Protecting America's economy, environment, health, and security against invasive species requires a strong Federal Program in Systematic Biology

Situation Report on U.S. Systematic Biology

Federal Interagency Committee on Invasive Terrestrial Animals and Pathogens (ITAP)

Systematics Subcommittee

2008

Systematics is the science that identifies and groups organisms by understanding their origins, relationships, and distributions. It is fundamental to understanding life on earth, our crops, wildlife, and diseases, and provides the scientific foundation to recognize and manage invasive species. Protecting America's economy, environment, health, and security against invasive species requires a strong Federal program in systematic biology.

Systematics is in crisis. As systematists retire, they are not replaced, and universities train too few professionals in systematics. Furthermore, the biological collections needed to support systematics languish in substandard facilities lacking adequate staffing, technology, and coordination. As a result of this inadequate support, the U.S. cannot effectively manage the threat posed by invasive species.

The purpose of this report is to increase awareness of the crisis in systematics and to advocate the need for a permanent, viable, and coordinated Federal Systematics Program. Systematics expertise and use is distributed across the Federal sector so participation will be inclusive; no single agency can serve as the steward for the proposed Systematics Program. The proposed Systematics Program requires four components: research, specimen-based collections, an informatics network, and educating future systematists. These are collectively designed to provide the means to detect, identify, and predict the behavior and consequences of invasive species.

In working toward its mandate to limit damages from invasive species, the Systematics Subcommittee (SSC) of the Federal Interagency Committee on Invasive Terrestrial Animals and Pathogens (ITAP) has a 20-year vision:

"Strengthen national and global systematics to predict, prevent, and manage invasive species to ensure biosecurity; public health; economic, environmental, and agricultural security; and sustainability."

When achieved, the U.S. will have:

- Systematics expertise covering all groups of organisms.
- An effective communication network linking Federal, academic, and international taxonomic resources.
- A web-based information system that integrates organismal biology, geography, and taxonomy with diagnostic keys and specimen data.
- Adequate human and physical resources to manage Federal systematics collections.
- A reinvigorated capacity and commitment by universities to prepare professionals in systematics.
- A culture that values systematics and sustains its systematics resources.

The SSC will conduct a comprehensive survey of Federal agencies to determine the agencies' present and future needs as well as their capacity to promote research, collections, and information resources. Based on these findings, the committee will develop a 10-year plan for an enhanced, integrated Systematics Program. Phased in over ten years, an enhanced Federal Systematics Program will better counter national security threats posed by invasive species, foster a new generation of systematic biologists, and establish contingencies for continuing operations in case of emergency or catastrophic loss. An interagency body will monitor the Program's progress.

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Opposite page: Systematics and the ability to accurately identify the earth's biota are essential for developing effective conservation strategies. Belle Isle, Virginia. Photo: Marsha Sitnik, SI, NMNH.

Protecting America's Economy, Environment, Health, and Security against Invasive Species Requires a Strong Federal Program in Systematic Biology

Systematics is the science that identifies and groups organisms by understanding their origins, relationships, and distributions. It is fundamental to understanding life on earth, our crops, wildlife, and diseases, and provides the scientific foundation to recognize and manage invasive species. Protecting America's economy, environment, health, and security against invasive species requires a strong Federal program in systematic biology.

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INVASIVE SPECIES: A GROWING THREAT

Invasive species pose an ongoing and ever-increasing threat to our Nation in a number of critical areas:

Anoplophora chinensis on *Citrus* in Japan. This long-horn beetle has recently been intercepted at various ports of entry to the United States. Photo: S.Lingafelter, USDA, ARS, SEL

Biosecurity: Invasive species introduced intentionally and maliciously threaten our biosecurity. Terrorists could release deadly pathogens with local, regional, or global consequences. As a first line of defense, an active community of systematists is critical to provide rapid identification and characterization of disease agents. This is essential to respond effectively and timely to biosecurity threats.

Human and Animal Health: Invasive species threaten human and animal health, yet scientists know little about their potential to harm humans. Zoonotic pathogens that can move from animals to humans include West Nile virus, avian influenza, hantaviruses, and many parasites in our food (Orlandi *et al.*, 2002).

Agricultural Security and Trade: Potentially crippling economic consequences result when unexpected pathogens or parasites compromise U.S. agricultural supplies, security, or trade. The total cost of invasive weeds alone to the U.S. economy, through reductions of crop yields and control expenditures, is

Cultures of a destructive mold called *Phomopsis*-strains that infect both crop and non-crop plants. Photo: Scott Bauer, USDA, ARS.

INVASIVE SPECIES

Invasive species are plants, animals, and microorganisms whose introduction or spread threatens human and animal health, agricultural and environmental security, or the economy.

EXAMPLES

Plants - tamarisk, yellow star thistle

Fungi - chestnut blight, Dutch elm disease, soybean rust, sudden oak death

Insects - cactus moth, emerald ash borer, gypsy moth, Asian long-horned beetle, Mediterranean fruit fly, cockroaches

Amphibians - coqui frogs in Hawaii and Florida

Mammals - nutria, pigs, rats, invasive deer

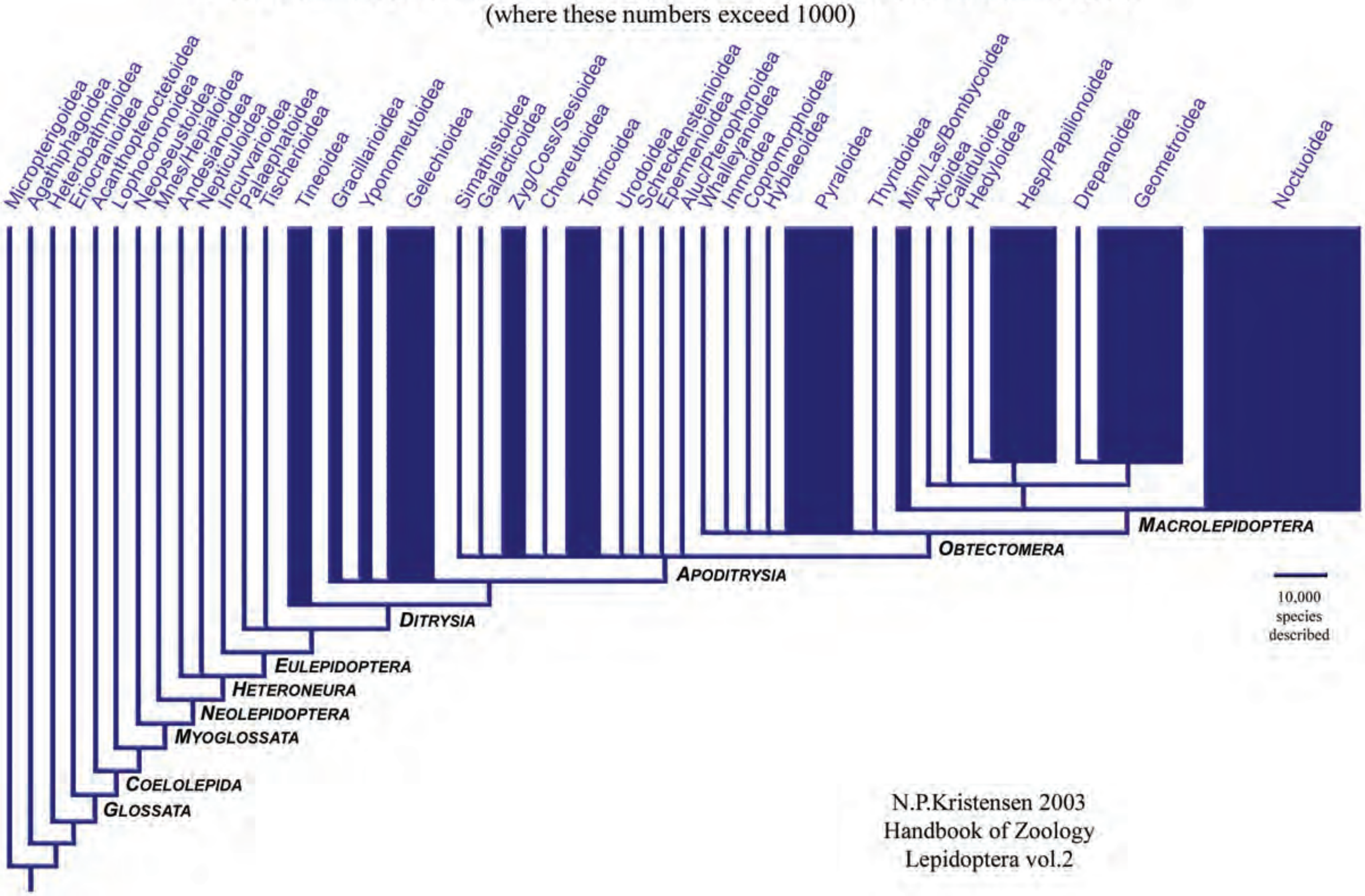
Birds - starlings, English sparrows, pigeons about $27 billion annually (Pimentel *et al.*, 1997, 2005). The difficulty in identifying these elusive agents exacerbates damage to U.S. and foreign agricultural products.

Environmental Security: Invasive species are one of the leading causes of species extinction, second only to habitat destruction. (Pimentel, *et al*., 2000; Gurevitch and Padilla, 2004) Invasive plants, fungi, and animals infest more than 100 million acres spanning all 50 states, and have contributed to the decline of 49% of U.S. endangered and threatened species (Wilcove *et al.*, 1998).

Economic Health: The estimated economic impact of invasive animals, pests, and pathogens in the U.S. is $120 billion in annual losses (Pimentel *et al.*, 2005). Invasive species are an economic drain on capital that otherwise would be available to sustain a healthy global economy. Newly invading pathogens and pests that evade or surpass our capacity to control them result in additional costs of $33-50 billion annually in the U.S. alone (Palumbi, 2001).

Taken together, the actual and potential damage of invasive organisms to human health, agriculture, animal production systems, the natural environment, and the economy is enormous and cannot be ignored. Moreover, the threat of such invasive species will only increase with the globalization of agriculture and global climate changes, which increase the ranges of hosts and parasites, allowing them to rapidly adapt to new environments, hybridize with native species, and escape control measures (Palumbi, 2001).

