

Regional and Altitudinal Differences in Aomori Prefecture Road Recovery Following the 2011 Tohoku Earthquake

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Abstract—We evaluate regional and altitudinal differences in road recovery in Aomori Prefecture following the 2011 Tohoku Earthquake. We divided Aomori Prefecture into six regions, i.e., Shimokita, Kamikita, Sannpachi, Tosei, Chunan, and Seihoku regions. Next, we divided Aomori Prefecture into two areas, namely Low Altitude Area and High Altitude Area. In this context, altitude means the height above sea level. Low Altitude Area is under 50 meters above sea level. And, High Altitude Area is over 50 meters above sea level. The cumulative usable road distance ratio of the main roads both for the Low Altitude Area and for the High Altitude Area had been precisely calculated for each city from telematics data using the open source geographical information software. Defining the cumulative usable distance up to September 30, 2011 as 100%, the percentages of usable road distances were calculated. According to the results of our study, we conclude that the recovery conditions of regional roads in different altitude areas of Aomori Prefecture following the 2011 Tohoku Earthquake differed. Furthermore, we also conclude that the land shape of the regions is closely related to road usage recovery.

Index Terms—2011 Tohoku Earthquake; Aomori Prefecture; big data analysis; telematics data; vehicle-tracking map

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], [5]. Furthermore, 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 Aomori Prefecture following the 2011 Tohoku Earthquake. Therefore, based on geographic position and features, we divided Aomori Prefecture into six regions, i.e., Shimokita, Kamikita, Sanpachi, Tosei, Chunan, and Seihoku regions.

During the disaster, these areas were affected differently. 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 Aomori Prefecture, the target of this study, compared to road recovery in Iwate, Miyagi, and Fukushima Prefecture, which was evaluated in our previous studies [3], [4], [5].

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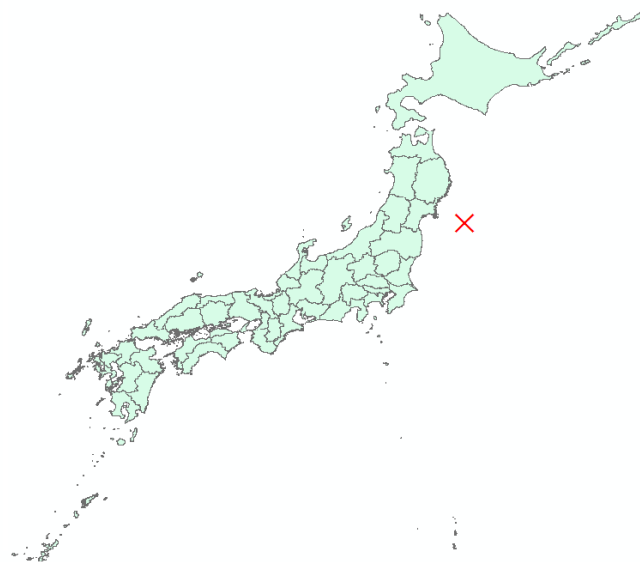


Fig. 1. The epicenter of the 2011 Tohoku Earthquake occurred on March 11, 2011.

II. 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. [7] 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 [Fig.2].

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.

III. RESEARCH METHODS

A. Research area

The current study was focused on the entire area of Aomori Prefecture (i.e., Shimokita, Kamikita, Sannpachi, Tosei, Chunan, and Seihoku regions) [Fig.2].

Next, we divided Aomori Prefecture into two areas, namely Low Altitude Area and High Altitude Area. In this context, altitude means the height above sea level. Low Altitude Area is under 50 meters above sea level. And, High Altitude Area is over 50 meters above sea level.

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 [6].

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 [10], LibreOffice Calc 4.2.7 spreadsheet software [11], 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 of the most popular geographic information systems used worldwide.

Prior to the abovementioned applications for geographical data processing, we have used the ogr2ogr software [12] on the Linux operating system along with Vine Linux 4.2 [13], which is a Linux distribution developed by a Japanese Linux community.

Note that QGIS, LibreOffice Calc, ogr2ogr, and Vine Linux are open source software 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.

