Geo Factsheet

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Natural & man-made disaster at Fukushima

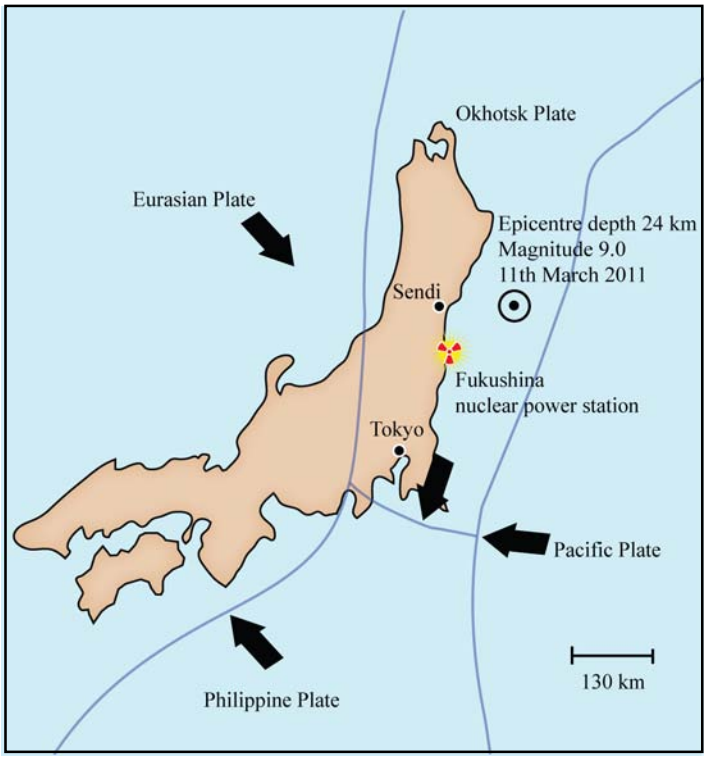
At 2:46pm local time, on 11 March 2011, Japan suffered one of the worst natural disasters in history. This huge composite disaster had many shocking elements, namely:

- that it should happen to a highly developed nation;
- that another event, on the same scale as the Boxing Day 2004 tsunami, should occur so soon after;
- that Japan was hit by an earthquake, tsunami and a potential on-going nuclear disaster.

Earthquake

Two days beforehand, there had been major tremors in the region, peaking at 7.2 on the Richter scale. But the earthquake measuring 9.0 was the world's 5th largest since 1900 and the largest in Japan since instrumental records began 130 years ago. The epicentre, 24 km deep, was 72 km off the coast of Sendai, where the Pacific Plate is being subducted below the Okhotsk Plate, which carries northern Japan (Figure 1).

Figure 1 Location map



The 1 in 1000 year event was due to seismic waves travelling along many interlinked fault systems for 500 km, building up energy as they went, and three earthquakes occurred consecutively. Horizontal crustal displacement of the seafloor was measured at 50m, and the seabed was raised by 16 m. Ground shaking occurred afterwards for 6 minutes. Within 20 minutes, a huge tsunami had developed and began to inundate the coastal lowlands. 5 weeks after the disaster, the region had experienced 420 aftershocks greater than magnitude 5.0, suggesting that there will continue to be large scale crustal adjustment.

