Initial field survey report of the 2011 East Japan Tsunami in Sendai, Natori and Iwanuma Cities

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UNESCO-IOC International Tsunami Survey Team

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1. INTRODUCTION

The East Japan Earthquake (Mw 9.0) and associated tsunami struck the Pacific coast of eastern Japan on March 11th, 2011 at 2:46 p.m. (Japan Standard Time). Maximum run-up heights reached about 40 m along the Sanriku region's coast and around 10 m on the Sendai coastline. The coasts of Iwate, Miyagi and Fukushima Prefectures in particular were badly damaged, and a considerable amount of time and money will be required to restore these areas.

Tsunami inundation up to 5 km inland occurred across the Sendai Plain, which remained partly flooded for several weeks after the event. Some areas were still under water 2 months after the earthquake, and are likely to remain flooded for some time as a result of subsidence.

The Disaster Control Research Center at Tohoku University conducted scientific research of the inundated coastal plains of Sendai, Natori and Iwanuma Cities in collaboration with other research institutes from Japan and overseas with the support of UNESCO-IOC (Intergovernmental Oceanographic Commission). Data and samples collected during the field survey are now being analyzed by various institutes around the World. This report is a summary of our field survey that focused on an area to the north of Sendai Airport. Radioactivity data recorded at the time of survey are also provided.

2. GLOSSARY

The terminology used in this report is shown in Figure 1. Please note that inundation/run-up height refers to the height or elevation in meters above mean sea level, while flow depth refers to the elevation above the ground.

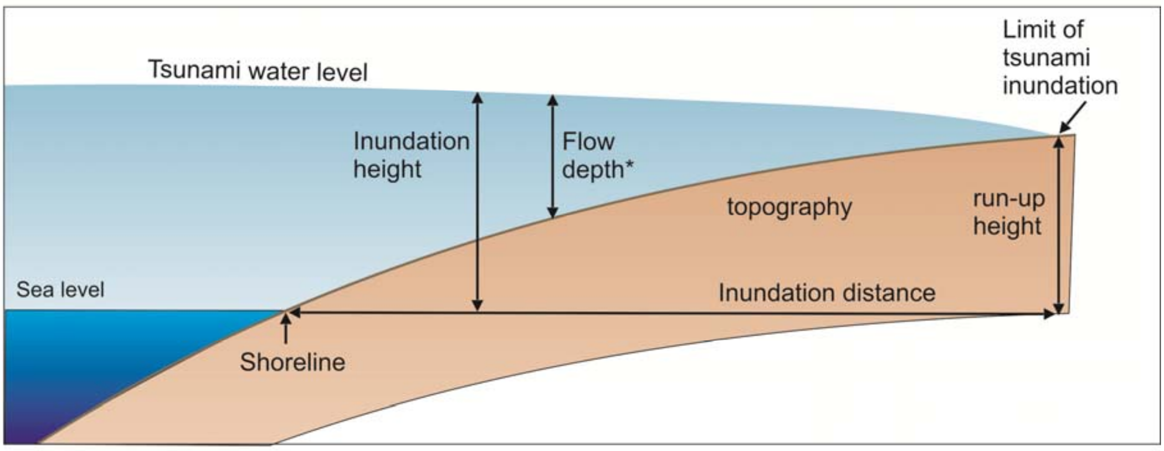

Figure 1. Tsunami terminology. Note that 'flow depth' is called 'inundation depth' in some Japanese reports. Inundation height and flow depth refer to maximum measured values.

3. SURVEY PLAN

- Duration: May 3rd–13th 2011.
- Study areas: Sendai, Natori and Iwanuma Cities, Miyagi Prefecture, Japan (see Fig. 2).
- Objectives: Understanding ground elevation changes, modes of sedimentation and liquefaction in the inundated areas.
- Survey methods: Sampling of sediments deposited by the tsunami, measurements of inundation height and topography, as well as conductivity and pH of water bodies. Soil sampled in paddy fields to ascertain the level of saltwater contamination.
- Members of the team (12 people):
    - Daisuke Sugawara (Disaster Control Research Center, Tohoku University)
    - Kazuhisa Goto (Planetary Exploration Research Center, Chiba Institute of Technology)
    - Shigehiro Fujino (Graduate School of Earth and Environmental Sciences, University of Tsukuba)
    - Yuichi Nishimura (Institute of Seismology and Volcanology, Hokkaido University)

