

# Impact of the discharge of treated water on residents' intention to return to areas near the TEPCO Fukushima Daiichi Nuclear Power Station a decade after the accident

A. Zabirova<sup>1</sup>, H. Matsunaga<sup>1</sup>, M. Orita<sup>1</sup>, Y. Kashiwazaki<sup>1</sup>, X. Xiao<sup>1,\*</sup>, T. Schneider<sup>2</sup> and N. Takamura<sup>1</sup>

<sup>1</sup> Department of Global Health, Medicine and Welfare, Atomic Bomb Disease Institute, Nagasaki University Graduate School of Biomedical Sciences, Nagasaki, Japan.

<sup>2</sup> Nuclear Protection Evaluation Centre (CEPN), Fontenay-aux-Roses, France.

Received: 4 May 2024 / Accepted: 12 August 2024

**Abstract** – This study examined how discharged ALPS-treated water (DTW), social capital (SC), health-related quality of life (HR-QOL), and radiation risk perception influence residents' intention to return (ITR) to the affected areas around TEPCO Fukushima Daiichi Nuclear Power Station (FDNPS), within a 20 km radius. The concerns about DTW were investigated six months before authorities began discharging treated water into the Pacific Ocean, in August 2023. It was revealed that residents who wanted to return were mostly concerned about the DTW ( $p < 0.05$ ). Compared to the residents who had already returned, the community trust and attachment was lower in non-returnees ( $p < 0.01$ ). Residents of areas affected by the FDNPS accident remain concerned about various issues regarding radiation. These results provide important suggestions for how to provide appropriate support that addresses the specific concerns of former residents of affected areas.

**Keywords:** Radiation risk / recovery / social impact / tritiated water

## 1 Introduction

On March 11, 2011, the east coast of Japan's Tohoku region experienced a magnitude 9.0 earthquake that triggered a destructive tsunami. As a consequence, a catastrophic nuclear accident occurred at the TEPCO Fukushima Daiichi Nuclear Power Station (FDNPS), and radioactive substances that exceeded accepted standards were released into the environment. Evacuation orders for those living near the FDNPP were issued that day, and the scope of the evacuation zone gradually expanded, depending on the radiation doses in local areas (IAEA, 2015). Consequently, approximately 164,000 people had to evacuate, by order of the government and local administrations, to avoid unnecessary radiation exposure. In time, evacuation orders were lifted in stages, based on the results of detailed radiation monitoring, decontamination of the environment, and the rebuilding of infrastructures, except in some "difficult to return zones" that exceeded the standard acceptable annual radiation dose (UNSCEAR, 2022). The return of residents is a complex process involving not only

radiological factors but also social factors, especially those related to the organization of temporary housing, economics (the impact of the compensation system), and environmental considerations (ICRP 146, 2020; Croûail *et al.*, 2020). The decontamination of residential areas encompassed by the evacuation order, including adjacent roads, residential neighborhoods, and agricultural lands, included in the decontamination program is almost completed (Takamura *et al.*, 2021). Nevertheless, the number of people who returned to the affected is limited. As of early 2024, approximately 27,000 people or more who evacuated still have not returned, even though more than 13 years have passed since the nuclear accident (Matsunaga *et al.*, 2021).

In August 2023, the FDNPS began discharging treated water that has been filtered through a special protocol, called the Advanced Liquid Processing System (ALPS), as part of the process of decommissioning and dismantling the FDNPS (Saito *et al.*, 2017). The discharged ALPS-treated water (DTW) is subject to strict safety management and monitoring. Results of screening analyses for alpha-, beta-, and gamma-emitting radionuclides indicate that their levels were below the most stringent applicable regulatory limits: 4 Bq/L for 238Pu, 239Pu, and 240Pu (alpha emitters) and 9 Bq/L for 129I (a beta