Phylogeny of extant lepidopteran superfamilies.
Width of extant superfamily lines indicate approximate numbers of described extant species
(where these numbers exceed 1000)



N.P.Kristensen 2003
Handbook of Zoology
Lepidoptera vol.2

SYSTEMATICS AS A SOLUTION

To confront this growing crisis, it is necessary to develop an increased understanding of the diversity and distribution of invasive species. This can be done by increasing our capacity in systematics. Systematics provides the foundation of knowledge essential for recognizing and managing invasive species in natural and agricultural ecosystems. Case studies in which systematic biology has solved problems in each of the above areas are presented in Appendix I.

Systematics, or the scientific study of biological diversity, provides a cornerstone for the agricultural, biological, and environmental security of the U.S. by providing accurate detection and identification of invasive pests, parasites, and pathogens along with knowledge of their origins and movements. Systematic biologists can predict the behavior and provide accurate detection and identification of new pests, pathogens, and parasites; distinguish invasive organisms from morphologically identical native species; create the biological reference collections needed to recognize invasive species (Ruedas, *et al.*); establish a systematics information network; train future systematists; educate the public and other scientists about invasive species; and contribute knowledge needed to develop control strategies to manage outbreaks of invasive species.

However, there is currently a crisis in systematics worldwide and in the U.S. due in part to inadequate support for systematics at the Federal level. Many insects, fungi, and parasites that cause diseases remain unknown and uncharacterized. Even the most basic biological information needed to understand the diversity and distribution of invasive species is often not available. Moreover, too few systematic biologists are available to characterize biodiversity to confront the growth of invasive species. As scientists retire, they are not replaced; thus the problem intensifies. (Erwin, T.L. 1988; Wilson, E.O. 1992)

U.S. science and society would benefit greatly from increased systematics resources. Strategic Federal investments in systematics research and communication promise to significantly enhance the Nation's ability to resolve agricultural trade issues, preserve the environment, and respond to the urgent and growing threats to its biosecurity**.** With greater resources, systematists can take advantage of technological developments to make great advancements in systematics knowledge. Using databases with enormous storage capacity and advances from the telecommunications revolution, systematists can develop an improved understanding of morphological and molecular data and elucidate the population genetics and genomics of invasive species. This will lead to the development of more cost-effective methods of identification, and result in quicker response times relative to the management of new invasive species.

SYSTEMATICS INTEGRATES THE FOLLOWING SCIENTIFIC DISCIPLINES:

Taxonomy: discovering, describing, and naming new species.
Phylogeny: elucidating relationships among organisms.
Classification: naming groups of species according to their relationships.
Biogeography: mapping geographical distributions of species in evolutionary and ecological time.
Biodiversity Informatics: integrating, interpreting, and disseminating information.
Phylogeography: examining relationships and global distribution within and among species.
Population Genetics: defining genetic relationships among populations within a species.
Landscape Genetics: assessing population structure across the landscape.

Opposite page: Phylogenetic tree of the Lepidoptera, moths and butterflies, showing relationships between families.
Image: Don Davis, SI, NMNH.

Steve O’Neil, mason at the Castillo de San Marcos National Monument, measuring vegetation regrowth after treatment with vegetation control agent. Photo: Judy Bischoff, U.S.Fish and Wildlife Service (former NPS).

Smithsonian scientist Richard Vari works with intern student at the National Museum of Natural History. Photo: Mary Sangrey, SI, NMNH.

Specimens and information databases of the National Parasite Collection are a unique and irreplaceable resource for parasite research. Zoologist Eric Hoberg examines a specimen. Photo: Peggy Greb, USDA, ARS.

DEVELOPMENT OF A COMPREHENSIVE SYSTEMATICS PROGRAM ACROSS THE FEDERAL GOVERNMENT

To meet the growing invasive species challenge, there is an urgent need to build the infrastructure for a comprehensive systematics program across the Federal government. This need has been recognized at the highest levels of the Federal government through the White House's Office of Science and Technology Policy (Marburger, 2005).

In response to this need, the Federal Interagency Committee on Invasive Terrestrial Animals and Pathogens (ITAP) has formed the Systematics Subcommittee (SSC) to strengthen the Federal Systematics Program. This will consist of coherent and coordinated programs across Federal systematics laboratories and facilities, coordinated plans for formulation and implementation of budgets, and effective lines of communication on all aspects of the Program.

MISSION, GOAL, AND OBJECTIVES OF SYSTEMATICS SUBCOMMITTEE

In response to the threat of invasive species, the SSC has identified the following 20-year mission, goal, and objectives:

Mission:

Strengthen national and global systematics to predict, prevent, and manage invasive species to ensure biosecurity; public health; economic, environmental and agricultural security; and sustainability.

Goal:

Catalyze efforts to improve and expand systematics resources and capabilities.

Objectives:

- Advocate the need for permanent, viable, and coordinated programs for systematics embracing research, collections, and bioinformatics.
- Obtain resources to ensure an effective Federal campaign against invasive species.
- Build systematics expertise, biological informatics, and specimen collections to provide accurate information and knowledge of biology, life history, and geographic distribution of organisms.
- Link Federal, academic, national, and international systematic knowledge in a web-based network that integrates information systems, interactive keys, and comprehensive specimen data. Plan and implement contingencies to ensure critical systematics information and services in the event governmental functions are abruptly interrupted.
- Reinvigorate university and government agency commitment to prepare professionals in systematics and provide them with viable careers.

This report's purpose is to increase awareness of the crisis in systematics and to advocate the need for a permanent, viable, and coordinated Federal systematics program. No single agency can serve as the steward for the Systematics Programs in the Federal sector. Thus, this report refers to "systematics program components" within each agency, and the entire Federal systematics effort is regarded as the Program.

Opposite page: Museum specialists capturing collection's data. Photo: K.Darrow, SI, NMNH.

COMPONENTS OF THE FEDERAL SYSTEMATICS PROGRAM

By strengthening and increasing the Nation's systematics resources into a comprehensive program, the U.S. can work to prevent and respond to emerging threats from invasive species. The proposed Federal Systematics Program requires four components, collectively designed to provide the means to detect, identify, and predict the behavior and consequences of invasive species. These components should include research, specimen-based collections, an informatics network, and educating future systematists. These will lead to the establishment of informed Federal priorities and the creation of viable career paths to maintain a foundation in Federal systematics.

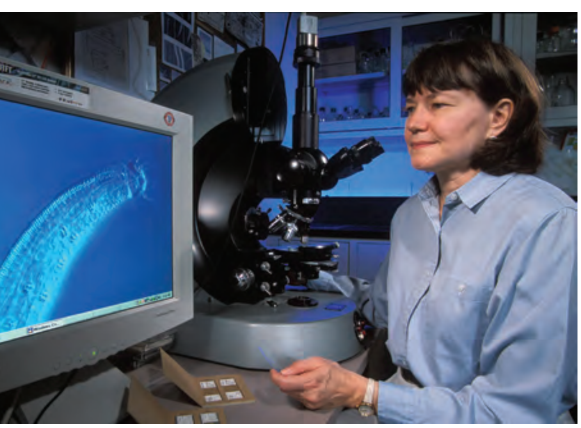
Conduct Systematics Research to Provide Critical Information

The Federal Systematics Program will require an increased number of systematic biologists.

Their research into the discovery, description, and identification of biological diversity provides the knowledge base to manage threats posed by invasive species and bioterrorism. U.S. systematists' research will:

Mycologist Lisa Castlebury extracts DNA from rust spores to determine whether specimens of daylily rust from different geographic locations belong to the same species. Photo: Stephen Ausmus. USDA, ARS.

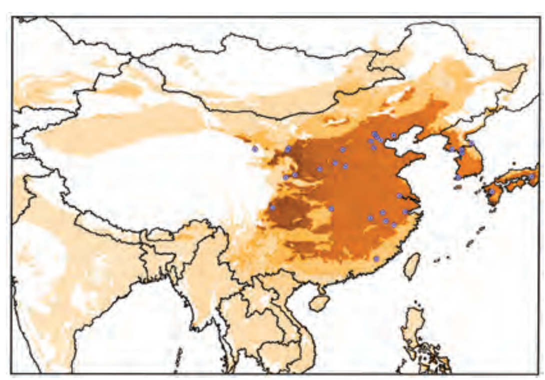
Develop new methods to identify species rapidly: With the development of new, rapid identification methods, scientists will be able to discover and characterize previously unknown species; develop comprehensive accounts with descriptions and illustrations of each species; and enable port, emergency, and regulatory personnel to rapidly and accurately identify invasive species and respond quickly to urgent situations.



Using a high-powered compound microscope, plant pathologist Lynn Carta examines the head and neck of a nematode. Photo: Peggy Greb. USDA, ARS.

Reveal and interpret relationships among species to predict ways that species might benefit humans and the economy: An improved understanding of relationships among species will facilitate the discovery of new treatments or cures for diseases, the discovery of new biological agents to control weeds and plant and animal diseases, and increase genetic resources available to improve crop quality and production.

Predict biological responses to environmental disturbances: By predicting the behavior of pests, parasites, and pathogens in new environmental settings and hosts, systematists can provide the knowledge needed for regulators to make science-based decisions.



Distribution map of the longhorn beetle in China provides data to predict its spread in the US and Canada. Image: USDA, ARS.

ACTIONS TO BUILD A BETTER FUTURE

Increasing the Federal capacity in systematics is an urgent action to deal with the invasive species threat. This needs to be done in the next 10 years, by:

- increasing the number of systematic biologists;
- properly housing and curating existing and new biological collections;
- increasing knowledge sharing; and
- improving future systematics' education.

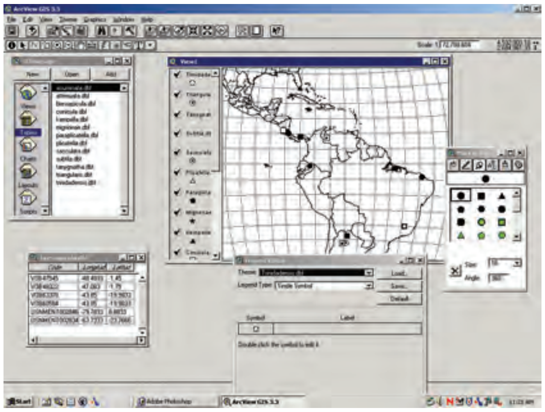
BUILD SPECIMEN-BASED COLLECTIONS TO SUPPORT SYSTEMATICS RESEARCH

Collections serve as the basis for biology and systematics and provide the core for biological information systems. Acquired over the past 250 years, specimen collections provide historical baselines to document global diversity, climate change, and disturbed ecosystems. Collections contain information on the wealth of biodiversity regionally and globally, documenting knowledge about organisms such as their morphological and genetic attributes, molecular sequences, and geographic and host distributions (Fanning, *et al.* 2002).