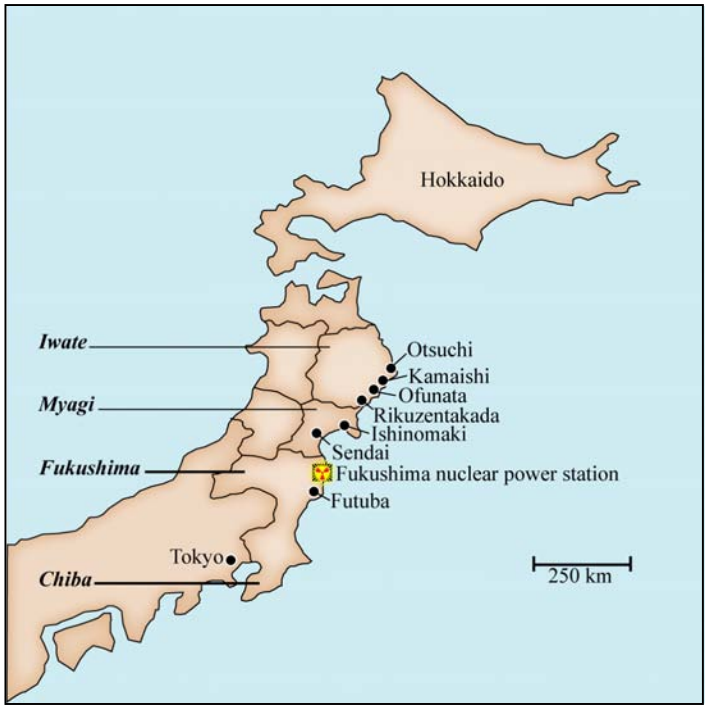
Factors that contributed to the high vulnerability of the area:

1. Off Sendai, there is very old oceanic crust and, being cooler and denser, was thought to readily slide into the mantle, so only small earthquakes were expected.
2. Warping of the Pacific Plate means it gets stuck rather than slides smoothly into the mantle, so strain quickly builds up.
3. The coastline is rugged and jagged with many inlets, known as a ria coast. Waves become concentrated in bays, which focus wave energy on to land and especially up rivers.
4. 70% of Japan is mountainous, forcing urban and industrial development into narrow, low-lying coastal areas.
5. Soft reclaimed land is susceptible to ground shaking, causing landslides.
6. The Prime Minister accepted that government officials were too complacent and had come to believe in technological infallibility.

Tsunami

The first tsunami warning was issued only three minutes after the earthquake for Iwate, Miyagi and Fukushima Prefectures (Figure 2), and within 45 minutes the 800 km long coastline to Chiba Prefecture

Figure 2 Worst hit prefectures and cities



was alerted to prepare for a 10 m or higher tsunami.

The highest wave height was 15 m and this reached the nearest coastline within 30-40 minutes. The massive force of water hit the coast, causing erosion of beaches and dunes by the inrush of turbulent water, and destroyed man-made structures such as seawalls and 95% of all vegetation. In total, 500 km^2 were inundated in north-east Japan.

The tsunami also affected the area by transporting huge amounts of sediment, up to 5 km inland on the Sendai Plain. Sand from the beaches and the shallow seabed was picked up and transported landwards, and as energy dropped, the load was deposited in paddy fields and forests. Some of the seawater from the runup of the tsunami remained on the surface for two months, and salt crusts formed in the paddy fields as water slowly evaporated.

Fukushima nuclear explosion

The most serious consequence of the tsunami was the damage to the Tokyo Electric Power Co.'s Fukushima No.1 nuclear power plant, which supplied 6% of the company's energy. There were six reactors – three were not operating, and the other three shut down successfully in response to the earthquake. However, two tsunami waves arriving 40-50 minutes later inundated the power station.

In any nuclear reactor, water is heated to form steam. This drives turbines that in turn generate electricity. When the earthquake happened, the reactors automatically closed down but because the power supply had been damaged by the tsunami, the cooling system in the basement failed, allowing water to heat and to continue generating steam. The fuel rods got hotter and reacted with steam to form hydrogen gas and actually melted, causing damage to the power station's structure. Pressure rose until there was an explosion and the hydrogen was released. In response, managers used seawater as an emergency coolant and sprayed it over the reactors. After the explosion, radioactive substances escaped and fires developed.

