I arrived in Tokyo on the evening of 29 February to participate in conferences on the first anniversary of the 11 March 2011 Tohoku, Japan earthquake. About half an hour before midnight I felt the very perceptible and persistent swaying of my 20 storey hotel in Tokyo due to a magnitude 5.8 earthquake off the Boso Peninsula east of Tokyo. At 7:30 am the following morning this sensation recurred with the occurrence of a magnitude 5.4 earthquake beneath the Tokai 2 nuclear plant, northeast of Tokyo. These events are a continuation of the earthquake sequence that began on 11 March 2011 (Figure 1). This newsletter surveys the impact of the Tohoku earthquake, including changes in thinking about earthquake hazards in Japan.

The 11 March Tohoku Earthquake – a Supercycle Event

Before the occurrence of the earthquake, it was thought that large earthquakes (magnitude 7.5 to 8) off Tohoku occurred in cycles of strain accumulation and release lasting about 100 years each (top of Figure 2) and that larger earthquakes did not occur. Now it is thought that superimposed on this cycle there is another cycle, called a supercycle, with a period of about one thousand years, that produces a much larger earthquake like the magnitude 9.0 11 March event (bottom of Figure 2). The 869 Jogan earthquake, which produced widespread inundation near Sendai, is thought to represent the previous event of this supercycle.

The fact that the 11 March 2011 earthquake caused subsidence of the Tohoku coast, not the uplift that was expected of a supercycle event, is a cause for concern. It is generally expected that this uplift may occur gradually over time without the occurrence of another large earthquake. However, it would not be a complete surprise if another giant earthquake were to occur off Tohoku.
How previous large tsunamis in Tohoku and warnings of future tsunamis were ignored

Although the magnitude of the 11 March 2011 earthquake (9 compared to the expected maximum of 8.2 to 8.4) was a surprise, there was clear historical evidence of tsunamis, including the 869 Jogan tsunami, that were as high as the one produced by the 11 March 2011 earthquake. In the 1600’s, villagers had built stone monuments in Tohoku that marked the limit of inundation of past tsunamis and warned people not to build any closer to the coast, a warning that was not heeded by the fishermen and others who populated the coastal towns of Tohoku.

Professor Shimazaki, a member of an influential government Cabinet Office committee on offshore earthquakes in northeastern Japan, warned in 2004 that the Fukushima coast was vulnerable to tsunamis more than twice as high as the forecasts of up to 5 metres put forth by the Nuclear Industrial Safety Agency (NISA) and the Tokyo Electric Power Company (TEPCO). Minutes of a meeting on 19 February, 2004, show that the government bureaucrats running the committee moved quickly to exclude his views from debate as too speculative and “pending further research.” In 2008, TEPCO engineers did calculations that showed that the Fukushima plant could be exposed to tsunamis as high as 15 metres, but TEPCO did not tell regulators at NISA for almost a year, and then did not reveal the most alarming calculation, of a 15 metre wave, until 7 March of last year, four days before the tsunami struck.

Future large subduction earthquakes off eastern Japan

Through the process of stress transfer, it is common for a large earthquake on the plate interface in a subduction zone to trigger large earthquakes on the adjacent segments. This has occurred along the Nankai Trough in southwestern Japan on several occasions. Earthquakes on the Nankai, Tonankai and Tokai segments of the Nankai Trough plate interface sometimes occur at almost the same time, suggesting that one event may trigger an event on the adjacent segment. Rupture of the Tonankai segment and sometimes the Tokai segment usually precedes that of the Nankai segment: the delay times were 32 hours for the 1854 Ansei events and two years for the 1944 Tonankai and 1946 Nankai events. Since 887 there have been seven Tonankai earthquakes, but their inter-event times have ranged from 90 to 262 years, indicating that these events do not recur in a uniform way as described in the idealised model shown on the left side of Figure 3.

A more recent example of stress transfer is the earthquake sequence that began with the Mw 9.15 Sumatra earthquake of 26 December 2004. This event was followed three months later by an Mw 8.6 earthquake on the segment of the plate interface that lies immediately southeast of the 2004 event on 28 March 2005. The next event in the sequence, the 2007 Mw 8.4 Bengkulu earthquake, jumped across a segment that is thought to occupy part of the rupture zone of a mega subduction earthquake that occurred in 1833.

