Regional Differences in Fukushima Prefecture Road Recovery Following the 2011 Tohoku Earthquake

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***Abstract*—We evaluate regional differences in road recovery in Fukushima Prefecture following the 2011 Tohoku Earthquake. We divided Fukushima Prefecture into seven regions, i.e., Soso, Iwaki, Kenhoku, Kenchu, Kennan, Aizu, and Minami-aizu regions. According to the results of our study, we conclude that the recovery conditions of regional roads in different areas of Fukushima Prefecture following the 2011 Tohoku Earthquake differed. The road recovery speeds in Coastal and Inland areas were not so different from each other. The road recovery speed in Aizu region was about a month slower than that in Coastal and Inland areas. The road recovery speed in Minami-aizu region was about a month slower than that in Aizu region. We concluded that the roads in these two regions whose recovery was significantly delayed were narrow, steep-walled, and located in mountainous regions.**

***Index Terms*—2011 Tohoku Earthquake; probe-car telematics data; vehicle-tracking map; Fukushima Prefecture; big data analysis**

I. Introduction

A. The 2011 Tohoku Earthquake

The 2011 Tohoku Earthquake [Fig.1] struck the northeastern coast of Japan on March 11, 2011. Subsequently, the region was severely affected by the tsunami. Following these natural disasters, the electricity, water, and gas supplies were shut down in both coastal and inland areas[1], [2], [3], [4]. Furthermore, the road travel was disrupted in many parts of the region.

B. Purpose

The primary purpose of our study was to evaluate the regional differences in road recovery in Fukushima Prefecture following the 2011 Tohoku Earthquake. Therefore, based on geographic position and features, we divided Fukushima Prefecture into seven regions, i.e., Soso, Iwaki, Kenhoku, Kenchu, Kennan, Aizu, and Minami-aizu regions.

During the disaster, these areas were affected differently. For example, due to differences in coastal features, the tsunami struck the northern coastal area more heavily than the southern coastal area. Therefore, we assumed that there were specific differences among the three studied regions during the road recovery process following the disaster.

The secondary purpose of our study was to compare the regional differences with regard to road recovery in Fukushima Prefecture, the target of this study, compared to road recovery in Iwate Prefecture and Miyagi Prefecture, which was evaluated in our previous studies [3], [4].

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II. Our previous studies

A. Previous study 1

Our previous study 1 [1] was focused on the use of the main roads in the Southern Coastal area of Iwate Prefecture. The usable distances of the main roads following the 2011 Tohoku Earthquake have been calculated from the G-BOOK telematics data [5].

The main findings of this study are as follows:

1) The usable distance of the roads in a weekly period has continuously increased from March 18 to April 7, 2011, but it has fluctuated thereafter.

2) Defining the cumulative usable distance up to September 30, 2011 as 100%, it has been determined that 80% of the road distance has been usable by April 7, 2011 and 90% by April 29, 2011.

3) The use of the main road in the coastal area of Iwate Prefecture has been completely recovered by April 29, 2011.

B. Previous study 2

Our previous study 2 [2] was focused on the use of the main roads not only in the Southern but also in the Northern Coastal area of Iwate Prefecture.

The cumulative usable road distance ratio of the main roads has been precisely calculated for each city using the free and open source geographical information system software QGIS. The main findings in this study [2] are listed below.

(1) The change in the cumulative usable road distance ratio during the research period differed from one city to the next.

(2) The ratio increases in the usable distances of Kuji, Iwaizumi, and Noda were extremely delayed.

In our study, we were able to determine related roads by analyzing the maps generated by the QGIS software. For Kuji and Iwaizumi, the road whose recovery was significantly delayed is the Iwate Prefectural Road number 7 (Kuji-Iwaizumi line). For Noda, the road whose recovery was significantly delayed is the Iwate Prefectural Road number 273 (Akka-Tamagawa line).

(3) In our previous study 1 [1], we determined that the use of the main road in the Southern Coastal area of Iwate Prefecture was completely recovered by April 29, 2011.

However, in this study, when we have precisely observed the change in the usable road distance ratio during the research period for each city, the ratio increase in the usable road distance of Kamaishi has been delayed compared with other Southern Coastal cities.

For Kamaishi City, the road whose recovery was significantly delayed is the Iwate Prefectural Road number 249 (Sakuratoge-Heita line).

