AFTER THE DELUGE

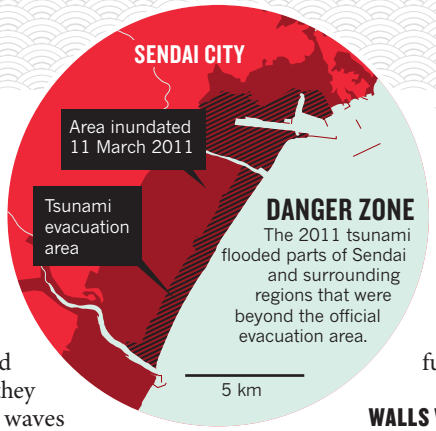
JAPAN IS REBUILDING ITS COASTAL CITIES TO PROTECT PEOPLE FROM THE BIGGEST TSUNAMIS.

BY DAVID CYRANOSKI

On a cold February day, the northeastern Japanese city of Sendai is a snow-covered wasteland. It might pass for out-of-season farmland were it not for the chunks of grey concrete arrayed in rectangles, reminders that houses once stood here.

The signs of devastation are all around, although eerily tidied up. Inside one abandoned house that is missing its first-storey walls, dishes have been neatly stacked on a shelf, perhaps by a compassionate rescue worker. The remnants of cars — 240,000 were washed away or destroyed — and other metallic wreckage are compressed into neat blocks and stacked. Nearby lie piles of uprooted trees that were supposed to provide protection against a tsunami, but instead became lethal battering rams in the raging water. A solitary street sign lies on the ground by the beach, warning of the risk posed by such events.

The sign shows areas that must be evacuated in the event of a tsunami, but the stretch of land at risk on the map is just a small fraction of the region of Sendai that was flooded on 11 March 2011 (see 'Danger zone'). Fumihiko Imamura, a tsunami researcher at Sendai's Tohoku University, quietly studies the map, which he helped to produce. "Some people have criticized us, but at that time we were just envisioning the Miyagi quake," he says, referring to an earthquake that occurs off the Sendai coast every 100 to 150 years, triggering tsunamis about 4 metres high. Instead, water levels here reached 10 metres; farther north they topped 20 metres. The waves inundated more than 500 square kilometres of land across six prefectures, destroying nearly 130,000 buildings and damaging 245,000 others. Some 15,000 people died, and several thousand more are missing and presumed dead.



Now the Japanese government is wrestling with how to rebuild cities such as Sendai to keep people safe should a monster tsunami hit again. Scientists, architects and city planners are debating how much to rely on coastal fortifications such as sea walls and forests. These protections helped in some places but many of them failed, and they gave people a false sense of security that may have contributed to the death toll. Despite this, many municipalities are already moving forward with reconstructing damaged defences.

A new institute, opening in Tohoku next month, will try to extract lessons from the disaster to aid the rebuilding efforts and to develop better public-education campaigns, which experts say are one of the most effective tools for protecting people. Tatsuo Hirano, minister of the recently launched Reconstruction Agency, says that Japan is setting its sights high as it starts to rebuild. "The goal is to have zero deaths in future tsunamis," he says.

WALLS VERSUS WATER

Japan has been pounded by tsunamis throughout its history, and so had prepared more for these floods than any other country. Over the centuries, communities have planted coastal forests as barriers against the sea. Many towns hold regular training drills and evacuations. And sea walls and breakwaters surround nearly half of the country's 34,500 kilometres of coastline. Maintaining and extending these bulwarks has cost the central government billions of yen per year. In areas of greatest tsunami risk, including the entire Tohoku region, 74% of sea walls were built to be higher than the expected tsunamis.

But those expectations were based on magnitude-8 earthquakes that occur every few decades or centuries, not the 1-in-1,000-year Tohoku event, which was ten times stronger at magnitude 9.0. The tsunami that came crashed over most of those walls. Although the giant waves shocked the public, they weren't a complete surprise to some researchers. A decade ago, geologists discovered a sedimentary

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layer from a massive tsunami that had flowed several kilometres inland in 869 (K. Minoura *et al. J. Nat. Disaster Sci.* **23,** 83–88; 2001). Some scientists had worried about a repeat. "We thought one like this might come, but it was not yet in the official model," says Imamura. During a meeting with Imamura last month, Tsuneaki Iguchi, the mayor of the city of Iwanuma south of Sendai, thanked the scientist for his efforts to protect the region but said he wished that researchers had done better at getting the message out about the 869 tsunami. "If only that work could have been done a little more quickly."

Japan is now taking steps to shore up its defences against such mega-tsunamis. In December, the parliament passed a law requiring the construction of "tsunami-safe cities". Sea walls and other structures are meant to provide complete protection from "the tsunami that comes every 200–300 years", says Hirano. In the case of the biggest tsunamis, local governments will use zoning restrictions to prevent people from living in low-lying areas and will improve evacuation protocols to augment the protection provided by sea walls.

