Impact of TEPCO Nuclear Accident and Associated Evacuation to the Demography in Fukushima

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Abstract

The nuclear accident at Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station resulted in evacuation orders being issued for the surrounding municipalities. These have been lifted one by one, and people have begun to return to their hometowns. When considering the reconstruction and long-term development of these areas, population recovery is the most fundamental factor. In this study, I analyze the demographics of these areas, including how the inhabitants' return is proceeding, from multiple statistical sources. The results show that out-migration according to official registration has returned to its previous trend again since 2013, that progress in evacuees' return after the lifting of the evacuation order varies from region to region, and that the proportion of women of reproduction age is low among residents in the areas where the evacuation orders have been lifted.

Key words : demographic transition, disaster recovery, evacuation, nuclear accident

1. Introduction

The accident at Tokyo Electric Power Company's (TEPCO's) Fukushima Daiichi nuclear power plant following the Great East Japan Earthquake in 2011, resulted in evacuation orders being issued for the surrounding areas. Since then, as the accident was brought under control and radiation levels dropped, the evacuation orders have been lifted one by one. In areas where the orders have been lifted, residents who had been evacuated are now returning to their hometowns. For areas forcibly evacuated due to the disaster, population recovery is the most basic element of reconstruction. Therefore, it is important to understand the demographics of these areas so as to plan for future recovery. It remains unclear, however, how many people will eventually return to the areas affected by radioactive contamination, as we have no experience in recovery from such large-scale evacuations and the longer the evacuation period, the more settled the residents will become in their evacuation sites. For example, according to a survey conducted by the Reconstruction Agency and local governments, more than half of the people in some areas have decided not to return (Reconstruction Agency, 2020). In this study, we will investigate the demographics of the evacuation areas from the time of the disaster to the present situation, analyze trends by factor, clarify the actual circumstances and identify issues from the perspective of recovery.

Morita et al. (2018) analyzed the evacuation behavior of people in Minamisoma, Japan, when the evacuation orders were issued in the month after the disaster, and found that (1) males were more likely to have stayed there against the evacuation orders than females, and (2) residents aged 40−64 years old were more likely to have stayed there than were those aged 75 years or older. Heuer et al. (2020) analyzed population migration patterns from the affected areas before and after the disaster on a prefecture-by-prefecture basis by comparing evacuees (those who remained registered at their original address) and out-migrants (those who had registered in other prefectures). Their results showed that the composition of the areas to which the out-migrants had moved had not changed from before the disaster, while the evacuees, unlike the out-migrants, chose to live in more neighboring areas. Higuchi et al. (2012) analyzed a variety of statistics for the first ten months after the disaster and found the number of excess out-migrants from the three affected prefectures to be four times greater than in 2010, with the largest number in April 2011, nearly 80% of the total number of the excess, was people moving out from Fukushima Prefecture, with the largest number of people moving to Tokyo. Hashimoto and Kawakami (2015) conducted an analysis of population movement by municipality based on the Basic Resident Registration System (BRRS) and found that the higher the average income and the greater the degree of damage, the higher the out-migration rate tended to be, and that even after adjusting for economic factors and the degree of earthquake and tsunami damage, the out-migration rate was higher from municipalities in Fukushima Prefecture than from the other two (Iwate and Miyagi). In relation to deaths, it has been noted that Fukushima Prefecture had a higher incidence of disaster-related deaths than other areas affected by the Great East Japan Earthquake due to the nuclear disaster (Kubo et al., 2017). It has also been shown that among the elderly in the same affected areas in Fukushima, the mortality rate was higher among the evacuees than among those who did not evacuate (Nomura, 2016).

Based on the fact that several more years have passed since the previous studies above, and that evacuation orders have been lifted and people have been returning to their hometowns in the meantime, this study targets the areas affected by the nuclear disaster, with a special focus on the areas where evacuation orders had been issued, and clarifies the overall demographic picture, including progress in evacuees' return, from multiple statistical sources. We present the results in Chapter 3 and discuss their implications from the perspective of recovery in Chapter 4.

2. Method

2.1 Target Areas and Periods

The target area was the 11 municipalities where evacuation orders had been issued. The scope and type of evacuation orders changed several times since immediately after the disaster. The following three zones, some of which were in place for a relatively long time and some of which are still in place today, were established in August 2013: Zones in preparation for the lifting of the evacuation order (herein, Zone 1), restricted residence areas (herein, Zone 2), and difficult-to-return zones (herein, Zone 3). In Kawauchi Village, all villagers were evacuated in 2011 after the accident and then began to return to their homes on January 1, 2012, except for some areas (later becoming zones 1 and 2), and then in 2016, evacuation orders for Zones 1 and 2, which together accounted for about 10% of the village's population, were lifted. Because of this history and the lack of detailed population information from the town, we treat the entire town as one area without distinguishing between the evacuation zones. Table 1 lists these municipalities and the populations of the evacuation zones, the timing of the lifting of the evacuation orders, and the scope of analysis of evacuees' return in this study. In principle, the period covered is until the end of June (or July 1, 2019). This is because, in Japan, the new fiscal year begins in April and many people relocate between March and April, and this kind of movement is thought to have settled down by the end of June. However, different time periods may be used in the individual analyses. In such cases, the periods are indicated in each item. In addition, most of the evacuation orders for Zones 1 and 2 had been lifted by that time.

2.2 Information Sources and Analytical Methods

Currently, there are four main sources of information for determining the population of the evacuated areas. The BRRS, national census, resident population according to municipalities' tallies, and mobile phone location information. Each of these has its own strengths and weaknesses, but by combining them, we can see the

Table 1 Basic profile of target municipalities in this study.
This study examines the 11 municipalities that appear in this table. They have different proportions of the three categories of evacuation zone (Zones 1, 2 and 3).