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C. Previous study 3

In our previous study [3], we calculated the regional differences for road recovery in Iwate Prefecture following the 2011 Tohoku Earthquake. We divided Iwate Prefecture into four areas, i.e., Northern Inland, Southern Inland, Northern Coastal, and Southern Coastal areas. The main results of the previous study are as follows.

First, we determined that, for Northern and Southern Inland areas, 80% of the road distance was usable by April 15, 2011 and 90% by May 27, 2011, which indicates that the recovery speed in these areas was slightly slower than that in the Southern Coastal area.

Second, we found that, for the Northern Coastal area, 80% of the road distance was usable by April 29, 2011 and 90% by June 24, 2011, which implies that the recovery speed in the Northern Coastal area was significantly slower than that in the Southern Coastal area.

Hence, we concluded that these findings are related to the fact that road recovery efforts were more focused on regions heavily affected by the earthquake and tsunami.

D. Previous study 4

In our previous study [4], we evaluate regional differences in road recovery in Miyagi Prefecture following the 2011 Tohoku Earthquake. We divided Miyagi Prefecture into three areas, i.e., Inland, Northern Coastal, and Southern Coastal areas. According to the results of our study, we conclude that the recovery conditions of regional roads in different areas of Miyagi Prefecture following the 2011 Tohoku Earthquake differed. In the Northern Coastal area, 80% of the road distance was usable by April 15, 2011 and 90% was usable by May 27, 2011. In the Southern Coastal area, 80% of the road distance was usable by March 31, 2011 and 90% was usable by April 8, 2011. Recovery in the Southern Coastal area was much faster compared to that in the Northern Coastal area. We assume that this is due to the shape of the coastlines. The coastlines in the Northern coastal area are primarily rias. The coastlines in the Southern coastal area are mostly sandy. Furthermore, we have concluded that the recovery conditions of the regional roads following the 2011 Tohoku Earthquake in the Northern Coastal area of Miyagi Prefecture were similar to those in the Southern Coastal area of Iwate Prefecture. In the disaster regions, similar recovery conditions were found according to geographic positions and features.

III. Telematics Data and Vehicle-Tracking Map

Telematics is a general term encompassing telecommunications and informatics. A telematics service provides various personalized information for users, especially for drivers of automobiles. G-BOOK is a telematics service provided by Toyota Motor Corporation.

To calculate the usable distance of the main roads, we applied the vehicle tracking map originally created by Hada et al. [6] after the 2007 Niigataken Chuetsu-oki earthquake.

That vehicle tracking map was based on telematics data provided by Honda Motor Company. Similarly, in our study, we used the vehicle tracking map based on telematics data provided by Toyota's G-BOOK system [Figs. 2].

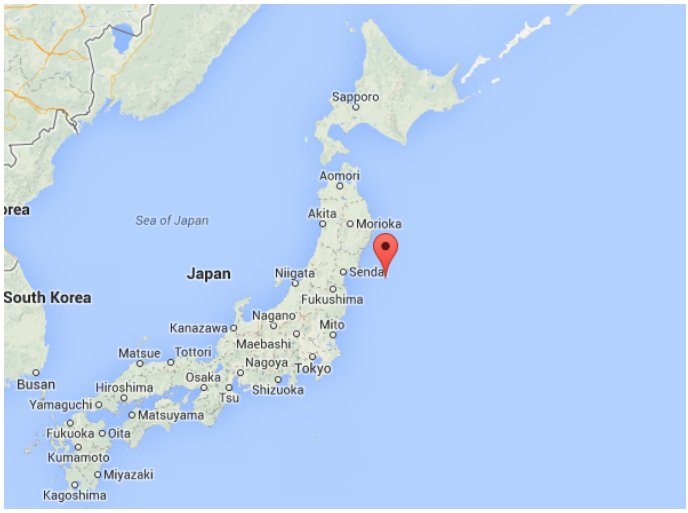

Fig. 1. The epicenter of the 2011 Tohoku Earthquake occurred on March 11, 2011 (https://www.google.co.jp/maps/)

Registered members of G-BOOK can access telematics services to acquire GPS data for car navigation systems and interactive driving data, such as traffic jam points, road closures, and weather reports.

