BIODIVERSITY ILLUMINATED
From Images to AI

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From microscopic images of cells to wildlife photos and satellite footage, imagery plays an essential role in documenting and analyzing our natural world. This exhibit showcases how scientists document biodiversity, using text and images to identify species in the wild and analyze their characteristics and behaviors. This information is critical to understanding patterns in the more than 3.7-billion-year history of life on Earth and predicting the future effects of environmental change.

The volume and variety of biological imagery available - historical photos as well as the new citizen-scientist contributions, remote sensor data, x-rays and scans of internal structures, and more being generated daily - present both opportunities and challenges in addressing pressing questions about biodiversity. Breakthroughs in machine learning and artificial intelligence are helping scientists analyze and extract biological information from the scores of online images. At the same time, cross-institutional collaborations are enabling new biodiversity research on a much larger scale than ever before.

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Documenting the Diversity of Life

Biologists have historically documented their observations about the diversity of life in scientific journal articles, books, and field guides. Their work often includes descriptions paired with colorful, detailed illustrations or images of plants, animals, anatomy, and the environment. Field biologists also record their observations of nature in field notebooks. These notebooks can contain sketches of organisms as well as measurements, environmental data, and weather information.

1. **Field notes on keeled earless lizard**
   by Robert C. Stebbins. UC Berkeley Museum of Vertebrate Zoology, 1950.

   Dr. Stebbins (1915–2013) was a UC Berkeley museum curator and professor of zoology. This page from his field notes describes the coloration he observed on a keeled earless lizard (Holbrookia propinqua) collected in Rio Grande City, Texas in 1950.

2. **Field notebook on Polygalaceae,**
   by George Engelmann. Biodiversity Heritage Library, 1865–1877.

   Dr. Engelmann (1809–1884) was a botanist and founder of the St. Louis Academy of Science. This page from his field notes includes sketches of plant species in the Polygalaceae, or milkwort family.

3. ***Butterfly species illustrations,***
   by Royal Entomological Society of London. In Transactions of the Entomological Society of London, 1891.

   Founded in 1833 to promote the study of insects, the Royal Entomological Society of London's transactions and proceedings cover aspects of entomology such as taxonomy, ecology, and behavior.

4. **Taxonomic assessment of new catfish species,**
by Mark Henry Sabaj. In *Neotropical Ichthyology*, 2005.

Sabaj's journal article describes three new species of catfish (Leptodoras) found in the Amazon and Orinoco Rivers of South America. Such taxonomic treatments summarize all the information known about a species, including anatomical variation, habitat, diet, and geographic distribution. They may also include detailed illustrations or images of specimens photographed in the field or preserved in museums.

Imaging Technologies

Advancements in imaging technology over recent decades have allowed scientists to observe nature at increasing detail and scale, deepening the questions that research can address. The range of images commonly collected by biologists includes everything from microscopic images of cells and tissue to aerial and drone footage of wildlife.

5. ***Seeing Science: The Art of Making the Invisible Visible,***
by Jack Challoner, 2022..

   This book describes the methods and tools scientists have used to visualize their discoveries, from the microscopic to vast scales.

6. ***Remote Sensing: Principles, Interpretation, and Applications,***
by Floyd F. Sabins Jr. and James M. Ellis, 2020.

   A growing number of images are collected using remote sensing technologies such as satellite, light detection and ranging (lidar), drones, and aircraft. Applications of these imaging technologies in biology include animal counts, land cover, animal distributions, and understanding the effects of climate change.

7. ***Jaw musculature of bat species,***
by Sharlene E. Santana. In "Comparative anatomy of bat jaw musculature via diffusible iodine-based contrast-enhanced computed tomography," *The Anatomical Record*, 2018.

   This anatomical study of the jaw musculature of 12 bat species includes detailed images of jaw muscles and skeletal structures produced using computed tomography (CT) scanning technology.

8. ***Electron microscope image of pollen grains,***
by NASA's Goddard Space Flight Center, 2009.

   This microscopic image of pollen grains from several common plant species (sunflower, morning glory, prairie hollyhock, oriental lily, evening primrose, and castor bean) was produced by NASA to help improve our understanding of Earth's energy balance and the factors involved in climate change.

Online Biodiversity Image Collections

Recent efforts to image biological specimens in museums and collections, along with citizen-science efforts to capture and share images of wildlife, have resulted in new, open access online resources that make vast collections of nature images available to research communities and the public.

9. **MorphoSource.org**

   MorphoSource is an image repository for 3D media of the world's scientific and cultural collections shared by museums and researchers. Users can view and download 2D and 3D media representing physical objects such as skeletons and fossils produced by CT, magnetic resonance imaging (MRI), photogrammetry, laser scan, and other technologies.

10. **Biodiversity Heritage Library,**
    BiodiversityLibrary.org

    The Biodiversity Heritage Library (BHL) is an open access digital library and archive for the world's literature on biodiversity. A consortium of museums and libraries, BHL is working to digitize and make publicly available the legacy print literature in their collections. Hundreds of thousands of titles and more than 60 million pages from as early as the 15th century are available to date.

11. **California Phenology Network,**
    CapturingCaliforniasFlowers.org

    The California Phenology Network is a collaborative project funded by the National Science Foundation to capture plant specimen images from the collections in 28 California universities, museums, and botanical gardens, including the UC Irvine Herbarium (IRVC) led by Dr. Peter Bowler. Digital images collected by the project are publicly available and include data on the timing of flowering or fruiting in California plants.

