Internal migration patterns to Fukushima following the nuclear accident based on vital statistics and the Fukushima health management survey

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Abstract

Background We examined the characteristics and mental health of people who migrated to the Fukushima Prefecture after the 2011 nuclear power plant accident through two studies. While the original community was disrupted by the nuclear accident, internal migrants from other prefectures in Japan have played an increasingly significant role in promoting the recovery process.

Methods Study 1 used data from the Vital Statistics of Fukushima database from January 1999 to October 2023 to analyze shifts in migration patterns before and after the nuclear accident, focusing on the proportion of internal migrants who relocated to Fukushima following the accident. The dataset was based on the population census collected by the national government and changes in resident registration records, providing monthly population dynamics for all municipalities in the Fukushima Prefecture. Study 2 examined the mental health status of internal migrants using data from the Fukushima Health Management Survey, which has been conducted annually since 2011. A total of 4,139 participants were included in the study including individuals who registered as residents in the 13 municipalities designated as evacuation zones and migration recorded from the 2013 fiscal year onward.

Results Study 1 showed that over 20% of the total population in the Fukushima Prefecture were internal migrants after the accident, and although the migration trends were originally declining, this trend was mitigated after the accident. The proportion of internal migrants from other prefectures in Japan was particularly high in Tomioka, Okuma, and Namie towns. Study 2 revealed that the mental health of the immigrants worsened year by year, with female internal migrants being more negatively affected in areas with a higher proportion of migrants.

Conclusions This study highlights the increasing presence of internal migrants in Fukushima following the nuclear accident and the need for mental health care tailored to the immigrants specific challenges.

Keywords Internal migrants, Nuclear disaster, Psychological distress, Gender, Great East Japan earthquake

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Introduction

When a disaster occurs, many people evacuate and leave their communities. A typical recovery model focuses on restoring hard infrastructure in the affected areas to enable evacuees to return home. This model assumes that people will naturally return to their original homes. However, this assumption does not hold in the case of nuclear disasters. The physical reconstruction of the affected areas and the mitigation of radiation-related anxieties often take a long time [1]. Meanwhile, many evacuees become settled in their new locations. In fact, after the Fukushima Daiichi Nuclear Power Plant accident, despite the Japanese government's unprecedented whole area decontamination and reconstruction efforts, the rate of return among evacuees remained low [2, 3]. Consequently, the current challenge for recovery is the reconstruction of local communities in the affected areas [4].

The national and local governments also continue to promote the return of evacuees while simultaneously highlighting advantages to attract immigrants in the basic guidelines for the second phase of reconstruction and revitalization announced in 2021 [5]. In line with these plans, governments have introduced a range of support measures targeting migrants from outside the affected prefecture. These include financial assistance for relocation and housing, job placement services, support for entrepreneurship, and childcare assistance. For example, since 2021, the Fukushima Prefectural Government has been offering a relocation support program, which provides financial aid to migrants moving from outside the prefecture. In addition, there is a demand for labor in Fukushima Prefecture related to the restoration of infrastructure and strengthening of the industrial and research and education sectors as part of the national reconstruction project. Additionally, workers such as decontamination workers, medical providers, educators, and researchers may also migrate to the area. It should be noted that "migrants" in this context refers not to international immigrants, but to domestic internal migrants relocating from other prefectures in Japan.

However, contrary to societal needs, there is a lack of sufficient academic research focusing on internal migrants in the context of disaster recovery. This may be because researchers interested in elucidating the effects of disasters do not consider internal migrants who move to affected areas after a disaster as being directly affected. Alternatively, researchers could not methodologically distinguish internal migrants from affected residents. Indeed, in epidemiological and social science studies examining the effects of the Fukushima disaster, post-accident migrants were often excluded from analysis or were included as part of the control group of unaffected people [6–8].

As a result, despite the significant social needs in the context of recovery, there is no established academic baseline for internal migrants moving into disaster-affected areas or their characteristics. Consequently, there is a lack of information on how to promote and support internal migrants, although the number of whom is expected to be significant. Importantly, this lack of attention to internal migrants in the context of disasters does not mean that their health issues can be ignored. Previous studies on international migration have highlighted that migrants are vulnerable to mental health problems [9, 10]. Although studies focusing on internal migrants are limited, they suggest that unemployment, loss of autonomy, identity threats [11], and a lack of shared experiences with major community events—such as disasters [12]—can also pose significant psychological burdens.

Therefore, we considered the significance of immigrants in relation to contributions to the recovery from the 2011 Fukushima disaster. First, we examined when and how many people migrated to the Fukushima Prefecture from other prefectures after the accident by analyzing the Vital Statistics data from the latest national census. Second, we examined the mental health status of the immigrants, using data from the annual Mental Health and Lifestyle Survey, part of the Fukushima Health Management Survey, which has been conducted in the disaster-affected areas since the accident, focusing on mental health and lifestyle habits.

Study 1

In Study 1, we analyzed the population dynamics in Fukushima after the disaster using data from the Vital Statistics of Fukushima, which holds data on the number of residents, households, and their movements in all municipalities within Fukushima. Data on the estimated population, natural dynamics, and social dynamics are accumulated monthly and made available to the public [13].

Methods

Data

Data were obtained from the monthly reports published on the website of the Fukushima Statistics Division, covering the period from January 1999 to October 2023. They include numerical information on population dynamics at the prefectural or municipal level, combined with age and gender. We analyzed the estimated population and the number of people moving into Fukushima from outside (the "observed" data).

The estimated population is based on the number of residents revealed in the population census conducted by the national government to clarify the actual state of the population and households in the country [14].

Since census workers visit each household directly, the number of residents can be determined relatively accurately. The estimated population in the Vital Statistics is based on the results of the population census, which has been announced every 5 years since October 1995, and is based on changes in resident registration. However, in the disaster-affected areas, there are places where no residents were present owing to evacuation orders following the earthquake, resulting in unclear data on who actually lived there. The number of people moving into Fukushima from outside is based on the changes in resident registration.

Analysis

First, to examine the effect of the nuclear accident on the overall number of internal migrants to Fukushima, we conducted a time-series analysis using a Poisson regression model. The dependent variable was the monthly number of internal migrants in the Fukushima Prefecture from other prefectures. The model included sex, the date relative to the accident (i.e., before or after March 2011), monthly time points, and their interaction terms as explanatory variables. The analysis included an offset term for analyzing the number of internal migrants relative to the population and a term for seasonal components using Fourier series expansion for seasonal adjustment. Exponentiated regression coefficients (i.e., rate ratios) and their 95% confidence intervals (CIs) were calculated to quantify the effects of each explanatory variable on internal migration flows.