	Population (July 31, 2013)						Evacuation order lifted before July 1, 2019	This stydy's target area for return analysis
	Total	Total area evacuated	Zone in preparation for the lifting of the evacuation order (Zone 1)	Restricted residence area (Zone 2)	Difficult-to-return zone (Zone 3)	Other areas		
Minamisoma City	65,175	12,238	12,238	510	2	52,425	Lifted in July 12, 2016 except for Zone 3	Lifted area
Iitate Village	6,250	784	784	5,192	274	0	Lifted in March 31, 2017 except for Zone 3	Lifted area
Kawamata Town	15,086	1,077	1,077	127	0	13,882	Lifted in March 31, 2017	Whole town
Katsurao Village	1,511	1,329	1,329	64	118	0	Lifted in July 12, 2016 except for Zone 3	Lifted area
Tamura City	39,996	351	351	0	0	39,645	Lifted in April 1, 2014	Lifted area
Namie Town	19,505	7,902	7,902	8,260	3,343	0	Lifted in March 31, 2017 except for Zone 3	Lifted area
Futaba Town	6,492	255	255	0	6,237	0	Not lifted yet	None
Okuma Town	10,958	23	23	362	10,571	0	Lifted in April 10, 2019 except for Zone 3	None
Tomioka Town	14,413	1,319	1,319	8,821	4,273	0	Lifted in April 1, 2017 except for Zone 3	Lifted area
Naraha Town	7,575	7,525	7,525	0	0	50	Lifted in September 5, 2015	Whole town
Kawauchi Village	2,809	276	276	58	0	2,475	All residents evacuated in 2011. Return started on January 1 2012 except for Zone 1 and Zone 2. The rest was lifted in June 4 2016.	Whole village
Total	189,770	33,079	33,079	23,394	24,818	108,477		

whole picture. Table 2 summarizes the advantages and disadvantages of each statistical source and how they are used in this study. The details of each statistical source and method of survey and analysis in this study are discussed below.

The BRRS is municipality-based, middle-frequency and detailed. It contains basic demographic statistics that provide a complete picture of births and deaths by sex and age, and are usually compiled by local governments on a monthly basis, while annual reports are made available to the public by the central government of Japan. However, because the data are based on registration by residents, people are sometimes registered in a different place from where they currently live. For this reason, it is not possible to obtain the actual population of areas from which residents have evacuated and begun returning to in this study. In addition, BRRS does not have information on the daytime population because it does not include information on where people work and go to school. Therefore, for example, if a business has reopened in the area due to reconstruction, but the employees do not live in the area but commute to work there from outside the area, it is not possible to determine the daytime demographics of the area from the BRRS. In this study, from the BRRS, we obtained the total population, net social change, net natural change and composition by sex and age on an annual basis. We compared pre-disaster trends between municipalities designated as evacuation areas and the rest of Fukushima Prefecture, focusing on 2011 and covering seven years before and after the disaster (2004 – 2018). However, due to municipal mergers within the region, social changes are calculated from 2007 to 2018, the year after the merger (as it is not possible to determine retrospective movements between merged municipalities). Regarding the composition of the population by sex and age, we compare the residential data for each municipality on January 1, 2018 with the composition of the number of residents in the area based on mobile spatial statistics (see the following chapter).

The number of residents in the municipality tally was compiled by the local governments in whose areas the evacuation orders had been lifted, and they asked returning residents to report on the status of their return. Many of the municipalities publish the population and number of households present as well as those still evacuated monthly on their websites. This information is very important for identifying the actual situation of people living in the evacuated areas. Each municipality, however, differs in whether it publishes the information, how long it is available on the websites, the details on age, sex and location of the population, and whether it classifies people who have moved into the area from outside after the disaster. In addition, because the system is not as enforceable as BRRS, there may be residents who do not report their immigration status or return to their hometowns, or residents who report their immigration status but actually live outside the area. In this study, we collected the number of residents and evacuees published by each municipality from the month when the evacuation order was lifted until June 30 (or July 1) 2019 to calculate the rate of return. The rate is defined as the sum of the number of residents in the area where the evacuation order was lifted plus the number of registered evacuees in the area, divided by the number of registered residents in the same area, and is calculated for the area and time period for which the information is available. To confirm progress toward population recovery and differences in rates, we show changes in the rate over time. We also briefly examine the factors behind the differences.

The census is the most fundamental source of statistics in the nation on a municipal basis. In the case of the evacuation in question, an individual is counted

Table 2 Comparison of information sources on population in the target areas.
Four different statistical information sources were adopted in this study to get an overall picture of the demography in the target area. Each of them has strengths and weaknesses as shown in the table, so it is necessary to combine them.

	Census	Basic Resident Registration System (BRRS)	Municipality tally	Mobile phone information
Temporal resolution	Low (every 5 years)	Middle (monthly, yearly)	Middle (monthly)	High (hourly)
Spatial resolution	Low (municipality)	Low to Middle (sub-municipality)	Middle (municipality, evaculation area)	High (500m mesh)
Demogprahic profile resolution	High (sex, age, working status, marriage status)	Middle (sex, age)	Low (total only in many cases)	Middle (sex, age)
Availability	High (provided on Web)	High (provided on Web)	Middle (varies by municipality)	Low (fee for use)
Use in this study	- Comparison of nighttime and daytime population and gender ratio in the municipalities before and after disaster (2010 and 2015) - Analysis of commuting structure in 2015	- Indicators of basic demographic dynamics of each municipality (social and natural increse, birth and death rate) on an annual basis - Comparision of age and gender composition against mobile phone information	- Progress of return to the areas where evacuation orders were lifted - Analysis of differences in progress between areas	- Analysis of gender and age structure in the areas where evaculation orders were lifted - Comparision of age and gender composition against BRRS

among the population of current residents if the person is still evacuated, and among the population of the evacuated area if the person has returned. Thus, the population living in the area can be determined in detail and with considerable accuracy. In addition, since the census also surveys work and school commuting areas, the daytime population and commuter OD (origin and destination) can be determined. On the other hand, the temporal resolution is low because it is conducted every five years. At the time of this study, the latest census had been conducted in 2015, the first survey conducted after the disaster, and evacuation orders had not yet been lifted in many areas. In addition, many of the tabulations are at the municipal level, making it impossible to distinguish between evacuated and non-evacuated areas within a municipality. In this study, we examine the 2010 and 2015 census data on the nighttime population, daytime population and sex ratios in municipalities with evacuation areas to identify changes in the basic population structure before and after the disaster. To determine the commuting structure, the residence of employees in municipalities with evacuation areas is determined from the census. The census is the only source of information on mobility in the evacuated areas available free-of-charge.