    - Catherine Chagué-Goff (Australia-Pacific Tsunami Research Centre, University of New South Wales, Sydney, Australia; Australian Nuclear Science and Technology Organisation, Kirrawee DC, Australia)
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    - Witek Szczuciński (Institute of Geology, Adam Mickiewicz University in Poznań, Poznań, Poland)
    - Dave Tappin (British Geological Survey, Nottingham, United Kingdom)
    - Eko Yulianto (Indonesian Institute of Science, Jakarta, Indonesia)
    - James Goff (Australia-Pacific Tsunami Research Centre, University of New South Wales, Sydney, Australia)

Planning and execution of this survey were conducted with the help of Prof. Fumihiko Imamura (Disaster Control Research Center, Tohoku University). Mr. Masahiro Yamamoto joined as an observer in the latter part of the survey. Prof. James Goff organized much of the pre-survey logistics for the international members of the team but was unable to travel to Japan.

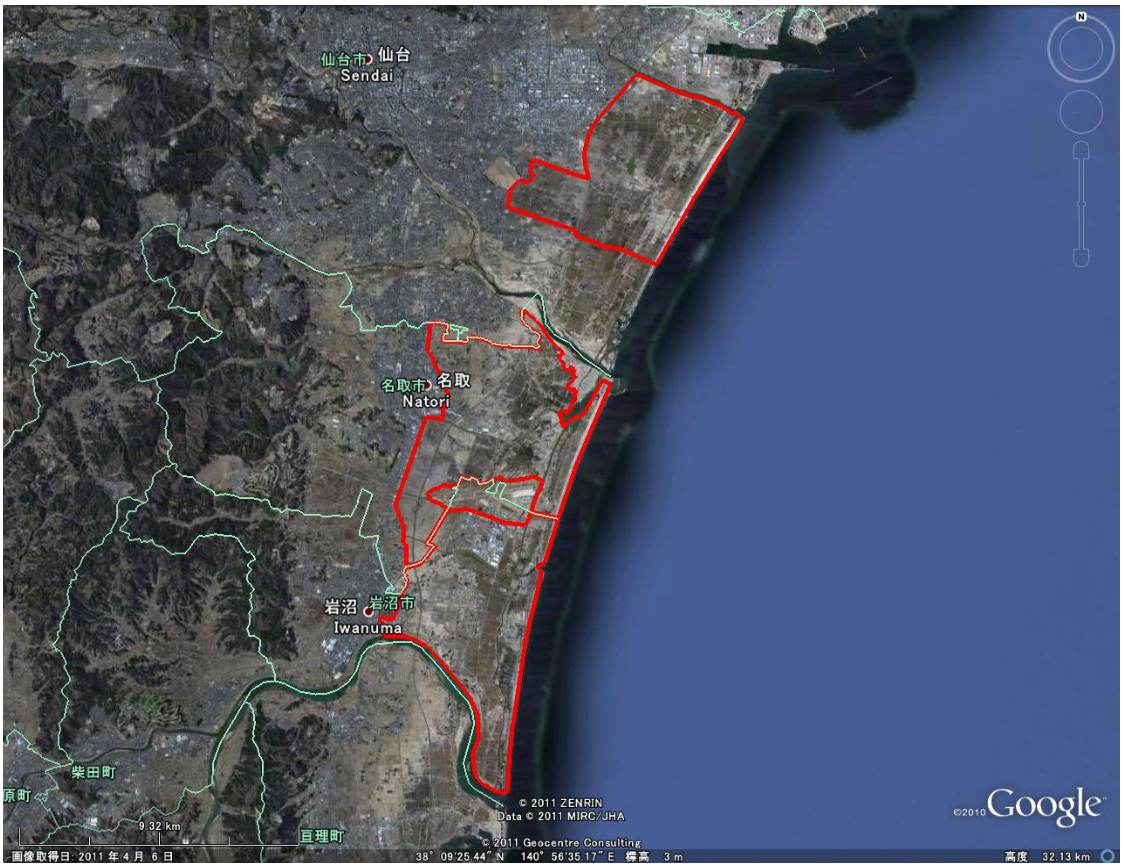

Figure 2. Index map of the study areas delineated by red lines (modified from Google Earth image)