Next, we analyzed the monthly percentage of internal migrants as a proportion of the total population in the prefecture after the accident. This was calculated by dividing the cumulative monthly total of internal migrants since March 2011 by the estimated population in each month. We used data from 2011 onwards to examine age and sex characteristics of internal migrants after the accident by conducting a Poisson regression analysis bases on the number of internal migrants (dependent variable), age and sex group as explanatory variables, and year as a control variable. Rate ratios and corresponding 95% CIs were used to interpret relative differences in internal migration patterns across age and sex groups.

Finally, we analyzed the percentage of internal migrants after the accident in the 12 municipalities (Tamura, Minamisoma, Kawamata, Hirono, Naraha, Tomioka, Kawauchi, Okuma, Futaba, Namie, Katsurao, Iitate) that were subject to evacuation orders due to the accident. Specifically, for each municipality, the cumulative number of migrants for each month since March 2011 was calculated and divided by the estimated population for that month. In the disaster-affected areas, there were months when the estimated population was missing or zero,

therefore the percentage of internal migrants was also treated as missing values for those months. This calculation method is expected to estimate changes in the percentages of internal migrants, but since the calculation does not include the fact that people who migrated after the accident moved out again, the migration rate is calculated to be higher than the actual percentages.

Ethics

Study 1 used open data managed by the Fukushima Statistics Division for our analysis. We followed the open data use policy (https://www.pref.fukushima.lg.jp/uploaded/attachment/103733.pdf) established by the prefecture in our use of the data.

Results

Transition of internal migrants before and after the disaster

After the accident, the number of female migrants significantly decreased (Rate Ratio = 0.15597, 95% CI [0.14388, 0.16906], $P < 0.0001$), while the migration rate among males was significantly higher during the same period (Rate Ratio = 2.03526, 95% CI [1.83053, 2.26290], $P < 0.0001$; Fig. 1). Before the nuclear accident, there was a slight downward trend in the number of internal migrants over time (Rate Ratio per month = 0.99992, 95% CI [0.99991, 0.99992], $P < 0.0001$). After the accident, this downward trend was modestly mitigated (Rate Ratio = 1.00012, 95% CI [1.00011, 1.00012], $P < 0.0001$), although the time-related increase was slightly lower among males compared to females (Rate Ratio = 0.99997, 95% CI [0.9999, 0.99997], $P < 0.0001$).

More specifically, the monthly change in the migration rate varied by sex and disaster period. Before the accident, the migration rate decreased slightly each month among females (0.99992 times per month) and males (0.99993 times per month). After the accident, the female migration rate increased modestly (1.00004 times per month), while the male migration rate remained virtually unchanged (1.00000 times per month).

Percentage and characteristics of internal migrants after the Fukushima disaster

The number of people who migrated to the Fukushima Prefecture from other prefectures after the nuclear accident has been increasing annually, reaching 20.4% of the total estimated population of Fukushima as of October 2023 (Fig. 2).

