Sanctuary or survival test? Scientists can only guess how pandas are faring in Baishuihe reserve, beyond the collapsed Xiao Yu Dong Bridge.

WENCHUAN EARTHQUAKE

A Deeply Scarred Land

Rock and mudslides in Sichuan have buried vast forested areas, ruined farmland, and disrupted the habitats of pandas and golden monkeys; the recovery will take decades

LONGMENSHAN, CHINA—In the morning of 12 May 2008, Ren Diandong gave a talk on landslide modeling at the Institute of Atmospheric Physics of the Chinese Academy of Sciences (CAS) in Beijing. A few hours later, Ren's model was put to the supreme test: a magnitude-7.9 earthquake in Sichuan Province's Longmenshan range (*Science*, 20 June 2008, p. 1578). As early reports came in that afternoon of a disaster that would leave nearly 90,000 people dead or missing, Ren, a climatologist at the University of Texas, Austin, knew the quake had struck in landslide country—and with the rainy season about to begin, the fractured land would soon be thick with mudslides.

In the weeks that followed, Ren and colleagues pored over satellite images of landslides, rock falls, and debris flows in an earthquake-ravaged area the size of Belgium. Their model suggests that slides buried about 235 million tons of carbon in vegetation from Longmenshan's forest ecosystem. As it rots in the coming decades, it should release more than 100 million tons of carbon dioxide (CO_2), according to the model—roughly equivalent to 2% of current annual global emissions from fossil fuel combustion. Soil in many landslide zones will also be nitrogen-poor for decades to come.

As China mourns the first anniversary of the Wenchuan earthquake, the ecological toll is just coming to light. Besides unleashing greenhouse gases, landslides caused widespread habitat fragmentation—threatening the region's unique assemblage of species, including its dwindling wild population of giant pandas. Landslides destroyed 122,000 hectares of vegetation, including 98,000 hectares of forest, says Bao Weikai, a plant ecologist at Maoxian Mountain Ecosystem Research Station of CAS's Chengdu Institute of Biology (CIB). It will take years of survey work, he and others say, to understand how Sichuan's biodiversity hot spot will respond.

Damaged habitats

On a misty late April day, schoolchildren on bicycles race home along a highway leading to the Longmenshan mountains. They blur past four elderly men playing mahjong outside a prefabricated shelter, past a group of women practicing tai chi moves in sync, past bustling construction sites in Tongji, where duplexes and townhouses will replace homes reduced to rubble by the Wenchuan earthquake. Most of the town's houses were destroyed, but by good fortune only a few dozen residents died. "When the earthquake struck, farmers were in their fields, and it was 3 minutes before the next class, so a lot of children were outside the school," says CIB ethnobotanist Luo Peng.

End of the line. The road to Baishuihe disappears just past this wrecked hotel in Longmenshan town.

In neighboring Longmenshan town, on the other side of the collapsed Xiao Yu Dong Bridge, the semblance of normality evaporates. Sheared-off slabs of highway lie in ravines, and landslides with patchy new grass entomb other sections. In a narrowing valley, just past a ruined hotel—ecotourism was Longmenshan's main source of revenue before the quake—the road leading to Baishuihe National Nature Reserve was wiped off the map.

That makes Zang Xuan's job difficult. Before the earthquake, the ranger lived in a field station deep inside the reserve. Zang and his fellow rangers escaped with minor injuries when their outposts collapsed. Nowadays, getting into Baishuihe is an arduous hike. "We can't carry out regular monitoring," Zang says. But from what they've seen in limited excursions, the damage is enormous: Landslides caused extensive forest fragmentation up to an altitude of about 2500 meters. "The earthquake damaged half of the giant panda's habitat in Baishuihe," says CIB forest ecology Pan Kaiwen. Rangers have no idea how the reserve's star attraction is faring, nor how other animals such as golden monkeys are coping. "With the road gone and no more tourists, maybe the pandas are happier. Or maybe they are struggling to find food," says Zang. "We just don't know."

Although the impact on the panda's food supply is still unclear, many farmers suffered real losses. "Landslides destroyed a lot of cultivated land," Pan says. One priority of the reconstruction effort is to identify new cropland—no easy task in the rugged earthquake zone. A failure to replace farmland could further harm the region's ecosystems, says Pan, if desperate former farmers were to start foraging in nature reserves for lucrative medicinal plants.

Slow recovery

Since the first days after the earthquake last May, a team led by geomorphologist Cui Peng of CAS's Institute of

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Some Unwelcome Questions About Big Dams

CHENGDU, CHINA—Soon after the magnitude-7.9 Wenchuan earthquake struck last May, geologist Fan Xiao uttered publicly what many anxious scientists were discussing privately: Could a large dam near the fault have triggered the devastating quake?

The 156-meter-high Zipingpu Dam began to fill in December 2004, and within 2 years the water level had risen to 120 meters. Following normal operation, the reservoir's level dropped as water was released downstream during the winter and early spring 2008 and was at a low level when the Wenchuan earthquake occurred. Removing the pressure of several hundred million tons of water on a slip thrust fault like Longmenshan may have destabilized it, increasing the risk of a rupture, argues Fan, a senior engineer at the Sichuan Bureau of Geology and Mineral Resources in Chengdu. Reservoir-induced seismicity is an accepted phenomenon, but Wenchuan's magnitude was much higher than that of the biggest earthquake previously linked to a dam, a magnitude-6.5 temblor in India in 1967 that killed nearly 200 people.