\*Corresponding author: [hmatsu@nagasaki-u.ac.jp](mailto:hmatsu@nagasaki-u.ac.jp)

emitter); concentrations of the gamma emitters  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ , and  $^{129}\text{I}$  were also well below the applicable regulatory limit (IAEA, 2022). So that tritium levels also fully satisfy safety standards, the water is diluted with seawater before being discharged, thus reducing the tritium concentration to under 1,500 Becquerels (Bq)/L, which is approximately one-seventh of the standard set by the World Health Organization for drinking water. ALPS-treated water tanks have been stored inside the FDNPS, and their number is increasing; as of 2024 it exceeded 1,000. To proceed safely with the decommissioning work, the space occupied by the tanks is needed for the construction of new facilities. However, the decision to DTW into the Pacific Ocean drew criticism both in Japan and in some neighboring countries. For instance, China announced a ban on seafood from Japan, and the Republic of Korea expressed protests against DTW from the FDNPS (Huaxia, 2022).

Tomioka and Okuma towns are both located within 20 km of the FDNPS and abut the Pacific Ocean. The FDNPS is located in Okuma town (Fig. 1). As the DTW process is expected to be conducted over 30 years it is therefore essential to assess how it affects former residents' intention to return. Furthermore, the return rates of former residents of Tomioka and Okuma towns are quite low, compared to some other evacuation order-lifted areas. It has been clarified that the low rate of return to the areas affected by the nuclear accident was linked to residents' sex, age, level of anxiety about radiation exposure, and mental and physical health (Hande *et al.*, 2023). However, the relationship among social connections, social capital (SC), and the intention to return (ITR) has not previously been clarified. Community connections among the continuous evacuees and the evacuation area might affect their ITR, even more than 10 years after the FDNPS accident.

This study examines the impact of the DTW, SC, quality of life, and radiation risk perceptions on the ITR in the affected areas. In particular, it focuses on people who may have faced great struggles due to the FDNPS accident. The results offer important suggestions for how to provide appropriate support that addresses the specific concerns of former residents of affected areas.

## 2 Methods

### 2.1 Study participants

This study was conducted in Tomioka and Okuma towns, on Japan's Pacific coast, in the Fukushima Prefecture (Fig. 1). Study participants were people aged 18 years and older who still held resident cards for these towns after the disaster. A few new residents had obtained cards since the accident occurred. Permission to conduct the study was obtained from the municipal governments of both towns, based on a partnership agreement with Nagasaki University. The questionnaire was prepared at the university and then distributed to the towns from the Radiation Health Management Section using the Basic Resident Ledger (Takamura *et al.*, 2021). A questionnaire was enclosed in the public relations magazine sent to potential survey participants who held a resident card for Tomioka and Okuma as of November 2022, based on data from the Basic Resident Ledger. The data collection period was from November 2022 through January 2023. The 702 in Tomioka and 676 in Okuma responses were received from the