A Poisson regression analysis of age and sex of internal migrants to Fukushima after the accident revealed distinct demographic trends. Using 20–24 years as a reference, female migrants aged 25–44 years had significantly lower migration rates, with rate ratios of 0.925 (95% CI [0.910, 0.941], $P < 0.0001$) for ages 25–29, 0.635
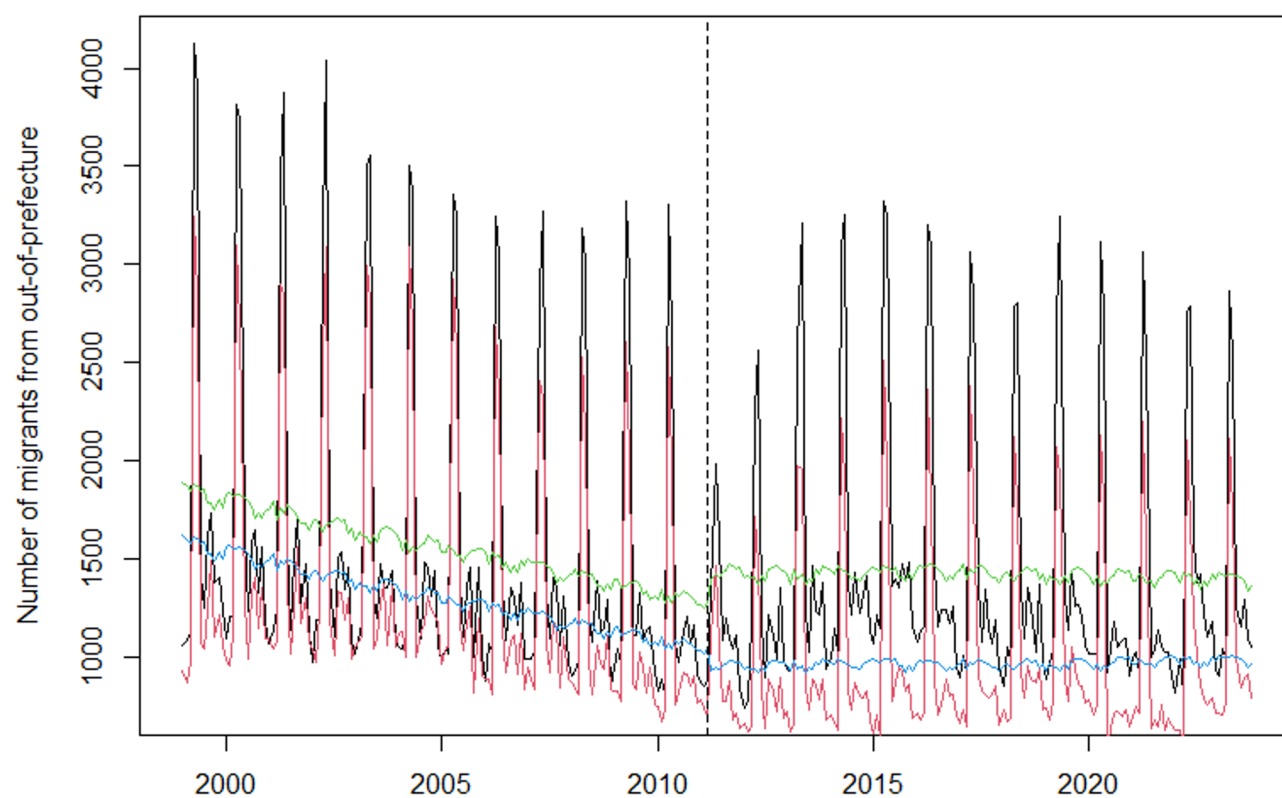
Fig. 1 Transition of numbers of male and female internal migrants. Note. Lines indicate the numbers of male (black) and female (red) internal migrants observed and of male (green) and female (blue) internal migrants predicted by the Poisson regression model. The dashed line marks March 2011, the date of the disaster
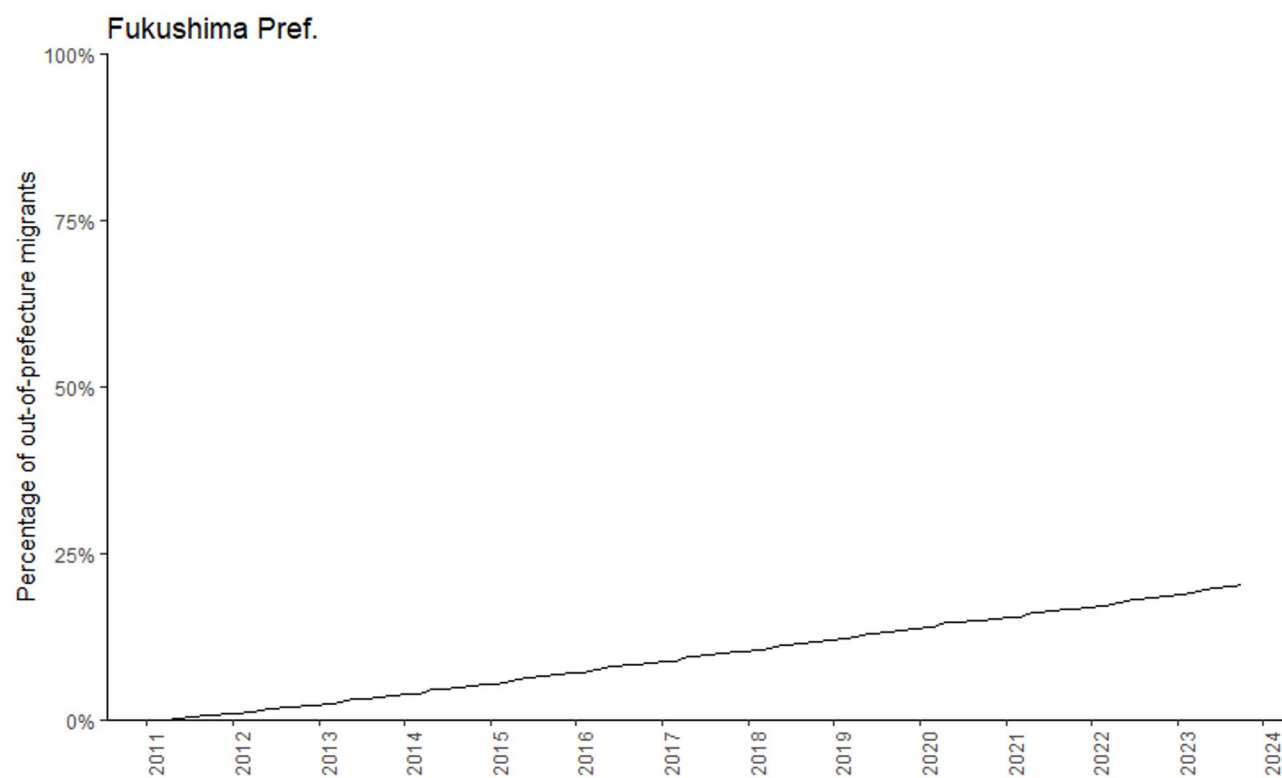

Fig. 2 Transition of percentages of internal migrants in Fukushima

(95% CI [0.624, 0.647], *P* < 0.0001) for ages 30–34, and 0.721 (95% CI [0.708, 0.733], *P* < 0.0001) for ages 35–44. Migration rates were even lower among females aged 0–19 or 45 years and older, with rate ratios of 0.316 (95% CI [0.309, 0.324], *P* < 0.0001) for ages 0–4, 0.264 (95% CI [0.258, 0.271], *P* < 0.0001) for ages 5–14, 0.251 (95% CI [0.245, 0.257], *P* < 0.0001) for ages 15–19, 0.346 (95% CI [0.338, 0.353], *P* < 0.0001) for ages 45–54, 0.226 (95% CI [0.220, 0.232], *P* < 0.0001) for ages 55–64, and 0.255 (95% CI [0.248, 0.261], *P* < 0.0001) for ages 65 years and older, indicating a concentration of migration among females aged 20–44.

Among male migrants, those aged 0–19 or 65 years and older had relationally lower migration rates, with the rate ratios of 0.316 (95% CI [0.309, 0.324], *P* < 0.0001) for ages 0–4, 0.264 (95% CI [0.258, 0.271], *P* < 0.0001) for ages 5–14, and 0.255 (95% CI [0.248, 0.261], *P* < 0.0001) for ages 65 years and older. The migration rates of immigrants aged 15–19 and 25–44 years were higher, with the rate ratios of 1.101 (95% CI [1.065, 1.137], *P* < 0.0001) for ages 15–19, 0.945 (95% CI [0.925, 0.965], *P* < 0.0001) for ages 25–29, and 0.945 (95% CI [0.923, 0.968], *P* < 0.0001) for ages 30–34, 1.126 (95% CI [1.101, 1.152], *P* < 0.0001) for ages 35–44. Moreover, migration rates were concentrated among males aged 45–64 years, with the rate ratios of 1.687 (95% CI [1.651, 1.745, *P* < 0.0001) for ages 45–54 years and 1.718 (95% CI [1.664, 1.774], *P* < 0.0001) for ages 55–64 years.

Among the 12 municipalities subject to evacuation orders, 9 municipalities (excluding Kawamata, Tamura, and Futaba) had a higher percentage of internal migrants than the 20.4% in Fukushima (Fig. 3). In particular, we observed a sharp increase in the percentage of migrants in Tomioka, Okuma, and Namie after 2020.