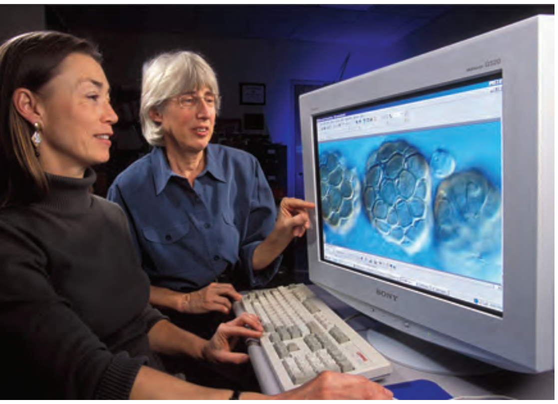
A healthy, productive stand of wheat in California. Photo: Stephen Ausmus, USDA, ARS.

COLLECTIONS DATA OPENS WHEAT MARKET TO CHINA

The market for wheat from California to China was closed due to the report of a prohibited pathogen. Specimens in a well-curated collection disproved this assertion, thereby permitting $8 million annual sales of wheat to China.



Accurate identification is required to manage invasive species and depends heavily on the existence of well-curated collections of biological specimens. A strategy to improve and enhance collections over the long term requires increased curation and electronic data management (e.g., Pennisi, 2000; Sugden and Pennisi, 2000), as well as surveys, inventories, and ecosystem monitoring to expand the collections. The enhanced Federal Systematics Program will provide the resources and scientific expertise needed to ensure that specimens are accurately identified and that the backlog of unidentified material is curated and available for scientific research. Biological collections should:



Mycologists Mary Palm (left) and Amy Rossman discuss the identification of a rust fungus. Photo: Peggy Greb, USDA, ARS.

Be housed in adequate facilities that meet physical specifications and are protected from environmental damage, fire, and weather.

Increase as specimens are acquired through systematics research, survey, and inventories.

Be managed by trained personnel to meet the needs of in-house researchers and visiting scientists.

Be digitized to provide researchers access to collections while limiting damage from use.

Serve as frozen-tissue, living cultures, and voucher specimen repositories to support molecular research.

Be linked electronically to incorporate collections at USDA, DOI, SI, other Federal agencies, museums, universities, and state organizations.

Museum Specialist organizes DNA samples in the cryogenic tank. Photo: Donald Hurlbert, SI, NMNH.

Summer intern studies a skull specimen at the National Museum of Natural History. Photo: M.Sangry, SI, NMNH.

Develop a Biodiversity Informatics Network to Serve a Diverse Community

Opposite page: Graph of specimen distribution. Image: Don R. Davis, SI, NMNH.

To meet increasing demands for facts about invasive species, biological collections data should be computerized in online databases. Organized, interpreted, and disseminated on the Internet, systematics information can meet the need for knowledge to prevent the introduction and respond to invasive species. Federal systematists will require additional personnel, financial support, and institutional commitment to provide informatics and databases needed for modern collections.

Components of a biodiversity informatics network should provide:

- Descriptions and illustrations of invasive species with keys for their identification
- Inventories of specimens
- Comprehensive species lists
- Valid taxonomic lists such as currently exist for some groups of organisms in ITIS (Integrated Taxonomic Information System)
- Summaries of phylogenetically diagnostic characters
- Summaries of biogeographical and ecological information
- Comprehensive morphological, molecular, and genomic data such as available in GenBank for molecular data.
- Integrated databases for biological, ecological, behavioral, host, and geographic information about existing and potential invasive species
- Integrated databases for morbidity and mortality linked to invasive animal and plant pathogens
- Web-based home pages for species, including information about global diversity of invasive species

The Encyclopedia of Life (EOL) project promises to develop a page per species. Courtesy: Encyclopedia of Life Webmaster.

Educate Future Generations of Systematists

A long-term partnership between the Federal sector, private sector, and academic institutions will be necessary to provide for a future generation of systematic biologists. Strategic plans for Federal systematics programs should provide means to attract students early in their career and equip them with the training to master modern approaches to systematics. Incentives and rewards, including the availability of a range of employment opportunities upon graduation, can help ensure that the best students enter fields that resolve significant problems to science and society.

These students will require extensive training; they will benefit from enthusiastic mentors to guide their career development and help them attain the firm foundation in biology, ecology, and evolutionary theory to be successful in systematics.

A new model to support and expand education will:

- Encourage the academic sector to revitalize educational programs in systematics.
- Establish lines of collaboration across Federal, private, and academic sectors to explore priorities and needs for systematics knowledge.
- Fund graduate, doctoral, and postdoctoral internships at Federal facilities to train new systematic biologists to fill specific gaps in expertise.
- Expand scholarships to advanced students in systematics.
- Develop specific programs leading to the education of professionals at all levels.

MCSE student in his laboratory at the National Museum of Natural History, SI works on his PhD dissertation. Photo: Jeff Costa, SI, NMNH.

A MODEL FOR EDUCATING SYSTEMATISTS

The Smithsonian Institution in partnership with the ARS Systematic Entomology Laboratory trains new insect systematists at the University of Maryland Center for Systematic Entomology (MSCE) through a consortium arrangement.

ACTION PLAN

Immediate action and a change in current practices are required to strengthen and increase systematics resources into a comprehensive program so the Nation can respond adequately to emerging threats to our agricultural and environmental security. SSC will conduct a comprehensive survey of Federal agencies to determine the agencies' present and future needs as well as their capacity to promote research, collections, and information resources. Based on these findings, the committee will develop a 10-year plan for an enhanced, integrated Federal Systematics Program. An interagency body will monitor the Program's progress.

A Federal Systematics Program will involve several departments with agencies that provide or need systematics knowledge, including the Department of Agriculture (USDA), Department of the Interior (DOI), Smithsonian Institution (SI) (see Appendix II), as well as the Centers for Disease Control and Prevention (CDC), National Institutes of Health (NIH), Department of Commerce (DOC), Department of Defense (DOD), the Department of Homeland Security (DHS), and Department of State (DOS). Each agency varies in how it develops and/or applies systematics information, according to its particular mandate.

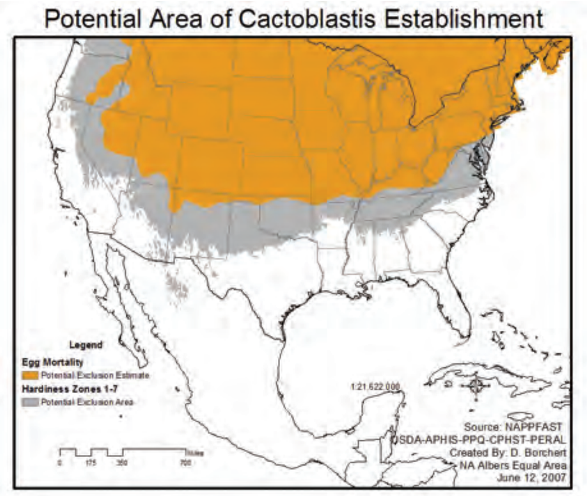
Conduct Survey to Assess Systematics Capacity

A survey of Federal agencies will be used to determine the agencies' present and future needs for human, fiscal, and capital resources as well as their capacity to promote research, collections, and information resources. To this end, a data call has been developed to solicit information from a broad array of Federal users and providers of systematics information. This survey (see Appendix III) will be used to determine respective levels of involvement in systematics and assess agencies' current and future capacity for research, collections, and information resources within an integrated national infrastructure. With the additional perspectives of decision-makers across the Federal arena, the SSC's current understanding of the invasive species crisis will be improved, and the committee will be better prepared to develop a 10-year Federal Systematics Program.

Develop a 10-year Plan for an Enhanced Federal Systematics Program

Based on the survey's findings, a 10-year plan for an enhanced, integrated Federal Systematics Program delineating actions and budget estimates for consideration by agency and decision makers will be developed. The Program's purpose is to enhance both the agencies that provide systematic knowledge as well as those using systematics. When this Program is achieved, we will have:

- Systematics expertise covering all groups of organisms.
- An effective communication network linking Federal, academic, and international taxonomic resources.
- A web-based information system that integrates organismal biology, geography, and taxonomy with diagnostic keys and specimen data.
- Adequate human and physical resources to manage Federal systematics collections.
- A reinvigorated capacity and commitment by universities to prepare professionals in systematics.
- A culture that values and sustains its systematics resources.



Distribution map of *Cactoblastis cactorum*.
Image: D.Bouchet, USDA, ARS.

What will the implementation of the advanced Federal program mean for invasive species work? We will be able to:

- Mitigate agricultural trade disruptions such as allegations that the U.S. exports invasive species
- Provide the means to detect and identify threatening, invasive species.
- Differentiate invasive pests and pathogens from those native to the U.S.
- Determine biological agents that may be useful in controlling invasive species.
- Predict how invasive species will behave in new hosts and environments.
- Assess the potential for and effects of hybridization among native and invasive species.
- Provide knowledge to determine control measures most effective to manage invasives.

Create Interagency Body to Monitor Progress of Program

To monitor the Program's progress in achieving these goals, an interagency body, the Systematics Interagency Coordinating Group, should be created. Agencies that provide or use systematics services should participate and name an official representative to the Group. The Group will be chaired by a representative from the Department of Agriculture, the Smithsonian Institution, or the Department of the Interior on a rotating basis. The Group will be responsible for submitting an annual report (by fiscal year) on the progress of agencies relative to the development of the Federal Systematics Program as well as on aspects of coordination of systematics among intra-agency, inter-agency, and international resources. The report will be submitted to all agency directors and the White House by December 1st of each year. It will publish findings on the success or failure of agencies responsible for implementing the enhancements of their systematics program components in a timely manner, and will identify problems, challenges, and opportunities to enhance the Program. The Group should also make specific recommendations to the agencies to resolve or clarify any issues raised in the findings.

Conclusion

We have a crisis. There is a solution. To effectively confront invasive species, the U.S. requires a strong systematics infrastructure. Phased in over ten years, an enhanced Federal Systematics Program will better counter national security threats posed by invasive species, foster a new generation of systematic biologists, and establish contingencies for continuing operations in case of emergency or catastrophic loss.

GLOSSARY

Bioinformatics - Knowledge derived from computer analysis of biological data

Biosecurity - The protection of the economy, environment, and health of living things from diseases, pests, and bioterrorism.

Bioterrorism - Terrorism using biological agents.

Genomic - Pertaining to the genome, all of the genetic information possessed by any organism.