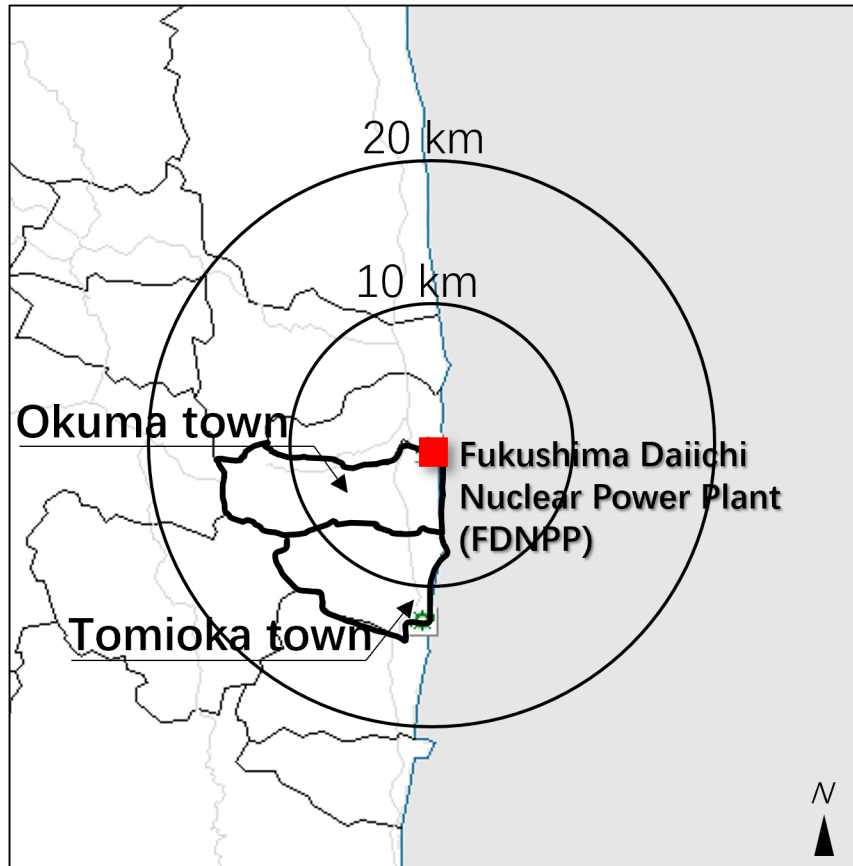
approximately 7,250 and 4,900 households to which each magazine was distributed in Tomioka and Okuma, respectively. Among the total responses, 678 in Tomioka and 660 in Okuma were regarded as valid after excluding incomplete responses. The study's purpose, methods, and ethical considerations were explained using a leaflet, and responding to the questionnaire was considered to indicate informed consent.

### 2.2 Questionnaire

The questionnaire was formulated based on the Fukushima Health Management Survey and previous research conducted in the area affected by the nuclear accident (Matsunaga *et al.*, 2021). The questionnaire encompassed inquiries on participants' demographic characteristics, such as age and sex. ITR to Tomioka/Okuma was described as follows: already returned, want to return, undecided, and do not want to return. Questions about the DTR, whether the respondent was concerned about DTR from the FDNPS, and whether the respondent was willing to acquire information about DTW were also asked.

Regarding radiation risk perception, respondents were asked whether they thought genetic effects would occur because of the FDNPS accident and whether they were reluctant to consume local foods from Tomioka or Okuma. These questions were answerable as "yes," "probably yes," "probably no," or "no."

After seeking the advice of experts in radiation risk communication, we proposed the following possible responses regarding the way in which the respondents wanted to be informed about the radiological situation in their municipalities: individual consultations, small group meetings (gatherings of less than 10 people) and conferences (groups of more than 10 people). To measure social connections with their latest local community, we applied a Japanese version of a health-related community social capital scale (SC) composed of 11 items on civic participation (five questions), social cohesion (three questions), and reciprocity (three questions) (Takamura *et al.*, 2021). Civic participation was assessed based on participation in five types of community groups: volunteering, sports, hobbies, culture, and skills teaching. We defined "participation" (scored as "1") as engaging with a social group once per month or more. Civic participation was evaluated as participating in none (0), participating in one group (low), two groups (middle), or three or more groups (high) among the five types noted above. Social cohesion comprised the degree of community trust and attachment the study participants felt for their local community. It was assessed using three questions: "Do you think people living in your area can be trusted in general?", "Do you think people living in your area often help others?", and "What is your level of attachment to the area where you currently live?" Social cohesion was scored "0" if respondents did not answer "very" or "moderately" to any of the questions. If respondents answered "very" or "moderate" to at least one of the questions, it was scored as "1." Replying "yes" one of the three questions was scored as low (1), two as medium (2), and all three as high (3). Reciprocity was assessed by receiving and providing emotional support and instrumental support from the local community. It was assessed using the