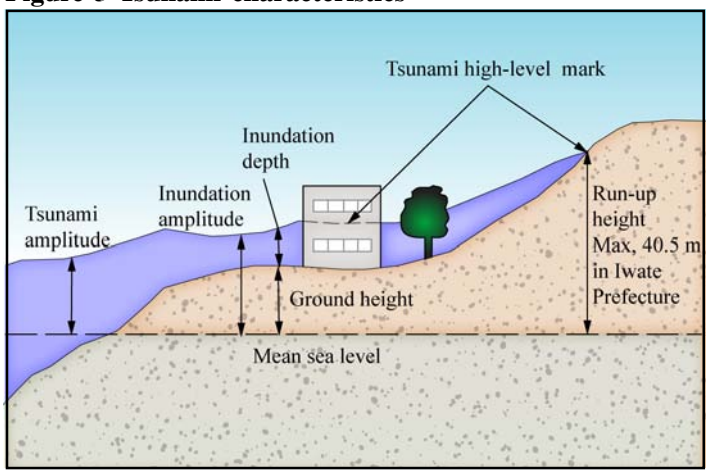
Impacts

Immediate impacts were to buildings and infrastructure, water and sanitation, food and fuel supplies but then secondary impacts set in. These included physical and psychological impacts on the local population that made the rescue effort more difficult.

Due to the scale of the inundation run-up (Figure 3), some designated tsunami shelters were within the flooding zone and failed to save lives.

A coastal forest, designed as an artificial breakwater, failed completely. Giant breakwaters, the largest in the world, had been built in the bay mouths to protect major cities such as Kamaishi and Ofunato, but the tsunami destroyed these structures, although they did reduce damage to some extent.

Figure 3 Tsunami characteristics



Deaths

The final death toll was around 20,000 with 3,000 never accounted for, making it the 20th most deadliest earthquake and tsunami in the last 100 years. In terms of actual numbers, the worst hit city was Ishinomaki, but Otsuchi lost 10% of its total population (nearly 2000) – see Figure 4. 65% of the victims were aged over 60 years old, demonstrating the repeated experience in natural disasters that the elderly are most vulnerable. In Otsuchi, the most heavily-affected town, many disaster-relief officers themselves were killed and it proved impossible to set up a recovery operation for a week, when trained people from other areas arrived.

Figure 4 Spatial impacts of the tsunami (Japan Weather Association)

Place	Inundation height (m)	% residential area inundated	Dead & missing	% Dead and missing
Rikuzentakada	15.8	43	2422	10.4
Otsuchi	12.6	52	1631	10.7
Ishinomaki	15.5	46	5538	3.5

Economic losses

In the short term, there was an impact on production, both in Japan and globally, as supply chains were affected but some companies recovered after six months to pre-quake levels, showing the resilience of Japan's economy (Figure 5). Some fear that improved figures are the result of the reconstruction effort and that economic activity will decrease with time.

Figure 5 Examples showing variation in economic impact on global branded companies

Company	Usual business activities	Impact	Financial impact over the following year
Sony	Blu-ray components, discs, lithium batteries	6 factories closed down	Loss of $2.9 billion
Nissan	Car production	2,000 cars ready for export were damaged. 4 factories closed. Car prices increased by 6%	Profit of $3.8 billion
Apple	iPad 2 launched the day before the quake.	Japanese component suppliers were damaged Negli (tablets assembled in China)	Negible effect- best ever earning year.
Panasonic	Electrical goods	Quake-related costs of $258 million. 17,000 jobs lost	$9 billion loss
Sapporo	Food and alcohol	Quake-related costs of $60 million.	Net profits fell by 83% to $7.3 million

Building and infrastructure loss

The main earthquake lasted 0.2 - 1.0 seconds, causing more than 300,000 buildings to be destroyed, and another million damaged (Figure 6). Almost 4,000 roads, 78 bridges and 29 railways were also affected, and 72.6 % of all structures in the port city of Ishinomaki were destroyed The Japanese government estimated damage to buildings and infrastructure at more than $300 billion, making it the world's costliest natural disaster.