Note In Naraha, Tomioka, Okuma, Futaba, Namie, Katsurao, and Iitate, because many people live outside the city or prefecture, population estimates could not be calculated. For these periods, data are missing in the figures. The percentage of internal migrants was calculated based on the cumulative number of monthly migrants since March 2011, so some migrant percentages reached 100%, which this is more than the actual percentage.

Minor discussion

Study 1 analyzed how the number of internal migrants to Fukushima changed following a nuclear accident. The results confirmed that immediately after the accident, the number of female migrants decreased to about one-sixth of the pre-accident level, while the migration rate among males during the same period was approximately twice as high as that of females. Before the accident, there had already been a slight downward trend in the number of migrants, with both females and males showing gradual monthly decreases. After the accident, this downward trend was modestly mitigated, with a slight monthly increase observed among females, while the rate among males remained largely unchanged. In disaster-affected areas, people flow in for various types of reconstruction work [4]. In the context of the Fukushima disaster, a significant amount of funds has been invested for post-accident reconstruction, creating a high demand for labor. The age distribution of post-accident internal migrants showed a concentration of working-age population. Among males, migration was most prominent in the 45–64 years age group, where the rates were approximately 1.7 times higher than those in the reference group (aged 20–24 years). Among females, migrants were mainly concentrated in the 20–44 years age group, particularly among those aged 25–29 years and 30–34 years, whose migration rates were about 90% and 64% of the reference group, respectively. In addition, there were younger female migrants than males.

In the 12 municipalities designated for evacuation orders, the percentage of internal migrants was often higher than the prefectural level. Especially in Tomioka, Okuma, and Namie, the increase in the percentage of internal migrants was rapid. Each of these areas had a large number of evacuees, and despite the gradual lifting of evacuation orders, the number of returnees remains low, especially in recent years, for different reasons, such as an unclear future for home towns, lack of medical and educational resources, change of community culture, or establishment of new lifestyles [15]. Therefore, these internal migrants could be considered as pioneers in areas where community strength has weakened, potentially playing a significant role in future community revitalization.

Study 2

Study 2 examined the mental health of internal migrants using data from the Mental Health and Lifestyle Survey (MHLS) of the Fukushima Health Management Survey.

Methods
Participants
The MHLS has been conducted annually since 2011 for residents of areas designated as evacuation zones following the earthquake and nuclear accident. Its aims are to identify people at high risk of mental health problems (depression, PTSD, alcohol abuse, sleep difficulties, etc.) and provide appropriate support for them [16–18].

Participants included those registered as residents in the 12 municipalities designated as evacuation zones (Tamura, Minamisoma, Kawamata, Hirono, Naraha, Tomioka, Kawauchi, Okuma, Futaba, Namie, Katsurao, Iitate) and parts of Date City from March 2011 to 1 April 2012, and from 1 April of each survey year from 2013. It
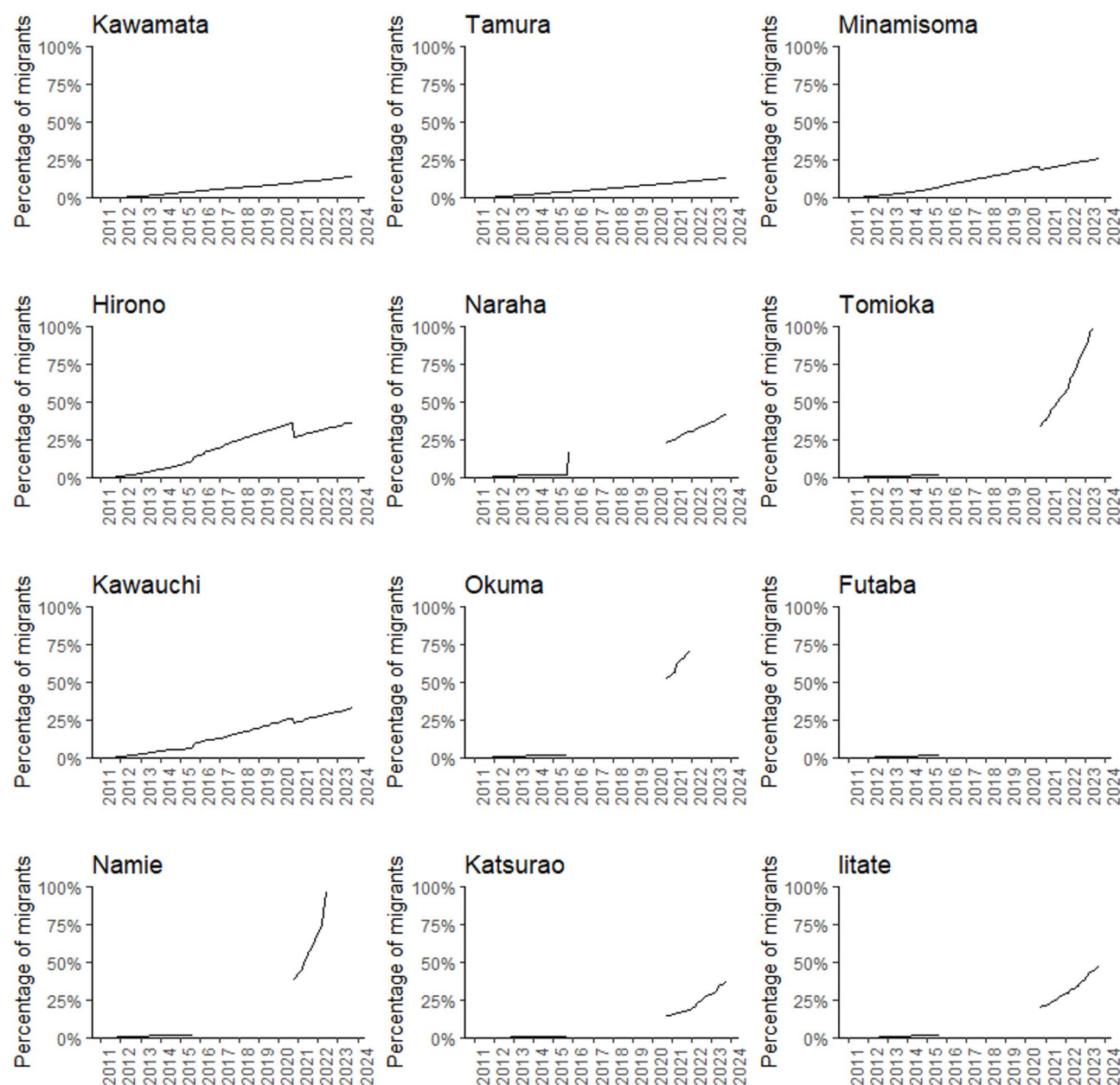
Fig. 3 Transition of percentages of internal migrants in 12 cities of Fukushima

is notable that MHLS follows not only those who experienced the disaster but also those who evacuated. In this study, those who became survey participants after the 2013 fiscal year were defined as internal migrants for analysis. Note that they included migrants who had moved to one municipality in the evacuation zones but were now living in another municipality in Fukushima Prefecture. In Study 2, further analysis focused on the areas identified in Study 1 as having a higher proportion of internal migrants after the accident (Tomioka, Okuma, Namie). The selection of analysis participants is shown in Fig. 4.