Interactive keys - An interactive computer program in which the user enters characteristics of the specimen in order to determine its identity.

Invasive species - Plants, animals, and microorganisms whose introduction or spread threatens human and animal health, agricultural and environmental security, or the economy.

Morphology - The study of the form or structure of an organisms.

Pathogens - Organisms that cause diseases.

Systematics - The field of science dealing with the diversity of life and the relationships of life's component organisms.

Zoonotic - A disease that can be transmitted from animals to people or, more specifically, a disease that normally exists in animals but that can infect humans.

Cultural landscape field of grain rotation in May 2006, Antietam National Battlefield. Photo: Carol DiSalvo, NPS, IPM.

Biosecurity

Invasive species entering the U.S. via traditional trade or the smuggling of agricultural products are a constant threat.

Human and Animal Health

The role of migratory birds in the dissemination and transmission of viral and bacterial pathogens requires detailed examination. Photo: Robert Fleischer, SI, NMNH/NZP.

Agricultural Security and Food

Grains are tested before being allowed into the United States. Photo: J. Tourtellote, U.S. Customs and Border Protection.

Environmental Security

Africanized bees threaten populations of honey bees in the United States. Photo: G. Nino, U.S. Customs and Border Protection.

Documenting the Crisis: Invasive Species Case Studies

Invasive species threaten the U.S. in four interconnected areas:

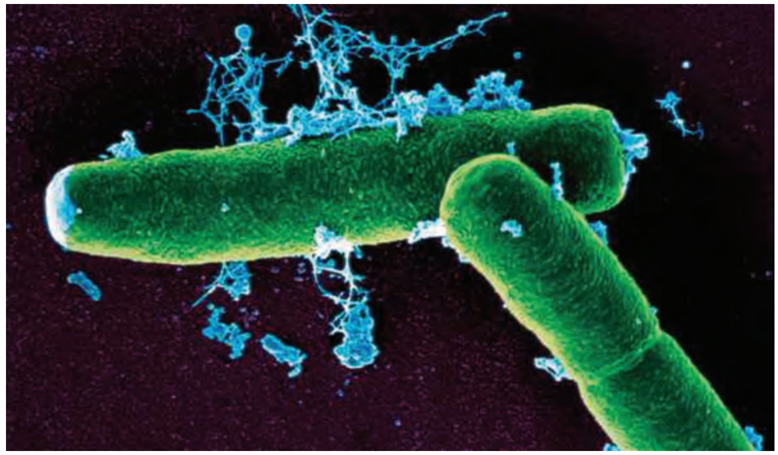
- **Biosecurity**
- **Human and Animal Health**
- **Agricultural Security and Food**
- **Environmental Security**

What follows are case studies illustrating ways in which systematic knowledge has contributed to solving problems in each of these areas.

Biosecurity

Invasive species entering the U.S. via traditional trade or the smuggling of agricultural products are a constant threat, but those introduced intentionally and maliciously also threaten our biosecurity. Terrorists could release deadly pathogens, including the causative agents of anthrax, brucellosis, plague, tularemia, and smallpox, with local, regional, and/or global consequences. While the threat is ill-defined, the risk from these agents is high. Such releases are infrequent, but the potential exists.

As a first line of defense against these pathogens, an active community of microbiological systematists is critical to providing the basis for rapid identification and characterization of disease agents. These systematists, using comparative genomics, will develop sequence data to determine the source and locality of origin for weaponized strains of pathogens. Developing such an in-depth knowledge of the pathogens is essential to responding effectively and in a timely manner to biosecurity threats.



Anthrax causing bacteria, *Bacillus anthracis*, shown at high magnification.
Photo: Centers for Disease Control & Prevention.

Anthrax—Rapid Response to an Emergency:

"Was it organized terrorism or just a madman with a grudge? Where did the attacker get the bugs? And how do you protect against anthrax anyway" (Enserink, 2001a). These are among the questions posed and answered by systematics. Assaults in 2001 were the first test of the Nation's capacity to deal with bioterrorism, and served to focus our cumulative knowledge of anthrax through an explosive expansion of research and development of new information. To respond effectively to the situation, it was crucial to have a thorough knowledge of the systematics and pathogen-genetics of *Bacillus anthracis* as well as the ability to identify strains based on the evolutionary history of these bacteria modified as bioweapons. The results of studies ".... demonstrate that genome-based analysis of microbial pathogens will provide a powerful new tool for investigation of infectious disease outbreaks" (Read *et al.,* 2002). On a more pragmatic level, there was also a need to rapidly identify the humans and animals that were infected and to address the challenges posed by a potential large-scale event (Enserink, 2001b).

Human and Animal Health

The following agents are recognized as emerging infectious diseases (Bengis *et al.*, 2004; Council for Agricultural Science and Technology (CAST), 2005):

West Nile virus (WNV)
Monkeypox
Highly Pathogenic Avian Influenza (HPAI)
Highly Pathogenic Avian Influenza (H5N1)
Lyme Disease

Systematics provides information crucial to forecasting the circumstances most conducive to epidemics. Surveillance programs for invasive pathogens should focus on the interface between managed and agricultural ecosystems where wildlife, domestic animals, and humans come into frequent contact. For example, the role of migratory birds in the dissemination and transmission of viral and bacterial pathogens requires detailed examination (Liu *et al.*, 2005). Veterinarians, zoologists, epidemiologists, physicians, and pathologists must collectively prioritize "organisms of concern" and manage them based on their systematics, ecology, epidemiology, and potential for rapid evolutionary change. Collections as baselines and sound field-based research and surveillance systems serve to document the distributions of pathogens and their associated diseases (Kuiken *et al.*, 2005).

West Nile Virus (WNV):

Emergence of WNV in New York was rapid and unexpected in 1999. Previously unknown in the Western Hemisphere, WNV has swept across the continent, decimated bird populations, and posed serious threats to human health. Systematists have an incomplete understanding of how transmission from birds to humans typically occurs and which mosquito vectors are most responsible for viral dissemination. Investigators at the Smithsonian and the Centers for Disease Control and Prevention evaluated whether migratory birds introduce, amplify, or disseminate WNV, and they developed a successful model for predicting disease outbreaks (Rappole *et al.*, 2000; Rappole and Hubálek, 2003). Working in collaboration, the National Zoological Park, U.S. Fish and Wildlife Service, Biological Resources Division of the U.S. Geological Survey, and the Hawaii Department of Agriculture are developing management plans for WNV. These strategies are aimed at preventing the spread of the virus to native host populations in Hawaii and Guam.

Mosquitoes transmit the West Nile Virus through their saliva. Photo: James Gathany, Centers for Disease Control & Prevention.

A Monkeypox Outbreak: Sharing Pathogens on the North American Great Plains

Monkeypox virus, a relative of smallpox endemic to Central Africa and infecting primates, rodents, and rabbits, has a 10% mortality rate for human infections; a natural reservoir host is unknown. The disease emerged in pet prairie dogs and humans in the Midwestern U.S. during 2003, and systematics and comparative molecular investigations rapidly implicated imported Gambian Pouched Rats as the epidemic's cause. A cycle for transmission was broken and establishment of the virus in North America was halted. Monkeypox would have posed serious health risks to wild and domesticated animals and humans if left unchecked (Enserink, 2003). Additionally, taeniid tapeworms of African origin, yet another zoonotic parasite, were also discovered in these Gambian Pouched Rats, illustrating the need to screen for multiple pathogens in invasive wild hosts introduced into the U.S.

Highly Pathogenic Avian Influenza (HPAI)—the Next Global Pandemic?

During the past five years, different strains of the HPAI virus have led to the death or culling of over 200 million birds globally, and represents a major emergence of these avian pathogens (CAST, 2005; Enserink, 2005). Among these, the H5N1 strain infecting both mammals and birds has devastated the Asian poultry industry, and has moved to humans where it threatens to lead to an influenza pandemic (Enserink and Buckheit, 2005; Normile, 2005). Molecular systematics has figured prominently as the basis for rapid diagnostics of HPAI and will be fundamental to understanding rapid evolutionary changes related to virulence in these pathogens. Dissemination from Asia may involve poultry, wild migratory birds, or in rare events birds smuggled from endemic regions, and represents a considerable concern for public health globally (Liu et al., 2005: Webby and Webster, 2003). Recent studies have further indicated reason for concern, as it has become apparent that the basis for the 1918 global pandemic was an avian virus that mutated and was able to directly infect and spread among humans (Holmes, 2004).

H5N1 Avian Influenza in the Western Hemisphere

The spread of highly pathogenic H5N1 avian influenza into Asia, Europe, and Africa has resulted in enormous impacts on the poultry industry and presents an important threat to human health. The pathways by which the virus has and will spread between countries have been debated extensively, but have yet to be analyzed comprehensively and quantitatively. We integrated data on phylogenetic relationships of virus isolates, migratory bird movements, and trade in poultry and wild birds to determine the pathway for 52 individual introduction events into countries and predict future spread. Kilpatrick, et al. (2006) show that 9 of 21 of H5N1 introductions to countries in Asia were most likely through poultry, and 3 of 21 were most likely through migrating birds. In contrast, spread to most (20/23) countries in Europe was most likely through migratory birds. Spread in Africa was likely partly by poultry (2/8 introductions) and partly by migrating birds (3/8). Our analyses predict that H5N1 is more likely to be introduced into the Western Hemisphere through infected poultry and into the mainland United States by subsequent movement of migrating birds from neighboring countries, rather than from eastern Siberia. These results highlight the potential synergism between trade and wild animal movement in the emergence and pandemic spread of pathogens and demonstrate the value of predictive models for disease control.

Opposite page: Monitoring wild bird populations for different strains of HPAI virus helps scientist to follow the dissemination patterns throughout the world. Photo: Robert Fleischer, SI, NMNH/NZP.

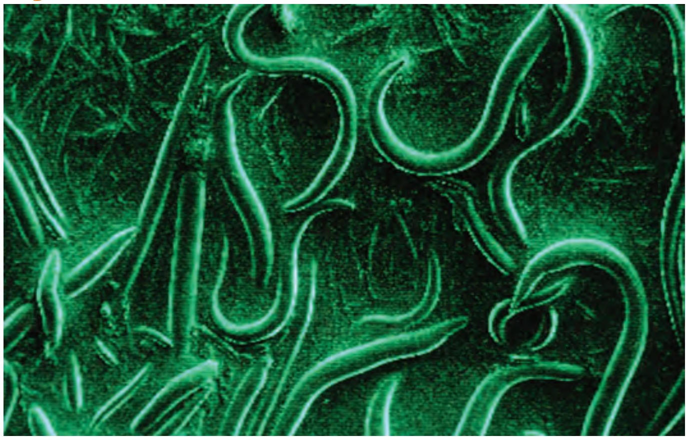
Tick specimens in museum collections were infected as far back as the 1940's, before Lyme Disease was recognized. Photo: James Gathany, Centers for Disease Control & Prevention.