Figure 6 Relative impacts of the compound disaster on building damage

Event	Buildings destroyed	Buildings partially destroyed	Buildings partially damaged	% of total damage
Earthquake	13,000 – 18,000	75,000 – 100,000	540,000 – 570,000	46%
Tsunami	100,000 – 105,000	80,000 – 100,000	45,000 – 70,000	44%
Nuclear disaster	An estimated 35,000 uninhabitable buildings lie within the Fukushima exclusion zone.			10%

Impact of Fukushima nuclear explosion

80,000 people in a 12-mile radius had to be evacuated due to radiation contamination. In December 2011, at the same time as the Fukushima plant was declared stable, (but decades before the area is decontaminated and people can return), 800 from the town of Futaba were still living in an abandoned school 100 miles away.

There has been concern about radiation in the food chain. Unsafe levels of caesium-137, which has a half-life of 30 years, were reported in beef, due to cattle being fed contaminated hay. Contamination was found in soils and crops up to 40 km away from Fukushima, and whilst the open ocean seems not to be affected, the near-shore sediments (up to 20 km offshore) were badly affected and hence seafood has high levels of caesium.

Environmental impacts

Due to the mountainous nature of Japan, the earthquake triggered many landslides on the steep slopes, as well as causing slope failure of flood protection schemes such as earth walls. Reclaimed land suffered **liquefaction** on soft alluvial plains and there was a huge transfer of sediment from seabed to land. The weight of sediment within the tsunami wave contributed significantly to building damage. The canals allowed water and sediment to penetrate inland and they became sediment traps as the energy dispersed, requiring dredging. The massive and sudden change to coastal ecosystems will have implications for fishing and farming.

Why did preparation systems fail?

Japan has some of the most advanced preparedness plans for natural disasters in the world and yet it proved susceptible to an unexpected, though not unknown, mega-event (Figure 7). Although it had coped with earthquakes of magnitude 8.0, a 9.0 quake is 30 times more powerful and design features were not built for this, and therefore neither were human response systems.

Figure 7. Disaster preparations and why they failed (Source: Nature, 29 March 2011)

Event	Preparations	Predictions prior to 2011	Why protection measures fell short
Earthquake	World's densest seismometer network and most extensive earthquake early-warning system. Seismic maps show probabilities of scale and occurrence.	Japan's latest seismic hazard map of 2009 predicted the region having a magnitude of 7.7 (the largest in history for the area), with only a 30-40% chance in the next 10 years.	Predictions assumed a point source of energy, not a rupture that interlinked different fault systems. Protection systems only cope up to an 8.0 magnitude. Frequent aftershocks confused the warning systems
Tsunami	Tsunami wall completed in 2008 after 30 years: 2 km long 8 m high 20 m thick 63 m deep foundations $1.4 billion cost	Expected a maximum 4-5 m tsunami for a predicted 7.5 magnitude earthquake.	False sense of security, as wall protects the region from a few 2-3 m tsunamis every decade.
Fukushima	Built in 1960s, designed to withstand a tsunami of 5.7 m.	Predicted a 7.4 earthquake, with <2% chance of occurring in next 10 years, and < 10% in next 50 years.	Risk map did not allow for a seismic wave travelling through many fault systems for 500 km, responsible for the 9.0 magnitude earthquake.

Preparedness successes

It should be noted that well-learnt preparedness drills and education programmes did much to save some communities. Tsunami hazard maps had been distributed to all households, and workshops to find local evacuation routes had been promoted. Some schools in Kamaishi got 3000 children to high ground as soon as the earthquake was felt, not waiting for official alerts. Vertical evacuation in the Sendai region saved many lives. The Japanese Earthquake Early Warning system provided up to 90 seconds' warning of the earthquake for some residents in Tokyo.

The Government's Immediate Response

In April 2011, one month after the disaster the recovery programme was established on three principles: safety, sustainability and compassion (Figure 8). The region is to be rebuilt to be highly resistant to natural disasters, together with social systems which recognise the need to live sustainably and which care in particular for its vulnerable members.

