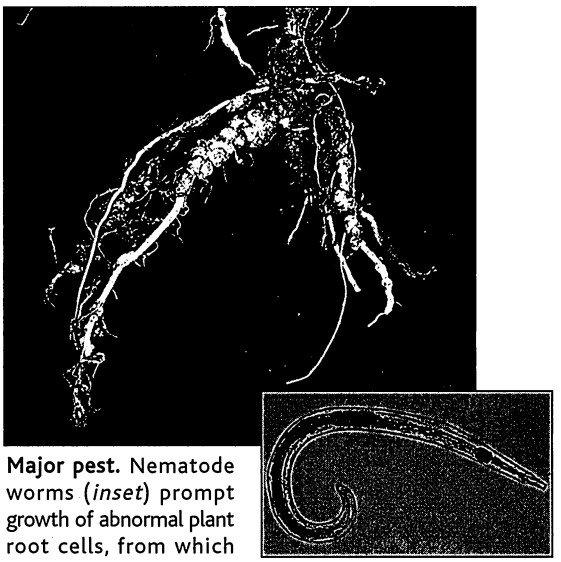
available nematocides are environmentally undesirable compounds," says plant scientist Chris Lamb, director of the John Innes Centre in Norwich, U.K. Using cell cycle disrupters to upset nematode feeding "is a new and interesting idea," he adds, although he cautions that it's still "untested."

When the tiny worms invade the roots of plants, they trigger the formation of either tumorlike growths called "galls," which contain large, multinucleated cells with dense cytoplasm and numerous mitochondria, or syncytia, large collections of cells that have fused. Either way, the nematodes feed on these abnormal cells, sucking out nutrients for themselves and severely damaging or killing the plant. Apparently, the worms trigger the formation of these abnormal cells by turning on a variety of plant genes, including some needed to drive the cell cycle. About a year ago, Inze and his colleagues showed that cell cycle inhibitors can prevent the formation of the multinucleated cells or syncytia—a change that could deprive nematodes of their preferred feeding grounds.

The Belgian workers have now performed a genetic manipulation on the small experimental plant *Arabidopsis* that essentially tricks invading nematodes into turning on a cell cycle blocker. The researchers had previously identified a gene regulatory element called a promoter that is activated in plant cells by nematode feeding. This leads to activation of the cell cycle and other genes needed to induce gall or syncytium formation. Inze and his colleagues have coupled this promoter to a gene that produces a kinase enzyme known to inhibit the cell cycle. When this hybrid gene was introduced into *Arabidopsis*, the cell cycle arrested specifically in the parts of the roots invaded by nematodes, preventing the formation of the large feeding cells. The nematodes could not feed anymore, and the plants became free of nematode infection.

So far, Inze says, "cell cycle studies in plants are in the early stages." Researchers will need to show that similar genetic manipulations can be achieved in crop plants. But Inze predicts that the work has the potential to produce plants resistant to nematodes and other pests and pathogens. "Plant development is quite plastic," he notes. "It can be managed."



Major pest. Nematode worms (*inset*) prompt growth of abnormal plant root cells, from which they remove nutrients.

–ANNE SIMON MOFFAT

EARTH-MONITORING SATELLITES

Will the U.S. Bring Down The Curtain on Landsat?

Researchers are fawning over improved images from the new Landsat 7 satellite. But they also worry that there may not be a suitable successor to the government-built spacecraft

Last month a small group of earth scientists got their first detailed look at data from a $700 million U.S. earth-monitoring satellite. It was a knockout. Landsat 7, launched in April 1999, was performing far above expectations, producing detailed images of forests, volcanoes, ice sheets, and other signs of global changes. "This is the finest terrestrial observatory we have ever flown," crowed Sam Goward, a geologist at the University of Maryland, College Park.

Their delight, however, was tempered by a big concern: Landsat 7 could be the last of a line of satellites first launched in 1972. Although the craft is scheduled to operate until at least 2006, there's already a struggle under way to decide who—if anyone—should build and operate a successor, at a cost of at least $400 million. That decision will shape the future of Landsat's 27-year-old data archive, which has been used for everything from monitoring desertification to identifying growing suburbs ripe for new fast-food outlets.

Private companies say they are the rightful heirs to the earth-sensing throne, and they want the government to get out of the burgeoning imaging business. But many researchers worry that science will suffer if private companies call the shots. They want the federal government to remain in charge, perhaps as part of an international consortium. "The question is how to make a transition without jeopardizing the [extension of the] largest existing land-observation data set in the world," says Donald Lauer of the U.S. Geological Survey (USGS) in Sioux Falls, South Dakota.