Such comprehensive data acquisition is possible because the telematics system server receives accurate location data (geographic coordinates) from its registered members.

Telematics services are extremely useful to drivers. Because the accurate driving routes of registered users remain in the system server, they are accessible to traffic researchers in various fields.

IV. Research Methods

A. Research area

The current study was focused on the entire area of Fukushima Prefecture (i.e., Soso, Iwaki, Kenhoku, Kenchu, Kennan, Aizu, and Minami-aizu regions) [Fig.3].

B. Research materials

In our current study, we have used the vehicle tracking maps built from the G-BOOK telematics data that is available on the Internet on March 18, 2011 following the 2011 Tohoku Earthquake [5].

The data used in this study have been collected between March 18 and September 30, 2011 (i.e., approximately six months following the 2011 Tohoku Earthquake).

C. System

Hardware:

The computations have been performed on a standard PC laptop with a Core i7-6700U CPU (2.6 GHz) and 16 GB memory (Hasee Z7M-SL7D2).

Software:

The software QGIS version 2.18.20 (the latest version available) [9] ,LibreOffice Calc 4.2.7 spreadsheet software [10], and Microsoft Excel 2010 running on the Windows 7 Professional operating system have been used in this study. It is well-known that QGIS is one f the most popular geographic information systems used worldwide.

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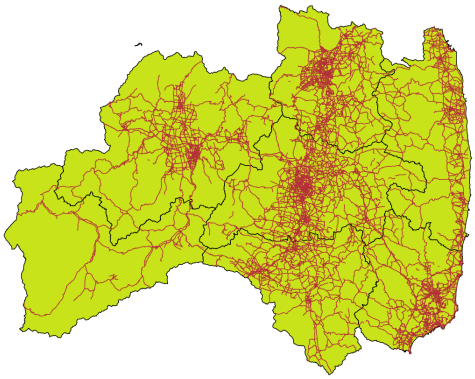

Fig. 2. Vehicle tracking map of Fukushima Prefecture

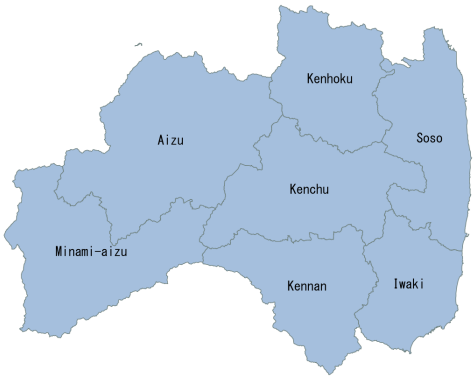

Fig. 3. Fukushima Prefecture divided into seven regions, i.e., Soso, Iwaki, Kenhoku, Kenchu, Kennan, Aizu, and Minami-aizu regions. The perimeter of a region is shown by a gray polygon.

Prior to the abovementioned applications for geographical data processing, we have used the ogr2ogr software [11] on the Linux operating system along with Vine Linux 4.2 [12], which is a Linux distribution developed by a Japanese Linux community.

Note that QGIS, LibreOffice Calc, ogr2ogr, and Vine Linux are open source softwares freely available on the Internet.

D. Data Processing

1) The vehicle tracking maps constructed from the G-BOOK telematics data have been provided in the Google map KMZ format. For our analysis, we have first converted the KMZ files to SHP files (i.e., shape-files), which are compatible with ArcGIS using the ogr2ogr software.

2) Next, the data coordinates have been converted from the terrestrial latitude and longitude to the x and y coordinates in a rectangular coordinate system.

3) To reduce the computation time, the data file has been clipped to small files containing only the research area.

4) After merging daily data into weekly data and removing duplicate data, we have been able to calculate the exact usable road distance available for a given week.

In this context, a usable road is one on which at least one vehicle has been probed during the observation period.

The purpose of converting the daily data to weekly data was to smooth the daily fluctuations in the traffic flows.

5) Next, we have calculated the proportion of the cumulative distance up to the specified date. Note that the cumulative distance up to September 30, 2011 was considered 100%.

V. Results

A. Regional road recovery differences

Defining the cumulative usable distance up to September 30, 2011 as 100%, the percentages of usable road distances are given in Table.II. In Table.II, the upper lines indicate the cumulative usable road distances (in kilometers), and the lower lines represent the ratio of cumulative usable road distance.

