Understanding Life

Biological Sciences

National Science Foundation

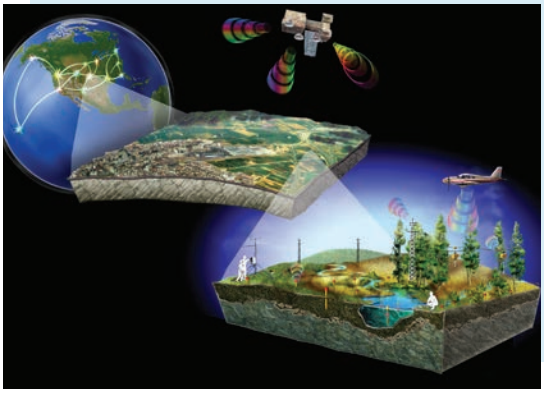
Focusing
on Life

We depend on the planet's plants, animals and microorganisms for our lives and livelihoods. Today, the scope and pace of Earth's environmental changes are unprecedented in recorded human history. These changes are increasing the necessity for research into the fundamental principles and mechanisms of life—research supported by the National Science Foundation's (NSF) Directorate for Biological Sciences (BIO).

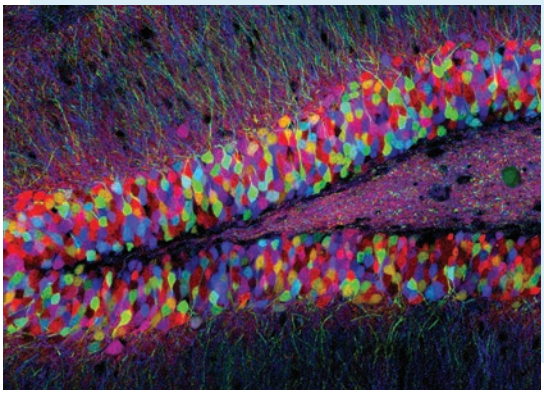
BIO-supported researchers produce a rapidly growing body of biological information about increasingly complex systems at scales. These scales range from molecules and cells to tissues, organs and organisms to populations and communities—all the way to ecosystems as large as the global biosphere.

Resulting new insights are essential to improving the understanding of life as well as to fostering wise stewardship of the changing planet. In addition, BIO is continuously working to empower the next generation of scientists and educators through various hands-on field and laboratory research experiences for students of all ages.

BIO recognizes that in order to fulfill its research agenda and produce new knowledge, it must increasingly support research that transcends traditional scientific disciplines. Indeed, to produce integrated models from biological data, more multidisciplinary work is needed that incorporates, for example, mathematical theory, computational analysis, physics, the social sciences and more comprehensive knowledge of linked biological and physical processes.



NSF supports the National Ecological Observatory Network (NEON), a continental-scale program of experimental and observational research focusing on major environmental challenges.



Scientists are using new imaging techniques to look at the brain with more clarity than ever before. These neurons have been marked with different fluorescent proteins in order to see individual cells, creating a "brainbow."

BIO's Broad Impact

BIO distributes over 1,300 awards annually to more than 17,000 researchers, including at least 4,000 undergraduate students and 2,500 graduate students. These awards are selected through NSF's gold standard merit review process and broadly support fundamental biology research and training. Essential to all activities across the directorate is a commitment to integrate research and education, broaden participation and promote international partnerships.

Many studies supported by BIO have serendipitously yielded unforeseen discoveries that benefit society in important ways. Many of these discoveries would probably not have been produced through mechanisms other than through basic research. This brochure provides examples of such discoveries and descriptions of their societal benefits in relation to health, food, energy and environment.

Credits: (cover) Thinkstock; (page 1 top): Nicolle Rager Fuller, NSF; (bottom) Jeff Lichtman, Harvard University

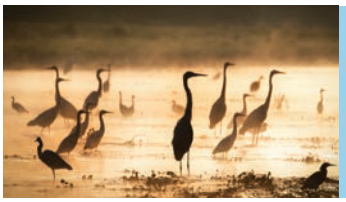
Illuminating Life's Complexity

BIO promotes research in a range of fields, from studies of the smallest proteins in cells to research on interactions between organisms and their environments. The breadth of current BIO research is captured in five priority areas: (1) synthesizing lifelike systems; (2) understanding the brain; (3) predicting individual characteristics from DNA sequences; (4) understanding biodiversity; and (5) understanding the interactions of the Earth, climate and biosphere.

