collaborative research across disciplines, institutions, and agencies by reducing administrative barriers and by nurturing and rewarding successful team-oriented investigators. The community should encourage the development of a long-term national interagency strategy for veterinary research. The strategy could include a specific focus at the National Institutes of Health (NIH) on integrated veterinary research via the Roadmap initiative. NIH should consider having a veterinary liaison like the veterinary-medicine and public-health liaison at the Centers for Disease Control and Prevention (CDC) to help to ensure integration of veterinary and human medical research. Other federal agencies, state agencies, private foundations, and supporters of veterinary research should recognize and provide long-term support for collaborative, integrated veterinary research.

Addressing critical issues in veterinary science requires adequate human, infrastructure, and financial resources. The infrastructure and financial resources for the conduct of veterinary research in institutions that play a major role were examined and compared with the resources needed to do the research proposed to meet societal needs (Box S-2).

The National Research Council report *National Needs and Priorities for Veterinarians in Biomedical Research* projected a deficit of 336 veterinary pathologists in the United States and Canada in 2007, and the American College of Veterinary Pathologists reported needs for 149 veterinary pathologists in 2004. Similar human resource needs have been reported by the US Department of Agriculture (USDA), CDC, and the American College of Laboratory Animal Medicine. The shortage of veterinary researchers is due partially to declining interests in research among veterinary students, which in turn could be attributed to the following:

- The long period required to attain a DVM, a PhD, and postdoctoral training.
- The substantial tuition debt accrued during DVM training.
- The sparse financial support for graduate students in veterinary science.
- The brief exposure of veterinary students to basic science and research throughout their academic curriculum and internships.

The extended training could be partially addressed by establishing more combined-degree programs, and financial incentives could be provided to veterinary students interested in research through grants, fellowships, and possibly a loan-forgiveness program. However, stimulating students' interest in veterinary

BOX S-2
Institutions and Organizations Considered in the Assessment of Resources for Veterinary Research in This Report

- Schools and colleges of veterinary medicine
- Colleges of agriculture
- Colleges of medicine and medical research institutions
- Wildlife and aquatic health institutions
- Zoological institutions
- National Institutes of Health
- U.S. Department of Agriculture
  - Agricultural Research Service
  - Cooperative State Research Education and Extension Service
  - Other subagencies
- Centers for Disease Control and Prevention
- Department of Defense
- Food and Drug Administration
- National Science Foundation
- Department of the Interior
- Private sector research resources

research may require a substantial change in the culture of colleges of veterinary medicine (CVMs). Academic faculties are driven to incorporate clinical learning processes into the early years of veterinary education and may not adequately integrate basic science and research in veterinary curricula. The capacity of academic veterinary curricula to incorporate and demand teaching of evidence-based medicine, including the use of research data and statistical analyses, will have a great impact on animal health and the mindset of those who support it. A consequence of failure to train the next generation of veterinary researchers adequately is that opportunities for veterinary science to address public-health needs and to improve animal and human health will be missed. A strong workforce of veterinary researchers is needed to provide the data required for informed decisions in matters that govern day-to-day activity in animal health and welfare—decisions that underlie the economic stability necessary for adequate national animal health care. Veterinary research is essential to informed decision-making by policy-makers who aim to develop effective legislation and regulations based on sound science.

Recommendation 2: Additional veterinary researchers must be trained to alleviate the demands and to meet societal needs for veterinary research. A debt-repayment initiative similar to the NIH Clinical Research Loan Repayment Program could address concerns about the large debt burden faced by graduates of CVMs. If NIH's Center for Cancer Research training initiative in comparative pathology and biomedical sciences and USDA's Agricultural Research Service PhD training program for veterinarians prove to be successful in recruiting and retaining veterinary researchers, they could be expanded and used as models for other agencies and companies.

Recommendation 3: To meet the nation's needs for research expertise in veterinary science, changes in recruitment and programming for graduate and veterinary students will be required. Changes would involve enhancing research cultures in veterinary colleges and strengthening of summer research programs, combined DVM/PhD degree paths, and the integration of basic science into clinical curricula. The AVMA Council on Education, which is charged to review colleges of veterinary medicine for accreditation and publishes guidelines for the process, should strengthen the guidelines for assessment of research in regard to opportunities for research experiences for veterinary students. Research scientists in training should be made aware of national problems in animal health and welfare, be given the opportunity to incorporate cutting-edge science into experimental design, and develop programs of high quality that compete nationally with other disciplines of science.

Increasing the veterinary research workforce requires an enlarged training capacity of educational institutions. The last major federal program to support construction of facilities for CVMs ended nearly 40 years ago. AAVMC has documented that 1,641,000 ft^2 of new and 611,000 ft^2 of renovated facilities are needed to train additional veterinary and graduate students to meet the demands of public practice. Space for classrooms, teaching, and research laboratories at all biosafety levels and housing for research animals is needed. Existing funding sources, such as state and university funds and gifts from foundations and private donors, are unlikely to meet the needs of the nation.

Recommendation 4: AAVMC and its members should identify ways in which the CVMs' facility needs can be met financially and logistically. They should consider mounting an extensive outreach effort to educate policy-makers in federal and state governments about the necessity of additional facilities to train adequate veterinary researchers. The committee did not find useful documentation on facility needs of federal or state agencies to fulfill their roles in veterinary research effectively, with the noted exception of the USDA *Report of the Strategic Planning Task Force on USDA Research Facilities: A 10-year Strategic Plan. Report and Recommendations*. The report recommended renovation of outdated facilities and noted that biocontainment facilities were required for research on high-risk pathogens. Although replacement facilities at the National Animal Disease Center in Ames, Iowa, were designed and the first phase was constructed in response to the report, not all the documented needs have been met. Expanded biocontainment facility space was one of the unmet recommended needs, which was also given high priority in Homeland Security Presidential Directive 9 (HSPD-9).

Recommendation 5: The recommendations of the 1999 Strategic Planning Task Force on USDA Research Facilities and the provisions of HSPD-9 should be implemented immediately. Biocontainment laboratories should receive special attention. Adequacies and shortfalls in facilities—both federal and nonfederal—needed to support veterinary research should be documented and quantified. Other research resources for veterinary research include libraries, databases, animal health monitoring and surveillance systems, electronic communication systems for sharing data and clinical information, specialized populations of animals, and collections of research materials, such as tissue samples. Effective communication among the various entities involved in veterinary research is needed to maximize the value of studies and to leverage the resources of the relatively small veterinary research community. In particular, databases with clinical records that can be exchanged among teaching hospitals, private practices, and diagnostic laboratories would provide data that could serve as valuable cost-efficient tools for retrospective and prospective research. Likewise, tissue samples and other specimens (for example, serum, DNA, and microorganisms) from both healthy and diseased animals offer exciting opportunities to study animal diseases and epidemiology if they are archived properly for research with client or owner confidentiality protected and made available to the research community. Of equal importance, surveillance systems that effectively and efficiently integrate animal health, food-product safety, and human health monitoring findings into user-friendly and easily accessed networks are needed.

Recommendation 6: The American Animal Hospital Association, AAVMC, and AVMA should address the need for more effective communication among the federal, university, and private sector entities involved in veterinary research. The need for databases, animal health monitoring and surveillance systems, specimen collections, and other sharable research tools to support veterinary research should receive special attention. Organization of a working task force or national workshop to devise an operating plan for developing and managing these clinical and research databases and collections and to identify methods for their support would be an important first step toward the formation of national databases and archives (such as specimen banks and clinical databases) for veterinary research.

In addition to databases and tissue samples, many disciplines in veterinary research have benefited substantially from access to well-characterized animal colonies with known diseases. Preserving the genomes of those unique model animals is critical to facilitate research in animal diseases. The genetic similarity between humans and other animals is a compelling argument that studies with such animals would reveal both normal and abnormal pathways and mechanisms. Those animal colonies are imperative for integrative physiology and pathophysiology studies.

Recommendation 7: NIH and USDA should address the importance of engineered and spontaneous model colonies of animals and ensure that these valuable resources are not lost. This can be accomplished for some species by cryopreservation and preservation of their germ plasm in tissue banks until it is needed for funded, targeted research or by transfer of their genetic mutations into smaller laboratory species. For other species, maintenance of the whole animal may be necessary.

A review of the organizations that are most likely to fund veterinary research reveals that some research disciplines do not have an identifiable source of financial support from government agencies. Those disciplines include ecological research on zoonotic emerging diseases, dynamics of select agent, biodefense pathogens in wildlife, companion-animal and equine research, wildlife and conservation research, and zoo animal and exotic-pet research. Those disciplines contribute to animal health and welfare and to important elements of human health research or have direct human social impact, but they do not have dependable, permanent financial resources that would ensure their continuing advancement in research.

Recommendation 8: The veterinary research community should actively engage NIH, USDA, the Department of the Interior, the National Science Foundation, and other federal agencies and urge them to recognize and address the need for financial support for the disciplines of veterinary research that lack identifiable sources of federal funding despite their contributions to public health, comparative medicine, and animal health and welfare.

SUMMING UP

In this age of reductionist research and the ascension of disciplinary endeavors, veterinary research stands apart because of its breadth and interdisciplinary orientation. The world today is full of unanticipated risks in the form of highly pathogenic avian influenza, foreign animal diseases, and transmissible spongiform encephalopathies, to name but a few examples. At the same time, unparalleled opportunities in biomedicine have been afforded by advances in molecular biology, genomics, and other disciplinary sciences. Veterinary research serves as the interface of basic science and animal and human health that is critical to the advancement of our understanding of and response to impending risks and to the exploitation of disciplinary advances in the pursuit of One Medicine. The urgent need to provide adequate resources for investigators, training programs, and facilities involved in veterinary research must be met to seize the opportunities to improve the well-being of humans and animals and to minimize risks to their health.

1

The Role of Veterinary Research in Human Society

"Between animal and human medicine there is no dividing line—nor should there be. The object is different but the experience obtained constitutes the basis of all medicine."
Rudolf Virchow (1821–1902)

Virchow's statement is as wise today as it was over a century ago. That all animal species, including *Homo sapiens*, are related and that knowledge gained in one species benefits all lead to the concept of "One Medicine". The One Medicine approach takes advantage of commonalities among species; few diseases affect exclusively one group of animals (wildlife, domestic animals, or humans). On the basis of that view, Schwabe (1984) asserts that veterinary medicine is fundamentally a human health activity. All activities of veterinary scientists affect human health either directly through biomedical research and public health work or indirectly by addressing domestic animal, wildlife, or environmental health. Moreover, veterinary scientists have a responsibility to protect human health and well-being by ensuring food security and safety, preventing and controlling emerging infectious zoonoses, protecting environments and ecosystems, assisting in bioterrorism and agroterrorism preparedness, advancing treatments and controls for nonzoonotic diseases (such as vaccine-preventable illnesses and chronic diseases), contributing to public health, and engaging in medical research (Pappaioanou, 2004). Just as the practice of veterinary medicine contributes to our understanding of all medicine or One Medicine, so must veterinary research. It follows that veterinary research is, at a fundamental level, a human health activity. The centrality of veterinary research and its critical role at the interface between human and animal health are often not understood and undervalued. A vision for veterinary research and its contribution to advancing One Medicine and providing solutions for today's and tomorrow's animal and human health problems is illustrated below (Figure 1-1).

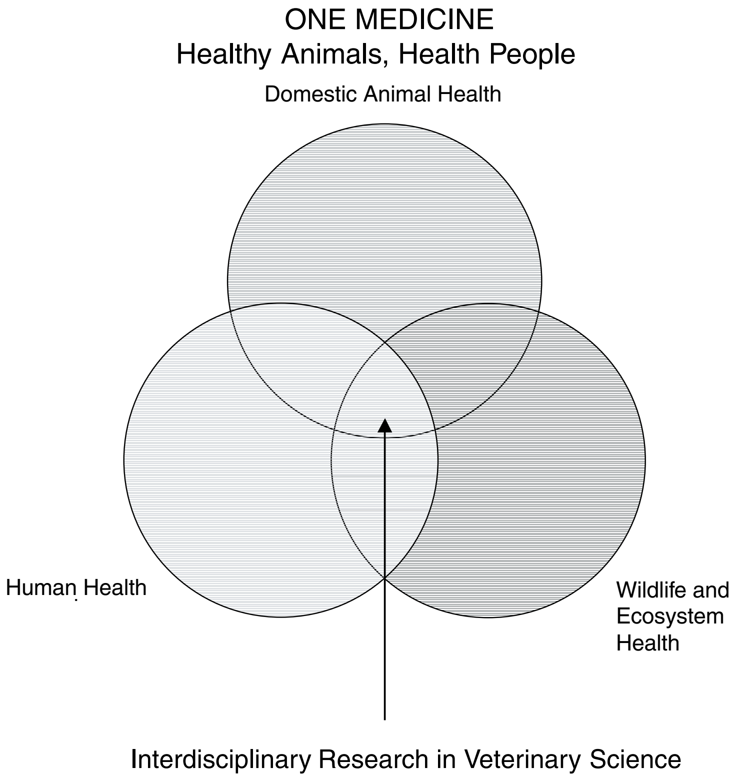


FIGURE 1-1 A vision for veterinary research. The One Medicine approach to human and animal health emphasizes the interconnectedness of relationships and the transferability of knowledge in solving health problems in all species.

Veterinary research includes research on prevention, control, diagnosis, and treatment of diseases of animals and on the basic biology, welfare, and care of animals. Veterinary research transcends species boundaries and includes the study of spontaneously occurring and experimentally induced models of both human and animal disease and research at human-animal interfaces, such as food safety, wildlife and ecosystem health, zoonotic diseases, and public policy.

By its nature, veterinary science is comparative and gives rise to the basic science disciplines of comparative anatomy, comparative physiology, comparative pathology, and so forth. Veterinary research occurs in colleges of veterinary medicine, human medicine, dentistry, agriculture, and life sciences; it is done by veterinarians, physicians, and other nonveterinarians in many disciplines. For 2 centuries, responsible public officials have recognized that veterinary research protects our draft animals, our supplies of meat and eggs, and our wildlife. It also advances our ability to maintain the health of all animals, domestic and wild; and informs policy decisions—for example, regulations to prevent and control tuberculosis and brucellosis in dairy cattle. During the same period, scientists have acknowledged the broad and robust contributions of veterinary research to human health.

Veterinary research has the potential to immensely impact the fields of comparative medicine, public health and food safety, and animal health; but its ability to reach its potential relies on adequate infrastructural, financial, and human resources. The National Research Council convened an ad hoc committee to assess the status and future of veterinary research in the United States on the request of the American Animal Hospital Association, the Association of American Veterinary Medical Colleges, the American Veterinary Medical Association, the Centers for Disease Control and Prevention, the National Association of Federal Veterinarians, the National Center for Research Resources (NCRR), and the National Institute of Environmental Health Sciences. Specifically, the committee was asked to identify national needs for research in three fields of veterinary science—comparative medicine, public health and food safety, and animal health; to assess the adequacy of our national capacity, mechanisms, and infrastructure to support the needed research; and, if appropriate, to make recommendations as to how the needs can be met. Specific budgetary or organizational recommendations were not to be included in the report. (Appendixes A and B present the complete statement of task and information on the committee members.)

The three fields of veterinary science encompass research with domestic animals (such as livestock and poultry), wild animals (such as deer and exotic species), companion animals (such as dogs, cats, and horses), service animals (such as horses and dogs), and laboratory animals. Specifically, future needs for research were assessed in the three fields of veterinary science, which are not limited to science conducted by veterinarians; they include science performed by professionals who have veterinary degrees and professionals who have various other degrees.

HISTORY

The contributions of veterinary research to advancements in medicine are rich. In ancient academic amphitheaters, comparative anatomical and physiological studies provided a basis for our understanding of embryonic development, human blood circulation and lymphatics, the brain and the rest of the nervous system, and the structure of virtually all organs. As modern medicine evolved, Pasteur's experiments on rabies and anthrax vaccination in sheep, Koch's studies of tuberculosis, and Salmon's direction of research in the US Bureau of Animal Industry—all of which depended on the knowledge of comparative or veterinary research—provided the basis of contemporary preventive medical treatments. More recent contributions of veterinary researchers include Brinster's pioneering studies in embryo transplantation and the immunological discoveries of Nobel Prize winner Peter Doherty. In the last half century, the widespread use of animal models in comparative medicine and the improved management of laboratory animals have been integral to the advancement of scientific knowledge in human medicine.

In 1878, Congress appropriated $10,000 for the US Department of Agriculture (USDA) to fund the first research in the United States specifically directed toward veterinary science. This study was "investigating diseases of swine and infectious and contagious diseases which all other classes of domestic animals are subject" and enabled D.E. Salmon to establish that quarantine and disinfection prevent spread of infectious diseases. Salmon's successful research led to an act of Congress on May 29, 1884, that established the Bureau of Animal Industry (BAI) in USDA. The act provided, in part, "that the Commissioner of Agriculture shall organize in this Department a Bureau of Animal Industry, and shall appoint a Chief thereof, who shall be a competent veterinary surgeon." Research in BAI made major scientific advances in the understanding of human diseases. BAI's findings included the isolation of the first species of *Salmonella*, the discovery of hog cholera and of how the virus and serum provide immunity, elucidation of the life cycle of the cattle tick, and the discovery of the protozoan parasite that caused Texas cattle fever. The latter made possible the scientific approach to conquering yellow fever in the Panama Canal Zone. In 1920, Simon Flexner of Rockefeller Institute of Medical Research noted that "our knowledge of yellow fever would in all likelihood have been delayed if the work of the Bureau of Animal Industry of the US Department of Agriculture on Texas fever had not been done."

BAI was a major contributor to public health, Secretary of Agriculture James Wilson's report for 1909 stated that the BAI "not only deals with the livestock industry, but has an important bearing upon public health through the meat inspection, through efforts for the improvement of the milk supply, and through the investigations, prevention and eradication of diseases which affect man as well as the lower animals. Indeed, the animal and the human phases of the Bureau's work are so closely related and interwoven that they could not be separated without detriment."

At the turn of the twentieth century, the university-based schools of veterinary medicine began to develop research units. Advanced medical institutions included comparative medicine in their structure and used animal disease models to elucidate the basic nature of human disease. Rous, in 1910, was the first to discover a virus that caused cancer (sarcoma in chickens). Other discoveries in comparative medicine include Shope's findings of the viral nature of papillomas in rabbits (1932) and Bittner's finding that viruses in milk cause mammary gland tumors in mice (1936). In 1938, the association of a bleeding disorder of cattle with sweet clover stimulated the search for the toxicant; it was found to be dicumarol, which was quickly developed as an anticoagulant for humans and as a rodenticide for public health.

Three factors led to a marked increase in veterinary research in the massive economic growth and academic reformation that followed World War II. First, the number of veterinary schools with specific dedication to veterinary research doubled. Second, veterinarians were specializing; they formed the American College of Veterinary Pathologists, the American College of Veterinary Preventive Medicine, and subspecialties with expertise in fields related to public health and medical science. Third, animal models were being used to make major advances in basic research, and institutions of veterinary science had access to the newly developing federal funding mechanisms. Veterinary scientists made contributions in the pathogenesis of yellow fever, plague, and smallpox. Gross isolated a virus that caused naturally occurring lymphomas in mice (1951), and Jarrett discovered that retroviruses were responsible for the transmission of leukemia among cats (1964). Brinster and Mintz inoculated teratoma cells into normal mouse blastocysts to produce normal but mosaic mice and showed that tumor cells lose malignancy and differentiate normally (1974). Slemons and Easterday discovered that wild ducks were a reservoir of avian influenza viruses (1974).

In recent times, the application of molecular biology to problems in veterinary science has blurred the distinction between medical science and veterinary science in many fields. As microbial and genetic discoveries were made, pathogenesis studies were required to integrate the new knowledge into useful clinical advances. Those advances include a creative model of enteric bacterial disease (Moon), demonstration of the transmissibility and pathogenesis of scrapie, a proposal that human kuru was a transmissible spongiform encephalopathy (Hadlow), and the isolation of bovine leukemia virus (Miller) and bovine immunosuppressive retroviruses (Van Der Maaten)—5 years before AIDS and HIV appeared. Now modern molecular and genetic sciences and their applications in integrative, whole-animal biology make possible exciting advances for the benefit of both animals and people.

CONTEMPORARY ISSUES IN VETERINARY SCIENCE

The historical contributions of veterinary research have been considerable, but its vital role in public health and food safety has been brought into stark reality in the last 2 decades. Concerns have been driven by the recognition that many emerging infectious diseases of humans are zoonotic (NRC 2002a). Such diseases as *Escherichia coli* O157:H7 infection, bovine spongiform encephalopathy (BSE), and avian influenza highlight the importance of research to improve veterinary public health and food safety. There is a need for more research on those diseases and many others, such as anthrax and Rift Valley fever, that may be used in terrorist attacks through agriculture and the food supply.

The need for research on animal health problems that do not threaten public health or food safety was emphasized by the 2001 outbreak of foot-and-mouth disease in the United Kingdom. The economic consequences of the outbreak—

through the loss of domestic and international trade and tourism and the costs of the eradication program—were devastating. Current knowledge and technology for preventing or responding to such a disease do not meet increasing public expectations for food security and are not adequate to mitigate the risks posed by the globalization of agriculture and increasing world travel and trade in animals and animal products or the threat of agricultural bioterrorism.

Veterinary research has evolved to address societal changes. Companion animals play a central role in the quality of life of an increasing proportion of the public; the beneficial psychosocial effects of the human-animal bond are widely accepted. Companion animals are also important sentinels for human disease and toxicant exposure, and companion-animal research improves our understanding of zoonotic diseases and how to address them; diagnostic and therapeutic data from companion animals can often be translated to human medicine. Because the health, well-being, and longevity of companion animals are a growing concern for a substantial portion of society, demand for research on companion animal health and disease has increased; indeed, it is crucial for improving the health and welfare of these animals, which serve not only as companions, but as aides, detectives, and soldiers.

In addition to the health of food and companion animals, the health of wildlife and ecosystems is of special importance to an increasingly urban and affluent society. The countryside is increasingly affected by urban development and industrial agriculture. There is growing concern about wildlife preservation and endangered species and growing recognition of the value of wildlife as sentinels for environmental health generally. The emergence of Lyme disease in the human population of New England partly due to changing land-use patterns and of Chronic Wasting Disease (a transmissible spongiform encephalopathy similar to BSE) in elk and deer in the western United States and Canada highlight the importance of research on wildlife and ecosystem health.

The contributions of veterinary research to the control of animal disease threats to human health, to the health and production of food animals, to the health of companion animals, to the advancement of biomedical sciences, and to the conservation of wildlife were reviewed in the Pew report *Future Directions of Veterinary Medicine* (Pritchard 1989). Other reports highlight the importance of veterinary research for countering agricultural bioterrorism (*Countering Agricultural Bioterrorism*, NRC 2003a), preventing the emergence of zoonotic diseases (*The Emergence of Zoonotic Diseases: Understanding the Impact on Animal and Human Health*, NRC 2002a), and preventing animal diseases (*Emerging Animal Diseases: Global Markets, Global Safety*, NRC 2002b). Despite the effect of veterinary research on animal and human welfare, support for it appears to be dispersed and inadequate as noted in the Pew report (Pritchard 1989). Schwabe (1984) points out that support for veterinary research tends to "fall between the chairs" and is not commensurate with its overall societal contribution. He further states that "improved human health is the single major social benefit that does result either directly or indirectly not only from veterinary research on farm animals but from virtually all other activities of the veterinary profession, no matter what other needs they may serve simultaneously" (p. 13). In 1998, the National Research Council released a report that addressed the role of NCRR in supporting models for biomedical research and their related infrastructure (NRC 1998a). In 2004, the National Research Council released another report that examined the veterinary workforce for comparative medicine and provided strategies for recruiting veterinarians into careers in biomedical research (NRC 2004a). However, those reports limited their scope to biomedical sciences. An overall review of past and current veterinary research in public health and food safety, animal health, and comparative medicine and of projections of research directions could help to identify infrastructure and manpower needs, the adequacies and deficiencies in research effort, and a strategy for using the available resources effectively to meet societal needs.

Past and future trends and gaps in topics considered, scientific expertise required, current funding levels and sources, and institutional capacity were identified on the basis of a review of published literature—including the Pew report and the National Research Council reports cited earlier—and other data. The committee also hosted a community workshop (see Appendix C for the agenda) to solicit input from researchers and stakeholders in veterinary science. The committee defined national needs for future research in the three fields of veterinary science; assessed the adequacy of our national capacity, mechanisms, and infrastructure to support the needed research; and made recommendations for meeting the needs.

THE STRUCTURE OF THIS REPORT

This report provides an overview of past and current research in the three disciplines and the progress and opportunities in veterinary research in Chapter 2. The intent is not to conduct an exhaustive review of all the research activities in veterinary science; they have been documented elsewhere. Rather, Chapter 2 highlights the successes, describes some of the pressing contemporary issues in veterinary research, and identifies research and knowledge that are critical if future societal needs are to be met. A research agenda, with short- and long-term goals, needed to fill the knowledge gap is outlined in Chapter 3 based on selected critical research needs. Some strategies to achieve the research agenda were suggested, including infrastructure, expertise, manpower, and education. Chapter 4 describes the major resources and infrastructure available for veterinary research at colleges of veterinary medicine and colleges of agriculture and those provided by different agencies, institutions, and organizations. Chapter 5 assesses whether the available resources and infrastructure could meet projected needs in veterinary research.

2

Progress and Opportunities in Veterinary Research

This chapter outlines some of the contributions of veterinary research and the promise it holds for the improvement of public health and food safety, animal health, and the advancement of comparative medicine. Because animal welfare—defined as the well-being of individual animals, that is, normal functioning and freedom from disease and injury—is an extension of animal health that involves veterinary research, it is appropriate to include it in the field of animal health. Research in several subdisciplines of the three fields has been identified as critical for advancing and protecting animal and human health. In addition, several emerging issues span two or more fields, so they cannot be neatly categorized as subdisciplines of public health and food safety, animal health and welfare, or comparative medicine (Box 2-1). Although the different aspects of veterinary research are grouped under four headings—public health and food safety, animal health and welfare, comparative medicine and emerging issues, they are intertwined. For example, research in comparative medicine contributes to animal health through development of preventive medicine and treatment. Study of wildlife diseases contributes not only to wildlife health and conservation but also to the study of emerging infectious diseases, many of which are zoonotic.

PUBLIC HEALTH AND FOOD SAFETY

Food Safety

Foodborne illnesses, as defined by the World Health Organization, are diseases—usually infectious or toxic—caused by agents that enter the body through

BOX 2-1
Subdisciplines of Veterinary Research that are Critical to Improving Public Health and Food Safety, and Animal Health and Advancing Comparative Medicine

Public Health and Food Safety
- Food Safety
- Biosecurity

Animal Health and Welfare
- Food-Producing Animals
- Aquaculture
- Companion Animals
- Laboratory Animals
- Wildlife and Conservation

Comparative Medicine
- Animal Modeling
- Emerging Areas of Research in Comparative Medicine

Emerging Issues
- Emerging Infectious Diseases
- Ecosystem Health
- Social Policies, Societal Needs and Expectations
- Exotic and Caged Pet Medicine

the ingestion of food. They are a major cause of human morbidity and mortality in the United States, responsible for an estimated 76 million illnesses, 325,000 hospitalizations, and 5,000 deaths a year (Mead et al., 1999). Animals—both domesticated and wild—are frequent reservoirs of foodborne pathogens that can cause human illness and animals are among the most common vehicles of enteric bacterial infections in humans (http://www.cdc.gov/foodnet/). For example, more than 70% of sporadic *Campylobacter* infections in the United States have been associated with eating foods of animal origin or contact with animals (Friedman et al., 2004). Eating contaminated poultry products is largely responsible for cases of *Salmonella* enteritidis infection (Kimura et al., 2004). *Escherichia coli* O157:H7 infections are associated principally with eating products of bovine origin, contact with ruminants, and consumption of water contaminated with bovine feces (Kennedy et al., 2002; Kassenborg et al., 2004). Primary risk factors for multiple drug-resistant *Salmonella* newport infections are contact with cattle and consumption of bovine products (Gupta et al., 2003). Most of those microorganisms are commensals that reside in the animal gastrointestinal tract and cause no apparent symptoms of illness and had no adverse effects on weight gain or milk or egg production. Most foodborne pathogen infections have no effect on animal health or on economic factors associated with animal production so there has been considerably less emphasis on veterinary food-safety research than on research to improve animal health, and greater advances have been made in controlling diseases of livestock and poultry than in reducing the occurrence of pathogens in these animals.

Animal-associated pathogen contamination of food occurs both before and after harvest. Livestock and poultry are the primary sources of many harmful microorganisms that are transmitted to foods and on the farm during harvesting, slaughter, and processing. Such foods as meat and poultry can be directly contaminated with pathogens through contact with animal manure during production and processing, and other foodstuffs, such as fruits and vegetables, can be indirectly contaminated through the environment, for example via irrigation water tainted with livestock manure. Various determinants influence the carriage and transmission of foodborne pathogens during animal production and processing. For example, an animal's diet can affect the microbial composition of its intestinal tract and can serve as a source of harmful agents, such as prions related to bovine spongiform encephalopathy from ruminant neurological tissue; in free-range conditions, outdoor exposure to wildlife presents a greater opportunity for transmission of indigenous pathogens of vermin, pests, and wild animals than does controlled indoor housing, which largely excludes vermin and wild animals; in some times of the year, such as summer, there is a dramatic increase in pathogen carriage by livestock and poultry; shipping of animals can induce stress and greater susceptibility to pathogen shedding; and slaughtering practices, such as cold-water chilling of poultry, can disseminate pathogens among carcasses during processing. There are many gaps in our understanding of where in the production and processing chain interventions will have the greatest effect on reducing pathogen loads and ultimately providing the greatest public-health protection.

Of the estimated 76 million cases of foodborne illness that occur each year in the United States, CDC estimates that there are 62 million cases of food-associated acute gastroenteritis of unknown etiology (Mead et al., 1999). Although the causative agents of many well-documented foodborne outbreaks of distinctive illness (such as Brainerd diarrhea) remain unknown (Bean et al., 1996), many new foodborne pathogens were identified in recent years. For example, during the late 1970s and early 1980s, three major bacterial pathogens were first identified by microbiologists and public-health epidemiologists as agents of foodborne illness: *Campylobacter jejuni, E. coli* O157:H7, and *Listeria monocytogenes*. Since then, *C. jejuni* has become recognized as the leading cause of acute bacterial gastroenteritis in many developed countries, *E. coli* O157:H7 has been identified as the leading cause of hemolytic uremic syndrome, and *L. monocytogenes* has become a primary cause of death among recognized foodborne pathogens. It is possible that many emerging foodborne pathogens are not newly evolved but already exist in nature and have yet to be identified or associated with foodborne disease.

Resistance to antimicrobial agents has become a major public health concern and subtherapeutic use of antibiotics as growth promoters in animals has been alleged to be one of the major factors in antibiotic resistance. Arguments for and against that association have been presented (Turnidge, 2004; Phillips et al., 2004), but surveillance systems that monitor the distribution, occurrence, and trends in numbers of antimicrobial-resistant pathogens in humans, animals, and environmental sources will be critical for resolving this issue. The United States, in 1996, created the National Antimicrobial Resistance Monitoring Systems (NARMS), which was a collaborative effort of the Center for Veterinary Medicine in the Food and Drug Administration (FDA), the US Department of Agriculture (USDA), and the Centers for Disease Control and Prevention (CDC). Major contributions to the field of antimicrobial resistance among pathogens of animal and human significance have been achieved through elucidation of mechanisms of development of antimicrobial resistance. The principal genetic force responsible for induction of antibiotic resistance in bacteria has been found to be horizontal gene transfer of plasmids, transposons, and integrons. Although it is known that the emergence and dissemination of bacterial antimicrobial resistance result from numerous complex interactions among antimicrobials, microorganisms, and the surrounding environment, the relative importance of specific factors in mobilization of these genetic factors between organisms is unknown.

The genetics revolution has led to potential introduction of desirable characteristics in food-producing animals, such as developing transgenic lines of food animals intrinsically resistant to traditional foodborne pathogens. However, methods used to modify animals genetically may introduce compositional changes, some of which may be undesirable. Potential hazards include toxicity, allergy, nutrient deficiencies and imbalances, and risks associated with endocrine activity. Research is needed to assess the safety and nutritional values of transgenic and cloned food animals.

Continuing veterinary research on food safety is needed to improve detection and surveillance of foodborne pathogens associated with livestock and poultry production, define the ecology of foodborne pathogens in food-producing animals and their environment, develop interventions to reduce the dissemination of foodborne pathogens by poultry and livestock, study the development and mechanisms of antibiotic resistance of foodborne pathogens associated with animals in the food chain, and develop methods to assess the safety and nutritional value of transgenic and cloned animals.

Examples of Critical Research Needs

- Rapid, sensitive, and accurate assays for detecting foodborne pathogens.
- Epidemiological approaches to identifying risk factors and intervention strategies that have the greatest effect on reducing foodborne pathogens and

antimicrobial-resistant microorganisms associated with livestock, poultry, and aquaculture. This includes a more comprehensive understanding of the epidemiology and genetic elements of the foodborne zoonotic agents, especially of those agents that have recently emerged.

- Practical and effective interventions for minimizing carriage of and contamination with food-associated pathogens of animal origin.
- Methods to assess the safety and nutritional value of transgenic and cloned food-producing animals.
- Identification of previously unrecognized foodborne pathogens of animal origin.

Importance and Contribution of Research

The US Department of Agriculture (USDA) Economic Research Service estimates more than $15 billion in annual medical expenses and lost productivity resulting from salmonellosis, *Campylobacter* enteritis, and enterohemorrhagic *E. coli* infections alone (USDA-ERS 2004). A concerted research effort to address food safety can prevent the recurrence and reduce the effects of the more than 3.5 million estimated cases of foodborne illness each year of which livestock and poultry are the primary sources of causative agents. Veterinary research will contribute to eliminating transmission of pathogens to foods of animal origin.

Biosecurity

Biosecurity is the integrated system of policies, training, and procedures designed to deter, interdict, detect, respond to, and recover from intentional introduction of biological agents or related products that can cause disease or death in humans, animals, or plants. Until 1997, almost all US research done for the purpose of developing countermeasures to biological warfare was done in the Department of Defense (DOD) (Zajtchuk, 1997). Veterinarians with board certification in laboratory animal medicine or comparative pathology or with doctoral degrees in specialty fields—such as physiology, pharmacology, toxicology, and microbiology—played an important role in that research. Research conducted at the US Army Medical Research Institute of Infectious Disease (USAMRIID) at Fort Detrick, MD—the lead DOD laboratory for medical biological defense—and in other laboratories led to important vaccines, drugs, and diagnostics for military personnel. Other government departments became involved in biodefense research—first the Centers for Disease Control and Prevention (CDC) in 1998 and then the National Institute of Allergy and Infectious Diseases (NIAID) in 2002. Several medical countermeasures developed at USAMRIID—such as cell-culture-derived smallpox vaccine and recombinant anthrax vaccine—have now been moved into advanced development by the Department of Health and Human Services.

Although food safety has been an integral part of veterinary medicine throughout history, food biosecurity is an emerging issue that affects the entire food chain. Preharvest biosecurity research is concerned with protection of animal health and production, and postharvest biosecurity research is related to food microbiology and toxicology (refer to food safety section above). Examples of agricultural and food-biosecurity research being conducted by veterinary scientists include the development of preharvest and postharvest surveillance systems, diagnostic and detection systems, vaccines, immunomodulating drugs, animal and product tracking systems, and ecologically sound means of disposal of animal carcasses.

A new awareness of the need for food and agricultural biosecurity research arose after September 11 and the "anthrax letter" attacks of 2001 because biosecurity research is closely related to maintaining a safe agricultural sector and food supply. The US food and fiber industry generates over $200 billion a year in farm cash receipts (USDA, 2003). From an economic standpoint, adulteration of food could alter market sentiment through fear and thus have substantial economic impact with enormous potential ripple effects. Furthermore, sequential or multifocal attacks on our food supply could undermine the trust of the American people in their government.

Agricultural bioterrorism and the vulnerability of the food-producing animal industries in the United States to such activity are addressed in a National Research Council report (NRC 2003a). That report provides an in-depth analysis of the known agents that could be used to disrupt food-animal production and discusses the research and infrastructure needed to develop countermeasures. The fact that animals cannot be easily protected from the group of diseases suggested as primary agents of agricultural bioterrorism is indicative that those conditions should be among those given high priority for veterinary research. (See Appendix D for list of bioterrorism agents.) In 2004, the Department of Homeland Security (DHS) awarded 3-year grants to two university consortia to study preharvest and postharvest agricultural biosecurity (DHS 2004). In addition, several academic centers—typically in land-grant universities—have established their own centers, and some have or are constructing biosafety level 3 laboratories in which to conduct agricultural research (see Appendix E).

Examples of Critical Research Needs

- Improved ability to detect and identify disease and pathogens in animal populations.
- Improved ability to detect pathogens and toxicants in food along the processing chain.
- Improved understanding of interactions between pathogens and hosts so that effective preventive measures and countermeasures can be developed.
- Rational development of cost-effective countermeasures, both vaccines and nonspecific therapeutic agents.

BOX 2-2
Species-Neutral Disease Surveillance

Species-neutral surveillance is defined as monitoring diseases of all animal species, including humans and domestic and wild animals, and communicating the findings throughout the health-care community. Animal health and human health are more closely related than has been recognized in the past. Therefore, monitoring animal diseases could provide foresight with respect to disease emergence in humans. For example, the emergence of West Nile virus in June 1999 was characterized by an unusual number of dead birds in the borough of Queens, New York City. Some 6-7 weeks later, local hospitals received an unusual number of patients with encephalitis—then diagnosed as St. Louis encephalitis, which is a mosquito-borne viral encephalitis that does not produce disease in birds. The misdiagnosis was not recognized until the animal and human disease findings were integrated. The West Nile virus case illustrates the utility of species-neutral disease surveillance.

One of the most important public-health lessons learned in recent years is that communication between animal health and human health professionals should be improved and maintained and that surveillance systems should be integrated to discover disease as early as possible irrespective of the host (GAO, 2000). Had such a system been in place for West Nile virus and monkey pox in the United States and for SARS internationally, our responses would have been more rapid and effective. Whether a disease develops naturally or is introduced by a terrorist, an integrated network of research, surveillance, and response that covers all species in the United States and internationally will save lives. Veterinary research is central to the development of such a system.

Importance and Contribution of Research

Although veterinary researchers are already addressing important research issues related to agricultural terrorism and emerging disease, we are slowly gaining an appreciation of the importance of integrating human and animal health issues through "species-neutral" disease surveillance (Box 2-2) and of combining findings internationally rather than only nationally.

ANIMAL HEALTH AND WELFARE

Food-Producing Animals

Food-producing animals include all species of mammals and birds (including wildlife) that are raised in captivity or domestic conditions primarily as sources of human food. Research on infectious diseases and noninfectious health problems of metabolic or genetic origin in food-producing animals has been going on for many years, conducted by a combination of veterinary and nonveterinary medical scientists and animal scientists. Much of the knowledge of nutrition, metabolism, and nutritional deficiencies that applies to humans was discovered as a result of observations on animals. Although frank clinical symptoms of specific nutrient deficiencies are rare today in food-producing animals because of the extensive knowledge of nutrient requirements, research on food and feed is needed because it represents the largest cost associated with handling food-producing animals.

As genetic modifications in animals are made and metabolic manipulation is imposed through pharmaceuticals to enhance or focus production, it will be increasingly important to meet the nutrient needs of these "harder-working" animals. (Safety of genetically modified animals as food is discussed in the "Public Health and Food Safety" section above.) Historically, such efforts focused on diseases that affected single animals or individual herds or flocks and addressed issues associated with production, such as reproductive diseases, nutritional deficiencies, and mammary gland infections; but zoonotic diseases, such as tuberculosis and brucellosis, and their eradication were also of great concern. New information, vaccines, and technologies have led to continued advances in understanding and improved early detection, prevention, control, and eradication. The success of that work has helped the United States to become the largest source of food-producing animals. Such contemporary issues as the increasingly important subject of zoonotic diseases have shown the need for new approaches to ensuring the health and well-being of food animals. Food-animal production is often near areas occupied by wildlife or other domestic species (such as companion animals), which can contribute to the transmission of zoonotic or other diseases. This is a complex issue that requires expertise in comparative medicine and epidemiology. (See also the sections in this chapter on "Animal Health and Welfare" under subsection "Wildlife and Conservation" and on "Emerging Issues" under subsection and "Emerging Infectious Diseases" for discussions of zoonotic disease transmission.)

Examples of the importance attached to those needs are found in recent documents published by the National Research Council (NRC 2002b). Emerging animal diseases and their effect on markets and the economy and on global animal and human health and safety have been addressed, with emphasis on foot-and-mouth disease (FMD) and bovine spongiform encephalopathy (BSE), (the international concerns of the time), each of which had an enormous economic impact. The cost of BSE in the United Kingdom in direct compensation was reported to be in billions of US dollars in 2002 (NRC 2003b), and there were substantial additional effects in international markets. The cost to North American cattle markets has been estimated at $3 to $5 billion. To add to the seriousness of the BSE and general prion issues, it has recently been reported that some people may act as subclinical carriers of variant Creutzfeldt-Jakob disease (vCJD) (Carrell 2004; Head and Ironside 2005); that BSE has been naturally transmitted to goats (Anon. 2005) and an array of zoo animals, including kudus, antelopes, and cheetahs (Kirkwood and Cunningham, 1994); and that in naturally infected captive greater kudu, BSE prions have an unprecedented wide distribution throughout tissues (Cunningham et al., 2004). The reports suggest that the impact of vCJD may be difficult to predict, that the potential host range for the BSE prion is very wide, and that transmission to humans or other animals through novel pathways is possible. In the case of FMD, a disease not known to be transmitted to humans (and thus primarily an issue of animal health and economics), the estimated cost in the United Kingdom in 2001 has been set at $30 billion (NRC 2003b).

Examples of Critical Research Needs

- Development of capacity and implementation of broad programs in comparative medicine to understand, rapidly detect, and control zoonotic and nonzoonotic diseases in food-producing animals raised in concentrated production units, with emphasis on techniques and technologies for field use in large animal populations.
- Evaluation of the implications of increases in productivity achieved through genetic or pharmaceutical means for animal health, nutrient, and metabolic requirements.
- Monitoring and assessment of trans-species disease transmission, epidemiology, and the delineation of resistance, susceptibility, and virulence factors across animals and pathogenic organisms.

Importance and Contribution of Research

A thorough understanding of diseases in food animals would improve our ability to detect diseases rapidly and control them effectively. Otherwise, the food-producing animal system will continue to be vulnerable to disease outbreaks with major consequences for animal health and the economy. Failure to address the issues above noted will erode the ability of the food-animal industries of the United States to be globally competitive and economically viable and will subject them to the potential devastation created by natural or human-made biodisasters. A critical issue on the global level is the understanding, detection, and control of the various diseases that are associated with prions (such as BSE and CJD).

Aquaculture

For the purposes of this report, *aquaculture* is defined as the farming of aquatic animals including finfish (such as salmon and catfish) and shellfish (such as clams, mussels, and shrimp). Freshwater catfish production dominates aquaculture in the United States and generates about $1 billion per year. Marine aquaculture—involving primarily salmon, clams, and shrimp—represents about one-third of aquaculture production by weight. From 1989 to 1998, there were marked increases in the aquaculture production of catfish (by 40%), salmon (468%), clams (379%), and shrimp (193%) (Goldburg et al., 2001).

Aquaculture has only recently involved veterinary research. Increases in the quantity and economic importance of farmed species and in intensive production practices, have led to a rising need for disease detection, treatment, and prevention. Veterinary researchers have contributed substantially to the identification and characterization of important aquaculture diseases, such as infectious salmon anemia (Kibenge, et al., 2004). In addition, scientists of the FDA Center for Veterinary Medicine have been conducting studies on the effectiveness of treatment of fungal infection and internal parasites in fish (FDA 2003).

Examples of Critical Research Needs

- Improved understanding of immune responses (especially cell-mediated) in fish to facilitate the development of effective vaccines and appropriate delivery systems.
- Improved methods of pathogen detection.
- Increased effectiveness and safety of medications used to treat diseases in aquaculture species.
- Enhanced understanding of the impact of aquatic animal production systems on marine and freshwater ecosystems.

Importance and Contribution of Research

Lack of effective disease identification, prevention, and control strategies (for example, efficacious vaccines) in aquaculture species results in the overuse of antibiotics and chemicals. Overuse leads to economic losses (for example, high mortality in fish production facilities), human health hazards (for example, compromised food safety because of drug or pollutant residues and zoonotic pathogens) (Benbrook, 2002), and adverse environmental effects (for example, antimicrobial and pesticide use, and transmission of disease to wild populations).

Companion Animals

Over the last several decades, veterinarians and animal scientists have contributed to advancing the diagnosis and treatment of disease and to the understanding of companion-animal welfare and the human-animal bond (Badylak et al., 1998; Dodds, 1995a,b; Lawrence, 1994; Ostrander et al., 1993; Parker et al., 2004; Patterson et al., 1988; Smith, 1994). Advances in companion-animal research have led to markedly increased expectations for animal and human medical services (Lawrence, 1994; Eyre et al., 2004). The breadth and sophistication of veterinary diagnostic and treatment methods have increased the need for timely high-quality research (Boothe and Slater, 1995; Smith, 1994; Dodds, 1995a).

Research involving companion animals has been conducted by many investigators at a wide array of institutions and organizations. Companion animal-research has typically been in three categories: research on the diseases or conditions of companion animals for their direct benefit, research on diseases of comparative medical or pathological significance that provides direct benefits to companion animals and indirect benefits to humans, and research on basic physiological, pharmacological, molecular, or pathological processes that primarily benefits humans but benefits companion animals indirectly. (See section on Comparative Medicine for details on animal models for biomedical research.) Basic-science researchers, pathologists, and clinicians have all made useful contributions to companion-animal research.

The scope of companion-animal research has increased considerably over the last several decades. There are still important disease-related problems in most of the traditional medical disciplines (for example, pharmacology, immunology, pathology, internal medicine, orthopedics, cardiology, oncology, and ophthalmology), but attention is increasingly directed at emerging matters related to animal welfare (such as quality-of-life determination and animal abuse), animal-shelter medicine and control of unowned and feral animal populations, the human-animal bond (including the role of service animals), complementary medicine, and the cause and treatment of behavioral disorders.

Companion animals play important roles in service work, not only in assisting people with special needs but also in herding, search and rescue, drug and chemical detection, police and military assistance, and hunting and retrieving. Research into the behavioral and training needs of this special group of companion animals will increase their quality of life and enhance their performance as assistants, protectors, and life-savers.

Horses have historically been used as companion animals and performance. Therefore, equine research has been directed primarily at improving overall health and soundness by developing diagnostic screening tests for heritable traits and studying the causes of common debilitating diseases, such as laminitis (founder) and exercise-induced pulmonary hemorrhage. Of specific importance to the viability of some horse breeds is the need to restrict breeding of horses that carry deleterious genetic traits. For example, hyperkalemic periodic paralysis in quarterhorses can be traced to one famous foundation sire, combined immunodeficiency of Arabians is traceable to a particular group of animals, and the lethal white gene of paint foals is produced by matings of the overo-to-overo color pattern.

Companion-animal research improved the health of animals and humans by the enhanced control of infectious diseases through vaccines (such as distemper, parvovirus, and rabies), development of pharmaceutical agents, and the study of disease processes (such as retroviral disease; comparative hematology, immunology, and oncology; and animal models of human disease).

Epidemiological studies of animal populations historically have been directed primarily to public health and control of infectious diseases. More recently, comparative epidemiologists and geneticists have turned their attention to studying populations of related animals to identify biochemical markers that can be used in screening for genetic diseases and to performing health surveys to more accurately describe the health problems affecting the population as a whole. The goals have been to learn more about diseases and to reduce the number of affected and carrier animals (Dodds, 1995b; Patterson et al., 1988; Smith, 1994). The widely appreciated screening programs include those for hip and elbow dysplasia; inherited blood, cardiac, thyroid, and eye diseases; and congenital deafness. Many infectious agents can be transmitted to humans from companion animals (for example, *Toxoplasma gondii*) and some organisms have the potential for bi-directional transmission (for example, methicillin-resistant *Staphylococcus aureus*) (Weese, 2005). The proximity of humans and their companion animals increases the need to understand diseases that may be passed between them.

Examples of Critical Research Needs

- Preventive-medicine and wellness strategies—vaccination and other means to control infectious disease, appropriate nutrition, methods or strategies for disease monitoring, and better methods for diagnosing and treating behavioral disorders.
- Improved understanding of and treatment for geriatric and immune disorders—such as cancer, organ failure, arthritis, and immune-mediated disease.
- Rapid and minimally invasive diagnostic methods.
- Randomized controlled clinical trials (of sufficient power to detect clinically significant differences) to address many long-standing diagnostic and treatment questions.
- Concentrated efforts in reproductive efficiency and orthopedic issues of performance animals.
- Improved understanding of the ecology of microbial organisms that may be transmitted to humans from companion animals and vice versa.

Importance and Contribution of Research

Failure to address issues involving companion-animal health and well-being will result in substantial morbidity and mortality in companion-animal populations; adversely affect the psychological well-being of their owners and the family and social framework; and delay or prevent advances in pharmaceutical and biologics development and in the understanding and treatment of many important human and animal diseases.

Companion-animal health research will improve the length and quality of life for companion animals, which in turn will have favorable effects on their caregivers. Such research will also provide valuable comparative-disease information that will benefit human and animal health.

Laboratory Animals

Laboratory animals are integral to our understanding of basic biology and physiology and have contributed to the discovery and development of virtually every human and animal health product and technique used in contemporary medical practice. The sophisticated specialty of laboratory animal medicine has evolved over the years to provide expertise in the breeding, management, and humane care of research animals and expertise in experimental design and methodology. Laboratory animal veterinarians have also provided leadership in developing national standards for laboratory animal care, use, facilities, and housing.

Some valid nonanimal alternatives have been developed for research, testing, and education, but the advancement of biological and medical knowledge will continue to depend on whole-animal models (primarily rats and mice) which represent the complex interactions between organ systems. Moreover, recent advances in genomics and proteomics will probably require an increase in the number of animals used in research (Lancet, 2004). Recent predictions (NRC, 2003b) suggest that the number of mice used in research in the United States will increase by 10-20% a year from 2000 and 2010. If this is true, more than 200 million mice and rats will be used each year in the United States by the end of this decade. As the number of animals used in research increases, the demand for high quality, well-defined animal models is likely to intensify. To meet that need, additional research and new methods to ensure animal health and well-being are required.

The credibility of the data generated from animal research depends in large part on the quality of laboratory animals with regard to their health status and genetic integrity, the quality of their environment and care, and how they are handled. Reproducible research requires that animal subjects be maintained in a stable environment to minimize experimental variables. For more than 50 years, the need for reliable experimental animal models has driven advances in their health quality and care. However, naturally occurring viral, bacterial, and parasitic infections continue to be detected in institutional rodent colonies throughout the United States. The adverse effect of such infectious diseases on the quality of research is well established. For example, mouse parvovirus infection affects the immune system and therefore may confound studies involving immune system functions (McKisic et al., 1993, 1996). The presence of *Helicobacter* species in the intestinal flora of laboratory mice may influence the research in pathogenesis of inflammatory bowel disease and other gastrointestinal disease (Sadlak et al., 1993; Kullberg et al., 2003). Infections often lead to disruption of the research process until the disease is eradicated from the rodent colony. Better methods for preventing the introduction of pathogens and the development of more specific and sensitive methods of disease detection are required to minimize the potential for variables and to ensure the validity of research data.

Relatively few published, peer-reviewed scientific studies support or refute the effects of cage or pen size or environmental enrichment on animal well-being. Few research studies have addressed the optimal frequency of cage changes or pen sanitation. Even the *Guide for the Care and Use of Laboratory Animals*, on which most of the housing standards and sanitation practices used in contemporary animal facilities are based, acknowledges that research on laboratory animal management continues to generate scientific information that should be used in evaluating performance and engineering standards. It also recognizes that for some issues, insufficient information is available and continued research into improved methods of animal care and use is needed. Research into those factors, the effects of noise levels and frequency, and optimal environmental temperature and humidity at the cage or pen level is needed for different species and strains.

In accordance with the Public Health Service policy on the Care and Utilization of Vertebrate Animals used in Testing, Research, and Training, appropriate animal care and use includes the "avoidance or minimization of discomfort, distress, and pain when consistent with sound scientific practices." Procedures that may cause more than momentary or slight pain or distress should be performed with "appropriate sedation, analgesia, or anesthesia," and "animals that would otherwise suffer severe or chronic pain or distress that cannot be relieved should be painlessly killed at the end of the procedure or, if appropriate, during the procedure." The assessment and management of pain and distress are often based on the laboratory animal veterinarian's training, knowledge, judgment, and experience with the various laboratory species. However, much of what we know about animal pain is extrapolated from human requirements, which may not be appropriate for all species or for individual animals. Studies are needed to assess and manage pain and distress in laboratory animals and to provide guidance for humane end points for animal-research protocols.