Intense interest is now focused on the evolution of the earthquake sequence that began with the 11 March 2011 Tohoku earthquake (Figure 1). The shallow portion of the plate interface south of the rupture zone and adjacent to the trench, located in the offshore region east of the Boso Peninsula east of Tokyo (Figure 4), produced a large tsunami earthquake in 1677. It is not known whether this part of the plate interface has been slipping without generating quakes, or is locked and building strain that could be released in a future large earthquake. The timing of such an earthquake is not known, but the histories of stress transfer from one earthquake to the next on the Nankai and Sumatra subduction zones suggest that it could occur within the next few months to years.

Larger earthquake on the Nankai trough off southwest Japan

On 1 March a government Cabinet Office committee including Professor Shimazaki announced that the Nankai Trough subduction zone (Figure 4), which had been thought capable of generating earthquakes up to magnitude 8.5, might be capable of generating earthquakes as large as magnitude 9, the size of the 2011 Tohoku earthquake. This earthquake would affect a much larger population and industrial area than was affected in the 2011 Tohoku earthquake. The affected area (Figure 4) would include most of western Japan including Nagoya and the Kansai district (the second largest population region of Japan, containing Osaka, Kobe, and Kyoto). It has been projected that a 3.5 metre high tsunami could cause significant inundation of Osaka.

Figure 3. History of large earthquakes (left) on segments of the Nankai Trough, southwestern Japan (right). Dashed lines in the table indicate uncertainty that the earthquake ruptured that segment, and numbers on the right side of the table indicate inter-event times.
More likely and more damaging earthquakes below Tokyo

At the monthly seminar held at the Earthquake Research Institute (ERI) of Tokyo University in September 2011, Dr Sakai noted that earthquakes up to magnitude 6 in the Tokyo region had been occurring with five times their normal frequency since the occurrence of the 11 March 2011 Tohoku earthquake. This information received a large amount of media publicity on 23 January, 2012. The media statement said there was a 70 percent chance a magnitude 7 quake would occur in the southern part of the Tokyo metropolitan area in the next four years, in contrast with the pre-Tohoku earthquake expectation of a 70 percent chance in the next 30 years. This media statement was criticized by other seismologists on several grounds, including that the earthquake frequency in Tokyo had decreased in the intervening five months, and that the forecast involved an extrapolation of earthquake frequencies from magnitude 6 to magnitude 7.

On 9 March it was reported by Professor Hirata of ERI that the depth of the plate interface beneath northern Tokyo Bay was 30 km rather than 40 km, implying that large earthquakes beneath Tokyo may occur at shallower depths than previously thought. The combination of more frequent and shallower (and hence more damaging) earthquakes forecast beneath Tokyo became a major issue for the renewal of reinsurance contracts for the new fiscal year in Japan, which begins on 1 April.

Although it is clear that the current hazard level has in Tokyo increased, the implications for earthquake risk are less clear. Historically, Tokyo’s magnitude 7 earthquakes, which were probably deep events, have caused major damage to Tokyo, but these events occurred before the development of earthquake resistant structures in Japan. Earthquakes occurring at depths of 30 km or more beneath Tokyo have considerably less damage potential than shallow crustal earthquakes, such as the 1995 Kobe earthquake, that occur in the depth range of 0 to 20 km. There are very few identified active shallow crustal faults in the Tokyo region of the type that could generate a Kobe-type earthquake.

Magnitude 7 earthquakes occurring now beneath Tokyo would probably be less destructive than they have been in the past. If the performance of buildings in Sendai during the 11 March 2011 earthquake is any guide, the damage to buildings may be limited, with the main impacts likely to be due to the disruption of infrastructure and lifelines. The main disruptions in the Tokyo region during the 11 March 2011 Tohoku earthquake were caused by soil liquefaction, the ignition of fires in oil refineries located on the soft soils of the shores of Tokyo Bay, and the need to interrupt rail transportation to inspect the tracks for potential damage due to embankment failure. The interruption of rail transport caused significant disruptions in places with large concentrations of highrise buildings such as Shinjuku, where there was insufficient standing room on the ground for people evacuating the towers.