To accomplish such varied, yet vital, research, BIO features five unique research divisions and activities. Collectively, they maintain a long tradition of encouraging excellence and promoting the skills, imagination and creativity driven by scientific curiosity.

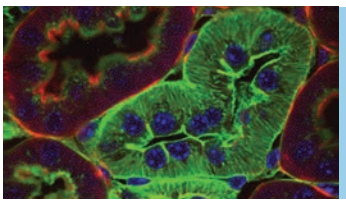
Biological Infrastructure supports varied activities that provide the infrastructure needed for contemporary research in biology.

Emerging Frontiers supports innovative interdisciplinary activities that emerge from traditional research disciplines.



Environmental Biology supports fundamental research on the origins, functions, relationships, interactions and evolutionary history of populations, species, communities and ecosystems.

Integrative Organismal Systems supports research aimed at achieving an integrative understanding of organisms as units of biological organization, with particular emphasis on systems-level approaches to the study of development, function, behavior and evolution.



Molecular and Cellular Biosciences supports research and related activities that contribute to a fundamental understanding of living systems at the molecular, subcellular and cellular levels.

Credits: (top to bottom) Thinkstock; National Ecological Observatory Network (NEON); Thinkstock; NSF Cedar Creek Long-Term Ecological Research (LTER) site; Marcos Dantus, Department of Chemistry, Michigan State University (MSU), photo by Kurt Stepnitz, MSU

BIO's Commitment to Innovation and National Needs

For more than 60 years, NSF has invested in fundamental research that has fueled scientific, technological and engineering innovation. Here are a few examples of the many BIO-funded projects that have directly fostered long-term economic growth and addressed national needs.

Printing Organs, Saving Lives

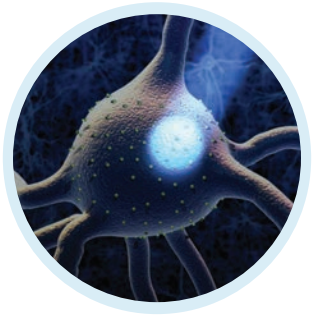
Almost 115,000 people are waiting for an organ transplant, but fewer than 5,000 transplants take place each year. Bioprinting in 3-D may change that. Organovo Inc., which was founded by NSF-supported biologists, has developed the world's first commercial 3-D bioprinting platform for organs, one of *TIME* magazine's "Best Inventions of 2010." In addition to being used for organ transplants, printed organs will greatly reduce the costs of drug development because they can be used to screen new drugs before clinical trials. Award # 0526854

Catching Bacteria and Criminals

DNA fingerprinting, an essential tool in the courtroom since 1986, identifies individuals based on their genetic profiles. This crime-fighting technology was made possible by the NSF-funded discovery of a bacteria in hot springs at Yellowstone National Park. An enzyme from this bacteria underpins a technique called polymerase chain reaction, which is one of the most important tools in the biotechnology industry, worth over $95 billion today. Award # 7202186, 0416568

Stomping Out Disease

NSF-funded researchers are pioneering new vaccine development techniques to combat livestock diseases such as contagious bovine pleuropneumonia (CBPP), which is decimating African cattle herds. The current vaccine for CBPP has severe side effects and is not always effective. Scientists are using genome engineering to create weakened bacterial strains suitable for new vaccines. This work is funded by NSF's Basic Research to Enable Agricultural Development (BREAD) program, a partnership with the Bill & Melinda Gates Foundation. The partnership advances basic research on key problems involving small farmer agriculture in the developing world. Award # 1110151



Pond Scum Lights Up the Brain

How are algae helping scientists understand complex connections in the human brain? Researchers found unique algal proteins that generate an electric current when hit by light. BIO-funded neuroscientists selectively inserted these proteins into target neurons, enabling the researchers to turn them on and off by exposing them to light. Now widely used, this process called optogenetics is helping researchers identify the functions of target neurons. It is being used to advance understanding of neurological disorders such as schizophrenia and Parkinson's disease, which collectively affect 3.4 million Americans. Award # 0724593, 1247950

Biodiversity is a Disease Defender

Why should we care about biodiversity? One reason, according to BIO-funded researchers, is that plant and animal extinctions are bad for your health. Infectious diseases such as West Nile virus and Lyme disease, which were contracted by over 35,000 Americans in 2012, are transmitted by mosquitoes and ticks. Intact ecosystems support more predators that prey on disease carriers. Hence, humans are less likely to be exposed to disease. Award # 0940830, 0815413