Although the use of whole-animal models is expected to increase in the foreseeable future, development of valid alternatives should be included among the scientific community's long-term goals. USDA regulations and Public Health Service (PHS) policy require scientists to consider alternatives, including reduction in the number of animal used, to refine techniques to prevent or minimize pain or distress, or to use in vitro methods before initiating an animal-research protocol. Several federal regulatory and research agencies, under the auspices of the Interagency Coordinating Committee on the Validation of Alternative Methods and the National Toxicology Program Interagency Center for the Evaluation of Alternative Toxicological Methods, are working on the development, validation, acceptance, and national and international harmonization of toxicity testing methods.

Examples of Critical Research Needs

- Prevention, detection, and management of laboratory animal diseases.
- Laboratory animal management standards and practices—including the identification of optimal cage and pen sizes, environmental enrichment, sanitation, noise, and temperature and humidity—based on research data.
- Assessment and management of pain and distress.

Valid alternatives to reduce, refine, or replace animal testing.

Importance and Contribution of Research

Additional research on infectious diseases is needed to understand how they affect the quality of research data and to guide disease management. Gaps in our knowledge of laboratory animal care and housing requirements must also be addressed through sound scientific research and should be used to develop and implement standards of care. To enhance animal welfare, studies are needed to identify optimal methods for pain assessment and management and test systems that reduce, refine, or replace the use of animals.

Wildlife and Conservation

Wildlife diseases have three important implications for society. First, anthropogenic activities continue to bring humans closer to wildlife so transmission of zoonotic diseases from wildlife to humans and domestic animals or vice versa is of increasing concern. Second, wildlife populations are increasingly at risk for diseases that cause severe population declines, which in turn may affect ecosystem health. (See section on "Emerging Issues" in this chapter.) Third, harvested wildlife is culturally and economically important in many regions of the United States, and captive wild animals in zoological collections are invaluable national assets for education, conservation, and our cultural understanding of wildlife.

Veterinary researchers' involvement in wildlife biology originally stemmed from the need to support the health of hunted or captive wildlife. More recently, veterinary researchers have been active in studying diseases that affect endangered species in the wild and developing techniques to treat and control the spread of disease in wildlife populations. Veterinary researchers in wildlife diseases have contributed to our understanding of and management of disease effects on wild and captive populations—for example, brucellosis in bison, tuberculosis transmission between deer and cattle populations in the upper Midwest, and *Mannheimia* sp. transmission from domestic sheep and goats to bighorn sheep.

Wildlife diseases can have important consequences for our economy. For example, chronic wasting disease (CWD) is a spongiform encephalopathy similar to BSE, which emerged in the United Kingdom and cost over $100 billion in lost cattle production and outbreak control (NRC 2002b). CWD was seen first in the late 1960s in captive mule deer and then in the 1980s in free-ranging deer and elk in northeastern Colorado and southeastern Wyoming. Confirmed cases have been found in at least eight more states, including Wisconsin and New Mexico. In 2002, Wisconsin reported first cases of CWD in deer (Wisconsin DNR, 2002). The economic costs of CWD are due largely to depopulation, loss of hunting-license revenue, and huge efforts by affected and unaffected states in surveillance monitoring and diagnostics. CWD cost Wisconsin $10 million and Colorado $19 million in 2002 alone (Bishop, 2002).

The importance of veterinary research to hunted wildlife species has led to increased veterinary research activities in state and federal agencies. USDA, under the Animal and Plant Health Inspection Service, conducts veterinary research on wildlife species in its Veterinary Services section and its Wildlife Services section. The US Fish and Wildlife Service undertakes a number of wildlife veterinary research activities as part of its mission. In 1975, the US Geological Survey National Wildlife Health Center was set up to assess the effects of disease on wildlife with particular reference to wildlife losses, especially on federal land, of migratory species or federally listed endangered species.

Over the last few decades, many of those agencies have begun to shift their agendas to veterinary research on nongame wildlife. The shift has occurred in response to outbreaks of infectious disease that have become widely recognized by scientists and the public as threats to survival of wildlife species (Box 2-3). The conservation effect of wildlife diseases has been highlighted in a series of mass deaths (Daszak et al., 1999, 2003), some of which were linked to species extinction (Daszak et al, 2000). Infectious diseases and the ecological factors that cause them to emerge are a threat to the conservation of biodiversity.

The shift of veterinary research away from hunted species was a response to the effects of pollution on wildlife or of illness with unknown etiologies. For example, amphibians have undergone severe population declines in some regions, including in parts of the Rocky Mountains and other regions of the United States. The discovery of a fungal disease responsible for amphibian population declines highlights a role for veterinary researchers in understanding such phenomena (Berger et al, 1998). The causative fungal disease is now recognized as a major threat for global amphibian extinction (Green and Sherman, 2001).

In addition to conservation, veterinary researchers can play a role preventing transmission of wildlife diseases between agricultural and other animal species. Brucellosis in bison in the greater Yellowstone ecosystem poses a risk to ranched cattle, and recent canine distemper viral infections in more than 100 domestic

BOX 2-3
Examples of Wildlife Disease Outbreaks

- Canine distemper in black-footed ferrets and plague in their prairie dog prey base.
- Chytridiomycosis, a newly discovered fungal diseases that led to widespread decline in amphibians.
- A series of coral diseases in subtropical waters.
- Canine and phocine distemper in marine mammals.
- West Nile virus linked to increased mortality in greater sage grouse.
- Whirling disease affecting native salmonid fish.
- Mycoplasmal conjunctivitis resulting in loss of one-third of the eastern population of house finches.
- Avian malaria and avian pox that continue to threaten Hawaii's endemic avian fauna.
- Canine parvovirus linked to declines in the gray wolf.
- Duck virus enteritis and duck cholera in various U.S. sites.
- Protozoal encephalitis in sea otters on the West Coast.

dogs, raccoons, and zoo animals in the Chicago area have been attributed to an initial outbreak in raccoons (Lednicky et al., 2004; R.D. Schultz, personal communication, December 3, 2004).

Besides free-ranging wildlife, captive wildlife in zoos also provide opportunities to examine the important interfaces among domestic animals, free-ranging wildlife, and humans. Historically, studies of animals in zoological collections have yielded important discoveries and advances in animal and human medicine. For example, spontaneously occurring hepatitis in woodchucks was used to further the understanding of the pathogenesis of a form of hepatitis in humans, and the appreciation of the importance of dietary estrogens in wild and domestic animals has been enhanced by studies in zoos. A group of novel molecules important in local defense against microbial invasion were discovered first by studies of captive frogs.

Zoos are increasingly concerned with in situ management and conservation of wild species and their habitats. Many large zoos in the United States have veterinary clinicians on staff, and some have teams of veterinarians and veterinary researchers that study diseases and reproduction in captive and wild animals. Notable discoveries made by zoo veterinary researchers include the discovery that herpes viruses that are benign in Asian elephants can be lethal to African elephants when the two coexist in zoos (work conducted at the US National Zoological Park) and the first demonstrated case of a pathogen's causing extinction of a *Partula* snail species (at the Zoological Society of London).

A number of zoos now have extensive research programs on wildlife diseases outside their collections, both at home and abroad. They include research on the use of bushmeat, the origins of some zoonoses and socioeconomic connections between human and wildlife health (Wildlife Conservation Society), formation of interinstitutional partnerships to link wildlife and public health (Brookfield Zoo), and avian health studies in the Galapagos (St. Louis Zoo).

A group of institutions related to zoos is wildlife-rehabilitation centers that take in native wildlife to help foster their recovery and release into their native habitats. Rehabilitation centers sometimes use veterinary researchers and clinicians to manage the health of the wildlife populations in their care. Wildlife rehabilitation centers also conduct research on free-ranging wildlife populations. For example, the Marine Mammal Center in California has published key papers on domoic acid poisoning of free-living marine mammals, and the Wildlife Center of Virginia has led research on aural abscessation of native turtles.

Events such as the emergence of West Nile virus and monkeypox and bioterrorism incidents involving zoonotic agents have focused attention on zoos and wildlife-rehabilitation centers. West Nile virus first came to public attention in the United States in 1999, but the virus clearly had been found in captive birds at the Wildlife Conservation Society in New York during the early stages of the outbreak in wild birds and probably before it was found in humans (Lanciotti et al, 1999). Thus, wildlife or captive wild species can act as sentinels for emerging diseases or even bioterrorism agents. Efforts to form networks of zoo veterinarians and wildlife rehabilitators to develop such sentinel capacity are under way (for example, the West Nile virus surveillance program led by Lincoln Park Zoo, which includes the Wildlife Center of Virginia and other rehabilitation centers).

Examples of Critical Research Needs

- Research on the risk of transmission of zoonotic and other emerging diseases between wildlife, domestic animals, livestock, and humans.
- Research on wildlife diseases that affect both game and nongame species.
- Assessment of the mechanisms for disease introduction and spread in the United States via trade or natural movement of wildlife populations.
- Research to establish diagnostic criteria and protocols, and to validate and standardize protocols.
- Development of improved tools for detection and controlling diseases in free-ranging wildlife populations.
- Research on conservation including comparative reproduction, assisted reproduction, contraception, habitat restoration and protection, and on reintroduction of captive wildlife.
- Comparative pharmacology and nutrition, including the study of improved anesthetics, antimicrobials, and vaccines.

Importance and Contribution of Research

Wildlife research can reduce the economic impact on states substantially by preventing the spread of diseases in hunted or game species (for example, CWD) and the transmission of wildlife diseases to agricultural animals and humans. Such research can also contribute to the prevention of emerging zoonotic diseases. The veterinary research outlined must be accomplished to prevent population declines in wildlife species that are of interest for ecological balance, recreation, tourism, or conservation and to prevent the emergence of potentially serious pathogens in humans. Veterinary research in zoos is critical to conservation of endangered wildlife, providing unique insights into disease processes in captive animals that can be extrapolated to free-living wild populations.

COMPARATIVE MEDICINE

Animal Modeling

Animal Models for Human Diseases

Research on animal models has been essential to our understanding of basic and applied sciences and has led to important improvements in the management of human and animal diseases (NRC, 2004a; see Box 2-4 for medical advances achieved through animal research). Over the last 50 years, the study of naturally occurring or induced animal models of human disease has led to tremendous growth of knowledge in many disciplines—including hematology, immunology, vaccinology, virology, and genetics—and has contributed to new fields of research, such as transplantation and gene therapy (Badylak et al., 1998; Dodds, 1995a,b; Ostrander et al 1993; Parker et al., 2004; Patterson et al., 1988, Smith, 1994).

Over 90% of the animals used in biomedical research are mice and rats. However, many other animal models have been used to study human and animal diseases. For example, the field of comparative immunology deals with many aspects of immunological function, which includes not only the clinical disorders, such as systemic and organ-specific autoimmune diseases and primary and secondary immune deficiency states, but also understanding of host-parasite interactions and the immunological effects of genetics, nutrition, and toxicity on disease expression (Perryman, 2004; Tizzard and Schubot, 2000). Swine have been used in atherosclerosis and hemostasis research (Bowie and Dodds, 1976; Dodds, 1982, 1987; Edwards et al., 1985). Pregnancy immunology is studied in ruminants to investigate embryonic survival, fetal growth, and uterine defense mechanisms; and artificial-organ and organ-xenograft research, development, and testing have used and continue to use sheep, cattle, and goats (Chiang et al., 1994; Dodds, 1987; Lewis and Carraway, 1992; Martini et al., 2001). Nonhuman-primate research has long played a key role in comparative research on atherosclerosis, respiratory disease, retroviral diseases, infectious hepatitis, and aging (Clarkson et al., 1996; McClellan, 2000; NRC, 1997).

BOX 2-4

Medical Advances Achieved Through Animal Research

1790	Vaccine for smallpox developed (cow)
1880	Vaccine for anthrax developed (sheep)
1888	Vaccine for rabies developed (dog and rabbit)
1902	Malarial life cycle discovered (pigeon)
1919	Mechanisms of immunity discovered (guinea pig, horse, and rabbit)
1923	Insulin discovered (dog and fish)
1932	Function of neurons discovered (cat and dog)
1933	Vaccine for tetanus developed (horse)
1939	Anticoagulants developed (cat)
1945	Penicillin tested (mouse)
1954	Polio vaccine developed (mouse and monkey)
1956	Open-heart surgery and cardiac pacemakers developed (dog)
1968	Rubella vaccine developed (monkey)
1984	Monoclonal antibodies developed (mouse)
1989	Organ transplantation advances developed (dog, sheep, cow, and pig)
1992	Laproscopic surgical techniques developed (pig)
1995	Gene transfer for cystic fibrosis developed (mouse and nonhuman primate)
2000	Brain signal transduction discovered (mouse, rat, and sea slug)
2001	Promising drug for prevention of AIDS developed (monkey)

SOURCE: Foundation for Biomedical Research, 2001.

Animal Models for Animal Diseases

Information generated by animal-based experiments has been used primarily to benefit human health and well-being, but parallel benefits have been accorded to animals (Dodds, 1995a; Wagner, 1992); for example, with respect to inherited bleeding disorders (Dodds, 1995b), congenital cardiac disease and inborn errors of metabolism (Patterson et al., 1988), neuromuscular and copper-storage disorders (Brewer et al., 1992), and inherited eye diseases (Smith, 1994). These basic and comparative medical advances have improved diagnosis and treatment in clinical veterinary medicine.

Emerging Areas of Research in Comparative Medicine

Molecular Markers for Research and Clinical Applications

For 4 decades, veterinary and comparative geneticists have developed and relied on biochemical markers of specific genetic traits to identify carrier and affected animals can be used as models of human disease (Patterson et al., 1988; Dodds, 1995a,b; Dodds and Womack, 1997). More recently, molecular approaches have been developed used to study gene-therapeutic approaches for advancing human health and well-being (Ostrander et al., 1993). Examples of diseases that commonly affect humans and companion animals and lend themselves to molecular and gene therapy are autoimmune thyroid disease (Happ, 1995), such inherited bleeding disorders as hemophilia and von Willebrand disease (Dodds, 1995b; Kay et al., 1993), and organ-specific autoimmune disease (Ford, 2001; Schultz, 1999). Future technological developments, particularly in gene delivery and cell transplantation, will be critical for the successful practice of gene therapy (Dodds and Womack, 1997).

Animal Genome and Phenome Research

Substantial advances have been made in sequencing the genomes of humans and other mammalian species. Large-scale genome-sequencing projects have focused on completing the sequencing of the genome of the human (Freimer and Sabatti, 2003), the chimpanzee, the dog (Parker et al., 2004), the cow (Gibbs, et al., 2002), the mouse, the rat and the chicken, several insects, nematodes, fungi, yeast, and bacteria (AVMA, 2004a). In the near future, scientists will begin to sequence the genomes of nine more mammals, including the domestic cat, the guinea pig, the rabbit, the orangutan, and the elephant (AVMA, 2004a).

Interest in the human and canine genomes has spawned related research in "phenomics" to identify specific genotypes that are associated with the species phenotype. The purpose of the human, mouse, and canine phenome projects is to learn about both genetic and nongenetic factors that contribute to the variability of the species (Bogue, 2003; Freimer and Sabatti, 2003; Grubb et al., 2004; Pletcher et al., 2004). For example, dog research will focus on the phenotypic characteristics that distinguish one breed from another and that distinguish one animal from another in the same breed. Size, anatomy and appearance, composition and metabolism, behavior and temperament, and disease susceptibility will be investigated.

Effective Animal Models to Establish Safety and Efficacy of Therapeutic Compounds

The challenge today is to develop better treatments for the many serious diseases that afflict human and animal populations. FDA's Critical Path Initiative focuses on targeted scientific efforts to modernize methods to evaluate the safety, efficacy, and quality of medical products as they move from product selection and design to mass manufacture. Critical-path research complements basic research, but results in the creation of new tools for product development. Medical-product development starts with basic research that leads to discovery and prototype design and then proceeds to preclinical trials in animal models to test for efficacy and finally clinical trials and FDA approval. The costs of that process are increasing rapidly, but the failure rate of candidate drugs in clinical development has increased. Extensive use of computer modeling ("silicotechnology") could improve predictability, shorten time for drug development, and reduce the overall cost of drug development by as much as 50%. Improved data-mining efforts to combine in vitro and in vivo animal studies with human clinical outcomes (while protecting proprietary data effectively) could form the basis of useful predictive safety models.

Animal models have been informative for efficacy and safety studies of new lead compounds and therapeutics, but improvements are still needed. Further characterization of existing and newly developed disease models in rodents and other laboratory animal species will lead to better validation of potential therapeutic disease targets and analysis and understanding of disease pathways in animal models (Kinkler, 2004).

Stem-Cell Research

The goal of stem-cell research is to engineer cell lines for use in tissue, organ, or cell transplantation or for gene therapy for treatment of diseases (NIH, 2004). The future of regenerative medicine depends on further exploration of the biological, ethical, and funding questions prompted by the therapeutic potential of adult and embryonic human and mouse stem cells (NRC, 2002c).

Stem-cell transplantation has been effective in treating diseases in animal models. However, although effective outcomes of stem-cell transplantation have been obtained—for example, in neurodegenerative diseases—the underlying mechanisms leading to re-establishment of neurological function are still unclear. Such mechanisms as stem-cell promotion of growth-factor release, cell fusion, and transdifferentiation are some explanations of the favorable outcomes. Additional work with animal models of disease will result in a better understanding of the mechanisms of stem-cell therapies.

Genetically Engineered Animals

The capacity to manipulate the DNA of mammals by adding or deleting specific genes has made the laboratory mouse a robust tool for advancing biomedical research. Genetic engineering has substantially increased the number of mutant strains available compared with induced-mutagenesis methods, such as N-ethyl-N-nitrosourea (ENU) mutagenesis. For example, genetically engineered mouse models have advanced the understanding of such neurodegenerative diseases as Alzheimer's disease, Parkinson's disease, and motor neuron disease (Wong et al., 2002).

Transgenic sheep and goats express foreign proteins in their milk that may be used to treat such genetic defects as human and canine hemophilia. Transgenic pigs may serve as a source of organs for transplantation into humans (xenotransplantation). Further development of transgenic animals will permit investigations that will eludicidate the cellular components of tissue remodeling that are essential to regenerative medicine.

Advanced Surgical Techniques (Microsurgery) and Biomedical Devices

Research in advanced surgical techniques includes the development of the skills needed for microvascular, microneural, and microtubular surgery, which are used in plastic and orthopedic surgery, urology, general surgery, neurosurgery, otolaryngology, obstetrics and gynecology, and cardiothoracic surgery. Training courses typically use rabbits and rats as experimental models. A research model of arterial thrombosis that mimics human vascular thrombosis (for example, coronary arterial occlusion) has been used extensively by investigators interested in the development of thrombolytic agents, particularly urokinase and tissue plasminogen activators, for human use (Badylak et al, 1998). A biomaterial derived from porcine small intestinal submucosa was developed from a throw-away product of the pork industry; this "bioscaffold" material has been used in a variety of animal models and in human patients for repair, replacement, and reconstruction of the esophagus, dura mater, lower urinary tract, acutely and chronically injured skin, and the cardiovascular system (Badylak et al, 2000).

Vaccine-Related Research

Understanding of basic immune mechanisms in laboratory animals has made it possible to design vaccines that protect against infectious diseases, to induce effective responses to tumor antigens, and to control graft rejection and autoimmune diseases (Tizard, 1990; Lanzavecchia, 1993). However, there is an emerging need for new approaches to protect against immunological and infectious challenges (Cohen, 1994) and to understand adverse reactions to vaccines in humans and animals (Oehen et al., 1991; Paul et al., 2003; Schultz, 1999; Scott-Moncreieff et al., 2002; Tizard, 1990; Vascellari et al., 2003).

Examples of Critical Research Needs

- Advanced training of comparative-medicine scientists to support and facilitate biomedical research, with emphasis on expertise in phenotype and behavior assessment of unique rodent strains.
- Further development and refinement of animal models to advance biomedical research.
- Expansion of resources and methods for characterizing the genetic background, phenotype, and behavior of unique mouse and rat strains.
- Enhanced methods for preserving valuable models and improving the reproductive efficiency of laboratory animals.
- Improved methods for genetic engineering in laboratory animal species other than the mouse to advance understanding of select diseases.

Importance and Contribution of Research

Research in comparative medicine is critical to the advancement of biomedical research, which will lead to improvements in human and animal health. Comparative-medicine research contributes to the improved quality of laboratory animals and the quality of research that uses them.

EMERGING ISSUES IN VETERINARY SCIENCE

Emerging Infectious Diseases

Emerging infectious diseases (EIDs) have become recognized as one of the most important threats to public health over the last 30 years (Binder et al., 1999; IOM, 1992; NRC, 2003b). Emerging diseases are those which have recently expanded in geographic range, moved from one host species to another, increased in impact or severity, or undergone a change in pathogenesis, or were caused by recently evolved pathogens (other definitions are available in IOM, 1992). Combating emerging diseases is a key goal of public-health efforts nationally and globally, and it is hindered by poor knowledge of potential emerging zoonoses—for example, diseases caused by wildlife parasites, viruses, and other microorganisms that move into humans (Morse, 1993).

The reason emerging diseases (most of which are zoonotic) require and attract so much attention is that they are usually complex and not well understood, are not susceptible to rapid diagnostic or detection methods, and usually not subject to vaccines, other therapeutics, or readily applied prevention programs. Of the 175 organisms considered to be pathogenic in humans and commonly cited as emerging, 132, or 75% are zoonotic (Taylor et al., 2001). The emergence of new diseases, such as SARS, has been linked to increased contact between humans and the animals carrying the diseases. The spread of H5N1 avian influenza virus in Asia that infected domestic poultry, swine, cats, wild birds (pigeons and crows), and humans is related to changes in agricultural practices of livestock industries. Animals are also carriers of many insect-transmitted pathogens. When the uncertainties associated with transmission from one species to another are added to the ever-increasing mobility of society, the potential interface between those conditions and human food safety, and the heightened concerns about possible effect of bioterrorism on animals (intentional introduction of an animal disease with the intention of causing economic consequences or transmission of disease to humans), the urgency of comprehensive research and implementation becomes obvious.

Veterinary researchers are employed in a number of capacities in EID research. Because of the predominance of zoonotic pathogens in EID outbreaks, veterinarians have been key parts of the teams attempting to identify wildlife reservoirs of hantavirus, Lyme disease, West Nile virus, leptospirosis, Lassa fever, Ebola virus, Nipah virus, Hendra virus, and others. Veterinarians with epidemiological training have been involved in most of the major outbreak investigations undertaken by CDC.

Outbreaks of new zoonotic agents occur almost every year, and they have serious health and economic consequences. For instance, SARS coronavirus, which appears to have wildlife origins, caused over 700 deaths and $50 billion in losses to the global economy in 2003 (Guan et al., 2003; Rota et al., 2003). The zoonotic predominance among EIDs suggests a growing need for veterinary researchers to understand dynamics of wildlife pathogens that have emerged or are likely to emerge into human populations (for example, West Nile virus and viruses related to SARS coronavirus or Nipah virus). The ability of these emerging pathogens to spread rapidly across the planet is enhanced by a large and increasing volume of trade in wildlife species that can act as introduction vectors. For example, monkeypox was imported into Wisconsin through the exotic-pet trade industry.

The scope of EID research has been widened to include emerging diseases of marine and terrestrial wildlife and domestic animals (Anon, 1998; Daszak et al., 2000; Dobson and Foufopoulos, 2001; Harvell et al., 1999; Nettles, 1996). EIDs are responsible for population declines and mass mortality of wildlife (Daszak et al., 2000), loss of coral reefs and other marine resources globally (Harvell et al, 1999), and threats to global food-animal markets (NRC, 2002b; see also section on food-producing animals).

Veterinary involvement in EID research is critical. For example, BSE was originally discovered by veterinary pathologists, and the dynamics of its spread were understood by veterinary epidemiologists working with mathematical modelers, all before it emerged in the human population. In addition, veterinary institutes and veterinary medical researchers were critical in studying the pathogenesis of the 1918 human pandemic influenza virus in animal models to understand the molecular development and prevention of human influenza pandemics (Kash et al., 2004; Tumpey et al., 2004). Understanding how environmental or population changes select for emergence of new zoonotic pathogens from the "zoonotic pool" (Morse, 1993) is a goal discussed in both National Research Council reports on EIDs (NRC, 2003b). Useful models are a number of studies funded through the National Institutes of Health/National Science Foundation initiative in ecology of infectious diseases (NIH, 2002) and a recent study of retrovirus emergence in bush meat-hunters in west Africa (Wolfe et al., 2004).

Examples of Critical Research Issues

- A preemptive approach to predict and prevent infectious diseases.
- New tools to identify novel, potentially zoonotic pathogens in wildlife populations that may be the next HIV/AIDS or SARS coronavirus. Such tools will include microarrays and other sophisticated biotechnological applications based on the pool of known zoonotic EIDs that wildlife populations harbor.

- Increased involvement of veterinary researchers in understanding the wildlife trade as a mechanism of EID introduction and in understanding how zoonotic bioterrorism agents may behave if released in the United States.
- The causes, anthropogenic, ecological and environmental drivers, and effects of emerging diseases of livestock and wildlife.

Importance and Contribution of Research

Veterinary research in EID would reduce human mortality due to new emerging diseases, help to prevent future outbreaks of unknown diseases, and help to prevent or deter the introduction and dissemination of pathogens into the United States. This research will also have important economic benefits in reducing public-health costs and disruption of trade and industry.

Ecosystem Health

The field of ecosystem health developed in Canada with the formation of the International Society for Ecosystem Health in 1994 and the launch of its journal *Ecosystem Health* (superseded by *Ecohealth*). The field approaches health as a metaphor in that a healthy ecosystem is one with the full assemblage of species, each with healthy populations. Research in ecosystem health allows a more complete understanding of how disease organisms, toxicants, and health issues affect animal and human populations and the functioning of ecosystems. Ultimately, breakdown of ecosystem health leads to loss of ecosystem functions and affects human health and welfare through effects on agriculture, hunting, fishing and livestock production, and food animal safety.

Veterinary researchers have an important role to play in the advancement of ecosystem health and can contribute in numerous and diverse ways. For example, veterinary researchers have been involved in the characterization of a multispecies (human, companion animal, and marine mammal) outbreak of cryptococcosis (Stephen et al., 2002), in identifying indicators of ecosystem health (Stephen and Ribble, 2001), and in using ecosystem-health concepts for wildlife conservation (for example, Wildlife Conservation Society Field Veterinary Program). Understanding the effects or ecological footprint of terrestrial and aquatic animal agriculture on ecosystems and social systems and how sustainable practices can be developed is critical in both developed and developing nations (Tilman et al, 2003).

Examples of Critical Research Needs

- Definition of what constitutes a healthy ecosystem.
- Development of reliable and predictive indicators of ecosystem health.
- Characterization of the complex interaction between humans, domestic and wild animals, and the environment to predict risks to the health of these populations.

• Studies of the interaction between human and animal communities by multidisciplinary teams that include zoo veterinarians, ecologists and toxicologists, and public-policy experts to understand how human activities affect ecosystems and all their inhabitants, including humans.

Importance and Contribution of Research

Failure to address research in ecosystem health would lead to substantial and unpredictable risks (such as infectious disease, food safety, water-borne illness, toxins) to the health of humans and domestic and wild animals. Biodiversity in wild animal and plant populations would be at risk as a result of unhealthy and unsustainable ecosystems.

Social Policies, Societal Needs, and Expectations Including Animal Welfare

The care and use of research animals are governed by USDA regulations and PHS policy, which were implemented to address societal concerns about laboratory animal welfare. These regulations and standards include requirements for the oversight of animal research by Institutional Animal Care and Use Committees and standards for laboratory animal husbandry, housing and enrichment, environmental conditions, and veterinary medical care. However, some of the standards are not supported by scientific analysis. In particular, studies that objectively define, measure, and validate the benefits of social housing and environmental enrichment are inadequate. In the absence of scientific studies that support animal care standards, arbitrary guidelines can lead to inappropriate care, cause undesirable changes in an animal's physiological or behavioral status, produce confounding research results, and unnecessarily increase the cost of animal research. It is imperative that the guidelines and recommendations be strongly supported by scientific study. (See subsection on Laboratory Animals under the Animal Health section.)

Although government standards have been established for laboratory animals, the management of food-producing animals is based largely on practices developed and implemented by animal scientists and food-animal producers. The science-based, objective literature on the impact of physical environment—such as space requirements and the impact of confinement or group housing—on food-producing animals is far from adequate and represents a major and critical area for future comprehensive research (Mench, 1992; Fraser, 2003). Pressure from major users of animal food products (such as fast-food chains) is expected to advance the urgency of the need, but the expertise needed to achieve the needed results is lacking in the scientific community, although excellent progress is being made in animal handling and transportation, livestock behavior and facility design, and humane slaughter practices (Grandin, 2000; see also http://www.grandin.com/). In addition, research is being conducted in Europe, notably the

Netherlands, on the physical environments of pigs and poultry. Some common management practices—such as veal calf production; sow gestation crates; beak-dubbing and comb removal in chickens; and dehorning, castration, and branding of cattle—were developed to improve production or prevent injuries to other animals and humans, but have also raised public concerns about animal welfare. In addition, the effects of new products and technologies used to enhance animal production, including growth hormones and genetic modification, have caused some public concerns.

In addition to laboratory animals and food-producing animals, welfare is an important consideration for animals used for entertainment, racing, hunting, military and police activities, pet therapy, service (such as Eye Seeing dogs), recreation, and companionship. Science-based methods for measuring stress and distress and stress-related effects in animals are essential if substantial progress is to be made in ensuring the welfare of various species. Such efforts require complex multifaceted studies involving expertise in veterinary medicine, animal science, animal behavior, endocrinology, neurology, and pharmacology.

Scientifically based studies can and should be used to make sound public policy and to set responsible regulatory standards. For example, research data have demonstrated that commercially available rabies vaccines will protect dogs for at least 3 years and are therefore federally licensed for a 3-year duration. However, some individual states and counties have established regulations that require more frequent vaccination, despite research evidence that demonstrates the potential adverse effects of such practices. Rabies vaccination can produce tumors in dogs and cats at the injection site, cause serious neurological and immunological adverse effects and death in any species, and induce autoimmune thyroiditis in dogs (Paul et al., 2003; Schultz, 1999; Scott-Moncrieff et al., 2002; Vascellari et al., 2003). Guidelines for canine and feline vaccination have also been developed by the AVMA Council on Biologic and Therapeutic Agents and AAHA task force the American Association of Feline Practitioners and the Academy of Feline Medicine Advisory Panel on Feline Vaccines, on the basis of evidence from veterinary research and published studies (Elston et al., 1998; Klingborg, 2002; Paul et al., 2003).

Risk analysis is an important public-policy framework being used both nationally and internationally to make regulatory decisions regarding food safety and to formulate animal trade policies. Science-based risk assessments on the relation of specific pathogens or toxicants to animal and human health are a critical component of the risk analysis. Findings derived from research to identify and characterize hazards and assess exposures are the bases of modeling risk assessments. Sound risk assessments will require a wide array of research on the hazards of and exposure to diseases.

Valid scientific studies should also help to determine the outcome of legal decisions, which may otherwise be driven by emotionally based considerations. During the last decade, for example, several municipalities have adopted the term guardian instead of pet owner. Such changes may eventually lead to court challenges regarding the legal standing of animals and how they are used by society. In addition, many law schools have established centers that specialize in animal "rights". Again, scientific evidence will be important to validate or refute legal challenges with respect to animals.

Examples of Critical Research Needs

- Studies that objectively define, measure, and validate the benefits of social housing and environment enrichment.
- Science-based methods to measure stress and distress and stress-related effects in animals.
- Scientific analysis that uses quantifiable indicators to measure the effects of pharmaceutical agents and genetic modifications on animal welfare.
- Multidisciplinary studies of detection, control and prevention of large-scale zoonotic disease outbreaks that require disposal of large numbers of animals.

Importance and Contribution of Research

Additional research is required to determine the optimal care and use of animals and to support the development of sound public policies governing animal welfare. Research is also required to ensure best management practices of animals in the face of a widespread disaster involving animals and to protect human health.

Exotic and Caged Pets

Exotic and caged pets typically include birds, small mammals (such as ferrets, rabbits, hamsters, guinea pigs, and gerbils), reptiles (such as turtles, lizards, and snakes), and amphibians (such as frogs). Exotic-pet trade is a growing industry that is estimated to be worth more than $10 billion (Kuehn, 2004a). In the case of most species—such as reptiles, amphibians, marsupials, exotic birds, and mammals—little research has been done on their behavioral and husbandry needs. Many medical problems in exotic pets are related to poor husbandry (Kuehn, 2004b). In addition, limited information is available on the treatment of their diseases. Although the volume of information available on exotic and caged pets has increased considerably over the last few decades, most of it is anecdotal or derived from case reports, because most veterinarians involved with exotic pets provide clinical services and are not actively engaged in research.

The recent outbreak of monkeypox transmitted by prairie dogs that were housed or transported with African rodents from Ghana and the resurgence of salmonellosis contracted from reptiles (iguanas and turtles), marsupials (sugar gliders), and small mammals (hedgehogs) readily illustrate the potential risk that exotic-pet ownership poses (Check, 2004; Gross, 2003; Woodward et al., 1997). There has been considerable growth in the demand for and ownership of exotic and caged pets (Doolen, 1996; http://epw.senate.gov/hearing_statements. cfm?id2=212880). The demand is putting increasing pressure on veterinarians who treat exotic and caged animals to keep up with the highly species-specific needs of their patients.

Examples of Critical Research Needs

- Characterization of the zoonotic pathogens capable of being carried by exotic species and also those pathogens that may be transmitted to domestic and wild animal populations.
- Improved methods of diagnosis and treatment of exotic animal diseases, especially in regards to safe and effective anesthetic and analgesic protocols.
- Determination of appropriate husbandry requirements for many exotic species.

Importance and Contribution of Research

Given the increasing number and diversity of exotic pets, veterinary research is necessary to identify important infectious diseases that may pose a risk of transmission to humans and domestic and wild animals. Research on the behavioral, husbandry, and medical needs of exotic pets is also necessary to enhance their quality of life and to contribute to the comparative understanding of diseases in other species.

CONCLUSION

This chapter illustrates that veterinary research is a diverse enterprise that involves many disciplines and species and has a substantial effect on human health and the economy. In many fields, veterinary research is about characterizing the health implications of changing relationships and the boundaries between species and their environments. The compelling but difficult question is, What is the most important? Although research priorities have been outlined in each area, the different areas of veterinary research were not prioritized against each other. Clearly, issues related to homeland security (such as biosecurity) and food safety stand out because of the potential for catastrophic effects on human and animal health. However, problems often arise from fields that have been overlooked (for example, exotic pets) and many important advances come from fields that may not be recognized by some as priorities so that a balanced approach to support research in the above areas must be sought. The key question regarding research priorities is not what topic should be investigated first, but how a strong and flexible national capacity for veterinary research can be built and maintained to maximize the contribution of veterinary research to the health and welfare of animals and people.

3

Setting and Implementing an Agenda for Veterinary Research

Modern veterinary research has markedly improved the quality of life of animals and humans, as indicated by numerous historical achievements. The demands on veterinary research have not diminished but rather have increased, with such emerging threats as bioterrorism and emerging infectious diseases. As shown by the critical research issues outlined in the previous chapter, veterinary and comparative medicine research is becoming a more pressing need than ever before. The ability of veterinary researchers to address the threats of animal disease and to meet societal needs depends largely on the nation's research capacity. Because research resources are finite, it is important to set a research agenda that will address high-priority issues and anticipate future needs and that can be executed effectively.

In this chapter, the committee attempts to set a research agenda for veterinary research related to public health and food safety, comparative medicine, and animal health and welfare. Examples of critical research needs in each of the disciplines are given in Chapter 2 (which appear in a box at the beginning of each subsection in this chapter). The committee then identifies the short-, intermediate, and long-term research that must be done in order to address the selected critical issues. The committee also assesses the expertise and some of the major infrastructure needed, suggests some possible strategies to achieve the research agenda, and discusses the current sources of funding for the research.

In devising strategies to achieve the agenda for different elements of veterinary research, the committee has noticed that there are overarching strategies that are applicable to most, if not all, of the disciplines in veterinary science discussed in this report. The especially compelling scientific opportunities to improve quality of life and minimize threats include the following:

• Implementation of the concepts of one medicine and interdisciplinary research in the broader biomedical research agenda.

– Substantially improve the integration of molecular biology, genomics, immunology, whole-animal physiology, pathophysiology, and other disciplines in disease research.

– Encourage scientists, through grant mechanisms and other means, to work collaboratively across disciplines, institutions, and agencies.

– Encourage research institutions to foster an environment that nurtures and rewards successful team-oriented investigators and research.

– Expand veterinary-student involvement in ecosystem health and the ability to work collaboratively to study and understand complex systems and the intricate relationships between human beings (individuals, cultures, and societies), animals (domestic and wild), and the environment.

• Setting of priorities research to expand our knowledge, detection, and control of infectious diseases.

– Emphasize classes of disease agents that have the highest economic importance, including those most likely to cause massive epizootics or epidemics, new and emerging diseases, and candidate bioterrorism agents.

– Emphasize the eradication of laboratory animal diseases that adversely affect the quality of biomedical data.

– Focus on understanding the molecular bases of virulence and how pathogenic organisms replicate and survive in the environment including studies of vector biology, wild animal hosts and reservoirs, host defense factors, and host-pathogen interactions.

– Develop and validate rapid, sensitive, reliable, and, where possible, quantitative systems for detecting and monitoring disease-causing organisms.

• Expansion of the study and use of bioinformatics and development of databases and other resources that are readily accessible to the scientific community to enable

– A population-level view of disease and research on interactions between wildlife, domestic animals, and humans.

– Tracking of pathogen prevalence in animals, including companion, food-producing, and laboratory animals.

– Tracking of foodborne diseases.

– Maximizing of the sharing and efficiency of developing, preserving, and housing important rodent and other animal models.

• Quantification of critical, scientifically based animal health and welfare characteristics to optimize sustainable and socially responsible food-animal production and laboratory animal research.

• Expansion of research on the human-animal bond and the overall role of animals in society.

PUBLIC HEALTH AND FOOD SAFETY

Food Safety

Examples of Critical Research Needs

- Rapid, sensitive, and accurate assays for detecting foodborne pathogens.
- Epidemiological approaches to identifying risk factors and intervention strategies that have the greatest effect on reducing foodborne pathogens and antimicrobial-resistant microorganisms associated with livestock, poultry, and aquaculture. This includes a more comprehensive understanding of the epidemiology and genetic elements of the foodborne zoonotic agents, especially of those agents that have recently emerged.
- Practical and effective interventions for minimizing carriage of and contamination with food-associated pathogens of animal origin.
- Methods to assess the safety and nutritional value of transgenic and cloned food-producing animals.
- Identification of previously unrecognized foodborne pathogens of animal origin.

Research Agenda

Immediate Priorities

A critical factor in reducing animal-associated foodborne illnesses is the ability to detect and isolate the responsible agents. A high priority for the near term is to develop rapid, sensitive, and accurate assays for detecting foodborne pathogens in feces and meat and on animal surfaces. Most highly sensitive microbiological assays for detecting pathogens in meat and feces take days to complete. Real-time, easy-to-perform assays are needed to enable point-of-contamination detection and monitoring so that corrective actions can be taken promptly to reduce pathogen dissemination. The more quickly interventions can be implemented at critical points of contamination, the more effective pathogen control strategies will be in reducing foodborne illness.

Functional genomics presents an additional research opportunity. Knowledge of a microorganism's genome can be used to determine the functions of genes and their products and may be useful for developing real-time assays that not only detect pathogens but also predict their pathogenicity, identify novel pathogenic mechanisms, and trace pathogens to their sources. Identifying in animals virulence-associated genes in commensal microorganisms that are pathogenic to humans may lead to recognition of pathogens heretofore believed to be innocuous.

Mid-term Priorities

Foodborne illnesses are caused by a complex interaction of factors in the path from farm to consumption. Most foodborne disease cases are preventable, and there is a need to develop a more science- and risk-based food-safety system that will enable the best allocation of resources to provide a continuous, effective reduction in the incidence of foodborne illnesses. Practical and effective food-safety interventions need to be developed to reduce human illnesses. Mathematical models can be used to identify the most critical sites along the food chain where pathogen reduction would have the greatest impact.

Mathematical modeling and risk assessment are needed to identify intervention points or strategies that will be most useful in reducing foodborne pathogens and antimicrobial-resistant microorganisms associated with animals used in food production. To apply the models, we need to obtain fundamental data through an integrative approach involving epidemiology, clinical and laboratory studies, and surveillance to identify how pathogens enter the farm environment, how they persist and spread in that environment, and what dosage causes disease in humans. In addition, a systematic elucidation of the ecology of antimicrobial-resistant microorganisms associated with animals and the farm environment is needed and will be instrumental in development of a risk model that ranks the modes of acquisition of antimicrobial resistance among pathogens of public health significance. Moreover, if the model is used as a guide, the most effective intervention strategies for reducing the prevalence of antimicrobial-resistant microorganisms may be identified.

Many procedures are available for reducing pathogen contamination on the farm, but several have not been suitably validated. Controlled studies are needed to evaluate the procedures, and research is needed to develop more effective and practical intervention strategies for controlling pathogens in production and slaughter environments.

Long-term Priorities

Tens of millions of food-associated cases of acute gastroenteritis are caused by agents of unknown etiology each year in the United States. If we identify the responsible agents, research can be focused on developing effective detection and intervention strategies to reduce their occurrence in the food chain. A multi-targeted research approach is needed to reveal and characterize these yet-to-be discovered harmful microorganisms.

Studies are needed to elucidate the roles of environmental and other exogenous factors in the emergence of newly evolved pathogens. Examples of such factors are the introduction of new antibiotics, changes in production practices, and climate changes, all of which may provide conditions that influence genetic modification and selection and enable microorganisms to compete better under new, more stressful conditions.

The development of transgenic and cloned animals is impeded by concerns about the safety and nutritional value of the foods they produce. Validated methods are needed to assess the potential acquisition of toxins, allergens, undesirable endocrine activity, and other adverse properties that may result from genetic manipulation.

Strategies to Achieve Research

Research on foodborne illnesses requires biocontainment facilities, development of and access to databases and pathogen banks, and expertise in animal microbiology, mathematical modeling, genomics, and immunology. Veterinary researchers should apply modern technologies to detection of pathogens in feces and foods of animal origin. Genomic and immunological research on foodborne pathogens would speed up the development of rapid detection. Such research requires access to properly equipped laboratories, genomic and sequence data, and banks of well-characterized reference microorganisms. In addition, research on methods for assessing the safety and nutritional value of transgenic and cloned animals requires an interdisciplinary approach involving toxicologists, nutritionists, biochemists, microbiologists, and veterinary scientists to develop a set of well-documented protocols and assays for risk assessment of foods from genetically altered animals.

Development of mathematical models to identify intervention points could begin with integrating animal and environmental surveillance systems into established human surveillance systems. Pathogen-prevalence and food-attribution databases should be developed and should be readily accessible to all. Once the models are developed, they can be applied to determine the most effective on-farm intervention strategies for reducing human illnesses attributed to animal-associated foodborne pathogens. Development of practical on-farm interventions requires the application of genomics, proteomics, sequencing, and genetic modification to the elucidation of foodborne-pathogen colonization of animals and the application of innovative vaccines, competitive microorganisms, phage, antimicrobials, diet modification, and genetic modification of animals to the reduction of pathogen carriage by animals.

Veterinary researchers should collaborate with food microbiologists, statisticians, and nonveterinary scientists to strengthen and advance food-safety research. Collaboration with federal agencies engaged in food safety issues—such as Food and Drug Administration (FDA), the US Department of Agriculture (USDA) Food Safety and Inspection Service and Animal and Plant Health Inspection Service, and the Centers for Disease Control and Prevention (CDC)—would also be beneficial.

Funding Sources

Funding for veterinary-science-related food-safety research has been available through the USDA National Research Initiative (NRI), the USDA Cooperative State Research, Education, and Extension Service (CSREES) National Integrated Food Safety Initiative, the USDA Agricultural Research Service (ARS), the FDA Center for Food Safety and Applied Nutrition, the FDA Center for Veterinary Medicine, the National Institutes of Health (NIH), the Department of Homeland Security (DHS), and veterinary pharmaceutical companies. However, research on the safety of food products from transgenic and cloned animals does not have an identifiable funding source, because most programs address food safety in relation to pathogens.

Biosecurity

Examples of Critical Research Needs

- Improved ability to detect and identify disease and pathogens in animal populations.
- Improved ability to detect pathogens and toxicants in food along the processing chain.
- Improved understanding of interactions between pathogens and hosts so that effective preventive measures and countermeasures can be developed.
- Rational development of cost-effective countermeasures, both vaccines and nonspecific therapeutic agents.

Research Agenda

Immediate Priorities

The most important factor in limiting the impact of any disease outbreak—natural or human-made, preharvest or postharvest—is quick identification. Accurate clinical recognition and differential diagnosis should have high priority for research in the short term to make rapid response and eradication or containment possible. The need for diagnostics research is discussed in detail in another National Research Council report *Animal Health at the Crossroads* (NRC, 2005). We must develop technical means of either securing food products physically or identifying the presence of adulterants before they can be consumed in the food of humans or animals.

Species-neutral disease surveillance should be adopted as the norm and continually improved; it will entail bringing together information from all health-care providers and agricultural professionals to discover disease wherever it originates rather than waiting until disease occurs in humans. In light of today's increased communication and travel, this species-neutral disease monitoring should be international, and there should be broad and open datasharing. Understanding how to control an outbreak will be facilitated by the use of disease-specific mathematical risk-assessment models for prediction of outbreak dynamics.

Mid-term Priorities

A better understanding of how to stimulate acquired immunity in large populations of livestock (for example, by vaccination) is imperative. Because of its potential unprecedented impact, foot-and-mouth disease should be at the top of the list of research priorities. New methods of antigen presentation and effective adjuvants are needed for animal immunization. Ideally, the nation should be capable of producing animal vaccines rapidly with the latest techniques in the event of an outbreak. Research on vaccines will also be applicable to human health.

Long-term Priorities

We are little beyond the era of using "blunt" immunological tools as medical countermeasures; improving this situation dramatically may require 20-30 years of human and veterinary research. Improving our understanding of the complex interplay of antigens, virulence factors of potential threat agents, and immunological responses in animals and humans should have high priority for veterinary research in biosecurity. A better understanding of the extreme complexity of the immune system in humans and animals would enable us to exploit its protective effects without inadvertently causing harm.

Long-term research should also emphasize how to detect and interpret host responses to disease agents better. That would allow us to make earlier diagnoses—even before the onset of clinical illness—and to exploit innate immunity (nonspecific protection from disease) and other resistance mechanisms in target species.

Strategies to Achieve Research Agenda

An improved understanding of the pathogens that affect biosecurity will require application of genomics, proteomics, sequencing, and transgenic technologies. The critical infrastructure for such research will include biocontainment laboratories and animal housing facilities that are now being planned or under construction; access to genome and sequence data and antibody, nucleic acid, and protein arrays to help us understand the immune system; and banks of well-characterized reference agents and reagents. As we wage the war on terrorism and emerging infectious diseases, critical subspecialties of veterinary medicine will include infectious disease, immunology, epidemiology, food safety, agricultural economics, and public health. An absolute necessity for the most rapid progress will be the formation of interdisciplinary teams of other medical specialties working across scientific, geographic, and national borders. One example of a strategy for training personnel in biosecurity research is the incorporation of food-security concepts into food-safety curricula; similarly, we must leverage educational programs targeting naturally occurring disease to deal with intentional outbreaks. Moreover, cross-disciplinary training, such as exposing veterinary students or researchers to human medical training and faculties and vice versa, will prove to be beneficial over the long term. Finally, we must constantly seek to discover, understand, and respond to disease by agent, not by species, and seek to enhance awareness, communication, and understanding internationally.

Funding Sources

The needed research regarding diagnostics and identification and pathogenesis of threat agents was traditionally funded only by the Department of Defense. Since 2003, DHS and, to some extent, USDA have supported the diagnostic work, and NIH the fundamental pathogenesis and immunological research, at least in humans and nonfood-animal species. Much less funding is available to do similar work on foreign animal diseases that do not directly affect humans but could devastate our roughly $160 billion livestock economy.

ANIMAL HEALTH AND WELFARE

Food-Producing Animals

Examples of Critical Research

- Development of capacity and implementation of broad programs in comparative medicine to understand, rapidly detect, and control zoonotic and nonzoonotic diseases in food-producing animals raised in concentrated production units, with emphasis on techniques and technologies for field use in large-animal populations.
- Evaluation of the implications of increases in productivity achieved through genetic or pharmaceutical means for animal health, nutrient, and metabolic requirements.
- Monitor and assess trans-species disease transmission, epidemiology, and the delineation of resistance, susceptibility, and virulence factors across animals and pathogenic organisms.

Research Agenda

Immediate Priorities

The increasing tendency to concentrate food animals in large production units that require complex distribution and societal interaction suggests that the most critical veterinary-science research goals associated with food animals are to develop and implement capacities and broad programs in comparative medicine to understand, detect, and control endemic and emerging diseases. High priority should be given to

- Development of rapid, accurate field-applied systems for detection of endemic and zoonotic diseases of food animals to prevent unnecessary quarantine, slaughter, and indemnification.
- Development and deployment of appropriate and safe techniques to control diagnosed critical food-animal diseases (for example, foot-and-mouth disease).
- Determination, evaluation, and quantification of critical, measurable environmental conditions and physiological stress and welfare (including nutritional) characteristics in food animals that affect health, well-being, and productive performance. That should include measurement of the effect of genetic selection or metabolic modifiers (such as bovine somatotropin and porcine somatotropin) on focused and increased performance.

Mid-term Priorities

Although our ability to detect, respond to, and recover from disease outbreaks in food-producing animals is important, prevention of diseases is even more desirable. Research should aim to develop effective measures to prevent critical and economically important diseases of food animals. Research is also needed to develop and facilitate delivery systems for rapid immunization of food animals.

Long-term Priorities

Great progress is being made in the determination of the genome of each species of food animal, and the process will probably be completed far sooner than originally expected. The mapped genomes enable correlation between components of the genome with resistance to and avoidance of diseases. That and other new knowledge should be incorporated to develop, isolate, and deploy resistance to critical endemic and economically important diseases.

Strategies to Achieve Research Agenda

The implementation of appropriate management systems with reduction in excessive quarantine and indemnification practices would have enormous economic implications and would require significant investment in facilities and personnel trained to undertake the necessary investigations. Because some of the diseases of food-producing animals are highly pathogenic, biosafety level 3-agriculture laboratories are necessary for some of the research. The research community could benefit from an inventory of its capacity for research on diagnostics and on development and production of preventives (such as vaccines) against priority-identified zoonotic diseases. Studies on genetic resistance to zoonotic diseases in food animals are needed and they could be initiated on the basis of emerging understanding of the genome of each food-animal species. Thus, veterinary researchers could benefit from an inventory of all relevant research in food-animal species and in nonfood-animal species that has transferability to food-animal species.

Research on critical factors that affect the health and welfare of food-producing animals (such as the environment, genetic selection to enhance performance, or pharmaceutical manipulation of metabolism on the physiological response to stress) has been limited. Morbidity and mortality associated with plant toxicities in grazing animals continue to be a problem in many parts of the country. There is an immediate need for an organized effort in this area, which will require investment in trained personnel, organization of appropriate facilities, and assembly of appropriate teams of scientists with veterinary and animal science training. Priority for this work must be made by appropriate funding agencies, and a national coordination is needed to establish the necessary cooperation, collaboration, and personnel training. Until this effort is made, animal agriculture will remain unable to address adequately and respond to questions of the welfare impacts associated with commercial food-animal production practices.

Funding Sources

USDA provides some funds through such initiatives as the animal health funds administered through CSREES, the NRI and formula funds to the land grant universities and colleges of veterinary medicine. In many cases, the funds are split between the animal-production research departments in colleges of agriculture and veterinary colleges. Funds given by USDA for basic research, such as NRI, are available for health-related work, but the evaluation and administrative process may not have adequate representation or expertise to offer balanced and unbiased review of proposals. USDA funds in-house basic and translation food-animal health research through ARS.

As in human medicine, some funding opportunities for clinical research on food animals are provided by private industry (pharmaceutical, animal-health and so on). However, that source funds individual projects and is not adequate to build a sustainable and unbiased research program.

Aquaculture

Examples of Critical Research Needs

- Improved understanding of immune responses (especially cell-mediated) in fish to facilitate the development of effective vaccines and appropriate delivery systems.
- Improved methods of pathogen detection.
- Increased effectiveness and safety of medications used to treat diseases in aquaculture species.
- Enhanced understanding of the impact of aquatic animal production systems on marine and freshwater ecosystems.

Research Agenda

The primary role of veterinary researchers in aquaculture is the prevention, control, and treatment of diseases. Intensive farming of aquatic species facilitates the spread of diseases in a population. A thorough understanding of the host, infectious agents, and environment is critical to the design of management practices and therapeutic interventions that optimize health and minimize environmental impact. Challenges in this field include inadequate understanding of the physiology of many farmed aquatic species, as opposed to mammals; of how varying body temperatures affect disease processes and responses to therapeutic interventions and vaccines; and of the environmental effects of farming practices, medications, and transgenic species.