Dam or no, the Wenchuan earthquake was inevitable, Fan says. But he asserts that Zipingpu, just 5.5 kilometers from the quake's epicenter, may have caused the Longmenshan fault to fail decades or even centuries earlier than it might have without added stress. Fan's outspokenness—and *Science*'s coverage (*Science*, 16 January, p. 322)—has provoked the wrath of hydropower proponents and scientists who rule out a Zipingpu-Wenchuan link. *Science* spoke with Fan about his views. **–R.S.**

Q: What further evidence would support a Zipingpu-Wenchuan link?
X.F.: According to the State Council, every dam higher than 100 meters and with a capacity of more than 50 million cubic meters of water must have a special monitoring system to detect slight tremors. Zipingpu has such a system. A reservoir-triggered earthquake should have more foreshocks than a natural earthquake. Last fall, a paper in *Geology and Seismology* reported that before the Wenchuan earthquake, there were many small foreshocks around the dam. And this activity correlated to changes in the reservoir's water levels.

Q: You mean the earthquake swarm near Dujiangyan [a town near the epicenter badly damaged in the quake] in February 2008?
X.F.: Yes, it was spectacular. There were about 200 small earthquakes, including five bigger than magnitude 3 during the evening on 14 February. Many people in Dujiangyan ran out of their homes. Then there was another swarm at the end of February and early March between Dujiangyan and Pengzhou. All these earthquakes happened when the water level in Zipingpu reservoir was low.

SSB [Sichuan Seismological Bureau] has data that would let us examine this more closely. Last October, SSB's director promised to release the data. I hope this happens soon.

Sticking his neck out. Fan Xiao.

Q: There are many dams planned or under construction in seismic areas in western China. Are there any you are especially worried about?
X.F.: Jinping on the Yalong River. When it's finished, it will be one of the highest dams on Earth—305 meters high—and it will accumulate four times as much water as Zipingpu. It's in an earthquake-prone area [of southwestern Sichuan]. Last year, SSB found that the dam's developers hadn't yet established the required monitoring system.

Q: What should be done about this?
X.F.: There's no possibility to delay or stop building dams, even in high-risk areas. What we can do is raise building standards and improve monitoring of foreshocks. Early warning might give people a chance to escape.

Q: Have you come under pressure for expressing your views?
X.F.: Scientific issues are open to discussion. But hydropower companies—it is fair to say they are not happy with me.

Mountain Hazards and Environment in Chengdu has made a few dozen expeditions into the disaster area to chart the extensive scarring of the slopes. Because landslide scars tend to be midway up slopes, the loss of shearing resistance makes slides at higher elevations more likely. The dramatic loss of stability "is a huge change" that could last 5 years or more, says Cui.

Ren's group took stock using a model that he calls "a unified approach for a disparate set of poorly understood geophysical phenomena," from landslides to glacier movements. The team cut its teeth on southern California's wildfires in 2007, successfully predicting which burn scars would be most unstable and prone to slides. Applied to the Wenchuan quake, the model produced staggering figures for how much carbon and nitrogen will seep into the atmosphere, the team reported in March in *Geophysical Research Letters*. And those releases could become chronic: "If a warming climate causes more frequent storms of greater intensity, it's likely that the affected ecosystem will become a net CO_2 source," Ren says.

CIB researchers are eager to ground-truth Ren's predictions, which they feel may be an overestimate. Data in Ren's paper are "coarse," says Bao. On many Longmenshan slopes the soil is "very thin," he says, and could not support the amount of vegetation Ren's group says was uprooted or smothered. The CIB team also notes that satellite-based estimates of landslide-degraded land are imprecise. "Monitoring should give us a more exact understanding," says plant ecologist Wu Ning, CIB's director. According to Bao, CIB plans to assess carbon loss at as many as 200 landslide sites in various ecosystems and climate regimes.

Another wildcard is how fast vegetation will recover—and that will not be uniform across the Longmenshan range. Areas to the south and east "are very moist and should recover more easily," says Pan. Grasses and shrubs are already gaining footholds on landslides in those areas. But it could take much longer for more arid land to the west, where the soil is thinner and nutrient-impoverished, to regain its pre-earthquake vitality, he says. Even 30 years after the magnitude-7.2 Songpan earthquake rattled the northern Longmenshan, some steeper slopes are still mostly bare. It could take a century or longer for forests to return on similar dry slopes destabilized by last year's earthquake, says Bao.

For most slopes, CIB researchers will be content to watch natural restoration unfold. But they are planning to restore destroyed sections near towns and along highways, mainly by planting indigenous shrubs. When they are able to lay hands on seedlings, that is: No organization has been responsible for breeding these species, says Wu. CIB also hopes to minimize the impact of a major reconstruction project, a new railway line that will connect Chengdu and Lanzhou. The tracks will run through several reserves and could further degrade habitats, CIB researchers say. Bisecting the reserves could be a particular problem for pandas, which range widely for food.

In the meantime, some researchers could spend the rest of their careers measuring the earthquake's ruinous environmental footprint. "We'll need at least 30 to 50 years to get a true picture of how the region recovers its ecological function," says Wu.

–RICHARD STONE

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