**Fig. 1.** Map of Tomioka and Okuma.

questions “Do you have someone who listens to your concerns and complaints?”, “Do you listen to someone’s concerns and complaints?” and “Do you have someone who looks after you when you are sick for a few days?” The question was scored “0” if respondents answered “no one” for all of the three questions. Reciprocity was scored between “1” and “3” if respondents answered “one or more persons exist,” depending on the number of questions to which they gave this reply. The evaluation of quality of life was conducted using the validated Japanese iteration of the Health-Related Quality of Life Short Form-8 (SF-8). This instrument gauges health status across eight dimensions: general health, physical functioning, physical role (limitations in the role due to physical health dysfunction), bodily pain, vitality, social functioning, mental health, and emotional role (limitations in the role due to emotional health dysfunction). Responses were collected on a five- or six-point scale ranging from “1” (very well/no interference) to “5” or “6” (very poor/unable to function). The SF-8 is interpreted based on scale scores encompassing two overarching classifications: the physical component summary (PCS, comprising general health, physical functioning, physical role, and bodily pain) and the mental component summary (MCS, encompassing vitality, social functioning, mental health, and emotional role). Scores surpassing  $50 \pm 10$  were deemed indicative of good health and guided by the average values among the Japanese population. We classified scores  $< 50$  and  $\geq 50$  on both the PCS and MCS based on previous studies (Tokuda *et al.*, 2009).

### 2.3 Statistical analysis

If responses were found to be incomplete or contradictory (*i.e.*, if multiple answers were selected incorrectly), we regarded them as missing, and a pairwise exclusion of such values was applied. Data were categorized based on distributions for age into two groups,  $< 65$  and  $\geq 65$ . The chi-square test was used to clarify the differences between each ITR level and each variable. The “no responses” were excluded from the chi-square test. A multinomial logistic regression analysis was applied to the reference group “already returned,” to clarify the association with ITR. The items in the multinomial logistic regression analysis were selected among those that resulted in statistically significant differences in the chi-square test for ITR. The age was added to the model as covariates. Contents of SC were divided between those who scored “0” and others in the models. Data analyses were performed using IBM SPSS Statistics version 29, and  $p$ -values  $< 0.05$  were considered statistically significant.

## 3 Results

Table 1 shows the results of sociodemographic factors, radiation risk perception, DTW, SC, and HR-QOL in the chi-square test among each level of ITR. Of the 1,338 responding residents, 119 (8.9%) had already returned, 131 (9.8%) wanted to return, 279 (20.9%) were undecided, and 809 (60.5%) did not want to return at the time of the survey.