As a population estimate based on mobile phone location data, we used mobile spatial statistics in this study. Mobile spatial statistics are population estimates from NTT DoCoMo, Inc. based on the location of their own mobile phone users. They have a high spatio-temporal resolution and are provided in hourly, administrative boundary or 500-meter mesh units. Since they are based on the number of mobile phone users who were present at a given location at a given time, it is possible to estimate the daytime population and also to capture temporary increases in the number of people due to stays or events. On the other hand, the estimates are uncertain because they are based on the percentage of mobile phone subscribers of that company. This is especially true in areas with small populations. The same is true for younger and older people, who are less likely to have mobile phones. In addition, it should be noted that the number of residents who are staying in the area without being registered is also estimated (e.g., employees of businesses involved with work such as decontamination, decommissioning of the nuclear plant and interim storage of decontamination waste). With this information, in this study, the total number of people in December 2017 (average at night between 18:00 and 8:00 a.m.) is compared with the BRRS data (January 1, 2018). The profile of residents in the area (composition ratios by sex and age) is compared between BRRS and mobile spatial statistics to identify relatively greater or fewer people by sex and age using the Jaccard distance. The Jaccard distance is an application of the Jaccard coefficient, which was proposed by Jaccard (1912) as a method of comparing the size of the common parts of two sets, and it has been applied in various ways since then. To determine the similarity of two vectors, we compute the Jaccard distance Jd using the formula below. This indicator is for two non-negative vectors of the same dimension. It ranges from 0 to 1, taking the minimum value 0 when the two vectors coincide perfectly. The larger the value, the greater the difference between the two vectors. Here, i is the population profile (by sex and age), x_i is the population composition ratio based on mobile spatial statistics, and y_i is the population composition ratio based on the BRRS.

$$Jd\ (x,y) = 1 - \frac{\sum_i \min(x_i, y_i)}{\sum_i \max(x_i, y_i)} \qquad \text{......} (1)$$

3. Results

3.1 BRRS Data

Figure 1 shows the total population (ratio to that of January 1, 2011). The population of most areas had been decreasing even before the disaster (the exception being Okuma Town), and after a significant decrease from 2011 to 2012, the pre-disaster trend of population decline resumed again. However, the post-disaster population of most of the 11 municipalities has declined at a greater rate than in the rest of Fukushima. The social growth rate (Fig. 2) has been negative in most areas, including the rest of Fukushima, for most of the period since before the disaster. An exception is Okuma town. Before 2011, relatively young workers were constantly migrating to the town because of steady growth in industries related to the nuclear power plants (Okuma Town, 2016). In 2011, in seven out of 11 municipalities, the rate was lower than that of the rest of Fukushima. After a significant drop in 2012, the rate of natural increase remained stable in the rest of Fukushima. Nine of the 11 municipalities, except for Okuma and Tomioka, had a lower rate of natural increase in 2012 than did the rest of Fukushima. More municipalities had lower natural growth rates than rest of Fukushima in other periods as well. Although the crude birth rate has been declining over the long term, there are large year-to-year fluctuations in each of the municipalities involved, so a clear trend cannot be readily discerned from the figure. In the rest of Fukushima, because of the smoothing effect of aggregation of many municipalities, there is a clear trend toward lower birth rates in 2012 and 2013 than in the other years. This may be because people were discouraged from having children due to the 2011 disaster. Crude mortality rates had been increasing overall since before the disaster, with an overall increase in 2011 and an even higher rate in 2012. The increase in mortality rates in 2012 compared to 2011 was higher in all 11 municipalities in the study area than in the rest of Fukushima Prefecture.