Bats: A Farmer's Best Friend

As bats hunt for insects each night, they reduce the pesticide bill of the U.S. agriculture industry by over $22 billion per year. However, a new incurable disease called White-nose Syndrome is decimating bat populations in North America, putting many species on the road to extinction. BIO-funded scientists identified one species, the little brown bat, that is avoiding complete extermination by changing its social behavior and roosting singly instead of in groups, thereby limiting spread of the disease. Award # 1115895, 1336290

Credits: (left top to bottom) Organovo; (left middle and bottom) Thinkstock; (center) Sputnik Animation, Ed Boyden and MIT McGovern Institute; (right top to bottom) Thinkstock

Contributing to a Cleaner World

Ecological processes take place over long periods of time. In order to ask big questions about how the environment will react to climate change and human disturbance, researchers need long-term datasets. That's why NSF has been funding sites like the Hubbard Brook Experimental Forest since the 1960s and why it created the Long-Term Ecological Research Program in 1980. Experiments conducted at Hubbard Brook were crucial to demonstrating the damage done to forests by acid rain, contributing toward the passage of the landmark Clean Air Act Amendments in 1990. Award # 0423259

Coping With Invasive Insects

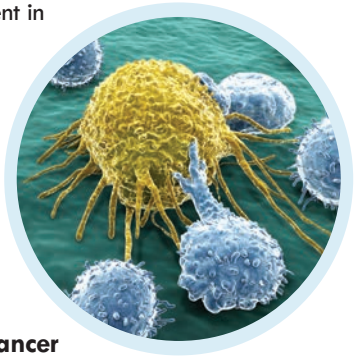
The fire ant, introduced into the U.S. in the 1930s, has been wreaking havoc ever since. Its large colonies overwhelm native species and cause $5 billion in damages to agriculture and recreation resources every year. Because standard insecticides have not stopped the invasion, BIO-funded researchers have taken a new approach. They recently sequenced the genome of the fire ant, identifying genes that underlie social structure and communication within colonies. This allows for the development of new treatments against fire ants that work by disrupting the chemical signals they use to communicate. Award # 1020979

A Botanical Lab Rat

Among the 250,000 species of flowering plants, one small weed has become a veritable rock star to scientists: *Arabidopsis thaliana*. Since 1990, NSF has led the effort to identify the sequence, location and function of every gene in this weedy mustard. *Arabidopsis*, the first plant to have its entire genome sequenced, paved the way for the sequencing of over 90 other plant genomes and made possible the genetic engineering of crops with improved disease resistance, enhanced nutritional value and increased yields. For example, BIO-funded researchers have genetically modified tomatoes to express up to 25 times more folate than normal—enough to provide an individual's complete daily requirement in one serving. Award # 0707451, 0129944

Obscure Disease Linked to Weather

In 1993, 20 people suddenly got sick and died of a previously unknown type of hantavirus in the American Southwest. NSF-funded scientists identified the unlikely culprit: deer mice. It turns out deer mice can carry hantavirus. When El Niño climate patterns caused a mild winter and a 10-fold increase in mouse numbers from the previous year, this led to more human contact with infected mice. Researchers are still working to understand the ecology of hantavirus, which kills 36 percent of its victims. Award # 0108892



Unraveling Cancer

Researchers have been working for decades to understand why normal cells suddenly go haywire and turn into cancer cells. Enter telomerase—the enzyme normally responsible for preventing chromosomes from shortening as we age. However, 80 to 90 percent of cancer cells have abnormally high telomerase activity, prolonging their lives. BIO-funded scientists have uncovered the 3-D structure of the enzyme, helping researchers develop drugs that target cancer cells directly. Award # 1022379

Jellyfish Revolutionize Biotechnology

NSF-funded biologist Osamu Shimomura wanted to know what caused certain jellyfish to glow green. The protein he found in the jellyfish, called green fluorescent protein (GFP), revolutionized how scientists study cells. GFP markers allow researchers to track specific biological activities such as the spread of cancer, the production of insulin and the movement of HIV proteins. In 2008, Shimomura received the Nobel Prize in Chemistry for the discovery and development of GFP. Award # 9303842

Credits: (left top to bottom) NSF Hubbard Brook LTER Site; Rick Griffiths, composition by Barbara Corbett, Virginia Tech; all others Thinkstock

More Ways

BIO Impacts Our Lives

The BIO directorate has a long history of supporting transformative research that meets national needs. Here are more examples of BIO-supported research that improve our daily lives.