**Table 1.** Comparisons of each factor concerning the ITR to areas affected by the FDNPP.

	Response	Overall (N=1338)	Already returned	Want to return	Undecided	Do not want to return	<i>p</i> -value
		% (n)	% (n) 8.9 (119)	% (n) 9.8 (131)	% (n) 20.9 (279)	% (n) 60.5 (809)	
Age (years)	< 65	39.8 (533)	42.9 (51)	31.3 (41)	38.4 (107)	41.3 (334)	0.142
	≥ 65	60.1 (804)	57.1 (68)	68.7 (90)	61.6 (172)	58.7 (474)	
	No response	0.1 (1)					
Sex	Male	50.2 (672)	65.5 (78)	55.8 (72)	50.7 (141)	47.4 (381)	0.002
	Female	49.1 (657)	34.5 (41)	44.2 (57)	49.3 (137)	52.6 (422)	
	No response	0.7 (9)					
Genetic effects will occur because of the FDNPP accident	Yes	15.2 (203)	8.5 (10)	12.5 (16)	15.6 (43)	16.7 (134)	<0.001
	Probably Yes	29.4 (394)	17.1 (20)	29.7 (38)	36.0 (99)	29.6 (237)	
	Probably No	32.4 (433)	42.7 (50)	31.3 (40)	35.3 (97)	30.8 (246)	
	No	21.7 (290)	31.6 (37)	26.5 (34)	13.1 (36)	22.9 (183)	
	No response	1.3 (18)					
Reluctant to consume food from Tomioka/Okuma	Yes	17.3 (231)	8.4 (10)	11.5 (15)	19.1 (53)	19.1 (153)	<0.001
	Probably Yes	30.4 (407)	16.8 (20)	30.8 (40)	36.6 (102)	30.5 (245)	
	Probably No	32.9 (440)	42.9 (51)	36.2 (47)	33.1 (92)	31.1 (250)	
	No	18.8 (252)	31.9 (38)	21.5 (28)	11.2 (31)	19.3 (155)	
	No response	0.6 (8)					
Concerned about DTW	Yes	25.6 (343)	23.7 (28)	20.9 (27)	27.6 (76)	26.3 (212)	0.047
	Probably Yes	32.1 (429)	23.7 (28)	31.8 (41)	37.8 (104)	31.7 (256)	
	Probably No	26.3 (352)	30.5 (36)	27.9 (36)	23.6 (65)	26.6 (215)	
	No	15.3 (205)	22.0 (26)	19.4 (25)	10.9 (30)	15.4 (124)	
	No response	0.7 (9)					
Willingness to acquire information about DTW	Yes	29.7 (398)	31.6 (37)	37.0 (47)	34.1 (94)	28.0 (220)	0.014
	Probably Yes	37.5 (502)	37.6 (44)	28.3 (36)	42.8 (118)	38.7 (304)	
	Probably No	20.9 (280)	21.4 (25)	27.6 (35)	17.0 (47)	22.0 (173)	
	No	9.4 (126)	9.4 (11)	7.1 (9)	6.2 (17)	11.3 (89)	
	No response	2.4 (32)					
SC, Civic participation	None (0)	65.3 (874)	71.9 (82)	66.1 (82)	65.6 (177)	67.4 (533)	0.761
	Low (1)	15.8 (212)	16.7 (19)	16.9 (21)	18.5 (50)	15.4 (122)	
	Middle (2)	9.5 (127)	6.1 (7)	8.1 (10)	9.3 (25)	10.7 (85)	
	High (3)	6.4 (86)	5.3 (6)	8.9 (11)	6.7 (18)	6.4 (51)	
	No response	2.9 (39)					
SC, Social cohesion	None (0)	32.7 (437)	18.1 (21)	43.3 (55)	38.5 (106)	32.0 (255)	<0.001
	Low (1)	22.6 (303)	31.0 (36)	23.6 (30)	20.7 (57)	22.6 (180)	
	Middle (2)	21.0 (281)	25.0 (29)	21.3 (27)	21.1 (58)	21.0 (167)	
	High (3)	22.0 (294)	25.9 (30)	11.8 (15)	19.6 (54)	24.5 (195)	
	No response	1.7 (23)					
SC, Reciprocity	None (0)	3.4 (45)	5.1 (6)	9.4 (12)	4.4 (12)	1.9 (15)	0.001
	Low (1)	3.4 (45)	6.0 (7)	3.9 (5)	2.6 (7)	3.3 (26)	
	Middle (2)	8.4 (112)	12.0 (14)	8.7 (11)	8.4 (23)	8.0 (64)	
	High (3)	83.0 (1111)	76.9 (90)	78.0 (99)	84.6 (231)	86.8 (691)	
	No response	1.9 (25)					
HR-QOL, PCS	Low	55.5 (742)	59.5 (66)	66.1 (84)	59.0 (160)	55.2 (432)	0.109
	High	41.1 (550)	40.5 (45)	33.9 (43)	41.0 (111)	44.8 (351)	
	No response	3.4 (46)					
HR-QOL, MCS	Low	52.4 (701)	47.7 (53)	59.1 (75)	60.5 (164)	52.2 (409)	0.034
	High	44.2 (591)	52.3 (58)	40.9 (52)	39.5 (107)	47.8 (374)	
	No response	3.4 (46)					

