Linnaeus's Legacy Carries On

Following the tradition of its most famous taxonomist, Sweden aims to be the first country to complete an inventory and pictorial guide to its biodiversity

UPPSALA, SWEDEN—Nestled in the heart of this historic university city is a quiet garden with tidy rows of raised beds. It has been restored to the way it looked 260 years ago, when Carl Linnaeus occupied the adjacent house and paced the garden paths, formulating his influential *Systema Naturae*—a scheme for grouping and naming organisms according to their shared characteristics.

Linnaeus is a source of national pride for Swedes, many of whom share his appreciation of nature, says Ulf Gärdenfors, deputy director of the Swedish Species Information Center (SSIC), which compiles "red lists" of threatened flora and fauna that are used to guide national and international conservation policy. An entomologist, Gärdenfors is spearheading an effort that would continue the legacy of Linnaeus by making Sweden the first country to create a complete inventory of all of the multicellular species living within its borders. Known as Svenska Artprojektet, or the Swedish Taxonomy Initiative (STI), the project has just entered its fourth year and, Gärdenfors says, is on track to meet its goal of completing the inventory by 2021.

This is not the first attempt to create an all-taxa biodiversity inventory, as such catalogs are known. But although many biodiversity inventories, including the better-known INBio project in Costa Rica, have struggled to find secure funding (see sidebar), the Swedish project, headquartered at SSIC's woodsy campus just outside of Uppsala, seems to be picking up steam. Last fall, the Swedish government nearly doubled STI's budget to $9.3 million for 2005. If the money keeps coming, supporters say, it will not only fund the inventory but also help revitalize Sweden's natural history museums, train a new generation of taxonomists, and produce a lavishly illustrated set of encyclopedias-cum–field guides written for laypeople.

The project's two audiences, scientific and popular, are equally important, says STI co-founder Fredrik Ronquist, who's now on sabbatical from Uppsala University at Florida State University in Tallahassee. "There's a lot of emphasis in Sweden on the broader impact of scientific research," Ronquist says. "[We recognize] the importance of spreading scientific knowledge to the public and making sure it's used by policymakers."

Rich heritage. In this house 260 years ago, Linnaeus formulated his system for classifying organisms.

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No rainforests

It's fair to say that Sweden is not a biodiversity hot spot. Its 450,000 square kilometers contain an estimated 60,000 species. The same number might be found in a few hundred square kilometers of tropical rainforest, says Daniel Janzen, an ecologist at the University of Pennsylvania in Philadelphia and INBio co-founder. Still, Janzen and others applaud the taxonomy effort. All-taxa inventories "are building blocks that can get us closer to understanding biodiversity," says

Taxonomy's Elusive Grail

A complete catalog of life on Earth ranks near the top of biologists' all-time wish list. To date, fewer than 2 million species have been described—perhaps a fifth of the planet's total.

In 2001 an ambitious group of Silicon Valley–types teamed up with several prominent researchers, including Harvard's E. O. Wilson and Peter Raven of the Missouri Botanical Garden in St. Louis, to launch the All Species Foundation, with the goal of cataloging every species on Earth in 25 years (*Science*, 26 October 2001, p. 769). Unfortunately, says Raven, the dream died when the dot-com bubble burst and donations dried up. A recent visit to the All Species Foundation Web site brought up a page simply titled: *Gone*.

Several other efforts are under way to inventory all of the species in a restricted area within some limited time frame—what's known as an all-taxa biodiversity inventory (ATBI). Three major projects are up and running, says Daniel Janzen, an ecologist at the University of Pennsylvania in Philadelphia.

The most recently launched ATBI, based in Uppsala, Sweden, aims to inventory that country's estimated 60,000 species within 20 years (see main text). Janzen helped set up the first in Costa Rica in 1989. The mandate of Costa Rica's Instituto Nacional de Biodiversidad (INBio), based outside San José, was to inventory all of that country's estimated 500,000 species. Janzen initially hoped to jump-start INBio with a 7-year project to inventory the species-rich Area de Conservación Guanacaste. But those plans fell apart amid political wrangling in 1997 (*Science*, 9 May 1997, p. 893).

The national survey continues today, Janzen says, but efforts are dispersed across the country with no definite time frame for completion. Part of the problem is inconsistent funding. INBio is not supported by the Costa Rican government; instead, it patches together money from a variety of sources, including contributions from foreign governments and ticket sales from its conservation theme park, INBioparque. In 2003, INBio raised $6.1 million.

The first project in the United States, the Great Smoky Mountains National Park All Taxa Biodiversity Inventory, started in 1999 (*Science*, 11 June 1999, p. 1747). It is run jointly by the National Park Service and a nonprofit organization called Discover Life in America. Work on the inventory reaches a fever pitch each summer when scores of scientists and thousands of volunteers converge on the park. Keith Langdon, the National Park Service's coordinator for the project, says it's hard to say how many species have been cataloged because each taxa goes into a separate database, but others say it's in the neighborhood of 12,000 to 15,000 of the 100,000 species estimated to live there. And the project may spark imitations: Langdon says several other parks and conservation areas in the United States have approached him for advice on setting up their own inventories.