Data

The study examined six variables related to mental health, exercise, problem drinking, smoking, livelihood, and radiation risk perception.

Mental health was measured on the Kessler 6-item scale (K6) [19, 20]. Respondents were asked about their mental state over the past 30 days on six items, each rated from 0 (none) to 4 (always). A K6 score of ≥13 is considered to indicate severe depression or anxiety disorder [20].

Exercise frequency was categorized into four levels: almost every day, 2–4 times a week, about once a week, or hardly ever. According to the standards set by Ministry
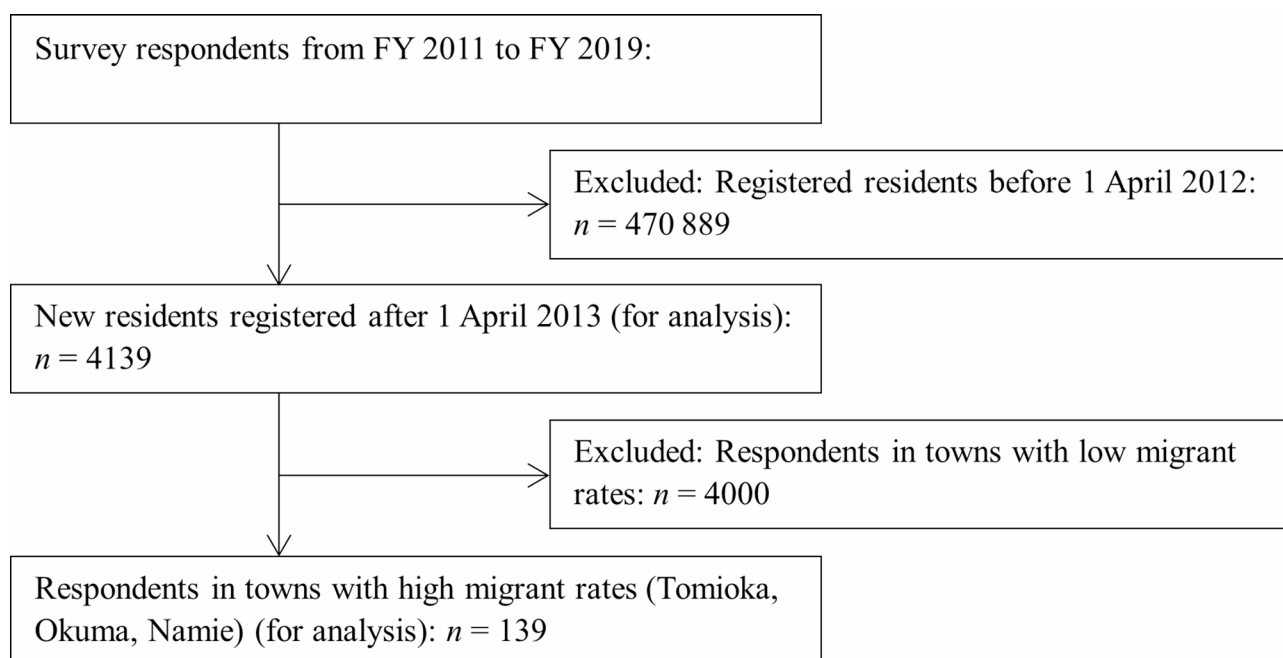
Fig. 4 Flowchart for participant selection in Study 2

of Health, Labour and Welfare in Japan, exercising at least twice a week is ideal [21]. In this study, those who exercised almost every day or 2–4 times a week were coded as 1 and others as 0.

Problem drinking was measured using the CAGE questionnaire for screening alcohol abuse [22]. CAGE consists of four items related to cutting down drinking, annoyance by criticism, guilty feelings, and eye-openers. Respondents who answered "drink (more than once a month)" to the question "Do you currently drink alcohol?" responded "yes" or "no" to each item. A score of ≥2 on the CAGE is considered to indicate likely alcohol abuse or dependence.

Smoking status was categorized as never smoked, quit, or currently smoking. In this study, those who smoked currently were coded as 1 and others as 0.

Livelihood was rated on a scale of 1 (difficult) to 5 (comfortable).

Radiation risk perception was rated on a scale of 1 (very low possibility) to 4 (very high possibility) regarding the likelihood of health problems due to radiation exposure in later years.

The study also analyzed age, sex, employment status (full-time, part-time, unemployed), and disaster experiences during the earthquake (earthquake, tsunami, nuclear accident, none).

Analysis

For basic information, mental health, and lifestyle of internal migrant respondents, the number and percentage of respondents for each item were calculated. Age was presented by decade, livelihood by responses of "difficult" or "somewhat difficult", and radiation risk perception by "very high" or "high" possibility. Mental health and lifestyle habits were compared against the target standards provided by the Japanese government [23].

A Poisson regression analysis was conducted to examine factors related to the mental health of internal migrants, with K6 as the dependent variable, and survey year, age, sex, employment status, exercise, problem drinking, smoking, livelihood, and radiation risk perception as explanatory variables. The disaster experiences during the earthquake were excluded from this analysis as they were not measured in the 2014 and 2015 surveys.

A similar analysis was conducted for internal migrants in areas with a high proportion of internal migrants (Tomioka, Okuma, and Namie), as identified in Study 1.

Ethics

The data for Study 2 are part of the data from the MHLS of the Fukushima Health Management Survey. The data were obtained from respondents who gave their paper informed consent and agreed to do so. The survey was approved by the Ethics Committee of Fukushima Medical University (Approval No.: General 2020 – 239).