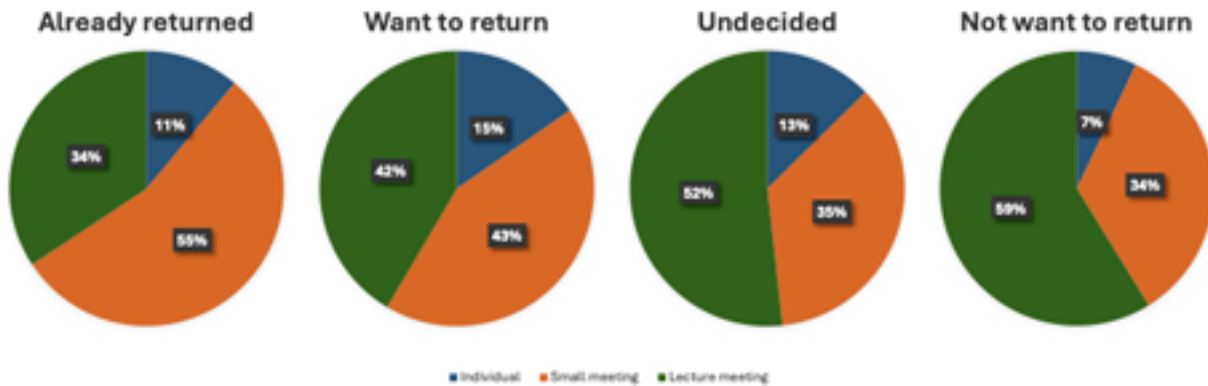


Fig. 2. The ideal methods of risk communication with the ITR.

### 3.1 Relationship between sociodemographic and ITR

Among the participants, there were slightly more whose age was  $\geq 65$ y (60.1%) than those  $< 65$ y (39.8%), but we found no statistical differences between the age and each level of ITR. Regarding sex, the proportion was almost equal among participants (males = 672, females = 657); however, more males had already returned (male vs. female, 65.5% vs. 34.5%), wanted to return (male vs. female, 55.8% vs. 44.2%), or were undecided (male vs. female, 50.7% vs. 49.3%), whereas more females did not want to return (male vs. female, 47.4% vs. 52.6%), as indicated with the chi-square-test ( $p = 0.002$ ).

### 3.2 Relationship among DTW, methods of radiation risk communication, and ITR

Among the respondents, 57.7% were concerned about DTW and 67.2% were willing to acquire information about DTW. Regarding the relationship between DTW and ITR, those who were undecided about ITR were the most highly concerned about DTW (65.4%), while those who had already returned were less concerned about DTW (47.4%) ( $p = 0.047$ ). Further, those with an undecided ITR were highly willing to acquire information about DTW (76.9%), among the ITR groups ( $p = 0.014$ ). Figure 2 shows methods of radiation risk communication, as preferred by those in each level of ITR. Among the returnees, the most preferred means of consultation was a small group meeting (54.6%), followed by lecture meetings (34.3%) and individual consultations (11.1%). The respondents who wanted to return were also most interested in small group consultations (43.1%). By contrast, the respondents who were undecided about returning (51.8%) or who did not want to return (58.8%) preferred lecture meetings. There were statistical differences among the methods of risk communication and each level of ITR, as shown in the chi-square test ( $p < 0.001$ ).

### 3.3 Relationship factors about SC, radiation risk perception, SF-8 scores, and ITR

Social capital was measured in three components: civic participation, social cohesion, and reciprocity. Regarding civic participation, 65.3% of respondents answered “none” to

participating in group activities in the local community; 15.8% had a low level of participation, 9.5% had a middle level, and 6.4% had a high level, and there was no confirmed statistical significance among these levels of civic participation and ITR levels ( $p = 0.761$ ). Social cohesion refers to the participant’s degree of community trust and attachment; 33.7% reported none, 22.6% had a low level, 21.0% had a middle level, and 22.0% reported a high level. Compared to returnees (18.1%), non-returnees had significantly higher distributions in the “none” category related to their current living area, compared to those who want to return (43.3%), who were undecided (38.5%), or who did not want to return (32.0%). By contrast, most respondents (83.0%) felt reciprocity levels were high in their present living area.