3. RESULTS

3-1. Survey line and sites studied

We conducted an initial survey of Sendai, Natori and Iwanuma Cities to confirm that it was possible to carry out a full survey under the existing conditions. An area just north of Sendai Airport (Natori City) was chosen as the location for a survey line. The 4.4 km long transect encompassed a representative area of damaged housing, roads and paddy fields (Fig. 3). GPS measurements of ground elevation and inundation heights were taken along this transect. We surveyed modes of sedimentation and erosion at 70 study sites spaced 50 to 100 m apart along the transect. Additional sites were sampled farther inland, as well as on either side of the transect, for assessment of environmental impact (level of saltwater contamination in soil underlying the tsunami deposit). The specific conductivity of water in paddy fields, canals, irrigation and drainage channels was also measured to assess the salinity. Study sites were numbered from 3-01 to 3-88 in a seaward to landward direction.

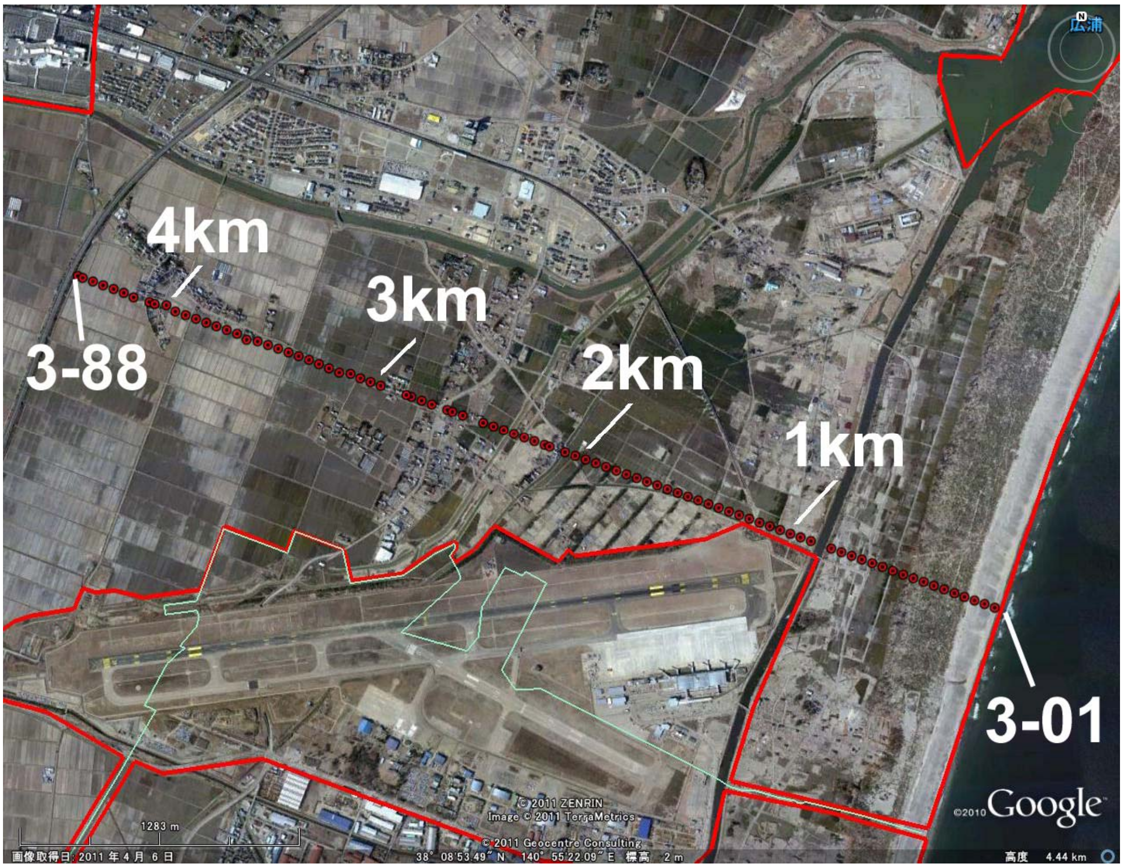

Figure 3. Location of the survey line studied (modified from Google Earth image).

3-2. Ground elevation and inundation heights of the tsunami

Figure 4 shows the ground elevation above Tokyo Peil (TP, mean sea level in Tokyo Bay). The ground elevation is generally around 3-4 m at the coastal dunes and 0-1 m in the inland paddy fields except where roads and other elevated structures were present. The paddy fields are visible as the dark colored areas in the satellite image (Fig. 3) and these also generally correspond with water-covered sections of the transect.