1) Soso region of Coastal area (Hama-dori): It was determined that 80% of the road distance was usable by April 8, 2011 and 90% was usable by April 22, 2011.

2) Iwaki region of Coastal area (Hama-dori): It was determined that 80% of the road distance was usable by March 31, 2011 and 90% was usable by April 15, 2011.

The recovery speed in Iwaki region was slightly faster than that in Soso region.

3) Kenhoku region of Inland area (Naka-dori): It was determined that 80% of the road distance was usable by April 8, 2011 and 90% was usable by April 29, 2011.

The recovery speed in Kenhoku region was almost the same as that in Soso region (a very little slower).

4) Kenchu region of Inland area (Naka-dori): It was determined that 80% of the road distance was usable by March 31, 2011 and 90% was usable by April 15, 2011.

The recovery speed in Kenchu region was almost the same as that in Iwaki region.

5) Kennan region of Inland area (Naka-dori): It was determined that 80% of the road distance was usable by April 8, 2011 and 90% was usable by April 22, 2011.

The recovery speed in Kennan region was almost the same as that in Soso region.

As a whole, road recovery speeds of region one to five were not so different from each other.

6) Aizu region of Far-inland area: It was determined that 80% of the road distance was usable by April 22, 2011 and 90% was usable by May 27, 2011.

The recovery speed in Aizu region was about a month slower than that in Coastal and Inland area.

7) Minami-aizu region of Far-inland area: Minami means south in Japanese language. It was determined that 80% of the road distance was usable by May 27, 2011 and 90% was usable by June 24, 2011.

The recovery speed in Minami-aizu region was about a month slower than that in Aizu region.

VI. Discussion

A. Two far-inland regions whose road recovery was extremely delayed after the 2011 Tohoku Earthquake

We could evaluate the road recovery speed after the 2011 Tohoku Earthquake clearly by observing Table I and Figure 4.

The recovery speed did not differ so much in the Coastal (Soso and Iwaki) and Inland (Kenhoku, Kenchu, and Kennan) regions. In these regions, each recovery difference was within a week or so.

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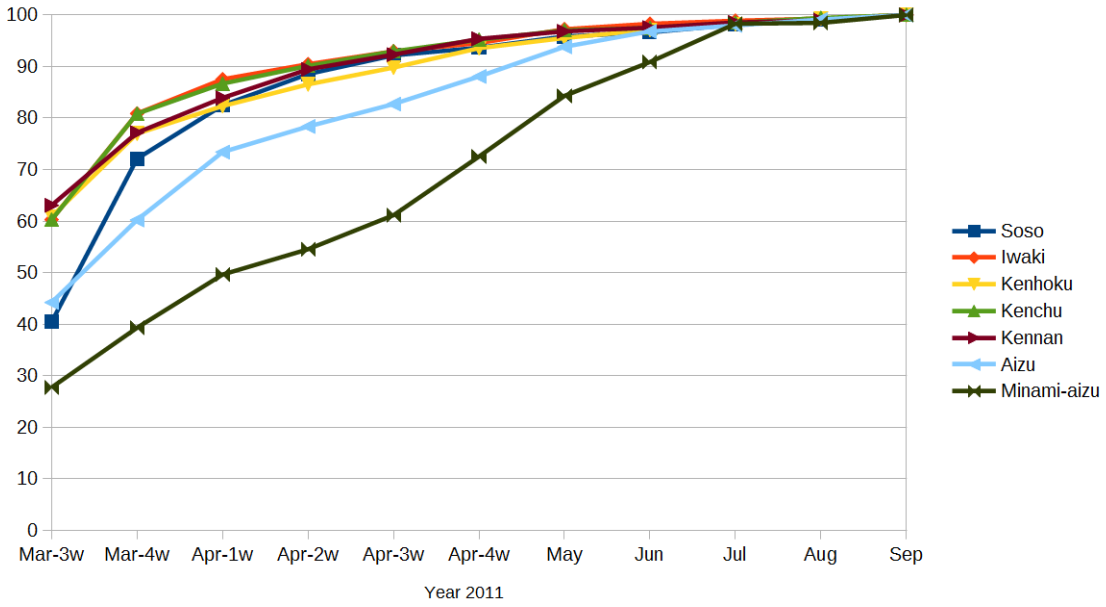

Fig. 4. Cumulative usable road distance ratio for each area. The vertical scale displays the cumulative distance proportion of the usable roads relative to the cumulative distance on September 30, 2011) for each date.