Immediate Priorities

High priority should be given to developing accurate and cost-effective diagnostic tests to allow rapid treatment and prevent spread of diseases. Therapeutic agents should be developed and tested for efficacy. FDA recognizes that there are several aquatic-animal diseases for which no drugs have been approved (FDA, 2003). It is estimated that 10% of production (about $71.4 of 714 million in finfish aquaculture in 2000) is lost each year because of parasites and other infectious disease (USDA-ARS, 2004a). Studies to develop effective countermeasures should be conducted immediately for control of diseases in aquatic animals to minimize risks to food safety and the environment (Haskell et al., 2004) and to reduce economic losses.

Mid-term Priorities

Effective vaccines and methods for their delivery should be developed to prevent disease occurrence. Ongoing research is needed to improve our understanding of the immune response in different aquatic species and how to manipulate it effectively with vaccines or other immunomodulating agents. Understanding of pathophysiological mechanisms in aquatic species would help to prevent and predict emergence of diseases.

Long-term Priorities

Long-term research should address concerns about environmental and food safety (for example, drug and chemical residues). Environmental issues that deserve attention include biological pollution (escaped farmed species), chemical pollution (drugs and chemicals), sustainability of the use of wild-caught fish for fish feed, organic pollution and eutrophication, and the habitat effects of marine aquaculture facilities (Goldburg et al., 2001).

Important risks to food safety from drug and chemical residues in species farmed in and imported from outside the United States require further investigation. The development of disease-resistant stocks and of environmentally benign drug and chemical alternatives is needed (Goldburg et al., 2001). The welfare of aquatic animals in production systems is also an emerging issue.

Strategies to Achieve Research Agenda

A thorough understanding of pathophysiological mechanisms requires the application of genomics, proteomics, and sequencing to the study of infectious agents and their interactions with host species. Collaboration between laboratories capable of aquatic-animal research and genome sequencing is necessary. Successful prevention, control, and treatment of diseases in aquatic animals would require collaborative efforts among aquatic-animal physiologists, pathologists, and immunologists and experts in epidemiology, population health, and facilities engineering. Better integration of funding sources—such as USDA, the US Geological Survey (USGS), state agricultural research programs, and sea grant programs of the National Oceanic and Atmospheric Administration (NOAA)—and outlining of the roles of different categories of research funding would facilitate veterinary research in aquatic species.

Funding Sources

Most aquaculture operations in the United States are small to medium companies with little capacity to fund research and development (Goldburg et al., 2001). Consequently, government sources of funding (such as USDA and NOAA) are important for addressing the many research needs.

Companion Animals

Examples of Critical Research Needs

- Preventive-medicine and wellness strategies—vaccination and other means to control infectious disease, appropriate nutrition, and methods or strategies for disease monitoring and better methods to diagnose and treat behavioral disorders.
- Improved understanding of and treatment for geriatric and immune disorders—such as cancer, organ failure, arthritis, and immune-mediated disease.
- Rapid and minimally invasive diagnostic methods.
- Randomized controlled clinical trials (of sufficient power to detect clinically significant differences) to address many long-standing diagnostic and treatment questions.
- Concentrated efforts in reproductive efficiency and orthopedic issues of performance animals.
- Improved understanding of the ecology of microbial organisms that may be transmitted to humans from companion animals and vice versa.

Research Agenda

The positive human health effects of animal companionship and the selfless service that companion animals render society in their many roles (for example, search and rescue) are compelling reasons to enhance their health and well-being through research.

Immediate Priorities

An immediate and continuous need in companion-animal medicine is to determine the prevalence of important companion-animal diseases. Randomized controlled clinical trials should be conducted to address treatment questions (for example, treatment of cancers and immune-mediated diseases) and to clarify the role and effectiveness of complementary therapies (for example, acupuncture, chiropractic, and herbal therapy). An increasing number of companion-animal owners and veterinarians are using complementary therapies in a wide array of applications (Schoen and Wynn 1997).

Mid-term Priorities

In the medium term, research should be conducted to identify reliable markers of diseases that are substantially influenced by genotype (for example, breed-associated diseases) and to develop diagnostic methods that permit rapid and noninvasive diagnosis and monitoring of important diseases. The many breeds of dogs and cats have relatively conserved genetic makeup (about 30% genetic variation among breeds) but marked phenotypic variability (Parker et al., 2004). Breed-associated disorders are common but are often not documented and characterized early enough to prevent widespread dissemination. Other research issues to be addressed in the medium term include population-control and disease-management strategies for shelter and feral animal populations. Studies are also needed to characterize disease agents that are potentially zoonotic and to identify better diagnostic and treatment modalities for behavioral disorders.

Long-term Priorities

Long-term studies are needed to establish the influence of nutrition and other variables on the prevention of diseases and promotion of wellness. Because the life span of companion animals is increasing, geriatric diseases and issues are more prevalent. Research should aim to improve our understanding of the development, detection, and treatment of age-related diseases (such as chronic renal failure, cancer, and osteoarthritis) and associated welfare issues (such as the determination of quality of life). Continuous efforts to develop more rapid, minimally invasive, and cage-side diagnostic methods are needed because the ability to diagnose, monitor, or image important patient variables or structures noninvasively and accurately can markedly improve quality of care and minimize stress on animal patients.

Strategies to Achieve Research Agenda

Increasing research into issues that affect companion-animal health and well-being requires researchers with advanced training in clinical specialties, epidemiology, behavior, animal welfare, immunology, pharmacology, and other disciplines. There is a need for collaborative research across institutions and involving private practices to investigate complex diseases and to carry out large-scale and scientifically rigorous clinical trials.

Genomics, proteomics, and metabolomics should be applied to study breed-related diseases, cancer, infectious diseases, and progressive chronic diseases. Such studies would require ready access to genomic, phenomic, and sequence data and to banks of well-characterized reference material (Box 3-1).

Funding Sources

Dedicated resources for companion-animal research are sparse. Most research is supported by small grants from a small number of funding organizations. Examples of the organizations are the Morris Animal Foundation (MAF), the American Kennel Club (AKC) Canine Health Foundation (CHF), the Winn

BOX 3-1
A Research Agenda for Canine Behavior and Genetics Studies

Canine phenome research addresses both genetic and nongenetic factors that contribute to the wide variability of this species (Parker et al., 2004). The research focuses on phenotypic characteristics that distinguish one breed from another and individual from another in the same breed. Behavior and temperament and susceptibility to health and disease are being studied, as are size, anatomy, appearance, composition, and metabolism. Because the principal reason for pet euthanasia is undesirable behavior, research is focused not only on the various medical causes but also on underlying problems of a psychological nature, such as occurs with thyroid dysfunction in the dog (Beaver and Haug, 2003; Dodds, 1999).

Feline Foundation (WFF), the American Animal Hospital Foundation (AAHF), the American College of Veterinary Internal Medicine (ACVIM) Foundation, and the American College of Veterinary Surgeons (ACVS) Foundation. Those organizations collectively provided approximately $5.72 million for research in 2003 (MAF, 2003; AKCCHF, 2003; WFF, 2004; K. Saunders, AAHF, personal communication, 2004; A. Frimberger, ACVIM Foundation, personal communication 2004; ACVS Foundation, 2004). Some organizations that fund equine research are the American Association of Equine Practitioners, the American Quarter Horse Association, and the Grayson Jockey Club Foundation. Some funding for equine research may also be available through the NRI of USDA CSREES. In addition to funds provided by nonprofit organizations and government, industry (for example, pharmaceutical and pet-food companies) and internal veterinary-college research funds (for example, pet or companion-animal trust funds) provide an undetermined amount of support. Many canine breed associations fund research on targeted diseases or conditions. A major constraint for most of the nonprofit funding agencies and internal college research funds is the limited amount of funding available on a per-project basis.

For research that focuses on comparative medicine with direct and indirect benefits to companion animals and human beings, respectively, funding may be available from human-oriented national granting agencies, such as NIH. For example, veterinary research programs in comparative oncology and ophthalmology have benefited from such funding. Information on the amount of funding made available through that mechanism is not available to the committee. Nor is information on the amount of funding directed at basic-science research that may provide indirect benefits to companion animals.

In summary, the small number of funding agencies that support companion-animal research and their limited financial resources are barriers to research that requires multicenter collaboration, long-term horizons, large clinical trials, or detailed investigations at the molecular level.

Laboratory Animals

Examples of Critical Research Needs

- Prevention, detection, and management of laboratory animal diseases.
- Laboratory animal management standards and practices—including the identification of optimal cage and pen sizes, environmental enrichment, sanitation, noise, and temperature and humidity—based on research data.
- Assessment and management of pain and distress.
- Valid alternatives to reduce, refine, or replace animal testing.

Research Agenda

Immediate Priorities

High priority should be given to the development of rapid, accurate, inexpensive, and minimally invasive diagnostic systems to detect common pathogens in laboratory animals and their environment. Identification and elimination of diseases in laboratory animals are essential to prevent confounding variables that affect the quality of research data.

Mid-term Priorities

Research should focus on preventing the introduction and transmission of pathogens and aim to eliminate potential sources of pathogens. Epidemiological surveys could help to identify trends in infections, identify potential sources of infection, and lead to strategies to eradicate pathogens. To minimize research variables and to ensure animal welfare, additional research is needed to establish the optimal environmental characteristics for laboratory animals and to optimize management practices, such as the frequency of cage or pen sanitation and the use of enrichment devices.

Long-term Priorities

Research to validate and refine the products and methods for sedating, anesthetizing or providing analgesia to laboratory animals should be continued as part of the commitment to minimize or prevent pain in animals while supporting research objectives. Research is needed to develop, test, apply, and validate alternatives to the use of animals in biomedical research.

Strategies to Achieve Research Agenda

The highest priority is attached to increasing the number of qualified laboratory animal veterinarians available to facilitate the research enterprise. The serious shortage of qualified laboratory animal veterinarians constitutes a major challenge in addressing the critical research needs. Those specialized professionals are essential to ensure appropriate laboratory animal husbandry and management, to provide clinical care for laboratory animals, and to advise investigators on pain prevention and intervention. Recruitment and training of veterinarians in the specialty of laboratory animal medicine are essential to the health and welfare of laboratory animals and to ensure the quality of in vivo research. Furthermore, USDA regulations and Public Health Service (PHS) policy require qualified veterinarians to provide oversight of laboratory animal welfare and to serve on Institutional Animal Care and Use Committees. Failure to train qualified laboratory animal veterinarians will result in widespread noncompliance with federal regulations and PHS policy governing animal welfare. To help to recruit veterinarians into this specialty, some courses in the veterinary curricula should include laboratory animal medicine as a component. Postdoctoral training for laboratory animal clinicians should be supported through NIH and other major funding sources for biomedical research, and programs to forgive or minimize student debt should be implemented (NRC, 2004a).

Although diagnostic tools for common laboratory animal diseases are available, they should be refined to enhance their speed, sensitivity, and accuracy. Diagnostic laboratories and qualified personnel dedicated to the identification, development, and validation of new technologies for disease detection are needed. Research to improve the prevention, detection, and management of laboratory animal diseases requires an integrated approach, including expertise in laboratory animal medicine, immunology, clinical pathology, molecular biology, and epidemiology. Research in the design and operation of facilities where these animals are housed is also needed and should involve mechanical, electrical, and other specialized engineers.

An integrated approach is needed to develop or refine methods for assessing and managing animal pain and distress. Laboratory animal veterinarians, behaviorists, neuroscientists, and other scientific experts should coordinate their efforts to evaluate and validate products and methods for minimizing pain and distress.

Scientific integrity and the safety and welfare of people and animals must be considered when refining proven test systems or replacing reliable animal-based methods with new in vitro processes. The advancement of refinements in animal research and testing procedures and of the development of valid non-animal alternatives require cooperation between regulatory agencies, funding sources, and the biomedical research community. Expertise in many disciplines—including laboratory animal medicine, toxicology, pharmacology, and clinical pathology—is needed to achieve such advancement.

Funding Sources

A dedicated source of funding is needed to achieve the research agenda for laboratory animals. NIH and other major funding sources provide financial support for biomedical research that depends on laboratory animals. However, there are no substantial funding sources for training laboratory animal clinicians or for studies designed to improve laboratory animal disease detection or prevention. Funding is also needed for studies to establish science-based environmental conditions for laboratory animals and to expand our understanding of the behavioral needs of laboratory animals. To help ensure optimal animal care and use, which are essential to the research enterprise, federal funds are needed for both clinical training and research regarding laboratory animal care and infectious diseases. The research community could benefit from identifying other potential sources of funds from foundations and other nonprofit organizations.

Wildlife and Conservation

Examples of Critical Research Needs

- Research on the risk of transmission of zoonotic and other emerging diseases between wildlife, domestic animals, livestock and humans.
- Research on wildlife diseases that affect both game and non-game species.
- Assessment of the mechanisms for disease introduction and spread in the United States via trade or natural movement of wildlife populations.
- Research to establish diagnostic criteria and protocols, and to validate and standardize protocols.
- Development of improved tools for detection and controlling diseases in free-ranging wildlife populations.
- Research on conservation including comparative reproduction, assisted reproduction, contraception, habitat restoration and protection, and on reintroduction of captive wildlife.
- Comparative pharmacology and nutrition, including the study of improved anesthetics, antimicrobials, and vaccines.

Research Agenda

Immediate Priorities

There is an immediate need for research on the ecology of diseases that are causing mass deaths, population declines, and extinctions of wildlife. The capacity of National Wildlife Health Center—a USGS laboratory dedicated to assessing the impact of disease on wildlife and to identifying the role of various pathogens in contributing to wildlife losses—can be increased by setting up a system of regional laboratories for wildlife health, based on collaboration among colleges of veterinary medicine and university departments, and other institutions that conduct wildlife research or diagnostics. Studies should focus on the underlying causes of wildlife diseases, to understand how such factors as habitat change, wildlife trade, encroachment, livestock-wildlife interactions, and disease introduction change the dynamics of wildlife pathogens.

Zoo animals would benefit from research on mortality in captive programs, including rigorous disease monitoring and necropsy of captive wild animals in zoos and other collections. Disease monitoring and necropsy should be conducted for translocated, released, and reintroduced captive wild animals. Such monitoring would benefit from development of programs that link zoos, wildlife rehabilitation centers, and others; captive wildlife can then act as "sentinels" for zoonotic and wildlife disease emergence.

Mid-term Priorities

A focused effort is required to discover the pathogens that cause serious wildlife diseases, and new tools need to be developed for rapid diagnosis. Such efforts would be facilitated by an integrated, national system for mapping the spread and occurrence of wildlife diseases.

Long-term Priorities

Veterinary research is also needed to:

- Improve understanding of stress and its alleviation in captive wildlife.
- Assess the effectiveness of cage design and other strategies to alleviate stress and behavioral problems in captive wildlife.
- Study life history, diet, social structure, and reproductive strategies of some endangered species to aid in the maintenance of adequate, healthy captive populations and future reintroductions.
- Improve anesthetics, antimicrobials, and vaccines for captive wildlife.
- Develop advanced reproductive techniques, including cloning, of captive endangered wildlife and to assess their consequences.

Strategies to Achieve Research Agenda

Understanding wildlife disease dynamics requires knowledge of the ecological and environmental factors that affect transmission dynamics in and between populations. Estimating the risk of disease transmission between wildlife, livestock, and human populations will demand close collaboration among ecologists, microbiologists, and veterinary researchers (NRC, 2002a). Increasingly, collaboration with mathematical modelers of disease dynamics, risk-assessment modelers, geographers, economists, and others will be required to fulfill the agenda. That has already begun in many groups, but increased integration is required to integrate veterinarians into these communities fully.

One approach to the increasing complexity of wildlife-disease research is to form interinstitutional consortia to develop the collaborative research strategy. The formation of consortia of university departments, and federal and state agencies allows an institutional framework for collaborative research. Many states have primacy in the stewardship of most native wildlife species throughout the United States so that those responsible agencies should be involved in developing and implementing research agendas related to veterinary aspects of wildlife management. A number of US-based institutions have begun to develop the field of conservation medicine (for example, The Consortium for Conservation Medicine, The Wildlife Trust, The Conservation Medicine Center of Chicago), which uses an approach that involves bringing veterinary researchers into multidisciplinary teams that address infectious disease threats to conservation of wildlife species.

Disease surveillance can be enhanced by increased collaboration between federal and state agencies and institutions that house captive wildlife or conduct wildlife research. In a National Research Council workshop summary, Friend and McLean (NRC, 2002a) suggested the development of a common database for disease surveillance and monitoring to track infectious diseases and the emergence of new ones.

Wildlife disease investigations could benefit greatly from biological repositories that archive materials for retrospective and comparative studies. Such repositories should include isolates of infectious-disease agents, serum banks, histological specimens, and other biological reference materials that would be readily accessible to veterinary researchers (NRC, 2002a). New molecular-biology tools for surveillance and pathogen discovery will also add to the capacity to investigate wildlife-disease outbreaks.

Veterinary curricula should include study of wildlife diseases of nongame animals and of the conservation consequences of wildlife diseases in response to growing importance of such a discipline. Veterinary schools, curricula should include the conservation implications of wildlife diseases and the principles of conservation medicine. For example, a number of veterinary-college curricula and summer programs offer an opportunity to conduct research on wildlife diseases that are of conservation significance. The University of Illinois at Urbana-Champaign hosts a program titled Envirovet (see http://www.cvm.uiuc.edu/envirovet/) that provides summer training for doctoral students in veterinary medicine in developing countries to study health issues related to environmental or conservation problems. Veterinary curricula should emphasize the interconnections of domestic-animal, wildlife, and human health in the context of healthy ecosystems. They should also provide education in the techniques that ecologists, mathematical modelers, and others use to understand disease transmission so that veterinarians can become the key members of collaborative teams that study wildlife diseases. The recent development of a strategy for wildlife disease in Canada highlights many of those themes (Canada Wildlife Service, 2004).

Finally, wildlife-disease research is vital for public health, livestock health, and conservation. Many emerging diseases and potential bioterrorism agents are carried by wildlife in the United States. The introduction of diseases via the wildlife trade is an unknown risk factor for public health. Furthermore, a number of diseases have recently caused substantial loss of natural diversity and affected hunting, conservation, and the functioning of ecosystems. Highlighting the applied agenda for wildlife veterinary research could enhance the recruitment of veterinarians into wildlife-disease research and increase the awareness of their work among the public and policy makers.

Funding Sources

Wildlife-disease research is funded through a variety of mechanisms but often as a byproduct of research that has different aims. Support for wildlife-disease research is poor and spotty at best and is usually dedicated to only a few species and a few problems and found at a few institutions where researchers have been persistent and creative in patching it together (AAWV, 2004). Many commercial timber companies fund extramural and intramural research on wildlife health, focusing on species present in their commercial forest operations. Extramural funding for veterinary research on wildlife diseases comes from the state agencies, the US Fish and Wildlife Service (FWS), USGS, private foundations, and others. There are no official programs in any federal funding agencies that specifically fund wildlife-disease research. The National Science Foundation (NSF) does not specifically support disease research but funds work on the ecology of diseases in many wildlife species, which is used to understand ecosystem functioning. NIH does not specifically fund research on wildlife diseases, but some research projects focused on ecology of infectious diseases and how they interface with wildlife, domestic animal, and human populations. A joint NSF-NIH program, Ecology of Infectious Diseases, funds research projects on the ecology of wildlife diseases and is discussed in detail in Chapter 4. CDC does not have specific programs on wildlife disease but funds research through studies of wildlife reservoirs of zoonotic diseases.

COMPARATIVE MEDICINE

Examples of Critical Research Needs

- Advanced training of comparative-medicine scientists to support and facilitate biomedical research, with emphasis on expertise in phenotype and behavior assessment of unique rodent strains.
- Further development and refinement of animal models to advance biomedical research.
- Expansion of resources and methods for characterizing the genetic background, phenotype, and behavior of unique mouse and rat strains.
- Enhanced methods for preserving valuable models and improving the reproductive efficiency of laboratory animals.
- Improved methods for genetic engineering in laboratory animal species other than the mouse to advance understanding of select diseases.

Research Agenda

Immediate Priorities

Increasing the number of comparative-medicine scientists to meet the demand for interdisciplinary and translational research should have high priority. Translational research aims to move basic-biology research from the bench to applications for patient care. Biomedical research has evolved to become more interdisciplinary; research is conducted by teams or individuals with backgrounds in two or more scientific disciplines. Veterinarians with training in biomedical research provide an invaluable perspective that is necessary for the advancement of interdisciplinary and translational research. Comparative-medicine veterinarians provide critical research, expertise, and advice in animal modeling and experimental design. Furthermore, as the genetically engineered mouse has become a vital tool for advancing biomedical research in this genomics era, there is an increased demand for phenotype and behavior analysis of these unique strains. Highly trained comparative-medicine veterinarians and scientists are critical for scientific analysis of such unique strains and will have an important influence on the advancement of biomedical research as a whole.

Another effort that warrants high priority is improvement in our understanding of factors that affect the phenotype behavior of unique mouse and rat stains. The phenotype of the genetically engineered mouse can be seriously affected by environmental factors and modifier genes (Nadeau, 2001), but mutations have different phenotypes on different mouse-strain backgrounds (Abeliovich et al., 1993; Smithies and Maeda, 1995; Threadgill et al., 1995). Better understanding is needed to characterize effects of the modifier genes and environment on mutant mouse phenotypes.

Mid-term Priorities

Efficient methods for preserving important rodent strains are needed to maximize the efficiency of laboratory animal housing resources. For example, because of strain phenotype effects, mutant mouse strains are increasingly bred into different mouse-strain backgrounds to uncover phenotypes of the mutations being studied. However, cryopreservation technologies are not consistently well developed in rodent species. Further technological advances with in vitro fertilization techniques that use a frozen sperm from mice and rats are needed. In addition, advances in cryopreservation techniques for rodent and other animal models are needed and would benefit the veterinary research enterprise.

Long-term Priorities

Advances in genetic-engineering technologies in laboratory animal species besides the mouse would be valuable in advancing biomedical research in many respects. However, the technological efficiencies of generating genetically engineered mice have not been easily transferable to other laboratory animal species. For example, fertilized ovum collection, microinjection, and implantation procedures are not nearly as efficient in other species, and that precludes the generation of large numbers of these transgenic animals. Research to develop and use embryonic stem cells to generate "knockout" animals of other species should be expanded. Rapid and streamlined approaches to the transfer of mutations and genomic segments from one strain background to another would foster rapid progress.

Strategies to Achieve Research Agenda

The shortage of veterinary scientists in comparative medicine must be addressed by establishing mechanisms to train additional veterinarians in biomedical research. Veterinary curricula should emphasize research during undergraduate and graduate animal science and veterinary education. Colleges of veterinary medicine should encourage mentoring to give research faculty the opportunity to serve as role models to interest students in careers in comparative-medicine research. Additional programs are needed to provide postdoctoral training of veterinarians in comparative medicine in molecular and cell biology and to characterize the large number of naturally occurring and induced animal models, including rodents.

More institutions should develop phenotype and behavior-assessment cores to facilitate analysis and characterization of unique rodent strains generated. Funding to improve efficient methods for the preservation of unique models will lead to substantial reductions in costs associated with animal research. Finally, improved methods for developing genetically engineered animals of other laboratory animal species could be used to advance understanding of select diseases.

Funding Sources

The NIH National Center for Research Resources (NCRR) provides grant support to advance the training of comparative-medicine scientists to support and facilitate the biomedical research enterprise. Some awards, such as the K26 midcareer Investigator Awards in Mouse Pathobiology Research, are designed specifically to provide research training in phenotype and behavior assessment; other awards, such as the K01 and F32 individual awards and the T32 Institutional Research Training Grants, are designed to train veterinarians in biomedical fields in comparative medicine or comparative pathology. Those are successful programs, but the number of awards falls short of the current demand. NCRR also has R13 (Investigator-Initiated Conference Grants) and U13 (Conference Cooperative Agreements) awards to support scientific meetings.

There is insufficient funding for studies focused on developing efficient methods for preserving important laboratory animal strains or on advancing genetic-engineering technologies for other laboratory animal species. Small awards in those fields may be made by grant foundations, such as the American College of Laboratory Animal Medicine Foundation. NCRR has a mutant-mouse regional resource centers program that supports centers that provide induced mutant-mouse lines to investigators.

EMERGING ISSUES IN VETERINARY SCIENCE

Emerging Infectious Diseases

Examples of Critical Research Needs

- A preemptive approach to predict and prevent infectious diseases.
- New tools to identify novel, potentially zoonotic pathogens in wildlife populations that may be the next HIV/AIDS or SARS coronavirus. Such tools will include microarrays and other sophisticated biotechnological applications based on the pool of known zoonotic EIDs that wildlife populations harbor.
- Increased involvement of veterinary researchers in understanding the wildlife trade as a mechanism of EID introduction and in understanding how zoonotic bioterrorism agents may behave if released in the United States.
- The causes, anthropogenic, ecological and environmental drivers, and effects of emerging diseases of livestock and wildlife.

Research Agenda

Emerging diseases are often associated with substantial human mortality and morbidity. Research is required to achieve a predictive, preemptive approach to EID research. National strategies to deal with the EID threat should focus on predicting the risk of EIDs and developing strategies to alleviate the risk (for example, preventing underlying causes, such as trade in wildlife and high-risk wildlife-human interaction). Models for the predictive approach include a number of projects supported through the NSF-NIH ecology-of-infectious-diseases initiative (NIH, 2002) and a recent study of the risk of non-SIV retrovirus emergence in bush-meat hunters in Cameroon (Wolfe et al.,2004).

Immediate Priorities

To deal with EIDs early during their emergence, diagnostics and rapid screening capacity are required on a global scale that would avoid excessive depopulation in areas of outbreaks. Tools for pathogen discovery have to be integrated into a predictive risk assessment. Surveillance of potential wildlife reservoirs for unknown, potentially zoonotic agents is possible with such molecular tools as microarrays, nucleic acid detection technology (including novel chip technology), and reverse transcription-polymerase chain reaction. Those approaches should be used in areas that are hot spots for EIDs and on wildlife reservoirs known to harbor other zoonotic agents. Research is needed to assess how environmental and ecological drivers of EIDs cause changes in pathogen dynamics between and within populations and allow diseases to emerge.

Mid-term Priorities

There has been a great deal of concern about a number of potential bioterrorism agents, some of which are relatively newly emerged pathogens. Little is known about how such agents as Rift Valley fever, if artificially released in the United States, might persist in wildlife populations and present a continued threat to public health. Research is needed on the role that livestock and native wildlife will play in allowing released bioterrorism agents to become endemic in the United States and cause long-term problems (Box 3-2).

Long-term Priorities

Long-term and on-going research should aim to improve our understanding of the biology and ecology of infectious diseases in wildlife, domestic animals, and other reservoirs. Such knowledge would help in the development of timely responses to and countermeasures against disease emergence and in the rapid identification of emerging agents. Research on the causes of EIDs is required to

BOX 3-2
Example of an Interdisciplinary Research Approach to Studying Diseases—Rift Valley Fever

Rift Valley fever (RVF) is a mosquito-borne viral disease whose cyclic epidemics since the 1930s have had devastating economic effects on livestock populations throughout much of sub-Sahara Africa. Although the virus was not initially thought to be lethal to humans, an epidemic in East Africa in 1997-1998 resulted in the death of several hundred people.

Research with laboratory rats in the early 1980s clearly established that a single gene in LEW inbred strains conveyed resistance to the RVF virus. Anderson et al. (1987) constructed a congenic strain in which the LEW resistance gene was backcrossed onto a susceptible WF inbred strain. Identification of the gene and its variation in resistant and susceptible strains would be a major step in production of resistant livestock or development of effective vaccines for both livestock and humans. Rat-genetics resources were not available in the 1980s to identify and clone the gene, and funding agencies were not sufficiently interested in RVF to sustain the research initiated by those and other scientists.

September 11, 2001, changed our collective thinking about the importance of research on RVF. The disease has been identified as one of many with potential for use in agricultural bioterrorism and is also one of the high-priority diseases identified for attention by the Food and Agriculture Organization's Emergency Prevention System (http://www.fao.org/). The implementation of two very important biotechnologies will permit current science to exploit the valuable rat strain developed by Anderson et al.

- Although resources were not available to maintain the congenic strain as a breeding colony, the scientists and the NIH Division of Veterinary Resources (http://www.ors.od.nih.gov/dirs/vrp/ratcenter/) had the foresight to preserve the congenic strain as frozen embryos.
- A rat genome project has generated a complete sequence of the rat genome and maps of several thousand markers (http://rgd.mcw.edu/about.shtml), which will permit scientists to identify the LEW region in the congenic strain and to identify the specific genetic difference between resistant and susceptible rats.

Rederivation of the cryopreserved colony is under way as this report is being written, and a map- and sequence-based strategy to identify and clone the gene is being funded by the Department of Homeland Security. This work is possible only because the disciplines of epidemiolgy, virology, and mammalian genetics were tied to twenty-first-century genomics through embryology and cryobiology.

understand how such factors as trade, encroachment into wildlife habitat, unnatural mixing of species, hunting, and overpopulation affect pathogen dynamics in animals and cause emerging diseases in humans. Research is needed to develop control strategies, drug candidates, and other therapies for key emerging diseases for which few therapies exist, for example, hemorrhagic fevers; encephalitides, such as Nipah virus disease; and now-endemic emerging diseases, such as West Nile virus fever and hantavirus pulmonary syndrome.

Strategies to Achieve Research Agenda

EID research is multidisciplinary, because these diseases are almost always linked to an ecological factor (such as populations of wildlife reservoirs that migrate or change in patterns seasonally) or to a physical environmental factor (such as climate or pollution) (NRC 2003b). Teams of researchers that include veterinarians, wildlife biologists, geographers, mathematical modelers of disease dynamics, and ecologists have been particularly successful in investigating new EIDs (such as SARS, Nipah virus disease, West Nile virus fever, and highly pathogenic avian influenza) and in dealing with outbreaks of disease once they have emerged in human, domestic animal, or wildlife populations. For example, West Nile virus fever is a disease primarily of avian hosts that spills over into mammalian species, most of which are dead-end hosts for the virus (including humans). Understanding its spread and predicting its effects will require collaboration among vector biologists, climatologists, microbiologists, veterinary researchers, ecologists, and modelers.

Increased collaboration among veterinary researchers working at federal agencies—such as DHS, FWS, and USDA—will allow them to study the role of international wildlife trade in disease introduction and the potential dissemination of bioterrorism agents in wildlife populations.

Veterinary medical curricula should be adjusted to reflect the growing demand for veterinarians versed in issues of bioterrorism, emerging diseases, novel molecular biological approaches to diagnostics, and collaborative team research. Short research projects with laboratories dealing with EIDs would be useful and cost-effective in training the next generation of collaborative research veterinarians.

Funding Sources

Research on emerging diseases is funded largely by NIH programs, including a National Institute of Allergy and Infectious Diseases (NIAID) special emphasis program on biodefense and emerging diseases focused on agents listed as potential or actual bioterrorism agents by CDC and NIAID. NIH programs are heavily targeted to vaccine and drug development to counter traditional biological-warfare agents, with a relatively small focus on epidemiology of zoonotic EIDs. Research on EIDs of livestock, poultry, and aquaculture, including zoonoses and biothreat agents, is funded through CSREES and ARS and has focused on diagnostics, pathogenesis, and vaccines. Other EID research is funded through CDC (including epidemiology and vector-biology research), NSF (biocomplexity program, the NSF-NIH program on ecology of infectious diseases), other federal agencies, state agencies, and private foundations.

Ecosystem Health

Examples of Critical Research Needs

- Definition of what constitutes a healthy ecosystem.
- Development of reliable and predictive indicators of ecosystem health.
- Characterization of the complex interaction between humans, domestic and wild animals, and the environment to predict risks to the health of these populations.
- Studies of the interaction between human and animal communities by multidisciplinary teams that include zoo veterinarians, ecologists and toxicologists, and public-policy experts to understand how human activities affect ecosystems and all their inhabitants, including humans.

Research Agenda

Immediate Priorities

To maintain the health of an ecosystem, we must first define a healthy ecosystem and the thresholds that indicate health. Development of reliable and predictive indicators of ecosystem health should have high priority. It is a complex and time-consuming undertaking, and there appears to be no core set of indicators that can be applied to all ecosystems (Hodge and Longo, 2002; Eyles and Furgal, 2002).

Ecosystem health could benefit from research to develop sentinel-species monitoring. Sentinel species are particularly sensitive to some agents (for example, pathogens and toxins) and act as indicators of their presence. Good examples are crows for West Nile virus and freshwater fish for some tumor-inducing chemicals.

Mid-term Priorities

Domestic and wild animals may be used as bioindicators or sentinels of ecosystem health (Tabor and Aguirre, 2004), and other reliable predictive indicators of ecosystem health could be developed, such as seabird dieoffs, which are often due to algal blooms, and amphibian deformities, which appear to be caused by increased prevalence of limb-bud parasites due to eutrophication of waterbodies or chemical pollution.

Studies should be conducted on the effects of management practices on ecosystems and thus the health of domestic and wild animal populations and on which features of the interaction of humans and domestic and wild animals with the ecosystem give rise to EIDs or risks to food safety. Ecologists and veterinary researchers should work together to determine the adequacy of information that is needed to support decision-making, especially if the decisions involve complex ecosystems that are not well understood.

Long-term Priorities

Systems theory and complexity-modeling approaches can be used to capture the important interactions that characterize open systems and to determine how social, economic and ecological variables should be weighed. Continuous research is needed to validate our concept of a healthy ecosystem.

Strategies to Achieve Research Agenda

The complex and wide-ranging interactions that characterize ecosystems require veterinary researchers trained in epidemiology, ecology, conservation, infectious disease, and other biological and social-science disciplines. A key strategy to move ecosystem-health research forward is to foster interdisciplinary research. Facilitating interdisciplinary research through interinvestigator, team, or institutional collaboration and a flexible posture on the part of agencies that fund the research are important.

Funding Sources

Funding for ecosystem-health research tends to be sporadic and is usually based on ecological studies on the effects of environmental changes on ecosystems. The research is not supported by one major agency but tends to be supported by small grants from a wide variety of state and federal government agencies (NOAA's Sea Grant Program, NSF, the National Institute of Environmental Health Sciences), nongovernment and private agencies (various foundations committed to understanding environmental issues). Under NIH, NIEHS funds programs on the effects of toxic chemicals on ecosystem health. The establishment of large-scale and long-term interdisciplinary and collaborative research on ecosystem health is limited by changing and differing research priorities among funding agencies.

Social Policies, Societal Needs, and Expectations Including Animal Welfare

Examples of Critical Research Needs

- Studies that objectively define, measure, and validate the benefits of social housing and environment enrichment.
- Science-based methods to measure stress and distress and stress-related effects in animals.
- Scientific analysis that uses quantifiable indicators to measure the effects of pharmaceutical agents and genetic modifications on animal welfare.
- Multidisciplinary studies of detection, control and prevention of large-scale zoonotic disease outbreaks that require disposal of large numbers of animals.

Research Agenda

Immediate Priorities

An immediate need for veterinary research pertaining to social policies is to quantify measurable stress and distress characteristics in animals of all types to be used in objective evaluation of management practices for animal welfare. The physiological and welfare-related effects of pharmaceuticals used to alter metabolism or performance in animals should be evaluated.

Effective methods for disposing of large numbers of animals subjected to diseases of natural or human introduction or to natural weather-related disasters need to be developed. The methods should be safe and socially acceptable.

Mid- and Long-term Priorities

New knowledge of the genome of each species should be applied in ways that enhance disease resistance, and minimize stress and distress responses to existing environmental conditions.

Strategies to Achieve Research Agenda

The critical kinds of research noted here receive only minor attention. The critical strategies to be used include priority-setting among the needs by funding agencies, provision for sustained support to enable the building of human and physical resources to conduct the needed research, and recognition that implementation of its results will have social and economic benefits.

Funding Sources

A small amount of research to assess welfare requirements of agricultural animals is supported by USDA. Welfare studies on other animals rely on spotty financial support from private industry and foundations.

Exotic and Caged Pets

Examples of Critical Research Needs

- Characterization of the zoonotic pathogens capable of being carried by exotic species and also those pathogens that may be transmitted to domestic and wild animal populations.
- Improved methods of diagnosis and treatment of exotic animal diseases, especially in regards to safe and effective anesthetic and analgesic protocols.
- Determination of appropriate husbandry requirements for many exotic species.

Research Agenda

Immediate Priorities

The discipline of exotic and caged-pet medicine should give high priority to the detection and characterization of new and emerging zoonotic infectious agents. Diagnostic tests are needed to identify zoonotic agents rapidly, and effective treatment and control measures for those zoonotic agents should be identified.

Mid-term Priorities

The growth of exotic-pet ownership has put considerable pressure on practicing veterinarians as they attempt to diagnose and treat little-known diseases with pharmaceutical agents that have never been investigated in the species of concern. Research is needed especially on appropriate and effective anesthetic and analgesic protocols in many species.

Long-term Priorities

A key long-term research issue is the appropriate husbandry requirements (nutrition, behavioral, and environmental) of the most commonly kept species and species that are new and emerging. Because of the demanding and, in some cases, little understood husbandry requirements of many exotic species, there is concern about the welfare of many species kept in captivity (Keeble, 2003). Some commentators and animal-welfare advocacy groups take the position that exotic animals should not be kept as pets (Engebrestson et al., 2003). They believe that the complex behavioral and nutritional requirements cannot be met in captivity and that suffering and shortened life spans result. Research on the animal-welfare issues related to exotic-pet ownership and appropriate husbandry practices is required to determine which species should not be kept as pets.

Strategies to Achieve Research Agenda

The assessment of risks posed by and effects of zoonotic agents requires the application of genomics, proteomics, and sequencing of the agents. Research expertise in exotic- and caged-pet physiology, pathology, and immunology; advanced molecular biological techniques; epidemiology and population health; and diagnostic tests and therapeutic agents is needed. Experts would have to work with genome-sequencing centers and would require access to the appropriate biosafety laboratories.

Funding Sources

Funding for research on exotic-pet health and husbandry issues is sparse. Funds are available from some private funding organizations (for example, the Morris Animal Foundation) and from internal veterinary-college research funds (for example, pet- or companion-animal trust funds).

4

Resources for Veterinary Research

Veterinary research takes place in many venues and is supported by varied agencies, foundations, companies, and donors. Much of the research in veterinary science takes place in academic institutions, such as schools and colleges of veterinary medicine, agriculture, medicine, and biology. Research on diseases of food-producing animals, including poultry, occurs also in the US Department of Agriculture, Agriculture Research Service (ARS). Other entities include private industries, especially those committed to animal health and nutrition, and the medical pharmaceutical industry.

Support for research comes from several federal agencies, such as the National Institutes of Health (NIH) and USDA; state governments; private foundations; public and privately held companies; and academic institutions. Some federal agencies support research through internal research programs and extramural research grants to investigators in academic institutions and other research organizations. USDA is especially noteworthy because it has a large internal research program in ARS and provides extramural research support via the Cooperative State Research, Education and Extension System (CSREES). To a lesser extent, NIH, the Centers for Disease Control and Prevention (CDC), the Department of Defense (DOD), and other federal agencies also have both internal and external research programs in veterinary science.

This chapter reviews the research capacity—such as infrastructure, expertise, human resources, education, and financial resources—that has been built for veterinary science at universities, zoological parks, government agencies, and some other institutions.

OVERARCHING RESOURCES

The USDA CSREES maintains the Current Research Information System (CRIS), which compiles information on all funding sources used in agriculture, including those for such broad fields as animal systems and animal health and protection. USDA research agencies, state agricultural experiment stations (SAESs), state land-grant colleges and universities, state schools of forestry, cooperating schools and colleges of veterinary medicine, and USDA grant recipients at other institutions contribute information to CRIS. In 2003, research funding for animal systems (RPA 301-315) was close to $1 billion: the largest contributors of funding were the states and USDA (Table 4-1). However, the greatest

TABLE 4-1 Source of Funds for Animal Systems Research in FY 1998-2003 as reported by Current Research Information System for 15 Fields[a]

	Funds (thousands)					
	Fiscal Year					
Source	1998	1999	2000	2001	2002	2003
USDA[b]	$104,760	$117,121	$122,219	$133,855	$144,408	$152,445
Other USDA[c]	10,682	11,004	12,970	18,856	22,878	23,713
CSREES ADM[d]	77,336	74,978	79,088	83,637	87,178	91,870
State funds	289,771	302,520	304,970	315,566	296,144	299,943
Other nonfederal[e]	160,103	151,063	167,922	180,900	187,261	197,655
Other federal[f]	110,999	151,320	156,458	181,552	219,499	232,644
Total	$753,651	$808,007	$843,627	$914,366	$957,368	$998,270

[a]CRIS reporting categories RPA 301-315 (reproduction, nutrition, genetics, animal genome, animal physiology, environmental stress, animal production and management, improved animal products, animal disease, external parasites and pests, internal parasites, toxicology, and animal welfare).

[b]USDA: regular USDA appropriations used for inhouse research by USDA research agencies and centers (excludes CSREES programs). (Form AD-418 field 131)

[c]Other USDA: expenditure of funds received by SAESs and other cooperating institutions from contracts, grants, or cooperative agreement with one of the USDA research agencies other than CSREES. Identification of awarding agency is not collected. (Form AD-419 field number 219)

[d]CSREES ADM: expenditure of formula and grant funds administered by CSREES and distributed to SAESs and other cooperating institutions (OCIs). Programs included are National Research Initiative, Hatch, McIntire-Stennis, Evans-Allen, Animal Health, Special Grants, Competitive Grants, Small Business Innovation Research Grants, and other CSREES grant programs. (Form AD-419 field 31)

[e]Other nonfederal: expenditures by USDA agencies, SAESs, and OCIs of funds received from sources outside federal government, such as industry grants and sale of products (self-generated).

[f]Other federal: expenditures by USDA agencies, SAESs and OCIs of funds received from federal sources outside USDA through contracts, grants, and cooperative agreements directly with other federal agencies. Sponsoring agencies may include National Science Foundation, Department of Energy, DOD, Agency for International Development, NIH, Public Health Service, Department of Health and Human Services, National Aeronautics and Space Administration, and Tennessee Valley Authority. (Form AD-418 field number 332 / Form AD-419 field number 332 minus field 219)

SOURCE: USDA-CSREES.

TABLE 4-2 Funding of Research in FY 1999-2003 for Animal Systems, Food Safety, and Zoonoses as Reported by Current Research Information System

Code and Research Subject	1999	2000	2001	2002	2003
301 Reproductive performance	$86,055	$85,758	$87,737	$90,751	$94,219
302 Nutrient use	80,981	88,822	97,706	98,526	94,129
303 Genetic improvement	49,031	49,082	51,930	55,018	60,459
304 Animal genome	16,088	26,268	26,417	37,081	46,778
305 Animal physiology	118,314	118,220	131,177	139,370	143,077
306 Environmental stress	18,460	19,615	18,943	17,879	20,042
	368,929	387,765	413,910	438,625	458,704
311 Animal disease	302,338	313,703	348,745	369,125	379,650
312, 313 Parasites	33,037	34,362	34,283	36,657	36,594
314 Toxicology	24,836	23,926	25,886	26,348	31,472
315 Animal welfare	12,371	13,067	13,921	14,812	16,799
	372,582	385,058	422,835	446,942	464,515
711 Food-product safety	16,228	13,689	15,769	19,321	22,630
712 Preventing food contamination	90,907	107,383	122,639	134,015	145,095
721 Insects and pests	19,774	20,615	22,783	25,648	27,740
722 Zoonotic diseases and parasites	7,090	8,220	9,705	10,550	14,350
723 Hazards to human health	17,178	18,743	23,269	29,709	37.186
	151,177	168,659	194,165	219,243	247,001

SOURCE: USDA CSRESS CRIS.

increase in funding (109%) from 1998 to 2003 was in the other federal category, and this indicates the growing importance of animal health research as it affects public health, bioterrorism mitigation, such basic science fields as ecology, laboratory animal medicine, and other nonagricultural fields of research.

The $1 billion of funding in animal systems includes fields other than animal health and protection. Closer analysis suggests that direct funding for diseases, their agents, and their effects (RPA 311-315) is at a much lower level of $464 million and includes cross-cutting areas of zoonoses. Food safety accounts for an additional $247 million (Table 4-2). However, any of those three funding levels are lower than what is needed to solve animal health and protection problems.

SCHOOLS AND COLLEGES OF VETERINARY MEDICINE

There are 28 schools and colleges of veterinary medicine (CVMs) in the United States. Almost all are parts of major land-grant universities. The first CVM was founded in 1877, the youngest was founded in 1998 and admitted its first class in 2003. Because the youngest has been operating for less than 2 years, it was omitted from many of the resource analyses in the following sections.

The mission of all every CVM includes teaching the art and science of veterinary medicine to professional students: providing postgraduate education for graduate students, interns, residents, and practicing veterinarians; and advancing veterinary research. The CVMs operate teaching hospitals to provide clinical education for their professional students and referral resources for the practicing veterinary community. Many also operate field patient-care units to serve farms and ranches. Research is an important component of CVMs and is included as one of the points of evaluation in the accreditation process (AVMA, 2004b). The CVMs conduct much of the academically based veterinary research in the United States.

Facilities and Infrastructure

Facilities and infrastructure related to research in CVMs consist of buildings for classrooms, research laboratories, offices, and the like: barns and pastures; non-CVM support laboratories, such as laboratory animal facilities and central research service laboratories; libraries; diagnostic laboratories; and a variety of CVM and campus-based information-technology resources, such as super computers and electronic information management and exchange. Some CVMs have access to other, specialized research-support infrastructure, such as unique databases, computerized patient-record systems, and banks of specialized research materials (for example, tissue banks).

Libraries constitute an important resource for veterinary research. Libraries range from large collections, such as the National Agricultural Library and the National Library of Medicine, to small collections in individual departments. Every university, many schools and colleges, many departments, and essentially all other research venues, such as research institutes and industry, have libraries. Collections can number in the millions and often extend back many decades or even several centuries. Those collections set new research into proper historical context and help to avoid duplication of work. In addition to collections of books and periodicals, all research libraries nowadays have electronic search capabilities and large collections of electronic data and publications. Librarians who are well trained and experienced in both conventional and electronic literature searches can develop extremely useful searches not only of the traditional peer-reviewed scientific literature, but also of Web sites and other on-line information sources that are invaluable in many research projects. Libraries are sometimes overlooked when funds for research resources and infrastructure are allocated.

Estimating the size and adequacy of the facility infrastructure available to CVMs for research is difficult because some resources are not devoted solely to veterinary research. CVMs engage in multiple activities in addition to research, including teaching of professional students, clinical patient care, and diagnostic services. Perhaps because of the difficulty in defining resources dedicated to veterinary research, there is no centralized source of information on the size of the infrastructure of CVMs. Moreover, much of the research infrastructure listed above may be shared with other, nonveterinary research activities. For example, libraries, animal housing, research laboratories and centralized facilities for such activities as electron microscopy, molecular sequencing, electronic data management, and statistical analyses are often shared with faculty outside the CVMs.

There seem to be no data on the amount of research space available in CVMs. The only relevant data the committee could locate are in a survey conducted by the Association of American Veterinary Medical Colleges (AAVMC). CVMs were asked to identify their needs for space and equipment to train an additional 241 veterinary students and 658 new graduate students (AAVMC, 2004). The results of the survey are summarized in Table 4-3. Separating infrastructure devoted to professional-student instruction from that for research is difficult. Although some facilities, such as classrooms, are used mostly for professional-student instruction, they also are often used for graduate-student instruction, research symposiums, and seminars. The same holds for teaching laboratories. CVMs reported that about 400 new faculty persons and about 2.25 million square feet of new and renovated research space would be needed for education and training of additional veterinary and graduate students.

Laboratory equipment is another major category of research infrastructure, and obtaining data on this category is even more problematic. The best figure obtained was from the AAVMC survey of CVMs (AAVMC, 2004), which reported the need for about $37 million in one-time funds for equipment. The proportion of the proposed new equipment funds allocated for research is not known, and the numbers do not show the total amount, condition, or value of research equipment now available in CVMs.

Every CVM provides some level of patient care as part of its clinical teaching program, and some CVMs have large patient populations, including access to large numbers of farm animals and horses through a variety of outreach programs (Table 4-4). Collectively, CVMs have over 10 million animal patients or patient visits a year (Table 4-4). However, not all patients are suitable for research programs, and owner consent is required.

Clinical records can be useful resources if they are archived properly and kept in a uniform format that allows comparison and analysis. However, teaching

TABLE 4-3 Infrastructure Needed for Colleges of Veterinary Medicine to Support 241 Additional Veterinary Students and 658 New Graduate Students

Category	New (gross square feet)	Renovated (gross square feet)
Classrooms	165,197	79,392
Teaching laboratories	188,714	106,932
Research laboratories	656,662	309,085
Faculty offices	147,216	44,086
BSL-3 laboratories	146,454	12,456
BSL-3 animal housing	336,743	58,700
Totals	1,640,986	610,651

SOURCE: AAVMC member survey, 2004.

TABLE 4-4 Total Patient Contacts by Faculty Members in All CVMs in 2002

	Hospital Visits (Small Animal) or Animals Examined (Food Animals and Horses)[a]			
Animals	Mean	Median	Range	Total, All CVMs
Small animals	12,700	12,000	4,500-27,700	354,500
Cattle	14,000	11,600	2,300-62,000	439,500
Swine	12,600	276	3-175,300	276,300
Horses	3,400	2,000	7-16,220	88,300
Poultry	342,000	353	2-8,152,000	8,890,000

[a]CVMs that did not examine animals of a given category were excluded in all cases.

SOURCE: AAVMC, 2004.

hospitals commonly maintain paper or electronic records in formats that are not easily interchangeable or manipulated. With the exception of the Veterinary Medical Database (www.vet.purdue.edu/depts/prog/vmdb.html), there are no national databases and no centralized records for patients or data on patients—such as radiographs, clinical laboratory data, or necropsy or biopsy data—as far as the committee is aware. A number of repositories or collections of material are sometimes available for research. For example, the Armed Forces Institute of Pathology Department of Veterinary Pathology, housed at Walter Reed Army Medical Center in Washington, DC, maintains a large collection of lesions of domestic and some wild animals. The Registry of Tumors in Lower Animals is a collection of lower-vertebrate and invertebrate tumors at the George Washington University Medical Center in Washington, DC. Those collections can be considered as national databases because the centers accept material from the entire country and from around the world, but they do not represent the incidence or prevalence of diseases in domestic animals in the United States, because they rely on voluntary submissions.

There is a recent effort to make all the clinical records from a large private practice's database available to the research community (Wiese, 2003). That is a commendable effort, but it is still in its early stages, and insufficient time has elapsed to see whether successful collaborations can be sustained and expanded. Nonetheless, the collaborative effort illustrates the potential power of data-sharing among CVMs and large private practices. Many changes need to occur before veterinary researchers can take full advantage of the relatively large numbers of patients seen by CVM faculty members, and even more effort will be needed to involve the private-practice sector in research. Adding public and private diagnostic laboratories would further enhance the research value of clinical data.

Some clinical research is conducted. Prospective and retrospective studies are carried out. Patients are entered into a variety of intrainstitutional or multicenter research protocols. Successful programs in which patients are screened for targeted diseases and entered into appropriate research programs have been maintained. Chemotherapy for malignant disease in small animals has been advanced greatly through multicenter trials (Vail et al., 1995). The multisite coordinated study of the so-called vaccine-site fibrosarcomas is another example of a successful clinically based research program (Morrison and Starr, 2001). Industry uses the unique expertise of CVM faculty and their access to patients to further the development of new and improved vaccines, pharmaceuticals, diets, and diagnostic tests. All those research and development projects could be enhanced and facilitated if there were more comprehensive national databases.

Expertise and Human Resources

A wide variety of both clinical and basic-science expertise is represented among about 2,665 full-time equivalent (FTE) faculty in the nation's CVMs. The major research credential for veterinary researchers is the doctoral degree. In contrast with human-medicine researchers, who often prepare for research careers with non-degree-granting research fellowships, veterinary researchers are likely to have obtained advanced graduate degrees. Members of the clinical departments almost always have DVMs (or the equivalent). Most members have specialty certification, and many have master's degrees. Veterinarians in basic-science departments are very likely to have PhDs and may or may not have specialty certification,[1] depending on the subject-matter responsibilities of the department.

In addition, many members of CVM faculties do not have DVMs, but almost all such persons have PhDs or the equivalent. The committee could not obtain quantitative data on the number of nonveterinary PhD scientists in the nation's CVM faculties. The most recent data available are from the AAVMC Comparative Data Report for the academic year 1995-1996. The report shows that the 27 CVMs in existence at that time had a total of 2,303 faculty members (assistant professors and above), of whom 479 (21%), including 10 administrators, had PhDs without DVMs. On the basis of that information and the experience of many committee members with faculties of CVMs, the committee estimated that scientists with PhD degrees but without DVM degrees now constitute 20-35% of most CVM faculties, that is, about 530-930 FTEs nationwide. The majority of those scientists work in basic-science departments, and many engage in research. Indeed, nonveterinary PhD scientists form the heart of many basic-science research programs in many CVMs. About 25% of the full-time faculty of the nation's schools and colleges of medicine have PhDs, or other health doctorates

[1]The American Veterinary Medical Association lists 20 recognized veterinary specialty colleges that certify clinical specialization, but many include diplomates who engage in research. Examples of specialty colleges that have many diplomates engaged in research are the American College of Veterinary Pathologists, the American Board of Veterinary Toxicology, the American College of Laboratory Animal Medicine, and the American College of Veterinary Microbiologists.

such as in dentistry or veterinary medicine—without MDs (AAMC, 2001; AAVMC 2004.)