Assembling a tree of life

Deciphering how biological systems function

Designing new drugs to fight cancer

Detangling ecological relationships

Determining the spread of infectious disease

Empowering Native Americans to address environmental issues

Encouraging children to learn about science

Engaging the general public through citizen science

Exploring the origins of life

Improving biological education

Launching new databases to track biological data

Modeling the effects of climate change on plants and animals

Monitoring ecological long-term change

Protecting the food supply

Shedding light on nature versus nurture

Strategizing to save endangered species

Synthesizing life

Thriving crops, reducing pollution

Uncovering the benefits of biodiversity

Understanding the brain

Visualizing life's smallest structures

Biologists and engineers have collaborated to develop a synthetic adhesive based on the bristle system under a gecko's foot. The adhesive is being used to construct bio-inspired sticky robots.

NSF-funding engages the public in projects such as Project BudBurst, a citizen science project that helps people across the U.S. monitor plants as the seasons change.

The first analysis of the wheat genome involved identifying essentially all 94,000-96,000 wheat genes and mapping their relationships to other grass genes such as those from rice and barley.

Credits: (top to bottom) Kellar Autumn, from Autumn, K., et al. 2002. Evidence for van der Waals adhesion in gecko setae. Proceedings of the National Academy of Sciences USA 99, 12252-12256.; Dennis Ward, Project Budburst, NEON; Thinkstock

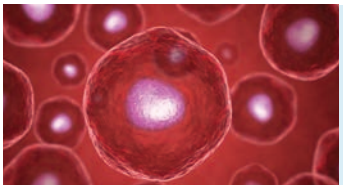
Funding the Brightest:
Notable NSF-supported Biologists

Of the hundreds of thousands of investigators funded by the BIO directorate, many individuals stand out for their remarkable contributions to science and the nation. Here are some examples of BIO-funded researchers who have been recognized for their work.

A 2010 MacArthur Foundation Fellow, **Marla Spivak** has a real bee in her bonnet. The pollination services provided by honey bees in North America are currently valued at $20 billion annually, but colony collapse disorder and other losses are threatening America's bee populations. Spivak's studies of bee health are helping to combat these declines and "get bees back on their own six feet."

Every year, NSF's Waterman Award honors outstanding research from a young scientist. **Casey Dunn**, the 2011 Waterman awardee, studies the origins of multicellular life using deep-sea creatures called siphonophores, which are related to jellyfish. Using integrative approaches and a high-powered genome analysis technique pioneered by Dunn, this work has already advanced the understanding of the tree of life.

How does a single-celled, fertilized egg develop into an embryo complete with head, middle and tail? This question drove the work of scientists **Edward Lewis** and **Eric Wieschaus**. Along with Christiane Nusslein-Volhard, they won the 1995 Nobel Prize in Physiology or Medicine for their discoveries of the genes controlling early embryonic development in fruit flies. Researchers have since found similar genes, called *Hox* genes, in mammals.



In the seventh grade, **Randy Schekman** walked into a science fair and immediately knew what he wanted to do with his life. Schekman ended up working with yeast to understand how molecules are correctly delivered to the right place at the right time inside cells. He was awarded the 2013 Nobel Prize in Physiology or Medicine, along with James Rothman and Thomas Sudhof, for his insight.

NSF researchers **Martin Karplus** and **Arieh Warshel** were co-awarded the 2013 Nobel Prize in Chemistry for developing innovative tools for predicting chemical processes. These tools, which are now commonly used, have helped scientists understand important chemical problems related to life such as photosynthesis in green leaves.

White House Champion of Change **Julia Parrish** heads the Coastal Observation and Seabird Survey Team (COASST). Hundreds of COASST volunteers monitor over 350 sites on the Pacific Coast for seabird carcasses. The project documented the world's single largest die-off of seabirds from harmful algal blooms and aims to translate long-term monitoring into effective marine conservation solutions.

Credits: (top to bottom) MacArthur Foundation; Gonzalo Giribet; Thinkstock (3); J. Dolliver

NSF 14-804

March 2014

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