Inundation heights 10.6 m above TP (flow depth 9.6 m) were measured immediately landward of the coastal dunes. Between 0.5 and 2.5 km inland the inundation height was 3-4 m above TP (flow depth 2-3 m). At the landward end of the transect over 4 km from the ocean the flow depth was only about 20 cm where the ground elevation was 2.7 m adjacent to the Tobu Highway. Most of the severe damage to houses and roads occurred across a zone from the coast to around 2.5 km inland where flow depths were highest.

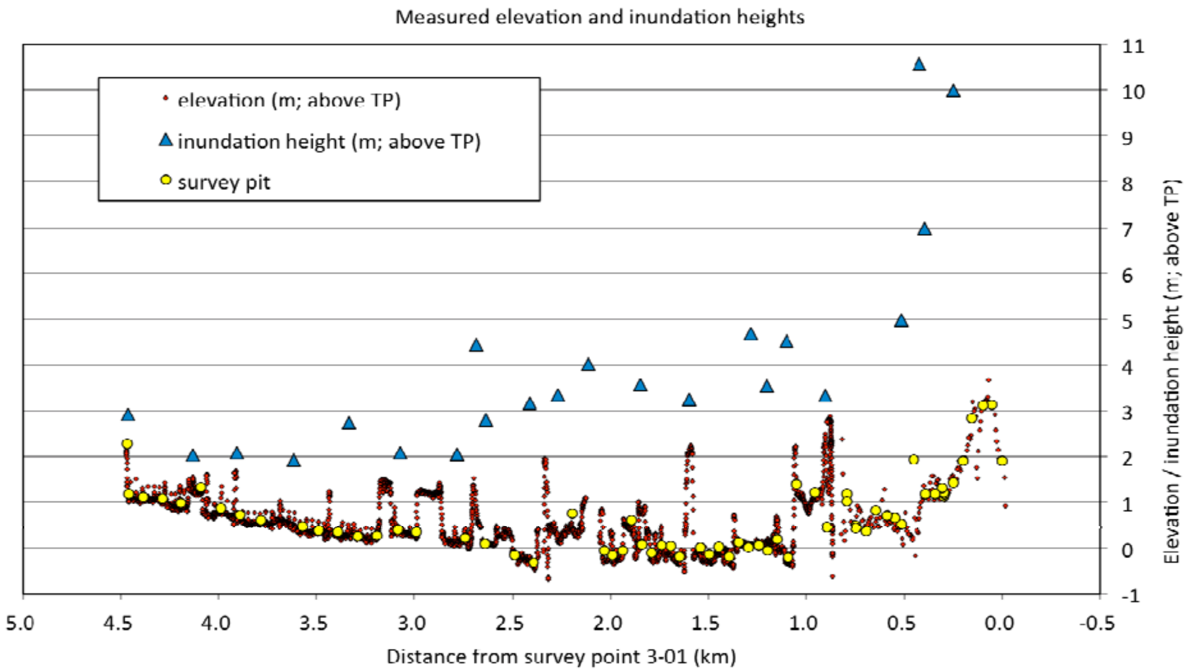

Figure 4. Inundation height and ground elevation after the earthquake and tsunami along the survey line.

3-3. Distribution of tsunami deposit

Figure 5 shows the thickness of the sediments deposited by the tsunami (tsunami deposit). The tsunami deposit generally thins landward ranging from 15-20 cm thick 1 km inland, to about 10 cm thick 2 km inland and less than 5 cm thick 3 km inland. Observations in a few pits around each study site showed that the thickness of the tsunami deposits varied significantly over short distances. Evidence for both erosion and deposition was common at sites that were at similar distances inland. Erosion however, was predominant on the landward side of elevated features such as breakwaters or coastal dunes.

The tsunami deposit was composed mainly of sand within 1 km of the ocean (Fig. 6) changing to sand covered by about 5 mm of mud between 1-3 km from the shore (Fig. 7). Further landward of 3 km from the shore, the deposit was composed almost entirely of mud underlain by a very thin (<1 mm thick) lamina of fine to very fine sand (Fig. 8). Numerous soil rip-up clasts were observed on some of the more seaward paddy fields.