Among the 2,665 FTE faculty in the nation's CVMs, about 130 are administrators. The faculty receive some assistance, either with teaching or clinical patient care, from interns (about 177), nonclinical residents (about 70), and clinical residents (about 600), but interns and residents require supervision and assistance from faculty. Graduate students and postdoctoral researchers also contribute to the research programs and require supervision, assistance, and mentoring.

The committee attempted to estimate how much time, on the average, faculty have for research, as opposed to formal teaching, patient care, student advising, committee work, and other professional commitments that make up academic life. Even when one includes as "research time" such important activities as informal teaching of graduate students and postdoctoral researchers in laboratories, journal clubs, seminars, research discussions and the like, it is unlikely that the estimated 2,665 FTE faculty have more than 50% of their time, on average, to devote to research. That suggests that the entire country has perhaps about 1,300 FTE faculty in schools and colleges of veterinary medicine available to conduct research in veterinary science. Given the heavy teaching and patient-care loads of many faculty (the veterinary student:faculty ratio is about 3.6:1 compared with the medical student:faculty ratio of about 0.63:1), the committee believes that, on the average, veterinary faculty have considerably less than 50% of their time available for research.

Postdoctoral fellows also contribute substantially to research in CVMs. They bring their scientific experience and ideas and provide laboratory support for faculty, who have competing demands. Most postdoctoral fellows are supported by individual investigators' research grants (Singer, 2004). Postdoctoral fellows as a human resource in CVMs cannot be quantified, because data are not available.

Education

A primary mission of all CVMs is education. In addition to educating students to become doctors of veterinary medicine, CVMs educate interns and residents, graduate students and postdoctoral fellows, and often undergraduate students. Some CVMs have large degree-granting undergraduate programs that are independent of the professional programs and have hundreds or thousands of enrollees. Continuing professional education for veterinarians and public outreach via extension or client education are provided by all CVMs. CVMs also serve as a general resource for the community for a broad variety of topics related to animals. Education of the scientific community via presentations at scientific meetings and publications in refereed literature is a fundamental responsibility of veterinary researchers.

In 2003, 28 CVMs in the United States reported an enrollment of 9,587 students (2,270 men and 7,317 women) in the professional veterinary medical-education programs leading to the DVM or VMD degree (AAVMC, 2003a; Appendix F). Of those, 2,308 were enrolled in the fourth year and thus expected to graduate in spring 2003, which is comparable with the numbers of graduates in the past several years. From 1995 to 2004, the number of professional students enrolled in CVMs increased by 733 and the number of full-time equivalent faculty increased by 448. Student/faculty ratio has remained steady at about 3.5 since 2001 (Appendix F). In the 2003 AAVMC report, CVMs reported graduating 1,882 students with bachelor of science (BSc) degrees,[2] 315 with master of science (MSc) degrees, and 284 doctor of philosophy (PhD) degrees. The committee is not aware of any sources of the numbers of students enrolled in degree-granting programs other than the professional and graduate curricula.

Figures 4-1 and 4-2 show the data on graduate enrollment in CVMs in 1993 to 2000 and graduate degrees awarded in 1993 to 2003. (Data on enrollment are not available beyond 2000.) The number of US veterinarians and nonveterinarians enrolled in MS and PhD programs declined from 1993-1994 to 1994-1995 for unknown reasons. After that, enrollment in graduate programs remained steady, with a slight upward trend in non-DVMs and a slight downward trend in DVMs enrolled in MS and PhD programs. The enrollment numbers for foreign students remained more or less constant (Figure. 4-2). Foreign students constitute 31-35% of PhD students enrolled in CVMs. With the exception of 1996-1997, the number of PhD degrees awarded to US and foreign students increased, albeit somewhat irregularly, from 159 in 1993-1994 to a high of 318 in 2001-2002, followed by a decline to 284 in 2002-2003. The number of MS graduates followed a similar pattern (Figure 4-2). The gradual rise in the number of PhDs awarded coupled with decreases in DVMs seeking PhDs and the increase in non-DVMs enrolled in PhD programs suggests that fewer DVMs are earning PhDs now than a decade ago (Freeman, 2005; NRC, 2004b).

Because of the length of time required and the attendant costs, most veterinarians do not continue their research education with postdoctoral experience. In contrast, researchers who are nonveterinarians commonly spend 2 years or more as postdoctoral fellows. Typically, veterinarians can expect to spend 3-4 years in a general undergraduate curriculum, 4 years in a school or college of veterinary medicine, and 4-5 years to obtain a PhD. The time for postgraduate training may also include preparation for a specialty certification. Those who do not obtain DVMs can go directly from undergraduate to graduate programs and may then pursue postdoctoral training. Thus, the time required for a veterinarian to obtain a DVM and a PhD is comparable with the time required for a nonveterinarian to obtain a PhD plus postdoctoral training. However, the cost to the person may differ substantially because the high tuition fees of veterinary school are rarely

---

[2]Some CVMs routinely offer qualified students enrolled in the professional curricula the opportunity to obtain a BSc as part of their professional educational program so that veterinary students who are also earning BSc degrees may be counted twice.

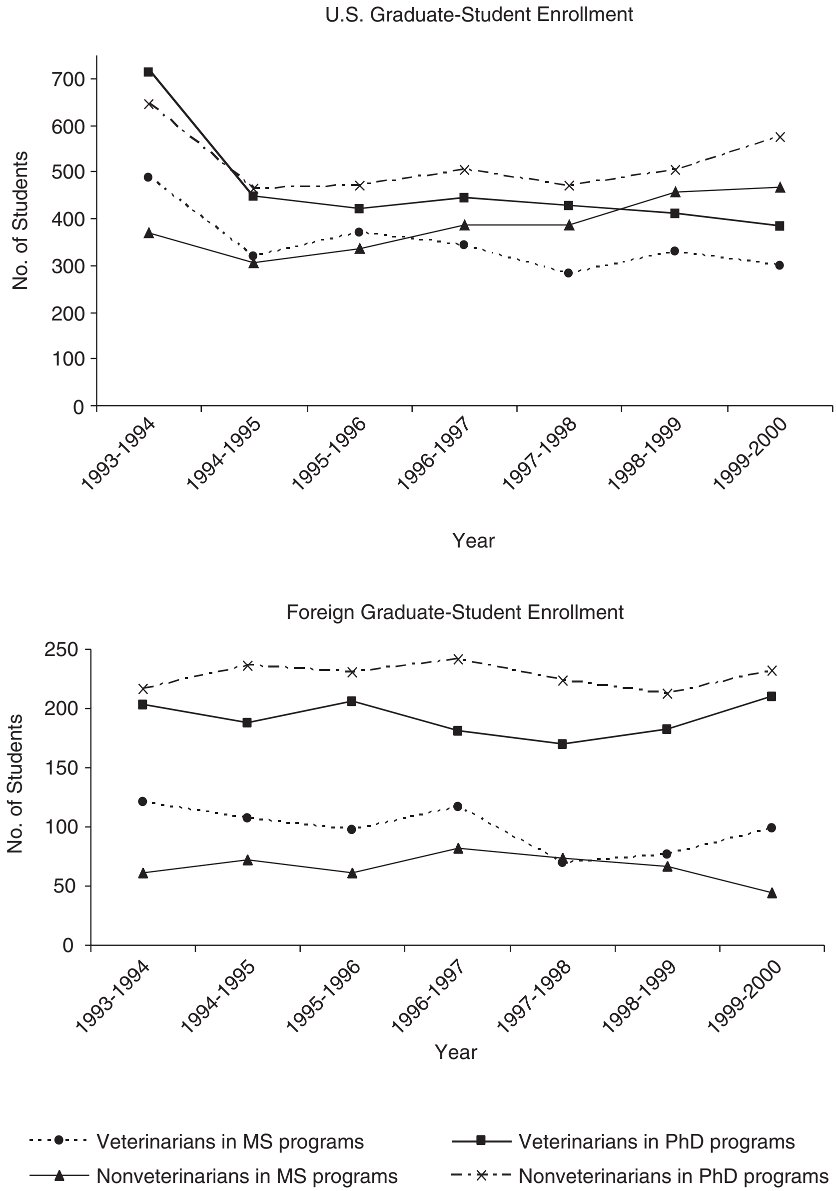


FIGURE 4-1 Number of US and foreign graduate students enrolled in colleges of veterinary medicine in the United States, 1993-2000. Veterinarians (DVMs) in MS and PhD programs include those with or without concurrent enrollment in residency programs. SOURCE: Association of American Veterinary Medical Colleges.

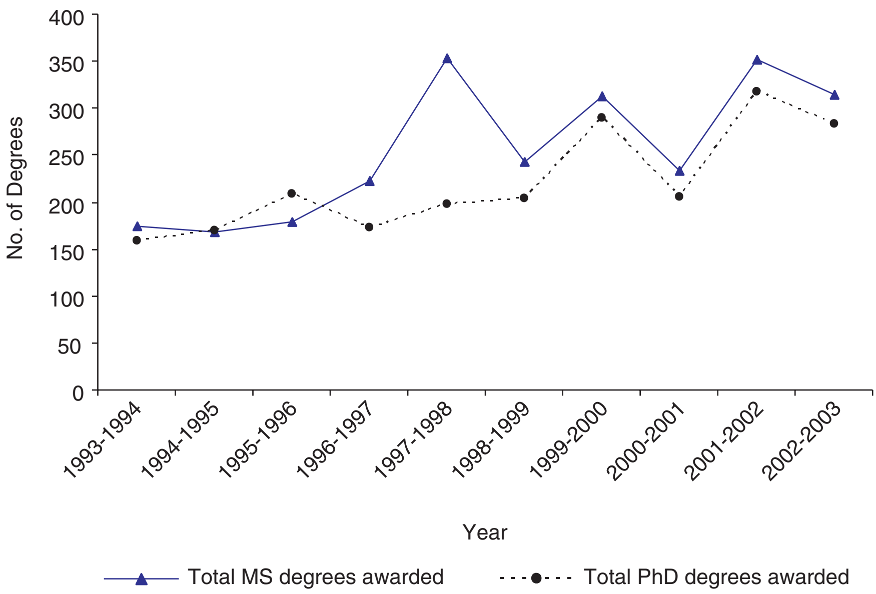


FIGURE 4-2 Number of MS and PhD degrees awarded to US and foreign students by colleges of veterinary medicine in the United States, 1993–2003. SOURCE: Association of American Veterinary Medical Colleges.

offset by scholarships or training stipends. Most veterinarians and nonveterinarians obtain at least partial financial support for graduate and postdoctoral training. Veterinarians often find themselves facing substantial debt at the end of graduate school. Many opt to enter their research careers directly instead of pursuing postdoctoral training, which allows a scientist to mature and become an independent investigator. A postdoctoral researcher has an opportunity to get research experience as a semiautonomous investigator, obtain a research grant relatively independently, and perhaps most important, establish a network of contacts and collaborators that often lasts throughout one's career. In fact, many believe that the major debt owed by veterinarians at the end of the professional curriculum is a substantial deterrent to their even considering graduate education (Freeman, 2005). The mean educational debt of 2004 graduates reporting debt was $81,052, and 76.9% of new graduates had incurred debt of $40,000 or more. Some 91% of the mean debt of 2004 graduating veterinarians was incurred while they were enrolled in CVMs (Shepherd, 2004).

In 2004, 1,814 (81.5%) of 2,225 new graduates of 26 of the 27 CVMs responded to an American Veterinary Medical Association (AVMA) survey about their employment and career choices. Among the 1,391 respondents who answered the question, 358 (25.7%) were entering advanced-study programs (Shep-

TABLE 4-5 NIH Training Awards to CVMs

	1993		2003	
Award Category[a]	Number of Awards	Amount (millions)	Number of Awards	Amount (millions)
F	42	$1.1	38	$1.5
K08	2	0.2	39	4.1
T32	19	2.2	33	6.8
T35	5	0.2	11	0.7
T37	7	1.5	0	0

[a]F = fellowship awards, including F08, individual national research service awards
K08 = clinical investigator awards
T32 = institutional national research service award
T35 = short-term training
T37 = minority international research training grants

SOURCE: NIH Office of the Director.

herd 2004), but it is unclear how many were pursuing graduate studies in CVMs. The total number of interns and residents employed by CVMs in 2002 was reported to be about 845. Although the duration of most internships is 1 year, most residencies last longer than 1 year. Furthermore, not all newly employed interns and residents are new graduates of professional programs. Because current data on the total number of graduate students enrolled in CVMs and the number of veterinarians seeking graduate degrees or nondegree research training outside CVMs are not available, the committee cannot accurately estimate the number of veterinarians actively preparing for research careers in CVMs.

There are very few data on sources of support for graduate students in CVMs. Schools and colleges provide some internal funds as stipends, scholarships, or paid tuition, but many students pay part or all of their educational expenses. A variety of organizations—such as USDA, the military, and CDC—have grants and other mechanisms for supporting graduate education for veterinarians. NIH provides a number of awards for support of advanced training (Grieder and Whitehair, 2005), some of which go to CVMs (Table 4-5). K08 awards to veterinarians affiliated with CVMs increased from two in 1993 to 39 in 2003—a factor of almost 20. K08 awards to all recipients in the same period increased by about 86% (data not shown).

Financial Resources for Research

In 2002-2003, CVMs reported total research expenditures of $321.2 million on a total of 5,794 research awards (Table 4-6). Of those, 1,247 were from the Department of Health and Human Services (mostly from NIH), with expenditures totaling $155.6 million. Data from NIH for 2003 show 590 awards (in all

TABLE 4-6 Research Expenditures in Colleges of Veterinary Medicine, FY 2002-2003

Funding Source[a]	Amount (millions)[b]	Number of Awards
NIH, FDA, and CDC	$155.6[c]	1,247
USDA	34.4	595
DOD	5.9	53
EPA	1.8	31
NASA	2.6	24
NSF	3.5	48
DOI	0.8	34
Other Federal Agencies	7.6	116
State Agencies	38.8	558
Industry	25.2	942
Private	30.4	1,291
Other	14.6	855
Totals	$321.20	5,794

[a]FDA=Food and Drug Administration, EPA=Environmental Protection Agency, NASA=National Aeronautics and Space Administration, NSF=National Science Foundation, DOI-Department of the Interior.
[b]Including indirect costs if applicable.
[c]About $154 million from NIH.

SOURCE: AAVMC, 2004.

categories except contracts) totaling about $181 million to investigators in CVMs. The discrepancy between the two figures can be explained by the fact that the CVMs and NIH fiscal years are different and NIH reports amount awarded, whereas the CVMs report amount expended. About 200 of the NIH awards (worth about $63 million) were to veterinarians, so about 390 awards valued at about $118 million went to nonveterinarians in CVMs.

All faculty in CVMs (including veterinarians and nonveterinarians) were awarded 331 R01 grants from NIH in 2003 with a total value of $97 million. On the average, each FTE accounted for 0.124 R01 award with an average value of about $36,500. In comparison, all faculty in colleges of medicine obtained 0.148 R01 award per FTE with an average value of about $50,000 in 2003. That suggests that CVM faculty members are competitive at the highest level, especially in light of the average student:faculty ratio in CVMs of 3.6:1 compared with 0.6:1 in colleges of medicine. The accomplishments of CVM faculty also are impressive in that the 5,794 research awards totaling $321 million in research expenditures were obtained by 2,665 CVM FTEs, most of whom spend less than 50% of their time on research.

The number of awards and amount of funding from NIH dominate, reflecting the importance of comparative medicine in veterinary research and the relatively large extramural research budget of NIH. Data from NIH show that veterinarians affiliated with CVMs received 134 awards in all categories (excluding contracts) in 1993 with a value of $25 million.[3] By 2003, the number of awards had increased to 197 with a value of $63 million. When all NIH awards (excluding contracts) to all investigators affiliated with CVMs are considered, the numbers in 1993 were 407 awards and $67 million, and those for 2003 590 and $180 million. The data indicate that veterinarians account for about one-third of the awards and 35% of the funds awarded to CVMs by NIH in 2003, a slight improvement from the roughly 27% of the funding to veterinarians in 1993. The data also emphasize the importance of the nonveterinary PhD scientists to the research programs of CVMs. Given that those scientists constitute 20-35% of the CVM faculty FTEs, it follows that about one-fifth to one-third of the CVM faculty account for about two-thirds of the research funds from NIH.

Table 4-7 shows another breakdown of awards from NIH from FY 1997 to FY 2001, when the NIH budget doubled. (FY 2003 awards are included to evaluate whether increases have been sustained.) The number of awards to veterinarians in CVMs increased at about the same percentage as did those to all investigators. When both veterinarians and nonveterinary investigators in CVMs are taken together, the percentage increase for R01 awards was considerably higher than that of all investigators. Nonveterinarians were responsible for 74% to 81% of all R01 awards to CVMs in each of the years shown.

USDA is not the second-largest source of extramural research expenditures, but rather the third, being exceeded by the state. At least one CVM includes state funding for a large diagnostic laboratory in its total of state funds for research, and others may do so as well. Therefore, the expenditures of state funds for research, as opposed to diagnostic laboratory activities (granted that some of these activities may be research) may be overstated. When those two sources are grouped, the number of awards (1,153) is about the same as the number from the Department of Health and Human Services (DHHS) (1,247), but the amount of funding is less than half ($155 million from DHHS and $73.2 from USDA plus state sources). Funds from USDA and some state funds support projects relevant to agriculture (including horses), but the amounts seem small, considering that the US food and fiber industry generates over $200 billion a year in farm cash receipts (USDA, 2003). Disease costs the livestock industry and consumers about $1 billion a year (USAHA, 2004).

Funding to CVMs from industry and private sources is comparable with that from USDA. The number of awards from private sources slightly exceeds the number from DHHS and from industry. The relatively large number of awards suggests that the small awards seem to be needed to address significant voids in available public funding, such as support for research on diseases of pet or exotic animals.

Table 4-8 shows CVMs sorted into quartiles by faculty FTE size and student: faculty ratios in FY 2002. (See Appendix G for CVMs sorted into quartiles by

[3]All figures include indirect costs.

TABLE 4-7 NIH Awards to Veterinarians and CVMs

Category of Investigators	1997 Number of Awards	2001 Number of Awards	2001 Increase from 1997	2003 Number of Awards	2003 Increase from 1997
			All NIH Awards		
All DVMs	370	457	24%	522	41%
DVMs in CVMs	142	170	20%	197	39%
All Non-DVMs	36,666	45,444	24%	50,845	39%
			R01 Awards		
All DVMs	159	210	32%	243	53%
DVMs in CVMs	55	75	36%	82	49%
All investigators in CVMs	213	405	90%	430	102%
All Non-DVMs	19,318	26,120	35%	28,583	48%

NOTE: R01 grants to DVMs reported here differ from the numbers reported in the National Research Council report *National Needs and Priorities for Veterinarians in Biomedical Research* (NRC, 2004a) owing to recent updates in the NIH database search system. The upgraded search system could identify all the degree qualifications of a principal investigator with multiple degrees even if the person reported himself or herself as a DVM and PhD in one grant application and as a PhD in another. Later, both those grants would be identified as grants awarded to a DVM and PhD.

SOURCE: NIH, Office of the Director.

research expenditures from different sources.) CVMs with fewer faculty FTEs not only have smaller total research expenditures but also have lower research funds expended per individual when averaged over the entire faculty. Furthermore, the student:faculty ratios are considerably higher in the CVMs in the first than in the fourth quartile. As faculty size (FTEs) increases and student:faculty ratios decrease, total research funds and average research funds per faculty FTE increase. Average funds from all sources per faculty FTE doubles from the smallest to the largest faculty quartile and the total funds increase by a factor of almost 5. Those data may be explained in part by the fact that CVMs and their home universities vary in their approaches and missions: some emphasize research much more than others. Moreover, some CVMs have severe limitations on physical facilities, faculty expertise, and other resources required for research.

The data also suggest that the number of faculty FTEs must reach a "critical mass" for faculty to spend more time on research and compete for funds effectively. That viewpoint is supported by the fact that the student:faculty ratio of the CVMs in the first quartile (4.80:1) is about 62% higher than the ratio in the fourth quartile (2.97:1). Average research funding per faculty FTE from NIH, USDA, states, industry, and all sources increases dramatically in the third and fourth quartiles as faculty FTEs exceed 100 and student:faculty ratios decrease to 3.8:1 and lower (Table 4-8). The impact of critical mass extends even to research funded by a CVM's home state, where research funds per faculty FTE in the fourth quartile are almost 6 times as high as in the first quartile.

TABLE 4-8 FY 2002 CVMs Sorted into Quartiles based on Faculty Size (full-time equivalents—FTE). The average faculty FTE size, student/faculty ratio, and average research expenditures from USDA, state, industry, private sources and NIH by CVMs in each quartile are reported.

		1st Quartile[a]	2nd Quartile[a]	3rd Quartile[a]	4th Quartile[a]
Average Faculty FTEs		60	82	101	143
Average Student:Faculty Ratio		4.80:1	3.64:1	3.83:1	2.97:1
USDA	Average amount[b]	$391,839	$914,477	$1,629,066	$2,168,747
	Amount per faculty FTE	$6,483	$11,201	$16,201	$15,179
States	Average amount[b]	$264,982	$409,678	$1,263,677	$3,648,673
	Amount per faculty FTE	$4,384	$5,018	$12,568	$25,538
Industry	Average amount[b]	$448,575	$398,274	$1,263,584	$1,552,710
	Amount per faculty FTE	$7,422	$4,879	$12,567	$10,868
Private	Average amount[b]	$302,671	$1,155,759	$576,094	$2,353,134
	Amount per faculty FTE	$5,008	$14,157	$5,739	$16,470
NIH	Average amount[b]	$2,447,974	$3,267,116	$5,252,496	$11,413,416
	Amount per faculty FTE	$40,503	$40,020	$52,238	$79,886
TOTAL ALL SOURCES[c]	Average amount[b]	$4,845,384	$7,390,228	$11,443,605	$22,905,480
	Amount per faculty FTE	$80,169	$90,525	$113,812	$160,322

[a]First quartile is composed of six CVMs; the others seven CVMs. One CVM in existence less than 2 years was omitted.
[b]Average amount is average research expenditure per CVM in each quartile for funding source shown.
[c]Total all sources includes some sources not shown in table.

Amounts of research funds obtained by CVMs do not depend solely on increasing faculty size, as shown by the three pairs of CVMs with the largest total research expenditures. When the six CVMS with the largest total research expenditures were paired up on the basis of similar total research expenditures, we found that in each of the three pairs, the college with the fewer faculty FTEs had more research dollars per FTE. Differences ranged from \$50,000 to nearly \$150,000 in average research expenditure per FTE. In all but one pair, student: faculty ratios were nearly identical. In the one where differences occurred, the school with the higher student:faculty ratio had the larger amount of research funds per FTE, although the total amount of research funds was smaller. (Data not shown.)

Another element that may influence the amount of funds received by CVMs is the presence or absence of other facilities with relevant programs, such as a college of medicine (CoM) or a USDA ARS research laboratory on the same campus or nearby. The presence of such facilities does not itself result in more campus resources for research in biomedicine, nor does it mean that CVMs have access to more or better physical resources or collaborative opportunities. Nevertheless, it is reasonable to assume that the presence of additional biomedical or agricultural research programs may have some favorable influence on the research climate that may be reflected in the research expenditures of CVMs. The committee examined data on CVMs that had CoMs on the same campuses and on CVMs that had USDA ARS laboratories on or near the campuses, and on CVMs that had neither. (See Appendix H for details of the analysis.) CVMs at universities that CoMs that were not on the same campuses were excluded from the analysis. The main findings are as follows.

- Of the 27 CVMs studied, 10 CVMs have co-located CoMs, and three of the 10 also have ARS laboratories nearby. The 10 reported about 46% of the research expenditures by all 27 CVMs from NIH, 44% from USDA, and 47% from all sources.
- Two groups of six CVMs each with similar faculty size (but different student:faculty ratios) were selected for comparison on the basis of the presence or absence of a co-located CoM. The group of six with co-located CoMs reported about twice the research expenditures from NIH and from all sources of the group of six without CoMs.
- Nine CVMs were selected because they each have an ARS laboratory nearby. (Three of the nine also have co-located CoMs.) The nine account for about 50% of the research expenditures from USDA even though they amount to only one-third of the CVMs.
- Two groups of four CVMs each with comparable faculty sizes (but different student:faculty ratios) and no co-located CoMs were compared. One group of four had ARS laboratories nearby, and the other group of four did not. The former group reported about twice the research expenditures per faculty FTE from USDA of the latter group.

Those and the previous data do not establish size (faculty FTEs), student: faculty ratio, and the presence of additional research programs as causative factors in determining whether some CVMs obtain more research funds than others. They do, however, suggest that critical mass and campus research environments play a role in the relative research funding of CVMs. Although data were not available for analyses, favorable research environments may include the presence of schools of public health, integrated shared research resources, and other research-oriented programs. The larger amounts of research funding in CVMs co-located with research facilities of other related disciplines suggest that those CVMs may benefit from collaborative interdisciplinary research with those facilities. In fact, the CVM with the largest reported expenditures from NIH and all sources has a large CDC laboratory and several other federal research laboratories on or adjacent to the campus even though it is not co-located with a CoM or an ARS laboratory. That CVM also has a large faculty and a low student:faculty ratio.

COLLEGES OF AGRICULTURE

Colleges of agriculture in the United States are typically components of land-grant institutions. They contribute substantially to animal health research, particularly on diseases of production animals, and often through interaction with agencies of USDA. Colleges of agriculture vary in size, focus, and expertise in veterinary science. Among their diverse curricula and research programs, emphases that fall within veterinary science include animal science, agricultural and food biosecurity, agricultural systems, animals and animal production, biology, biotechnology and genomics, nutrition and health, natural resources and environment, and pest management. Other disciplines that contribute greatly to veterinary science include biochemistry, statistics, and information technology.

Infrastructure

Research facilities of land-grant universities include over 25 million square feet of laboratory and office space, about 885,860 acres of land, and about 3.56 million square feet of greenhouse space (USDA, 1999). Greenhouse space is used for studies of effects of poisonous plants on animals, for growing plants used for vaccines and nutritional research, and for entomology research. In colleges of agriculture, the facilities of several academic departments and units are directed toward research on some aspect of animal health or veterinary science, and those facilities should be considered in assessing current infrastructure. Furthermore, most colleges of agriculture have specialized interdepartmental technological units for electron microscopy, DNA development, transgenic animals, proteomics and so forth, and these units contribute in major ways to research in veterinary science. Animal housing facilities, which may be extensive in large departments of animal science, rarely contain facilities for infectious-disease research in production animals. The following academic departments and units make particularly important contributions to veterinary science:

- *Departments of veterinary science*. Most departments of veterinary science in colleges of agriculture, especially in states that do not have CVMs, have facilities dedicated to production-animal health research. Existing under various names, those departments have been funded by at least 12 states. Traditionally, financial and commodity-group support for veterinary science—although strong in some states—is less than in states that support 4-year CVMs. Research facilities, faculty, and funding are directed to disease, of livestock, poultry, and aquaculture and are mostly dedicated to state and local animal health problems. The largest share of funding is typically directed to infectious diseases of economic importance.
- *Departments of animal science*. Departments of animal science traditionally contribute to research on the genetics, nutrition, physiology and metabolism, reproductive management, and toxicology of domestic food-producing animal species. Much of the research overlaps with animal health research. In the last decade, the role of animal science departments has expanded to include companion-animal physiology and behavior.
- *Departments of entomology*. Major contributions to medical and veterinary science are made by entomologists in colleges of agriculture. For example, the transmission and infectivity cycle of West Nile virus was elucidated by medical entomologists who tracked patterns of infected mosquitoes that were similar to patterns of the disease in birds and mammals. Colleges of agriculture in major land grant institutions typically support insectaries, which are critical to successful research in veterinary entomology.
- *Departments of wildlife and fisheries*. The movement of infectious diseases among domestic and wild mammals, birds, and aquatic species is a major concern of veterinary science. Furthermore, the interface between wildlife and domestic animals is of increasing importance and concern to the livestock industry. Academic departments and research facilities dedicated to wildlife, fisheries, and other ecological components exist in nearly all colleges of agriculture. Although the departments handle the obligations of wildlife biology, few play a substantial role in animal health problems in wildlife and fish. With few exceptions, their mission statements have narrow focus, lack the demands of extramural forces (such as commodity groups, industry, and National Park Service missions) to drive the research, and have inadequate training of faculty to handle cutting-edge approaches to infectious and noninfectious diseases of animals. In universities that also have CVMs, opportunities and facilities for cooperation are common. However, the facilities are typically inadequate to deal with wildlife disease or the wildlife-domestic animal disease interface seriously over an extended period.

- *State agricultural experiment stations*. Funds from SAESs support research facilities in a wide variety of disciplines. The Hatch Experiment Station Act, passed by Congress in 1887, created a system of state agricultural experiment stations with the land-grant universities and provided a mechanism to channel federal funding to colleges of agriculture. In 1914, the Smith-Lever Act created the Cooperative Agricultural Extension Service as a partnership of county, state, and federal governments (Fuglie et al., 1996). Those acts and the Morrill acts were created to "deliver the benefits of scientific research and education in the colleges of agriculture to the public citizens to improve the economic viability and life of farmers and rural communities" (USDA, 1999).

Expertise and Human Resources

Much of the wide variety of animal research expertise available in colleges of agriculture applies to veterinary science and related animal health fields. Faculty members in colleges of agriculture participate as team members in research of high national importance—for example, departments of entomology and virology in research on West Nile virus disease and departments of economics, animal science, and chemistry in research on bovine spongiform encephalopathy in beef and dairy cattle.

In the last decade, brucellosis in bison and elk in the greater Yellowstone ecosystem (GYE) has been a focus of national attention. The persistence of brucellosis in the GYE (caused by *Brucella abortus* in elk and bison) and in marine mammals (caused by *Brucella spp*. in dolphins, seals, whales, and others) in the face of the elimination of this disease from domestic animals requires a substantial research program plan (NRC, 1998b). The formation of the Greater Yellowstone Interagency Brucellosis Council in the early 1990s to drive cooperation was effective but flawed by bickering among those involved. The Department of the Interior (DOI) National Park Service (NPS); the USDA ARS, Animal and Plant Health Inspection Service (APHIS), CSREES; state livestock and wildlife agencies; commercial groups; recreationalists; and Indian intertribal associations have widely opposed views, and there is no simple solution for the eradication of brucellosis. At the heart of the controversy is the lack of current research, which translates into lack of support for departments of wildlife and fisheries throughout the United States.

Educational Resources

Courses in the veterinary sciences in colleges of agriculture typically include one or two dedicated to agricultural undergraduate students and the remainder directed at graduate work in some phase of veterinary science. In most land-grant institutions, those educational resources and funding that supports them play little role in research.

Agricultural libraries, separate or as parts of major university libraries, provide major educational resources for research in veterinary science, particularly in production-animal medicine. Those facilities connect with AGRICOLA (Agriculture Online Access), a bibliographic database that contains veterinary medicine as a subject at http://stneasy.cas.org.

Financial Resources for Research

Funding for animal health research in colleges of agriculture comes from federal, state, and private sources. Much of the research in those facilities is under the sponsorship of agencies of the federal government. USDA's CSREES has provided major funding to colleges of agriculture for research, graduate education, and infrastructure construction and maintenance. Funding has been through competitive and noncompetitive funding mechanisms that include Hatch funds (formula funds), the competitive grants of the National Research Initiative (NRI), Small Business Innovation Research grants, Biotechnology Risk Assessment grants (BRAGs), Animal Health Funds (1433), special grants program, and various programs targeted to help disadvantaged universities to develop and support agricultural research.

Although ARS is USDA's in-house research agency, it has provided sparse research funds for production-animal research to universities and other institutions through specific cooperative agreements. ARS has the mission to develop and transfer solutions to agricultural problems of high national priority and provide information access and dissemination to ensure high-quality, safe food and other agricultural products. When outside expertise is needed to meet its mandated mission, ARS provides financial assistance to collaborative partners. Other sources of competitive and noncompetitive federal research funding to colleges of agriculture have included NIH, DOD, National Science Foundation (NSF), the Food and Drug Administration (FDA), DOI, the Department of Homeland Security, and the Department of Energy.

Since the middle 1950s, there has been a consistent increase in private support from industry and commodity groups for research in colleges of agriculture: "Between 1960 and 1992, private spending for food and agricultural research tripled" (USDA, 1999). By 1991, USDA expenditures for research and development (R&D) were less than 2% of all federal R&D spending ($1.2 of $61.3 billion), and about 4% of federal support for research in universities and college, was for agriculture ($408 million of $10 billion) (USDA, 1999).

The National Association of State Universities and Land-Grant Colleges (NASULGC) functions under the Board on Agriculture Assembly. This group does not fund or track research but supports colleges of agriculture in the funding process in Congress; for example, NASULGC supports the current presidential budget proposal to increase NRI grants by $120 million.

In the post-World War II period, federal funding for research was massively increased in the United States but less in USDA than in NIH, NSF, and other federally supported research institutions. Much of the private support has been driven by commercial development of biotechnology, improved government-to-private technology transfer and establishment of intellectual property rights, and a closer association between research and economic development and marketing.

COLLEGES OF MEDICINE AND OTHER MEDICAL RESEARCH INSTITUTIONS

A portion of research in veterinary science occurs in schools and colleges of medicine and other medical research institutions, but it is essentially impossible to quantify. Some of the research takes place in departments of comparative medicine. The *AVMA Membership Directory and Resource Manual* (2004b) listed seven units in medical schools under the title "Departments of Comparative Medicine," but some units have other names, such as "Section" and "Division." Although the NIH National Center for Research Resources (NCRR) of NIH is listed in the *AVMA Membership Directory Resource Manual*, the Department of Comparative Medicine at Johns Hopkins University is not, nor is a unit of comparative medicine at the University of California, San Diego. A recent National Research Council, study *National Needs and Priorities for Veterinarians in Biomedical Research* (NRC 2004a), listed 27 (of a total of 38) clinical residency programs in laboratory animal medicine not associated with CVMs, giving some idea of the scope of research in veterinary science in medical schools and medical research institutions. The seven Regional primate research centers discussed later, all associated with colleges of medicine, also are sites of important research in veterinary science. There are a number of other medically oriented research institutions and centers throughout the country, including NIH, where research in veterinary science also takes place. Substantial advances in such subjects as animal genomics and infectious diseases occur in such research venues, but quantifying the resources available for such research is impossible (Sutter and Ostrander, 2004; Troyer et al., 2004).

The need for veterinarians in biomedical research was examined in the Research Council report *National Needs and Priorities for Veterinarians in Biomedical Research* (NRC, 2004a). The author committee studied national needs in comparative medicine, and its report included an analysis of the training opportunities in comparative medicine in schools and colleges of medicine. The committee's major findings included the following:

- "From 1995 through 2002, the number of NIH-funded competitive grants utilizing animals increased by 31.7%. There were approximately 1,300 more competitive grants utilizing animals in 2002 than in 1995."
- "Currently there are an estimated 1,608 research institutions in the US that are USDA-registered and/or hold NIH assurances indicating those institutions utilize animals in research programs."

- "The number of active laboratory animal medicine residency programs was the same in 1995 as it was in 2002. Of the 32 currently active programs, 9 of these programs did not have anyone complete a residency from 1996 to 2002." This finding seems to be supported by a recent survey (2004) conducted by AAVMC. Seven departments of comparative medicine that are members of AAVMC were asked about the enrollment of graduate students. Two replied; one of the two reported that three students were seeking PhD degrees, and the other reported no graduate students.

Those and the data from NIH recorded elsewhere in this chapter are all the data the committee could locate regarding research in veterinary science conducted in medical schools and colleges and medical research institutions.

WILDLIFE AND AQUATIC HEALTH INSTITUTIONS

Research programs to solve wildlife and aquatic health, food safety, and well-being issues were created from pre-existing established programs focusing on conservation, and management of wildlife and more recently on improving production and quality in freshwater and salt-water farming operations of fish and other aquatic species. (See Appendix I for list of organizations in which major resources are directed to wildlife and aquatic health, food safety, and well-being.) Today, the ecological, societal, and financial importance of wildlife and aquaculture are enormous; but despite the importance and size of these sectors, neither has comprehensive centralized professional or government oversight or coordination of research priorities, funding, or sharing of information.

The research programs in wildlife and aquatic health, food safety, and well-being developed independently of the historical established research entities—that is outside the existing federal land-grant university and federal grants programs. That has not deterred individual scientists or groups of scientists or conservation and ecological organizations from developing successful and productive core programs of research at various universities and government and private institutions, which have emphasized and solved many wildlife and aquatic health, food safety, and well-being issues. In free-living wildlife, health research has focused largely on a few high-profile diseases. Those research programs tend to have narrow scope and short duration (AAWV, 2004). Seldom have big-picture efforts—such as comprehensive land-use planning for improving wildlife, livestock, and human health; ecosystem-level approaches; or even sustained efforts at managing very damaging diseases—been initiated or maintained for sufficient periods to make a difference (AAWV, 2004). Zoonotic issues at wildlife and domestic animal-human interface are emphasized in wildlife health research.

Infrastructure

Infrastructure, human resources, and physical resources are fragmented as small pieces scattered among multiple institutions. Institutions that have contributed to such research have included colleges and universities, state and federal government institutions, zoos and wildlife parks and aquariums, and private-foundation or corporate research institutions. The precise numbers of scientists and staff and square footage of research space are unknown, but the general impression from individual interviews is that resources dedicated to wildlife and aquatic health research are meager and much smaller than those dedicated to public health and to domestic livestock and poultry health and protection.

Some colleges of agriculture and CVMs have one to three faculty members studying wildlife and aquatic health. In a few institutions, there is a critical core of five to ten faculty members, and a formal program is established to focus on wildlife and aquatic health in an individual state or region. For example, the Southeast Cooperative Wildlife Disease Study in the University of Georgia CVM provides regional research and diagnostic services in wildlife health to southern states through five faculty and 24 other staff. In general, such larger formal programs are in states where wildlife, forestry, or aquaculture is financially important to the state or regional economy. The emphasis is on resource contribution by state governments through universities or game and fish departments. Examples are the Sybille Wildlife Research Facility at the University of Wyoming, Laramie, and the Center for Bison and Wildlife Health at Montana State University, Bozeman. In addition, research has been conducted through both in-house and extramural programs of USDA's ARS and APHIS and DOI's NPS and US Geological Survey (USGS) in their core missions. Large federal programs in wildlife and aquatic health include

- ARS: Aquatic Animal Health Research Unit Auburn, AL; and National Animal Disease Center, Ames, IA.
- USGS: National Wildlife Health Center, Biological Research Division, Madison, WI.
- APHIS: National Wildlife Research Center, Fort Collins, CO.
- DOI's US Fish and Wildlife Service: Fish and Wildlife Forensics Laboratory, Ashland, OR.

In wildlife health, the major dedicated wildlife research facilities are in Madison, WI; Ft. Collins, CO; Laramie, WY; and Athens, GA. Livestock facilities of ARS in Ames, IA, and Pullman, WA, are used for specific wildlife health research on infectious agents that cross between wildlife and domestic livestock (AAWV, 2004). Additional laboratory facilities and animal housing are available at various universities with general laboratory animal facilities, but they often are not constructed or staffed for wildlife care, and costs may be prohibitive or specific budgets to support wildlife research lacking (AAWV, 2004).

Expertise and Human Resources

Some 125-150 full-time veterinarians have clinical service, research, or teaching commitments in wildlife health in the United States, but their major commitment is to clinical service and not research (AAWV, 2004). The American Association of Wildlife Veterinarians estimated the distribution of veterinarians in different sections to be about 30-35 in federal government employment; 30-35 in state government employment; 25-30 employed by universities, institutions or cooperatives; 20-25 employed for tribes, under contract, or self-employed; and 20-25 employed by zoological societies, nongovernment organizations, or companies. The number of nonveterinarians in wildlife health research and the number of veterinarians and nonveterinarians in aquatic health are unknown.

Education

Educational opportunities for veterinarians and nonveterinarians in wildlife and aquatic health vary with job requirements and individuals needs. Experiential learning through on-the-job training has been the major method for developing expertise in clinical field research. Limited financial and formal training resources have been available through CVM's and colleges of agriculture for training in wildlife and aquatic health. Some student training opportunities and externships are provided in zoological medicine, clinical care, and wildlife rehabilitation, but few externships or training programs are available that provide substantial experience in free-ranging wildlife. There are only two residency opportunities for wildlife veterinarians in the United States: one every third year at North Carolina and one focused on clinical care at the Wildlife Center of Virginia. Graduate studies (MS and PhD) in wildlife and aquatic health focusing on training and careers in research are available at institutions that have focused programs in wildlife and aquatic health, but funding and physical resources are scarce. Postdoctoral opportunities to work on wildlife are competitive and not abundant. Although classroom space can generally be found to support wildlife veterinary teaching needs, more-specialized facilities for wildlife veterinary and health research are almost nonexistent (AAWV, 2004).

ZOOLOGICAL INSTITUTIONS

The mission of most zoos is to conserve wildlife and to promote wildlife habitat conservation by increasing public understanding of their importance and their interdependence with humans. Few zoos can afford to support laboratory-based research programs in veterinary science (AZA Animal Health Committee, 2004). Therefore, only a few large zoos include research in their mission statements—for example, the National Zoological Park (NZP), the Saint Louis Zoo, and the San Diego Zoo. This section discusses the infrastructure and resources of a few selected zoos that have substantial research activities. (The selection of zoos was based on the availability of information on their Web sites.) However, we note that such zoos are the exception, and that most zoos have only minor research capacities. Research programs at most zoos are designed to address specific problems in their collections (AAZV, 2004).

Organizational Structure

The scope and size of research programs vary from zoo to zoo. The Saint Louis Zoo's research program focuses on reproduction, including behavior, physiology, endocrinology, and gamete biology. Its research unit is organized into three divisions—the Contraception Center, the Endocrinology Laboratory, and the Pathology Laboratory. The San Diego Zoo's research is carried out at the Conservation and Research for Endangered Species Center (CRES). The center's research focuses on applied conservation behavioral biology, ecology and evolution, endocrinology, genetics, giant panda conservation, pathology, and reproductive physiology. Research at NZP spans many disciplines, including reproductive biology, veterinary medicine, behavior, ecology, population biology, nutrition, migratory birds, and biodiversity monitoring.

Infrastructure

One of the largest research facilities associated with the zoo is the Conservation Research Center of the NZP. The center is a 3,200-acre facility in Front Royal, VA. The facility includes a geographic information systems laboratory, endocrine and gamete laboratories, a veterinary clinic, a radio tracking laboratory, 14 field stations, biodiversity monitoring plots, a conference center, dormitories, and education offices. Research is also carried out in the zoo in Washington, DC, where there are state-of-the-art nutrition laboratories, genetics laboratories, a reproductive-sciences facility, and a genome resource bank. Veterinary researchers have access to about 7,700 ft^2 of laboratory space and share access to hospital, surgical, necropsy, and clinical laboratory space.

The San Diego Zoo completed the Arnold and Mabel Beckman Center for Conservation in 2004. The center is a two-story, 50,000-ft^2 facility that includes 20,000 ft^2 of laboratory space (with an additional 6,000 ft^2 for future renovations) and 24,000 ft^2 for offices, a library, a conference room, and a cryopreservation repository of biomaterials for endangered species. The center houses all divisions of the CRES except the giant panda conservation division.

Financial Resources

To the committee's knowledge, there are no federal, state, or local government agencies whose mission is focused on veterinary research in zoos and aquariums; considerable support for research relevant to zoos and wildlife comes from small foundations (Zoological Society of San Diego, 2004; AZA Animal Health Committee, 2004; NZP, 2004). However, research programs at zoos receive some support from federal agencies, such as NSF and NIH, provided that the projects are consistent with their missions. In 2004, NZP received about $1.1 million for research in veterinary science. Funds were obtained from competitive peer-review grant programs (for example that of NIH), endowments, foundations, corporate donors, and private donations.

Human Resources

In October 2004, the NZP reported that it had 23 full-time staff and 5 unfilled positions that are involved in veterinary science. Among the staff, 5 hold a DVM, 11 hold a PhD, and 8 hold both (NZP, 2004).

Educational Resources

NZP, the Saint Louis Zoo, and the San Diego Zoo all offer internships for college students and recent graduates. The San Diego Zoo offers veterinary internships exclusively to the University of California, Davis and Mesa College.

Graduate students and postdoctoral researchers could apply to study at NZP through the Smithsonian Fellowship Program. NZP also offers a veterinary student preceptorship that is targeted to students with a serious interest in veterinary medicine. It also leads one of the 14 residency training programs accredited by the American College of Zoological Medicine. The other zoos with such training programs include the Bronx Zoo, the Lincoln Park Zoo, and the Saint Louis Zoo.

Distribution of Resources and Disciplines

The ability of zoos to conduct research in animal health and veterinary science depends heavily on veterinary staffing levels because most staff can participate in research only on a part-time basis (AAZV, 2004). For example, the research capacity at the NZP's Department of Animal Health was limited by a shortage of staff. Veterinarians have to meet the clinical needs of the zoo's animal collection before they can participate in and contribute to veterinary research. Similarly, NZP's Department of Conservation Biology has reduced research capacity because of delays in filling the vacant position for a PhD-level clinical nutritionist (NZP, 2004).

NATIONAL INSTITUTES OF HEALTH

NIH is the leading federal agency for health research in the United States and one of the world's foremost medical research centers. "NIH provides leadership and direction to programs designed to improve the health of the Nation by conducting and supporting research: in the causes, diagnosis, prevention, and cure of human diseases; in the processes of human growth and development; in the biological effects of environmental contaminants; in the understanding of mental, addictive and physical disorders; in directing programs for the collection, dissemination, and exchange of information in medicine and health, including the development and support of medical libraries and the training of medical librarians and other health information specialists" (http://www.nih.gov/about/almanac/index.html).

Organizational Structure

NIH is organized into 27 institutes and centers that are managed under the Office of Director. Veterinarians and veterinary scientists are involved in research, program direction, and management in several institutes and centers, including the National Cancer Institute (NCI), the National Heart Lung and Blood Institute (NHLBI), the National Institute on Aging, the National Institute of Neurological Disorders and Stroke, and especially the National Institute of Allergy and Infectious Diseases (NIAID), the National Institute of Environmental Health Sciences, and NCRR.

Expertise and Human Resources

NIH employs veterinarians in various roles, such as staff scientist, veterinary medical officer, supervisor of veterinary medicine, research fellow, senior investigator, senior scientist, staff veterinarian, and research veterinary officer. The number of veterinarians employed at NIH has been difficult to determine but most likely is at least 65. It is unclear how many DVMs are involved directly in research as opposed to the support of the overall mission of NIH.

Financial Resources

The extramural programs of most centers and institutes do not provide direct support for research in veterinary science, because NIH's primary mission is to improve human health. Nevertheless, most centers and institutes provide extramural funds for animal research that contributes to the enhancement of human health and welfare. For example, from 1990 to 2002, research based on the use of live vertebrate animals accounted for about 43% of competitively funded NIH grants (NRC, 2004a). During the period 1995-2002, the total number of research grants increased, which resulted in a 31.7% increase in the number of competitive grants involving animals; this translates into funding for about 1,300 more grants using animals in 2002 than in 1995 (NRC, 2004a).

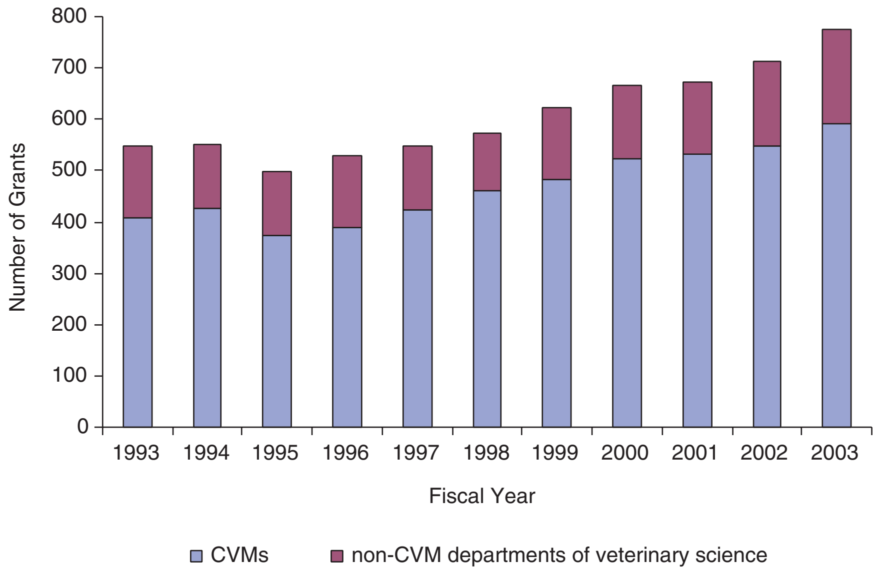
Another example of success in funding veterinary medical initiatives came through NHLBI. In the early 1980s, the institute initiated the Transfusion Medicine Academic Award (TMAA) program, intended to provide more academic and postdoctoral training in the growing field of transfusion medicine. That was in response to the discovery of AIDS and an increasing concern about transfusion-transmitted diseases and blood safety in human medicine. As with any federally funded program, physicians and members of allied health professions are eligible to apply. The deans of CVMs were contacted and alerted to the availability of funds, which would be provided to a successful faculty applicant for 5 years to develop a program in the basic and clinical aspects of transfusion medicine for students and residents and for continuing education. After the award period, the recipient institutions were expected to continue the program on their own. In 1985, the first veterinary schools applied for the TMAA; there were 16 applications—12 from CoMs and four from CVMs. Four applications were funded, and CVMs received two of them. Since the program's inception in 1983, 40 TMAAs have gone to 35 CoMs and five to CVMs, and NHLBI has invested $1.5 million in transfusion medicine programs in CVMs.

In 1998, NCI announced an initiative titled "Mouse Models of Human Cancers Consortium"; it funded 19 groups of investigators at 30 institutions to develop models related to how human cancers develop, progress, and respond to therapy or preventive agents. NIAID has been the primary sponsor of programs in the use of animal models for the prevention and treatment of hepatitis B and C, nonhuman-primate heart and lung transplantation tolerance, research in biodefense and emerging infectious diseases, and construction of regional biocontainment laboratories.

NCRR is most closely tied to research in veterinary science and provides substantial funding. It supports animal research that contributes to biomedical sciences but is not in the categorical interest of a single NIH institute or center. It also supports projects that address such direct animal needs as the welfare of laboratory animals, and animal pain perception. The mission of NCRR is to support "primary research to create and develop critical resources, models, and technologies. NCRR funding also provides biomedical researchers with access to diverse instrumentation, technologies, basic and clinical research facilities, animal models, genetic stocks, biomaterials, and more. These resources enable scientific advances in biomedicine that lead to the development of lifesaving drugs, devices, and therapies" (http://www.ncrr.nih.gov). The number and types of research and training grants awarded to veterinary researchers by NCRR were discussed in another National Research Council report (NRC 2004a).

CVMs and departments of veterinary science and comparative medicine (DVS/CMs) have received various NIH awards (Figure 4-3), including R01 (research project; Figure 4-4), P01 (research program projects; Figure 4-5), and P40 (animal model & animal and biological material resource grants; Figure 4-6). (See Appendix J for 10-year funding trend of other NIH awards to CVMs).

The total number of NIH grants—including all C, D, F, G, K, S, P, R, T, and U grants—awarded to CVMs increased 45% (from 407 to 590) and award dollars



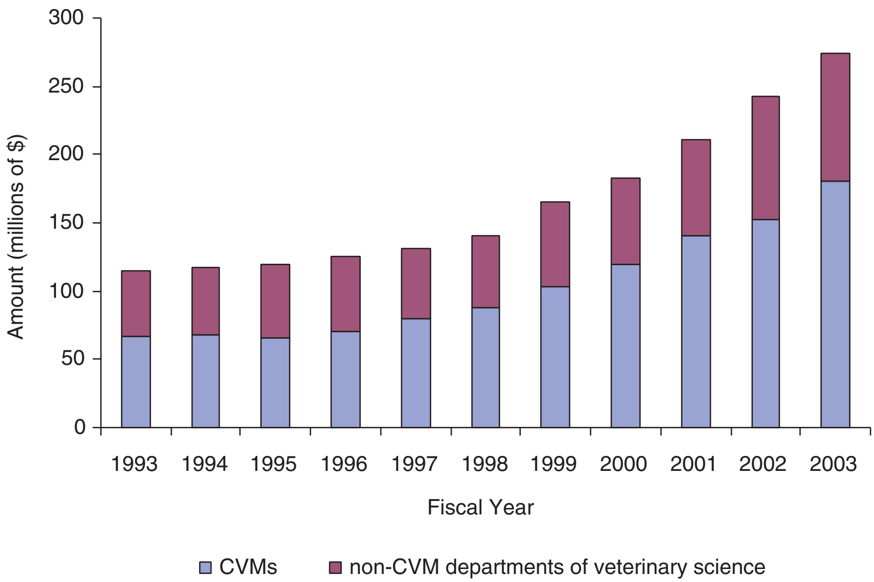
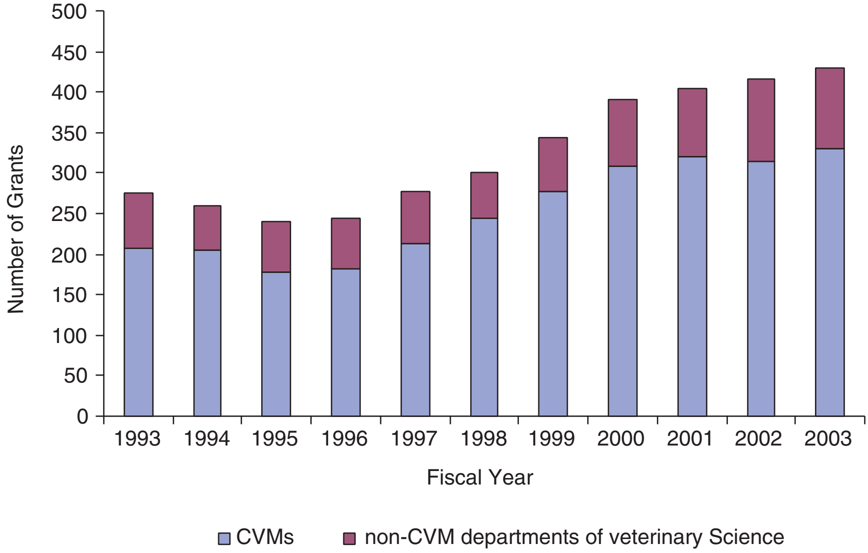


FIGURE 4-3 Total number and value of NIH grants. Number and total value of NIH grants (including all C, D, F, G, K, S, P, R, T, and awards) awarded to colleges of veterinary medicine and departments of veterinary science that are not affiliated with Colleges of Veterinary Medicine. SOURCE: NIH Office of Director.