Figure 8. Reconstruction objectives (from: Towards Reconstruction: Hope beyond the Disaster)

Major reconstruction objectives	Principles of recovery
Relocate onto higher ground – "Compact Cities"	Safe/Sustainable
Integrated land use regulations for building on low-lying land	Safe
Huge-scale coastal levees to protect coastal plains where community relocation to higher ground impossible	Safe
Municipality-led consultation with citizen groups	Sustainable
New government led disaster response structure	Safe
Restore community life and livelihood	Sustainable/Compassionate
Provide comprehensive community care facilities	Compassionate
Ensure education and restore culture	Sustainable/Compassionate
From emergency employment to employment restoration	Sustainable
Recovery of agriculture, forestry and fisheries	Sustainable
Strengthening of infrastructure	Safe
Improved energy efficiency and promotion of renewable energy	Sustainable

One year on: The Reconstruction Agency

Following the report: "Towards Reconstruction: Hope beyond the Disaster", the Reconstruction Agency was established in February 2012, with the government helping to rebuild Tohoku communities to be resilient to natural disasters, and to be attractive to new investment and businesses.

With so much destruction in the Sendai region, the most pressing problem is unemployment –70% do not have work, with small to medium sized firms suffering the most and requiring governmental financial support. There is also an imbalance of workers – many health professionals left the Fukushima area, and schools hit by the tsunami lost large numbers of staff.

Although many Japanese are deeply unhappy with the manner and speed with which the government has responded, they are reluctant to openly criticise. People are disappointed that normal politics have not been put aside in order to prioritise help for the victims. However, many communities are still in shock and dislocated, making local agreement on the way forward very difficult.

Continuing issues:

Displacement

The major social issue facing the Reconstruction Agency and city governments is the resettlement of thousands of people. More than 330,000 are still living in some kind of temporary accommodation, including those staying with friends and family or in hotels. More than 500 remain in evacuation centres. Many evacuees, still waiting for compensation, want to remain close to their original homes.

Resettlement

There are two options – either to build higher sea walls, or to rebuild communities on higher land. However, sea walls are costly, unsightly and there will always be the question – how high is enough? Equally, moving ravished communities away from their home surroundings can have a long-term traumatic effect, when people need the support of the familiar to recover from the experience.

Japan has limited habitable space for relocation on this scale and there are legal and funding problems, especially if new-build is to be in a different prefecture.

And for whom should places be rebuilt? Japan has the world's most rapidly ageing society and with diminishing resources, should it build for the future, for young people? What is appropriate regeneration when there was already a declining and ageing population, and the effects of the disaster are expected to lead to a further decrease in population? Despite these important questions, older people have more political influence and their preferences to rebuild things as they were before the disaster is a common complaint.

Local governments have been given a total of $25 billion for reconstruction, as they will understand the local conditions better than the central government in Tokyo. However, some fear that local officers, dealing with people they know, will not be able to make hard decisions such as making communities more compact and sacrificing small isolated settlements.

Tohoku Sky Village

Elevated land-based "islands" have been designed to form entire towns in the tsunami-affected region. Each 3-story island would be bolted into the bedrock with steel pillars, and oval-shaped to force water to flow around it. Each would have a particular function - most would be residential (100-500 units) with fuel stations, waste disposal and car parking at lower levels, and other islands would have commercial functions such as food processing of agricultural and fisheries products. The central islands within each cluster would house schools, health centres, council offices and leisure facilities.

There are also plans for the first indoor marina so that fishing vessels can be protected. In the event of a tsunami warning, gates would close and people working on the coastal plain would use steps on the outside walls to reach safety.

It would cost £160 million per island, some of the cost mitigated by recycling the debris from the tsunami, and it is anticipated the region would become a tourist attraction. The project has the advantage of allowing people to stay in their home area of Sendai, and so preserve the community. Although its futuristic look may put off some conservative Japanese, one district is in the process of building an island.