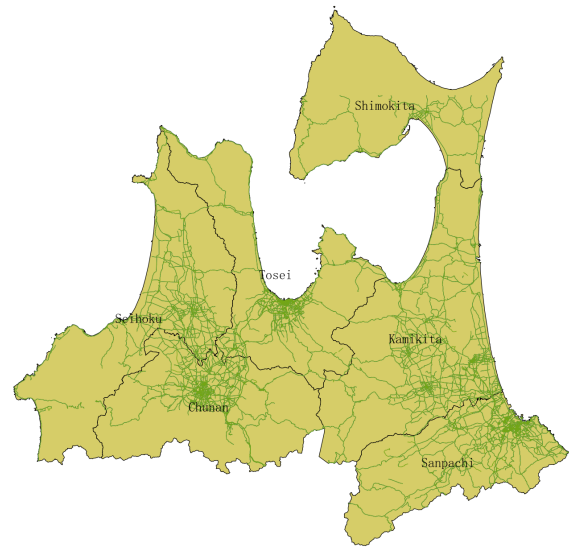


Fig. 2. Vehicle tracking map of Aomori Prefecture. Aomori Prefecture is divided into six regions, i.e., Shimokita, Kamikita, Sannpachi, Tosei, Chunan, and Seihoku regions. The perimeter of a region is shown by a gray polygon.

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%.

IV. RESULTS

A. Regional road recovery differences in Low Altitude Areas

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) *Shimokita region of Low Altitude Area:* It was determined that 80% of the road distance was usable by April 15, 2011 and 90% was usable by April 29, 2011.

2) *Kamikita region of Low Altitude Area:* It was determined that 80% of the road distance was usable by April 8, 2011 and 90% was usable by April 22, 2011.

3) *Sannpachi region of Low Altitude Area :* It was determined that 80% of the road distance was usable by March 31, 2011 and 90% was usable by April 22, 2011.

The recovery speed in Sannpachi region was almost the same as that in Kamikita region.

4) *Tosei region of Low Altitude Area:* It was determined that 80% of the road distance was usable by April 8, 2011 and 90% was usable by April 29, 2011.

5) *Chunan region of Low Altitude Area:* 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 Chunan region was almost the same as that in Sannpachi region.

6) *Seihoku region of Low Altitude Area:* It was determined that 80% of the road distance was usable by April 8, 2011 and 90% was usable by April 29, 2011.

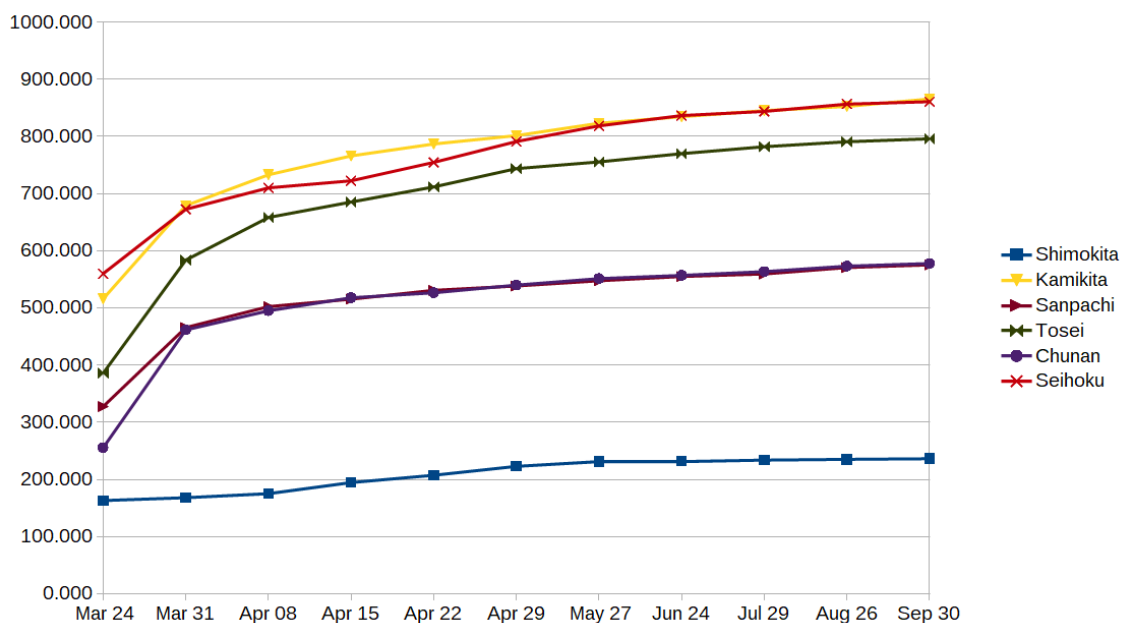


Fig. 3. Usable road distance for Aomori Prefecture’s Low Altitude Areas. The vertical scale displays the distance of the usable roads (kilometers) for each date.