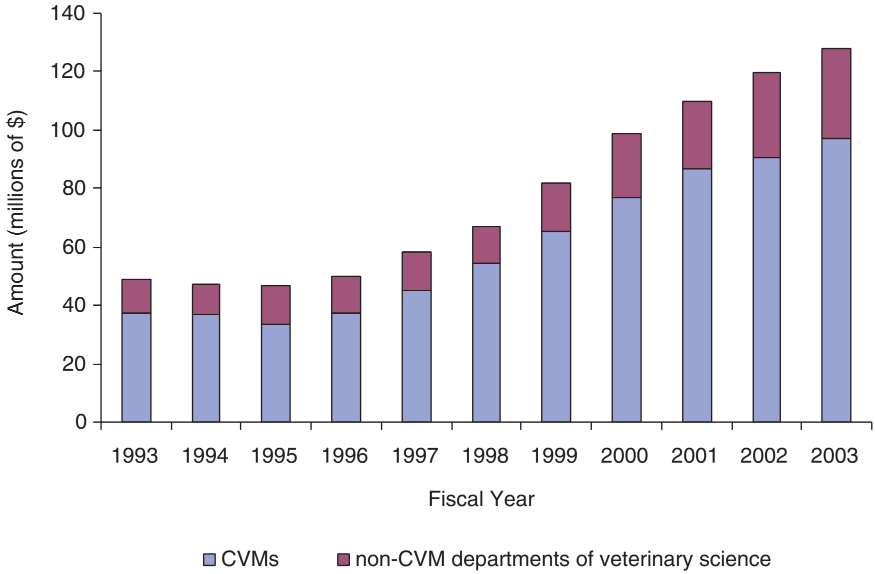
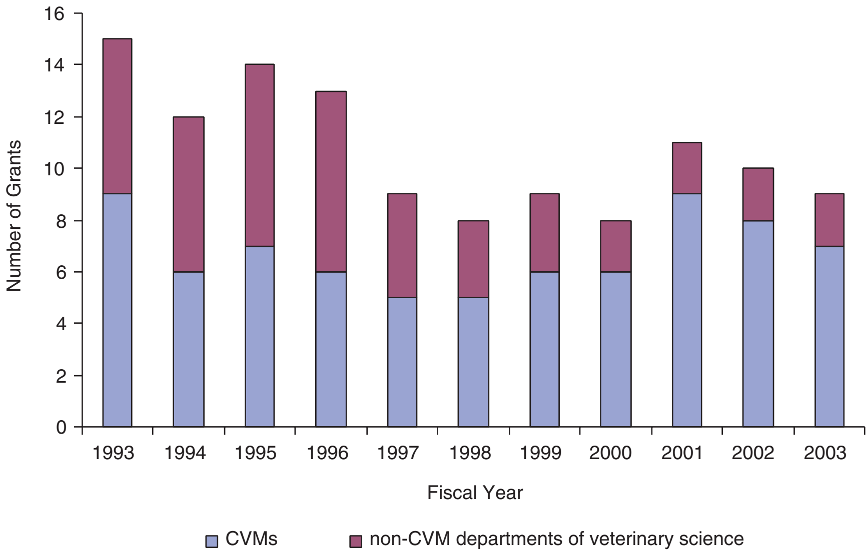


FIGURE 4-4 Number and total value of Research Project (R01 awards) awarded to colleges of veterinary medicine and departments of veterinary science that are not affiliated with colleges of veterinary medicine by NIH. SOURCE: NIH Office of Director.



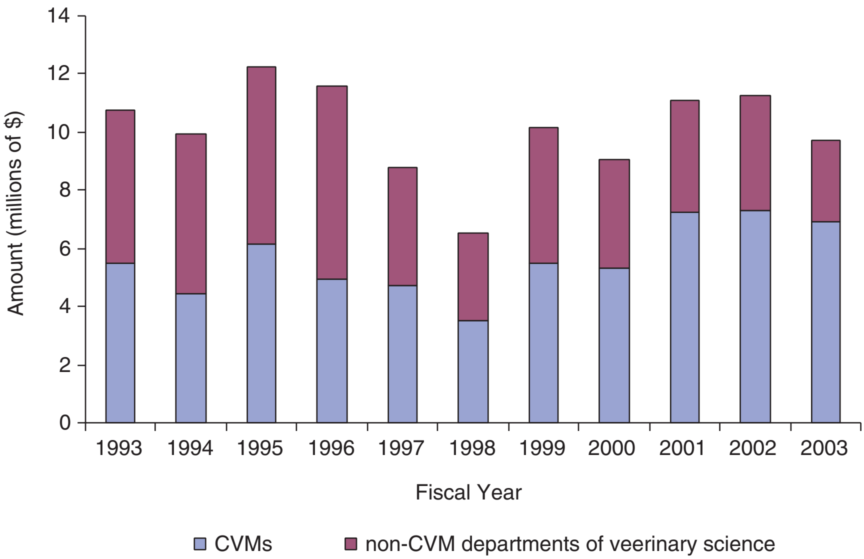


FIGURE 4-5 Number and total value of research program projects (P01 awards) awarded to colleges of veterinary medicine and departments of veterinary science that are not affiliated with colleges of veterinary medicine by NIH. SOURCE: NIH Office of Director.

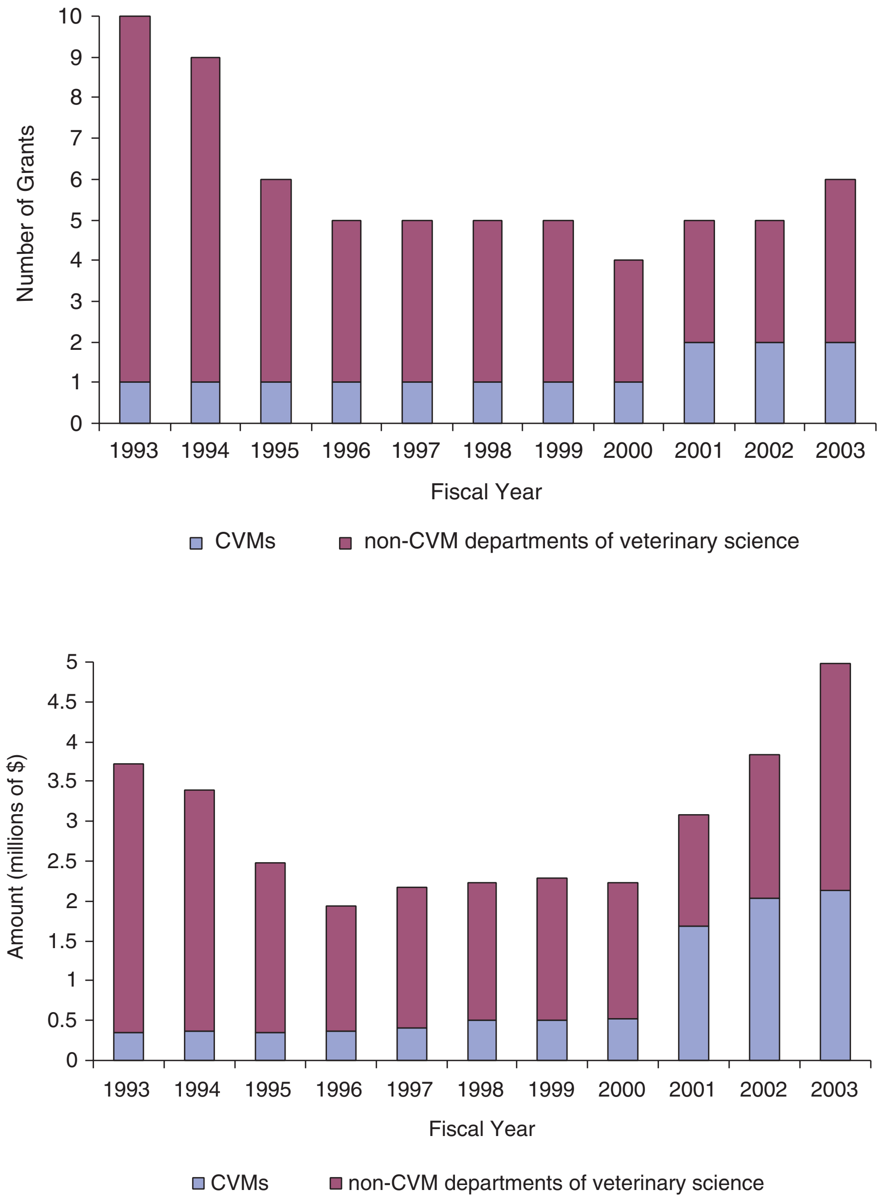


FIGURE 4-6 Number and total value of Animal Model and Animal/Biological Material Resource (P40) Grants awarded to Colleges of veterinary medicine and departments of veterinary science that are not affiliated with colleges of veterinary medicine by NIH. SOURCE: NIH Office of Director.

increased by 170% (from $67.2 million to $180.8 million) from FY 1993 to FY 2003 data (Figure 4-3). It is presumed that most of those awards pertained in a broad sense to veterinary science research, research training, or construction of research facilities. The data reflect grants awarded to investigators at CVMs, not just veterinarians.

Among the broad spectrum of NIH grants awarded to scientists at CVMs or DVS/CMs, the R01 is the most important because it is the competitive award for meritorious, investigator-initiated research. R01 awards to faculty at CVMs or DVS/CMs serving as principle investigators increased by about 50%, and the total award amount increased by about, 50% from FY 1993 to FY 2003 (Figure 4-4).

NIH awards of all types to veterinarians (as principal investigators) increased by 54% and award amount increased by 130% from FY 1993 to FY 2003 (Table 4-9). The increase in funding to veterinary scientists generally paralleled the increases in numbers of grants (1.53 fold) and dollars (2.6 fold) awarded to all scientists and exceeded the number of grants and dollars awarded to dental scientists, who represent an allied-health profession of similar size (Table 4-9). However, in award numbers and dollars, veterinarians and dental scientists each accounted for only 1% or less of the total NIH awards and dollars during the decade. The mean grant award (in dollars) to veterinarians increased from $238,235 in FY 1993 to $357,605 in FY 2003, during the period that the mean award to all types of investigators increased from $226,998 to $382,365. Those data show that veterinarians have competed favorably with all types of scientists in receiving NIH awards. However, data are not available on the number of veterinarians serving in the capacity of coprincipal investigator (shared leadership) or investigator (collaborating or team scientist) on NIH grants of any type.

TABLE 4-9 NIH Awards (All Types) to Veterinarians, Dentists and All Degree Holders

	Veterinarians		Dentists		All Degrees	
Fiscal Year	Number of Awards	Amount (millions)	Number of Awards	Amount (millions)	Number of Awards	Amount (millions)
1993	340	$81	347	$67.35	33,645	$7,637.35
1994	362	83.76	369	72.22	34,905	8,066.06
1995	350	88.69	351	70.93	34,707	8,349.25
1996	357	87.99	323	79	35,360	8,836.71
1997	370	95.3	312	80.74	37,036	9,509.06
1998	387	94.22	321	86.62	38,394	10,276.61
1999	399	108.27	327	90.48	40,745	11,802.89
2000	436	128.97	326	93.1	43,289	13,659.35
2001	457	155.76	371	108.19	45,910	15,608.25
2002	483	160.24	374	119.6	48,694	17,580.23
2003	522	186.67	395	126.75	51,367	19,640.94

In Table 4-10, NIH awards to veterinary scientists are categorized by institutional affiliation. In most years, the highest number of awards has gone consistently to veterinarians working at CVMs, which represent 37-43% of all awards to veterinarians. The second-highest category of institution is other higher education, namely, medical schools, arts and sciences institutes, and graduate schools. Third is DVS/CMs (Table 4-10).

In addition to supporting research projects, NCRR funds eight national primate research centers (NPRCs). They are a network of highly specialized facilities for nonhuman-primate research. The aim of the centers is to facilitate development of nonhuman-primate models for human health and diseases. The centers are accessible to eligible biomedical researchers who have research funding. Veterinarians serve in a number of important roles in NPRCs—from research scientist to support personnel for the overall research enterprise. NPRCs have a long and distinguished history of contributing to a better understanding of the normal biology of nonhuman primates and the pathophysiology and prevention of important human diseases, such as AIDS, diabetes mellitus, infertility, cardiovascular disease, and atherosclerosis.

Research support for NPRC investigators from FY 2001 through FY 2004 was evaluated (Table 4-11). The number of awards (PHS, federal non-PHS, and nonfederal) to core and noncore faculty (an undetermined number of whom are veterinarians) increased by 64% and award amount by 201% during the 3-year period. Those figures do not include additional base funding (P51) for the NPRCs, SPF monkey breeding colony (U24 and U42), or construction (C06 and G20), for which total award amount increased by 40% during the 3-year period (Table 4-12).

On September 30, 2003, NIH Director Elias Zerhouni announced the implementation and details of the NIH roadmap: "The NIH Roadmap is an integrated vision to deepen our understanding of biology, stimulate interdisciplinary research teams, and reshape clinical research to accelerate medical discovery and improve people's health" (http://nihroadmap.nih.gov). The NIH roadmap is designed to accelerate basic research discoveries and their translation into clinical research. The roadmap includes 28 initiatives grouped under three major themes: "New Pathways to Discovery", "Research Teams of the Future", and "Reengineering the Clinical Research Enterprise (Zerhouni, 2003). The different initiatives are estimated to cost $2.2 billion over 6 years (Table 4-13). Research Teams of the Future is designed to stimulate new ways of combining skills and disciplines in the physical and biological sciences and to encourage partnerships between private and public sectors. Veterinary researchers should seek the opportunity to pursue interdisciplinary research with various partners under this initiative to further biomedical sciences.

Educational Resources

As noted in the Research Council report *National Needs and Priorities for Veterinarians in Biomedical Research* (NRC, 2004a), NCRR provides resources

TABLE 4-10 FY 1993-FY 2003[a] NIH Awards to Veterinarians in Different Institutions

Fiscal Year	CVMs	DVS/CMs	Primate Centers	Other Higher-Education Institutions	Research Institutions	Independent Hospitals	Other Domestic	For-Profit Institutions	Foreign Institutions
				Number of Grants					
1993	134	52	5	111	17	12	4	3	2
1994	155	45	4	118	17	10	5	7	1
1995	131	43	3	133	14	17	4	5	—
1996	144	44	1	127	15	15	7	4	—
1997	142	44	2	130	20	20	3	9	—
1998	160	31	2	132	26	21	5	10	—
1999	151	41	2	142	32	19	3	9	—
2000	171	35	6	159	25	22	7	9	2
2001	170	34	9	181	21	26	6	9	1
2002	178	45	11	179	32	21	4	12	1
2003	197	50	11	185	36	22	3	16	2
				Amount (millions)					
1993	$25.2	$20.4	$1.7	$24.0	$5.1	$2.1	$0.9	$1.5	$0.1
1994	26.1	21.0	1.5	25.8	5.3	1.7	0.4	1.8	0.1
1995	24.1	21.0	0.6	32.5	4.0	4.2	0.4	1.9	—
1996	26.1	21.3	0.4	29.9	4.5	3.9	0.4	1.6	—
1997	27.1	21.2	0.6	31.7	6.4	5.5	0.2	2.5	—
1998	31.7	11.2	0.8	34.3	7.5	5.7	0.9	2.2	—
1999	34.5	13.7	0.9	40.3	9.6	6.3	0.7	2.4	—
2000	39.1	11.9	2.8	52.2	9.5	7.3	0.7	5.1	0.3
2001	49.4	15.7	4.5	63.5	10.0	8.1	1.0	3.4	0.1
2002	39.1	22.7	7.3	64.3	13.5	7.2	0.4	4.9	0.9
2003	63.1	21.8	7.6	66.8	12.8	7.2	0.3	5.7	1.4

[a]Excludes contracts and interagency agreements.

SOURCE: NIH Office of the Director.

TABLE 4-11 Awards to NPRC Investigators (Excluding P51 RR Support), FY 2001-FY 2004

	Core Faculty			Noncore faculty		Total	
Fiscal Year	Type of Support	Number of Awards	Amount (millions)	Number of Awards	Amount (millions)	Number of Awards	Amount (millions)
2001	PHS	241	$67.59	838	$312.85	1,079	$380.44
2001	Federal non-PHS	11	1.63	34	10.70	45	12.33
2001	Nonfederal	91	12.58	192	19.77	283	32.36
2001 Total		343	81.81	1064	343.32	1,407	425.13
2002	PHS	269	104.44	1140	463.67	1,409	568.11
2002	Federal non-PHS	7	0.96	40	12.25	47	13.22
2002	Nonfederal	75	6.93	310	29.02	385	35.95
2002 Total		351	112.34	1490	504.94	1,841	617.27
2003	PHS	301	132.71	1906	833.77	2,207	966.49
2003	Federal non-PHS	9	2.02	11	1.43	20	3.45
2003	Nonfederal	102	14.97	130	16.72	232	31.69
2003 Total		412	149.70	2047	851.92	2,459	1,001.62
2004	PHS	286	110.86	1783	1,133.50	2,069	1,244.36
2004	Federal non-PHS	8	3.85	13	2.57	21	6.42
2004	Nonfederal	96	15.15	119	14.80	215	29.95
2004 Total		390	129.86	1915	1,150.87	2,305	1,280.73

SOURCE: NPRC annual progress reports.

TABLE 4-12 NIH Base Funding (P51) and Other Financial Support to NPRCs, FY 2001–FY 2004 (millions)

	Fiscal Year			
Funding	2001	2002	2003	2004
Base (P51)	$60.10	$69.51	$77.93	$77.79
SPF Monkey Breeding Colony (U24 and U42)	5.07	12.29	12.72	12.48
Construction (C06 and G20)	10.82	10.57	9.24	15.85
Total	75.98	92.36	99.89	106.12

SOURCE: NIH Office of Director.

TABLE 4-13 Funding for NIH Roadmap Initiatives (millions)

Fiscal Year	Pathways to Discovery	Research Teams	Clinical Research	Total
2004	$65	$27	$38	$130
2005	137	39	61	237
2006	169	44	120	332
2007	182	92	174	448
2008	209	96	214	520
2009	188	93	227	507
Total	948	390	883	2,172

SOURCE: Norka Ruiz-Bravo, NIH, presentation to committee on July 19, 2004.

for career training and development in veterinary research through its special-emphasis research-career awards, postdoctoral fellowships, and training grants. For example, CVMs and DVS/CMs in FY 2003 were granted $8.71 million in K (research-career) awards, $9.04 million in T32 (institutional national research service) awards, and $1.66 million in F (fellowship) awards. Those awards encourage veterinarians to pursue careers in veterinary research and provide research experience for veterinary students. NIH also offers predoctoral and post-doctoral intramural research-training awards for graduate students and post-doctoral researchers to gain experience at one of the NIH laboratories (Grieder and Whitehair, 2004).

US DEPARTMENT OF AGRICULTURE

USDA has the mission of providing federal and national leadership on food, agriculture, natural resources, and related issues on the basis of sound public policy, the best available science, and efficient management (USDA, 2004a). USDA is divided into seven mission areas, of which several affect animal health and protection directly. The subagencies that are related to research in veterinary medical and associated sciences include APHIS, ARS, CSREES, the Food Safety and Inspection Service (FSIS), and the Foreign Agriculture Service (USDA, 2004b) and they will be discussed in the context of this report.

Agricultural Research Service

ARS is the principal inhouse research agency of USDA. It conducts innovative basic and translation research to find solutions to problems of high national priority, especially problems that are uniquely federal in responsibility (USDA, 1999). ARS often selects high-risk scientific endeavors that may bring substantial breakthroughs in important problems, but it complements research of and often collaborates with university, private-sector, and other government research-institution partners.

ARS provides direct research support related to federal regulations, national and international trade, conservation, and national and international disease control to federal action agencies, including APHIS, FSIS, EPA, FDA, CDC, and NIH. Commonly, ARS research requires expensive, dedicated biocontainment facilities; long-term funding; and specialized scientific expertise. ARS has more than 2,200 scientists conducting research in 1,200 permanent research projects at over 100 locations in the United States and in five international laboratories (USDA-ARS, 2004c). ARS research is organized into 22 national programs in four areas, which bring coordination, communication, and empowerment to the research projects. The national programs focus on relevance, impact, and quality of ARS research.

Research projects pertinent to this report are classified in Animal Health and Protection (STP 3.2 code) and include projects not only in the national program for animal health (NP103) but also in the national programs for veterinary, medical, and urban entomology (NP104); animal well-being and stress control (NP105); aquaculture (NP106); preharvest food safety (NP108); and manure and byproducts use (NP206).

Infrastructure

ARS has a centralized national program staff in Beltsville, MD, with multiple research locations that conduct laboratory and field research. Much of the research is conducted in ARS or other federally owned facilities with locations for animal health and protection research programs in Alabama, Florida, Georgia, Iowa, Maryland, Michigan, Mississippi, Texas, Utah, Arkansas, West Virginia Nebraska, and New York. Locations in the first eight of those states are co-located with or near CVMs and have substantial research collaboration with them which includes bidirectional sharing of expertise, facilities, and equipment. Some of the ARS animal health and protection programs are co-located with and use university facilities, either in CVMs or colleges of agriculture, including those of the University of Arkansas, Purdue University, the University of Wyoming, and Washington State University. The three largest laboratories dedicated to animal health and protection research are the National Animal Disease Center for livestock (Ames, IA), the Southeast Poultry Research Laboratory for poultry (Athens, GA) and the Aquatic Animal Health Research Laboratory for fish (Auburn, AL). ARS animal health and protection locations, location names, research subjects, and other pertinent information are reported in Appendix K.

Much of the animal health and protection research, including the study of foreign and emerging animal diseases, involves the use and manipulation of pathogens that require biosafety level 2 (BSL2), BSL3, and BSL3 agriculture (BSL3 AG) laboratory and animal-housing facilities. Many of the facilities were built in the 1960s and 1970s and are at the end of their life cycle. Those facilities need to be replaced urgently, especially those at the National Animal Disease Center; the Southeast Poultry Research Laboratory; the Plum Island Animal Disease Center in Orient Point, NY; the Avian Disease and Oncology Laboratory in East Lansing, MI; and the Arthropod-Borne Animal Disease Research Laboratory in Laramie, WY (USDA-ARS 2004c; USDA, 1999). Federal legislative and procurement processes have created long delays in renovation or replacement of critical facilities while funding for initiation of new research projects has moved faster. In some instances, biocontainment facilities have been temporarily closed because of biosecurity and biosafety inadequacies and productivity has been delayed.

The design for a replacement of the existing USDA animal health facilities in Ames, IA, has been completed, and construction is under way. The $455 million state-of-the-art facility will merge the National Veterinary Services Laboratories, the Center for Veterinary Biologics, and with the National Animal Disease Center into a single USDA research, diagnostic, and animal health service center. However, the new facility does not contain any additional space to accommodate new ARS research programs in livestock and poultry health.

The larger research locations support core specialized research facilities in bioinformatics, DNA sequencing and analysis, proteomics, functional genomics, microarrays, and electron microscopy. A large infrastructure component for the research is the specialized biocontainment facilities used to conduct whole-animal research in livestock, poultry, and wild animals with infectious agents.

Expertise

Animal health and protection programs conduct multidisciplinary research in microbiology, virology, parasitology, pathology, toxicology, immunology, epidemiology, molecular biology, biocontainment, physiology, agricultural engineering, genomic, chemistry, proteomics, bioinformatics, and vaccinology. The programs focus on basic and translation research to solve national-priority animal health and protection problems. Whole-animal research is emphasized. Collaborations with co-located or adjacent universities have capitalized on scientific expertise and physical assets not present in the ARS-owned laboratories.

Human Resources

Scientists (category 1) responsible for conducting research in ARS are classified principally as microbiologists (series GS-403) and veterinary medical officers (series GS-701), but occasionally physiologists (series 413), chemists (series 1320), geneticists (series 440), agricultural engineers (series GS-890), and other scientists in miscellaneous biological fields (series 401) are used. The microbiologists include immunologists, molecular biologists, and others. The diversity of training, expertise, and background of all scientist positions is critical for a successful multidisciplinary approach to animal health and protection research. With few exceptions, category 1 scientists have PhDs as their terminal educational degree; they usually complete one or two postdoctoral programs before being recruited to ARS. Research support staff provide individual scientists and research projects with technical assistance in the research process and include biological laboratory technicians or aids (category 7), postdoctoral research associates (category 2), support scientists (category 3), and animal caretakers.

For all programs in animal health and protection, the number of scientists employed by ARS increased from 177 to 282 from FY 1999 to FY 2004 (Figure 4-7). For animal health alone (NP 103), the increase has been a more modest 96 to 118 (Figure 4-7). For all ARS programs, the number of microbiologists (GS-403) increased from 138 to 191 from FY 1986 to FY 2001 while the number of veterinary medical officers (VMOs) (GS-701) decreased from a high of 64 in FY

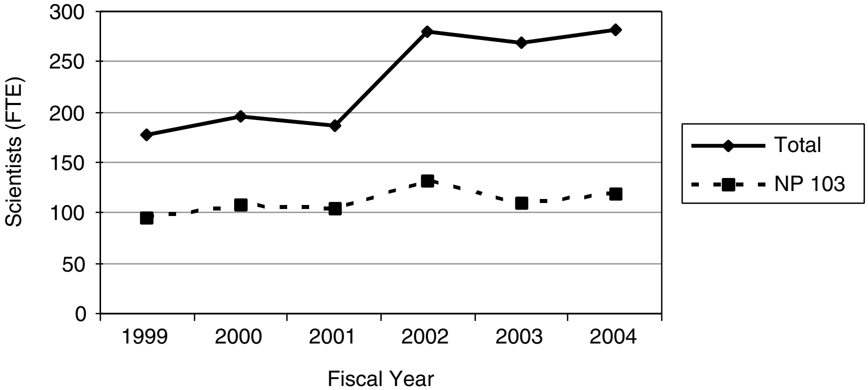


FIGURE 4-7 ARS scientists in animal health and protection (STP 3.2) and animal health national program (NP 103). SOURCE: USDA-ARS, 2004c.

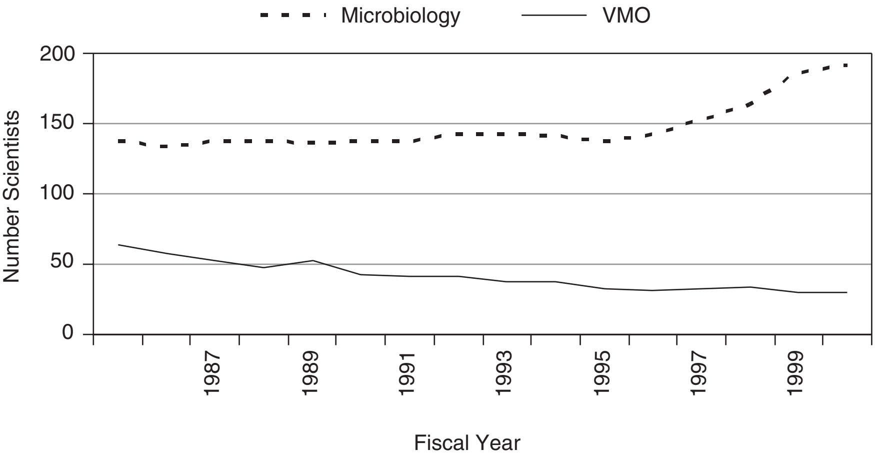


FIGURE 4-8 Veterinary medical officers (VMOs) and microbiologists employed by ARS. SOURCE: USDA-ARS.

1986 to a low of 30 in FY 2001 (Figure 4-8). During FY 2001 and FY 2002, ARS faced the challenge of filling 13 and 11 vacant VMO positions, respectively. In FY 2003, the number of VMO positions rebounded to 45 (AAVMC, 2004). However, the number of positions that were vacant was not reported (AAVMC, 2003a). The increase in microbiologists reflects a changing need in the research program for more basic scientists in new disciplines of molecular biology, proteomics, and other biotechnology fields.

The decline in VMOs has reached a crisis in ARS and reflects both a difficulty in recruitment and retention of DVM with PhD degrees to those positions and a deemphasis on whole-animal and translational research to solve field health problems (Witter, 2005). In response to such a personnel crisis, ARS has developed a recruitment and retention policy to improve success in locating and hiring qualified VMOs by offering more competitive salaries, recruitment and retention bonuses, and student loan payments. The shortage of qualified VMO candidates has been in the specialty disciplines of pathology, infectious diseases, laboratory animal medicine, and microbiology (in the subspecialties of immunology, virology, and bacteriology). The ability of the recruitment and retention policy alone to meet the needs of ARS for VMOs is unknown.

Education

Although the ARS mission does not have an education component, employees—both scientists and support staff—are provided training opportunities to improve knowledge, skills, and abilities to complete their research tasks. In addition, ARS provides cooperative research training for graduate students at CVMs and departments of veterinary science through mentorship, graduate-faculty committee participation, and cooperative research projects conducted at ARS facilities and with ARS scientists. In addition, some ARS employees have furthered their education and have become better equipped to accomplish their jobs by completion of PhD degree programs.

In FY 2003, ARS added a PhD training program for veterinarians in association with various CVMs with the goal of educating and training new VMOs with noncompetitive conversion to category 1 scientist positions after completion of the PhD program (USDA-ARS 2003c). The first position was filled at the University of Georgia early in FY 2004. Four positions will be filled in FY 2005 at the University of Kentucky, Iowa State University, Michigan State University, and Auburn University. The program will be expanded with eligibility of additional CVMs in the future. In exchange for the funding of the PhD educational program, the students will complete a 3-year research service period as scientists at an ARS laboratory after completion of the PhD degree program.

Financial Resources for Research

Funding for research in ARS comes primarily from funds appropriated directly by Congress for Current Research Information System (CRIS) research projects. For animal health and protection (STP code 3.2), direct appropriated funds have grown from $77 million in FY 1999 to $128 million in FY 2004 (Figure 4-9). For the animal health component (NP 103), the funding rose from $44 million FY 1999 while to $59 million in FY 2004 (Figure 4-9). The individual research locations

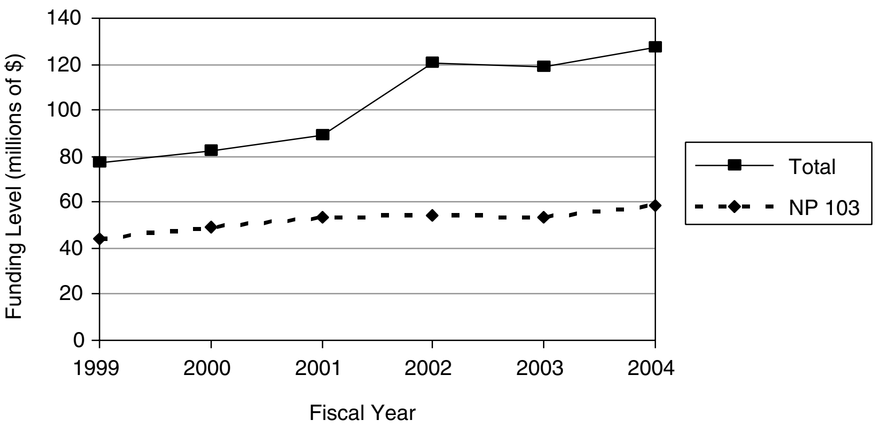


FIGURE 4-9 ARS funding for animal health and protection (STP 3.2) and in animal health national program (NP 103). SOURCE: USDA-ARS.

receive 90% of the appropriated funds, and 10% is allocated for central and area administration. The CRIS project funds pay for all direct and indirect (overhead) research costs, including all salaries, local administrative costs, utilities, facility and equipment maintenance, research equipment, research animals, and supplies and materials. In addition to congressionally appropriated funding, individual scientists can obtain extramural funds to conduct complementary research studies that are not funded by the appropriation process. In FY 2004, ARS scientists in animal health and protection had extramural funding of $13.4 million in reimburseable agreements and $7.1 million in trust agreements. The trust-fund agreement involves cooperative research between ARS and another party; ARS is paid in advance to conduct research. Reimbursable agreements are similar, but the payment to ARS is in arrears. The trust agreements funded in 2004 included about $1.4 million in cooperative research and development agreements, (CRADAs), which are trust agreements between ARS and industrial partners. In addition, ARS, through cooperative research projects, has enhanced the research productivity of in-house projects by using and funding outside expertise principally at CVMs and colleges of agriculture. During FY 2004, ARS funded $18.3 million through specific cooperative agreements for STP code 3.2 (J. Stetka, USDA-ARS, personal communication, September 20, 2004).

Distribution of Resources and Disciplines

Research priorities are developed on the basis of input from stakeholders with a major contribution by commodity and professional associations and federal action agencies. Ideas for specific research projects originate from the national program staff (NPS) and each research location and are implemented through a coordinated effort. The placement of new and continuation of existing research projects at individual research locations depend on preexisting fiscal, physical, and personnel resources; scientific expertise; commodity focus of the program; and congressional mandates for funding. Large multidisciplinary research projects are coordinated between several locations through the NPS. This system has led to some congressionally mandated projects, not being placed despite the scientific need and the availability of appropriate expertise because of location or congressional districts. In other situations, much-needed research has gone unfunded despite preexisting expertise and scientific need because of the lack of congressional support.

The expertise needed to solve health and food-safety problems for a commodity is scattered among a few large locations and multiple small locations. Some of the small locations have inadequate scientific personnel and expertise, so a critical mass needed to solve the animal health problems efficiently does not exist. Such inefficiency has increased the cost of the research through duplication of facilities, equipment, and personnel. For example, several regional poultry health laboratories were built during the last century to solve regional health issues. Critical research needs in poultry health have shifted to solving national and international health issues. However, the preexistence of multiple dedicated poultry health laboratories at the Southeast Poultry Research Laboratory (Athens, GA), the Avian Disease and Oncology Laboratory (East Lansing, MI), the South Central Poultry Laboratory (Starkville, MI) and the Poultry Products and Safety Laboratory (Fayetteville, AR) and poultry health programs in large ARS laboratories at the Beltsville Agricultural Research Center (Beltsville, MD) and the National Animal Disease Center (Ames, IA) has perpetuated inefficient research programs in poultry health based on regions. Some projects are coordinated among laboratories to share expertise—for example, the Marek's projects between Georgia and Michigan—but in general, the poultry facilities operate as separate entities. The USDA Strategic Planning Task Force has recommended consolidation of some poultry health programs (USDA, 1999).

Cooperative State Research, Education, and Extension Service

CSREES was formed in 1994 through the Department Reorganization Act, combining the Cooperative State Research Service and the Extension Service (USDA, 2004f). The CSREES mission is to "advance knowledge for agriculture, the environment, human health and well-being, and communities through national program leadership and federal assistance." CSREES is the primary agency in USDA that provides competitive and noncompetitive extramural funding for research, education, and extension programs and has long-term ties with the land-grant university system (Wagner, 2004). The CSREES links to land-grant universities include historically black colleges and universities, American Indian institutions, Hispanic and other universities, and other public and private organizations (USDA, 2004f). The 28 CVMs in the United States are among the institutions that receive support through formula funds, competitive grants, and other funding programs. For the competitive grants, each proposal undergoes a rigorous peer review by outside experts, Grant award periods range from 6 months to 3 years.

Infrastructure, Expertise, and Human Resources

CSREES does not directly conduct research, and it has no laboratory or facility infrastructure for such endeavors. Facilities for administration of programs are in Washington, DC, and national program leaders (NPLs) and support staffs administrator the grants programs. Scientists with experience in research, higher education, or extension programs fill the NPL positions (Wagner, 2004). Such NPLs are expected to represent the agency and present policy in their fields of scientific expertise. For the animal protection program, five veterinarians are employed as NPL, and a person is being sought to fill a sixth position.

CSREES is responsible for CRIS, USDA's reporting system for information financial, administrative, and research progress on current research projects in agriculture, forestry, and food and nutrition. The CRIS program is used by ARS, SAESs, the state land-grant university system, and other cooperating state institutions.

All research sponsored by USDA is subject to annual review and mandatory CRIS reporting. In the Agricultural Research, Extension, and Education Reform Act of 1998, Congress addressed the need for review of research facilities: "The Secretary shall continue to review periodically each operating agricultural research facility constructed in whole or in part with federal funds . . . pursuant to criteria established by the Secretary to ensure that a comprehensive research capacity is maintained" (USDA 1999, p. ix). This is a valuable tool for management of USDA research programs and serves as a tool for information access and coordination of research programs.

Education

Because of the linkages between research and educational programs at universities (on campus or extension), CSREES is in a unique position to support development of knowledge and its dissemination and implementation. Some of the funding is directed toward education grants to Alaska native-serving and native Hawaiian-serving universities, Hispanic-serving institutions, tribal colleges, special international study thesis/dissertation research travel allowance, and food and agricultural science national needs graduate and postgraduate fellowships. This is a critical link with the education process at universities to address shortages of human resources in research through their support of programs to educate and train the next generation of animal health researchers.

Financial Resources for Research

The core of CSREES competitive grant funding is provided through the NRI grants program (D. Morris, USDA-CSREES, personal communication, December 10, 2004). The funding for all fields of agricultural research was flat at $100-110 million per year in FY 1999-2002 but was increased to around $150 million in the last two funding cycles and to $180 million in 2005 (Figure 4-10).

Examination of all CSREES research funding that is targeted for animal health and protection shows that various types of specific grant programs other than NRI have provided valuable support, including Small Business Innovation Research, special research grants, the National Integrated Food Safety Initiative, Hatch funds, animal health and disease (1433) funds, Evan-Allen funds (historical black land-grant universities and Tuskegee University), McIntire-Stennis funds (forestry schools) and biotechnology risk assessment grants.

For FY 1999-2003, a broader analysis of research in animal systems that included reproduction, nutrition, management, genetics and genomes, physiology, and animal health and welfare showed funding (RPA# 301-315) of $75-91.9 million (Table 4-15). Funding of research in four major divisions in animal

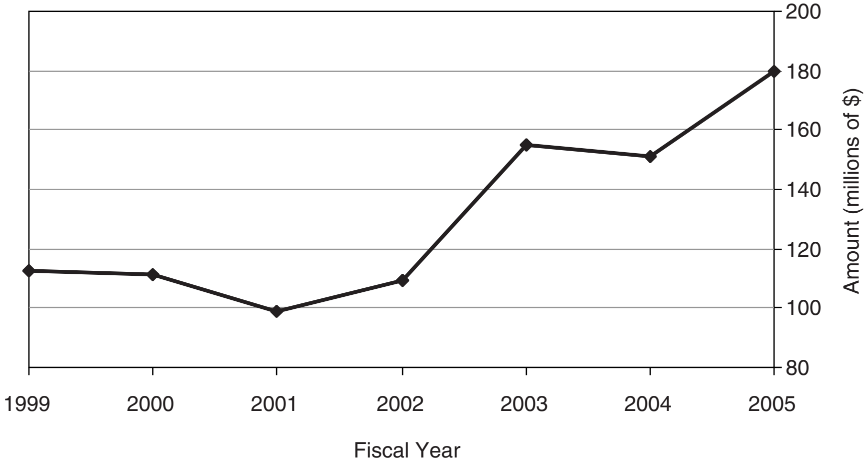


FIGURE 4-10 Total NRI funding to states for FY 1999 to FY 2004. SOURCE: P. Johnson, USDA-CSREES, personal communication, January 4, 2005.

protection (RPA#311-315) ranged from $29.8 to $40.4 million (Table 4-14); they were animal diseases; internal and external parasites and pests; toxic chemicals, poison plants and other hazards affecting animals; and animal welfare, well-being, and protection. The largest sources of CSREES funds for animal protection research have been the NRI and Hatch funds, which account for 53-69% of the funds per year (FY 1999-2003).

A review of FY 2004 and FY 2005 funding of research related to animal protection was similar to that in FY 1999-2003 with some moderate increases for animal health (1433), food safety, critical issues, agrosecurity, and the Food and

TABLE 4-14 CSREES Research Funding by Grant Category for Animal Protection in RPA#311-315, FY 1999-2003 (thousands)

Grant Category	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
Hatch	$7,979	$9,275	$8,435	$8,201	$7,680
McIntire-Stennis	52	69	76	106	112
Evan-Allen	826	1,402	1,323	995	627
Animal Health (1433)	3,706	3,990	3,847	3,664	3,639
Special research grants	1,351	2,238	2,185	2,856	3,427
National Research Initiative	12,753	7,941	10,249	17,911	12,512
Small Business Innovation Research	735	$500	855	728	1,117
Other CSREES	2,447	5,414	8,335	5,963	3,829
Total CSREES	**29,848**	**30,829**	**35,305**	**40,424**	**32,943**

SOURCE: USDA-CSREES, 2004.

TABLE 4-15 CSREES Funding in Selected Fields for FY 2004, FY 2005, and Proposed in President's FY 2006 Budget (thousands)

Program Area	FY 2004	FY 2005	FY 2006 (Proposed)
Animal Health (1433)	$4,532,000	$5,057,000	$0
Minor Use Animal Drugs	526,000	583,000	588,000
Higher Education Agrosecurity	0	0	5,000,000
Critical Issues	444,000	1,102,000[a]	0
Food Safety	13,305,000	14,847,000	0
Food and Agriculture Defense Initiative	7,953,000	8,928,000[b]	30,000,000

[a]Funds to be used equally between animal and plant diseases.
[b]These funds will support the National Plant Diagnostic Laboratory Network, the National Animal Health Laboratory Network, and the Extension Disaster Education Network.

SOURCE: Wagner, 2004.

Agricultural Defense Initiative (Table 4-15). However, the proposed budget has eliminated funding for Animal Health (1433), Critical Issues, and Food Safety. Funds from the National Integrated Food Initiative are proposed to be reallocated to another food-safety program. Similarly, some funds from the Hatch Act funding of agricultural experiment stations are redirected to NRI for competitive grants, so the Hatch Act is reduced from $178,707,000 in FY 2005 to a proposed $89,354,000 in FY 2006.

One of the CSREES programs is targeted only to animal protection, that is, the USDA 1433 animal health formula-funds program used for animal health and disease research. The program was created specifically to provide resources for research on methods for detection, prevention technologies, agent characterization, and dose-response relationships for high-consequence agents in the food supply. Funds are distributed to states on the basis of animal inventory and research capacity. The nation's agricultural experiment stations and CVMs have the necessary expertise and infrastructure to respond effectively to this critical need.

A 1989 National Research Council study addressed the needs for research in agricultural, food, and environmental systems (NRC, 1989). The study identified the need for investment in human capital and the scientific knowledge base to maintain and expand the US national and international markets, create new products or new uses for existing products, and protect animal health and food safety (NRC, 1989). A central part of the recommendation was the creation of NRI (which would be a new federally funded competitive grants program at that time) and a proposed increase in USDA competitive research funding from $50 to $550 million per year. The proposed funding would be new money, not from redirection or reallocation of existing research and education funds, such as formula funds and ARS in-house research funds. However, the maximal appropriation for the NRI program was $154 million in FY 2004, and that funding was for all fields of research in agricultural, food, and environmental systems (Figure 4-10).

Other Subagencies

Several additional USDA agencies affect and are affected by research in veterinary medicine and associated sciences. FSIS is an action subagency whose mission is to ensure that the nation's commercial supply of meat, poultry, and egg products is safe, wholesome, and correctly labeled and packaged (USDA, 2004c). FSIS does not have a direct mission of research, which is the responsibility of ARS (intramural) and CSREES (extramural). However, FSIS has initiated and completed some limited in-house development and validation of diagnostic tests for use in its food-safety service laboratories. In addition, it has on rare occasions partnered with ARS, FDA, APHIS, and universities to provide small sums for emergency special projects in food safety. In addition, FSIS depends on veterinarians trained in food-safety inspection for its core food-safety mission. For research information and results, FSIS depends on ARS- and CSREES-funded universities and other institutions. Current funding at ARS and CSREES for veterinary research is insufficient to address expanding food-safety issues, including Bovine Spongiform Encephalopathy, Avian Influenza, Salmonella, and toxic residues (N. Bauer, FSIS, personal communication on December 17, 2004).

APHIS is responsible for protecting and promoting US agricultural health, administering the Animal Welfare Act, and carrying out wildlife-damage management activities (USDA, 2004d). In APHIS, Veterinary Services protects and improves the health, quality, and marketability of our nation's animals, animal products, and veterinary biologics by preventing, controlling, or eliminating animal diseases and monitoring and promoting animal health and productivity (USDA, 2004e). Research is not a direct element of the APHIS mission, but some research is necessary to fulfill its action-agency mission. For example, some research on wildlife control is conducted at the National Wildlife Research Center, Fort Collins, CO, and some research on risk assessment and surveillance is conducted at the Center for Animal Health and Epidemiology, Fort Collins, CO. ARS- and CSREES-funded universities and other institutions conduct most of the research necessary for APHIS to fulfill its mission. ARS and APHIS meet each year to develop a research priority list for APHIS. APHIS relies heavily on veterinarians in its work force. It provides small amounts of research funding for special emergency projects directly to ARS or university researchers—less than $300,000 per year (J. Korshun, APHIS, personal communication. December 10, 2004).

CENTERS FOR DISEASE CONTROL AND PREVENTION

Veterinary scientists play a critical role in the research capabilities of the Centers for Disease Control and Prevention (CDC), where most are employed as epidemiologists and are associated with applied or field research directed toward the public-health mission of the agency.

Infrastructure

CDC comprises 12 centers, institutes, and offices each with facilities dedicated to a specific mission; each unit responds individually in its field of expertise. For example, the National Center for Infectious Diseases (NCID), which depends heavily on expertise in veterinary science, is dedicated to "prevent illness, disability and death caused by infectious diseases in the United States and around the world." Global needs to combat terrorism and the resulting expansion of the mission of CDC implies an expanded need for veterinary scientists (AAVMC, 2003b; Hoblet et al., 2003; Nielsen, 2003; NRC, 2003a; NRC, 2004a)

External self-standing and collaborative programs are funded by CDC. The Arthropod-borne and Infectious Disease Laboratory (AIDL) at Colorado State University has 30 researchers directed to prevention, diagnosis, and control of mosquito-borne encephalitis, yellow fever, dengue, hantaviruses, parasitic disease, and Lyme disease. AIDL cooperates both with CDC and with laboratories in USDA (see http://www.cvmbs.colostate.cvmbs/aidl.html). CDC also funds small cooperative programs that include a companion animal syndromic surveillance program with Banfield Pet Hospital and Purdue University.

In 2000, CDC established the Specialty Centers for Public Health Preparedness Program, a national effort focused on improving the capacity of frontline public-health staff to address public-health threats in academic centers. Its mission is to provide public-health practice curricula, training to support preparedness for bioterrorism, disease-outbreak investigation, and other public-health emergencies. The Center for Food Security and Public Health in the College of Veterinary Medicine at Iowa State University is designated a CDC Specialty Center for Public Health Preparedness for Veterinary Medicine and Zoonotic Diseases—the only center so dedicated to veterinary medicine (see http://www.cfsph.iastate.edu/).

Expertise and Human Resources

Veterinarians and other veterinary scientists in CDC work in disciplines as diverse as environmental toxicology, environmental health tracking, zoonosis surveillance, occupational safety and health, laboratory animal training, and models of animal sentinels for ecosystem health events (Table 4-16). Veterinarians are assigned as leaders and team members for such programs as NCID, the National

TABLE 4-16 Veterinarians at CDC

Discipline or Department	Number of Veterinarians
State health departments	6
CDC: Emerging infectious disease	36
CDC: Occupational safety and health	7
CDC: ADIS/STC	6
Immunizations	4
Environmental health	5
Other[a]	5

[a]Assignment of veterinarians in other disciplines or departments: global health, laboratory safety, and terrorism, three each; health statistics one; and reproductive health, one.

SOURCE: Pappaioanou et al. 2003.

Center for Environmental Health, the National Institute for Occupational Safety and Health, the Epidemic Intelligence Service (EIS), and Public Health Emergency Preparedness. Of those, NCID is particularly attuned to the critical need for a strong interface of CDC with veterinary science. NCID has created a new position, associate director for veterinary medicine and public health, which is dedicated to enhancing partnerships among the human and veterinary medical, research, and public-health communities. The mission of NCID is accomplished by conducting epidemiological and laboratory research and surveillance, epidemic investigations, training, and public-education programs to develop, evaluate, and promote prevention and control strategies for infectious diseases.

Recognizing the contributions of veterinarians and veterinary scientists to public health in the United States, Julie Gerberding, director of CDC, stated that "veterinarians are important team members in public health." She has identified a critical need to replace losses of such scientists in the next decade. An estimated 200 veterinarians will be required. In 2004, 99 veterinarians were in the commissioned Public Health Corps. Of those, about 50% were eligible to retire by 2006.

Considering the global threats of emerging zoonotic disease, threats to food safety, and bioterrorism, there is an unprecedented demand for the expertise of veterinary scientists in research in the public-health workforce. Research skills and experience in problem-solving, use of quantitative and qualitative analytical methods, preventive large-population medicine, field epidemiology, public-health surveillance, cost-effective therapies for production medicine, and global communication are required for effective work of teams of professionals drawn from diverse biomedical fields. "With their broad training in the health and management of multiple species and the environment, in herd health, and in a populations base approach to problem solving, veterinarians are uniquely suited to participate in solving problems across the public health spectrum" (Pappaioanou et al. 2003).

Educational Resources

Training in CDC is centered in EIS fellowships and graduate stipends that support veterinarians. EIS offers a 2-year postgraduate intensive program of training for health professionals in epidemiology and public health for 60-80 physicians, veterinarians, and doctoral-degree professionals in related fields. Veterinarians applying to the program must have a master of public health or equivalent degree or have demonstrated public-health experience or course work. A review of EIS alumni records from a the period 1951 through 2002 revealed that veterinarians made up 195 of 2,629 EIS officers, only 7% (Pappaioanou et al. 2003) (Figure 4-11 and Table 4-17). The mean percentage of veterinarians in EIS classes each year was 6.7% (range, 0-29.7%). The type of veterinarians accepted into EIS has changed over 51 years in several ways:

- The first veterinary EIS officer in a minority group was accepted in 1971, and the proportion in minority groups increased to 15% during 2000-2002.
- The proportion of veterinarians having one or more graduate degrees increased from 15% in 1951-1959 to 88% during 1990-1999.
- Assignments of students after completion of the course has shifted from 64% assigned to state health departments in 1950-1959 (with 27% to regional rabies or general field stations and 9% to headquarters positions) to 62% assigned to headquarters positions in 1990-1999 (38% to state health departments).
- Veterinarians entering directly from veterinary school decreased from 64% during 1951-1959 to 3% during 1990-1999.

In the 1990s, 18 (26%) of veterinarians entering the EIS program came from

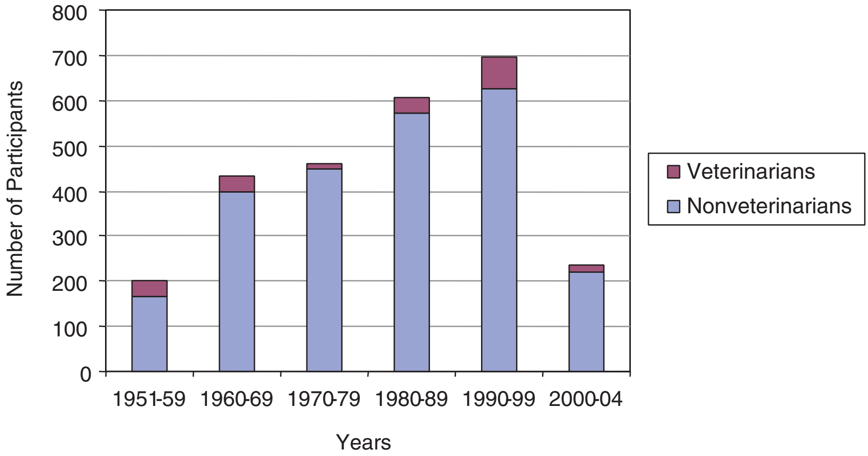


FIGURE 4-11 Veterinarians and nonveterinarians participating in Epidemic Intelligence Service program, 1951–2004. SOURCE: Pappaioanou et al. 2003.