TABLE I
REGIONAL DIFFERENCE FOR ROAD RECOVERY IN FUKUSHIMA PREFECTURE (CUMULATIVE USABLE ROAD DISTANCES (KILOMETERS) AND RATIOS)

	Mar 24	Mar 31	Apr 08	Apr 15	Apr 22	Apr 29	May 27	Jun 24	Jul 29	Aug 26	Sep 30
Coastal (Hama-dori)	501.60	894.71	1023.22	1098.45	1143.27	1161.89	1188.78	1198.79	1217.53	1230.06	1240.69
Soso	40.4	72.1	82.5	88.5	92.1	93.6	95.8	96.6	98.1	99.1	100
Coastal (Hama-dori)	877.30	1176.65	1273.40	1316.11	1352.35	1375.66	1414.69	1429.99	1438.81	1444.68	1455.02
Iwaki	60.3	80.9	87.5	90.5	92.9	94.5	97.2	98.3	98.9	99.3	100
Inland (Naka-dori)	1150.32	1454.07	1555.05	1634.73	1696.24	1767.36	1804.52	1834.23	1855.28	1875.95	1889.07
Kenhoku	60.9	77.0	82.3	86.5	89.8	93.6	95.5	97.1	98.2	99.3	100
Inland (Naka-dori)	1549.99	2079.07	2229.02	2317.43	2390.14	2447.85	2494.98	2506.59	2532.57	2556.73	2571.73
Kenchu	60.3	80.8	86.7	90.1	92.9	95.2	97.0	97.5	98.5	99.4	100
Inland (Naka-dori)	906.70	1109.48	1206.45	1286.18	1327.17	1371.37	1391.99	1402.48	1416.81	1422.61	1437.81
Kennan	63.1	77.2	83.9	89.5	92.3	95.4	96.8	97.5	98.5	98.9	100
Far-inland	796.17	1084.43	1321.46	1410.88	1489.16	1585.62	1689.17	1743.03	1763.68	1784.55	1800.42
Aizu	44.2	60.2	73.4	78.4	82.7	88.1	93.8	96.8	98.0	99.1	100.0
Far-inland	130.29	184.69	233.22	256.31	287.31	340.83	396.12	426.97	461.83	462.66	469.88
Minami-aizu	27.7	39.3	49.6	54.5	61.1	72.5	84.3	90.9	98.3	98.5	100.0

TABLE II
REGIONAL DIFFERENCES FOR ROAD RECOVERY IN MIYAGI PREFECTURE (CUMULATIVE USABLE ROAD DISTANCES (METERS) AND RATIOS) [4]

	Mar 31	Apr 08	Apr 15	Apr 22	Apr 29	May 27	Jun 24	Jul 29	Aug 26	Sep 30
Whole	3710404.71	4070465.56	4302746.51	4432316.59	4555942.55	4689705.40	4784541.96	4853809.92	4898789.43	4951562.17
Inland	0.749	0.822	0.869	0.895	0.920	0.947	0.966	0.980	0.989	1.000
Northern	689499.47	760734.33	798356.91	820800.18	861329.64	884760.76	917857.84	938069.52	946266.16	959149.12
Coastal	0.719	0.793	0.832	0.856	0.898	0.922	0.957	0.978	0.987	1.000
Southern	1401296.10	1501843.72	1544385.42	1576106.64	1589184.41	1610740.67	1621919.88	1634768.72	1639012.45	1643175.95
Coastal	0.853	0.914	0.940	0.959	0.967	0.980	0.987	0.995	0.997	1.000

TABLE III
REGIONAL DIFFERENCE FOR ROAD RECOVERY IN IWATE PREFECTURE (CUMULATIVE USABLE ROAD DISTANCES (METERS) AND RATIOS) [3]

