Instruments on a 50-metre-tall tower in western Virginia will monitor the metabolism of the forest by measuring carbon dioxide and water vapour.

ECOLOGY AIMS HIGH

The United States is sinking nearly half-a-billion dollars into a grand ecological observatory, but the project has been dogged by budget overruns and delays.

BY CHRIS CESARE

Overgrown shrubs thwack the sides of a pick-up truck as it bounces along a dirt road through a forest in western Virginia. On the drive, ecologist Ty Lindberg calls out the names of the invasive species crowding either side of the path. There is mile-a-minute weed, which spreads with alarming speed. A flowering annual called Asian stiltgrass carpets the ground and stifles native plants. And a particularly prickly species of rose tears at the clothes of anybody who ventures too close. "My field techs don't enjoy that one," Lindberg says.

Farther along, he stops the car at a break in the brush and picks his way through the undergrowth towards a set of plastic and aluminium stakes poking out of the ground. They mark out a 40-by-40-metre plot, one of dozens scattered throughout 1,300 hectares of forest and pasture near the town of Front Royal. From April to October, field technicians spend their days cataloguing the location, diameter and height of nearly every tree in the plot, collecting fallen leaves out of a trap and archiving pressings from invasive plants. Their main goal is to measure the ecosystem's metabolism, especially how much biomass it generates each year.

At other plots, technicians trap rodents and draw blood samples to test for diseases, including those that could spread to humans. The staff collects and stores ticks and beetles, and takes soil samples to study the bacteria underfoot. Higher up in the hills, a 50-metre-tall metal tower juts above the trees, loaded with long booms holding sensors that monitor air temperature, wind speed and solar radiation at multiple altitudes. When the tower has its final instrument package installed in 2016, it will watch the forest breathe by monitoring how carbon dioxide and water vapour concentrations rise and fall.

This site is one of more than 80 planned for the National Ecological Observatory Network (NEON), a US$434-million project to build a biological observatory that spans the United States. Its goals are grand. If all goes well, it will document the effects that climate change and land use have on ecosystems and provide scientists with a nearly real-time measure of the country's ecological vital signs. Many of the sites will operate for three decades, whereas others will be packed up and relocated periodically in response to environmental changes. And the data collected will be freely

CHRIS MADDALONI/NATURE

available to all through an online portal.

Lindberg, who manages three NEON sites in Virginia and Maryland, says that the long-term record generated by NEON could transform ecology by helping scientists to answer questions ranging from how invasive species are altering the landscape to how quickly infectious diseases are spreading through ecosystems. The network, he says, "is really an instrument". Ecologists call it their first foray into big science — a massive project that rivals the scale of big-budget physics facilities such as particle colliders or telescopes (see 'Sentry posts').

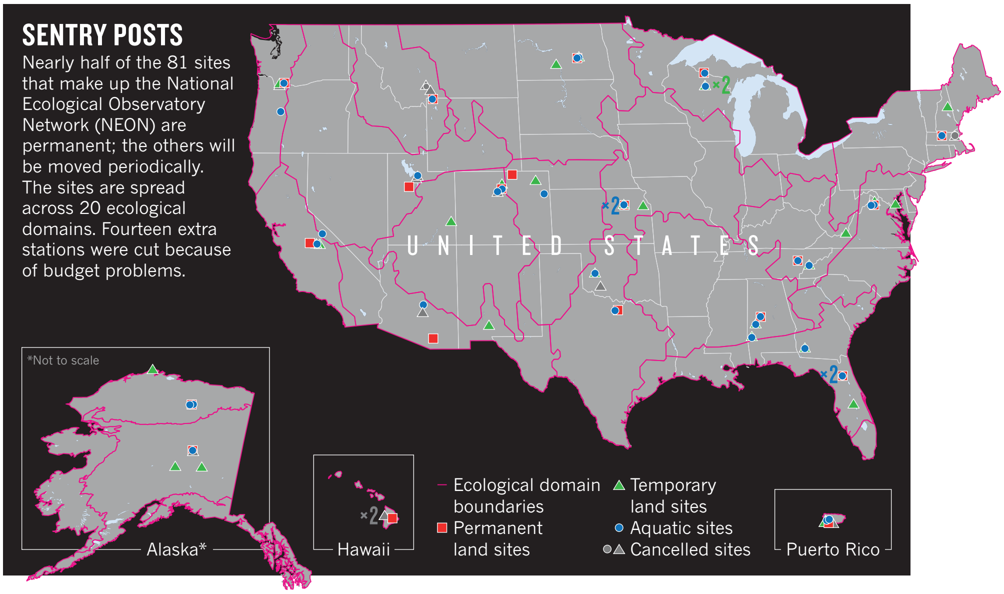
But ecologists have not had an easy journey into the world of big science. During its five-year construction phase, NEON has encountered a series of high-profile problems that have raised concerns about the programme, which is funded entirely by the US National Science Foundation (NSF). In June 2015, the network came under fire from the NSF and Congress after NEON, Inc. — the non-profit organization that manages the project — reported that it was running \$80 million over budget. Amid revelations that the company had spent federal money on parties, Congress levied charges of mismanagement and convened hearings with officials from NEON and the NSF. Events came to a climax in December, when the NSF decided to take NEON, Inc. off the project, citing a lack of confidence in the company after years of delays and questions about accounting irregularities.