TABLE 4-17 Veterinarians in Epidemic Intelligence Service,: 1951–2004.

	Decade					
	1951–59	1960–69	1970–79	1980–89	1990–99	2000–01
Number of veterinarians	33	34	13	33	69	29
CDC: Infectious disease	2	5	9	11	30	14
CDC: Environment	—	1	—	7	6	5
CDC: Other	1	8	2	3	7	—
Regional field post	9	3	—	—	—	—
State health department	21	7	2	12	26	10

SOURCE: Pappaioanou et al. 2003.

a post-DVM-graduate degree program, 13 (19%) from academic positions, 25 (36%) from positions with the federal government, five (7%) from state or local government, four (6%) from clinical practice, and one (1%) from a nongovernment organization. To increase trained epidemiologists, APHIS signed an agreement with the EIS program at CDC in 1984 that dedicated two positions each year for veterinarians who would return to APHIS for employment. Similar programs were arranged for the Air Force and Army in 1994; and in 2001 USDA signed a similar agreement with FSIS.

The number of veterinarians in CDC's Agency for Toxic Substances and Disease Registry has grown since 2001. In August 2002, there were 75 veterinarians, of whom 42 (56%) were graduates of the EIS program. Eleven veterinarians held program-management positions, one was a division director, four were associate directors of divisions or offices, and four were branch chiefs (Pappaioanou, et al. 2003 p. 389, col. 1, par. 5).

Of the 118 veterinarians that entered the EIS in the period 1977-2000, 84 are employed by federal, state, or local government agencies (Pappaioanou et al. 2003). Of the 69 veterinarians that entered federal employment, most work with CDC (30), USDA (16), and DOD (10); the remainder work in FDA, NIH, the DHHS Office of the Secretary, and the Environmental Protection Agency. State agencies employed 22 veterinarians, and three are in local agricultural or health departments. Sixteen post-EIS veterinarians are employed in nongovernment positions: academic programs seven, industry three, and nonprofit organizations six (Pappaioanou et al. 2003).

Under the CDC program of emerging-infectious-disease laboratory fellowships, college graduates are recruited for 1-year assignments and postdoctoral scientists for 2-year assignments in public-health laboratories. The intramural program is effective and responsive to national needs. CDC has an established competitive-grants program that is open to veterinary scientists in the United States; it emphasizes zoonotic disease, food safety, occupational health, parasitic disease, global health, and laboratory animal medicine.

In the professional curriculum, core courses in veterinary public health, epidemiology, and preventive medicine vary widely among veterinary schools in the United

States. Veterinary schools with specific courses indicate a median of 60 hours in these disciplines with contact time ranging from 30 to 150 hours; advanced training was available in the subjects at 79% of 27 schools in 2004 (Riddle et al., 2004). There is a consensus that high-quality postgraduate training is the key to increasing the supply of veterinarians and veterinary scientists in the biomedical-sciences workforce (NRC 2004a) and that the absence of commitment by CVMs, which do not prepare veterinary students adequately for careers in other than private clinical practice, should be corrected by changes in recruitment of applicants and in curricula (NRC 2004a).

Financial Resources for Research

CDC has direct appropriations from the federal budget directed to the mission of regulatory public health, but research on risk-analysis systems, on models of disease, and in other applied fields is critical to its mission. Financial resources for collaborative programs directed by CDC come from several sources. The Laboratory Response Network is a classified system of laboratories with diagnostic capabilities that are dedicated to identification and confirmation of specialized agents useful to bioterrorists. At least 75% of category A infectious agents are zoonotic so strategies to control and prevent disease must include the expanded databases on animal disease that are available from the National Animal Health Laboratory Network and other veterinary diagnostic systems. Two surveillance projects are dedicated to food safety: FoodNet, a network of CDC, USDA, FDA, and nine state institutions; and PulseNet, an international network of public-health laboratories for typing and electronic database comparisons of foodborne bacteria (King 2003). Veterinary institutions' access to and participation in collaborative surveillance projects is critical, and field research is essential for currency in these programs.

DEPARTMENT OF DEFENSE

DOD uses animals in research, development, testing, and evaluation programs critical to military operations in defense of our national interests (Box 4-1). Most research programs are directed to health protection of forces operating in various hazardous environments around the world. Development of vaccines, drugs, and therapies for protection of service members and their families has high priority. Other high-priority activities are improved medical care of battlefield casualties and defense against chemical and biological warfare. At the end of the cold war, Congress directed DOD to oversee medical research benefiting the civilian population. As a result, considerable research is directed toward breast, prostaic, and ovarian cancer and other important human diseases. However, most of that research is done through an extramural program of DOD. Animal research programs not directly related to human health include the study of hazard sensors, of learning and memory, and of improved use of working animals, including dogs

BOX 4-1
End Points of DOD Directed Animal Research

Clinical Investigations
- Development and testing of HIV vaccines.
- Better understanding of the development, diagnosis, and treatment of colon carcinomas.
- Identification of induced antibody responses to vaccine development.
- Treatment and prevention of hemorrhagic shock.
- Treatment of acute lung injury.
- Treatment of advanced prostaic cancer.
- Treatment and prevention of neuropsychiatric disorders.
- Determination of active mechanisms affecting altered fluid handling in alcohol exposure.
- Skin transplantation.

Medical
- Development and evaluation of malaria vaccines.
- Antigen detection during vaccine development.
- Development of meningococcal and anthrax vaccines.
- Mechanisms of dermal tissue damage during lesion development.
- Methods for inducing controlled hypothermia.
- Evaluation of acute effects of laser exposure.
- Mechanisms of occupational and chronic fatigue.
- Quantification of munitions compound toxicity on wildlife.
- Development of lymphoma.
- Blast overpressure exposures.
- Development of active topical skin protectants against chemical-warfare agents.
- Determination of molecular mechanisms, detection, and treatment of breast, prostaic, and ovarian cancers and neurofibromatosis.

Nonmedical
- Updating of national and international laser safety standards.
- Identification of environmental and human health risks.
- Developing methods and technologies for toxicity testing.
- Developing preventive measures for environmental toxins.
- Developing biomonitoring systems.
- Evaluating toxic hazards of occupational chemical exposure.
- Training.
- Graduate medical training.
- Training of surgical residents in critical skills.
- Advanced trauma life-support and medical-emergency training.
- Veterinary personnel medical-emergency training.
- Training for research and animal care personnel to improve handling techniques and protocol procedure performance.

SOURCE: DOD 2001

and marine mammals. Veterinarians are essential to all components of this work in both principal-investigator and support roles.

Infrastructure

According to the DOD Animal Use Profiles, the US Army accounts for about 45% of DOD intramural animal use, the Navy 30%, the Air Force 5%, and other DOD 20%. Total animal use by DOD declined by about 40% from 1994 to 1996 and has since remained steady (DOD, 2001). All intramural DOD laboratories engaging in animal research are accredited by the American Association for the Accreditation of Laboratory Animal Care. Telephone interviews with veterinary officers in all branches of the service revealed a general satisfaction with the animal research infrastructure, given the current scope of biomedical research conducted in the military.

Expertise

Most veterinarians involved in research in DOD are board-certified in laboratory animal medicine or pathology or have the PhD degrees in physiology, pharmacology, toxicology, or microbiology, reflecting their research leadership and support roles in the various DOD programs. The US Army employs 418 veterinarians (R.G. Webb, Veterinary Corps Branch, personal communication, March 31, 2005), more than any other uniformed service. Of them, 29 are diplomates in laboratory animal medicine, 29 are diplomates in veterinary pathology, and 19 are DVM-PhDs.

Human Resources

AVMA's Veterinary Market Statistics (AVMA 2004c) show 474 veterinarians employed in the uniformed services as of December 2004. We were unable to determine the number of veterinarians involved in investigator or support roles in research, nor to determine the number of nonveterinarians contributing to animal research programs.

Financial Resources

Financial resources for medical research and related nonmedical research are relatively unchanged in recent years and have been directed mostly toward chemical and biological defense and naturally occurring infectious disease. Thus, animal use will continue to be important in DOD. Research for the improvement of human health with animal models suggests a continued need for veterinarian involvement, although veterinary research for the sake of animals will probably not be a major focus in DOD.

FOOD AND DRUG ADMINISTRATION

"The mission of the US Food and Drug Administration (FDA) is, in part, to protect the public health by assuring the safety, efficacy, and security of human and veterinary drugs, biological products, and medical devices. The FDA is also responsible for advancing the public health by helping to speed innovations that make medicines more effective, safer, and more affordable; and helping the public get the accurate, science-based information they need to use medicines to improve their health" (FDA, 2004).

Organizational Structure of FDA

FDA is organized into eight main offices and centers—the Office of the Commissioner, Office of Regulatory Affairs, Center for Biologics Evaluation and Research, Center for Devices and Radiological Health, Center for Drug Evaluation and Research, Center for Food Safety and Applied Nutrition, Center for Veterinary Medicine (CVM), and National Center for Toxicological Research (NCTR). CVM is the most relevant to this study. Some other centers also conduct veterinary research, but it is not their main focus. For example, many research programs NCTR use animal models to assess the toxicity and carcinogenic risk associated with specific products, such as drugs, cosmetics, biologics, food, and veterinary products. NCTR, in conjunction with CVM, is also studying antimicrobial resistance in relation to food-producing and non-food-producing animals. However, tearing apart research in those centers that is peculiar to veterinary science would be impossible. Therefore, this discussion focuses on the CVM.

CVM is a consumer-protection organization whose core functions include animal-drug review, compliance-related actions, postapproval monitoring, and animal-feed safety. The staff are organized into five offices: the Office of the Director, Office of New Animal Drug Evaluation, Office of Surveillance and Compliance, Office of Management, and Office of Research. The Office of Research conducts basic and applied research in broad fields of analytical chemistry, pharmacology, toxicology, immunology, microbiology, animal nutrition, and residue chemistry to support regulatory decision-making by the CVM (FDA, 2004).

Infrastructure

The Office of Research is housed in a state-of-the-art research complex consisting of offices, laboratories, animal facilities, and animal pastures in Laurel, MD. The facilities include radioactive laboratory, mass-spectrometry laboratory, analytical-instrument rooms, and animal-research buildings that can accommodate beef cattle, lactating dairy cattle, calves, swine, sheep, dogs, poultry, and a variety of aquatic species (FDA, 2001).

TABLE 4-18 Annual Budget of Office of Research in the Center of Veterinary Medicine of the Food and Drug Administration, FY 2001–FY 2005

Fiscal Year	Budget for Premarket Research	Budget for Postmarket Research	Total
2001	$2,816,201	$5,466,743	$8,282,944
2002	3,102,544	6,022,585	9,125,129
2003	2,977,380	5,779,620	8,757,000
2004	2,666,620	5,176,380	7,843,000
2005	2,728,500	5,296,500	8,025,000

Educational Resources

The CVM initiated its Student Summer Internship Program in 1997. The program provides training with a stipend to undergraduate, graduate, and professional students with the goal of stimulating the students' interests in pursuing careers important to the center. About 70 interns have participated in the program since its initiation.

Financial Resources for Research

Because the Center of Veterinary Medicine's role includes research and other regulatory activities, the committee discusses only the budget of its Office of Research, which bears direct relevance to veterinary research. In support of the premarket or drug-review function of FDA, the Office of Research conducts studies in standardization of test methods, pharmacokinetics and pharmacodynamics, and antibiotic resistance. The office develops analytical methods and evaluates screening tests for detection of drug residues in imported and domestic food products. It also conducts postapproval monitoring of retail meats for drug-resistant foodborne pathogens under the National Antimicrobial Resistance Monitoring System and molecular typing of those pathogens as part of the national PulseNet program. The budget of the Office of Research for FY 2001-FY 2005 is shown in Table 4-18. In addition to in-house research, the Center of Veterinary Medicine funds a small number of extramural grants and cooperative agreements; this funding has been declining in the last 5 years (Table 4-19).

NATIONAL SCIENCE FOUNDATION

NSF, an independent agency of the government, was established in 1951. Its mission is "to promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense." Unlike CDC, FDA, and USDA, NSF does not conduct laboratory research, but it initiates and supports scientific and engineering research through grants and contracts.

NSF is structured as seven disciplinary directorates: Biological Sciences; Computer, Information Science and Engineering; Education and Human Re-

TABLE 4-19 Extramural Grants and Cooperative Agreements Funded by Center of Veterinary Medicine, FY 2000–FY2005

Fiscal Year	Number of Grants and Cooperative Agreements
2000	10
2001	8
2002	8
2003	4
2004	3

sources; Engineering; Geosciences; Mathematics and Physical Sciences; and Social, Behavior and Economic Sciences. Although the Directorate for Biological Sciences may be the most relevant to veterinary research, other directorates may also provide funding for veterinary research. For example, the Directorate for Engineering supports research in biomedical engineering. The Directorate for Education funds the Integrative Graduate Education and Research Traineeship (IGERT) program, which aims to develop models of graduate education and training that emphasize collaborative research among multiple disciplines (Box 4-2). Veterinary researchers can also seek funding from other crosscutting programs that span the NSF directorates (Zamer, 2005).

BOX 4-2
An Opportunity for Development of Scientific Expertise Needed in Veterinary Science Research

"The Integrative Graduate Education and Research Traineeship (IGERT) program [was] initiated in 1997 and [comprised about] 125 award sites [in 2004]. The IGERT program has been developed to meet the challenges of educating U.S. Ph.D. scientists, engineers, and educators with the interdisciplinary backgrounds, deep knowledge in chosen disciplines, and technical, professional, and personal skills to become in their own careers the leaders and creative agents for change. The program is intended to catalyze a cultural change in graduate education, for students, faculty, and institutions, by establishing innovative new models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries. It is also intended to facilitate greater diversity in student participation and preparation, and to contribute to the development of a diverse, globally-engaged science and engineering workforce.

"IGERT is an NSF-wide endeavor involving the Directorates for Biological Sciences (BIO), Computer and Information Science and Engineering (CISE), Education and Human Resources (EHR), Engineering (ENG), Geosciences (GEO), Mathematical and Physical Sciences (MPS), Social, Behavioral, and Economic Sciences (SBE), the Office of Polar Programs (OPP), and the Office of International Science and Engineering (INT).

SOURCE: NSF, 2004.

TABLE 4-20 Awards by Each Agency under joint NIH-NSF Program in Ecology of Infectious Diseases, FY 2000–2004

	Awards[a]							
	FY 2000		FY 2002		FY 2003		FY 2004	
Awards by FIC[b]	3	2	3	2	1	0	0	0
Awards by NIEHS[c]	1	0	1	1	0	0	0	0
Awards by NIAID[d]	3	1	0	0	0	0	0	0
Awards by NSF[e]	5	3	7	3	7	1	6	4
Total	12		11		8		6	

[a]Numbers in right column under each fiscal year numbers of awards that involve veterinarians.
[b]Fogarty International Center, NIH.
[c]National Institute of Environmental Health Sciences, NIH.
[d]National Institute of Allergy and Infectious Diseases, NIH.
[e]NSF.

SOURCE: J. Rosenthal, Fogarty International Center, National Institutes of Health and NSF 2004.

In FY 2000, NSF and NIH announced the multiyear interagency program on ecology of infectious diseases. Because many emerging diseases are zoonoses or vector-borne diseases and many are linked to environmental changes, the agencies recognized that a concerted effort among experts in different disciplines was needed to understand the emergence and transmission of infectious diseases. The mission of the program is to develop predictive models for the dynamics of infectious diseases. The program has funded 37 interdisciplinary research projects in FY 2000-2004, many of which involve veterinarians (Table 4-20). It has brought together researchers in different disciplines (for example, veterinarians, ecologists, and virologists) and illustrates the benefits of interdisciplinary studies and interagency coordination.

Although NSF supports research on animals in various programs, it does not support research with disease-related goals, nor research on animal models for studying diseases or testing of drugs. Some veterinary researchers are supported by NSF awards, but no NSF program is targeted to veterinary science (Zamer, 2005). In FY 2002-2003, 16 of the 28 CVMs reported collective expenditures of about $3.5 million on 48 research projects supported by NSF. Most of the CVMs expending NSF funds had one or two projects supported by NSF, and one reported that it had 14 NSF-funded projects. Amounts of NSF funds expended at individual CVMs ranged from below $5,000 to over $770,000. Because NSF does not track the number and amount of grants awarded for veterinary research, the committee cannot assess the trends of NSF funding for veterinary research (S. Scheiner, The National Science Foundation, personal communication on July 12, 2004).

PRIVATE-SECTOR RESEARCH RESOURCES

The private sector conducts considerable research in veterinary science, but the resources, specific activities, and outcomes are not easily determined. Private businesses do not release much of the information that is available on the other research venues discussed. Nevertheless, the animal health and human pharmaceutical and biologics industries, companies that manufacture feeds and pet foods, private animal diagnostic laboratories, contract animal research laboratories, laboratory animal suppliers, and other private enterprises are major participants.

The Animal Health Institute (AHI), an organization that represents 16 manufacturers of animal health products, reported that its members spent $516 million in 2003 and about $511 million in 2002 on R&D for products registered or intended for registration in the United States. Large portions of those funds ($439 million in 2003) were directed toward development of new products and the remainder to further studies of existing products. About $65 and $72 million were directed to studies outside the companies' internal R&D budgets in 2002 and 2003, respectively (Animal Health Institute, 2004). It is not known what proportion of the reported expenditures was directed to CVMs or other academic entities. Other companies are active in animal health research but are not members of AHI. The human-pharmaceutical industry spends billions on research, but the amount that is related to research in veterinary science is not known. Some products originally intended for application in human beings become useful for animals instead. In addition, many of the drugs used regularly in companion-animal veterinary practice are directly from human-drug formularies.

Private veterinary diagnostic laboratories are potential sources of research data because they receive many tissue and clinical laboratory samples from veterinary patients, especially companion animals. Research on animal nutrition is conducted by companies that produce pet foods, nutritional supplements, and other animal feeds. Indeed, considerable research on nutrition of companion animals is conducted by pet-food companies. Suppliers of laboratory animals conduct research on the genetics, nutrition, and welfare of laboratory animals. Private foundations support research laboratories that conduct animal research. Some contract research laboratories also conduct animal research. However, the committee was unable to quantify any of the resources devoted to those activities because of lack of data.

5

An Assessment of Current and Projected Resource Needs for Research in Veterinary Science

This chapter outlines the resources that researchers in veterinary science require to meet pressing societal needs effectively. In this age of reductionist research and the ascendancy of disciplinary endeavors, veterinary research stands apart because of its breadth and interdisciplinary orientation. The world is different from what it was, and full of risks that were unanticipated only a matter of years ago. The first half of the twentieth century brought great victories over infectious disease in animals and humans. Improvements in public health, diagnostic methods, and nutrition, coupled with the development of vaccines and antimicrobial drugs, ushered in an era of complacency. Epidemics of polio, cholera, influenza, tuberculosis, brucellosis, and rabies in the United States became distant memories. As noted by Hughes (2001), Sir MacFarlane Burnett wrote in the early 1960s that "one can think of the middle of the twentieth century as the end of one of the most important social revolutions in history, the virtual elimination of the infectious disease as a significant factor in social life." No more. That notion has been shattered irrevocably over the last decade. Today, danger looms in the form of highly pathogenic avian influenza, foreign-animal diseases (such as foot-and-mouth disease), and transmissible spongiform encephalopathies, to name but a few examples. Veterinary research is critical to the advancement of our understanding of and response to those risks and many other animal health problems—for example, chronic debilitating diseases.

As noted in Chapter 1, support for veterinary research tends to "fall between the chairs" (Schwabe, 1984). There is an urgent need to provide adequate resources for investigators, training programs and facilities involved in veterinary research. Almost 40 years have elapsed since there has been significant investment in facilities to support veterinary education and research; HR 490 and HR 3348 and similar bills authorized a 3-year program of grants for construction of veterinary medical education facilities. Since that time, many reports have outlined changing research and educational needs and the impact on animal and human health (Pritchard, 1989; NRC, 1989; NRC 2002b; NRC, 2004).

The veterinary research enterprise must address a very large number and variety of animal genera, species, and breeds—from horses and mice to oysters and bison—and a vast array of challenges—from models to evaluate new human drugs to molecular dissection of agents of bioterrorism. Animals occupy an extraordinary number of different environments—from shrimp-rearing ponds to mouse cages and from wilderness areas to feed lots—and they meet diverse human needs—from models of human disease to competitive athletics and from service and companionship to esthetic pleasure and sources of food and livelihood for millions of Americans.

All the examples of critical research needs outlined in Chapter 3 require facilities (for example, laboratories, animal housing, and containment laboratories), infrastructure (for example, equipment and databases), financial resources, and well-educated research scientists. Research cannot be carried out effectively without all those physical, financial, and human resources. The goals of this chapter are to

- Determine the extent to which the available resources outlined in Chapter 4 are sufficient to address the challenges, implement the strategies, and address the research priorities identified in Chapters 2 and 3.
- Identify where current or future resources and activities are likely to be inadequate.
- Recommend approaches to address the inadequacies.

COLLABORATIVE AND INTERDISCIPLINARY RESEARCH—A "ONE MEDICINE" APPROACH

Veterinary research aims to prevent, control, diagnose, and treat animal diseases to ensure animals' health and welfare, and it contributes to both animal and human health, as illustrated in earlier chapters. Research in veterinary science and veterinary medicine as a whole are at the center of domestic and wild animal and human health (see Figure 1-1 in Chapter 1). Because veterinary research intersects human and animal health, it is interdisciplinary. Translational research aims to accelerate transformation of basic biological research from the bench to applications for animal and human patients in care by translating parallel learning applicable to biological systems across species and using new tools to gather information about the divergence of species to illuminate important differences. Translational research is needed to link basic-science discoveries to studies involving animals and human health. A disease that has been viewed at the molecular or cellular level can look different at the organ system or whole animal level. To realize the potential for translating scientific advances into animal health, veterinarians and animal scientists must bring their whole-animal understanding to every phase of research and development (R&D), from basic biological research to applied studies. A sustainable model for translational research will take full advantage of the substantial R&D investment in human drugs and other therapies (Kinkler, 2004).

New discoveries at the bench include basic biology and pathways, molecular libraries, bioinformatics and computational biology, and structural biology. Applied research is needed to transform discoveries to development of products and procedures that can be used for patient care. High-priority elements of translational research include the following (Kinkler, 2004):

- Sequencing of the genomes of multiple species and research in all the "omics" for animals—functional genomics, proteomics, metabolomics, and metabonomics.
- Development of effective animal models, in addition to existing rodents models, to validate safety, efficacy of candidate pharmaceutical agents and to predict clinical outcomes.
- Animal-based stem-cell research with appropriate models to evaluate therapies.
- Research to identify targets for drug development in humans and for treatment of other animal disorders.
- Identification of new targets for drug development, using well-characterized rodent and nonrodent animal models.
- Development and promotion of preventive medicines and therapies—such as nutraceuticals, anti-infectives, immune modulators, and vaccines—that use new immunogenic modalities to keep animals healthy.

Financial constraints on research often put pressure on investigators to select applied-research topics rather than address basic-science questions even though basic science contributes fundamental information to applied research. That pressure tends to stifle inquiry into the fundamental principles underlying scientific phenomena, which form the backbone of knowledge that can eventually be translated into clinical benefits (Patterson et al., 1988; Dodds and Womack, 1997; Dodds, 1995a).

The idea of translational research and the "One Medicine" approach described in Chapter 1 imply that fragmentation of the research effort into disciplines must be overcome. A multidisciplinary approach is needed in which basic scientists, veterinary and medical researchers, and clinical specialists with different but complementary skills work together. Basic scientists and veterinary and medical researchers tend to have highly specialized training, but few clinicians have independent scientific-specialty training, so the collaboration among the different groups could be difficult to achieve. Most academic settings administratively foster interaction between the researchers and clinical specialists and try to identify people who can be leaders in the research (Wagner, 1992). However, forced interactions among clinical specialists and researchers may not achieve the desired outcome. The culture of a multidisciplinary approach to veterinary and human medicine should be promoted in early professional training. That is discussed further in this chapter.

The National Research Council report *Facilitating Interdisciplinary Research* (NRC, 2005) defines interdisciplinary research as "a mode of research by teams *or individuals* that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice" (emphasis added). The report says that although interdisciplinary research has been conducted in many industrial and government laboratories and other nonacademic settings, researchers in academe often face obstacles and disincentives in pursuing interdisciplinary research despite its apparent benefits (NRC, 2005). In academe, collaborative interdisciplinary research is often impeded by administrative, funding, and cultural barriers between departments and universities. Other barriers are related to "the tradition in academic institutions of organizing research and teaching activities by discipline-based departments—a tradition that is commonly mirrored in funding organizations, professional societies, and journals" (NRC, 2005). Recognizing the importance of interdisciplinary research, NIH set up the Roadmap Initiative that is designed to conduct such work (see Chapter 4).

On the basis of its members' experience, this committee concurs that researchers in different colleges of veterinary medicine (CVMs) and colleges of agriculture who are interested in collaborative interdisciplinary research encounter some of the barriers to interdisciplinary research mentioned in the National Research Council report. a US Department of Agriculture (USDA) report has noted that "there is very little coordination of a research agenda between the intramural, extramural, and private sector research system" (p. 53, USDA, 1999). Yet, many of the research objectives identified in Chapter 3, the translational research, and the One Medicine approache discussed above imply that the participation of two or more research entities would be effective. Therefore, the committee assessed whether CVMs colocated with colleges of medicine (CoMs) or USDA Agricultural Research Service (ARS) laboratories reported higher research expenditures from the National Institutes of Health (NIH), USDA, and all other sources than those without the benefit of colocation of such facilities. (See detailed analysis in Appendix H.) The analysis suggests a positive correlation between research expenditures of CVMs and colocation with CoMs or ARS laboratories. The analysis is preliminary and does not imply a causal relationship. Furthermore, whether CVM faculty members collaborate with their colleagues in colocated CoMs or in nearby ARS laboratories could not be determined. Many other factors may affect research programs in veterinary science on a given campus—for example, university emphasis on research, adequacy of the physical plant, availability of ancillary resources, and seed money for young investigators from internal sources. However, the data suggest that CVMs may derive some benefits from proximity to CoMs and ARS laboratories.

Elimination of administrative barriers, sharing of resources, and financial agreements are key elements in successful interactions among and between research units. How science is practiced and how students are taught about science must undergo major change if the issues raised in this report are to be addressed effectively and efficiently. Collaborative research should not be limited to the United States; many of the critical research issues raised in this report have global implications (for example, bovine spongiform encephalopathy and emerging infectious diseases). Collaborations with international partners could facilitate knowledge transfer between countries and avoid duplication of effort. To say that interdisciplinary collaborative research is needed is not to say that all scientists must work in teams or that all research and education must be interdisciplinary. But some of the most interesting scientific questions are found at the interfaces between disciplines, so they can be approached most effectively by researchers in complementary disciplines (NRC, 2005). Future needs in science, especially those at the interfaces between science and social needs (see Chapters 2 and 3), cannot be met unless there is more cooperation among the various programs that conduct research and educate the veterinary scientists of the future. Furthermore, as noted later in this chapter, there are far too few researchers in veterinary science to afford fragmentation due to fears of administrative retribution, turf wars, and other nonproductive activities that sometimes dominate the culture of academic research.

FINDING 1

Veterinary research integrates advances in basic science (such as genomics) and animal health, and it is a critical component of human medical research. Because veterinary research occurs in many disciplines, collaborative and interdisciplinary research is crucial in translating scientific advances from one traditional discipline to another. However, such research may be hampered by administrative barriers, cultural barriers, and lack of economic resources. For example, USDA supports veterinary research on the health of food-producing animals, poultry, and aquatic food species, whereas NIH supports research in comparative medicine and biomedical sciences. National needs would be addressed more effectively if those and other entities that support veterinary research had a comprehensive plan and a national strategy for support of veterinary research.

RECOMMENDATION 1

The veterinary research community should facilitate and encourage collaborative research across disciplines, institutions, and agencies by reducing administrative barriers and by nurturing and rewarding successful team-oriented investigators.

The community should encourage the development of a long-term national interagency strategy for veterinary research. The strategy could include a specific focus at NIH on integrated veterinary research via the Roadmap Initiative. NIH should consider having a veterinary liaison, like the veterinary medicine and public health liaison at the Centers for Disease Control and Prevention (CDC), to help ensure integration of veterinary and human medical research and adequate support for the research needs outlined in this report, including loan-repayment programs, veterinary research input into study sections, and long-term support. Other federal agencies, state agencies, private foundations, and supporters of veterinary research should recognize and provide long-term support for collaborative, integrated veterinary research. Establishing and maintaining joint interagency collaborative programs, such as the NIH-National Science Foundation program in the ecology of infectious disease, would facilitate and enhance interdisciplinary collaborative research.

HUMAN RESOURCES

As alluded to in Chapter 4 and in many other reports (AAVMC, 2003; ACVP, 2004; NRC, 2004a; Smithsonian Institution, 2004), veterinary research faces a shortage of qualified personnel. Many institutions and professional societies report unfilled positions for veterinary researchers. Research priorities established by this and previous reports cannot be met with the present pool of scientific investigators. The combination of the decline in production of trained veterinary scientists in the last decade and the predicted retirement losses of veterinary scientists indicates that the United States will be unable to meet critical research needs of animal health in the next decade. The shortage is due to the combined reluctance of veterinary students to pursue research, lack of financial incentives, and lack of funding for some kinds of research.

A shortage of veterinary expertise in biomedical research was also reported in a National Research Council report (NRC, 2004a) that found that position announcements for laboratory animal veterinarians had increased by about 255%, from 56 in 1995 to 199 in 2001. Recognizing the need to recruit qualified veterinary scientists for biomedical research, the NIH Center for Cancer Research (CCR) announced the CCR Training Initiative in Comparative Pathology and Biomedical Science. The initiative includes the Comparative Molecular Pathology Research Training Program, which offers veterinary professionals the opportunity to earn a PhD and gain eligibility for certification as medical specialists in veterinary pathology (Box 5-1).

The American College of Laboratory Animal Medicine (ACLAM) reports that there are about 50 unfilled job openings in laboratory animal medicine in 2004, 25 of which are at the director level (M.W. Balk, Executive Director, ACLAM, personal communication and September ACLAM Newsletter, 2004).

BOX 5-1
CCR Training Initiative in Comparative Pathology and Biomedical Science

"Translational research is critical for the discovery, development and delivery of therapies and interventions for combating human disease. A key component of this research process is the ability to translate findings from animal models to the clinical setting. The Center for Cancer Research (CCR), NCI has recognized a need for investigators capable of integrating molecular mechanisms of disease within the complexity of whole living biosystems that have been designed and validated as predictive models of human disease. A foundation for training this kind of translational research investigator incorporates interdisciplinary education in veterinary medicine with training in human biomedical research. To respond to this unmet national research training priority, the intramural research program of the CCR NCI has developed two training programs in collaboration with The National Institute of Allergy and Infectious Diseases (NIAID), The National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK), and The National Heart, Lung, and Blood Institute (NHLBI)."

SOURCE*:* http://ccr.nci.nih.gov/resources/training/default.asp.

The current shortage of laboratory animal veterinarians is expected to increase because of increasing demand and the large number of laboratory animal medicine specialists nearing retirement without an expected net increase in the number of new diplomates. Although not all laboratory animal veterinarians engage directly in research, it is estimated that 10% of ACLAM diplomates are principal investigators and another 25% coinvestigators on peer-reviewed research grants (M.W. Balk, Executive Director, ACLAM, personal communication, 2004).

The Research Council report (2004) also found that there was an estimated deficit of 67 veterinary pathologists in the United States and Canada in 2002 and projected that the deficit would reach 336 in 2007. An American College of Veterinary Pathologists (ACVP) survey in 2004 reported immediate needs for 149 veterinary pathologists and a cumulative deficit of 417 by 2007 (Table 5-1). Many ACVP pathologists engage directly in veterinary research, and almost all others contribute indirectly to research—for example, those engaged in drug-safety research in industry and diagnosticians in government, university, and private laboratories. In addition, highly trained scientists with expertise in phenotyping and behavior assessment are needed for characterization of generated animal models.

The critical shortage in human resources stimulated the formation of an innovative alliance between ACVP and the Society of Toxicologic Pathologists, which has similar needs and interests. The purpose of the alliance is to develop a

TABLE 5-1 Supply of and Demand for Veterinary Pathologists

	Supply		Demand	
	Number in Training	Graduates in Last 5 Years	Current Openings	Expected Cumulative Deficit by 2007
Anatomic pathologists	170	185	127	347
Clinical pathologists	43	55	22	70
Total	213	240	149	417

SOURCE: Ochoa et al. 2004.

collaborative relationship between industry—the major employers of such professionals and thus in the greatest need of them—and academe to identify, support, and educate more persons who will be available to meet the growing employment demands. Similar alliances between professional societies and government might be effective in addressing some of the human-resources needs described herein. Certainly, various sectors of the academic community could do a better job of identifying and encouraging bright young students to seek careers in research. Effective joint efforts might also attract extramural support for graduate stipends and aid in bringing newly graduated scientists to the attention of those seeking new employees.

Although the adequacy of veterinary researchers in food-animal health and food safety has not been assessed, anecdotal evidence suggests a likely shortage. For example, ARS has difficulties in recruiting and retaining DVM-PhDs (such as veterinary medical officers) partly because of lack of financial incentives. The agency had to fill 13 and 11 vacant positions in FY 2001 and FY 2002, respectively. In response to such a personnel crisis, the agency has developed the Recruitment and Retention Policy to improve the location and hiring of qualified DVM-PhDs into veterinary medical officer positions by offering more-competitive salaries, recruitment and retention bonuses, and student-loan repayments. The shortage of qualified DVM-PhDs candidates has been in the specialty disciplines of pathology, infectious diseases, laboratory animal medicine, and microbiology (in the subspecialties of immunology, virology, and bacteriology). The ability of that policy to meet the needs of ARS for DVM-PhDs is unknown. USDA's Animal and Plant Health Inspection Service, the federal agency responsible for food-animal disease detection and control, has only 300 veterinarians and 30 veterinary diagnosticians.

CDC Director Julie Gerberding acknowledged the critical need to replace losses in veterinary scientists in the next decade. CDC estimates that it will need about 200 veterinarians in the next decade. For example, about half of the 99 veterinarians in the commissioned Public Health Corps in 2004 will be eligible to retire by 2006 (Chapter 4). The US Public Health Service is having difficulty in recruiting and retaining veterinary officers and has had over 50 unfilled veterinary positions for over 6 months (David A. Ashford, US Public Health Service, personal communication, March 30, 2005). There are only 100-150 wildlife veterinarians, but they have clinical and teaching responsibilities and cannot devote their efforts only to research (AAWV, 2004). The evidence of a personnel shortage presented above is limited to a few disciplines and key institutions. The shortage of human resources in veterinary research is likely to be more widespread.

The few examples above make it obvious that there is a need to train additional veterinarians and veterinary researchers. But, the number of master's degree and doctoral students graduating from CVM's has not increased in the last 10 years (Figure 4-2). In 2003, the Association of American Veterinary Medical Colleges (AAVMC) established the Task Force on Emergency Needs in Veterinary Human Resources to develop a focused action plan addressing human-resources needs in veterinary public practice. The task force estimated that an additional 241 veterinary students and 658 graduate students need to be trained each year to alleviate the critical shortage of veterinarians in public practice (for example, in food safety, food security, and prevention and control of foreign-animal diseases). In response to the task force report, AAVMC surveyed its members to estimate how many new faculty members would be needed to support the additional students. The survey indicated that an estimated 400 new faculty persons would be needed in various disciplines (Table 5-2).

In addition, AAVMC recently surveyed its members about projected faculty replacement needs based on anticipated retirements. The CVMs that responded represented 1,595 of the total 2,665 FTE faculty members in all 28 CVMs. They reported that about 14% (220) of their faculty members are at least 61 years old. Replacing the retirees will be another challenge for the future. The additional CVM recruitment will contribute not only to teaching but also to veterinary research because CVM faculty collectively conduct a large proportion of research in veterinary science.

The veterinary research enterprise will probably benefit from increased

TABLE 5-2 New Faculty Requirements of CVMs

Discipline	Number of New Faculty Needed
Animal health, food safety and security	65
Comparative medicine and laboratory animal medicine	63
Population medicine, public health, and epidemiology	70
Infectious diseases, zoonoses, and emerging diseases	91
Basic biomedical sciences	79
Miscellaneous disciplines including the above	34
Total	402

SOURCE: AAVMC Member Survey, 2004.

faculty sizes at CVMs. First, more veterinary researchers can be trained. Second, the analysis in Chapter 4 indicates that CVMs with larger faculties and lower student:faculty ratios tend to have higher research expenditures per faculty. Because CVMs have multiple responsibilities, a larger faculty may mean that more faculty members are sharing administrative and clinical duties so that each member can devote more time to obtaining funds for and conducting research.

FINDING 2

Veterinary research faces a critical personnel shortage that is not limited to biomedical sciences. Some agencies and institutions report difficulties in recruiting and retaining researchers who have the veterinary expertise needed to fulfill the organizations' roles in public health and food safety, animal health, and comparative medicine.

RECOMMENDATION 2

Additional veterinary researchers must be trained to alleviate the demands and to meet societal needs for veterinary research. A debt-repayment initiative similar to the NIH Clinical Research Loan Repayment Program could address concerns about the large debt burden faced by graduates of veterinary colleges. If the CCR training initiative and the ARS PhD training program for veterinarians, started in FY 2003, prove successful in recruiting and retaining veterinary researchers, they could be expanded and used as models by other agencies and companies.

EDUCATION AND TRAINING

The number of research scientists who graduate each year with training and expertise in veterinary science is not sufficient to meet the national demands in academe, industry, and government. Many veterinary researchers are trained in CVMs; others are trained in departments of comparative medicine, departments of veterinary sciences, colleges of agriculture, animal science departments, and other academic or research institutions. Data on education and training of veterinary researchers in CVMs were presented in Chapter 4, but the committee did not gather similar information from colleges of agriculture, CoMs, or other biology programs, because there is no rational way to tell which students are likely to pursue careers in veterinary research in those colleges or programs. Therefore, the following discussion is focused primarily on CVMs even though other colleges and departments also train veterinary researchers.

An estimated 658 additional graduate students need to matriculate each year in all disciplines to meet the needs of public practice (Table 5-3). In an AAVMC survey, responses indicated that $272 million in new funds would be required for graduate fellowships and related expenses (R. Dierks, AAVMC, personal communication, August 11, 2004). The need for additional veterinary researchers cannot be met unless students are willing to pursue research. The proportion of

TABLE 5-3 Proposed New Graduate Students in CVMs

Discipline	Number of Students
Animal health and food safety security	109
Comparative medicine and laboratory animal medicine	120
Population medicine, public health, and epidemiology	145
Infectious diseases and zoonoses, and emerging diseases	156
Basic biomedical sciences	128
Total	658

SOURCE: AAVMC.

veterinary students pursuing graduate studies and research is smaller than the proportion pursuing private practice. CVMs need to recruit students who have an interest in research and clinical medicine and provide a curriculum that stimulates and maintains their interest throughout their professional education. As Freeman (2005) stated, "individually and collectively as a profession, we are concerned that veterinary medicine is failing both to sustain its academic base and to meet the national needs for research in the fields of comparative medicine (translational research), public health, and food production." Students' hesitation to pursue research careers can be attributed to several factors (Freeman, 2005):

- The long period required to attain a DVM or PhD and postdoctoral training.
- The substantial tuition debt accrued during DVM training.
- The lack of financial support for graduate students in veterinary science.
- The failure to stimulate veterinary students' interests in research.

The issues raised by Freeman have been discussed in other documents and at the AAVMC Symposium on The Future of Veterinary Graduate Education held on March 11-12, 2004, in Washington, DC. (See Appendix L for issues raised in the symposium.) Combined PhD-DVM and residency-PhD programs are mechanisms to reduce the duration of DVM and PhD training, and they are offered in some CVMs. One college created a veterinary public-health specialization within the master's of public health degree program (http://vet.osu.edu/vetpublichealth).

Financial disincentives to pursue careers in veterinary research can be addressed by loan-forgiveness programs. For example, a severe shortage in the availability of practicing veterinarians for underserved areas was addressed via a student-loan forgiveness program under the National Veterinary Medical Service Act (PL108-161), which has been signed into law but not yet funded. Persons who agree to serve in areas of national need, such as rural communities, will be eligible for repayment of their student loans. A similar program could be set up to provide incentives for students to pursue and sustain careers in veterinary research.

Financial disincentives for student recruitment to veterinary research can be overcome by financial aides, fellowships, and loan forgiveness, but adequate veterinary researchers will not be recruited if students are not interested in or aware of such career paths. A declining interest in careers in research among veterinary students is evident in nearly all academic disciplines in CVMs (Freeman, 2005). CVMs must identify, admit, and nurture more students who are interested in hypothesis-driven research and in specialty training, such as laboratory animal medicine, pathology, and toxicology, or food-animal health and food safety. The national deficit of veterinary researchers is critical and will be a major determining factor in the effective use of veterinary skills in national efforts. For example, CVMs have until recently provided little training in rodent-based comparative medicine, and this has contributed to a shortage of veterinary expertise in the discipline (NRC2004a). That shortage adversely affects medical research in as much as rodent models are used often, and the interpretation of data from rodents requires a thorough understanding of mouse biology, anatomy, diseases, pathology, and genetics (Barthold, 2002).

If veterinary science cannot adequately train the next generation of veterinarians for research careers, there will be insufficient scientific data to support decisions that affect animal health. Not only will national animal health care suffer, but the nation will suffer socially and economically from the inability to safeguard and protect our animals.

To develop successful research programs in comparative medicine, public health and food safety, and animal health, academic institutions must have a highly qualified faculty with a culture dedicated to national prominence in such research. From that must arise a first-rate graduate curriculum and recruitment of graduate-student pools consistent with a first-rate program. The capacity of academic veterinary curricula to incorporate and demand teaching of evidence-based medicine, including the use of research data and statistical analyses, will have a great influence on animal health and the mindset of those who support it. The ramifications of graduates' failure to appreciate the need for research data and for dealing with risk analysis are dispersed throughout all animal health fields and have a serious adverse effects on all veterinary institutions, whether academic, government, or commercial. Academic faculties are driven, appropriately, to incorporate clinical learning processes into the early, basic-science years of veterinary education. They fail to incorporate the basic sciences into the clinical curriculum, which is more serious. That failure damages the education of veterinarians in the short term, but the long-term effect is a decline in the understanding of science as the basis of medicine.

Most CVMs have origins in and are conceptually part of the US land-grant system of universities. Within that system is the uneasy dichotomy of service to users vs basic and applied research for science. Thus, academic leaders may fail to set aside established quotas of faculty, space, and funding for basic research that is dedicated to veterinary science. Such dedication is necessary to provide the high-quality, authoritative research data that are required for national policy decisions.

The ability to explain the importance of basic research to commodity, government, and other user groups is a requisite art form of tomorrow's leaders. In short, the culture of undergraduate, professional, and graduate education and the veterinary profession itself must undergo changes to produce the next generations of scientists who are ready and able to meet the needs outlined in this and other reports (Pritchard, 1989; Hobblet et al., 2003; Eyre et al., 2004; NRC, 2004a).

CVMs in the United States are accredited by the American Veterinary Medical Association (AVMA) under its authority granted by the US Department of Education. The AVMA Council of Education, working through an appointed committee and established guidelines, reviews each CVM every 7 years. Research is one of the designated elements for assessment. Reviews do not examine the quality or quantity of research effort in institutions but emphasize the availability of research programs to veterinary students. The committee believes that such availability is important in enhancing research in veterinary science and in teaching the value of science to practicing veterinarians of the future. In addition to making research programs available to students, CVMs should promote existing internship programs—for example, internships provided by NIH, the Food and Drug Administration, and other federal and state agencies, zoos, companies (such as the Merck-Merial veterinary scholars program), and private foundations—so that students can discover and pursue careers in research.

The importance of integrating research into education programs is emphasized earlier in this report. Many of the research priorities discussed in Chapter 3 call for expertise in genomics, proteomics, metabolomics, bioinformatics, animal well-being, translational research, mathematical modeling, and several other categories not usually as the subjects of degree programs in CVMs. The importance of integrating basic-science research into education programs is also highlighted in the Homeland Security Presidential Directive 9 (HSPD-9) (http://www.whitehouse.gov/news/releases/2004/02/20040203-2.html), which directs the secretaries of agriculture and health and human services to "provide capacity building grants to colleges and schools of veterinary medicine, public health, and agriculture that design higher education training programs for veterinarians in exotic animal diseases, epidemiology, and public health" and "interdisciplinary degree programs that combine training in food sciences, agriculture sciences, medicine, veterinary medicine, epidemiology, microbiology, chemistry, engineering, and mathematics (statistical modeling) to prepare food defense professionals." The secretaries of agriculture, health and human services, and homeland security also are directed to "establish opportunities for professional development and specialized training in agriculture and food protection, such as internships, fellowships, and other postgraduate opportunities that provide for homeland security professional workforce needs."

As noted in Chapter 4, nonveterinarians are critically important members of many veterinary research entities, none more than in the CVMs, where nonveterinary PhDs obtain a large amount of NIH research project grant (R01) funding. Scientists without DVM degrees are also key members of many other research programs in veterinary sciences—including departments of animal science, veterinary science, and comparative medicine—and of research programs in zoos, government, and industry. The committee could find no data that revealed how many of the scientists in such settings conduct research in veterinary science as defined here.

A National Research Council report (2004) recommended how to address the needs of veterinarians in biomedical research (see Appendix M for recommendations relevant to this report). Those recommendations can be applied broadly to veterinary research, including public health and food safety and animal health. In addition, the committee suggests that CVMs set up joint internship and research programs with other colleges (such as medical and agricultural colleges and departments of biology and animal science), federal agencies, and industry for veterinary, undergraduate, and graduate students. Joint programs would not only introduce veterinary students to research but also expose nonveterinary students to veterinary research. Moreover, the programs would provide students with the interdisciplinary training needed for translational research. Faculty serving as advisers for the programs would also serve as role models and mentors for students interested in pursuing veterinary research. Experience in a different college or research organization provides a different perspective, offers far greater diversity of scientific exposure, and introduces both veterinary and nonveterinary students to the importance of and opportunities in veterinary research.

FINDING 3

Interest in research careers has been declining among veterinary students in nearly all academic disciplines. Some students are deterred by financial costs and the required extended training; others are not aware of that career option. Without the next generation of adequately trained veterinary researchers, veterinary science cannot provide the data required for informed decisions that govern day-to-day activity in animal health, such as decisions that underlie the economic stability necessary for adequate national animal health care.

RECOMMENDATION 3

To meet the nation's needs for research expertise in veterinary science, changes in recruitment and programming for graduate and veterinary students will be required. These include the following:

- Strengthening of summer research programs, combined DVM-PhD degree paths, and the integration of basic science into clinical curricula.
- Innovative programs for graduate training that emphasize quality of research experience over formal coursework.
- Increases in stipends and salaries for graduate students who hold profes-

sional degrees.

- Academic programs that support high-quality, competitive, cutting-edge scientific research.
- Creative research environments that emphasize information technology, global involvement, and national competitiveness.

The AVMA Council on Education, which is charged to review colleges of veterinary medicine for accreditation, publishes a set of uniform regulations and guidelines that identify ten areas of concern for review process. The guidelines for assessment of research with regard to opportunities for research experiences for veterinary students should be strengthened. The effectiveness of these student programs should also be incorporated into the outcomes-assessment category for review. Research scientists in training should direct their expertise to national problems in animal health, incorporate cutting-edge science into experimental design, and develop programs of high quality that compete nationally with other disciplines of science. And they should adapt and market their research through personal leadership and participation in national committees and review boards that manage scientific research related to animal health and welfare.

FACILITIES AND INFRASTRUCTURE

In most scientific disciplines, research must be conducted in laboratories (for example, wet, dry, bench, clinical, experimental, and high-security laboratories). In addition, researchers require office space and classrooms, and lecture halls and teaching laboratories are necessary for the training and education of the next generation of researchers. Research with and about animals also requires barns, pastures, ponds, field sites, and other conventional facilities where large numbers of research animals can be maintained as suitable subjects and housed in conditions conducive to their welfare. Zoos and other specialized facilities for housing animal collections are essential for better understanding of many of the world's most important, at-risk species.

Facilities in Universities

CVMs conduct a large proportion of research in veterinary science and provide all the professional education for veterinarians and much of the clinical and research graduate education. The CVMs recently reported on their capacity to educate more professional and graduate students and on the additional resources required to support this expansion. To expand their current training capacity to accommodate 240 additional veterinary students and 658 new graduate students per year, new and renovated facilities would be required. Space for classrooms, teaching and research laboratories, and biocontainment housing for research animals would be needed, as shown in Table 4-3. Existing funding sources, such as state and university funds and gifts from foundations and private donors, are unlikely to meet needs of this magnitude. In recognition of the importance of building the veterinary workforce for public-health service, Senator Wayne Allard introduced S 914, the Veterinary Workforce Expansion Act, on April 27, 2005. The act would be an amendment to the Public Health Service Act to establish a competitive-grants program to build capacity in veterinary medical education and expand the workforce of veterinarians engaged in public-health practice and biomedical research.

Research in colleges of agriculture at most land-grant institutions is an integral part of state economic creativity and inventiveness and provides an economic engine for biotechnology in food safety, livestock-animal health, and animal modeling for the life sciences. Among the 50 states, the willingness of legislatures to invest in research infrastructure largely defines the research-rich and research-poor universities. The colleges of agriculture must have modern laboratories and the necessary research facilities to conduct state-of-the art research, maintain a high scientific profile, and assure others of their credibility.

FINDING 4

The last major federal program to support construction of facilities for CVMs ended nearly 40 years ago. AAVMC has documented that new and renovated facilities are needed to train additional veterinary students to meet the demands of public practice. The committee believes that meeting the facility needs will allow training of veterinary researchers (of whom there is a critical shortage) and provide additional space for research.

RECOMMENDATION 4

AAVMC and its members should identify ways in which the CVMs' facility needs can be met financially and logistically. They should consider mounting an extensive outreach effort to educate policy-makers in federal and state governments about the necessity of additional facilities to train adequate veterinary researchers.

Facilities in Government Agencies

USDA conducted a study of its needs for facilities in 1999 (USDA, 1999). The National Animal Disease Center (NADC) in Ames, IA, was badly outdated, and the 1999 Strategic Task Force on USDA Research Facilities strongly recommended that it be given priority for renovation. Replacement facilities were designed and the first of two funded construction phases was completed. The new facilities house offices and laboratories of NADC, the Center for Veterinary Biologics, and the National Veterinary Services Laboratories. However, additional livestock and poultry laboratory and animal space are still needed to meet the needs of research projects listed in the USDA Current Research Information System (CRIS).

The task force also noted that "Animal health research, including research on foreign animal diseases and human/animal (trans-species) interactions, is and will continue to be a high priority for the future. Biocontainment facilities capable of operating at Level 3 and Level 4 are required for research with pathogens of highest risk. The Agriculture Research Service currently operates 4 biocontainment facilities for animal diseases, each of which is in severe need of renovation to maintain human and animal health security." The task force then presented four recommendations that are directly related to animal research: immediately developing plans for a state-of-the-art animal health research, veterinary services, and biocontainment facility; upgrading current level 2 and level 3 biocontainment units for animals; constructing a level 4 biocontainment unit; and addressing issues pertinent to the fact that the primary foreign-animal health research unit is on an island (Plum Island, off the coast of Long Island, NY). It also recommended that the Avian Disease and Oncology Laboratory (Biosafety Level 2) program be merged with the Southeast Poultry Research Laboratory (Biosafety Level 2 and Biosafety Level 3 Agriculture).

Some of the recommendations have been addressed. For example, the NADC addresses some of the needs for state-of-the-art facilities. But other needs, such as construction of level 4 biocontainment facilities, have not yet been met. The United States lacks food-animal and laboratory space to work with zoonotic agents under the BSL-4 classification (USDA, 1999). Those facilities are needed to conduct food-animal and laboratory studies on such agents as Nipah and Hendra viruses, which cannot now be conducted in the United States. The urgency of the need for state-of-the-art biocontainment facilities was emphasized in February 2004 with the release of HSPD-9, whose paragraph 24 states that "the Secretaries of Agriculture and Homeland Security will develop a plan to provide safe, secure, and state-of-the-art agriculture biocontainment laboratories that research and develop diagnostic capabilities for foreign animal and zoonotic diseases."

Similar needs probably exist at other federal and state agencies that conduct veterinary research and at nonuniversity research institutes, including zoos. The committee was unable to find specific data on such needs as related to research in veterinary science, but it points out that adequate facilities are critically important for such research.

FINDING 5

USDA documented its research needs in the 1999 Strategic Planning Task Force report. Not all those needs have been met, including biocontainment facilities, which were given high priority in HSPD-9. Over the next 2-3 years, new containment laboratories may be built in academic institutions to provide additional space for veterinary research under high containment.