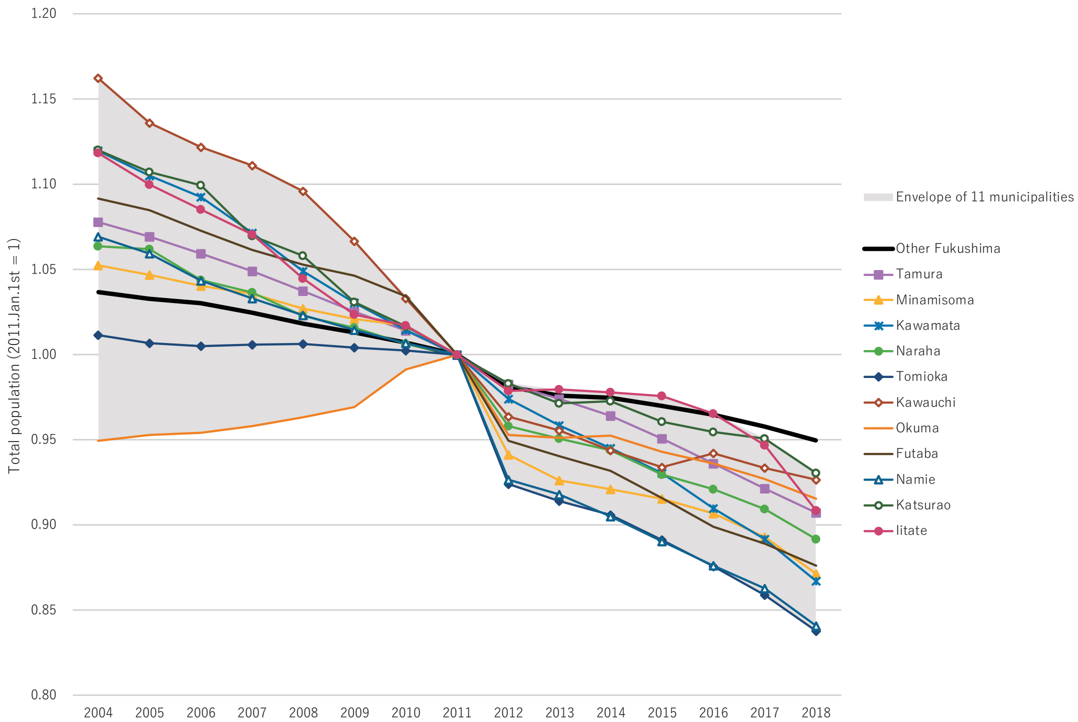

Fig.1 Time-series of registered population in target municipalities and rest of Fukushima Prefecture.
The registered population of the target area in the Basic Resident Registration System shows that the 11 municipalities experienced a faster population decline than rest of Fukushima Prefecture.

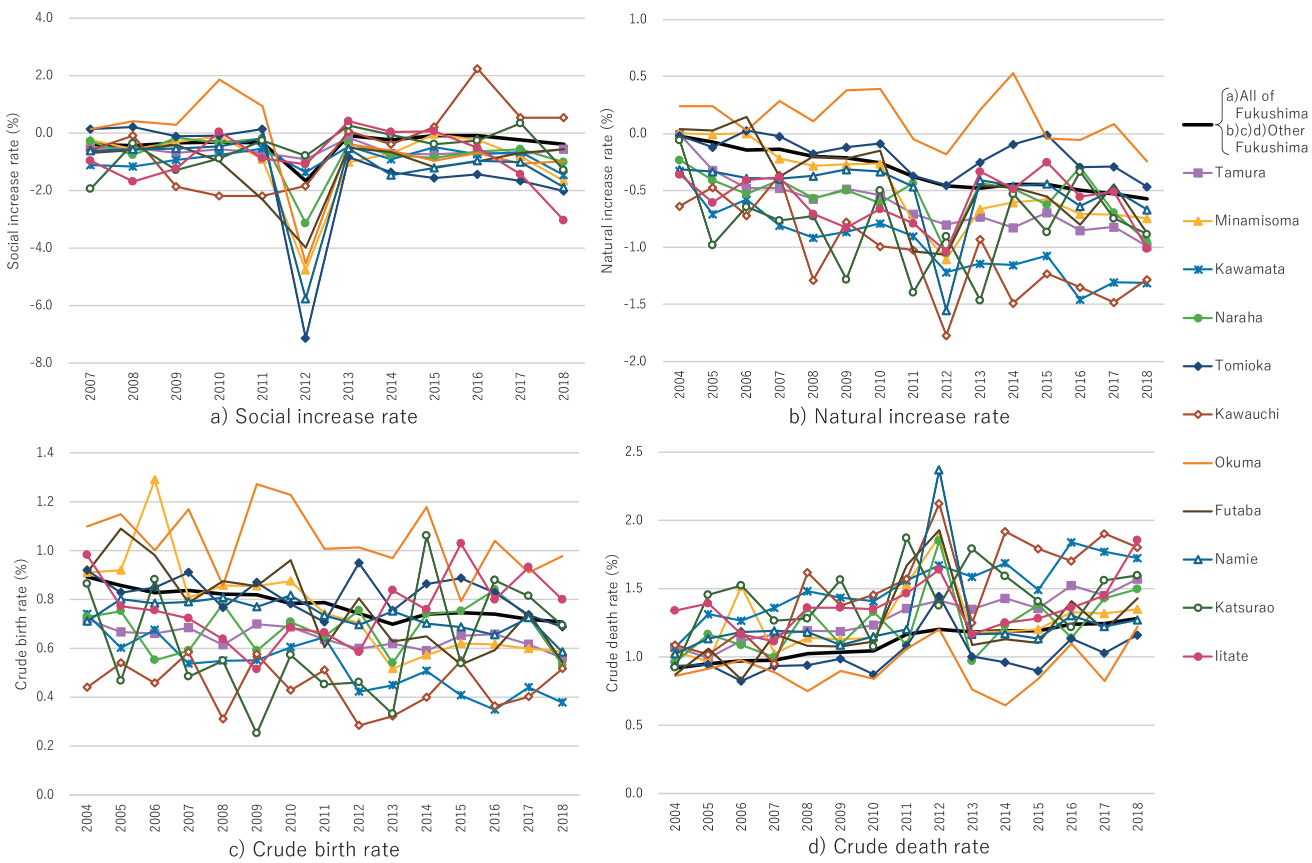

Fig. 2 Factors in population changes before and after 2011 in BRRS.
Out-migration from Fukushima was larger in 2012 than in other years. The main contributor to the natural decrease in year 2012 was a high death rate, rather than a low birth rate. Death rates in 2012 in the target municipalities were higher than in the rest of Fukushima, indicating that evacuation from the nuclear accident caused excess deaths among the evacuees.

Table 3 Population living in the evacuated areas.

Local governments in the target area have reported the numbers of residents living in the areas where evacuation orders have been lifted. Progress in population recovery varies significantly region by region. Large differences are found in the populations reported by local governments and estimates from mobile phone information.