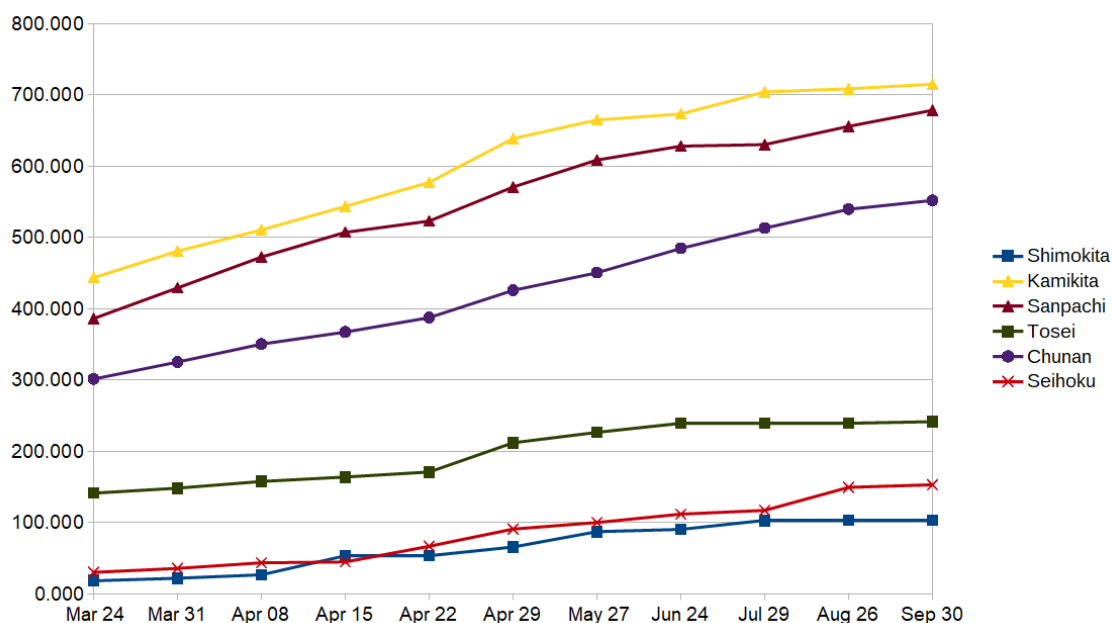


Fig. 4. Usable road distance for Aomori Prefecture’s High Altitude Areas. The vertical scale displays the distance of the usable roads (kilometers) for each date.

B. As a whole in Low Altitude Areas

In Low Altitude Areas, road usage recovery speed in Kamikita, Sanpachi, and Chunan regions was slightly faster than that in Shimokita, Tosei, and Seihoku regions.

C. Regional road recovery differences in High Altitude Areas

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

1) *Shimokita region of High Altitude Area*: It was determined that 80% of the road distance was usable by May 27, 2011, and 90% was usable by July 29, 2011.

2) *Kamikita region of High Altitude 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 Kamikita region was faster than that in Shimokita region.

3) *Sanpachi region of High Altitude Area*: It was determined that 80% of the road distance was usable by April 29, 2011, and 90% was usable by June 24, 2011.

The recovery speed in Sanpachi region was slightly slower than that in Kamikita region according to the values in