What the Government knew but did not say immediately following the 11 March 2011 earthquake

Some prominent Japanese businessmen formed a new think-tank, the Rebuild Japan Initiative Foundation, in part to make their own independent inquiry into the disaster. On 29 February it was revealed by the media that Industry Minister Mr Edano, the government’s chief spokesman during the crisis, had told the members of this inquiry that in the days following the disaster, the government feared that cascading meltdowns at the Fukushima plants could impact the Tokai plant further south and might require the evaluation of Tokyo, a city of more than 30 million people. On 10 March it was further revealed that the government was made aware of the possibility of nuclear meltdown at the Fukushima plant within 4 hours of its inundation by the tsunami. Publically, it took months for the government to acknowledge that meltdowns had occurred in three of the reactors. The same delays occurred in the release of government information on radiation exposure. As a result, the Japanese public’s confidence in the government’s willingness to tell the truth about these matters in a timely fashion has reached a critically low level.

The population in the affected area has a similarly low confidence in the ability of the government to provide effective assistance. There is a notable contrast between the slowness of government response initiatives and the speed of the people and their local governments in...
Risk Frontiers has approved a total of $US175 billion in recovery programs for a disaster that took over 19,000 lives and rendered over 325,000 people homeless. But the government’s Reconstruction Agency, whose role is to coordinate the spending of this money by the ministries, did not begin its work until 11 months after the disaster.

**Observations in Sendai and the southern Tohoku Coast**

My visit to the Tohoku region provided a stark contrast between the modest impact caused by the ground shaking and the devastating impact caused by the tsunami. Sendai, the largest city in the Tohoku district, suffered almost no building damage, although it was shaken very strongly for a very long time. Signs of massive tsunami inundation are all around the Sendai airport, which was closed for a month. Ishinomaki, on the coast east of Sendai, is a tsunami wasteland with massive piles of unsorted and sorted debris. The Onagawa nuclear power plant, located 15 metres above sea level, underwent a small amount of tsunami inundation, but there was almost no damage to the reactor buildings and equipment, which shut down safely following the earthquake.

**National and global economic impact**

Had the Fukushima plants been sited like Onagawa at 15 metre elevation or protected by adequate sea walls, coolant water could have been supplied to the nuclear plants following their shut down and the nuclear disaster at Fukushima would probably have been avoided. Within Japan, 53 of 54 nuclear power plants are now shut down, and the remaining one will shut down in May. The Prefectural governments in Japan are able to effectively veto the restart on nuclear plants, and it is unclear when (or if) that is going to occur. The resulting power shortages threaten to permanently drive a significant fraction of Japanese industrial production offshore to countries with secure power supplies. The cost of importing fossil fuels into Japan to make up for the 30% of the power that nuclear plants previously supplied has driven Japan into a trade deficit for the first time in many decades, and may in the long run hasten the feared descent of Japan into fiscally and demographically driven insolvency.

Globally, the Fukushima disaster has triggered the beginning of an arguably irrational but nevertheless huge reduction in nuclear power generation around the world (for example in Germany, Switzerland and Italy as well as in Japan). These Japanese and global impacts were entirely avoidable if Japanese government and industry had done due diligence in recognizing and mitigating tsunami hazards at Fukushima. The impact of this global transition from nuclear to fossil fuel power generation may mark a serious setback in the struggle to control global warming.

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**Hunter-Leigh Scholarship**

Risk Frontiers is seeking a suitably qualified applicant for a PhD scholarship at Macquarie University in the area of Global Food Security. The scholarship is in memory of Laraine Hunter and Roy Leigh, two foundation members of Risk Frontiers.

The volcanic eruption of Laki in Iceland (1783-84) and Tambora in Indonesia (1815) led to large scale famine as crops failed. Last year a spike in food prices was one trigger for aggravating political unrest in the Middle East. The 2011 explosion at the Fukushima-Daiichi nuclear power plant in Japan disrupted food supplies as well as affecting supply chains for electronic components and car manufacturing.

This study will examine how resilient today’s agricultural systems and food supply chains are to perturbation by extreme events. The scholarship is open to any suitably qualified student and Macquarie University will provide further scholarship to cover overseas tuition fees should the successful applicant come from outside Australia or New Zealand. All applicants will be judged on merit but the position may suit a person with previous experience in multi-disciplinary studies and an interest in economics. Risk Frontiers (www.riskfrontiers.com) has in-house expertise in volcanic ash modelling and network analysis and the successful applicant will work in conjunction with these staff members.

Expressions of interest and curriculum vitae should be sent to Carol Robertson (carol.robertson@mq.edu.au)

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