Results

Basic information of internal migrant respondents for each year is shown in Table 1.

Mental health and lifestyle habits are presented in Table 2. The percentage of respondents with a K6 score of ≥13, indicative of severe depression or anxiety disorder,

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Table 1 Demographic information of internal migrant respondents

Variable	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
Sex							
Man	84 (39.1%)	124 (39.4%)	223 (43.4%)	271 (46.7%)	318 (46.4%)	420 (48.3%)	483 (50.3%)
Woman	131 (60.9%)	191 (60.6%)	291 (56.6%)	309 (53.3%)	367 (53.6%)	450 (51.7%)	477 (49.7%)
Age							
10s	4 (1.9%)	1 (0.3%)	5 (1.0%)	3 (0.5%)	6 (0.9%)	6 (0.7%)	5 (0.5%)
20s	60 (27.9%)	70 (22.2%)	103 (20.0%)	108 (18.6%)	107 (15.6%)	122 (14.0%)	122 (12.7%)
30s	67 (31.2%)	96 (30.5%)	152 (29.6%)	176 (30.3%)	209 (30.5%)	248 (28.5%)	261 (27.2%)
40s	32 (14.9%)	62 (19.7%)	90 (17.5%)	95 (16.4%)	112 (16.4%)	150 (17.2%)	178 (18.5%)
50s	22 (10.2%)	36 (11.4%)	74 (14.4%)	86 (14.8%)	96 (14.0%)	137 (15.7%)	128 (13.3%)
60s	22 (10.2%)	34 (10.8%)	56 (10.9%)	82 (14.1%)	108 (15.8%)	136 (15.6%)	175 (18.2%)
≥ 70s	8 (3.7%)	16 (5.1%)	34 (6.6%)	30 (5.2%)	47 (6.9%)	71 (8.2%)	91 (9.5%)
Work style							
Full-time	108 (52.7%)	168 (54.5%)	263 (51.8%)	315 (55.8%)	354 (54.0%)	483 (57.9%)	524 (56.2%)
Part-time	21 (10.2%)	37 (12.0%)	67 (13.2%)	58 (10.3%)	83 (12.7%)	99 (11.9%)	128 (13.7%)
Unemployed	76 (37.1%)	103 (33.4%)	178 (35.0%)	192 (34.0%)	218 (33.3%)	252 (30.2%)	281 (30.1%)
Disaster experience							
Earthquake	183 (85.1%)	—	—	463 (79.8%)	520 (75.9%)	625 (71.8%)	674 (70.2%)
Tsunami	24 (11.2%)	—	—	47 (8.1%)	41 (6.0%)	58 (6.7%)	64 (6.7%)
Nuclear accident	109 (50.7%)	—	—	168 (29.0%)	177 (25.8%)	207 (23.8%)	206 (21.5%)
None	21 (9.8%)	—	—	100 (17.2%)	141 (20.6%)	203 (23.3%)	252 (26.2%)

Table 2 Psychological status and lifestyle of internal migrants

	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
K6 (≥ 13)							
Man	4.76%	4.03%	4.48%	4.43%	6.92%	6.19%	4.35%
Woman	6.87%	6.28%	5.15%	5.50%	7.08%	3.78%	4.40%
Work style (unemployed)							
Man	20.99%	15.70%	16.67%	18.94%	18.81%	18.81%	20.64%
Woman	47.58%	44.92%	49.30%	47.18%	45.74%	40.93%	39.74%
Exercise (< 2× a week)							
Man	78.05%	72.36%	67.42%	71.75%	73.58%	70.12%	66.38%
Woman	80.65%	84.13%	81.47%	80.52%	79.84%	76.46%	74.52%
CAGE (≥ 2)							
Man	22.41%	12.22%	13.13%	14.44%	16.43%	16.97%	13.85%
Woman	8.51%	11.59%	10.00%	10.53%	6.60%	12.99%	8.97%
Smoking							
Man	35.80%	31.97%	28.18%	33.09%	30.55%	30.36%	25.79%
Woman	19.17%	14.89%	15.19%	12.50%	15.98%	14.16%	10.02%
Livelihood (difficult or somewhat difficult)							
Man	44.44%	38.84%	29.41%	34.08%	37.91%	36.76%	30.66%
Woman	40.68%	39.25%	36.36%	40.67%	38.14%	36.09%	36.40%
Radiation risk perception (very high or high possibility)							
Man	32.10%	18.97%	24.31%	21.64%	22.19%	23.90%	20.43%
Woman	47.97%	32.60%	33.09%	32.89%	35.39%	32.95%	28.20%

was consistently higher in both men and women than the 3% national average among Japanese people in normal times [24].

The percentage of unemployed internal migrants was consistently higher among women, nearly half of whom did not have a job.

Compared with the target standards for health promotion in Japan for the amount of physical activity and smoking [23], the percentage of men and women exercising at least twice a week was still lower than the target standards of 36% and 33% respectively. The percentage of smoking was higher among men than the target of 12%.

The Poisson regression analysis of mental health showed that K6 scores increased over the years. Higher K6 scores were associated with younger age, problem

Table 3 Poisson regression analysis for K6 scores

Predictors	Rate ratio	95% CI	Coefficient	SE	Z value	*P* value
Intercept			**−38.944**	**9.724**	**−4.005**	**<0.0001**
Year	**1.021**	**[1.011, 1.030]**	**0.020**	**0.005**	**4.217**	**<0.0001**
Sex (ref: man)						
Woman	1.027	[0.987, 1.068]	0.026	0.020	1.297	0.195
Age	**0.993**	**[0.992, 0.995]**	**−0.007**	**0.001**	**−9.963**	**<0.0001**
Work style (ref: full-time)						
Part-time	0.960	[0.909, 1.014]	−0.041	0.028	−1.454	0.146
Unemployed	1.018	[0.977, 1.061]	0.018	0.021	0.863	0.388
Exercise (ref: about once a week or almost never)						
Twice a week or every day	**0.884**	**[0.847, 0.922]**	**−0.123**	**0.022**	**−5.711**	**<0.0001**
CAGE (ref: 0–1)						
≥2	**1.477**	**[1.393, 1.566]**	**0.390**	**0.030**	**13.026**	**<0.0001**
Smoking (ref: non-smoker or quit)						
Smoke	1.023	[0.982, 1.066]	0.023	0.021	1.112	0.266
Livelihood	**0.711**	**[0.697, 0.725]**	**−0.341**	**0.010**	**−33.610**	**<0.0001**
Radiation risk perception	**1.171**	**[1.150, 1.193]**	**0.158**	**0.009**	**17.062**	**<0.0001**