Lyme Disease: Emergence of an "Old" Pathogen

Museum specimens contain important baseline information documenting the spread of the deer tick and the Lyme disease bacterium. Although Lyme disease was only recently recognized, genetic tests have shown that museum specimens of deer ticks collected in the 1940's were infected. Other specimens indicate that Lyme disease has been present in America even before that time.

Agriculture, Food and Trade Security

Globalization of agriculture has led to the widespread introduction of an array of pathogens and parasites with dramatic consequences to society (Diamond, 1997). Billions of dollars in losses are incurred annually in attempts to control or eradicate plant and animal pathogens and even the relatively well known internal parasites of livestock. Systematics is the first line of defense, providing the basis for identification of invasive species, for understanding host and geographic distributions, and in planning strategies for control and management. Translocation is the most important factor in determining the distribution of invasive parasites and pathogens; it is a process that continues to escalate annually. This observation provides the rationale for a comprehensive regional and global survey and inventory, which will document the distribution of invasive and local biodiversity and help predict the cascading effects of rapid changes in distributions among pests, parasites, and pathogens (Brooks and Hoberg, 2000, 2006).



Bacterial-feeding nematodes, *Operculorhabditis* sp. LKC10, frozen in liquid nitrogen. Magnified about 30x. Photo: Keith Weller. USDA, ARS.

Animal Diseases and Parasites

Invasion of a Nematode Pathogen in American Livestock

A nematode parasite in sheep and cattle was listed by the Animal and Plant Health Inspection Service (APHIS) as an “agent of foreign animal disease” significantly threatening American livestock production. In 1986, systematists at Oregon State University and the U.S. National Parasite Collection (USNPC) of the Agricultural Research Service (ARS) discovered and identified this intestinal nematode shortly after it was inadvertently introduced into livestock in Oregon. A nationwide survey for this nematode was conducted, and molecular diagnostic criteria indicated that this parasite had been introduced to the U.S. from the United Kingdom through Canada. With the accurate and comprehensive assessments of animal parasite biodiversity established by systematists, the rapid detection of and response to this newly introduced parasite was made possible (Hoberg, 1997).

Large Stomach Worms Expanding Distribution in Cattle

An invasive stomach worm in the genus *Mecistocirrus* is a significant pathogen in cattle that is predicted to become established in the southwestern U.S. as the climate changes (Hoberg, 2005). With the introduction of zebu cattle from southeast Asia, this worm was introduced into South America and subsequently spread to Central America and Mexico. Systematists at the U.S. National Parasite Collection (USDA) confirmed the identification of the pathogen and examined the geographic distribution and species diversity globally as baselines for predicting the response of native hosts, anticipating its eventual introduction into the U.S.

Cactus Devastated by Invasive Moths

Cactus moths (*Cactoblastis cactorum*) in America exemplify how a beneficial biological control agent can become an invasive threat. The cactus moth was intentionally introduced into Australia from Argentina (its area of origin) in the 1920's to eradicate prickly pear cactus (*Opuntia*), an invasive plant in some regions of the world. These moths were first reported in the U.S. at Big Pine Key, Florida, in 1989, and since then have dispersed north and westward along the Gulf of Mexico, destroying populations of native *Opuntia* (Soberon, *et al.* 2001). This insect could spread into Mexico, where it would have a serious economic impact on Mexican agriculture, as prickly pear cactus is food for Mexicans and figures prominently in Mexican history, culture, and religion. In early 2005, USDA's ARS and APHIS, with the USGS, launched an effort to monitor the cactus moth to detect the leading edge of an expanding range for this species. Federal systematists have aided in the effort to identify this moth and other closely related species that can be confused with *C. cactorum*. Unequivocal identification is crucial for determining the actual distribution of these serious pests and in determining the efficacy of current control efforts.

Mediterranean Fruit Fly Halted on the Shores of the U.S.

Billions of dollars of commodities pass through ports of entry to the U.S. annually on ships, planes, trucks, and trains. Detecting new pests is essential in keeping our crops and commodities free from damage by insects. Cargo inspectors collaborate with ARS systematists to provide thousands of authoritative identifications of unknown animal and plant species each year. Following the identification of Mediterranean fruit fly larvae on Clementine oranges imported into Florida, trade was suspended before the fly could cause millions of dollars of damage to American citrus crops.

Fruit in produce section of a supermarket in Virginia. Photo: Ken Hammond, USDA.

The Mayaguez Root-Knot Nematode in Florida

Meloidogyne mayaguensis, the Mayaguez root-knot nematode, has long plagued tropical America. Occurrence of this nematode poses a major constraint on vegetable production at a time when such fumigants as methyl bromide are being eliminated due to the Food Quality and Protection Act (1996). This alien species could easily gain a foothold in the U.S., because nematode identification is difficult and many root-knot nematodes infect imported ornamental plants. In 2002, genetic analyses of a root-knot nematode led to the discovery of *M. mayaguensis* in Florida, having been identified in two nursery fields and one tomato field in three geographically distinct locations. Following this identification, researchers demonstrated that this species is able to reproduce on all nematode-resistant varieties of tomato currently used in Florida and elsewhere.

The Wheat Seed Gall Nematode in Brazil

The wheat seed gall nematode is one of few species that infects seed and thus can be transported globally with grains and have a major impact on trade. For example, Brazil was the largest South American importer of U.S. wheat until 1995, when its government prohibited trade because of concerns about the possible presence of the wheat seed gall nematode in U.S. grain exports. The ban was partially lifted in 1998 after ARS systematists demonstrated to Brazilian scientific and regulatory personnel that rigorous cleaning eliminated the nematode from wheat, but was reinstated in 2000. A team of Brazilian scientists was sent to ARS to search for the nematode, and the delegation failed to detect a single plant-parasitic nematode in any wheat sample; also during that visit, a 50-year-old Brazilian specimen of seed gall nematode was discovered in the USDA Nematode Collection. These discoveries helped convince Brazil that U.S. wheat did not threaten to introduce the pathogen, and Brazil once again imports wheat from the U.S. The value of wheat exports to Brazil rose from $0 in 1995-1998 to $70 million annually in 2001-2003.

A New Species of Nematode Infecting Potatoes Threatens Million Dollar Losses

California long white potatoes in produce section of a supermarket in Virginia. Photo: Ken Hammond, USDA.

Northern root-knot nematodes were a recognized pest of potatoes in the fields of the Pacific Northwest, and for decades were controlled by rotation with wheat. In the late 1970's, control by wheat rotation began to fail, particularly in the Columbia and Snake River basins. Concerned that the $1 billion value of potatoes in this region would be threatened, ARS scientists analyzed potato specimens and discovered subtle differences between the nematodes that reproduced on wheat and those limited to potatoes; this led to the discovery of a new species, the Columbia root-knot nematode. With subsequent testing, scientists identified crops better suited for rotations with potatoes, permitting successful control of the nematode. In 1988, when concerns arose that the species might occur in Maine, ARS analyzed 744 Maine soil samples and failed to detect the Columbia root-knot nematode, protecting a region where the value of potatoes exceeds $100 million annually.

Crops-Fungal Diseases

$6 Billion U.S. Wheat Trade Threatened

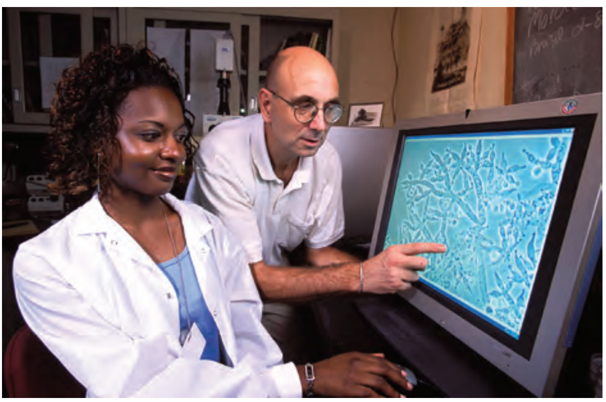
The fungus causing Karnal bunt gives wheat a fishy odor; therefore, infected wheat is not welcomed by most countries. When this noxious fungus appeared in the U.S., many countries refused to accept wheat exported from the Nation. Matters worsened when molecular tests for Karnal bunt suggested that the disease was widespread in the U.S. However, ARS systematists determined that the test was inaccurate, giving false positive results from a closely related but distinct bunt fungus on ryegrass. The researchers determined that the newly detected bunt fungus species was unknown when the original molecular test for Karnal bunt was developed, thus illustrating the importance of good systematic knowledge in developing accurate molecular diagnostic tests. As a result of solving this systematics problem, the $6 billion U.S. wheat export market was saved (Castlebury and Carris, 1999).

No TCK Bunt on Wheat in California—New Market Opened to China

A devastating pathogen on wheat, TCK bunt fungus was thought to occur in California, and China blocked trade of this commodity from that state based on an unidentifiable specimen collected in the early 20th century. Using web-based historical data from the U.S. National Fungus Collection (USDA), scientists matched the dates and localities of the specimens collected by the plant pathologist traveling in the western U.S. with the pathologist's daily route. It became evident that the bunt specimen was not from California; rather, the specimen had been collected farther north in Oregon where the bunt does occur, suggesting that the plant pathologist had mislabeled the specimen from Oregon. Based on this evidence, China reopened its borders to wheat grown in California (Rossman, 1994). In this case, the use of historical records as baselines to understand pathogen distribution resulted in annual revenues of $8 million for California wheat producers.

Wheat harvest in El Centro, CA.
Photo: Tim McCabe

Edible Gourmet Mushrooms Threatened by Disease



Mycologist Gary Samuels and University of Maryland student Lutorri Ashley discuss the morphology of the *Trichoderma* that causes green mold of mushrooms. Photo: Stephen Ausmus, USDA, ARS.

The cultivated mushroom crop is worth $920 million annually in the U.S. Recently, an epidemic of a new devastating disease called green mold threatened to destroy the cultivated mushroom beds in the U.S. and England. At first, green mold was mistakenly determined to be a fungus used in biological control of crop plant diseases; ARS systematists thought otherwise, and after identifying and characterizing the cause of green mold, proved that the fungus causing the mold on cultivated mushrooms was different and was easily distinguishable from the biological control agent. This research contributed to the control of green mold disease on cultivated mushrooms and led to the use of environmental friendly agents to control plant diseases (Samuels *et al.,* 2002).