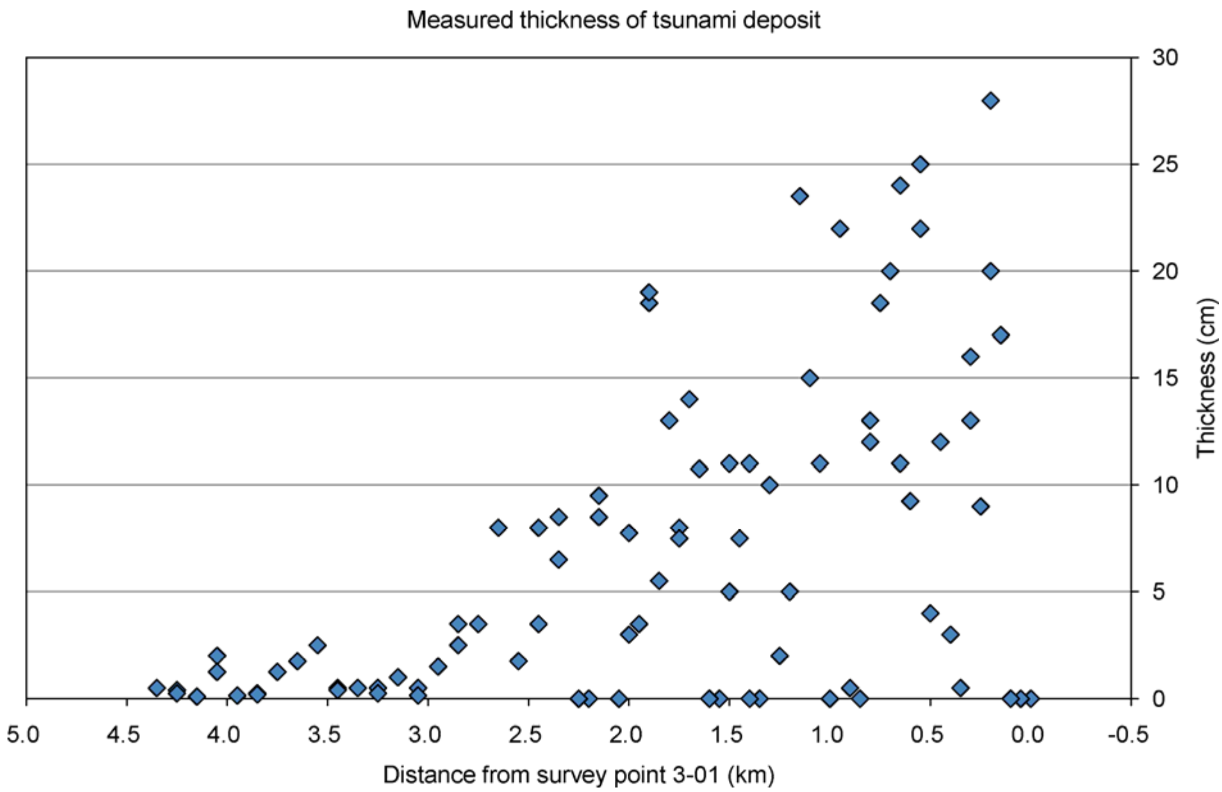

Figure 5. Measured thickness of the tsunami deposit (sand and mud) along the transect.

Figure 6. 20 cm thick tsunami sand deposit at site 3-12 (550 m from shore, Natori City).

Figure 7. Tsunami deposit at site 3-30 (1.45 km from shore, Natori City) composed of 7 cm thick sand overlain by 5 mm thick mud.

Figure 8. Tsunami deposit at site 3-64 (3.15 km from shore, Natori City) represented by a 5 mm thick mud layer.

Ground level lowering due to erosion and dewatering from liquefaction was observed at several places along the transect (Figs. 9, 10). The tsunami deposit therefore appears to consist mainly of sand transported from the beach and dunes east of the coastal forest, mud from the erosion of paddy field soils west of the

Teizan Canal, and redeposited sand vented by liquefaction. In some places, road asphalt, gravel, organic and other anthropogenic debris have also been incorporated into the deposit (Fig. 11).

It appears that the mud overlying the sand in the tsunami deposit was laid down from standing water. Most of this fine material was most likely sourced from soil eroded from paddy fields (sometimes incorporated as rip-up clasts), although deposition of seafloor mud mixed with terrestrial mud is also likely. Furthermore, black colored mud covering paddy fields was reported immediately landward of Hakken Canal (Fig. 12). The black color most likely indicates that it was sourced from the bottom of the canal where the oxygen-depleted mud is rich in organic matter and/or iron sulfide, and preliminary chemical analysis appears to support this.