The debate over how to protect cities has sometimes been fierce. Some have questioned the value of expensive sea walls. According to Hirano, of 300 kilometres of such walls in the Tohoku region, 180 kilometres were swept away or destroyed after the Tohoku quake. That includes sections of a ¥120-billion (US$1.5-billion) breakwater in Kamaishi Port, which had been completed just three years earlier. The government announced last year that ¥55 billion would be allocated to repairing it.

Supporters say that the Kamaishi breakwater helped to reduce damage from the tsunami. According to simulations by the Port and Airport Research Institute in Yokosuka, the wall reduced the wave's height at landfall from 13.7 metres to 8.0 metres, cut its maximum height inland by 50% and gave residents an extra 6 minutes to evacuate.

But those estimates may not be reliable, says Ioan Nistor, a coastal engineer specializing in tsunamis at the University of Ottawa in Canada, who visited Kamaishi just after last year's quake. He says the analysis incorrectly assumed that the breakwater remained intact during the tsunami. "Although the presence of this breakwater has had a certain positive benefit," he says, "given that a number of sections were knocked off by the tsunami impact, I am not sure if one can quantify so precisely its benefits."

FAILED FORESTS

At the other end of the cost spectrum are coastal forests, says Kentaro Imai of Tohoku University. During the past few centuries, coastal cities all around Japan have planted them, especially those in the tsunami-prone Tohoku region. But of the 230 kilometres of protective coastal forests, two-thirds were heavily damaged by last year's tsunami.

For the most part, the trees did more harm than good, says Hermann Fritz, who studies the fluid dynamics of natural disasters at the Georgia Institute of Technology in Savannah. Fritz and some Japan-based colleagues carried out a survey of the city of Rikuzentakata, where the tsunami reached heights of 15 metres and destroyed a 200-metre-wide forest before heading inland and laying waste to large sections of the city. Only one tree — later named the 'tree of hope' — stood firm.

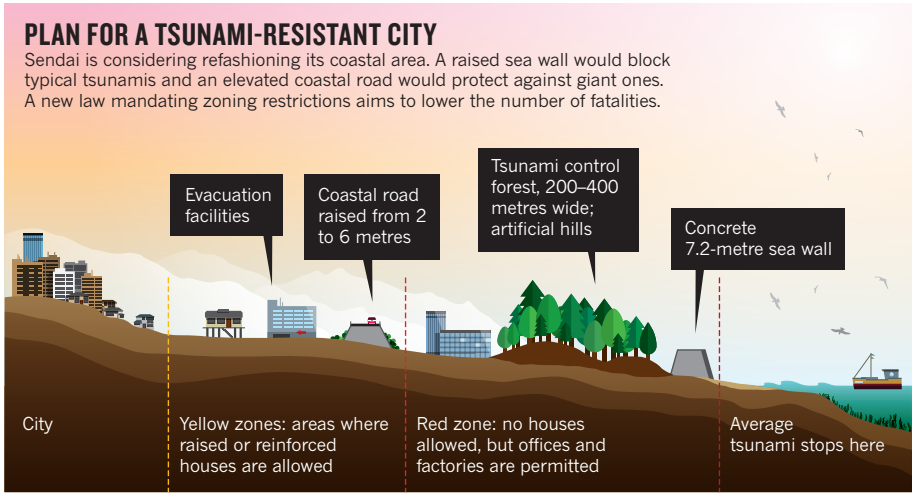
"There was no 'tsunami control' by the forest," says Fritz. "It became 70,000 rams of floating debris impacting buildings." He is not surprised. In a post-disaster survey of Tohoku's Kesennuma Bay, his team measured flow velocities of about 10 metres per second for the water that coursed through the city of Kesennuma (H. M. Fritz *et al. J. Geophys. Res.* **39,** L00G23; 2012). "There is no way a forest will survive that," Fritz says.

Yet the Japanese government has decided to invest ¥59 billion in replanting trees in Tohoku. Proponents argue that the trees also serve other purposes, such as providing a wind break that stops sand from blowing inland. And there is evidence that the forests have slowed tsunami waves resulting from some smaller quakes. Even last year there were some examples of success. In Hachinohe, which was hit by waves higher than 6 metres, the trees stood firm and blocked more than 20 boats from being swept inland and causing further destruction.

Researchers hope that clues from last year's disaster can help them to improve the performance of coastal forests. Toyohiko Miyagi,

H. KAWAHARA/AFP/GETTY

Raging waters breached defences and destroyed cities such as Sendai when a tsunami hit the coast of Japan last year.



who studies Earth and environment interactions at Tohoku Gakuin University in Sendai, examined the trees and found that those that caused the most damage still had their roots. "They didn't break — they came right out of the ground," says Miyagi. Trees with roots reaching deeper than 3 metres were usually able to withstand the force of the tsunami, however. "Our recommendation is to build up the land under the trees so they hold," says Miyagi. This raised land would allow roots to grow longer and would create an extra barrier to protect inland areas.