	June 30 or July 1, 2019*				End of 2017 or January 1, 2018			
	Registerd population in the evacuated area	Population living in the evacuated area	Ratio	Months since evacuation order lifted**	Average increase in ratio of population in the area per month	Population living in the evacuated area	Nighttime population by mobile phone information (average of December 2017)	Difference in demographic composition (Jaccard distance)***
Minamisoma	9,542	4,161	43.6%	34	1.28%	2,798	4,841	0.156
Iitate	4,240	1,324	31.2%	26	1.20%	602	2,487	0.376
Kawamata	1,022	480	47.0%	26	1.81%	279	1,413	0.218
Katsurao	1,570	421	26.8%	34	0.79%	267	640	0.439
Tamura	277	225	81.2%	36	2.26%	230	-	-
Namie	16,074	729	4.5%	26	0.17%	291	3,131	0.326
Tomioka	12,905	1,064	8.2%	26	0.32%	358	6,689	0.316
Naraha	6,881	3,761	54.7%	44	1.24%	2,203	5,924	0.282
Kawauhci	2,677	2,165	80.9%	63	1.28%	2,197	1,852	0.288
Total	55,188	14,330	26.0%	-	-	9,225	26,976	0.252

* August 31, 2019 in Kawauchi.
** Months by the ratio of population living in the region exceeds 80%.
*** Comparison of sex and age composition between registered population in BRRS and mobile phone information.

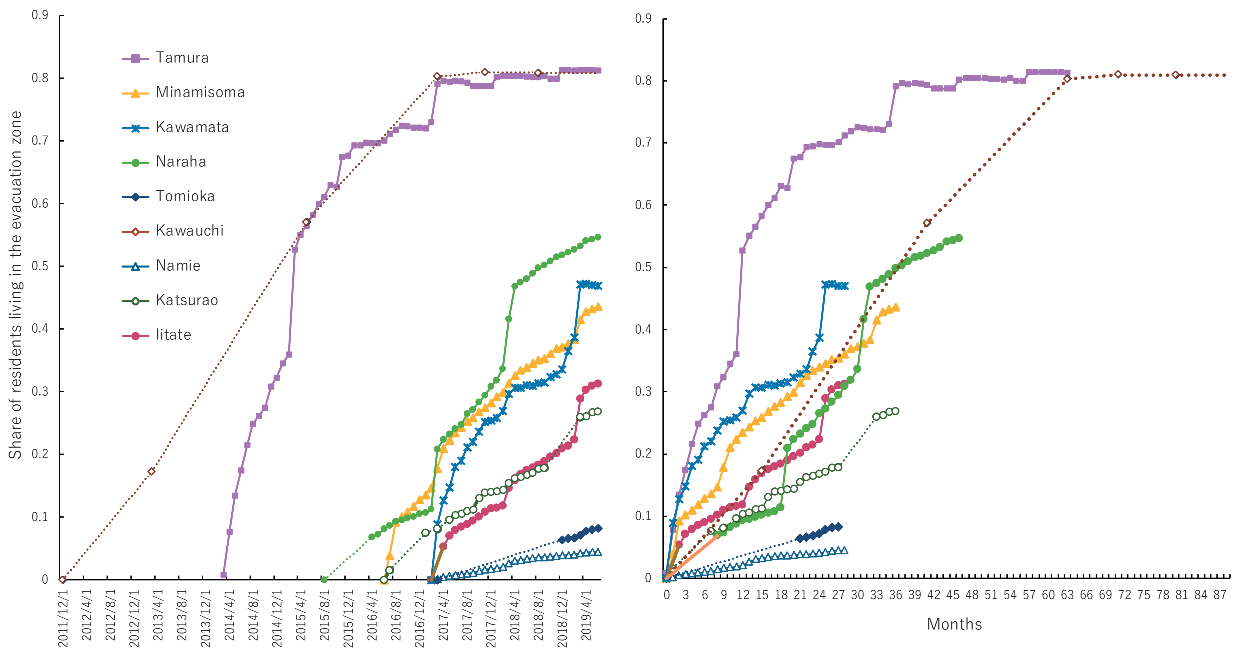

Fig. 3 Progress in population recovery in areas where evacuation orders were lifted.
The figure shows the share of population living in the area of the population registered there after the evacuation order was lifted. A "jumping" increase occurs in March or April, when the new fiscal and school year starts in Japan. The rate of recovery (slope of the lines) varies region-by-region, and is especially low in Namie and Tomioka, which are near to the nuclear power plant and experienced severe contamination.

3.2 Municipality Tally Data

Table 3 shows the status of the percentage of people living in the area at the end of June or beginning of July 2019. The changes in the percentage of people living in the area are shown in Fig. 3. The left side of the figure shows the rate by each year and month, and in Tamura and Kawauchi, where the evacuation orders were lifted early, it has recently leveled off at about 80%. A large increase in March or April is common, probably because in Japan, the new fiscal year and school year start on April 1, so the evacuees are expected to return in March or April. The right-hand side of the figure shows the percentage of people living in the region according to the number of months after the evacuation order was lifted. The larger the slope, the greater the increase in the rate of settlement per given period, and the faster the return and recovery of the population. There is considerable variation in the progress in population recovery by region (see also the "Average increase of …" column in Table 3). The variation might be explained partly by the

Table 4 Basic statistics from censuses of 2010 and 2015.

The census is the most basic form of population statistics in the nation. The region is the area of the municipalities, i.e., in the case that a municipality has evacuation zones and non-evacuation zones, this table will not differentiate between them but shows the total in the municipality. Even in municipalities with zero nighttime population, a significant daytime population existed in 2015. The sex ratio (number of males divided by number of females) is quite large in some regions, i.e., there are many more males than females.

