Evaluation of Coastal Forests Recovery in Miyagi Prefecture's Iwanuma City Following the 2011 Tohoku Earthquake

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***Abstract*—In the Sendai Bay Area of Japan's Miyagi Prefecture, a 10-year coastal forest recovery project began in 2011 following the Tohoku Earthquake earlier that year. We should pay attention to the status of the restoration in order to maintain regional resilience in the aftermath of the earthquake and tsunami as well as to promote the recovery of agriculture and daily life. Therefore, we evaluated the recovery of coastal forests in Miyagi Prefecture following the 2011 Tohoku Earthquake. We analyzed satellite images taken by the Sentinel-2 satellite for several years following the disaster. Using the Google Earth Engine, we searched for and loaded Sentinel-2 images taken from 2016 to 2020. We concluded that the vegetation activity in the coastal forests in Iwanuma City gradually recovered during the 5-year research period. Therefore, we assume that the coastal forests in Miyagi Prefecture's Iwanuma City have been recovering well following the 2011 Tohoku Earthquake. Nevertheless, some field surveys or other proper methods would be needed to confirm the computed results and to make a final conclusion, because the normalized difference vegetation index (NDVI) is a relative rather than absolute value.**

***Index Terms*—2011 Tohoku Earthquake; coastal forests; Google Earth Engine; Iwanuma City; Miyagi Prefecture; NDVI**

I. Introduction

A. The 2011 Tohoku Earthquake

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

B. Coastal forests

In general, coastal forests [Fig. 2] protect inland areas from damage caused by high waves, strong winds, and blowing sands in coastal areas. When a tsunami disaster occurs, forests can decrease the tsunami energy, catch debris, and delay the time in which a tsunami inundates the inland area [4].

However, the energy of the tsunami in this case was extremely large, completely destroying almost all coastal forests in many parts of the region, especially in Miyagi Prefecture. In the Sendai Bay Area of Miyagi Prefecture, the 10-year recovery project began in 2011 following the earthquake [4], [5]. We should pay attention to the status of the restoration in order to maintain regional resilience in the aftermath of the earthquake and tsunami as well as to promote the recovery of agriculture and daily life.

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II. Purpose

The purpose of this study is to evaluate the recovery of the coastal forests in Miyagi Prefecture following the 2011 Tohoku Earthquake. To this end, we analyzed satellite images taken by the Sentinel-2 satellite for several years following the disaster.

III. Research methods

A. Research area

The study focused on Iwanuma City, in southern Miyagi Prefecture [Fig. 1]. This area is near the Sendai International Airport (SDJ Airport), which was severely damaged by the tsunami following the earthquake [6].

B. Research materials

We analyzed Sentinel-2 images taken from 2016 to 2020, which we searched and loaded from Google Earth Engine.

C. System

1) Hardware: The local client system was a standard PC laptop, SONY VAIO-Z with an Intel Core i5-2450M CPU @ 2.50 GHz, 8 GB memory, and a 128 GB RAID-0 SSD.

2) Software: We used Google Earth Engine [7] operated on the Google Cloud System. We used it free of charge for educational and research purposes by courtesy of Google.

For simple calculations, we used LibreOffice Calc 7.0.6.2 (x64) spreadsheet software [8] running on the Windows 10 Professional operating system. For statistical analysis, we used R System version 4.0.5 [9] running on the same operating system. Both are well-known open source software systems used worldwide.

D. Data Processing

We modified the Google Earth Engine codes presented by Mizuochi on his website [10] and used them in the present study. The analytic procedure is as follows.

1) First, we searched Google Earth Engine for Sentinel-2 images containing the Iwanuma area taken from 2016 to 2020 and loaded them on the system. We excluded images in which cloud cover was greater than 20%.

2) Next, we created a polygon for the analysis of this study[Figs. 3 and 4]

3) Then, the normalized difference vegetation index (NDVI) [11] value of each image was calculated. This score expresses the vegetation activity. The numerical expression of NDVI is as follows.