	Mar 31	Apr 08	Apr 15	Apr 22	Apr 29	May 27	Jun 24	Jul 29	Aug 26	Sep 30
Northern	1850873.51	2070475.04	2152283.40	2251706.55	2296780.33	2403134.24	2483876.38	2532471.47	2571798.73	2603629.91
inland	0.711	0.795	*0.827*	0.865	0.882	*0.923*	0.954	0.973	0.988	1.000
Southern	2386739.37	2722218.13	2870724.95	2991566.34	3074037.86	3201569.09	3310978.41	3396994.03	3429255.89	3465835.57
inland	0.689	0.785	*0.828*	0.863	0.887	*0.924*	0.955	0.980	0.989	1.000
Northern	394082.91	449373.30	471389.15	524694.94	564884.21	589275.55	614317.97	618734.27	668603.07	675390.65
coastal	0.583	0.665	0.698	0.777	*0.836*	0.872	*0.910*	0.916	0.990	1.000
Southern	666655.53	779216.76	814157.35	821573.46	843427.24	855066.71	903310.83	910464.22	920120.72	934580.47
coastal	0.713	*0.834*	0.871	0.879	*0.902*	0.915	0.967	0.974	0.985	1.000

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But the recovery speed in Aize was significantly slower than that in the Coastal and Inland regions. And the recovery speed in Minami-aizu (located in the south of Aizu) was significantly slower than that in Aizu.

B. Far-inland regions, namely Aizu and Minami-aizu

We have watched some Youtube video images of the roads in these regions.

We concluded that the roads in these regions whose recovery was significantly delayed were narrow, steep-walled, and located in mountainous regions.

We would like to build the similar system which we had built in a previous study. The system would allow us to browse video images of such vulnerable roads easily.

C. Comparison of regional differences for road recovery in Fukushima Prefecture, MiyagiPrefecture, and Iwate Prefecture

According to the results of our study, we have concluded that the recovery conditions of the regional roads following the 2011 Tohoku Earthquake in the Aizu region of Fukushima Prefecture were similar to those in the Northern and Southern Inland area of Iwate Prefecture [Table I and III].

Furthermore, the recovery conditions of the regional roads following the 2011 Tohoku Earthquake in the Iwaki region of Fukushima Prefecture were almost similar to those in the Southern Coastal area of Miyagi Prefecture [Table I and II].

We had already discussed in our previous paper [4], in the disaster regions, similar recovery conditions were found according to geographic positions and features. Now, it has become more clear in this research.

D. A huge incident regarding the Fukushima Dai-ichi nuclear plant in Soso region

In Soso region, there was a huge incident regarding the Fukushima Dai-ichi nuclear plant when the 2011 Tohoku Earthquake [Fig. 5] occurred.

Regarding this region, we need more precise analysis of traffic recovery, therefore we avoid further discussion of it in this research.

We would like to conduct that kind of analysis in the near future.

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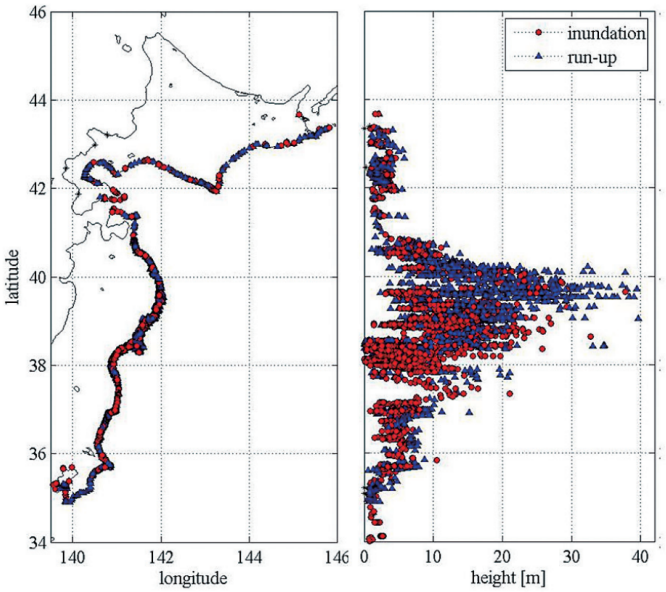

Fig. 5. Tsunami inundation following the 2011 Tohoku Earthquake. The left shows examination points. The right shows inundation and run-up (meters) of the points (cited from The 2011 Tohoku Earthquake Tsunami Joint Survey Group 2011 [7]).

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