An eye on change

While other earth-sensing satellites are focused on the oceans or atmosphere, Landsat keeps an eye on terra firma. The 4-meter-long, 2200-kilogram current model, for instance, carries sensors that collect data in eight wavelengths of visible and infrared radiation, producing snapshots that cover 183-km-by-170-km patches of ground. The images, which allow researchers to identify different kinds of soil, vegetation, and land uses, detail objects down to 30 meters across and feed a community that ranges from military planners to geologists. Although new commercial satellites have much finer resolution—down to 1 meter—Landsat's broader view "is more appropriate for studying large-scale changes," says earth scientist Curtis Woodcock of Boston University (BU). And because Landsat 7 returns to the same spots every 16 days and follows paths blazed by older siblings, researchers can monitor changes over time scales ranging from weeks to decades.

The Landsat archive's value for tracking long-term landscape changes was highlighted at a recent meeting in Boulder, Colorado, of the satellite's science team, a group of 14 investigators funded by NASA and USGS. Woodcock, for instance, documented the growing holes that loggers have carved into Oregon's old-growth forests over the past 15 years (see images). Geologist Alexander Goetz of the University of Colorado, Boulder, has quantified the vast expansion of pivot-arm irrigation—in which a long sprinkler arm turns around a central pivot, like the spoke of a wheel—over the same period in a 1-million-square-kilometer arid patch of the western United States. The irrigation pattern could influence how ancient sand dunes in the area behave if an extended drought strikes, or when farmers exhaust groundwater supplies. "We're trying to develop a model that will tell us if we're going to get a dust bowl, or something even worse," he says.

The improved performance of Landsat 7's Enhanced Thematic Mapper Plus (ETM+)—its primary instrument—was the focus of other researchers. David Skole of Michigan

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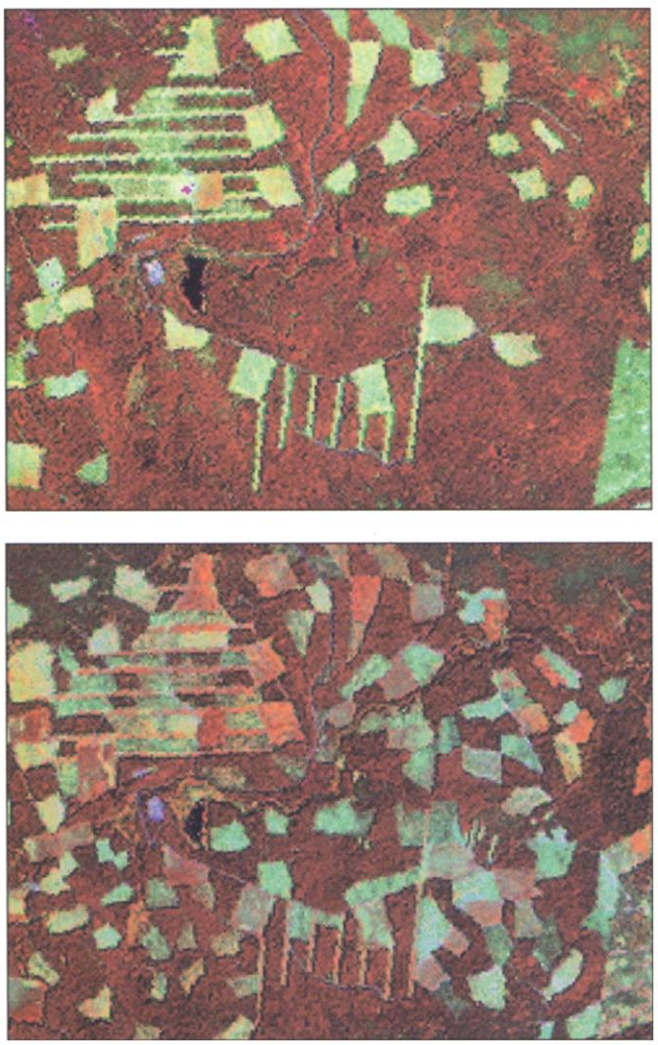
State University in East Lansing showed that new sensors carried by the ETM+ are better able to spot the subtle electromagnetic clues left behind by logging and other activities occurring beneath the canopy of the Amazon rainforest. Those changes were invisible to earlier sensors, raising questions about the accuracy of previous estimates of Amazon deforestation using Landsat data. Drawing on images taken thousands of kilometers to the south, Robert Bindschadler of NASA's Goddard Space Flight Center in Greenbelt, Maryland, is assembling the first comprehensive picture of Antarctica since the first Landsat.