12. ***AllAboutBirds.org,***

All About Birds is an online guide to North American birds produced by the Cornell Lab of Ornithology. The website features in-depth species information, photos, sounds of bird calls, videos, and range maps to help users identify bird species and contribute their observations to research projects.

AI for Biodiversity

Advancements in the development of AI tools are helping drive new discoveries about biodiversity. At the intersection of computer science and biodiversity, these tools are being used to address fundamental questions about species behavior, interactions, and distributions; the environment; and the structure of the tree of life.

13. **Imageomics Institute,**

    The Imageomics Institute (imageomics.osu.edu), a National Science Foundation funded cross-institutional collaboration, is creating digital resources and innovations in machine learning (ML) to aid scientists in studying wildlife and their habitats and behaviors. Institutional partnerships, including the Ohio State University, Virginia Tech, and UC Irvine Libraries, enable interdisciplinary collaboration among biologists, computer scientists, and information professionals to enable advances in ML applications for biology.

14. **Machine learning in wildlife conservation**
    by Devis Tuia et al. In "Perspectives in machine learning for wildlife conservation," *Nature Communications*, 2022.

    A range of information about organisms can be extracted from images with ML tools. This paper shows how ML tools can detect body posture to infer animal behavior, extract features of organisms to identify individuals in the wild and during encounters with other individuals, and analyze drone or satellite images to locate or track animals.

15. ***Real-time imaging using unmanned aerial vehicles,***
    by Jenna M. Kline et al. In "Integrating biological data into autonomous remote-sensing systems for in situ imageomics: A case study for Kenyan animal behavior sensing with unmanned aerial vehicles (UAVs)," 2024.

    Autonomous, unmanned aerial vehicles (UAVs) can cover remote and diverse terrain efficiently to collect real-time image data about wildlife. The autonomous remote-sensing systems track wildlife to yield data that supports conservation efforts.

16. **Discovering evolutionary traits using machine learning,**
by Harish Babu Manogaran et al. In "What do you see in common? Learning hierarchical prototypes over tree-of-life to discover evolutionary traits," 2024.

    Machine learning can be used to extract the unique, identifying features of species from their images, just as a human would when examining a physical specimen or photo. This study uses ML to discover "hierarchical prototypes" of features that are common to a group of species, which evolutionary biologists can use to identify relatedness of species on the tree of life.

17. **Flukebook.org**

    The online research platform Flukebook uses computer vision algorithms and AI to identify whale and dolphin species and individuals in photos. Algorithms create a digital profile for each individual based on features such as body coloration or the shape of fin edges.

Nature Field Guides

Designed to be taken into the field, field guides help biologists and nature enthusiasts identify wildlife. Photographs and illustrations are usually labeled with key physical features to help identify species. Other details include information about habitat, similar species, and conservation status as well as diet and nesting (for animals) and fruit and uses (for plants). Range maps also help users hone in on the possible species occurring near their locations.

18. ***Sibley birds west : field guide to birds of western North America,***
    by Sibley, David, 1961- author, illustrator.

19. ***Peterson field guide to North American bird nests,***
    by Casey McFarland, Matthew Monjello, and David Moskowitz; with contributions by Emily Gibson.

20. ***Insects of North America : a field guide to over 300 insects,***
    by David M. Phillips, PhD.

21. ***Peterson field guide to western reptiles and amphibians,***
    by Samuel M. McGinnis and Robert C. Stebbins; illustrations by Robert C. Stebbins ; sponsored by the National Audubon Society, the National Wildlife Federation and the Roger Tory Peterson Institute.

22. ***California plants : a guide to our iconic flora,***
    by Matt Ritter; [foreword by Edmund G. Brown Jr., Governor of California].

23. ***A field guide to coastal fishes. from Alaska to California,***
    by Val Kells, Luiz A. Rocha, Larry G. Allen.

Citizen Science

Citizen science involves public participation in research with the goal of expanding scientific knowledge. Volunteers contribute to research projects by observing local animals and plants, collecting ecological data, identifying wildlife species, and analyzing images. Citizen-science projects help facilitate research projects while fostering community involvement in scientific discovery.

24. **iNaturalist.org,**

    iNaturalist is an online social network of citizen scientists, naturalists, and biologists sharing observations about wildlife. The platform's computer vision model provides automatic species identification, which is verified by the iNaturalist community.

25. **Seek mobile app,**

    The Seek app (inaturalist.org/pages/seek_app) uses computer vision technology to help users identify species in real time as they explore nature. Observations can be uploaded to the iNaturalist biodiversity repository to help scientists find and use the data.

26. **Zooniverse.org,**

    Zooniverse is a popular platform for people-powered research. Volunteers help scientists create large-scale datasets, and completed projects are made available to the wider research community. In the sample image from the "Plants to Pixels" project, users examine high-quality images of plant specimens and transcribe the information on the museum labels to create searchable text.

27. **eBird.org,**

    eBird is an online resource and mobile app developed by the Cornell Lab of Ornithology. Users can keep track of their bird sightings, photos, and sounds and contribute their data to scientific research and conservation. The sample image is of a great-tailed grackle (*Quiscalus mexicanus*) sitting on a car's side-view mirror taken at Carl Thornton Park in Santa Ana, California.