U.S. Cocoa Supply Susceptible to Fungal Diseases

Cocoa is of major importance to producers of chocolate as well as milk, sugar, grain, fruit, nuts, and rice in the U.S. A continuous supply of cocoa is essential for the companies in the U.S. that produce chocolate and the components of chocolate products (Samuels *et al.*, 2000). However, cocoa grown in South and Central America and West Africa for U.S. markets is seriously affected by fungal diseases, for which chemical control is no more than 10% effective and is economically prohibitive when the market value of cocoa is low. ARS scientists have characterized and developed control agents as an alternative to costly chemicals, and these agents are now used in South and Central America to control the most serious diseases of cocoa. Annual benefits to the chocolate industry are valued at $15 billion worldwide.

Source of Late Blight of Potato that caused the Irish Famine: Could it Happen Again?

Biological collections provide important baseline data for tracking the movement of plant and animal pathogens. Potato late blight is the devastating disease that caused famine in Ireland in the 1840's and led to the subsequent emigration that changed the social structure on both sides of the Atlantic Ocean. Fortunately, voucher specimens of the organism that causes potato late blight were deposited in museum collections such as the U.S. National Fungus Collections (USDA), and were used to determine the movement of the organisms that cause the disease. DNA was extracted from these old specimens and used to reveal when the potato blight fungus moved from South America to Europe and later to North America. Knowledge of the historical distribution of this pathogen will help in the development of resistant strains of potato and ensure the continuity of a significant global crop and food resource (May & Ristaino, 2004).

Environmental Security

Ecosystem integrity and continuity are vital to the national and world economy and hold benefits for soil formation, biological nitrogen fixation, crop and livestock genetic improvements, biological control of pests, plant pollination, drug and medicine development, organic waste disposal, and the genetic resource maintenance required for sustainability of the environment and human society. Environmental security is threatened by free-living and parasitic organisms ranging from vertebrates/invertebrates to viruses, bacteria, fungi, and pathogens of animals and plants. Systematics and the ability to accurately identify the earth's biota are essential for developing effective conservation strategies.

Erin McCray, collections manager, and David Farr, mycologist for ARS, examine a fusiform rust of pine, one of more than 1 million specimens in the U.S. National Fungus Collections. Photo: Peggy Greb, USDA, ARS.

White Pine Blister Rust in the U.S.

The pathogen that causes white pine blister rust was accidentally introduced into North America in the beginning of the 20th century on pine seedlings grown in outdoor nurseries (Maloy, 1997). Since then, the disease has caused widespread mortality of five-needled pines and the destruction of forest ecosystems across North America, and continues to spread. Management efforts have included the removal of infected trees, *Ribes* (alternate host) eradication, the breeding of rust-resistant pines of several species, and other practices. Recently, it was discovered that white pine blister rust infects non-*Ribes* alternate hosts in North America (McDonald *et al*., 2006). Comparisons with similar but endemic pathogens and their hosts on other continents are needed to understand the naturalization process and to develop systems for predicting the potential for other pathogens to invade North American forests (Richardson *et al*., 2005).

Phylogeography of Fungi Causing Root Rot of Forest Trees

Root-rot pathogens, such as *Armillaria* species, cause widespread mortality of diverse tree species. *Armillaria* species are global in distribution, with some species existing on multiple continents. Systematists have used phylogeographic and population genetic analyses to assess the potential risks of invasive *Armillaria* species (Kim *et al*., 2006), and have determined that intercontinental or interregional movement of *Armillaria* species poses a significant threat. Each *Armillaria* population exhibits its own ecological behavior, and the accidental introduction of *Armillaria* species could allow isolates from other continents to mate, hybridize,and introgress with endemic North American species and lead to increased pathogenicity and/or host-range expansion (Kim *et al*., 2001; Kim *et al*., 2006). Such damage from intercontinental introductions of *Armillaria* species has already been documented (Coetzee *et al*., 2001; 2003).

Asian Long-horned Beetles Threaten Forests in the U.S.

Asian long-horned beetles gained entry to the U.S. in 2004 and pose a serious threat to deciduous forests in the eastern U.S. Systematists in the Agricultural Research Service (ARS), working with colleagues at Cornell University, pursued an in-depth study of the Asian long-horned beetle and its close relatives, a study that contributed to the development of control strategies for this pest. Knowledge about the systematics of these beetles permitted the rapid and accurate identification of a second invasive insect species from this genus in the northwestern U.S., including its likely country of origin, and provided critical biological information for regulatory officials. This alien beetle has since been eradicated from northwestern forests, halting the establishment of a potentially serious pest.

A tree killed by the Asian Long-horned beetle Photo: USDA, ARS.

Adult of Asian Long-horned beetle inside a gallery eaten into the tree trunk. Photo: USDA, ARS.

Emerald Ash Borer Devastates Deciduous Forests in the U.S.

Metallic green wood-boring beetles native to Asia arrived in the U.S. probably in wood packing material on cargo ships or airplanes. Identified as emerald ash borers, these invasive beetles have caused massive destruction in ash forests, killing at least 8 to10 million trees in Indiana, Michigan, and Ohio since their introduction. ARS systematists provided timely identification of the beetle and are helping to provide descriptions of new species of parasitic wasps collected by APHIS and Forest Service scientists from China that might be used for the biological control of this pest.

Damage caused by the Emerald Ash Borer, on trunk of ash. Photo: Joseph O'Brien, USDA Forest Service, Bugwood.org

94% of the native dogwoods in the Catoctin Mountains were killed by the dogwood anthracnose, *Discula destructiva.* Photo: M.Sitnik, SI, NMNH.

New Fungus Devastates Flowering Dogwood Trees

The flowering dogwood is a beautiful understory tree essential for wildlife in the eastern U.S. A new disease of dogwood called dogwood anthracnose has killed many of the native dogwoods in Maryland, including up to 94% of the native dogwoods in forests of the Catoctin Mountains. Dogwood anthracnose is caused by a previously unknown fungus. An ARS systematist provided a meaningful scientific name, *Discula destructiva*, and an accurate description of the fungus that causes the disease. Armed with the ability to communicate about the fungus and to distinguish it from the many other fungi that occur on dogwoods, plant pathologists have developed control strategies for this disease and improved their understanding of the environmental conditions that favor dogwood anthracnose (Redlin, 1991).

Brown Treesnake Invades the Pacific Basin Islands

The accidental introduction of the brown treesnake (*Boiga irregularis*) to Guam around 1950 induced an unprecedented series of extinctions (Fritts and Rodda, 1998), including most of Guam's indigenous forest birds, bats, and lizards by 1990, when only three native vertebrates remained. Because the nation lacked large snakes throughout most of its history, the birds and other vertebrates on Guam evolved in the absence of snake predators and were easy prey for brown tree snakes. Since 1981, there have been seven documented occasions in which the brown treesnake has been transported from Guam to Hawaii (Fritts *et al.,* 1999), posing a similar ecological threat to this island. This example serves to demonstrate the importance of monitoring and surveying the changing patterns of distributions of invasive pests or predators.

The brown treesnake, *Boiga irregularis*, was accidentally introduced to Guam, causing an unprecedented series of extinctions. Photo: Steve W. Gotte, USGS.

Raccoon Systematics Aids Conservation in the West Indies

The North American raccoon, *Procyon lotor*, was introduced to the Lesser Antilles Islands. Photo: Jessie Cohen, SI, NZP.

In the Lesser Antilles, raccoon populations have traditionally been recognized as distinctive species endemic to their respective islands. All three populations have been given official conservation status. After examining all available museum specimens, systematists concluded that these Caribbean raccoons could not be distinguished from the North American raccoon *Procyon lotor*. Furthermore, the historical, biogeographic, genetic, and morphological evidence demonstrate that these West Indian raccoon populations were recently introduced from the eastern U.S. In light of their alien origins, these populations should not be considered conservation priorities, but rather ecological threats to these island ecosystems.

Deer Threaten Endangered Plant Species

Overbrowsing by white-tailed deer threatens rare plant species and harms tree regeneration, which are critical to the long-term ecosystem health of our national parks (Horsley *et al.,* 2003). Expanding deer populations also spread pathogens and parasites such as the agent of Lyme disease and its tick vectors. The Smithsonian Institution's National Zoological Park is studying the impact of deer and invasive species in the Potomac Gorge, one of the most biologically diverse sites in the Eastern U.S., in which invasive species are also prevalent. Reducing deer browsing could "tip the balance" in favor of native species over their invasive competitors.

White-tailed deer in Maryland threaten plant species. Photo: William J. McShea, SI, NZP, CRC.

The Entomology Collection at the National Museum of Natural History, Smithsonian Institution, holds 35 million specimens that are accessed by 400 researchers every year. Photo: Chip Clark, SI, NMNH.

Federal Agencies Providing or Requiring Systematic Information

The Federal government currently invests considerable resources in systematics. A number of Federal agencies are mandated to develop systematic knowledge and regulatory agencies depend on its availability to complete their missions. These agencies work in collaboration with national and international museums, universities, and the private sector. Collections maintained and curated by agencies such as the U.S. Department of Agriculture (USDA), the Department of the Interior (DOI), and the Smithsonian Institution's National Museum of Natural History (NMNH), among others, provide invaluable information to a diverse national and international constituency (Lichtenfels *et al*., 1998). This Federal systematics capacity provides a first line of defense against inadvertent and intentional introduction of plant pathogens.

Research Entomologist A. Konstantinov, from the USDA-ARS Systematic Entomology Laboratory surveys results of a beetle invasion to a crop field. Photo: USDA, ARS, SEL.

Department of Agriculture (USDA)

Many USDA agencies conduct research to provide systematic knowledge, use systematics for regulatory activities, and carry out natural resource conservation and land management work with the use of systematics. Research is undertaken by the Agricultural Research Service (ARS), the Forest Service, the Natural Resources Conservation Service, and the Cooperative State Research, Education and Extension Service; of these agencies, ARS maintains major systematics resources such as the Systematic Entomology Laboratory, which curates many of the Smithsonian Insect Collections; the USDA Nematode Collection, part of the Nematology Laboratory; the U.S. National Fungus Collections, part of the Systematic Botany & Mycology Laboratory; and the U.S. National Parasite Collection. Regulatory agencies regularly using systematics include the Animal and Plant Health Inspection Service (APHIS), the Food Safety Inspection Service, and the Foreign Agricultural Service. APHIS provides molecular diagnostics and LUCID keys. The Forest Service and Natural Resource Conservation Service carry out natural resource conservation and land management activities with the use of systematics knowledge.