Table 4 Poisson regression analysis for K6 scores in the pioneer internal migrants' area

Predictors	Rate ratio	95% CI	Coefficient	SE	Z value	*P* value
Intercept			99.211	62.278	1.593	0.111
Year	0.953	[0.898, 1.014]	−0.048	0.031	−1.546	0.122
Sex (ref: man)						
Woman	**1.749**	**[1.384, 2.207]**	**0.559**	**0.119**	**4.699**	**<0.0001**
Age	**0.988**	**[0.980, 0.996]**	**−0.012**	**0.004**	**−2.819**	**0.004**
Work style (ref: full-time)						
Part-time	0.755	[0.493, 1.113]	−0.281	0.207	−1.357	0.175
Unemployed	**1.309**	**[1.034, 1.660]**	**0.270**	**0.121**	**2.232**	**0.026**
Exercise (ref: about once a week or almost never)						
Twice a week or every day	**0.717**	**[0.559, 0.912]**	**−0.332**	**0.125**	**−2.658**	**0.008**
CAGE (ref: 0–1)						
≥2	**1.624**	**[1.219, 2.132]**	**0.485**	**0.142**	**3.409**	**0.001**
Smoking (ref: non-smoker or quit)						
Smoke	1.244	[0.976, 1.580]	0.218	0.123	1.777	0.076
Subjective economic status	**0.656**	**[0.593, 0.727]**	**−0.421**	**0.052**	**−8.115**	**<0.0001**
Radiation risk perception	0.953	[0.838, 1.039]	−0.068	0.055	−1.237	0.216

drinking, and higher radiation risk perception, and lower K6 scores with exercising and better livelihood (Table 3).

In areas with a high proportion of internal migrants ($n = 139$), K6 scores changed non-significantly over the years. However, the K6 score of females had 1.749 times higher than of male. Higher K6 scores were associated with younger age, unemployment, and problem drinking, and lower K6 scores with exercising and better livelihood (Table 4).

Minor discussion
Study 2 analyzed the mental health and lifestyle habits of internal migrants. The distribution of K6 scores indicated that the proportion of internal migrants suspected of depression or anxiety disorder in evacuation-ordered areas was consistently higher than the national average. The distribution of scores worsened over the years in Fukushima. Factors contributing to the deterioration of mental health included younger age, problem drinking, livelihood, and higher radiation risk perception. Although healthy exercise habits contributed to improved mental health, the proportion of people with such habits was lower than the target. In areas with a high proportion of internal migrants, women had lower mental health scores. These results are not so different from those obtained from the respondents who met the disaster in 2011 [25]. Previous studies identified female sex, younger age, and economic hardship as factors hindering health among international immigrants [10], and similar trends were observed among internal migrants in the disaster-affected areas.

Major discussion

This study examined internal migrants to the Fukushima Prefecture following the nuclear accident, as their characteristics and mental health protection had not been sufficiently clarified. The results suggest that 20.4% of the population in Fukushima are internal migrants since the accident, with even higher numbers in the affected municipalities. Moreover, their mental health was worse than the national average. We infer that the proportion of internal migrants in some disaster-affected municipalities was increasing rapidly.

Internal migration driven by the nuclear power plant accident

One key finding of this study is that the decreasing trend in the number of internal migrants eased after the accident.

Pais and Elliott [4] pointed out that the labor population increases in disaster-affected areas following major disasters. According to their recovery machine hypothesis, significant reconstruction funds are injected into disaster-affected areas. There is a political drive to create more extensive and superior facilities and infrastructure in the reconstruction process than before the disaster, aligning with the ethical acceptability and public sentiment of moving past the disaster (e.g., "Build Back Better" project in the context of the Great East Japan Earthquake [26]). This reconstruction movement promotes the activities of companies and organizations driving growth in the affected areas, increasing labor demand and creating employment opportunities, attracting not only local labor supply in the affected areas but also newcomers from outside [27].

Indeed, after the nuclear accident, employment opportunities arose not only in rebuilding the damaged infrastructure but also in decontamination work, medical and public health needs for resident health management, and the development of industrial infrastructure, such as the Fukushima Innovation Coast Promotion Organization [28]. The concentration in certain age groups of internal migrants in the working population in this study supports the idea that the easing of the decrease of internal migrants is related to labor demand driven by reconstruction. In addition, the perception of radiation risk might be a barrier to migration to areas affected by the nuclear accident especially during the early phases after the disaster, even if there was labor demand. However, while radiation risk perception was a factor in mental health deterioration, fewer migrants had high risk perception.

The finding that the mental health of internal migrants has been worsening over the years implies that they have been overlooked in traditional disaster research. This study also found that factors such as lack of healthy exercise habits, problem drinking, livelihood, and radiation risk perception contribute to worsening mental health. In a systematic review of studies of immigrants and refugees, George and colleagues [10] showed that immigrants often face issues related to acculturation stress and economic uncertainty. Acculturation stress is the stress of adapting to a new culture [29]. Unexpected challenges to lifestyle may arise in new communities. Changes in diet and customs can disrupt lifestyle habits and harm physical health [30]. If migration forces changes in lifestyle habits, immigrants may be particularly prone to issues with exercise habits and drinking. Also, migration can involve career disruption [10]. Moving communities can render previous qualifications and skills irrelevant. If internal migrants to Fukushima were drawn by labor demand driven by reconstruction, as suggested by Pais and Elliot's recovery machine hypothesis [4], the risk of unemployment might be low. However, disproportionately greater representation of female migrants in younger age groups in Study 1 and in unemployment in Study 2 suggests that female migrants may be more likely to accompany their families than males [11]. Notably, the accompanying family members might not benefit from the same employment opportunities.

The factors of livelihood and radiation risk perception worsening mental health are similar to those that affected residents in Fukushima [25, 31]. If these are accompanied by difficulties in establishing stable lifestyle habits and by economic uncertainty, psychosocial care and support for employment opportunities for internal migrants in Fukushima is needed.