There are several reasons why researchers are excited about the Landsat 7 data. Better calibration means they won't have to massage the data to determine exact geographic coordinates or to compensate for glare or hardware glitches. That "will save the research community untold hours and expense," says Goward, the science team's leader. The improved quality also comes with a lower price tag and faster service: Landsat 7 images cost just $600 each, compared with $4400 for one picture in previous editions, and are available to users within days rather than months.



Clear-cut insight. A 1984 image from Landsat 5 (*top*) and a 1999 twin from Landsat 7 (*bottom*) reveal the spread of logging in Oregon's Cascade Mountains.

CREDIT: C. WOODCOCK/BOSTON UNIVERSITY

Orbital soap opera

Landsat's troubled history, however, suggests that researchers can't assume that the current flow of good, cheap, quick data will continue from a new satellite. Bureaucratic turf wars and funding crises have plagued the program since USGS researchers first proposed Landsat in 1969. "Each satellite has faced a *Perils of Pauline* situation," recalled Lawrence Pettinger, a remote-sensing scientist with the USGS in Reston, Virginia, at a recent meeting on Landsat's future.* Congress has never been a great fan of earth-imaging satellites, which lack the economic and life-saving lure of weather satellites or the romance of interplanetary probes. In addition, private companies have long argued that the government should stay out of the field of moderate-resolution imaging altogether.

In the late 1980s, such claims helped convince legislators, over the objections of some federal agency officials, to begin privatizing the program. Landsats 4, 5, and 6 (the last failed to reach orbit in 1993) were essentially run by contractors in an arrangement that proved disastrous for researchers. The companies "decided to collect not very much data, and to charge a whole lot for it," says BU's Woodcock. The rising costs of imagery "basically killed the [research] program" for years, he says.

That and other "truly ugly" privatization problems, Lauer says, prompted Congress to reverse course and make Landsat 7 a government project. But in another confusing move, legislators decreed that, after Landsat 7 died, the government should strive to obtain new earth images from private sources. As a result, NASA is looking for companies to continue the quality and coverage of Landsat 7 at an affordable price, and at least one has responded affirmatively.

"We can maintain Landsat continuity," asserts Tom Koger, an executive with Resource 21, a Boeing-backed satellite effort. The company wants to launch four craft that would provide farmers with information about everything from soil moisture to weed growth, helping them pinpoint where to fertilize, spray, or irrigate. Resource 21's data "will be very similar to Landsat's," he says.

But some researchers are skeptical of such assurances. One problem, they say, is that private firms have little motivation to build the expensive sensors that collect data in all of the wavelengths covered by Landsat 7, as most customers can get by with less. Another is that the government may be unwilling to buy the global coverage—amounting to some 250 scenes per day—that Landsat now provides. Goddard's Darryl Williams, chief Landsat scientist, wonders whether the private sector will bring "the same passion and concern for detail" to the project. NASA engineers, for instance, delayed Landsat 7 for nearly a year to improve balky diodes that lowered data quality. A company focused on profits would be unlikely to do the same, he says.

Finally, Williams and others doubt that the market for moderate-resolution satellite images is big enough for Resource 21, or any company, to make a profit. "Landsat is not commercially viable for cost recovery," says Williams, noting that other countries subsidize their moderate-resolution imagers. In light of such issues, "why is the government-owned option the leper here?" he asks. But Koger says his company isn't counting on imagery sales to make a profit and that any government contract to continue the Landsat archive would be a bonus. "The Landsat heritage is very important to us," he says.

One public alternative to a U.S.-built satellite, says USGS's Lauer, is an international consortium. Nearly a dozen nations already fly or are planning to launch moderate-resolution imagers, he notes. "If they could agree on a common set of goals," Lauer says, they could save money and researchers could be assured of a steady flow of data.

NASA officials are expected to decide on a strategy by early next year, meaning that Landsat's backers must move quickly to preserve the program in anything like its current form. That timetable could pose an obstacle to researchers, says Woodcock, given the diverging interests of the satellite's users. "In some ways our strength is also our weakness," he says. "Where out of all that diversity do you find a common voice?"

–DAVID MALAKOFF

* Viewing the Earth: The Role of Satellite Earth Observations and Global Monitoring in International Affairs, George Washington University, 6 to 7 June.