Department of the Interior (DOI)

The U.S. Department of the Interior's research arm is the U.S. Geological Survey (USGS), which focuses on earth and biological research. The USGS Biological Survey Unit (BSU), located in Washington, D.C., conducts research on systematics, nomenclature, and biodiversity of vertebrates, and are responsible for the curation of nearly a million specimens of North American vertebrates at the NMNH; meanwhile, the USGS National Wildlife Health Center evaluates the causes and consequences of major disease outbreaks among wild vertebrates and provides information about the distribution of pathogens, parasites, and diseases of vertebrates. Additional DOI conservation and land/water management bureaus include the U.S. Fish and Wildlife Service, the National Park Service, the Bureau of Land Management, and the Bureau of Reclamation. These DOI agencies address the impact of invasive species on the ecosystems under their jurisdiction.

Biologist plants hickory seedling grown from original genetic stock at Antietam NB's West Woods to recreate the cultural landscape. Photo: Michelle Carter, NPS.

Smithsonian Institution (SI)

The Smithsonian Institution is uniquely equipped to discover, describe, and classify the world's species and ecosystems. Of SI's 20 bureaus, NMNH, the National Zoological Park, the Smithsonian Environmental Research Center, the Smithsonian Marine Station, and the Smithsonian Tropical Research Institute are actively investigating invasive species, including terrestrial, aquatic, and marine invasive species. The biological collections include 83 million biological specimens (complemented by 40 million fossils, plus smaller living collections), forming one of the two greatest collections of biodiversity in the world. These collections are the basis for close interagency collaborations between the SI and the Agricultural Research Service/ Systematics Entomology Laboratory (ARS/ SEL), Department of Interior's Biological Survey Unit (BSU), Department of Defense's Walter Reed Biological Unit (WRBU) and the Department of Commerce's NOAA National Marine Fisheries Laboratory (NMFS), housed in the SI complex. In addition the NMNH Division of Birds works closely with the Federal Aviation Administration and United States Air Force in researching bird air strikes in the Bird Aircraft Strike Hazard (BASH) program. The Institution's research programs explore the diversity of our natural world through laboratory and field studies in the U.S. and over 122 countries around the world. Expertise includes research by the National Zoo on wildlife diseases and pathology.

Terry Erwin, Department of Entomlogy, applying fogging technique during a biodiversity survey of canopy insects. Photo: George Venable, SI, NMNH.

Ecosystem's integrity and continuity are vital to the national and world economy. Secondary growth of a typical Eastern forest in Maryland. Photo: P. Gentili-Poole, nearctica.com.

Data Call for Systematics

SYSTEMATICS AND INVASIVE SPECIES

Draft U.S. Federal Agency Survey 2008

Draft February 8, 2008

Interagency Taskforce for
Invasive Terrestrial Animals and Pathogens (ITAP)

ITAP Systematics Subcommittee

David Chitwood, U.S. Department of Agriculture (USDA)/Agricultural Research Service (ARS)
Hilda Diaz-Soltero, USDA
Eric Hoberg, USDA/ARS
Scott Miller, Smithsonian Institution (SI)
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Marsha Sitnik, SI
Alma Solis, USDA/ARS

SYSTEMATICS SURVEY

In response to the challenges posed by invasive species, ITAP will survey Federal agencies to develop a comprehensive 10-year plan to expand or create systematics programs in Federal agencies in the United States.

The survey will provide a snapshot of current conditions and postulate future needs. Your Agency's response to this survey will contribute to formulate plans to accurately identify organisms and to mitigate damages by invasive species that threaten our national security, public health, agriculture, natural environment and economic well-being. ITAP will use the survey results to prepare a policy paper to strengthen systematic biology programs in the Federal government.

We are assessing the needs for human, economic and facilities resources among Federal agencies that provide or receive systematics services.

Systematics services include:

1. **taxonomic knowledge** needed to identify and characterize invasive species;
2. maintenance, use and development of **biological collections**;
3. construction and maintenance of **specialized buildings** for systematics activities including collections;
4. biological or **biodiversity informatics**, including information about invasive species, biodiversity and natural history; and
5. **facilities and personnel** needed to guarantee continuation of operations and to provide systematics support in case of a terrorist attack in the Washington, DC area or other critical location.

The survey uses these scientific terms:

Taxonomy: *discovering, describing and naming living things - the science that makes possible accurate identification of organisms.*

Systematics: *determining the evolutionary relationships among living organisms.*

Biogeography: *mapping the distribution and movements of species.*

Bioinformatics: *integrating systematic, biogeographic, and ecological information to recognize species introductions and the impact of invasive species.*

Directions

Choose an appropriate Agency representative to answer the survey.

If your Agency provides systematics services, please answer all questions except 4. If your Agency receives systematics services, please answer all questions except 2.

Provide a separate Survey for each relevant Program in your Agency.

Send completed survey to Hilda Diaz-Soltero, hdiazsoltero@fs.fed.us, (202) 354-1880

SYSTEMATICS AGENCY SURVEY

1. Does your Agency identify organisms or use the expertise of others to identify organisms to accomplish its missions? (If not, skip all the questions. Complete contact information for your Agency on the final page and return the survey).

a. Name the program(s)/ function(s) in your Agency that use taxonomic expertise:
____

b. Mark the expertise that is critical for your operations:
__ identification of organisms,
__ use of taxonomic collections,
__ bioinformatics,
__ other? Please identify: ______________________________________.

c. Quantify the expertise that your Agency uses:
____ # of taxonomic identifications per week (# of specimens per week)
____ # of visits/use/loans of taxonomic collections per week
____ # of use of bioinformatics per week
____ # of (other) ____________ systematics expertise use per week

d. Name the Agency(s) and program(s) that provide you with systematics/taxonomic expertise.

1. Agency ____,
Program/Activity/Project ____.
2. Agency ____,
Program/Activity/Project ____.
3. Agency ____,
Program/Activity/Project ____.

e. Name systematics services contracted by your Agency and the cost of each.

- Contract to a Federal Agency _________________; cost per year $____________.
- Contract to a private contractor ________________; cost per year $____________.
- Contract to a university ______________________; cost per year $____________.
- Contract to other ____________________________; cost per year $____________.

2. Does your Agency have a systematics program or does your Agency provide systematics information/knowledge to other Agencies? If no, go to question 4.

a. Describe your Agency's FY 2007 systematics program.

1. **Program/Activity/Projects**:

- Program name (or activity) ____.
- What is its focus? Please mark all that apply : ___ Research; ___Collections;___Bioinformatics;___Systematics; ___ Education?

2. **Research in systematics**

- Staff (number of full time equivalents or FTE's, expertise, and GS level):

GS-15: __FTE's; expertise in _______________; funds per year $__________.
GS-14: __FTE's; expertise in _______________; funds per year $__________.
GS-13: __FTE's; expertise in _______________; funds per year $__________.
GS-12: __FTE's; expertise in _______________; funds per year $__________.
GS-11: __FTE's; expertise in _______________; funds per year $__________.
GS-9: __ FTE's; expertise in _______________; funds per year $__________.
GS-7: __ FTE's; expertise in _______________; funds per year $__________.
GS-5: __ FTE's; expertise in _______________; funds per year $__________.

3. **Collections**:

- Any research collections? Yes ___, No ___
- Official name(s) of collections?
  ____
- Do you collect specimens? Yes___, No ___
- Are they accessioned collections? Yes ___, No ___
- Do you maintain live cultures? Yes ___, No ___
- Do you maintain specimen collections? Yes ___, No ___
- Do you maintain frozen tissue collections? Yes ___, No ___
- Are there non-institutional or other research collections? Yes __, No___
- Give the number of specimens or lots your agency has in all your deposited collection(s): ___________________
- What taxonomic families or orders are represented?
  ____

4. **Bioinformatics**:

- Do you use or provide bioinformatics? Mark all that apply:

Users:

____ Databases
____ Electronic keys
____ Digitized images
____ Digitized images of types
____ Geographic reference
____ Mapping distribution and movement of species
____ Host associations

____ Publications
____ Other _______________

Providers:

____ Databases
____ Electronic keys
____ Digitized images
____ Digitized images of types
____ Geographic reference
____ Mapping distribution and movement of species
____ Host associations
____ Publications
____ Other _______________

- Are you part of a data network? Yes ___, No ___. Which one? ____
- Briefly describe your bioinformatics data including Web addresses (URLs). ____

5. **Education:**

- Do you have fellows training? Yes ___, No ___
- Do you have interns training? Yes___, No____
- Do you have professional education for staff? Yes___, No ___
- Do you have public outreach activities? Yes___, No___

6. **Budget**:

- Annual budget for each of the above in FY 2007. If no detailed budget is available, your best estimate is acceptable. Provide the budget in the following categories in as much detail as possible.

Personnel (FTE's, grade level, expertise, cost):

GS-15: __FTE's; expertise in ________________; funds per year $___________.
GS-14: __FTE's; expertise in ________________; funds per year $___________.
GS-13: __FTE's; expertise in ________________; funds per year $___________.
GS-12: __FTE's; expertise in ________________; funds per year $___________.
GS-11: __FTE's; expertise in ________________; funds per year $___________.
GS-9: __ FTE's; expertise in ________________; funds per year $___________.
GS-7: __ FTE's; expertise in ________________; funds per year $___________.
GS-5: __ FTE's; expertise in ________________; funds per year $___________.