RECOMMENDATION 5
The recommendations of the 1999 Strategic Planning Task Force on USDA Research Facilities and the provisions of HSPD-9 should be implemented immediately. Biocontainment laboratories should receive special attention. Adequacies and shortfalls in facilities—both federal and nonfederal—needed for support of veterinary research should be documented and quantified.

Research Resources

Resources for veterinary research include libraries, databases, data-management resources, electronic communication systems (such as systems for sharing clinical information), specialized populations of animals, and collections of research materials, such as DNA, serum, anatomical and pathological specimens, and histological materials. The power and value of such resources are well illustrated by the central databank on genetically modified mice maintained by the Jackson Laboratory's mouse center (see www.informatics.jax.org). Preceding chapters of this report show that several research resources are essential to almost every subdiscipline of veterinary research—for example, databases and tissue collections. The keys to making collections of animals, tissues, and data valuable as research resources include

- Availability to multiple investigators.
- Being statistically representative of the relevant populations.
- A rational and consistent basis for inclusion in the collection.
- Accurate, complete, and verifiable records.
- Reliable storage and rapid retrieval.
- Amenability to electronic retrieval and analysis.
- Quantity of material sufficient for study, ideally in multiple projects.
- Adequate, consistent, and reliable sources of support.

Although valuable information and material (stored tissue and serum samples) exist, they are often distributed in numerous small, isolated collections. Tissue samples in diagnostic laboratories could be valuable research resources that offer exciting opportunities to study animal diseases and epidemiology if they are archived properly and made available to the broad research community.

Clinical records of academic veterinary teaching hospitals could also provide valuable data for research (for example, on disease incidence), but they are often inconsistently recorded among hospitals. One CVM has begun to collaborate with a large corporate private-practice group on disease surveillance. If the disease surveillance could be expanded to yield an integrated, national database of clinical data that protects patient identity, data on many of the patients seen by private primary and referral veterinarians might become part of large, clinical databases for retrospective and prospective research.

Translating bench research to patient-care applications requires execution of appropriately designed and randomized controlled clinical trials. Randomized controlled clinical trials are especially important in evaluating potential benefits of therapies that are already used in human medicine. Chapter 4 noted that multicenter clinical trials and collaborations among industry, academe, and private veterinary practices already occur but that a national system for support of such efforts would be a powerful research and clinical tool. The increase in veterinarians with specialized training in the private sector should promote collaboration with academic institutions. Data-sharing and collaborative efforts would allow meta-analyses large enough to achieve the statistical power to detect significant differences between groups (Boothe and Slater, 1995). Integration of clinical-research networks requires linking existing networks so that clinical trials and studies can be conducted more effectively and ensure that patients, health-care providers, and scientists form true "communities of research."

In addition to databases and tissue samples, many disciplines in veterinary research will benefit substantially from access to well-characterized animal colonies with known diseases. With the exception of laboratory mice and rats and the national system of regional primate research centers, few higher-animal colonies with spontaneously occurring diseases are maintained for research purposes. Several decades ago, NIH offered support for such colonies, and many remarkable studies were conducted with the animals (Patterson et al., 1988; Dodds and Womack, 1997; Dodds, 1995a). However, the costs of maintaining the colonies are prohibitive today, and full or even substantial cost recovery from extramural sources is unlikely. With a few exceptions, such as the National Swine Resource and Research Center supported by NIH, animal colonies are maintained only if they have specific research purposes. Permanent loss of unique animal models could result in a serious loss of advances in both animal and human medicine; their preservation is critical to facilitate research in animal diseases. The genetic similarity between human beings and animals is a compelling argument that studies with animals would reveal both normal and abnormal pathways and mechanisms. Such colonies are imperative for the integrative physiological and pathophysiological studies mentioned in Chapters 2 and 3.

FINDING 6

Effective communication among the various entities involved in veterinary research is needed to maximize the value of continuing studies and to leverage the resources of the relatively small veterinary research community. In particular, databases with clinical records that can be exchanged among teaching hospitals, private practices, and diagnostic laboratories would provide data that could serve as valuable, cost-efficient tools for retrospective and prospective research. Likewise, tissue samples and other specimens (such as serum, DNA, and microorganisms) from healthy and diseased animals offer exciting opportunities to study animal diseases and epidemiology if they are archived properly, protect client or owner confidentiality, and are made available to the research community.

RECOMMENDATION 6
The American Animal Hospital Association, AAVMC, and AVMA should address the need for more effective communication among the federal, university, and private sector entities involved in veterinary research. The need for databases, animal health and surveillance systems, specimen collections, and other sharable research tools to support veterinary research should receive special attention. Organization of a working task force or national workshop to devise an operating plan for developing and managing these clinical and research databases and collections and to identify methods for their support would be an important first step toward the formation of national databases and archives (such as specimen banks and clinical databases) for veterinary research.

FINDING 7
Well-characterized animal colonies with known diseases have been an important resource for many remarkable studies and are imperative for integrative physiological and pathophysiological studies. Preserving the genomes of those unique model animals is critical to facilitate research in animal diseases.

RECOMMENDATION 7
NIH and USDA should address the importance of engineered and spontaneous model colonies of animals and ensure that these valuable resources are not lost. For some species, that can be accomplished by cryopreservation and preservation of their germplasm in tissue banks until it is needed for funded, targeted research or by transfer of their genetic mutations into other, smaller laboratory species. For other species, maintenance of the whole animal may be necessary.

FINANCIAL RESOURCES

Estimating the annual expenditures in veterinary science research is difficult for several reasons. First, *veterinary science* is not a term that is used in databases that record research activities, such as those of CRIS, NSF, or NIH. Second, some of the veterinary research conducted may not be reported as that, because of its direct contribution to other disciplines, such as human medicine and toxicology. Third, other than the data reported in Chapter 4, the committee was unable to obtain specific information on additional research expenditures that might be related to veterinary research; for example, some of the internal research done by industry reported by the Animal Health Institute may be relevant to this report, but the committee cannot decipher the proportion expended on veterinary research.

To assess the adequacy of financial support for different disciplines of veterinary research designed to meet societal demands, the committee used the following steps:

- Assess veterinary research that needs to be conducted to meet societal demands (Chapter 2).
- Set an agenda based on research needs and outline priorities (Chapter 3). List the current funding sources for each research priority.
- Document available financial resources (Chapter 4).
- Compare resource needs for each research priority with available resources.

The committee observed that some research disciplines (notably companion-animal and equine research, wildlife and conservation research, and zoo-animals and exotic-pet research) are unlikely to receive financial support from government agencies that would ensure continuing advancement in research. The committee noted in Chapter 4 that NIH and USDA are two of the largest sources of support for veterinary research. However, the mission of NIH is directly related to human health, so biomedical sciences and comparative medicine are two disciplines in veterinary research that are most likely to be supported by NIH. Although USDA's mission is directly relevant to animals, its focus is on food- and fiber-producing animals.

Although veterinary research has made many important contributions to biomedical sciences (see Chapter 2), the amount of funds awarded to veterinary research by NIH is small relative to the number of critical issues in biomedical sciences that need to be addressed by veterinary research. For example, CVMs reported about $154 million in research expenditures from NIH in FY 2002-2003. The relatively low expenditures from NIH are due partly to the small workforce in veterinary research (discussed earlier in this chapter) rather than concerns about scientific merit. In fact, when compared on a full-time equivalent basis, faculty in CVMs are nearly as successful in obtaining NIH R01 awards as faculty in colleges of medicine (see Chapter 4).

USDA contributes different types of resources to veterinary research related to agriculture. In FY 2002-2003, CVMs reported research expenditures from USDA of $34 million. Less than $1 billion is spent annually by all public-sector entities (including academic and nonacademic research institutes) reporting to CRIS[1] on research related to food and fiber animals, fish, poultry, and horses (Tables 4-1 and 4-2). The reported amount comes from multiple federal and nonfederal sources, including USDA internal (ARS) and external Cooperative State Research, Education, and Extension Service research expenditures. It also

[1]Primarily units of USDA state agricultural experiment stations and cooperating academic entities, such as colleges of agriculture and CVMs.

includes expenditures in some fields of research that are usually associated with animal science rather than veterinary science—for example, nutrient utilization and some aspects of animal physiology.

Protection of food-animal health requires preventive measures and treatment at local levels. During a major disease outbreak, veterinarians and veterinary scientists are responsible for diagnosis and risk management that lead to disease control and elimination. Failure to develop specific, sensitive, and rapid technologies for diagnosing infectious disease can lead to catastrophic loss of animal and human lives and major economic loss. Often overlooked are research methods using for target-disease models to determine risk, economic impact, and risk management and plans for recovery after a disease outbreak, including carcass disposal and repopulation of affected premises. USDA has the responsibility for conducting and funding much of that research.

USDA awards most of its competitive extramural research funds through the National Research Initiative (NRI) program, which was initially proposed in 1989 (NRC 1989). The initial proposal suggested a fund for competitive grants in agriculture (including plants and animals) that would reach an annual appropriation of $550 million (including an existing resource of $50 million at that time). Funding has been in the range of $100-150 million and has never reached the amount envisioned (Figure 4-10). Total NRI funds for animal research have usually been about $12 million per year (Table 4-14). Individual grants are of short duration and low funding compared with those given by NIH and the National Science Foundation (NSF).

Agriculture has lagged substantially behind in federal research support. Data from NSF show that federal support for agricultural research increased by only 0.5% in constant 1996 dollars from 1982 to 2001 compared with an increase of 3.9% for all life sciences (NSF, 2004). The recognition of new threats from agroterrorism places additional demands on agricultural research. In fact, HSPD-9 calls for acceleration and expansion in "development of current and new countermeasures against the intentional introduction or natural occurrence of catastrophic animal, plant, and zoonotic diseases," which will include "countermeasure research and development of new methods for detection, prevention technologies, agent characterization, and dose response relationships for high-consequence agents in the food and the water supply." Paragraph 26 of HSPD-9 directs the secretaries of agriculture, homeland security and health and human services to submit an integrated budget plan for "defense of the United States food system."

The need for more competitive funds for agricultural research prompted the Research, Education, and Economics Task Force of USDA to propose the formation of a new institute, to be called the National Institute for Food and Agriculture (NIFA) "for the purpose of ensuring the technologic superiority of American agriculture." "The mission of NIFA should be to support the highest caliber of fundamental agricultural research" ("research that addresses the frontiers of knowledge, while it leads to practical results and/or to further scientific discovery"). The task force proposed that "NIFA should accomplish its mission by awarding competitive peer-reviewed grants that support and promote the very highest caliber of fundamental agricultural research" and that its "annual budget should build to $1 billion over a five-year period." (USDA-ARS 2004d) The task force clearly suggested that direct support for agricultural research is critical and that veterinary research is a critical component of agricultural research (Chapter 2).

FINDING 8

The committee identified some disciplines of veterinary research that do not have identifiable sources of financial support from government agencies. Those disciplines include the ecology of zoonotic emerging diseases, dynamics of select agent, biodefense pathogens in wildlife, companion animal and equine research, wildlife and conservation research and, zoo-animal and exotic-pet research. Those disciplines contribute to animal health and important segments of human health research or have direct human social impact, but they do not have dependable, permanent financial resources that would ensure their continuing advancement in research.

RECOMMENDATION 8

The veterinary research community should actively engage NIH, USDA, the Department of the Interior, NSF, and other federal agencies and urge them to recognize and address the need for financial support for the disciplines of veterinary research that lack identifiable sources of federal funding despite their contributions to public health, comparative medicine, and animal health and welfare.

EPILOGUE

The impact of veterinary research extends beyond the prevention and treatment of animal diseases. Veterinary research also contributes to biomedicine through comparative medicine and to biosecurity via disease and ecosystem surveillance, establishes social policy regarding animals, and protects the nation's agricultural economy by protecting food animals from diseases and by ensuring the safety of our food supply. This report has identified many opportunities for veterinary research to improve animal and human health and welfare. Because of its small workforce and limited infrastructure and financial resources, the veterinary research community can devote little time and effort to developing and improving predictive and diagnostic tools for preventing the emergence and outbreak of disease. Early diagnosis or prevention can lessen the social and economic impact of diseases. The success, and indeed power, of any society rests in its ability to predict, prepare for, and prevent adverse events while taking advantage of opportunities. Today's veterinary research enterprise has little capacity to fulfill those important societal mandates. Expanding the veterinary workforce and providing trained personnel with research resources can lead to enduring advances in animal and human health.

References

AAMC (Association of American Medical Colleges). 2001. Growth of Ph.D. faculty in clinical departments of US medical schools, 1981-1999. Analysis in Brief. 1(2).

AAVMC (Association of American Veterinary Medical Colleges). 2003a. Emergency Needs in Veterinary Human Resources. Final Report of the AAVMC Task Force, April 15. Washington, DC: AAVMC.

AAVMC. 2003b. An agenda for action: veterinary medicine's crucial role in public health and biodefense and the obligation of academic medicine to respond. *Journal of Veterinary Medical Education* 30:90-190.

AAVMC. 2004. 2003-04 Comparative Data Report (revised).

AAWV (American Association of Wildlife Veterinarians). 2004. Information provided to NRC Committee on National Needs for Research in Veterinary Science on September 16, 2004.

AAZV (American Association of Zoo Veterinarians). 2004. Research Task Force. Information provided to NRC Committee on National Needs for Research in Veterinary Science on September 16, 2004.

Abeliovich, A.R. Paylor, C. Chen, J.J. Kim, J.M. Wehner, and S. Tonegawa. PKC gamma mutant mice exhibit mild deficits in spatial and contextual learning. Cell. 1993 Dec 31;75(7): 1263-71.

ACVP (American College of Veterinary Pathologist). 2004. Veterinary pathologists: Supply and demand survey results. Submitted to the NRC Committee on National Needs for Research in Veterinary Science on July 6, 2004.

ACVSF (American College of Veterinary Surgeons Foundation). 2004. Research Grants. Rockville, MD: ACVS Foundation. [Online]. Available: http://www.acvs.org/ACVSFoundation/Residents/ResearchGrants/.

AHI (Animal Health Institute). 2004. 2004 Market Research Report: US Animal health products industry.

AKCCHF (American Kennel Club Canine Health Foundation). 2003. Annual Report. [Online]. Available: http://www.ackcchf.org/annual2003/Annual%20Report%202003.pdf.

Anderson, G.W., T.W. Slone, Jr., and C.J. Peters. 1987. Pathogenesis of Rift Valley fever virus (RVFV) in inbred rats. *Microbial Pathogenesis* 2:283-293.

Anonymous. 1998. Emerging diseases: preparing for the challenges ahead. *Veterinary Record* 143:378.

Anonymous. 2005. BSE confirmed in a French goat. *Veterinary Record* 156:158-158.

AVMA (American Veterinary Medical Association). 2004a. Mammal mapping projects to move forward. *AVMA News* Nov 1:1322-1323.

AVMA. 2004b. Membership directory and resource manual. Schaumburg, IL: AVMA.

AVMA. 2004c. Veterinary Market Statistics. [Online]. Available: //http://www.avma.org/membshp/marketstats/usvets.asp.

AZA (American Zoo and Aquarium Association) Animal Health Committee. 2004. Information provided to NRC Committee on National Needs for Research in Veterinary Science. October 29, 2004.

Badylak, S.F., E. Poehlman, C. Williams, R.E. Klabunde, J. Turek, and W. Schoenlein. 1998. Simple canine model of arterial thrombosis with endothelial injury suitable for investigation of thrombolytic agents. *Journal of Pharmacological Methods* 19:293-304.

Badylak, S., K. Kokini, B. Tullius, A. Simmons-Byrd, and R. Morff. 2002. Morphologic study of small intestinal submucosa as a body wall repair device. *Journal of Surgical Research* 103:190-202.

Barthold, S.W. "Muromics": Genomics from the perspective of the laboratory mouse. *Comparative Medicine* 52(2002): 206-223.

Bean, N. H., J.S. Goulding, C. Lao, J., and F. Angulo. 1996. Surveillance for Foodborne-Disease Outbreaks 1992. Morbidity and Mortality Weekly Report. 45(SS-5):1-55. Centers for Disease Control and Prevention, Department of Human Services. Washington, DC: US Government Printing Office.

Beasley V. 1993. Ecotoxicology and ecosystem health: Roles for veterinarians; goals of the Envirovet program. *JAVMA* 203:617-628.

Beaver B.V., and L.I. Haug. 2003. Canine behaviors associated with hypothyroidism. *Journal of American Animal Hospital Association* 39:431-434.

Benbrook C. 2002. Antibiotic drug use in US aquaculture. The Northwest Science and Environmental Policy Center Sandpoint, ID. [Online]. Available //http://www.mindfully.org/Water/Antibiotic-Aquaculture-BenbrookFeb02.htm.

Berger, L., R. Speare, P. Daszak, D.E. Green, A.A. Cunningham, C.L. Goggin, R. Slocombe, M.A. Ragan, A.D. Hyatt, K.R. McDonald, H.B. Hines, K.R. Lips, G. Marantelli, and H. Parkes. 1998. Chytridiomycosis causes amphibian mortality associated with population declines in the rain forests of Australia and Central America. *Proceedings of the National Academy of Sciences of the United States of America* 95:9031-9036.

Bernstein B.J. 1987. The birth of the US biological-warfare program. *Scientific American* 256: 116-136.

Binder, S., A.M. Levitt, J.J. Sacks, and J.M. Hughes. 1999. Emerging infectious diseases: public health issues for the 21st century. *Science* 284:1311.

Bishop, R.C. 2002. The economic effect of chronic wasting disease (CWD). Staff Paper Series No. 450. University of Wisconsin.

Bogue M. 2003. Mouse Phenome Project: understanding human biology through mouse genetics and genomics. *Journal of Applied Physiology* 95:1335-1337.

Boothe, D.M., and M.R. Slater. 1995. Standards for veterinary clinical trials. *Advances in Veterinary Science and Comparative Medicine* 39:191-252.

Bowie, E.J.W., and W.J. Dodds 1976. Historical and current perspectives. 2. Porcine and canine von Willebrand's disease. Proc Workshop on Animal Models of Thrombosis and Hemorrhagic Diseases, PHS/ NAS/ILAR, DHEW Publication 76-982, pp. 14-20.

Canada Wildlife Services. 2004. Canada's national wildlife disease strategy. [Online]. Available: http://www.scf.ec.gr.ca/cnwds/draft 11.pdf.

Carrell, R. W. 2004. Prion dormancy and disease. *Science* 306:1692-1693.

Check E. 2004. Health concerns prompt US review of exotic-pet trade. *Nature* 427:277.

Chiang B.Y., G.M. Pantalos, G.L Burns., J.W. Long, P.S Kanwilkar, S.D Everett, S.F. Mohammed, and D. Olsen. 1994. Oxygen metabolism in animals with total artificial hearts. *ASAIO Journal* 40(3):M 510-513.

Clarkson T.B., J.R Kaplan, C.A Shively, J.R. Kaplan, and K.P. Klein KP. 1996. Benefits of exogenous estrogen in inhibiting stress-related coronary artery atherosclerosis. *BJOG* 103(Suppl) 13:73-79.

Coffey, B., J. Mintert, S. Fox, T. Schroeder, and L. Valentin. 2005. The Economic Impact of BSE on the US Beef Industry: Product Value Losses, Regulatory Costs, and Consumer Reactions. Manhattan: Kansas State University.

Cohen, J. 1994. Bumps along the vaccine road. *Science* 265:1371-1372.

Cunningham, A.A., J.K. Kirkwood, M. Dawson, Y.I. Spencer, R.B. Green, and G.A.H. Wells. 2004. Distribution of bovine spongiform encephalopathy in greater kudu (*Tragelaphus strepsiceros*). *Emerging Infectious Diseases* 10:1044-1049.

Daszak, P., L. Berger, A.A. Cunningham, A.D. Hyatt, D. Earl Green, and R. Speare. 1999. Emerging Infectious Diseases and Amphibian Population Declines. *Emerging Infectious Diseases* 5 (6):

Daszak, P., A.A. Cunningham, and A.D. Hyatt. 2000. Emerging infectious diseases of wildlife—Threats to biodiversity and human health. *Science* 287:443-449.

Daszak, P., A.A. Cunningham, and A. Hyatt. 2003. Infectious Disease and Amphibian Population Declines. *Journal of Diversity and Distributions* 9:141-150.

DHS (US Department of Homeland Security). 2004. Homeland Security Selects Texas A&M University and University of Minnesota to Lead New Centers of Excellence on Agro-Security. [Online]. Available: http://www.dhs.gov/dhspublic/display?content=3515.

Dobson, A., and J. Foufopoulos. 2001. Emerging infectious pathogens of wildlife. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* 356:1001-1012.

DOD (Department of Defense). 2001. Animal Care and Use FY01 Programs. [Online]. Available: http://www.dtic.mil/biosys/org/au.html.

Dodds, W.J. 1982. The pig in biomedical research. *Federation Proceedings* 41:247-256.

Dodds, W.J. 1987. Animal models for the evolution of thrombotic disease. *Annals of the New York Academy of Sciences* 516:631-635.

Dodds, W.J. (ed.) 1995a. Veterinary medical specialization: bridging science and medicine. *Advances in Veterinary Science and Comparative Medicine* 39:1-303.

Dodds, W.J. (ed.) 1995b. Estimating disease prevalence with health surveys and genetic screening. *Advances in Veterinary Science Comparative Medicine* 39:29-96.

Dodds W.J. 1999. Behavioral changes associated with thyroid dysfunction in dogs. *Proceedings of American Holistic Veterinary Medical Association* 80-82.

Dodds, W.J. and J.E. Womack (eds.) 1997. Molecular genetics, gene transfer, and therapy. *Advances in Veterinary Medicine* 40:1-227.

Doolen M. 1996. Dogs, cats and cockatoos: adding exotic pets to your patient roster. *Veterinary Medicine* 91:631.

Edwards, J.F., W.J Dodds, and D.O. Slauson. 1985. Mechanism of thrombocytopemnia in African swine fever. *American Journal of Veterinary Research* 46:2058-2063.

Elston, T.;I. Rodan; D. Flemming; R.B. Ford, D.R. Hustead; D.K. Rosen; M.A. Scherk-Nixon; and F.W. Scott.. 1998. 1998 Report of the American Association of Feline Practitioners and Academy of Feline Medicine Advisory Panel on Feline Vaccines. *JAVMA* 212 (2):227-241.

Engebrestson M., D. Giles, and N.G. Paquette. 2003. The dirty side of the exotic animal pet trade. Animal Protection Institute. [Online]. Available: http://www.api4animals.org/1563.html.

Eyles J., and C.M. Furgal. 2002. Indicators in environmental health: Identifying and selecting common sets. *Canadian Journal of Public Health* 93 (Suppl 1):S62.

Eyre, P., N.O. Nielsen, and J.E.C. Bellamy. 2004. Serving society first: the time for change in veterinary medicine. *JAVMA* 225:40-41.

FDA (US Food and Drug Administration). 2001. Office of Research. [Online]. Available: http://www.fda.gov/cvm/aboutor.htm

FDA 2003. Center for Veterinary Medicine 2003 Annual Research Report. Fiscal Year 2003-October 1, 2002-September 30, 2003. Rockville, MD: US Food and Drug Administration. [Online]. Available://http://www.fda.gov/cvm/Documents/CVMFY03AnnRpt.

FDA. 2004. Challenge and Opportunity on the Critical Path to New Medical Products. Rockville, MD: Food and Drug Administration.

Ford, R.B. (ed.). 2001. Vaccines and Vaccinations. *Veterinary Clinics of North America: Small Animal Practice* 31:439-588.

Foundation for Biomedical Research. 2001. The Proud Achievements of Animal Research and the consequences of halting it. Foundation for Medical Research: Washington, DC.

Fraser, D. 2003. Assessing animal welfare at the farm and group level: the interplay of science and values. *Animal Welfare* 12:433-443.

Fraser, D., and R. Preece. 2004. Animal ethics and the scientific study of animals: bridging the "is" and the "ought." Essays in Philosophy. Vol. 5, No. 2. Arcata, CA: Humboldt State University.

Freeman, L.C. 2005. Rx for Recruitment and Retention of Veterinarian Scientists: Money, Marketing, Mentoring. *Journal of Veterinary Medical Education* (in press).

Freimer, N., and C. Sabatti. 2003. The Human phenome project. *Nature Genet* 34:15-21.

Friedman C.R., R.M. Hoekstra, M. Samuel, R. Marcus, J. Bender, B. Shiferaw, S. Reddy, S.D Ahuja, D.L. Helfrick, F. Hardnett, M. Carter, B. Anderson, and R. V. Tauxe. 2004. Risk factors for sporadic *Campylobacter* infection in the United States: a case-control study in FoodNet sites. *Clinical Infectious Diseases* 34(Suppl 3):S285-96].

Fuglie, K., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee. 1996. Agriculture Research and Development: Public and Private Investments Under Alternative Markets and Institutions. Economic Research Report Number AER-735, Economics Research Service. Washington, DC: USDA.

GAO (General Accounting Office). 2000. West Nile Virus Outbreak: Lessons for Public Health Preparedness. GAO/HEHS-00-180. Washington, DC: US GAO.

Gibbs, R., G. Weinstock, S. Kappes, L. Schook, L. Skow, and J. Womack. 2002. Bovine Genomic Sequencing Initiative.[Online]. Available: http://www.genome.gov/12512284.

Goldburg R.J., M.S. Elliott, and R.L. Naylor. 2001. Marine Aquaculture in the United States: Environmental Impacts and Policy Options. Arlington, VA: Pew Oceans Commission.

Grandin, T. (ed.). 2000. Livestock Handling and Transport, 2nd Edition. Wallingford, UK: CAB International.

Green, D.E., and C.K. Sherman. 2001. Diagnostic histological findings in Yosemite toads (*Bufo canorus*) from a die-off in the 1970s. *Journal of Herpetology* 35:92-103.

Grieder, F., and L. Whitehair. 2005. Funding opportunities for research and graduate education: How the NIH can help you. *Journal of Veterinary Medical Education* (in press).

Gross, E. 2003. Update: Multistate Outbreak of monkeypox-Illinois, Indiana, Kansas, Missouri, Ohio and Wisconsin, *Annals of Emergency Medicine* 42:660-662.

Grubb S.C., G.A. Churchill, M.A. Bogue. 2004. A collaborative database of inbred mouse strain characteristics. *Bioinformatics* 20:2857-2859.

Guan, Y., B.J. Zheng, Y.Q. He, X.L. Liu, Z.X. Zhuang, C.L. Cheung, S.W. Luo, P.H. Li, L.J. Zhang, Y.J. Guan, K.M. Butt, K.L. Wong, K.W. Chan, W. Lim, K.F. Shortridge, K.Y. Yuen, J.S.M. Peiris, and L.L.M. Poon. 2003. Isolation and characterization of viruses related to the SARS coronavirus from animals in Southern China. *Science* 302:276-278.

Gupta, A., J. Fontana, C. Crowe, B. Bolstorff, A. Stour, S. Van Duyne, M.P. Hoekstra, J.M. Whichard, T.J. Barrett, and F.J. Angulo for the National Antimicrobial Resistance Monitoring System PulseNet Working Group. 2003. Emergence of multidrug-resistant Salmonella enterica serotype Newport infections resistant to expanded-spectrum cephalosporins in the United States. *Journal of Infectious Diseases* 188:1707-1716.

Happ, G.M. 1995. Thyroiditis—a model canine autoimmune disease. *Advances in Veterinary Science and Comparative Medicine* 39: 97-139.

Harvell, C.D., K. Kim, J.M. Bukholder, R.R. Colwell, P.R. Epstein, D.J. Grimes, E.E. Hofmann, E.K. Lipp, A.D.M.E. Osterhaus, R.M. Overstreet, J.W. Porter, G.W. Smith, and G.R. Vasta. 1999. Emerging marine diseases—climate links and anthropogenic factors. *Science* 285:1505-1510.

Haskell, S.R.R., K. Carberry-Goh, M.A. Payne, and S.A. Smith. 2004. Current status of aquatic species biologics. *Journal of American Veterinary Medical Association* 225:1541-1544.

Head, M.W., and J.W. Ironside. 2005. Mad cows and monkey business: the end of vCJD? *Lancet* 365:730-731.

Hoblet, K.H., A.T. Maccabe, and L.E. Heider. 2003. Veterinarians in population health and public practice: meeting critical national needs. *Journal of Veterinary Medical Education* 30: 287-294.

Hodge R.A., and L.M. Longo. 2002. International monitoring for environmental health surveillance. *Canadian Journal of Public Health* 93 (Suppl 1):S16-23.

Hughes, J.M. 2001 Emerging Infectious diseases: A CDC perspective. *Emerging Infectious Diseases* 7:494-496.

IOM (Institute of Medicine). 1992. Emerging Infections: Microbial Threats to Health in the United States. Washington D.C.: National Academy Press.

IOM (Institute of Medicine). 2003. Microbial Threats to Health: Emergence, Detection, and Response. Washington D.C.: The National Academies Press.

Kash, J.C., C.F. Basler, A. Garcia-Sastre, V. Carter, R. Billharz, D.E. Swayne, R.M. Przygodzki, J.K. Taubenberger, M.G. Katze, and T.M. Tumpey. 2004. Global host immune response: Pathogenesis and transcriptional profiling of type a influenza viruses expressing the hemagglutinin and neuraminidase genes from the 1918 pandemic virus. *Journal of Virology* 78:9499-9511.

Kassenborg, H.D., C.W. Hedberg, M. Hoekstra, M.C. Evans, A.E. Chin, R. Marcus, D.J. Vugia, K. Smith, S.D. Ahuja, L. Slutsker, and P.M. Griffin. 2004. Farm visits and undercooked hamburgers as major risk factors for sporadic *Escherichia coli* O157:H7 Infection: Data from a case-control study in 5 FoodNet sites. *Clinical Infectious Diseases Supplement* 38:271-278.

Kay, M.A., S. Rothenberg, C.N. Landen, D.A. Bellinger, F. Leland, C. Toman, M. Finegold, A.R. Thompson, M.S. Read, K.M. Brinkhous, and S.L.C. Woo. 1993. In vivo gene therapy of hemophilia B: sustained partial correction in factor IX-deficient dogs. Science 262:117-119.

Keeble E. 2003. Addressing the welfare needs of exotic pets. *Journal of Small Animal Practice* 44:517-518.

Kennedy, M., T. Rabatsky-Ehr, S. Thomas, S. Lance-Parker, J. Mohle-Boetani, K. Smith, W. Keene, P. Sparling, F.P. Hardnett, P.S. Mead, and the EIP FoodNet Working Group. 2002. Risk factors for sporadic *Escherichia coli* O157 Infections in the United States: A case-control study in FoodNet sites, 1999–2000. International Conference on Emerging Infectious Diseases. Atlanta, GA. March.

Kibenge F.S., K. Munir, M.J. Kibenge, T. Joseph, and E. Moneke. 2004. Infectious salmon anemia virus: causative agent, pathogenesis and immunity. *Animal Health Research Review* 5(1): 65-78.

Kimura A.C., V. Reddy, R. Marcus, P.R. Cieslak, J.C. Mohle-Boetani, H.D. Kassenborg, S.D. Segler, F.P. Hardnett, T. Barrett, and D.L. Swerdlow. 2004. Chicken consumption is a newly identified risk factor for sporadic *Salmonella enterica* serotype Enteritidis infections in the United States: a case-control study in FoodNet sites. *Clinical Infectious Diseases* 34(Suppl 3):S244-52.

King L. 2003. Converging issues in veterinary public health. *Emerging Infectious Diseases* 9:510-511.

Kinkler, R.J. 2004. National needs in research for veterinary science: an industry perspective, pp. 12.

Kirkwood, J.K., and A.A. Cunningham. 1994. Epidemiologic Observations on Spongiform Encephalopathies in Captive Wild Animals in the British-Isles. *Veterinary Record* 135:296-303.

Kuehn, B.M. 2004a. Laws take aim at wildlife pets. *JAVMA* 225:170, 173.

Kuehn, B.M. 2004b. Emerging zoonoses on the rise. *JAVMA* 225:12-13.

Kullberg, M.C., J.F. Andersen, P.L. Gorelick, P. Caspar, S. Suerbaum, J.G. Fox, A.W. Cheever, D. Jankovic, and A. Sher. 2003. Induction of colitis by a CD4+ T cell clone specific for a bacterial epitope. Proc Natl Acad Sci U S A. Dec 23;100(26):15830-5. Epub 2003 Dec 12.

Lanciotti, R.S., J.T. Roehrig, V. Deubel, J. Smith, M. Parker, K. Steele, B. Crise, K.E. Volpe, M.B. Crabtree, J.H. Scherret, R.A. Hall, J.S. MacKenzie, C.B. Cropp, B. Panigrahy, E. Ostlund, B. Schmitt, M. Malkinson, C. Banet, J. Weissman, N. Komar, H.M. Savage, W. Stone, T. McNamara, and D.J. Gubler. 1999. Origin of the West Nile virus responsible for an outbreak of encephalitis in the northeastern United States. *Science* 286:2333-2337.

Lanzavecchia, A. 1993. Identifying strategies for immune intervention. Science 260:937-944.

Lawrence, E.A. 1994. Love for animals and the veterinary profession. *JAVMA* 205:970-972.

Lednicky, J.A., J. Dubach, T.P. Meehan, M.J. Kinsel, M. Bochetta, L.L. Hungerford, N.A. Sarich, K.E. Witecki, M.D. Braid, C. Pedrak, and C.M. Houde. 2004. Genetically distant American Canine distemper virus lineages have recently caused epizootics with somewhat different characteristics in raccoons living around a large suburban zoo in the USA. *Virology Journal* 1, 2 (volume 1, article 2).

Lewis, S.M., and J.H. Carraway. 1992. Large animal models of human disease. *Laboratory Animal* Jan:22-29.

Martini L., M. Fini, G. Giavaresi, and R. Giardino. 2001. Sheep model in orthopedic research: a literature review. *Comparative Medicine* 51(4):292-299.

McClellan, R.O. 2000. History of aerosol science and health research. Proc. Symp. History of Aerosol Science, pp. 129-145.

McKisic M.D., D.W. Lancki, G. Otto, P. Padrid, S. Snook, D.C. Cronin II, P.D. Lohmar, T. Wong, and F.W. Fitch. 1993 Identification and propagation of a putative immunosuppressive orphan parvovirus in cloned T cells. *Journal of Immunology* 150:419-428.

McKisic, M.D, F. Paturzo, and A. Smith. 1996. Mouse parvovirus infection potentiates rejection of tumor allografts and modulates T cell effector functions. *Transplantation* 61:292-299.

Mead P.S., L. Slutsker, V. Dietz, L.F. McCaig, J.S. Bresee, C. Shapiro, P.M. Griffin and R.V. Tauxe. 1999. Food-related illness and death in the United States. *Emerg Infect Dis* 5(5):607-625.

Mench, J.A. 1992. The welfare of poultry in modern production systems. *Poultry Science Reviews* 4:107-128.

MAF (Morris Animal Foundation). 2003. Annual Report. [Online]. Available: http://www.morrisanimalfoundation.org/pdf/Morris_2003.pdf.

Morrison, W.B., and R.M. Starr. 2001. Vaccine-Associated Feline Sarcoma Task Force: Vaccine-associated feline sarcomas. *JAVMA* 218:697-702.

Morse, S.S. 1993. Examining the origins of emerging viruses. Pages 10-28 in S. S. Morse, editor. Emerging Viruses. New York: Oxford University Press.

Nadeau, J.H. 2001. Modifier genes in mice and humans. *Nature Reviews Genetics* 2:165-174.

Nettles, V.F. 1996. Reemerging and emerging infectious diseases: economic and other impacts on wildlife. ASM News 62:589.

Nielsen N.O. 1997. Reshaping the veterinary medical profession for the next century. *JAVMA* 210:1272-1274.

Nielsen, N.O. 2003. Will the veterinary profession flourish in the future? Journal of Veterinary Medical Education 30:301-307.

NIH (National Institutes of Health). 2002. Ecology of Infectious Diseases Initiative. Bethesda, MD: National Institutes of Health. [Online]. Available at: http://www.fic.nih.gov/programs/ecology.html.

NIH. 2004. Stem Cell Information. Bethesda, MD: National Institutes of Health. [Online]. Available at: http://stemcells.nih.gov/info/faqs.asp.

NRC (National Research Council). 1989. Investing in Research. A Proposal to Strengthen the Agricultural, Food, and Environmental System. Washington DC. National Academy Press.

NRC. 1997. Chimpanzees in Research: Strategies for their Ethical Care, Management and Use. Washington DC. National Academy Press.

NRC. 1998a. Biomedical Models and Resources: Current Needs and Future Opportunities. Washington, DC: National Academy Press.

NRC. 1998b. Brucellosis in the Greater Yellowstone Area. Washington, DC: National Academy Press.

NRC 2002a. The Emergence of Zoonotic Diseases: Understanding the Impact on Animal and Human Health. Washington, DC: National Academy Press.

NRC. 2002b. Emerging Animal Diseases: Global Markets, Global Safety. Washington, DC: National Academy Press.

NRC 2002c. Stem Cells and the Future of Regenerative Medicine. Washington, DC. The National Academies Press.

NRC. 2003a. Countering Agricultural Bioterrorism. Washington, DC: The National Academies Press.

NRC. 2003b. Microbial Threats to Health: Emergence, Detection, and Response. Washington, DC: The National Academies Press.

NRC. 2004a. National Needs and Priorities for Veterinarians in Biomedical Research. Washington, DC: The National Academies Press.

NRC. 2004b. The Development of Science-based Guidelines for Laboratory Animal Care: Proceedings of the November 2003 International Workshop. Washington, DC: The National Academies Press.

NRC. 2005. Animal Health at the Crossroads: Preventing, Detecting, and Diagnosing Animal Diseases. Washington, DC: The National Academies Press.

NSF (National Science Foundation). 2004. Federal Funds for Research and Development. Fiscal Years 2001, 2002, 2003. Volume 51. Arlington, VA: National Science Foundation.

NSF. 2004. Fiscal Year 2004 Awards Ecology of Infectious Disease. Arlington, VA: National Science Foundation. [Online].Available: http://www.nsf.gov/bio/pubs/awards/eid.htm.

NSF 2004. Introduction to IGERT Program. 2004. [Online]. Available: http://www.nsf.gov/crssprgm/igert/intro.jsp#

NZP (National Zoological Park). 2004. Information provided to NRC Committee on National Needs for Research in Veterinary Science. October 29, 2004.

Oehen, S., H. Hengartner, and R.M. Zinkernagel. 1991. Vaccination for disease. *Science* 251: 195-198.

Ostrander, E.A., J. Rine, G.H. Sack Jr., and L.C. Cork. 1993. What is the role of molecular genetics in modern veterinary practice? *JAVMA* 203:1259-1262.

Pappaioanou, M., P.L. Garbe, M.K. Glynn, and S.B. Thacker. 2003. Veterinarians and public health: the epidemic intelligence service of the Centers for Disease Control and Prevention, 1951-2002. *Journal of Veterinary Medical Education* 30 (4):383-391.

Pappaioanou, M. 2004. Veterinary medicine protecting and promoting the public's health and well-being. *Preventive Veterinary Medicine* 62 (3):153-163.

Parker, H.G., L.V. Kim, N.B. Sutter, S. Carlson, T.B. Lorentzen, T.B. Malek, G.S. Johnson, H.B. DeFrance, E.A. Ostrander, and L. Kruglyak. 2004. Genetic structure of the purebred domestic dog. *Science* 304:1160-1164.

Patterson, D.F., M.E. Haskins, P.F. Jezyk, U. Giger, V.N. Meyers-Wallen, G. Aquirre, J.C. Fyfe, and J.H. Wolfe. 1988. Research on genetic diseases: reciprocal benefits to animals and man. *JAVMA* 193:1131-1144.

Paul, M.A., M. Appel, R. Barrett, L.E. Carmichael, H. Childers, C. Cotter, A. Davidson, R. Ford, D. Keil, M. Lappin, R.D. Schultz, E. Thacker, E. Trumpeter, and L. Welborn. 2003. Report of the American Animal Hospital Association (AAHA) Canine Vaccine Task Force: Executive summary and 2003 canine vaccine guidelines and recommendations. *American Animal Hospital Association* 39:119-131.

Perryman, L.E. 2004. Molecular pathology of severe combined immunodeficiency in mice, horses, and dogs. *Veterinary Pathology* 41:95-100.

Phillips, I., M. Casewell, T. Cox, B. De Groot, C. Friis, R. Jones, C. Nightingale, R. Preston, and J. Waddell. 2004. Does the use of antibiotics in food animals pose a risk to human health? A critical review of published data. *Journal of Antimicrobial Chemotherapy* 53:28-52.

Pletcher, M.T, P. McClurg, S. Batalov, A.I. Su, S. W. Barnes, E. Lagler, R. Korstanje, X. Wang, De. Nussker, M.A. Bogue, R.J. Mural, B. Paigen, and T. Wiltshire. Use of a Dense Single Nucleotide Polymorphism Map for In Silico Mapping in the Mouse. PLoS Biology Vol. 2, No. 12, e393.

Pritchard,W. 1989. Future Directions for Veterinary Medicine. Durham, NC: Pew National Veterinary Education Program, Duke University.

Riddle C., H. Mainzer, and M. Julian. 2004. Training the veterinary public health workforce: a review. *Journal of Veterinary Medical Education* 31:161-167.

Rota, P.A., M.S. Oberste, S.S. Monroe, W.A. Nix, R. Campagnoli, J.P. Icenogle, S. Penaranda, B. Bankamp, K. Maher, M.H. Chen, S.X. Tong, A. Tamin, L. Lowe, M. Frace, J.L. DeRisi, Q. Chen, D. Wang, D.D. Erdman, T.C. T. Peret, C. Burns, T.G. Ksiazek, P.E. Rollin, A. Sanchez, S. Liffick, B. Holloway, J. Limor, K. McCaustland, M. Olsen-Rasmussen, R. Fouchier, S. Gunther, A. Osterhaus, C. Drosten, M.A. Pallansch, L.J. Anderson, and W.J. Bellini. 2003. Characterization of a novel coronavirus associated with severe acute respiratory syndrome. *Science* 300:1394-1399.

Sadlack, B., H. Merz, H. Schorle, A. Schimpl, A.C. Feller, and I. Horak. 1993. Ulcerative colitis-like disease in mice with a disrupted interleukin-2 gene. *Cell* 75:253-261.

Schoen, A.M., and Wynn, S.G. (eds.) 1997. Complementary and Alternative Veterinary Medicine, Principles and Practice. St. Louis, MO.: Mosby, Inc

Schultz, R.D. 1999. Veterinary Vaccines and Diagnostics. *Advances in Veterinary Medicine* 41:1-815.

Schwabe, C.W. 1984. Veterinary Medicine and Human Health 3rd ed. Baltimore, MD: Williams and Wilkins.

Scott-Moncrieff, J.C., J. Azcona-Olivera, N.W. Glickman, L.T. Glickman, and H. HogenEsch. 2002. Evaluation of antithyroglobulin antibodies after routine vaccination in pet and research dogs. *JAVMA* 221:515-521.

Shepherd, A.J. 2004. Employment, starting salaries, and educational indebtedness of year-2004 graduates of US veterinary medical colleges. *JAVMA* 224:1677-1679.

Singer, M. 2004. The Evolution of Postdocs. *Science* 306:232.

Smith, C.A. 1994. New hope for overcoming canine inherited disease. *JAVMA* 204:41-46.

Smithies, O. and N. Maeda. 1995. Gene targeting approaches to complex genetic diseases: atherosclerosis and essential hypertension. *Proceedings of the National Academy of Sciences USA* 92(12):5266-5272.

Stephen, C., and C.S. Ribble. 2001. Death, disease and deformity: Using outbreak of disease in animals as sentinels for emerging environmental health risks. *Global Change and Human Health* 2 (2):108-117.

Stephen, C., S. Lester, W. Black, M. Fyfe, and S. Raverty. 2002. Multi-species outbreak of cryptococcosis on Southern Vancouver Island, British Columbia. *Canadian Veterinary Journal* 43 (10):792-794.

Sutter, N.B., and E.A. Ostrander. 2004. Dog star rising: The canine genetic system. *Nature Reviews Genetics* 5(12):900-910.

Tabor, G.M., and A.A. Aguirre. 2004. Ecosystem Health and Sentinel Species: Adding an Ecological Element to the Proverbial "Canary in the Mineshaft." *Ecohealth* 1:226-228.

Taylor, L. H., S. M. Latham, and M. E. J. Woolhouse. 2001. Risk factors for human disease emergence. *Philosophical Transactions of the Royal Society of London, B*. 356:983-989.

Threadgill D.W., A.A. Dlugosz, L.A. Hansen, T. Tennenbaum, U. Lichti, D. Yee, C. LaMantia, T. Mourton, K. Herrup, R.C. Harris, J.A. Barnard, S.H.. Yuspa, R.J. Coffey, and T. Magnuson. 1995. Targeted disruption of mouse EGF receptor: Effect of genetic background on mutant phenotype. *Science* 269:230-234.

Tilman D., K.G. Cassman, and P.A. Matson, R. Naylor, and S. Polasky. 2003. Agricultural sustainability and intensive production practices. *Nature* 22 (6930):671-677.

Tizard, I. 1990. Risks associated with use of live vaccines. *J Am Vet Med Assoc* 196:1851-1858.

Tizard I.R., and R.M. Schubot. 2000. Veterinary Immunology: An Introduction, 6th ed. Philadelphia: WB Saunders. 480 pp.

Troyer, J.L., J. Pecon-Slattery, M.E. Roelke, L. Black, C. Packer, and S.J. O'Brien. 2004. Patterns of feline immunodefficiency virus multiple infection and genome divergence in a free-ranging population of African cats. *Journal of Virology* 78:3777-3791.

Tumpey, T.M., A. Garcia-Sastre, J.K. J.K. Taubenberger, P. Palese, D.E. Swayne, and C.F. Basler. 2004. Pathogenicity and immunogenicity of influenza viruses with genes from the 1918 pandemic virus. *Proceedings of the National Academy of Sciences of the USA* 101:3166-3171.

Turnidge, J. 2004. Antibiotic use in animals–prejudices, perceptions, and realities. *Journal of Antimicrobial Chemotherapy* 53:26-27.

USAHA (United States Animal Health Association). 2004. USAHA: The Nation's Animal Health Forum Since 1897. [Online]. Available: http://www.usaha.org/about_usaha.shtml.

USAMRMC (US Army Medical Research and Materiel Command). 2004. Animal Care and Use Review. [Online]. Available: https://mrmc.detrick.army.mil/index.asp?EntryURL=/crprcqaurd.asp?.

USDA (US Department of Agriculture). 1885. First Annual Report, Bureau of Animal Industry, 1884. Washington, DC: Government Printing Office.

USDA. 1999. Report of the Strategic Planning Task Force on USDA Research Facilities: A 10-year Strategic Plan. Report and Recommendations. Washington, DC: US Government Printing Office. 108 pp.

USDA. 2003. Agricultural Statistics 2001. National Ag Statistics Services. Washington, DC: US Printing Office.

USDA. 2004a. About USDA. Mission Statement. [Online]. Available: http://www.usda.gov/wps/portal/!ut/p/_s.7_0_A/7_0_1OB?navtype=MA&navid=ABOUT_USDA.

USDA. 2004b. Agencies & Offices. USDA Mission Areas. [Online]. Available: http://www.usda.gov/wps/portal/!ut/p/_s.7_0_A/7_0_1OB?navtype=MA&navid=AGENCIES_OFFICES.

USDA. 2004c. About FSIS. [Online]. Available: http://www.fsis.usda.gov/about/index.asp.

USDA.2004d. Welcome to the Animal and Plant Health Inspection Service Website. [Online]. Available: http://www.aphis.usda.gov/lpa/about/welcome.html.

USDA. 2004e. Veterinary Services, Safeguarding Animal Health. Who We Are. [Online]. Available: http://www.aphis.usda.gov/vs/who_we_are.html.

USDA. 2004f. CSREES Background. [Online]. Available: http://www.csrees.usda.gov/about/background.html.

USDA-APHIS (US Department of Agriculture, Animal and Plant Health Inspection Service). 2004. Select agent and toxin list. Avialable: http://www.aphis.usda.gov/programs/ag_selectagent/ag_bioterr_toxinslist.html.

USDA-ARS (US Department of Agriculture, Agriculture Research Services). 2003. Recruitment and Retention of D.V.M./Ph.D. Scientists. Memo provided to NRC Committee on National Needs for Research in Veterinary Science.

USDA-ARS. 2004a.Evaluation of Compounds and Strategies for Controlling Aquatic Animal Disease, Harry K. Dupree Stuttgart National Aquaculture Research Center. [Online]. Available: http://www.snarc.ars.usda.gov/Research/disease.htm.

USDA-ARS. 2004b. Agricultural Research Service. The in-house research arm of the US Department of Agriculture. [Online]. Available: http://www.ars.usda.gov/research/programs.htm.

USDA-ARS. 2004c. Agricultural Research Service. Briefing Paper for the NRC Committee on National Needs for Research in Veterinary Science. Presented on July 19, 2004.

USDA-ARS 2004d. National Institute for Food and Agriculture; A Proposal. Report of the Research, Education and Economics Task Force. [Online] Available: http://www.ars.usda.gov/SP2UserFiles/Place/00000000/NATIONAL.doc

USDA-ERS (US Department of Agriculture, Economic Research Service). 2004. Economics of Foodborne Disease. ERS/USDA Briefing Room. [Online]. Available: http://www.ers.usda.gov/Briefing/FoodborneDisease.

Vail, D.M., MacEwen, E.G., Kurzman, I.D., Dubielzin, R.R., Helfand, S.C., Kissel, W.C., London, C.A., Obradovich, J.E., Madewell, B.R., Rodriguez, C.O. Jr., Fidel J., Susaneck S., and Rosenberg M. 1995. Liposome-encapsulated muramyl tripeptide phosphatidylethanolamine adjuvant immunotherapy for splenic hamangiosarcome in the dog: a randomized multi-institutional clinical trial. *Clinical Cancer Research* 1:1165-1170.

VanLeewen, J, N.O. Nielsen, and D. Waltner-Toews. 1988. Ecosystem health: an essential field for veterinary medicine. *JAVMA* 212:53-57.

Vascellari, M., E. Melchiotti, M.A. Bozza, and F. Mutinelli. 2003. Fibrosarcomas at presumed sites of injection in dogs: characteristics and comparison with non-injection site fibrosarcomas and feline post-vaccinal fibrosarcomas. *Journal of Veterinary Medicine* 50:286-291.

Wagner, W. C. 1992. Animal research and veterinary medical research funding: a vision of the future. *JAVMA* 200:1474-1476.

Wagner, W.C. 2004. Future Research Needs in Veterinary Medicine. The USDA-CSREES Perspective. Information provided to NRC Committee on National Needs for Research in Veterinary Science on July 19, 2004.

Ward, J.W. Comment on the muromics "Garden Path," *Comparative Medicine* 52(2002) 302.

Weese, S. 2005. Methicillin-Resistant *Staphylococcus aureus*: An Emerging Pathogen in Small Animals. *Journal of American Animal Hospital Association* 41:150-157.

WFF (Winn Feline Foundation). 2004. Grant Announcement. [Online]. Available: http://www.winnfelinehealth.org/announce.html.

Wiese, E. 2003. Pets may be first bioterrorism alert Vets' database likely to spot outbreaks most quickly. [Online]. Available: http://www.usatoday.com/usatonline/20030331/5014277s.htm

Wisconsin DNR (Department of Natural Resources). 2002. Chronic Wasting Disease detected in three Wisconsin deer. DNR News Release Feb. 28. [Online]. Available: http://www.dnr.state.wi.us/org/caer/ce/news/rbnews/2002/022802co.htm.

Witter, R. 2005. The Veterinarian Scientist—An endangered species. *Journal of Veterinary Medical Education*. In press.

Wolfe, N.D., W.M. Switzer, J.K. Carr, V.B. Bhullar, V. Shanmugam, U. Tamoufe, A.T. Prosser, J.N. Torimiro, A. Wright, E. Mpoudi-Ngole, F.E. McCutchan, D.L. Birx, T.M. Folks, D.S. Burke, and W. Heneine. 2004. Naturally acquired simian retrovirus infections in central African hunters. *Lancet* 363:932-937.

Wong, P.C., H. Cai, D.R. Borchelt, and D.L. Price. 2002. Genetically engineered mouse models of neurodegenerative diseases. *Nature Neuroscience* 5(7):633-639.

Woodward, D.L., R. Khakhria, and W.M. Johnson. 1997. Human salmonellosis associated with exotic pets. *Journal of Clinical Microbiology* 35:2786-90.

Zajtchuk, R, (ed.) 1997. The US biological warfare and biodefense programs. In: Textbook of Military Medicine: Medical Aspects of Chemical and Biological Warfare. Washington, DC, US Dept of the Army, the Surgeon General, and the Borden Institute, pp. 425-436.

Zamer, W.E. 2005. NSF 101: Fundamentals of the proposal review process and funding opportunities at the National Science Foundation. *Journal of Veterinary Medical Education* (in press).

Zerhouni, E. 2003. The NIH roadmap. *Science* 302:63-64;72.

Zoological Society of San Diego. 2004. Conservation and Research for Endangered Species, 2003 Annual Report. San Diego: Zoological Society of San Diego.