The agency will now seek another operator to complete construction and take over the project's management. One of the toughest tasks will be winning the support of ecologists; some researchers felt alienated during the project's planning phase and have been critical of the way the observatory network is turning out.

Still, many ecologists are eager to get their hands on NEON's data and are already thinking about how to incorporate it into their studies. Ultimately, the science that they produce will determine whether the project succeeds or fails. "You build out NEON and in 30 years you're going to have unprecedented data on how ecosystems are changing," says Peter Groffman, an ecosystem ecologist at the City University of New York. "It's very exciting and very much the next logical evolution of long-term studies."

BIG BIOLOGY

The debates about NEON reach back to its early evolution, when it took shape in a manner very different from a major physics project. Scott Collins, an ecologist at the University of New Mexico in Albuquerque, was the first NSF programme director for NEON back in 2000. Collins says that the idea for a large ecological observatory sprang from NSF staff who were seeking ways for biologists to get a slice of the agency's big-science money: the Major Research Equipment and Facilities Construction budget. "That put us on a very different footing from the start because this was not



SOURCE: NEON

"I THINK IT'S GOOD FOR SCIENTIFIC COMMUNITIES TO DREAM BIG."

something that the community and vocal ecologists had wanted," Collins says.

Although researchers did not dream up the project, they quickly embraced the idea and took the lead in moulding NEON's design during workshops. At these meetings, attendees were encouraged to dream big, says Katherine Gross, the director of Michigan State University's W. K. Kellogg Biological Station in Hickory Corners and the current chair of the NSF's biological-sciences advisory committee.

During six workshops between 2000 and 2002, ecologists developed a plan for a flexible network of observatories and experimental centres spread across at least ten sites. But scientists disagreed over whether the NSF should specify research themes for each site or allow ecologists to choose their own focus.

In its 2002 budget request to Congress, the NSF asked for \$12 million to develop and build two prototype NEON sites, largely based on the reports from the workshops. But Congress denied the request, citing a lack of information about the project and an insufficient estimate of its costs.

At the time, the best model that US ecologists had for NEON was the Long Term Ecological Research network, a group of investigators in the United States who study the ecology of a particular spot for five or more years with sets of measurements specialized to each site. The leaders of NEON, however, eventually settled on a one-size-fits-all approach, with standard protocols and instruments that could be deployed across the entire network to study pressing issues, including changes to biodiversity and climate change. And instead of having principal investigators propose individual observatories, an expert panel recommended that the NSF develop NEON as a nationwide network managed by one entity.

Encouraged by Congress to continue refining its idea of NEON, the NSF issued a call for proposals in early 2004. A \$6-million grant to design NEON went to several members of the American Institute of Biological Sciences in Reston, Virginia, a non-profit organization that had been involved in the project's earlier planning. A little more than a year later, in December 2005, the lead designers created NEON, Inc.

Over the next several years, the structure of NEON took shape. The network split the country into 20 domains, each with several sites outfitted with instruments and collection protocols.

FEELING IGNORED

But when it came to choosing where to build sites and how best to make measurements, some ecologists objected to the choices and felt that their expertise had been ignored. Gene Kelly, a soil scientist at Colorado State University in Fort Collins — and now the interim chief executive of NEON, Inc. — says that the emphasis on measuring the same quantities everywhere meant that NEON had to sacrifice having the optimal protocol for every spot. "The only way to really handle it was to standardize it, but in doing that you lose a little," he says.

Kelly says that many ecologists, including him, stopped following the progress of the project closely after these decisions were made, partly because NEON, Inc. stopped asking for input.

Despite the loss of some engagement from the ecological community, the NSF approved

NEON's final design in 2009, and Congress authorized the money for construction in July 2011. The network would spread 17,000 sensors measuring hundreds of variables — from soil moisture to stream pH — across nearly 100 sites. And at each site, technicians would collect a suite of biological samples, including genomic data from many organisms and whole specimens of insects and small mammals. The result would be a standard set of ecological data that would allow scientists to compare and watch for changes in ecosystems and to produce ecological forecasts.

Concerns about the company's accounting and the NSF's oversight cropped up almost immediately after construction began in 2012. A review that year found that NEON's books were a mess: auditors questioned more than one-third of the total construction cost — \$154 million — and determined that NEON, Inc. did not provide enough information to support its proposed budget.