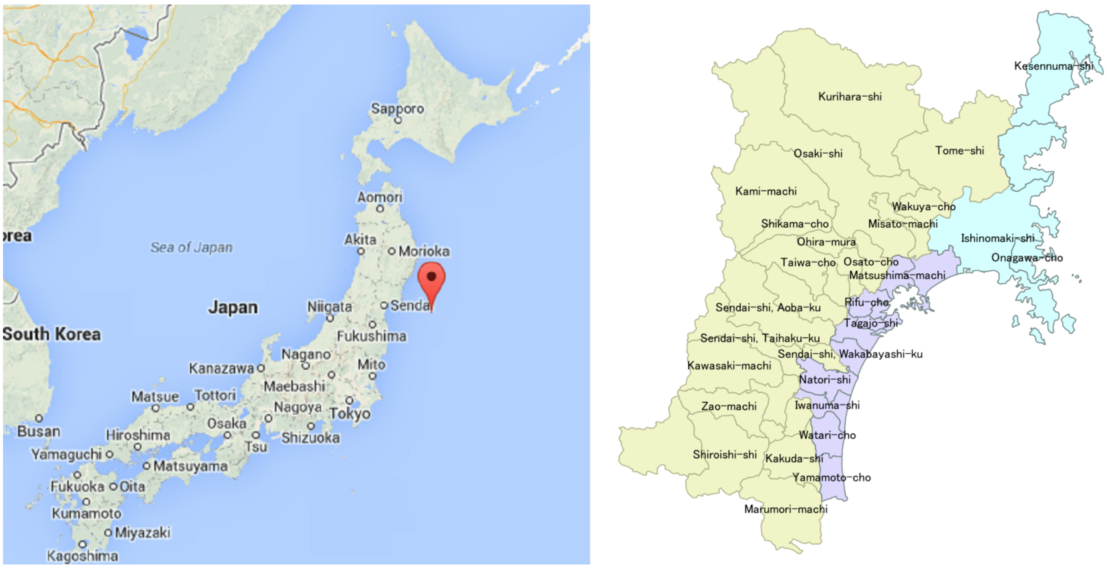

Fig. 1. Left: Epicenter of the 2011 Tohoku Earthquake on March 11, 2011. Right: Miyagi Prefecture divided into Inland, Northern Coastal, and Southern Coastal areas.

Fig. 2. Costal forests in Natori City, Miyagi Prefecture on the north of current research area, Iwanuma City [5].

NDVI = ((IR - R)/(IR + R))

IR = pixel value of Infrared, R = pixel value of Red, $-1.0 \leq$ NDVI ≤ 1.0

4) Based on these data, we made a spreadsheet of the NDVI transition from 2016 to 2020.

5) Using Tukey-Kramer test running on the R statistical system, we evaluated the yearly differences in NDVI values.

IV. Results

Figure 5 shows the NDVI chart of the coastal forests for mitigation in Iwamuna City. Based on the computed NDVI values, Tukey-Kramer test [12] has been conducted. Tukey-Kramer test compares the means of every measurement to the means of every other measurement. Namely, it applies simultaneously to the set of all pairwise comparisons. The results of Tukey-Kramer test are shown in Table I.

1) There is a statistically significant difference between the mean value of 2016 and those of 2018, 2019, and 2020.

2) There are statistically significant differences between the mean value of 2017 and those of 2019 and 2020.

3) There are statistically significant differences between the mean value of 2018 and those of 2019 and 2020.

V. Discussion

The present results have the following implications:

1) The levels of vegetation activity in 2018, 2019, and 2020 were significantly greater than that of 2016.

2) The vegetation activity levels of 2019 and 2020 were significantly greater than that of 2017.

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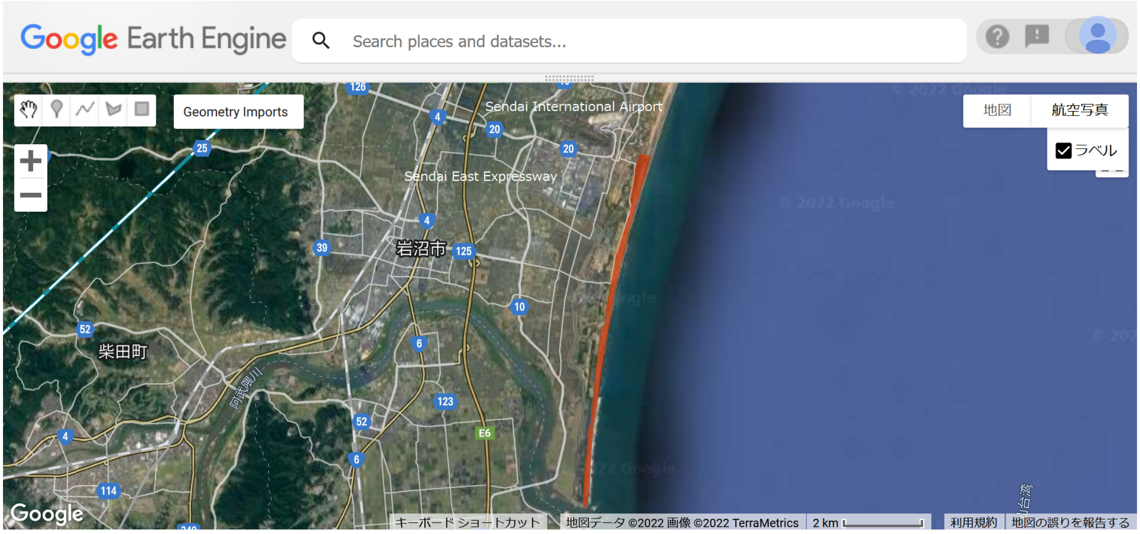

Fig. 3. The polygon created for the analysis of the coastal forests for mitigation in Miyagi Prefecture's Iwanuma City, and the background satellite images [7].