We established an additional transect line 280 m long across footpaths in adjacent paddy fields close to the sites between 3-32 and 3-38 in order to undertake more detailed thickness measurements (Fig. 13). An examination of the thickness of the tsunami deposit and ground elevation indicated that the landward side of footpaths was eroded, while deposition occurred on the seaward side (Fig. 14). Furthermore, vegetation on the footpath was eroded and torn off in many places (Fig. 15).

Figure 9. Remains of greenhouses north of site 3-10 (450 m from shore, Natori City). According to interviews, the surface of the farmland was at about the same level as the road prior to the tsunami, but erosion during the tsunami removed sediment from the farmland resulting in the elevation difference apparent in the photograph.

Figure 10. Possible liquefaction features close to site 3-32 (1.55 km from shore, Natori City). The depressions are thought to be due to sand liquefaction and collapse of the surface soil and were likely modified by erosion by tsunami waves. Liquefied sands would have been entrained and transported inland by the tsunami.

Figure 11. Asphalt from the road in tsunami deposit.

Figure 12. Tsunami deposit at site 3-48 (2.35 km from shore, Natori City) showing a 7 cm thick sand covered by 1.0-1.5 cm thick black mud.

Figure 13. Location of the additional survey line 1.5-2.0 km from shore (red line, modified from Google Earth image).

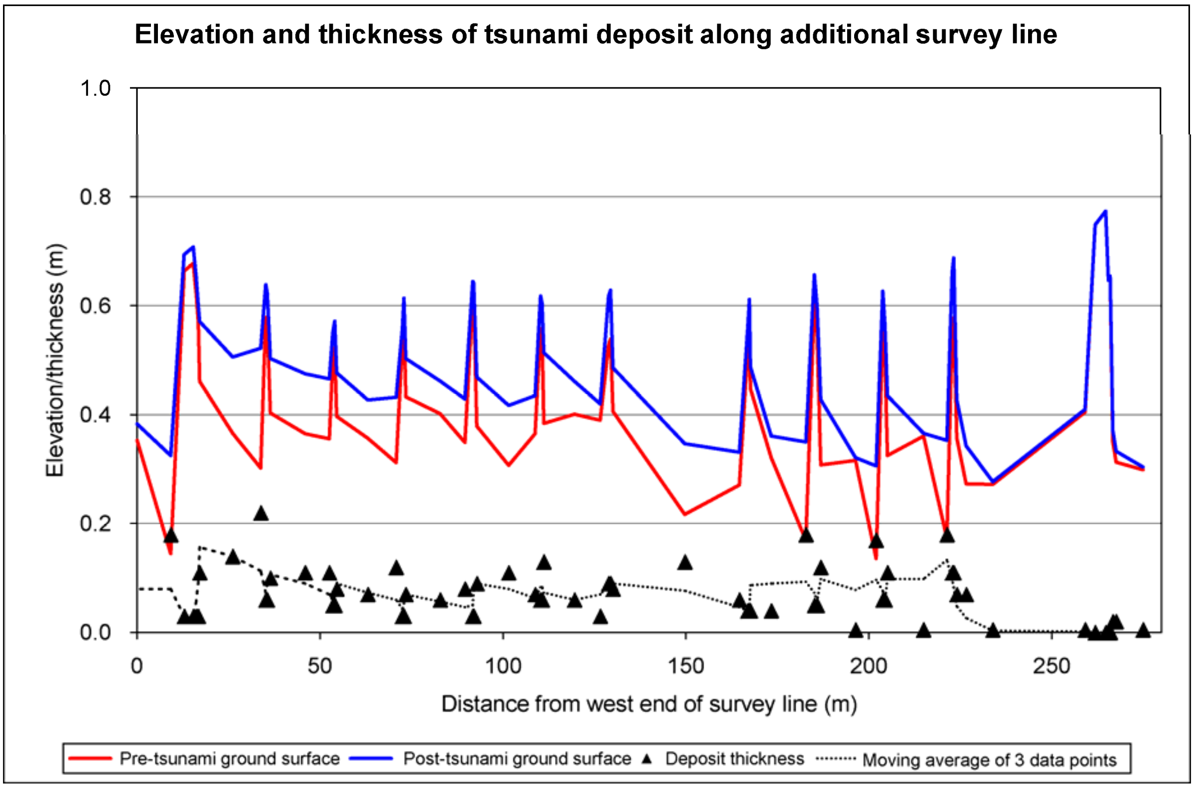

Figure 14. Thickness of the tsunami deposit and ground elevation before and after the earthquake and tsunami along the additional survey line.