	Nighttime population			Daytime population			Daytime/Nighttime		Sex ratio (nighttime)		Sex ratio (daytime)	
	2010	2015	2015 /2010	2010	2015	2015 /2010	2010	2015	2010	2015	2010	2015
Minamisoma	70,878	57,797	0.82	69,455	60,143	0.87	0.98	1.04	0.95	1.17	0.93	1.24
Iitate	6,209	41	0.01	5,628	3,246	0.58	0.91	79.17	1.00	0.21	0.93	9.64
Kawamata	15,569	14,452	0.93	14,496	14,928	1.03	0.93	1.03	0.95	1.02	0.89	1.10
Katsurao	1,531	18	0.01	1,240	979	0.79	0.81	54.39	1.12	2.00	1.04	14.30
Tamura	40,422	38,503	0.95	36,270	34,412	0.95	0.90	0.89	0.94	0.99	0.89	0.92
Namie	20,905	0	0.00	19,041	1,597	0.08	0.91	-	0.95	-	0.87	14.50
Futaba	6,932	0	0.00	6,462	322	0.05	0.93	-	0.95	-	0.85	17.94
Okuma	11,515	0	0.00	15,817	3,701	0.23	1.37	-	0.99	-	1.41	29.84
Tomioka	16,001	0	0.00	15,837	2,961	0.19	0.99	-	1.06	-	1.06	16.73
Naraha	7,700	975	0.13	8,046	3,002	0.37	1.04	3.08	0.94	6.56	1.09	5.60
Kawauhci	2,820	2,021	0.72	2,572	1,899	0.74	0.91	0.94	1.01	1.53	1.01	1.34
Total	200,482	113,807	0.57	194,864	127,190	0.65	0.97	1.12	0.96	1.11	0.96	1.36

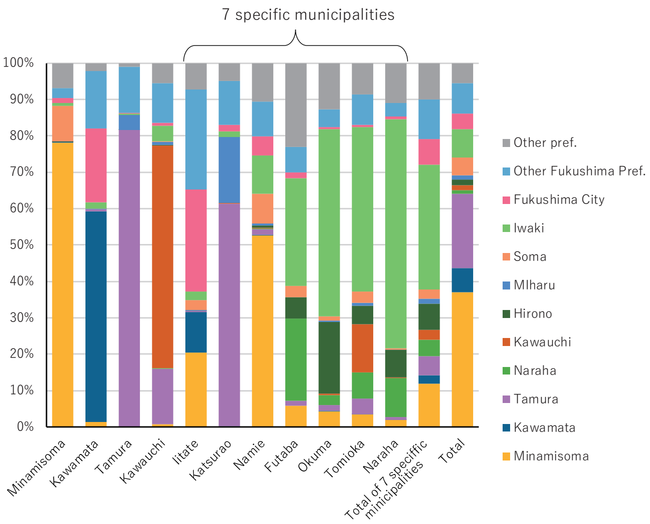

Fig. 4 Composition of residential locations of employees in the target municipalities in 2015.

Census data show where the employee in each municipality commutes from. In several specific municipalities that had relatively large evacuation zones compared to their whole area, many of the employees commute from outside even after evacuation order was lifted. Iwaki City has been a residential place for many of them in particular.

timing of lifting of the evacuation orders. In short, the rate is higher in Tamura (where the order was lifted in 2014) and Naraha (2015) than Namie and Tomioka (both in 2017). However, variation is also observed between the areas where the order was lifted at the same time (e.g., the rate was much higher in Iitate than Namie, even though the orders were lifted at the same time in both areas). A detailed quantitative analysis of the variation in progress is beyond the scope of this study, but more discussion is provided later in this paper.

3.3 Census Data

Table 4 provides the main information from censuses: areas with zero nighttime population in 2015, and areas with significantly fewer employees than in 2010, also have a decent sized daytime population. In 2015, the sex ratio in daytime was greater than 1 in all municipalities but Tamura, i.e., more males than females were there during the day. Especially in municipalities near the nuclear plant, the ratio was quite large (nearly 30 in Okuma and 18 in Futaba). Figure 4 shows the resident locations of employees by municipality to facilitate analysis of commuting OD. In Minamisoma, Kawamata, Tamura and Kawauchi, where the evacuation orders were lifted early, many employees commuted to work in their own municipality. On the other hand, in the areas where the evacuation orders had not been lifted or where they had been issued later, many people commuted from other areas. The total of seven specific municipalities with a particularly low or no daytime population are shown in the same figure. Many of the employees in these areas were commuting from nearby towns where no evacuation orders had been issued. This is especially true in Iwaki City, the southernmost coastal city and the most populated city in the prefecture.

3.4 Mobile Phone Location Information

There are differences in the numbers of people living in each area between the municipality tally and the nighttime population based on mobile spatial statistics (Table 3). In some areas, the latter is significantly higher than the former. This suggests the presence of reconstruction-related workers, temporary outsiders, residents who return without reporting to the municipality and residents who live primarily outside the area but frequently visit their homes or other places of residence. The Jaccard distance, an aggregated indicator of variations in demographic composition between two information sources, was the highest in Katsurao (0.439), followed by Iitate (0.376). It was lowest in Minamisoma (0.156) followed by Kawamata (0.218). These results indicate that the difference tends to be larger in areas where the ratio of people living in the evacuation area is lower (Table 3). Figure 5 shows the population pyramids for a total of the eight regions based on BRRS data (for