Divide living and working places in NE Japan

People would live in higher places inland, whilst working at the coastal areas because low-lying coastal areas are still effective and important for ports, fishing and commercial activities. Coastal defences would be reconstructed, such as dykes and coastal forests, for protection.

Waste disposal

25 million tons of wreckage were created in the 3 worst-hit prefectures alone, raising the risk of contamination to soil, beaches, rivers and ground water. Although much of the rubble and waste has been cleared from the streets, only 5% has been disposed of and 72% is still being stored at temporary sites. There is a lack of sites for incinerators in affected areas and other prefectures of Japan are reluctant to take the waste amid fears of radiation contamination. This means that the original goal of completing disposal by March 2014 is unrealistic.

Finance and businesses

The Reconstruction Agency estimated that rebuilding would cost nearly $300 billion over 10 years, causing national debt to rise sharply. In order to help fund reconstruction, Parliament voted to cut government salaries as well as issuing tax incentives for businesses to relocate in earthquake zones (30% of companies are considering relocating outside of Japan). 20% of 27,000 businesses in affected areas have not resumed operations. If societies relocate inland, then people will have to start new businesses that are not dependent on water, and learn new skills, adding to costs.

Energy

Despite the muted public health impact, Japan took the decision to close all 54 nuclear power plants for routine maintenance, following the Fukushima crisis. These supplied 30% of Japan's energy demand, which has since been met by importing expensive fossil fuels, adding $30 billion to Japan's energy costs and meaning that Japan will not meet its Kyoto targets. Despite widespread opposition to restarting nuclear plants, the Prime Minister announced that two nuclear reactors on the west coast were to begin energy production again in July 2012. This unpopular decision was deemed necessary to safeguard livelihoods and industry, and to prevent power shortages. The future policy is to increase renewable energy, and sales of solar cells have increased by 30% since the tsunami.

There has also been an international dimension to the energy debate, in that in May 2011, Germany decided to close its nuclear energy industry by 2022, which accounts for 25% of its energy. Italy and Switzerland have also voted against nuclear energy, although Britain and France have retained their support. China has continued with plans to build new nuclear power stations. Worldwide, in 2011-12, construction began on only two nuclear reactors, compared to 38 in the previous three years.

What is the long term future for Tohoku region?

The population trends of decline – ageing, shrinkage, out-migration - are likely to continue and even accelerate, as land clearance and rebuilding progresses slowly. (Other problems in reconstruction are seen in Figure 9). The inability to agree on reconstruction plans may deter young people, who might go and find employment elsewhere. Businesses have struggled to re-establish themselves and high unemployment saps morale, with finance not always easy to access. Nuclear energy will probably play a decreasing part in Japan's energy mix as renewables enter the market. Fukushima itself may eventually be decommissioned and converted into a mega solar array.

Figure 9 Obstacles to Recovery (adapted from P. Matanle, Univ. of Sheffield)

1. Securing financial stability and provision of funding.
2. Removal and disposal of irradiated debris to make way for rebuilding.
3. Ensuring adequate professional planning services at the local level.
4. Topographical difficulties in constructing new communities on higher ground.
5. Economic/environmental conflicts.
6. Securing labour and resources needed for reconstruction whilst maintaining a high quality of life elsewhere in Japan.
7. Maintaining a stable electricity supply whilst reforming the energy system.
8. Planning for regeneration in a shrinking and ageing society.
9. Recovering public trust in agricultural and marine products.
10. Resettlement/use of the areas around Fukushima nuclear power station.
11. Recovery/return of lost social, cultural, and human capital.

References

Towards reconstruction: Hope beyond the Disaster http://www.mofa.go.jp/announce/jfpu/2011/7/pdfs/0712.pdf
British Geological Survey http://www.bgs.ac.uk/research/earthquakes/honshuMarch2011.html

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