Later audits and investigations unearthed questionable spending by NEON management, including \$25,000 for a party and \$3,000 for T-shirts. Also, the company moved to a new office and paid nearly \$500,000 for time left on the old lease. After the audits, the NSF's inspector-general urged the agency to keep a closer eye on the project.

Despite the accounting problems, the NSF and NEON, Inc. forged ahead with construction — and ran straight into delays. Some could have been predicted, such as the difficulty of obtaining permits to build observation towers in cities. Others were simply bad luck. At the site in western Virginia, a tree fell over and destroyed a collection of atmospheric instruments. A bear damaged fibre-optic data lines running to soil-monitoring instruments near the Virginia site's tower. And concerns about the health of a pregnant cheetah at a nearby conservation facility forced NEON, Inc. to abandon plans to use a helicopter to hoist the topmost sections of the instrument tower into place. Instead, construction staff raised the final sections by hand.

The delays put NEON behind schedule and over budget. In June 2015, the company told the NSF that it would take an extra \$80 million on top of the \$434-million budget to complete construction.

With Congress already concerned about the NSF's stewardship, the agency demanded that the project be downsized to stay within its budget. It told NEON, Inc. to cull the number of sites from 95 to 81, cancel construction of its stream experiments and give up some of its embedded sensors. NEON, Inc. then fired its chief executive last September and appointed Kelly to serve as an interim. But the company sealed its fate in December when it submitted an updated budget that again had extra costs and delays. The NSF decided to look for a new company to manage the project.

Whoever takes over will step into a difficult role, as many ecologists remain disconnected from the project. Yet there are still big hopes for NEON in the research community. "I think it's good for scientific communities to dream big and say, 'OK this will be our unifying project,'" says Ash Ballantyne, a bioclimatologist at the University of Montana in Missoula. "It's analogous to our LHC."

Clockwise from top: a camera monitors stream depth, a tag marks invasive species and a marker delineates plots at a site in western Virginia.

CHRIS MADDALONI/NATURE

GLOBAL REACH

Interest is growing as money starts to flow towards individual researchers. In August, the NSF awarded \$4.8 million in grants to investigators and workshop organizers who are interested in using NEON data. Ballantyne received \$300,000 to study the effects of drought, fire and insect infestations on the carbon cycle. He plans to investigate how drought or other disturbances predispose trees to a beetle outbreak or fires.

Jim Clark, an ecologist and statistician at Duke University in Durham, North Carolina, won a grant to build more-sophisticated ecological models. "We've always modelled on a species-by-species basis," Clark says. "If there's 100 species, someone has fitted 100 different models and just added them together." This ignores the interactions between species, he says, and NEON data on species abundance could help to fit and train joint models for how species respond to ecosystem changes collectively.

Frank Davis, an environmental scientist at the University of California, Santa Barbara, says that he plans to use NEON's airborne observations to study tree cover at various scales, from a few centimetres to several kilometres. Many ecologists are not accustomed to thinking at the large scale that NEON covers, Davis says. "Ultimately, I think NEON will be ready for ecologists," he says. "But will ecologists be ready for NEON?"

Some are gaining valuable experience thinking at global scales by running their own distributed networks. The Global Lakes Ecological Observatory Network began in 2005 and ties together groups around the world that monitor human effects on lake ecosystems. The Nutrient Network, or NutNet, links researchers on six continents who perform a standard set of experiments looking at how plant production in grasslands is limited by phosphorus and nitrogen — two by-products of fossil-fuel combustion. Other networks are springing up to study plant populations and drought.

These projects are smaller in scope than NEON, which gives researchers more control over the work. With only a handful of voices deciding how to conduct experiments or take data, projects such as NutNet can maintain a tight focus on the science. "It's very hard for NEON to do this because the entire ecological community has a say," says Elizabeth Borer, an ecologist at the University of Minnesota in St Paul and a member of NutNet.

Ecologists are still struggling to learn how to manage large projects, says Nikki Thurgate, an ecologist at the University of Adelaide in Australia and leader of international engagement for the Terrestrial Ecological Research Network — a smaller, Australian cousin of NEON. But if ecology is to forecast the problems that arise from climate change and loss of biodiversity around the world, it will need the data from large-scale networks. And one of the challenges is to keep the community engaged and informed while they wait for a grand scientific instrument to be built. "You can't pop up continent-wide environmental monitoring and have data in a couple of years," Thurgate says. "It's just not that simple."

NEON's early struggles may fade when data start to arrive in the next few years from sites such as the one that Lindberg manages in western Virginia. On a cold day late last year, Lindberg — who still has his job for the time being — stood below the nearly finished observation tower rising high above the surrounding forest. In a nearby shed, dozens of boxes held sensors and electronics to be installed on the tower. Despite the work that remains here and at other sites around the country, Lindberg still thinks that the project can be successful — as long as researchers embrace it. "It's a scaffolding," he says. "But this thing doesn't work unless scientists use it." ■

Chris Cesare *is an intern with* Nature *in Washington DC.*