Appendixes

Appendix A

Statement of Task

The committee on National Needs for Research in Veterinary Science will identify national needs for research in three fields of veterinary science: public health and food safety; animal health; and comparative medicine. These three fields encompass research with domestic (e.g., livestock and poultry), wild (e.g., deer, exotic species), companion (e.g., cats and dogs), service (e.g., horses, dogs, marine mammals), and laboratory animals. Specifically the committee will assess the future needs for research in the three fields of veterinary science defined above, which are not limited to science conducted by veterinarians—they include science performed by professionals with veterinary degrees and by professionals with various other degrees.

Based on a review of published literature, including the ILAR report on increasing veterinary involvement in biomedical research, and other data, the committee will identify past and future trends and gaps in topics considered, scientific expertise required, current funding levels and sources and institutional capacity. The committee will define national needs for future research in the three fields of veterinary science listed above, assess the adequacy of our national capacity, mechanisms and infrastructure to support the needed research and, if appropriate, make recommendations as to how the needs can be met. The committee will identify areas of veterinary science that are deficient and areas requiring attention, but it will not make specific budgetary or organizational recommendations.

Appendix B

Committee Biographies

James E. Womack (chair) is a distinguished professor and the director of the Center for Animal Biotechnology and Genomics at Texas A&M University. He received his BS in mathematics education from Abilene Christian College and his PhD in genetics from Oregon State University. His research interest is comparative mammalian genomics, particularly comparative mapping of the bovine genome and the genomes of humans and mice. He launched the discipline of livestock genomics with his initial map of the bovine genome and the demonstration of extensive chromosomal conservation in cattle, humans, and mice. His international leadership resulted in a comprehensive bovine linkage map and the first genetic mapping of economically important traits in cattle. Dr. Womack is a fellow of the American Association for the Advancement of Science. He has received numerous awards, including the CIBA Prize for Research in Animal Health (1993) and the Wolf Prize in Agriculture (2001). He was a member of the National Research Council Steering Committee for Exploring Horizons for Domestic Animal Genomics.

Lynn C. Anderson is executive director of consulting and staffing services at Charles River Laboratories, Inc. She earned her DVM from Iowa State University and is certified by the American College of Laboratory Animal Medicine. Before joining Charles River Laboratories, she was executive director of global research safety and compliance at Merck Research Laboratories, and before that, she held management positions with Amgen and 3M, was an assistant professor of laboratory medicine and pathology at the University of Minnesota Medical School, and practiced small-animal medicine. She served as president of the

American Association for Laboratory Animal Science, the American College of Laboratory Animal Medicine, and the American Society of Laboratory Animal Practitioners. She has written numerous scientific and technical publications and presented at many national and international meetings on topics related to the humane care and use of laboratory animals.

Leonard S. Bull is professor of animal science and associate director of the Animal and Poultry Waste Management Center at North Carolina State University. He received his BS and MS in dairy science and dairy cattle nutrition, respectively, from Oklahoma State University and his PhD in animal nutrition from Cornell University. His research interests include food-animal production systems; animal nutrition, especially protein and energy metabolism in ruminants; ruminal fiber digestion; and animal-waste management. Dr. Bull served as president of the American Society of Animal Sciences (1997-1998) and vice president of the North American chapter of the World Association for Animal Production (1998-2003). He is a fellow of the American Association for the Advancement of Science and the American Society of Animal Science. He chaired the National Research Council Subcommittee on Nitrogen Usage in Ruminants and served on the Board on Agriculture and Natural Resources (1995-1997).

Charles C. Capen is a distinguished university professor in the Department of Veterinary Biosciences at Ohio State University. He has chaired his department (the Department of Veterinary Pathobiology until the integrated Department of Veterinary Biosciences was established in 1994) since 1982 and was acting chair for a year before that. He joined the faculty in 1965 after serving as an instructor for 5 years while pursuing his PhD in veterinary pathology. He also earned his MS at Ohio State University and his DVM at Washington State University. Dr. Capen is renowned for his work in the use of animal models to study human diseases and was elected to the Institute of Medicine in 1992. He has received dozens of honors, including being named a distinguished member of the American College of Veterinary Pathologists—one of only 22 diplomates of 1,300 in the college to receive such a designation. He also received Ohio State's Distinguished Scholar Award in 1993. He served on the National Research Council Committee on Review of the Smithsonian Institution's National Zoological Park and the committee to Assess the Health Implications of Perchlorate Ingestion.

Norman F. Cheville is retired dean of the College of Veterinary Medicine and Clarence Hartley Covault Distinguished Professor at Iowa State University. He received his DVM from Iowa State University, his PhD from the University of Wisconsin, and a Doctor Honoris Causa from the University of Liege. He chaired the Department of Veterinary Pathology at Iowa State University from 1995 to 2000. Before joining Iowa State University, he was chief of pathology (1964-1989) and of the Brucellosis Research Unit (1989-1995) at the National Animal

Disease Center. Dr. Cheville's expertise is in pathogenesis and cytopathology. He has received many awards and honors, including the American Feed Industry Award for Outstanding Research from the American Veterinary Medical Foundation (2001), the Pfizer Award for research in bovine disease from the American Veterinary Medical Association Foundation (1998), and the Outstanding Achievement Award from the US Department of Agriculture (1991). He has served on the National Research Ccouncil Committee on Ungulate Management in Yellowstone National Park and Study on Brucellosis in the Greater Yellowstone Area.

Peter Daszak is executive director of the Consortium for Conservation Medicine, a collaborative partnership between Harvard Medical School's Center for Health and the Global Environment, the Johns Hopkins School of Public Health, Tufts University's School of Veterinary Medicine, the US Geological Survey National Wildlife Health Center, and the Wildlife Trust. He directs the consortium's programs in research, education, policy, and practical conservation. He earned a BSc in zoology and a PhD in parasitology. His research focuses on the taxonomy, pathology, and conservation impact of parasitic diseases, particularly those of nonmammalian vertebrates and invertebrates. In collaboration with groups in Britain, Australia, and the United States, he discovered a previously unknown fungal disease of amphibians, chytridiomycosis, which is a major cause of frog population declines globally and may be transmitted by bullfrogs. The discovery highlights the link between global trade and disease emergence, a process known as pathogen pollution. Dr. Daszak has adjunct positions at three American and two British universities. He has served on committees of the World Conservation Union and the World Health Organization and has advised an array of government, commercial, and noncommercial organizations. Dr. Daszak has received a number of awards, including the 2000 CSIRO Medal for collaborative work on chytridiomycosis.

W. Jean Dodds is founder and president of Hemopet, the first nonprofit national blood bank program for animals. She received her DVM with honors from the Ontario Veterinary College, University of Toronto. In 1965, she accepted a position with the New York State Health Department in Albany, and she was later promoted to chief of the Laboratory of Hematology at the Wadsworth Center. In 1980, she became executive director of the New York State Council on Human Blood and Transfusion Services. Dr. Dodds has been a grantee of the National Heart, Lung, and Blood Institute and has over 150 research publications. She was formerly president of the Scientist's Center for Animal Welfare and chairman of the Committee on Veterinary Medical Sciences and vice chair of the Institute of Laboratory Animal Resources. She was also the editor of *Advances in Veterinary Science and Comparative Medicine*. Her awards include Outstanding Woman Veterinarian of the Year; American Veterinary Medical Association's Award for Outstanding Service to the Veterinary Profession, American Animal Hospital

Association; Gaines Fido Award as Dogdom's Woman of the Year; Award of Merit in Recognition of Special Contributions to the Veterinary Profession, American Animal Hospital Association; Centennial Medal of the University of Pennsylvania School of Veterinary Medicine; and Holistic Veterinarian of the Year Award of the American Holistic Veterinary Medical Association. She was elected distinguished practitioner of the National Academy of Practice in Veterinary Medicine. In 1986, she moved to southern California to establish Hemopet, and she is expanding Hemopet's nonprofit services and educational activities.

David R. Franz is chief biological scientist at the Midwest Research Institute and director of the National Agricultural Biosecurity Center at Kansas State University. He served in the US Army Medical Research and Materiel Command for 23 of his 27 years on active duty. Dr. Franz has served as deputy commander and commander of the US Army Medical Research Institute of Infectious Diseases (USAMRIID) and as deputy commander of the US Army Medical Research and Materiel Command. Before joining the command, he served as group veterinarian for the 10th Special Forces Group (Airborne). Dr. Franz was technical editor of the *Textbook of Military Medicine on Chemical and Biological Defense* and has been an invited speaker at many nationally and internationally recognized organizations. He served on the National Research Council Committee on Biological Threats to Agricultural Plants and Animals. He is serving on the National Research Council Committee on Genomics Databases for Bioterrorism Threat Agents and Committee to Review Research Proposals from Former Soviet Biological Weapons Institutes, which he chairs. Dr. Franz holds a DVM from Kansas State University and a PhD in physiology from Baylor College of Medicine.

Michael P. Doyle is regents professor of food microbiology and director of the University of Georgia Center for Food Safety at the University of Georgia. Before joining the University of Georgia, he was a distinguished professor of food microbiology and toxicology at the University of Wisconsin. In 1993, Dr. Doyle established the Center for Food Safety. He developed a research program that promotes collaboration among the food industry, universities, and federal and state agencies. His research focuses on developing methods to detect and control foodborne bacterial pathogens at all levels of the food continuum from farm to table. He is an authority on foodborne pathogens, especially *Escherichia coli* O157:H7.

John A. Shadduck is president of Shadduck Consulting LLC. He received his DVM, MSc, and PhD in veterinary pathology from Ohio State University. He pursued an academic career in colleges of veterinary medicine at Ohio State University, the University of Illinois, and Texas A&M University, where he was named dean emeritus. He also was on the faculty of the University of Texas Southwestern Medical Center at Dallas. Dr. Shadduck was chief executive officer of Optibrand Ltd., LLC and executive vice president of Heska Corporation. He is a past president and a distinguished member of the American College of Veterinary Pathologists. He was a member of the National Research Council Panel on Animal Health and Veterinary Medicine, which he chaired in 1996-1997.

Darcy H. Shaw is a professor of small-animal internal medicine and chair of the Department of Companion Animals at the Atlantic Veterinary College (AVC) of the University of Prince Edward Island. He received his DVM and MVSc from the University of Saskatchewan, Canada, and his MBA in educational administration from Royal Roads University, Canada. He is a diplomate of the American College of Veterinary Internal Medicine. His research interests include the role of the kidney in acid-base balance, mechanisms of progressive renal failure, and the role of cytokines in renal interstitial inflammation and fibrosis. Dr. Shaw was president of the Canadian Veterinary Medical Association (2000-2001). He has been service chief of small animal medicine and director of the AVC Veterinary Teaching Hospital (1992-1994).

David E. Swayne is laboratory director and supervisory veterinary medical officer at the Southeast Poultry Research Laboratory of the US Department of Agriculture (USDA), Agricultural Research Service. He leads a team of experts in studying exotic and emerging poultry viral diseases, including the H5 subtype of avian influenza virus. He received USDA's Secretary's Group Award and the Silver Plow Award for research that advanced the understanding of the pathobiology and epidemiology of Hong Kong H5N1 avian influenza and development of strategies to protect US poultry. He served on the Board of Governors of the American College of Poultry Veterinarians (ACPV) and the Board of Directors of the American Association of Avian Pathologists. Dr. Swayne received his BS in domestic-animal biology from the University of Arkansas, his DVM and MS in veterinary pathology from the University of Missouri, and his PhD in veterinary pathology from the University of Georgia. He is a diplomate of the American College of Veterinary Pathologists and of ACPV.

Ravi J Tolwani is an associate professor and director of postdoctoral training in laboratory animal and comparative medicine in the Department of Comparative Medicine at Stanford University. He received his DVM from Auburn University and PhD in molecular and cellular pathology from the University of Alabama, Birmingham. He is a diplomate of the American College of Laboratory Animal Medicine. Dr. Tolwani maintains an active research program that focuses on understanding the molecular mechanisms of plasticity in the nervous system and developing new therapies for neurodegenerative diseases. He is associate editor of *Comparative Medicine* and has served on the Board of Directors of the American College of Laboratory Animal Medicine. He received the Young Investigator Award from the American Association for Laboratory Animal Science in 1999 and the Special Emphasis Research Career Award from the National Institutes of Health in 1998.

Appendix C

Workshop on National Needs for Research in Veterinary Science

AGENDA

July 19-20, 2004
The National Academy of Sciences Building, Washington, DC

July 19, 2004

8:30 – 8:50 a.m.	Welcome and introduction James Womack, Texas A&M University

Session 1: Needs for veterinary research

8:50 – 9:10	Veterinary research needs in industry Rowland J. Kinkler, Pfizer Global Research and Development
9:10 – 9:30	Research needs in food and drug safety Stephen Sundlof, Food and Drug Administration
9:30 – 9:50	Research needs in companion animal research Edward Breitschwerdt, North Carolina State University
9:50 – 10:10	Resource, infrastructure and personnel needs in genetic disease and gene therapy research John Wolfe, University of Pennsylvannia
10:30 – 10:50	Questions and Answers
10:50 – 11:10	Break
11:10 – 12:10 p.m.	Breakout group discussion
12:10 – 12:50	Report to group
12:50 – 2:10	Lunch

Session 2: Vision for veterinary research: government perspectives

2:10 – 2:30	NIH program on disease ecology Joshua Rosenthal, Fogarty International Center, National Institutes of Health
2:30 – 2:50	How would NIH roadmap address research needs in veterinary science? Norka Ruiz-Bravo, Office of Extramural Research, National Institutes of Health
2:50 – 3:10	Program needs in Cooperative State Research, Education, and Extension Service (CSREES) William Wagner, US Department of Agriculture
3:10 – 3:30	CDC programs in veterinary research Nina Marano, Centers for Disease Control and Prevention
3:30 – 3:50	Questions and answers
3:50 – 4:10	Break
4:10 – 5:10	Breakout group discussion
5:10 – 6:00	Report to group
6:00	Wrap-up and adjourn for day

July 20, 2004

Session 3: Integration of veterinary science into tomorrow's research

8:30 – 8:50 a.m.	Need for integration of molecular and whole animal research Linda Saif, Ohio State University
8:50 – 9:10	Need for veterinary researchers in ecology of infectious diseases Gary Smith, University of Pennsylvania
9:10 – 9:30	Crosscutting research in veterinary science and integration of disciplines in veterinary college Anthony Frank, Colorado State University
9:30 – 9:50	Linkage opportunities in veterinary science research Eugene Allen, University of Minnesota
9:50 – 10:10	What expertise does USDA-NADC need in the next 5 years? Keith Murray, US Department of Agriculture
10:10 – 10:30	Questions and answers
10:30 – 10:50	Break
10:50 – 11:50	Breakout group discussion
11:50 – 12:30	Report to group
12:30	Wrap-up for workshop James Womack, Texas A&M University
12:35	Workshop adjourn

Appendix D

Bioterrorism Agents

Bacterial and Viral Threat Agents Associated with Animals

Category A Diseases and Agents	Zoonotic
Foot-and-mouth disease (*Picorna aphthovirus*)	No
Anthrax (*Bacillus anthracis*)	Yes
Botulism (*Clostridium botulinum* toxin)	No
Plague (*Yersinia pestis*)	Yes
Smallpox (*Variola major*)	No
Tularemia (*Francisella tularensis*)	Yes
Viral hemorrhagic fevers (Ebola, Marburg, Lassa, Machupo viruses)	No

Category B Diseases and Agents	Zoonotic
Brucellosis (*Brucella* spp.)	Yes
Epsilon toxin of *Clostridium perfringens*	No
Food safety threats (*Salmonella* spp., *Escherichia coli* O157:H7, *Shigella*)	Yes
Glanders (*Burkholderia mallei*)	Yes
Melioidosis (*Burkholderia pseudomallei*)	Yes
Psittacosis (*Chlamydia psittaci*)	Yes
Q fever (*Coxiella burnetii*)	Yes
Ricin toxin	No
Staphylococcal enterotoxin B	No
Typhus fever (*Rikettsia prowazekii*)	No
Viral encephalitis (VEE, EEE, and WEE viruses)	Yes
Water threats (*Vibrio cholerae, Cryptosporidium parvum*)	Yes

SOURCE: NRC 2002a, 2003a.

High-Consequence Livestock Pathogens and Toxins

USDA-Only Agents and Toxins[a]	USDA-HHS Overlap Agents and Toxins[b]
African horse sickness virus	*Bacillus anthracis*
African swine fever virus	Botulinum neurotoxin
Akabane virus	Botulinum neurotoxin-producing species of *Clostridium*
Avian influenza virus (highly pathogenic)	*Brucella abortus*
Bluetongue virus (exotic)	*Brucella melitensis*
Bovine spongiform encephalopathy agent	*Brucella suis*
Camel pox virus	*Burkholderia mallei*
Classical swine fever virus	*Burkolderia pseudonallei*
Cowdria ruminantium (Heartwater)	*Clostridium botulinum*
Foot-and-mouth disease virus	*Clostridium perfringens* epsilon toxin
Goat pox virus	*Coccidioides immitis*
Japanese encephalitis virus	*Coxiella burnetii*
Lumpy skin disease virus	Eastern equine encephalitis virus
Malignant catarrhal fever virus (exotic)	*Franscisella tulanrensis*
Menangle virus	Hendra virus
Mycoplasma capricolum/*M.*38/ *M.mycoides capri* (contagious caprine—pleuropneumonia)	Nipah virus
Mycoplasma mycoides mycoides (contagious bovine pleuropneumonia)	Rift Valley fever virus
Newcastle disease virus (VVND)	Shigatoxin
Peste des petits ruminants virus	Staphylococcus enterotoxins
Rinderpest virus	T-2 toxin
Sheep pox virus	Venezulan equine encephalitis virus
Swine vesicular disease virus	
Vesicular stomatitis virus (exotic)	

[a]Select agents and toxins that are only the USDA list of high-consequence livestock pathogens and toxins.
[b]Select agents and toxins that are on the USDA list of high-consequence livestock pathogens and toxins and on the HHS list of select agents and toxins.

SOURCE: USDA-APHIS

Appendix E

University Centers for Agricultural Biosecurity

University	Web Site
Auburn University Auburn Post-Harvest Food Protection Center	http://postharvestcenter.eng.auburn.edu
Iowa State University Center for Agricultural and Rural Development	www.card.iastate.edu
Kansas State University National Agricultural Biosecurity Center	www.ksu.edu/nabc
Louisiana State University Agricultural Center	www.agctr.lsu.edu
Oklahoma State University Oklahoma Food and Agricultural Products Research and Technology Center	www.fapc.okstate.edu
Ohio State University Ohio Agricultural Research and Development Center	www.oardc.ohio-state.edu
Penn State University College of Agricultural Sciences	www.cas.psu.edu
Purdue University National Biosecurity Resource Center for Animal Health Emergencies	www.biosecuritycenter.org
Texas A&M University Institute for Countermeasures Against Agricultural Bioterrorism	www.icab.tamu.edu
University of California, Davis Agricultural Issues Center	www.aic.ucdavis.edu
University of Georgia College of Agricultural & Environmental Sciences	www.caes.uga.edu

University	Web Site
University of Minnesota Center for Infectious Disease Research & Policy	www.cidrap.umn.edu
Washington State University Central Washington Animal Agriculture Team	www.animalag.wsu.edu

Appendix F

Student Enrollment and Faculty Size in Colleges of Veterinary Medicine in the United States

Number of Students Enrolled in DVM Program, Faculty Size (Full-Time Equivalent, Tenure, and Tenure Track) and Student/Faculty Ratio in Colleges of Veterinary Medicine in the United States from 1995-1996 to 2004-2005

Year	Number of Students in DVM Programs	Faculty Size	Student/Faculty Ratio
1995–1996	8,854	2,339	3.8
1996–1997	8,956	2,624	3.4
1997–1998	9,010	2,206	4.1
1998–1999	9,055	2,629	3.4
1999–2000	9,121	2,752	3.3
2000–2001	9,170	2,584	3.5
2001–2002	9,276	2,543	3.6
2002–2003	9,363	2,631	3.6
2003–2004	9,587	2,665	3.6
2004–2005	9,758	2,787	3.5

Appendix G

Research Expenditures for 27 Colleges of Veterinary Medicine

2002-2003 research expenditures for 27 colleges of veterinary medicine by quartiles and source. Quartile amounts are derived from research expenditures from each source. Faculty full-time equivalent (FTE) is average number of FTE faculty members in each quartile for each funding source.

Quartile[a]	National Institutes of Health	US Department of Agriculture	State	Industry	Private	Total All Sources[b]
		Average research expenditures of CVMs				
1st	$730,000	$219,000	$287	$17,160	$9,700	$2,587,000
2nd	2,780,000	717,000	80,900	372,500	36,900	6,967,000
3rd	5,212,000	1,258,000	703,870	898,000	71,100	11,100,000
4th	13,417,000	2,754,000	4,764,000	2,314,000	3,256,000	25,627,000
		Average number of faculty FTEs				
1st	66	64	75	71	80.5	67
2nd	85	90	98	87	112	86
3rd	99	97	99	102	91	96
4th	122	121	103	114	95	124
		Average research expenditures divided by average faculty FTEs				
1st	$11,000	$3,400	$4	$240	$120	$38,800
2nd	32,500	7,990	830	4,260	3,300	80,600
3rd	53,500	12,970	7,100	8,790	7,800	115,583
4th	110,400	22,760	46,300	20,350	34,360	206,700

[a]First quartile is composed of six CVMs; the others are each seven CVMs. One CVM in existence less than 2 years was omitted.
[b]Includes all research expenditures reported, including some from sources not shown in table.

Appendix H

Relationship Between Research Expenditures of Colleges of Veterinary Medicine and Co-location with Relevant Research Facilities

One element that may influence the amount of funds received by colleges of veterinary medicine (CVM) is the presence or absence of additional programs such as a medical school (CoM) or a U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) research laboratory on the same campus or nearby. The committee examined data on CVMs with CoMs co-located on the same campus, CVMs with ARS laboratories on or near the campus, and CVMs with neither nearby. CVMs at universities with CoMs that were not on the same campus were excluded from this analysis.

Ten of 27 CVMs are co-located on the same campus with a CoM. Three of the 10 also have an ARS laboratory nearby. Those 10 CVMs account for 46.4% of the all the CVMs research expenditures from the National Institutes of Health (NIH) and 47.3% of the total research expenditures ("total all sources") reported for all CVMs. The 10 CVMs co-located with CoMs have median faculty full-time equivalents (FTEs) of 101 (range, 72-151) and a student:faculty ratio of 3.8:1 (range, 2.76:1 to 5.43:1). The median research expenditure per FTE from NIH was about $60,600 (range, $36,500-121,100) and median research expenditure per FTE from "all sources" was about $153,600 (range, $84,800-202,300). Those figures are comparable with $52,000 and $104,000, respectively, for all CVMs. The same ten CVMs reported median research expenditures per school of about $1.24 million (range, $0.72-3.1 million) from USDA. Median expenditures per faculty FTE were about $12,200 (range, $4,800-27,100). The 10 schools accounted for 44.5% of the total research from USDA reported by all 27 CVMs.

Two groups of six CVMs each were selected for comparison on the basis of similar faculty FTEs and the presence or absence of co-located CoMs. Six CVMs with CoMs on the same campus had a median faculty size (FTE) of 85.3 (range, 72-114) and a student:faculty ratio of 4.06:1 (range, 3.84:1 to 5.43:1). Six other CVMs without CoMs on the same campus had a median faculty size (FTE) of 88 (range, 70-112), however, these six had a lower student:faculty ratio of 3.72:1 (range, 3.32:1 to 4.43:1). Two of the six CVMs with a CoM co-located on the same campus also had an ARS laboratory nearby, as did three of the six CVMs without a co-located CoM.

The six CVMs sharing campuses with CoMs reported median research expenditures from the NIH of $5.05 million (about $59,250/FTE; range, $36,500-115,000). The six CVMs not co-located with CoMs reported $2.37 million (about $27,000/FTE; range, $10,300-46,100) in median research expenditures from NIH. The expenditures from "total all sources" for the six CVMs on campuses with CoMs were about $12.5 million ($146,000/FTE; range, $84,800-202,400). The six CVMs not co-located with CoMs reported about $6.57 million ($74,700/FTE; range $37,800 to $102,000). Thus, for NIH and "total all sources", the six CVMs co-located with CoMs reported about twice as much research activity as the six without CoMs on the same campus. That was not the case, however, for research expenditures from USDA. The six schools with co-located CoMs reported median expenditures per FTE of about $12,200 (range, $4,800-27,100) and the six schools without co-located CoMs reported about median expenditures per FTE of $10,000 (range, $0-49,900).

Nine CVMs have an ARS laboratory on or near the campus. Three of the nine also have a co-located CoM. The median faculty FTE of the nine CVMs with ARS laboratories nearby was 91 (range, 76-151) with a student:faculty ratio of 3.59:1 (range, 2.69:1 to 4.48:1). The nine CVMs with ARS laboratories nearby account for 52% of the reported research expenditures from USDA by all CVMs, 23% of the research expenditures from NIH, and 26% of those from "total all sources" reported by all 27 CVMs. When the three CVMs with co-located CoMs are excluded, the remaining six CVMs have 31% of all the CVM expenditures from USDA, 12% from NIH, and 13% from "total all sources". Among the nine CVMs, the median expenditure per FTE from USDA was about $13,200 (range, $7,000-28,700), from NIH about $45,400 (range, $8,900-79,400) and from "total all sources" about $103,100 (range, $35,700-149,300). Average expenditures per faculty FTE for all 27 CVMs were as follows: USDA, $11,800; NIH, $51,800; and "total all sources" $104,100.

Four CVMs with ARS laboratories nearby but without co-located CoMs were compared with four CVMs with neither ARS nor CoM programs on or near campus. The median faculty FTEs for both groups were 83, but the student:faculty ratios were 3.27:1 (range, 2.69:1 to 3.68:1) and 3.81:1 (range, 3.65:1 to 4.40:1), respectively. The median research expenditures per faculty FTE for the four schools with ARS laboratories nearby were as follows: USDA, about $12,000 (range, $9,700-28,700); NIH, about $28,500 (range, $8,900-79,400); and "total all sources" about $76,300 (range, $35,800-132,300). For the four schools without ARS laboratories nearby median research expenditures per faculty FTE were as follows: USDA, about $6200 (range, $1,800-12,700); NIH, about $15,300 (range, $7,500-46,500; and "total all sources" about $67,200 (range, $37,800-100,600).

Ten CVMs with neither ARS nor CoM programs on or near the campus were analyzed. The 10 accounted for 24% of the research expenditures from USDA, 41% from NIH, and 38% from "total all sources" reported by all 27 CVMs. The median research expenditures per faculty FTE from USDA were about $8,800 (range, $2,100-14,500); from NIH, about $31,100 (range, $5,500-142,200); and from "total all sources", about $80,400 (range, $17,000-345,000). However, those 10 schools had a median of 91 (range, 29-206) faculty FTEs and a median student:faculty ratio of 3.81:1 (range, 2.81:1 to 7.03:1). The group of 10 schools has fewer median faculty FTEs, higher student:faculty ratios, and larger ranges than either the group of ten CVMs with co-located CoMs or the group of nine with ARS laboratories nearby but without co-located CoMs. (However, there is a negligible difference in median student:faculty ratio—3.80:1 vs. 3.81:1 between the groups with and without CoMs.)

The analysis implies that "critical mass" and campus research environments may play a role in the relative research funding levels of CVMs. The larger amounts of research funding in CVMs co-located with research facilities of other related disciplines suggest that these CVMs may benefit from collaborative interdisciplinary research with those facilities.

Appendix I

Institutions or Organizations that Contribute Major Resources to Wildlife and Aquatic Health, Food Safety, and Well-Being

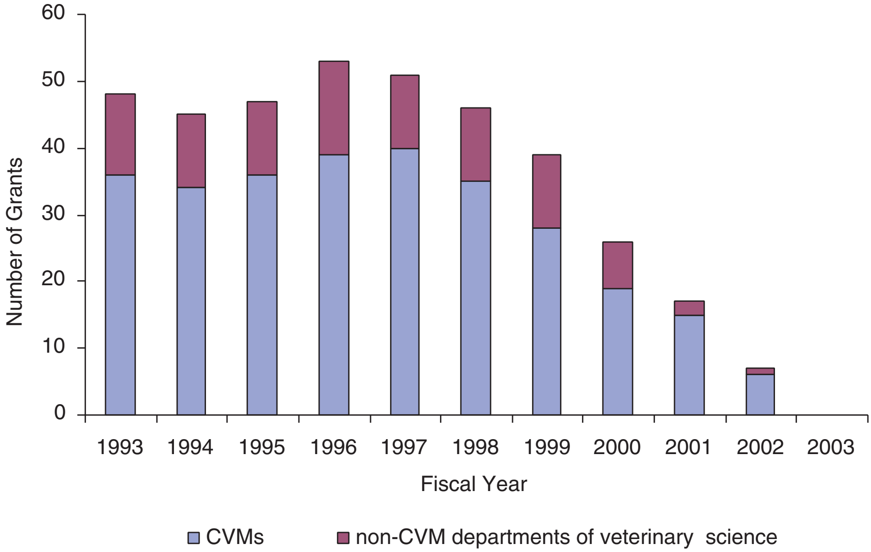
Institution or Association	Contact Person or Web site
American Association of Wildlife Veterinarians	http://www.aawv.net/
American Fisheries Society, Fish Health Section, Bethesda, MD	http://www.fisheries.org/fhs/
Aquatic Animal Health Program, Department of Microbiology and Immunology, Cornell University College of Veterinary Medicine, Ithaca, NY	http://www.vet.cornell.edu/Public/cFishDisease/AquaticProg/index.htm
Aquatic Animal Health Research, Agricultural Research Service, USDA, Auburn, AL	Phil Klesius; http://www.ars.usda.gov/main/site_main.htm?modecode=64-20-15-00
Aquatic Health Sciences, University of Prince Edward Island and the Atlantic Veterinary College, Charlottetown, P.E.I., Canada	http://www.upei.ca/research/UPEI_Canada_Research_Chairs/Aquatic_Health_Sciences/aquatic_health_sciences.html
Catfish Health Research Program, Mississippi State University College of Veterinary Medicine, College Station, MS	Jerald Ainsworth; http://www.cvm.msstate.edu/research/
Center for Aquatic Animal Medicine and Pathology, University of Pennsylvania, School of Veterinary Medicine, Philadelphia, PA	http://www.vet.upenn.edu/research/
Center for Bison and Wildlife Health, Montana State University, Bozeman, MT	http://www.montana.edu/~wwwcbs/
Consortium for Conservation Medicine, Palisades, NY	Peter Daszak; http://www.conservationmedicine.org/

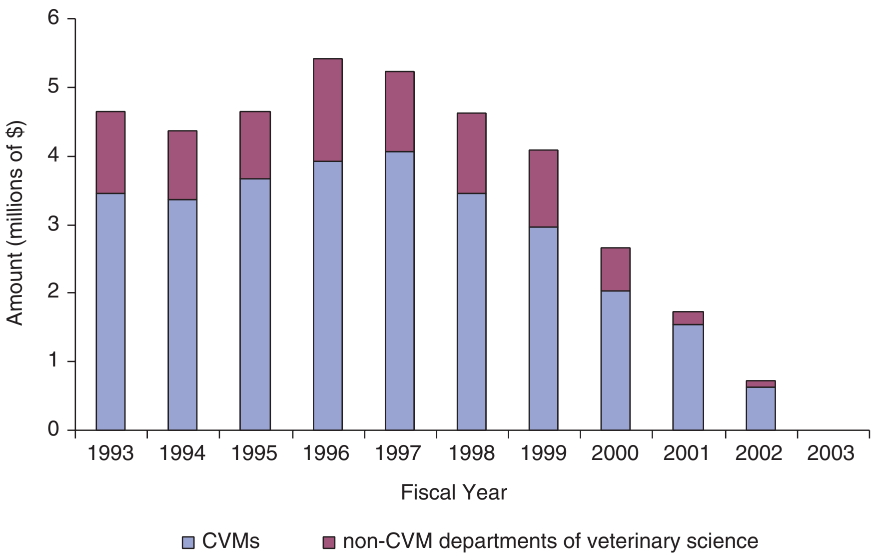
Institution or Association	Contact Person or Website
Fish Health Branch, Leestown Science Center, US Geological Survey, Department of the Interior, Kearneysville, WV	Frank Panek; http://www.lsc.usgs.gov/FHBindex.asp
Louisiana State University Cooperative Aquatic Animal Health Research Program, Baton Rouge, LA	Ronald L. Thune; http://www.vetmed.lsu.edu/caahrp.htm
Marrowstone Marine Field Station, US Geological Survey, Department of the Interior, Nordland, WA	http://wfrc.usgs.gov/labs/marrowstone.htm
National Fish and Wildlife Forensics Laboratory, US Fish and Wildlife Service, Department of the Interior, Ashland, OR	Ken Goddard; http://www.lab.fws.gov/
National Wildlife Health Center, Biological Research Division, US Geological Survey, Department of the Interior, Madison, WI	Leslie Dierauf; http://www.nwhc.usgs.gov/
National Wildlife Research Center, Wildlife Services, Animal and Plant Health Inspection Service, USDA, Fort Collins, CO	Margaret Wild; http://www.aphis.usda.gov/ws/nwrc/
Northeastern Research Center for Wildlife Diseases, Department of Pathobiology & Veterinary Science, University of Connecticut, Storrs, CT	Herbert J. Van Kruiningen; http://www.canr.uconn.edu/patho/
Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Department of Commerce, Seattle, WA	http://www.nwfsc.noaa.gov/
Patuxent Wildlife Research Center, US Geological Survey, Department of the Interior, Laurel, MD	http://www.pwrc.usgs.gov
Southeastern Cooperative Wildlife Disease Study, University of Georgia, Athens, GA	John Fischer; http://www.uga.edu/scwds/
Sybille Wildlife Research Facility & Conservation Education Unit, Wyoming Game and Fish, Wheatland, WY	http://gf.state.wy.us/admin/regional/sybille.asp
University of Georgia, College of Veterinary Medicine, Aquatic Health Research Program, Athens, GA	Harry Dickerson; http://www.vet.uga.edu/
Western Fisheries Research Center, US Geological Survey, Department of the Interior, Seattle, WA	http://wfrc.usgs.gov/
Wildlife Conservation Society, New York, NY	http://wcs.org/
Wildlife Health Center, University of California, Davis, Davis, CA	http://www.vetmed.ucdavis.edu/whc/wdp-rap.cfm

Appendix J

R29, R37, and T32 Grants Awarded to Colleges of Veterinary Medicine and Departments of Veterinary Sciences, FY 1993-FY 2003

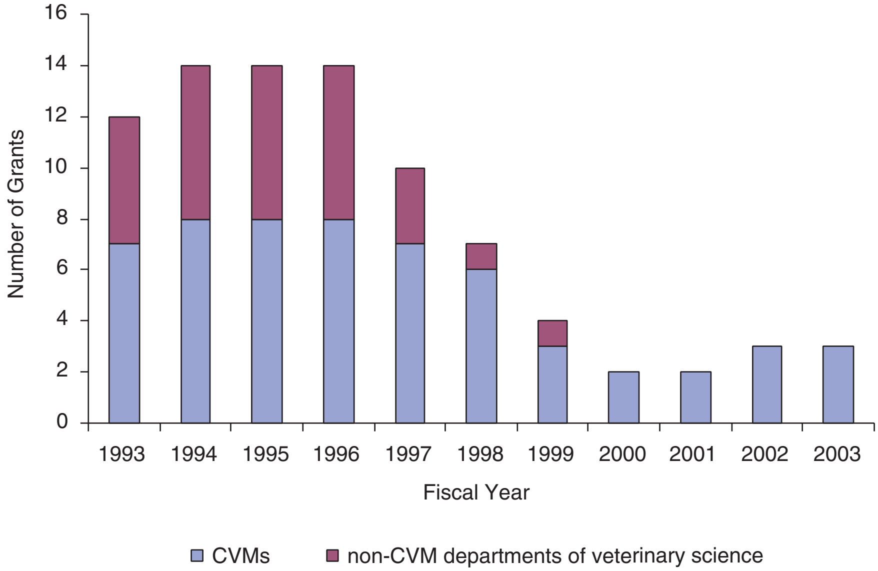
FIRST INDEPENDENT RESEARCH SUPPORT AND TRANSITION (R29) AWARDS

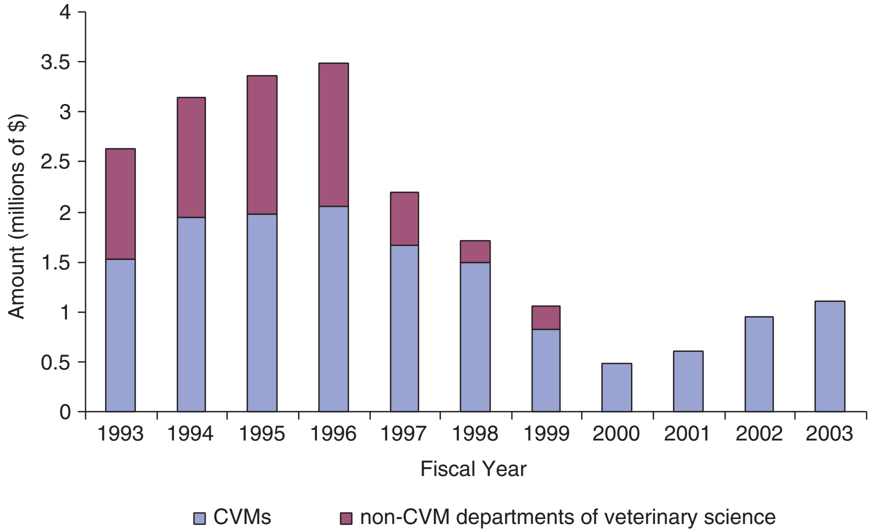




Number and total value of First Independent Research Support and Transition (R29) grants awarded by the National Institutes of Health to colleges of veterinary medicine and departments of veterinary science that are not affiliated with colleges of veterinary medicine.

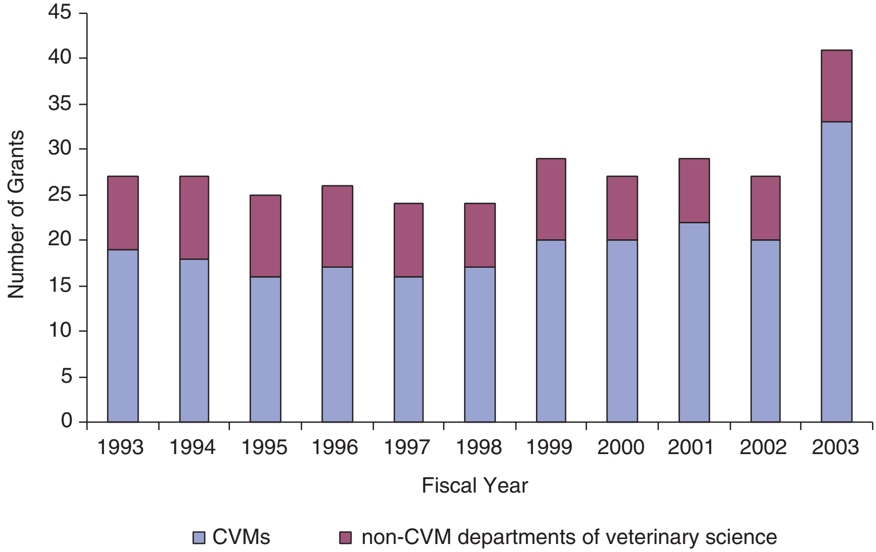
METHOD TO EXTEND RESEARCH IN TIME (R37) GRANTS

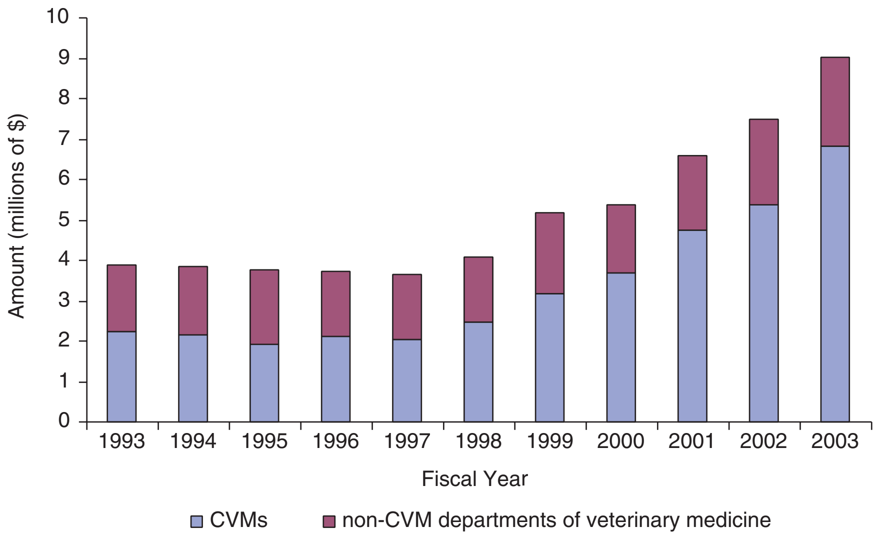




Number and total value of Method to Extend Research in Time (R37 MERIT) grants awarded by the National Institutes of Health to colleges of veterinary medicine and departments of veterinary science that are not affiliated with colleges of veterinary medicine.

INSTITUTIONAL NATIONAL RESEARCH SERVICE AWARD (T32)





Number and total value of Institutional National Research Service (T32) grants awarded by the National Institutes of Health to colleges of veterinary medicine and departments of veterinary science that are not affiliated with colleges of veterinary medicine.

Appendix K

Research Facilities of the USDA Agricultural Research Service and Its Partners

Location	Research Units	Relevant Research Project Areas
Auburn, AL	Aquatic Animal Health Research Laboratory	Health research for channel catfish, tilapia, and hybrid striped bass
Fayetteville, AR	Poultry Production and Product Safety Research Unit	Ascites, metabolic bone diseases, intestinal resistance to disease, antibiotic alternatives, and food safety in poultry
Stuttgart, AR[a]	Harry K. Dupree National Aquaculture Research Center	Health research for baitfish, catfish, and striped bass
Gainesville, FL[a]	Center for Medical, Agricultural, and Veterinary Entomology	Control methods for blood-sucking arthropods
Athens, GA[a]	Richard B Russell Research Center	Poultry meat and egg pre-harvest food safety, manure pathogen management, and antibiotic resistance
Athens, GA	Southeast Poultry Research Laboratory	Exotic and emerging viral diseases of poultry—avian influenza, Newcastle disease, avian metapneumovirus, enteric disease viruses, and Marek's disease
Ames, IA	National Animal Disease Center	Bacterial, viral, and prion diseases and food safety of livestock; food safety and bacterial diseases of turkeys
*West Lafayette, IN[a]	ARS Research Facility	Well-being of livestock and poultry
Beltsville, MD[a]	Henry A. Wallace Beltsville Agricultural Research Center	Parasites of livestock and poultry —control, immunology, and fhnctional genomics
East Lansing, MI	Avian Disease and Oncology Laboratory	Marek's and retroviral diseases of poultry
Mississippi State, MS[a]	ARS Research Facility	Mycoplasmosis of poultry
Clay Center, NE[a]	Roman L. Hruska U.S. Meat Animal Research Center	Food safety and respiratory viral pathogens of livestock
Orient Point, NY	Plum Island Animal Disease Center	Foot-and-mouth disease, vesicular stomatitis, and classical swine fever
College Station, TX[a]	Southern Plains Agricultural Research Center	Pre-harvest food safety of livestock and poultry
Kerrville, TX	Knipling-Bushland U.S. Livestock Insect Laboratory	Control of ticks and blood-feeding flies on livestock
Logan, UT[a]	Utah ARS Location	Effects of poison plants on livestock
Pullman, WA[a]	ARS Research Location	Protozoal and prion diseases of livestock and horses, malignant catarrhal fever, and lentiviruses

Number of Scientists	Number of Projects	Laboratory Area (ft^2)	Type of Facility
11	4	12,355	ARS
6	5	2,734	University
7	1	27,213	ARS
39.9	17	10,080	ARS
40.7	16	302,306	ARS
15	7	25,783	ARS
48	20	260,730	ARS
20	8	38,815	University
290	147	1,323.506	ARS
9	5	16,212	ARS
27.2	12	56,126	ARS
53	26	150,782	ARS
8.1	5	226,560	DHS
35.5	15	103,105	ARS
10	4	25,940	ARS
18.9	3	27,824	ARS
31.1	4	7,415	University

(continued on next page)

Location	Research Units	Relevant Research Project Areas
Leeto, WV[a]	National Center for Cool and Coldwater Aquaculture	Health research for salmon, rainbow trout, and chard
Laramie, WY	Arthropod-Borne Animal Disease Research Laboratory	Bluetongue, West Nile fever, and other arthropod-bome diseases of domestic livestock

[a]Animal health and protection account for only a portion of research projects at this location. The number of scientists, Current Research Information System projects, and facility space used for animal health and protection are less than the totals shown.

SOURCE: USDA 1999, http://www.ars.usda.gov.

Number of Scientists	Number of Projects	Laboratory Area (ft^2)	Type of Facility
Unknown	18	New	ARS
6	3	4,541	University

Appendix L

Issues and Concerns about Recruiting Students for Research Careers in Veterinary Science from the Association of American Veterinary Medical Colleges Symposium on Veterinary Graduate Education

The following points are excerpts from papers given at a symposium sponsored by the Association of American Veterinary Medical Colleges on The Future of Veterinary Graduate Education: Quality, Challenges and Opportunities. The papers are published in the 2005 issue of Journal of Veterinary Medical Education.

- Colleges of Veterinary Medicine (CVMs) do a poor job of recruiting students into veterinary research, as many of them are unaware that research is a career option. By the time students apply for entry into veterinary college, almost all of them are committed (or at least think they are committed) to careers in practice. Quoting Freeman (2005), "Although colleges of veterinary medicine are biomedical research institutions that contribute significantly to the national research effort, these endeavors are virtually invisible to constituencies outside of the profession. Only 11 to 24% of the general public is aware that veterinarians are employed in areas such as medical research, environmental protection, public health, and food safety. As a result, most applicants to veterinary school are more interested in the human-companion animal bond than either basic or applied research. Moreover, many pre-college students and undergraduates interested in scientific investigation do not even contemplate a career in veterinary medicine. In fact, a recent survey of the potential veterinary school applicant pool revealed not only that this group is poorly informed about careers in veterinary medicine beyond companion animal practice, but also that a subset of the students who choose not to apply to veterinary college are interested in research opportunities and environmental issues."

- CVMs have addressed the issue that clinical practice, especially small-animal (pet) practice, dominates the curriculum to the detriment of veterinary research.
- Visibility, excitement, role models, and mentoring for research careers are all deficient. Freeman described a number of programs aimed at addressing these issues, many of which seem successful and all of which can be adopted or adapted for application at many of the nation's CVMs.
- The best science in CVMs often is supported by agencies (such as the National Institutes of Health) whose main interest is human health, leaving veterinary students wondering how this excellent basic science contributes to animal health and therefore is related to their career aspirations.
- There are some welcome and appreciated opportunities for veterinary students to gain research experience, during both the summer months and the regular academic year, but they are too few and may fail to provide stipends sufficient to meet veterinary students' financial needs.
- The time and costs involved in obtaining adequate research training and experience after earning the veterinary degree seem to deter students from pursuing graduate education. There are too few sources of adequate support for combined PhD-DVM and post-DVM training.

Appendix M

Recommendations in the National Research Council Report *National Needs and Priorities for Veterinarians in Biomedical Research*[a] that Apply Broadly to Veterinary Research

- "Acquaint students with opportunities in comparative medicine throughout veterinary school."
- "Increase veterinary school recruitment of applicants with interest or experience in comparative medicine."
- "Effect change in veterinary school curriculums."
- "Address financial barriers to postgraduate training in comparative medicine."

[a]NRC, 2004a.

Appendix N

Examples of Funding Opportunities for Veterinary Research

Sponsor	Description
	General
Alpaca Research Foundation	Offers grants for alpaca research in four areas of emphasis, including: husbandry, health, genetics, and fiber
Alternatives Research and Development Foundation	Supports development of alternatives to use of animals in biomedical research, testing, and education
American College of Veterinary Internal Medicine Foundation	Supports studies related to diagnosis, treatment, and prevention of animal disease
American Veterinary Medical Foundation	Awards grants that meet its mission of "advancing the care of animals, with an emphasis on disaster preparedness and response"
Morris Animal Foundation	Supports research in canine, equine, feline, llama and alpaca, and wildlife and special species
National Association of Animal Breeders	Funds research in animal breeding and reproductive physiology with emphasis on artificial insemination; research interests include male fertility, genetics, sire health, female fertility, and market research
National Institutes of Health	Funds projects in veterinary science in animal models for reproduction, neuroscience, behavior, surgical techniques, blood substitutes, genetics of deformities, and pathogenesis; animal models for vaccines, drugs and diagnostics; research in animal care; sentinels for infectious diseases and environmental contaminants; and antibiotic resistance evolution

Sponsor	Description
National Science Foundation	Two divisions that are most relevant to veterinary research are the Division on Integrative Biology and Neuroscience and Division of Molecular and Cellular Biosciences in the Directorate for Biological Sciences; does not support research with disease-related goals or research on animal models for studying diseases or testing of drugs
Ohio Animal Health Foundation	Proposed research should contribute to improving or promoting health and general welfare of animal population.
Pharmaceutical Research and Manufacturers of America Foundation, Inc.	Offers financial support to people beginning their independent research careers at faculty level; research interests are in pharmaceuticals
Sandler Family Supporting Foundation	Mission of Sandler Program for Asthma Research is to develop important new pathways of investigation in basic research regarding asthma; program particularly encourages applications from investigators not currently studying asthma; innovation and risk are strongly encouraged
US Department of Agriculture	Has various funding programs that support research in animal growth, development, and nutrient utilization, and animal genome and genetic mechanisms
Whitaker Foundation	Research Grants program supports research projects that enable investigators to establish academic careers in biomedical engineering or closely related field
Small Animal Research	
American Animal Hospital Association Foundation	Funds practitioner-oriented research projects aimed at improving lives of companion animals through veterinary medicine; projects should be of immediate value to practicing veterinarian; project results, when published, should provide information that practitioners will find of use in dealing with patients; to degree possible, projects should use case material rather than laboratory or research animals
American Association of Feline Practitioners Academy of Feline Medicine	Offer research awards to persons doing meaningful research in feline medicine and/or surgery; awards are given for research whose application shows most clinical merit; strong preference will be given to noneuthanasia studies and to funding complete research projects, rather than partial funding of projects; this does not preclude matching funds; preference will be given to funding clinical studies of patients, rather than research animals
American College of Laboratory Animal Medicine Foundation	Funds research in laboratory animal science and medicine

Sponsor	Description
American Kennel Club Canine Health Foundation	Research interests include bloat, canine genetics, clinical research, cataracts, hip dysplasia, patellar luxation, and special studies; proposals addressing other diseases related to health of dogs are also encouraged
American Rabbit Breeders Association	Proposed research should benefit current needs for rabbit and cavy research in all phases of industry (commercial and fancy) and not single out any one or two breeds of rabbits or cavies
Association of Avian Veterinarians	Proposals should address conservations needs of wild avian populations
International Feline Foundation	Will provide single, competitively awarded grant for research on health and welfare of domestic cats; research topics considered include infectious disease and epidemiology, noninfectious diseases, genetic diseases, congenital disease, and control, prevention, or treatment of feline diseases and behavioral problems
Nestle Purina Company	Objective is to facilitate advancement of knowledge in canine and feline nutrition and health care; invasive research will not be considered
The Pet Care Trust	Supports research to improve understanding of environmental, humane, social, economic, and medical aspects of health, care, and possession of companion animals
Vaccine Associated Feline Sarcoma Task Force	Research goals are to facilitate investigations into epidemiology, etiopathogenesis, treatment, and prevention of soft tissue sarcomas in domestic cats occurring at sites of routine vaccinations and other injections
Veterinary Orthopedic Society	Funds studies in veterinary orthopedics.
Winn Feline Foundation	A nonprofit organization, affiliated with Cat Fanciers' Association, Inc., that supports research into medical problems affecting cats; studies of general scope are primarily encouraged, but foundation is interested in projects that address problems peculiar to individual breeds.
	Food Animal
American Association of Swine Veterinarians Foundation	Funds research with direct application to swine veterinary profession
National Mastitis Research Foundation	Supports research in subjects affecting udder and cow health and milk quality
National Pork Board	Solicits research proposals on pork production (environment and swine health) and pork products (quality, safety, and nutrition)
US Poultry & Egg Association	Funds research projects that benefit poultry and egg industry; proposed research projects should be designed to provide information that has potential to resolve real industry problems

Sponsor	Description
	Equine
American Horse Shows Association	Subjects of special concern to performance and show horses
American Quarter Horse Association	Supports research in equine infections, anemia, navicular syndrome, laminitis, glycogen storage disorders, and fertility in mares and stallions; also has matching funds program for research in specific horse health issues
Grayson-Jockey Club Research Foundation	Supports research relevant to equine cardiopulmonary disorders, infectious diseases, musculoskeletal disorders, and reproduction
US Equestrian Federation, Inc.	Solicits proposals of special concern to performance and show horses

Many of the funding sources listed above have limited resources so that they may offer small awards periodically.

SOURCE: Adapted from http://www.cvm.msu.edu/org/rgs/funding.