But they may face an uphill battle for funding. The Great Smokies project has relied almost entirely on donations, which have totaled about $150,000 per year. This year, however, Langdon is optimistic that the project will get some money—perhaps as much as $200,000—from Congress. In the meantime, he says, "we're doing the best we can with the limited funding we have."

–G.M.

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Peter Raven, director of the Missouri Botanical Garden in St. Louis. "Whatever someone has the resources and funding to do is great."

A complete inventory of all the flora and fauna in any particular area would be a huge boon for ecologists, says Ronquist. Without the full cast of characters, it's impossible to determine how all the players in an ecosystem work together, he says.

Such inventories are also key for conservation and management. In Sweden, Ronquist says, only about 20,000 species have been considered for inclusion in the red lists: "There is a large number of species for which there's not enough information to even say whether they're threatened or not."

Even so, most of Sweden's flora and fauna have already been discovered, which gives STI a big head start. In 2003, SSIC published a list of 50,741 known species. But about two-thirds of these are described in obsolete scientific literature, using outdated criteria, says Gärdenfors.

Revising the descriptions to bring them up to date with modern naming conventions and species delimitations is a large part of STI's task and will ultimately occupy about 100 taxonomists. Another 40 or so researchers are working on filling in the gaps. Sweden has never had a good inventory of its marine species, Gärdenfors notes: "We had one in the 1920s, but it wasn't systematically done." Last summer, STI led a team of scientists and divers on a pilot survey of 80 locations off Sweden's west coast, and they are gearing up for a larger and more systematic survey of the west coast in 2006.

To survey terrestrial organisms, STI scientists are enlisting the help of Sweden's amateur naturalists. Many Swedes, especially among the older generations, pride themselves on being able to identify all of the plants and animals near their homes, says SSIC director Torleif Ingelög, and more than 1000 amateur naturalists contribute data used to compile the Swedish red lists.

The largest survey at the moment is of two relatively understudied groups: *Diptera* (flies) and *Hymenoptera* (ants, bees, and wasps). Amateur naturalists monitor a network of insect traps located at select points throughout the country, periodically emptying the trapped insects into an alcohol solution and mailing them off to a natural history museum, where professional taxonomists identify and catalog them. The estimated 100 million insect specimens collected in 2003 and 2004 may contain hundreds of species previously unknown to science, Gärdenfors says. He adds that 20 new species already have been identified in a single fly genus, *Megalesia*. As the major gaps in the inventory are filled in, additional surveys will be planned to address the remaining holes.

But even in the country that gave birth to taxonomy, there aren't always enough taxonomists to go around. A major goal of STI is to bolster this taxonomic infrastructure. STI's current funding supports four or five new taxonomy Ph.D. students each year, a rate that would more than double the number of Ph.D.s in the field in Sweden over the project's 20-year lifetime. And nearly $3 million a year will go to refurbishing another neglected but important part of Sweden's taxonomy infrastructure, its natural history museums, some of which house important collections that date back to Linnaeus's time.

Pretty as a picture

While the scientists are busy collecting and cataloging, a team of illustrators is working hard to make the species look their best. Torbjörn Östman is one of nine Swedish artists STI has commissioned to work on the encyclopedias. In a 100-year-old schoolhouse near Lake Malvern that he's converted into his home and studio, Östman shows off a piece of recent work, a fantastically detailed rendering of the Eastern Puss Moth, *Cerura erminea*.

Back to nature. Ulf Gärdenfors oversees hundreds of scientists and amateur naturalists working on the all-taxa inventory.

To illustrate the moth, Östman worked from two museum specimens, both of which were in bad shape. Using a digital camera attached to a microscope, he captured a set of images of each specimen at different focal planes. He then merged those images and doctored the composite on a computer to create an archetypical example of the hairy black-and-white moth.

Perfect specimen. An artist's rendition of the Eastern Puss Moth, based on a blemished museum specimen (*inset*).

The illustrators working on the encyclopedias use a variety of techniques, but the images all end up looking more or less like watercolor paintings. That's partly because watercolor is a traditional medium for natural history illustrations, Gärdenfors says, and partly because it allows the artists to include all of the key markings and other characteristics for identification—a convergence that's rare in real-life specimens.

The first volume of the encyclopedia, on *Lepidoptera*, the order of insects that includes moths and butterflies, is scheduled for release in April, followed later this year by others on myriapods (centipedes and millipedes) and bryophytes (mosses and their relatives). In all, 120 volumes are planned and will include the roughly 30,000 species that can be identified easily by nonspecialists. The books will also contain distribution maps and identification keys.

Christer Engström, editor in chief of the series, envisions families passing the encyclopedias down through the generations, keeping the Swedish naturalist tradition alive. Indeed, there are signs that the naturalist spirit isn't lost on the younger generation. Sweden's popular Princess Victoria, 27, has given the project her blessing. Visiting the STI team last year, Victoria confided that biology was her favorite subject in school. "It's the best patronage we could have," says Engström. **–GREG MILLER**

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