TABLE I

REGIONAL DIFFERENCE FOR ROAD RECOVERY IN AOMORI 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
Shimokita	181.078 53.4	189.664 55.9	201.503 59.4	247.838 73.1	260.652 76.9	288.315 85.0	318.224 93.8	322.108 95.0	336.084 99.1	337.928 99.7	339.096 100.0
Kamikita	959.292 60.7	1159.550 73.4	1243.268 78.7	1309.422 82.9	1363.893 86.3	1440.071 91.1	1487.709 94.1	1507.609 95.4	1549.090 98.0	1560.852 98.8	1580.338 100.0
Sanpachi	713.567 56.9	894.579 71.4	974.673 77.7	1022.458 81.6	1053.589 84.0	1108.952 88.5	1156.057 92.2	1182.891 94.4	1189.534 94.9	1226.347 97.8	1253.628 100.0
Tosei	526.824 50.8	731.694 70.5	815.687 78.6	848.855 81.8	882.378 85.1	955.402 92.1	981.788 94.7	1008.837 97.3	1021.059 98.4	1030.012 99.3	1037.237 100.0
Chunan	556.567 49.3	786.529 69.6	845.162 74.8	884.930 78.3	913.809 80.9	965.573 85.5	1001.610 88.7	1041.253 92.2	1076.455 95.3	1112.416 98.5	1129.560 100.0
Seihoku	589.784 58.2	708.056 69.9	753.308 74.3	766.876 75.7	821.054 81.0	881.691 87.0	918.240 90.6	948.102 93.5	960.571 94.8	1005.656 99.2	1013.563 100.0
All	3527.115 55.5	4470.076 70.4	4833.604 76.1	5080.382 80.0	5295.379 83.3	5640.007 88.8	5863.633 92.3	6010.805 94.6	6132.797 96.5	6273.217 98.7	6353.42 100.0

TABLE II

REGIONAL DIFFERENCE FOR ROAD RECOVERY IN AOMORI PREFECTURE'S LOW ALTITUDE AREAS (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
Shimokita	163.026 69.0	168.013 71.1	175.042 74.1	194.463 82.3	207.277 87.7	222.870 94.3	231.233 97.9	231.964 98.2	233.748 98.9	235.091 99.5	236.259 100.0
Kamikita	515.913 59.6	679.019 78.4	732.879 84.7	765.978 88.5	786.851 90.9	801.486 92.6	823.066 95.1	834.519 96.4	845.189 97.6	852.478 98.5	865.556 100.0
Sanpachi	327.536 56.9	465.607 80.9	502.369 87.3	515.421 89.6	530.822 92.3	538.417 93.6	547.593 95.2	554.955 96.5	559.397 97.2	570.647 99.2	575.362 100.0
Tosei	385.818 48.5	583.686 73.3	658.268 82.7	685.273 86.1	711.719 89.4	743.703 93.4	755.430 94.9	769.869 96.7	782.043 98.3	790.770 99.3	795.949 100.0
Chunan	255.468 44.2	461.584 79.9	495.052 85.7	517.887 89.6	526.504 91.1	539.978 93.5	551.306 95.4	556.887 96.4	563.519 97.5	573.079 99.2	577.795 100.0
Seihoku	559.912 65.0	672.634 78.1	710.020 82.5	722.405 83.9	754.624 87.7	791.109 91.9	818.438 95.1	836.508 97.2	843.767 98.0	856.511 99.5	860.809 100.0
All	2207.673 56.4	3030.544 77.5	3273.629 83.7	3401.427 87.0	3517.797 89.9	3637.562 93.0	3727.066 95.3	3784.702 96.8	3827.662 97.9	3878.577 99.2	3911.729 100.0

Table.III.

4) *Tosei region of High Altitude Area*: It was determined that 80% of the road distance was usable by April 29, 2011, and 90% was usable by May 27, 2011.

5) *Chunan region of High Altitude Area*: It was determined that 80% of the road distance was usable by May 27, 2011, and 90% was usable by July 29, 2011.

The recovery speed in Chunan region was almost the same as that in Shimokita region.

6) *Seihoku region of High Altitude Area*: It was determined that 80% of the road distance was usable by August 26, 2011, and 90% was usable also by August 26, 2011.

The recovery speed in Seihoku region was about a month slower than that in Shimokita and Chunan regions.

D. As a whole in High Altitude Areas

In High Altitude Areas, road usage recovery speed in Kamikita, Sanpachi, and Tosei regions was faster than that in Shimokita and Chunan regions.

V. DISCUSSION

A. Low Altitude Areas

In Low Altitude Areas, road usage recovery speed in Kamikita, Sanpachi, and Chunan regions was slightly faster than that in Shimokita, Tosei, and Seihoku regions. Low Altitude Areas in Kamikita, Sanpachi, and Chunan regions

mainly consist of the plateau. On the other hand, Low Altitude Areas in Shimokita, Tosei, and Seihoku regions mainly consist of the alluvial plain. Therefore we suppose that road usage recovery speed in Low Altitude Areas was affected by these differences in land shape.