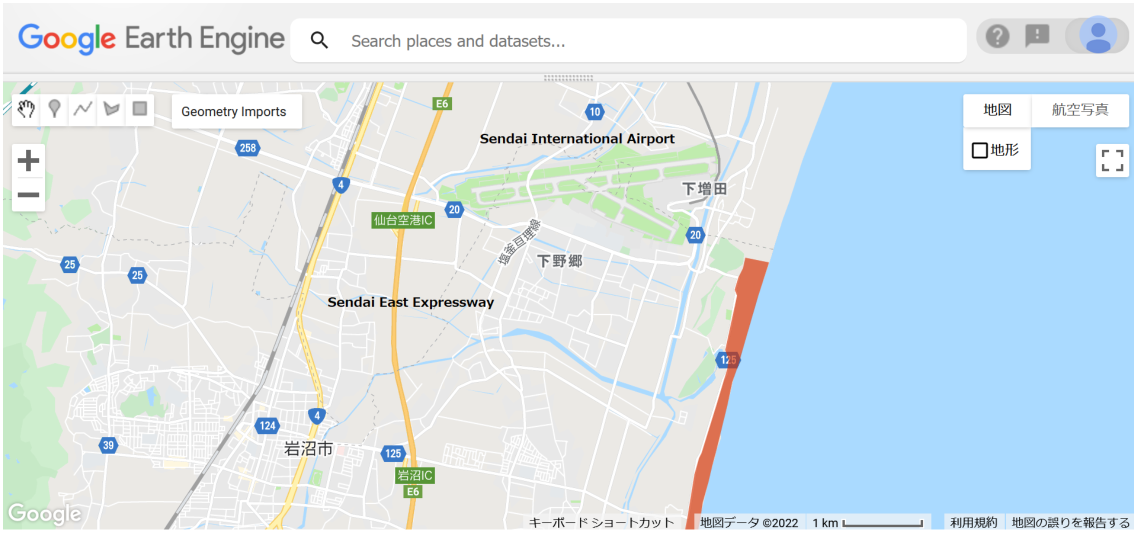

Fig. 4. The polygon created for the analysis of the coastal forests for mitigation in Miyagi Prefecture's Iwanuma City, and the background map [7].

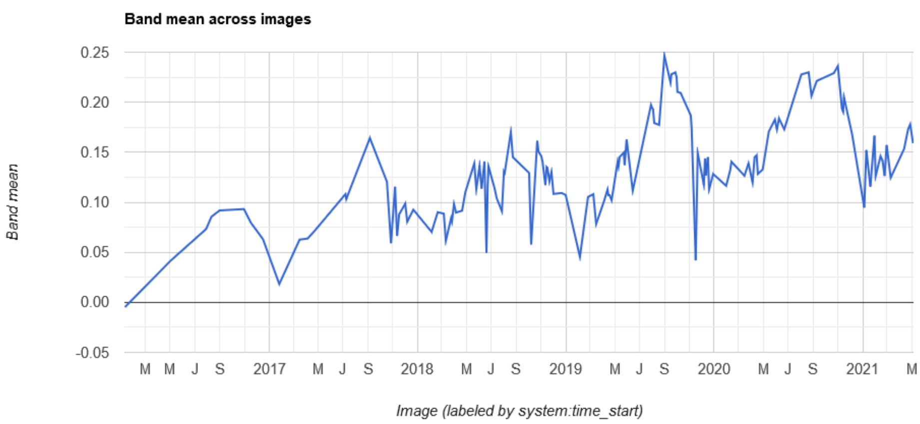

Fig. 5. Normalized difference vegetation index (NDVI) chart of the coastal forests for mitigation in Miyagi Prefecture's Iwanuma City

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TABLE I
RESULTS OF TUKEY-KRAMER TEST

	2016	2017	2018	2019	2020
2016	-	n.s.	P<0.01	P<0.01	P<0.01
2017		-	n.s.	P<0.01	P<0.01
2018			-	P<0.01	P<0.01
2019				-	n.s.
2020					-

3) The vegetation activity levels of 2019 and 2020 were significantly greater than that of 2018.

Overall, we conclude that the vegetation activity of the coastal forests in Iwanuma City recovered gradually throughout the 5-year research period. Therefore, we assume that the coastal forests in Miyagi Prefecture's Iwanuma City have been recovering well following the 2011 Tohoku Earthquake. Nevertheless, some field surveys or other proper methods would be needed to confirm the computed results and to draw a final conclusion, because the normalized difference vegetation index (NDVI) is a relative rather than absolute value.

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