"Pioneer migrants" in the affected area

In Fukushima, the evacuation following the nuclear accident led to the collapse and weakening of communities, with few residents returning. Internal migrants to these areas can be considered pioneers contributing to the reconstruction of new communities. This form of pioneering migration is relatively uncommon in previous migration patterns, as most immigrants in previous immigration and refugee studies move to safer and more developed countries or regions [9, 10]. In natural disasters, large-scale events produce many evacuees, but evacuees tend to return to their homes within months to years, so community weakening is not typically an issue. Given such a typical process of recovery from natural disasters, pioneering migration is a phenomenon possibly unique to the Fukushima disaster, which produced many evacuees and long-term damage, significantly lowering the return rate. This study confirms an extremely rapid increase in the percentage of internal migrants in some disaster-affected areas, notably Tomioka, Okuma, and Namie.

In areas where the original community is weakened, internal migrants may have fewer encounters with the host culture, potentially reducing acculturation stress [32]. However, the analysis of areas with a high percentage of internal migrants showed that exercise habits, problem drinking, and livelihood are related to poor mental health, requiring caution against the deterioration of lifestyle habits and economic uncertainty. On the other hand, radiation risk perception was not associated with mental health. This result may be due to the small sample size, but it is also possible that people who decided to migrate to affected areas were more likely to try to get accurate information and knowledge about radiation health effects, being highly prepared for the move.

Furthermore, in areas with a high proportion of internal migrants, women had poorer mental health. There is a lack of research specifically examining female migrants in the context of nuclear disasters. While previous studies on immigrants and refugees may not provide adequate evidence because the migration intentions may differ from those in Fukushima, they have pointed out that female migrants often face unstable employment, poverty, and gender role issues [33], with higher use of antidepressants [34] and sleep aids [35] and lack of adequate postnatal care [36]. In pioneering migrant areas, the environment may be challenging for women, necessitating more detailed surveys.

Implications for the care of internal migrants

This study confirms the worsening mental health of internal migrants to Fukushima over the years, suggesting the need for support aimed at improving their health. In promoting migration to accelerate reconstruction and revitalization in Fukushima, it is not enough to simply increase the number of internal migrants; it is crucial to increase the number of people who settle in Fukushima as members of the community. Despite significant attention to directly affected people, people relocating to affected areas after disasters might be regarded as being healthier and freer from substantial stressors. However, our results strongly suggest that appropriate care and measures for mental health of internal migrants are required to prevent them from feeling a psychological burden in their new life in Fukushima. Internal migrants, having significantly changed their living environment, are prone to deteriorating lifestyle habits because they lose the environment in which they were familiar with how to maintain their previous lifestyle. Therefore, issues related to exercise habits and drinking, which influence mental health, are of concern. Introducing facilities that encourage physical activity and health education that fosters awareness of health-related issues may be important. In addition, people outside Fukushima have limited access to information about radiation [37]. Since radiation

risk perception also influences mental health, providing information about radiation and risk communication is crucial.

Women, who often migrate as accompanying family members, tend to be forgotten in support frameworks and frequently do not receive adequate assistance [35]. In Fukushima, while labor migrants may receive more attention and support, their families may have less connection with companies and public institutions, leading to lower accessibility to support. Protecting the mental health of entire households is crucial for promoting the settlement of their internal migrants.

Limitations

Several limitations in this study warrant caution in interpreting the results. First, the reasons for internal migration were not directly examined. While this study analyzed the demographic and mental health characteristics of internal migrants, it did not investigate their motivations or reasons for relocating. We proposed hypotheses such as labor demand associated with reconstruction projects [4] and accompanying family member [35], however, these remain speculative. Given the context of Fukushima—where communities were devastated by the combined effects of the nuclear accident, tsunami, and earthquake—recovery has been slow, and anxiety regarding radiation remains high. Even residents with strong attachments to their hometowns have often chosen not to return. It remains unclear why people from other regions would voluntarily move to areas with such high psychosocial burdens. Possible explanations include appealing incentives that outweigh the risks or severe socioeconomic conditions in at the places of origin, that pushed individuals to relocate. Reconstruction-related subsidy programs may have attracted individuals or households who found it difficult to live elsewhere. In addition, unlike the evacuees, immigrants were not traumatized by the 2011 disaster, which made relocating to the affected area easier for them compared to evacuees. In any case, future studies should involve qualitative interviews and survey questions to identify reasons and motivations for migration. Understanding these migration motivations is crucial for interpreting migrant characteristics and designing appropriate support measures, and could help evaluate social support networks, access to mental health care, and resilience factors among migrants.

Second, the population estimates derived from Vital Statistics may not accurately reflect the actual resident population. Resident registration data used in this study may not have captured real-time population movement. As a result, the actual number of residents might differ from the estimates, possibly leading to an overestimation of the proportion of internal migrants in the population.

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Future studies should examine the retention rates and long-term settlement patterns of migrants after disasters.

Third, the sample size in Study 2 was relatively small. This limited sample size may have reduced the statistical power of the analyses and undermined the representativeness of the findings. Therefore, the results should be interpreted and generalized with caution.

Conclusion

We revealed the population dynamics and mental health of internal migrants from outside the prefecture after the Fukushima Daiichi Nuclear Power Plant accident. Although the internal migrants have been considered important for post-accident recovery, this study is the first to assess them. While many evacuees were displaced after the accident, internal migrants are continuously coming in from outside the prefecture, and the proportion of internal migrants has grown in several affected areas. Their mental health is not good enough and they require support to cope with economic uncertainty, radiation anxiety, and reduced wellbeing.

Author contributions
TK contributed to this work as a first and corresponding author and conducted the formal analysis and the writing of the original draft.TK, MMaeda, and NH contributed to the conception and design of this work, this study's methodology, and the interpretation of data. TK, MMaeda, NH, RM, MMomoi, TO, HY, and SY contributed to review and editing of this work and approved the final manuscript.

Data availability
The datasets analysed in Study 1 are available in the website of the Fukushima Statistics Division (https://www.pref.fukushima.lg.jp/sec/11045b/15847.html) in Japanese. The datasets analysed in Study 2 are not publicly available, as they originate from the Fukushima Health Management Survey and are property of the Fukushima Prefecture government, restricted to internal use. For guidance on data usage, please contact kenkan@fmu.ac.jp.

Declarations

Ethics approval and consent to participate
Study 1 was conducted by following the open data use policy established by Fukushima Prefecture. Study 2 was conducted with the approval of the Ethics Committee of Fukushima Medical University (Approval No.: General 2020 − 239).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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