The trees that stood saved lives in other ways. Some people who missed the call to evacuate were able to climb to safety and wait for rescue. As Imamura drives around Sendai, he points to trees where people rode out the tsunami. He also shows where panicked people took refuge on bridges, schools and river embankments. Many of the official evacuation zones were swept away because they were too low, so the level at which people can be considered safe clearly needs to be revised.

But that is the greatest challenge of the reconstruction, says Hirano. "Even with the general agreement that people should build on higher ground, it's difficult to agree on where to build," he says.

SAFETY ZONE

According to the new law mandating tsunami-safe cities, local governments in coastal areas nationwide must simulate a massive tsunami's effect on the region and then develop zoning policies around the results. Areas where water is likely to reach depths of more than 4 metres are the most dangerous; no residences or hospitals would be allowed to be built in such red zones because people would have difficulty evacuating, especially at night. Offices or factories could be sited there, because workers could easily evacuate. Yellow zones, where water could reach levels of between 2 and 4 metres, are suitable for residences only if they are built on stilts or made with reinforced concrete (see 'Plan for a tsunami-resistant city').

Imamura helped Sendai officials to plan the city's zoning by carrying out some 200 simulations that varied parameters such as the height of the coastal sea wall and the position of a road that serves as an embankment. In Imamura's most cost-effective scenario, the town's 6-metre-tall segments of sea wall would be replaced by one long wall 7.2 metres high, which would act as the first line of defence. Behind that, the city would restore a coastal tsunami-control forest 200–400 metres wide and 20–30 kilometres long. Farther inland, the coastal road would be raised from the current 2 metres to 6 metres above sea level.

The region between the coast and the road would be declared a red zone and dotted with artificial hills to serve as evacuation sites for those working there. Other evacuation sites would be located farther inland. Imamura says that this scenario would reduce the inundated area by 60% compared with last year and could, if people were properly trained, avoid deaths.

Although the proposal impressed local officials, many citizens were not happy that some 1,214 hectares and about 2,000 homes would be declared unsafe for habitation. Some have threatened to sue. But Fumio Yamada, head of Sendai's reconstruction division, agrees with the government's zoning law and says that he will enforce it. After tsunamis ravaged the town in 1896 and 1933, survivors moved up to the hills but later generations returned. "If you just warn people, if you don't have it in law, people will come back," says Yamada.

Yet Iguchi, Iwanuma's mayor, says he will not kick people off of their land. "I don't want them to live there. But people have their rights and there have been lawsuits," the mayor says.

Some researchers worry that the simulations used in zoning decisions are being pushed too far. Satoru Masuda, a specialist in risk communication and disaster-prevention city planning at Tohoku University, says that zoning officials have not given sufficient consideration to the uncertainties of the simulations.

And the debate looks set to spread, says Imamura, as local governments in all coastal areas conduct the mandatory simulation-based zoning. He sits on a committee expected to report back by next month with a reassessment of the tsunami potential of an earthquake in the Nankai Trough south of Tokyo. When all the maps are adjusted, millions of people will probably fall into red zones and could be told to move, he says. "Even after the disaster, some people in Tohoku are resisting," says Imamura. "Of course in places where there hasn't been a tsunami there will be debate. It will take time."

Imamura hopes that the new institute set to open at Tohoku University on 1 April will help. The International Research Institute of Disaster Science (IRIDeS) will receive ¥800 million per year in funding for ten years, and will have roughly 25 teams. These will analyse the performance of disaster-mitigation technologies; develop better ways to support victims; research early-detection systems for megaquakes and tsunamis; and establish a medical system for coping with disasters and a digital archive of them, says Imamura, who will be vice-director.

IGNORED WARNINGS

A key focus is how to make people more aware of the danger that tsunamis pose. Tohoku University's Toshiaki Muramoto, a cognitive psychologist who will take a position in the new institute, plans to look at the way people process information during disasters. He notes that a survey of 870 survivors found that 60% quickly evacuated when they heard the alarms, but the rest waited. Of those, 75% said they "finished what they were doing" first. "There's a tendency among some to hear a warning and think that they are ok," says Muramoto. He wants to understand why people usually play down risks and to use that information to devise better educational messages about natural hazards. "That could change things," he says.

The digital archive at IRIDeS, which will consist of images and records of the tsunami, could serve as a global resource for education and policy planning, says Shosuke Sato, another Tohoku University researcher and future member of the institute. He says the database will be "like Facebook for disasters".

The real test of the post-disaster research and planning will come when Japan faces its next massive tsunami. In many ways, it will be a memory test — of how well humans, in this age of information, can package and transmit a message that makes future generations conscious of their vulnerability.

It will take an emotional symbol, says a group of some 50 scientists, including Imamura, who propose preserving one of the boats that lodged in a house, an evacuation centre or the twisted warning sign on the beach. "We're thinking of making spots like this into memorials," Imamura says, "so that people don't forget." ■

David Cyranoski *is* Nature*'s Asia–Pacific correspondent.*