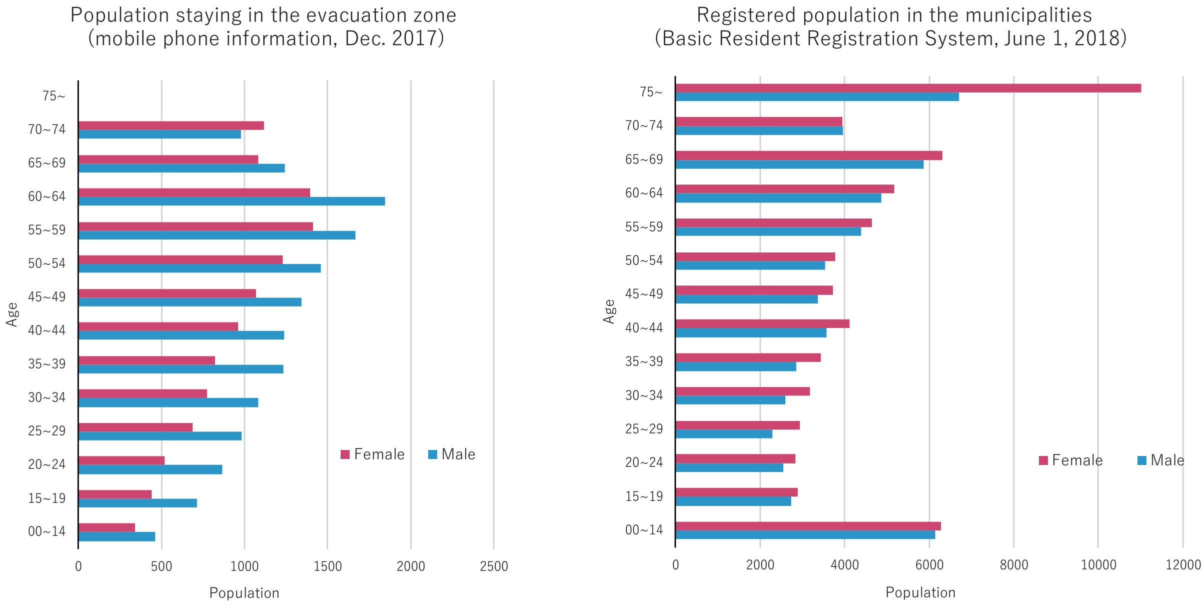

Fig. 5 Population pyramids in evacuation zones where the orders were lifted and whole municipalities, from different sources (a total of eight municipalities).

The figure indicates the population in a total of eight municipalities that have areas where evacuation orders had been lifted by the end of 2017. The age and sex composition in the former evacuation area (left) versus the whole municipality (right) are significantly different. In sex compositions, more males are found than females in most of the age groups in the left figure, while there are more females in the right.

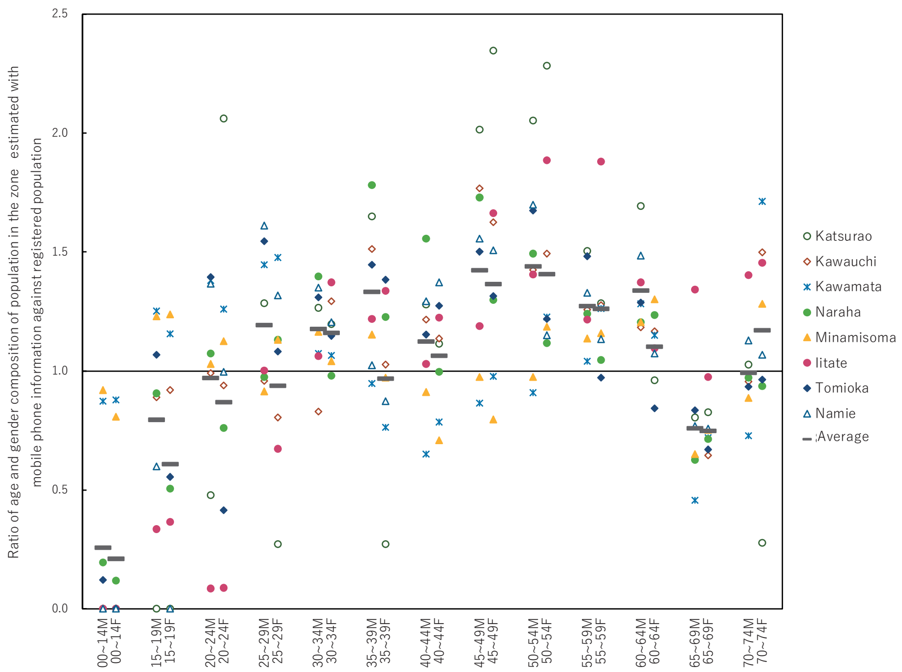

Fig. 6 Differences in population composition between evacuation zones where the orders have been lifted and whole municipalities.

Differences in population composition (age and sex) vary region-by-region, but in general, males of working age have a higher share in areas where evacuation orders have been lifted, while younger people and females of reproductive age have lower shares.

the entire municipality) and mobile spatial statistics (for areas where the evacuation orders had been lifted). According to a comparison of mobile spatial statistics with BRRS data, males are more likely to be there than females, and the working-age population is more likely to be there than the other age groups. The ratio of the composition of the two information sources is shown in Fig. 6. A higher value indicates a higher proportion of the resident population in each age and sex group in the mobile phone information compared to the registered population. There is considerable variation among regions. Among the working-age population, there are more males and females between the ages of 45 and 59. Among the younger age groups, there are more males than females in the same respective age group.

4. Discussion

From the results presented above, in general, we can say that the demographic phenomena are not uniform among the different municipalities. In this chapter we discuss implications of the above results to the recovery and sustainable development of this region.

4.1 Changes in Registered Population

It has been pointed out that the Earthquake, tsunami and accident have had an impact on the population decline in Fukushima Prefecture as a whole. The 11 municipalities that had been designated as evacuation zones have been affected more heavily than others. As for social changes, the tendency to move out of the areas evacuated has been higher in many areas than in the rest of Fukushima Prefecture. However, this trend was clear only until 2012. The number of registered residents declined significantly immediately after the disaster but has not changed much since 2013. This suggests that many people decided to move out in the first two years after the disaster, but from the third year onwards, the trend has been the same as it was before the disaster. In terms of natural increase or decrease, the 2012 mortality rate increase was higher in municipalities with evacuated areas than in the rest of Fukushima. This is consistent with the facts reported by Nomura (2016).

4.2 Population Composition

Fewer young people living in the area are in their teens or younger; there are more men in their late 40s to 50s, and fewer women in their 20s to 30s. This suggests that households with children to care for and women of childbearing age have tended not to return. If this structure does not change in the future as the number of residents increases, the long-term demographic structure of the area will be one of extreme aging, followed by a sharp decline in population. This may have a significant impact on communities' sustainability in the future.