Figure 15. Eroded and torn vegetation from footpaths by paddy fields, near site 3-32.

3-4. Specific conductivity

Figure 16 shows the specific conductivity of water in the paddy fields, canals, irrigation and drainage channels. The specific conductivity of ponded water on the paddy fields was 10-20 mS/cm, although it was considerably higher in the vicinity of the canals (Teizan Canal and Hakken Canal) with values exceeding those for seawater in some places (between 2.0-2.5 km inland it reached nearly 70 mS/cm). This high salinity results from the evaporation of seawater introduced by the tsunami. This abnormal saltwater influence is limited to the areas immediately surrounding the canals, although high specific conductivity was still recorded on paddy fields throughout the first 2.6 km of the transect . No ponded water was recorded along the transect further inland, but salt crusts were observed in many areas along the transect (Fig. 17).

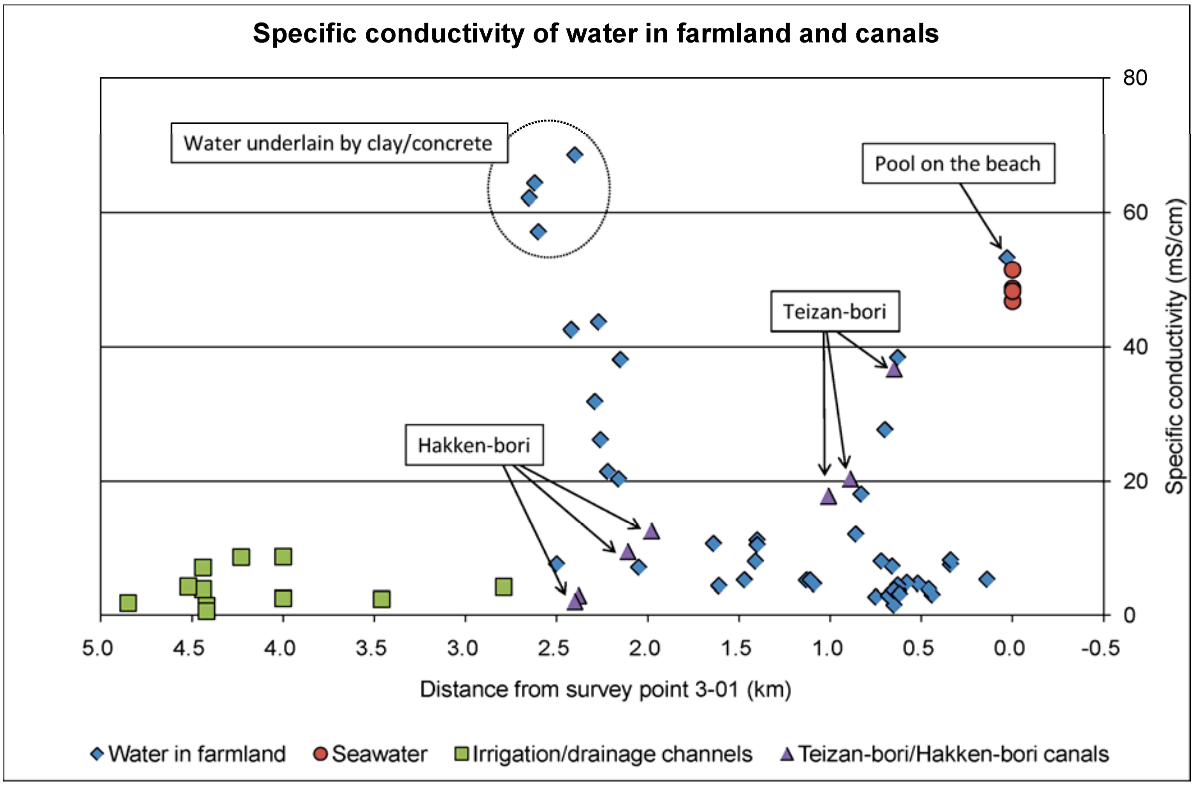

Figure 16. Specific conductivity of water in flooded paddy fields (farmland), seawater, canals, irrigation and drainage channels.