B. High Altitude Areas

In High Altitude Areas, road usage recovery speed in Kamikita, Sanpachi, and Tosei regions was faster than that in Shimokita and Chunan regions. High Altitude Areas in Kamikita, Sanpachi, and Tosei mainly consist of Mountains (equal to "Sanchi" in the Japanese word for a group of not so very high mountains). On the other hand, High Altitude Areas in Shimokita and Chunan mainly consist of the mountain range (equal to "Sanmyaku" in the Japanese word for a group of very high mountains). Therefore we suppose that road usage recovery speed in High Altitude Areas was also affected by these differences in land shape.

C. Land shape is closely related to road usage recovery

According to the results of this research, we conclude that the land shape of the regions is closely related to road usage recovery. For more precise evaluation, we have to use land shape classification figures for the analysis. Therefore, we would like to conduct that kind of analysis in the near future.

TABLE III
 REGIONAL DIFFERENCE FOR ROAD RECOVERY IN AOMORI PREFECTURE'S HIGH ALTITUDE AREAS (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
Shimokita	18.052 17.6	21.651 21.1	26.461 25.7	53.375 51.9	53.375 51.9	65.445 63.6	86.991 84.6	90.144 87.7	102.336 99.5	102.837 100.0	102.837 100.0
Kamikita	443.379 62.0	480.531 67.2	510.389 71.4	543.444 76.0	577.042 80.7	638.585 89.3	664.643 93.0	673.090 94.2	703.901 98.5	708.374 99.1	714.782 100.0
Sanpachi	386.031 56.9	428.972 63.2	472.304 69.6	507.037 74.8	522.767 77.1	570.535 84.1	608.464 89.7	627.936 92.6	630.137 92.9	655.700 96.7	678.266 100.0
Tosei	141.006 58.4	148.008 61.3	157.419 65.2	163.582 67.8	170.659 70.7	211.699 87.7	226.358 93.8	238.968 99.0	239.016 99.1	239.242 99.2	241.288 100.0
Chunan	301.099 54.6	324.945 58.9	350.110 63.5	367.043 66.5	387.305 70.2	425.595 77.1	450.304 81.6	484.366 87.8	512.936 93.0	539.337 97.7	551.765 100.0
Seihoku	29.872 19.6	35.422 23.2	43.288 28.3	44.471 29.1	66.430 43.5	90.582 59.3	99.802 65.3	111.594 73.1	116.804 76.5	149.145 97.6	152.754 100.0
All	1319.439 54.0	1439.528 59.0	1559.973 63.9	1678.951 68.8	1777.578 72.8	2002.442 82.0	2136.561 87.5	2226.099 91.2	2305.129 94.4	2394.634 98.1	2441.693 100.0

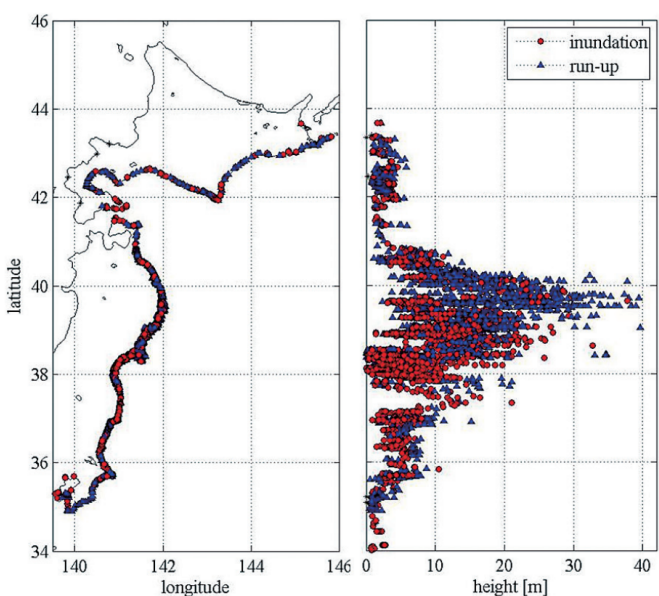


Fig. 5. Tsunami inundation following the 2011 Tohoku Earthquake. The left shows examination points. The right shows inundation and run-up (meters) of the points (cited from The 2011 Tohoku Earthquake Tsunami Joint Survey Group 2011 [8]).

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