Equipment, including IT hardware and software:_______________________
Materials and supplies: ____
Travel:____
Staff training:____
Contract Services: ____
Space: ____
Other: ____

7. **Recipients**:
Name all recipients of systematics information/knowledge provided by your Agency:____

b. Describe the FY 2007 physical facilities (buildings, etc.) that house staff, systematics collections, and bioinformatics facilities in your Agency.
   - Square footage? __________________ sq. ft.
   - Condition of the facility? (excellent, good, poor) _______________________.
   - Does it have a fire suppression system? Yes ___, No ___. Describe it: ____
   - Does it have alarms? Yes ___, No ___
   - Are they linked to fire and police? Yes ___, No __
   - Are there appropriate environmental and safety controls?
     a. For humidity? Yes ___, No ___
     b. For temperature? Yes ___, No ___
     c. For lighting? Yes ___, No ___
     d. For security? Yes ___, No ___

c. Is there adequate space for collections? Yes ___, No ___
d. Is there adequate space to accept orphan collections? Yes ___, No ___
e. Is there adequate room for growth of your collection? Yes ___; if so, how much? ___________________; No ___
f. Are any of your collections in jeopardy because of budget? Yes___. No___
g. Does your Agency have a "Continuation of Operations Plan" (COOP) for the systematics programs in case of a terrorist attack or natural disaster? Yes ___, No ___. If so, describe it fully:
   i. Location: ____
   ii. Buildings: ____
   iii. Personnel:
      GS-15: __FTE's; expertise in ________________; funds per year $___________.
      GS-14: __FTE's; expertise in ________________; funds per year $___________.
      GS-13: __FTE's; expertise in ________________; funds per year $___________.
      GS-12: __FTE's; expertise in ________________; funds per year $___________.
      GS-11: __FTE's; expertise in ________________; funds per year $___________.
      GS-9: __ FTE's; expertise in ________________; funds per year $___________.
      GS-7: __ FTE's; expertise in ________________; funds per year $___________.
      GS-5: __ FTE's; expertise in ________________; funds per year $___________.

   iv. Collections: ____
   v. Alternate bioinformatics Web and computer communications: ____
   vi. Please submit a copy of the plan.

   vii. Is it fully or partially funded? ____

3. If your Agency provides systematics services, answer the following questions. Looking at the future in a 10-year scenario, from FY 2009 to FY 2018, what does your Agency need?

A. Needs for a fully funded program in 10 years:

a. Research Capacity:

Personnel needs (number of people (FTE), grade level, and expertise)

GS-15: __FTE's; expertise in ________________; funds per year $___________.
GS-14: __FTE's; expertise in ________________; funds per year $___________.
GS-13: __FTE's; expertise in ________________; funds per year $___________.
GS-12: __FTE's; expertise in ________________; funds per year $___________.
GS-11: __FTE's; expertise in ________________; funds per year $___________.
GS-9: __ FTE's; expertise in ________________; funds per year $___________.
GS-7: __ FTE's; expertise in ________________; funds per year $___________.
GS-5: __ FTE's; expertise in ________________; funds per year $___________.

Equipment, including IT hardware and software:
____

Funds needed to exchange to a new generation of IT hardware and/or software $________.
Describe it: ____.
Materials and supplies:____
Travel: ____
Staff training: ____
Contract Services: ____
Space: ____
Other: ____

b. Collections needs:

Personnel needs (number of people (FTE), grade level, and expertise)

GS-15: __FTE's; expertise in ________________; funds per year $___________.
GS-14: __FTE's; expertise in ________________; funds per year $___________.
GS-13: __FTE's; expertise in ________________; funds per year $___________.
GS-12: __FTE's; expertise in ________________; funds per year $___________.
GS-11: __FTE's; expertise in ________________; funds per year $___________.
GS-9: __ FTE's; expertise in ________________; funds per year $___________.
GS-7: __ FTE's; expertise in ________________; funds per year $___________.
GS-5: __ FTE's; expertise in ________________; funds per year $___________.

Equipment, including IT hardware and software: ______________________________
Materials and supplies: ____
Travel: ____
Staff training: ____
Contract Services: ____
Space: ____
Storage needs: ____

Environmental controls: ____

Filling taxonomic gaps in your collection: ______________________________

Other: ____

c. Bioinformatics needs:

Personnel needs (number of people (FTE), grade level, and expertise)

GS-15: __FTE's; expertise in ________________; funds per year $___________.
GS-14: __FTE's; expertise in ________________; funds per year $___________.
GS-13: __FTE's; expertise in ________________; funds per year $___________.
GS-12: __FTE's; expertise in ________________; funds per year $___________.
GS-11: __FTE's; expertise in ________________; funds per year $___________.
GS-9: __ FTE's; expertise in ________________; funds per year $___________.
GS-7: __ FTE's; expertise in ________________; funds per year $___________.
GS-5: __ FTE's; expertise in ________________; funds per year $___________.

Equipment, including IT hardware and software: _________________________

Materials and supplies____

Travel: ____

Staff training: ____

Contract Services: ____

Space: ____

Other: ____

d. Fellowships:

For _____ (number) pre-doctoral students:

____

For ____ (number) post-doctoral students:

____

e. Physical facility needs

Maintenance of existing buildings or facilities: __________________________

Building new facilities: ____

f. "**Continuation of Operations Plan**" Cost of maintaining critical agency systematics functions in case of a terrorist attack or natural disaster detailed in the agency's COOP. Specific needs for:

Essential personnel (FTE's, expertise, GS level):

GS-15: __FTE's; expertise in ________________; funds per year $___________.
GS-14: __FTE's; expertise in ________________; funds per year $___________.
GS-13: __FTE's; expertise in ________________; funds per year $___________.
GS-12: __FTE's; expertise in ________________; funds per year $___________.
GS-11: __FTE's; expertise in ________________; funds per year $___________.
GS-9: __ FTE's; expertise in ________________; funds per year $___________.
GS-7: __ FTE's; expertise in ________________; funds per year $___________.
GS-5: __ FTE's; expertise in ________________; funds per year $___________.

Location (s) open: ____________________
Collections available: ____________________
Security: ____________________
Computer/Web communications for bioinformatics: ____________________
Other: ____________________

g. **Other needs**:
____

B. Use the information in 3A. above and **provide an annual plan 5 years out (FY 2014 scenario) and ten years out (FY 2019 scenario), starting with FY 2010.** Describe for each scenario (these are the rows for your matrix):
- Program elements,
- Funds needed (base funds and increase funds requested in that year)
- Research personnel (FTE's) (base funds and increase funds requested in that year),
- Building maintenance,
- Building construction,
- Collections maintenance,
- Collections development/enhancement,
- Informatics maintenance,
- Informatics development/enhancement,
- Continuation of operation needs,
- Other needs.

The titles of your matrix columns are: now (FY 2009); 5yr (FY2014); 10 yr (FY2019). Provide it as an Appendix to this survey.

4. If your Agency requires systematics services, please answer the following questions. Looking at the future, please describe what your Agency needs?

A. Needs for a fully funded program in 10 years:

a. Describe the services you expect to receive:
____

b. Describe the amount of services you expect to receive for each type of service. Quantify it.
____

c. Name each Agency(ies) and program(s) that provides you with systematics services:
____

d. Do you need services even during the time of a terrorist attack or natural disaster? Yes ___, No ___. If so, describe the type of services and the minimum services that your Agency will require:

____

e. Functions of your Agency that would be compromised if systematics information/ knowledge is not available during a terrorist attack or natural disaster:

____

B. Please use the information in 4.A. above and provide an annual plan 5 years out (FY 2014 scenario) and ten years out (FY 2019 scenario), starting with FY 2010. Describe for each scenario:

- Type of services you expect to receive,
- Amount of services you expect to receive,
- Agency from which you expect each type,
- Type of services needed during a terrorist attack or natural disaster,
- Amount of services needed during a terrorist attack or natural disaster.

Please translate these needs into a proposed annual budget estimate. Provide it as an Appendix to this survey.

5. Would your Agency benefit from a coordinated bioinformatics effort? For example, Web-based identification tools for field staff?

Yes ____, No _____. Give examples:

____

6. What other systematics products would be useful to you?

____

7. How can personnel in systematics be trained?

a. Your agency will require trained taxonomic staff in the future for these organisms:

____

b. If funded, can your Agency provide training, internships or fellowships to educate future systematic biologists? :

Professional Staff training: Yes ___, No ___
Internships: Yes ___, No ___

Fellowships (graduate and post-doc): Yes ___, No ___

c. Should universities reinvigorate their programs to train systematic biology experts? Yes ___, No ___ How?
____

d. Should the Federal government support and become more involved in systematics training and education with universities? Yes ___, No ___ How?
____

8. Would increased systematics coordination at national and international levels provide benefits to your Agency?

Yes ___, No ___. What benefits? ____

a. When you need systematics information, how do you obtain it? Circle all that apply: federal Agencies (ARS, APHIS, Smithsonian, USGS, other_______); states (Dept. of Agriculture, Dept. of Natural Resources, other_______?); university _____; botanical garden _______?; industry ___________?; private contractor ___________?; international entities __________? Other________?

b. How and with whom do you communicate about identification of organisms and systematics?
____

c. What communication barriers exist?
____

d. What other barriers hinder the use of systematics knowledge?
____

e. Do you know have access to a list of experts by taxon group? Yes ___, No ___, Sometimes ___

f. Do you know who has taxonomic expertise in each kind of organism that you encounter? Yes ___, No____

g. Would a mechanism to facilitate communication with experts with specific knowledge, by taxon, be helpful? Yes ___, No ___

9. How are systematics services financed?

a. Does your Agency pay for the systematics services that it receives from other Federal Agencies? Yes ___, No ___

b. Describe how and give details of fees-per-per service received. Specific examples:
____

c. Do you contract with universities for systematics services? Yes ____, No ____ How often? Cost? Give specific examples:
____

d. Do you contract with the private sector for systematics services? Yes ___, No ___ How Often? Cost? Give specific examples:
____

e. Does your Agency receive Congressional appropriations to pay for the systematics services that your Agency receives from others? Yes ___, No ___ How much per year?
FY 2007: $_________
FY 2008: $_________

f. Does your Agency have any other sources of funds to pay for systematic services? Yes ___, No ___ How much per year? What are the sources of those funds?
FY 2007: $_________, source ______________________________
FY 2008: $_________, source ______________________________

g. Does your Agency receive Congressional appropriations for its own systematics programs? Yes ___, No ___ How much per year?
FY 2007: $_________
FY 2008: $_________

h. Should the Administration reaquest and Congress allocate funding for systematics services to the Agencies providing the services? Yes ___, No ___

i. Should funds be allocated to both the Agencies providing systematic services and the Agencies receiving services? Yes ___, No ___.

10. Give us any additional information important to build the Federal sector's capability in systematics.
____

11. Give us an expert in systematics (scientific person) and an expert in the systematics program (that understands the budgets) as points of contact in your Agency (name, telephone number and email) in case we need to clarify any of your information.

Systematics scientific person: ____

Systematics program person: ____

Thank you for your time in answering this questionnaire.

Please return the Systematics Survey as soon as possible to:

Hilda Diaz-Soltero, diazsoltero@fs.fed.us

Lifestock grazing on U.S. grasslands are susceptible to bioterrorism attacks. While the threat is ill-defined, the risk from released agents is high. Photo: Kim Edmonds, Edmonds Farm.

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