Figure 17. Salt crust at surface of paddy field, near site 3-64.

4. RADIOACTIVITY LEVELS

The Australian Nuclear and Science Technology Organisation (ANSTO) provided one member of the UNESCO-IOC Post-Tsunami Survey Team, Catherine Chagué-Goff, with an electronic personal dosimeter (EPD) and two thermo luminescent dosimeters (TLD) before her departure. She also underwent a whole body monitor before and after her trip to Japan, and results show background levels (W. Kyu, pers. comm., May 2011). Radioactivity levels measured on a daily basis (8am to 10pm) with the EPD were less then 2 µS/14 hours (readings of 1 µS per day in average over 10 days), in accordance with radioactivity levels reported for the area on the webpage of the Ministry of Education, Culture, Sports and Technology-Japan (MEXT: http://www.mext.go.jp/english). There were also similar to radioactivity levels recorded in the Sydney (Australia) metropolitan area.

The radioactivity dose recorded by the TLDs was measured at the end of May 2011. The dose value from the TLD worn while doing fieldwork (0.73 mS) matched the dose from the control TLD that was left in the suitcase. Bearing in mind the low dose rate measured with the EPD, the radiation dose recorded by the TLDs can be attributed to airport x-ray checks and the cosmic ray during flights to and from Japan (Y. Hammami, pers. comm., May 2011).

5. SUMMARY

- We conducted measurements of ground elevation and inundation height along a 4.4 km transect. Land subsidence was evident especially in areas 1-2.5 km landward from the coast.
- The tsunami deposit thins landward over the length of the transect. The thickness is 15-20 cm 1 km from the shoreline, about 10 cm 2 km inland and less than 5 cm 3 km inland.
- Tsunami deposits at sites less than 3 km from the shore are composed of sand with overlying mud, and only mud (except for a one grain-thick sand layer) at sites 3 km or more inland.
- Specific conductivity of ponded water at some sites was extremely high because of seawater evaporation and little dilution by rainwater.
- Tsunami deposits consisting of sand and mud contain elevated levels of salt (and possibly iron sulfide) that can be harmful to crops.
- Radioactivity levels in the surveyed area were close to background.

6. RECOMMENDATIONS

Ground elevation is lower than mean sea level in several places between the landward side of the coastal dunes to around 2.5 km inland because of coseismic subsidence coupled with erosion by the tsunami. Thus the drainage infrastructure will need to be enhanced to ensure that seawater incursion is reduced and that freshwater flooding during heavy rain is controlled.

The removal of some of the tsunami deposit will probably be necessary to restore some of the paddy fields for cultivation. The tsunami deposit is 10-15 cm thick in an area between 1.0 and 1.5 km landward from the shore. In places, it also contains black mud, which probably originated from the canals (Teizan and Hakken Canal), and has high salt content and may also contain iron sulfide that can harm crops. Agricultural soil will need to be re-established in the area up to about 1.7 km from the shore, where collapse due to liquefaction and soil erosion by the tsunami are predominant. The area further than 2.5 km inland can be restored without removal of the tsunami deposit, because it is less than 5 cm thick and contains little sand.

Between tsunami inundation and our survey in early May the salinity of ponded saltwater increased through evaporation and minimal dilution due to limited rainfall. A number of saltwater removal operations may be required if dilution by rainfall is insufficient to bring salinities to an acceptable level in the near future. This needs careful monitoring.

Along with the restoration of paddy fields, consideration should also be given to reducing the effects of onshore winds. Windblown sand was frequently observed during the fieldwork. There is now considerably more salt spray and sand blowing into paddy fields close to the coast because much of the windbreak forests were destroyed by the tsunami.

ACKNOWLEDGMENTS

This survey was conducted with support from a special grant "Emergency tsunami field survey in the Pacific coast of Tohoku Region" by the Ministry of Education, Culture, Sports, Science and Technology, Japan. The Farmland Policy Planning Division and Disaster Countermeasures Office of Sendai, Natori and Iwanuma Cities provided considerable assistance to us with many and various tasks during this difficult time. Geosurf Ltd. and Sendaisokki Ltd. assisted us with GPS measurements and data analysis. Members of the UNESCO-IOC ITST wish to thank UNESCO-IOC and ITIC for their kind coordination of the field survey and their respective organizations and funding bodies for their support.

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