4.3 Progress in Evacuees' Return

In Tamura and Kawauchi, the percentage of people living in the region has remained almost unchanged at around 80%. This value is nearly identical to the combined total of "want to return" and "have not decided" in an opinion survey by the Reconstruction Agency (2015). Whether this applies to other regions as well is not clear at this time, but it may serve as a reference or a benchmark for the long-term population outlook. From the comparison of progress in evacuees' return and timing of the lifting, as we mentioned above, it has been suggested that the timing of lifting of the evacuation orders may be a factor affecting differences in the progress in evacuees' return (i.e., increase in the annual rate of residence in the area). Among the areas where the evacuation orders were lifted at the same time, the towns of Namie and Tomioka have town centers close to the nuclear power plant, and in Namie, where progress has been slower than in Tomioka, the proportion of Zone 3 areas is higher than in Tomioka in terms of both area and population (actually it is the highest of the all 11 municipalities). The same discussion may apply to Tamura, where contamination was relatively low and evacuation was ordered for only a small part of the city. These conditions suggest that factors that slow progress may include proximity to the nuclear power plant and large proportions of residents in areas that have not yet had their orders lifted . We think this is an important finding for predicting the progress in evacuees' return to the towns of Okuma and Futaba, which were not included in the analysis of evacuees' return, as well as to other specific centers for reconstruction and rehabilitation in Zone 3.

4.4 Commuting Structure

Where evacuation orders have been lifted, in general, many people commute from the outside, instead of living in those areas. Results of a survey by the Reconstruction Agency (2020) may explain the reason for that. Many respondents reported that a lack of medical and shopping facilities and support for housing were the main barriers hindering their return. From our results and the survey, even though economic activity has recovered thanks to policy initiatives, without such facilities and support, the nighttime population may not recover. Based on comparison of the areas where the evacuation orders have been lifted so far, though, the percentage of commuters from outside the areas is expected to decrease as the population recovers. However, especially in the areas where the evacuation orders have been lifted or will be later, many commuters will continue to commute from the outside until the population recovers. To mitigate this, it is important that those who wish to return should be able to do so as soon as possible. In addition, among those who work in the region, some were not residents before the accident, but arrived because new industrial development led by the government necessitated different expertise among employees compared to before the disaster. It will be necessary to remove obstacles for people moving into the area and joining the community.

5. Concluding Remarks

In this study, migration and return to the areas affected by the nuclear power plant accident were investigated using multiple sources of data to clarify the demographic situation. Each source had its own inherent limitations, and care needed to be taken in interpreting the results. Analysis using mobile spatial statistics is particularly subject to uncertainty: since the estimates are scaled up according to the percentage of subscribers to NTT DoCoMo's mobile phone service, deviations from the true values may be large, especially in small areas. In addition, in many areas, there is no differentiation among people living in the evacuation zone, evacuees and newcomers. Therefore, this study has not been able to discern how many of the residents in the area are returnees.

The information we have been able to obtain so far in this study is limited, and many issues remain to be addressed in analyzing the population of the evacuated areas. First, it will be necessary to continue to survey the situation among newer returnees, including those to areas where the evacuation orders have been lifted very recently. Next, quantitative analysis of factors affecting regional differences in the progress in evacuees' return could help project future progress of their return and identify what is needed to enable residents who wish to return to their homes to do so more quickly. Once these issues are addressed, many of the insights needed for estimating the future of the population over the long term will be available, allowing for a long-term socio-economic outlook that explicitly takes uncertainty into account.

References

Hashimoto, N. and Kawakami, Y. (2015) An empirical analysis of migration in the area affected by the Great East Japan Earthquake. *Japan NPO Research Association Discussion Paper*. (in Japanese) Retrieved from https://www.janpora.org/dparchive/pdf/2015001J.pdf (Accessed 26 November 2020)

Hauer, M.E., Holloway, S.R. and Oda T. (2020) Evacuees and migrants exhibit different migration systems after the Great East Japan Earthquake and Tsunami. *Demography*, 57, 1437–1457.

Higuchi, Y., Inui, T., Hosoi, T., Takabe, I. and Kawakami, A. (2012) The impact of the Great East Japan Earthquake on the labor market: Need to resolve the employment mismatch in the disaster-stricken areas. *Japan Labor Review*, 9(4), 4–21.

Kubo, M., Tsuchida, S. and Shizuma, K. (2017) A study of deaths related to the Great East Japan Earthquake in Fukushima Prefecture. *Journal of Atomic Energy Society of Japan*, 59(129), 49–53. (in Japanese)

Morita, T., Nomura, S., Furutani, T., Leppold, C., Tsubokura, M., Ozaki, A., Ochi, S., Kami, M., Kato, S. and Oikawa, T. (2018) Demographic transition and factors associated with remaining in place after the 2011 Fukushima nuclear disaster and related evacuation orders. *Plos One*, 13(3), e0194134. Retrieved from https://doi.org/10.1371/journal.pone.0194134

Nomura, S., Blangiardo, M., Tsubokura, M., Nishikawa, Y., Gilmour, S., Kami, M. and Hodgson, S. (2016) Post-nuclear disaster evacuation and survival amongst elderly people in Fukushima: A comparative analysis between evacuees and non-evacuees. *Preventive Medicine*, 82, 77–82. Retrieved from http://dx.doi.org/10.1016/j.ypmed.2015.11.014

Okuma Town (2016) *Creation of Towns, People and Jobs: Population Vision*. (in Japanese) Retrieved from http://cms.town.okuma.fukushima.jp/uploaded/attachment/4513.pdf (Accessed 26 November 2020)

Reconstruction Agency (2015) *Heisei 27 Resident Intention Survey in Evacuation Area due to the Nuclear Disaster*. (in Japanese) Retrieved from https://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-4/ikoucyousa/ (Accessed 30 August 2020)

Reconstruction Agency (2020) *Reiwa 1 Resident Intention Survey in Evacuation Area due to the Nuclear Disaster in Fukushima Prefecture*. (in Japanese) Retrieved from https://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-4/ikoucyousa/ (Accessed 30 August 2020)

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