Slightly more than half (54.6%) of the respondents believed that genetic effects would not occur because of the FDNPS accident. Among the returnees, only 25.6% thought that genetic effects would occur because of the FDNPS. By contrast, those who wanted to return (42.2%), who were undecided (51.6%), or who did not want to return (46.4%) thought that there would be genetic effects because of the FDNPS ( $p < 0.001$ ).

Regarding the consumption of local foods from Tomioka or Okuma, overall 47.7% responded that they were reluctant to eat these foods; this was also the case for 25.2% of returnees, 42.3% of those who wanted to return, 55.8% of the undecided, and 49.6% of those who did not want to return ( $p < 0.001$ ).

Health-related quality of life was evaluated using the PCS and MCS of the SF-8. Among the participants, 55.5% had low ( $< 50$ ) PCS on the physical component summary, and there were no significant differences among ITR levels; 59.5% had already returned, 66.1% wanted to return, 59.0% were undecided, and 55.2% did not want to return ( $p < 0.109$ ). Further, 52.4% of participants also responded with low MCS levels ( $< 50$ ) on the mental component summary. The undecided (60.5%) had the lowest MCS, compared to the already-returned (47.7%), want to return (59.1%), and do not want to return (52.2%), among the ITR groups ( $p = 0.034$ ).

### 3.4 Factors independently associated with ITR; DTW, SC, HR-QOL, and radiation risk perception

A multinomial logistic regression analysis was used to assess independent factors associated with each ITR, with

**Table 2.** Independent factors associated with residents' ITR to towns near the FDNPP.

Variable	Unit	Want to return OR (95% CI)	Undecided OR (95% CI)	Do not want to return OR (95% CI)
Age	≥ 65/< 65	2.09 (1.18–3.70) *	1.49 (0.92–2.42)	1.22 (0.79–1.89)
Sex	Female/Male	1.65 (0.92–2.95)	1.56 (0.95–2.59)	1.99 (1.26–3.15) **
Concerned about DTW	Yes/No	1.48 (1.05–2.09) *	1.13 (0.84–1.52)	1.15 (0.88–1.50)
Willingness to acquire information about DTW	Yes/No	0.95 (0.69–1.30)	0.94 (0.71–1.23)	1.23 (0.96–1.57)
Genetic effects will occur because of the FDNPS accident	Yes/No	1.81 (0.83–3.93)	1.63 (0.83–3.19)	1.73 (0.93–3.20)
Reluctant to consume food from Tomioka/ Okuma	Yes/No	2.36 (1.08–5.15) *	3.17 (1.61–6.25) **	2.55 (1.37–4.75) **
SC, Social cohesion	Yes/None	0.21 (0.09–0.43) **	0.21 (0.11–0.41) **	0.28 (0.15–0.53) **
SC, Reciprocity	Yes/None	1.06 (0.30–3.76)	1.92 (0.56–6.57)	3.33 (1.08–10.3) *
HR-QOL, MCS	Low/High	1.36 (0.77–2.41)	1.18 (0.72–1.92)	0.91 (0.59–1.42)

Note. Multinomial logistic regression analysis, reference; already returned; OR, odds ratio; CI, confidence interval; ITR, intention to return; FDNPP, Fukushima Daiichi Nuclear Power Plant; DTW, discharge of treated water; SC, social capital; SF-8, HR-QOL Short Form-8; MCS, Mental Component Summary;  $p < 0.05^*$ ,  $p < 0.01^{**}$ .

already returned (returnee) as a reference (Tab. 2). Compared with returnees, those who wanted to return had a significantly higher concern about DTW (odds ratio [OR]=1.48, 95% confidence interval [CI]: 1.05–2.09). The sense of social cohesion was significantly lower among non-returnees: want to return (OR=0.21, 95% CI: 0.09–0.43,  $p < 0.01$ ), undecided (OR=0.21, 95% CI: 0.11–0.41,  $p < 0.01$ ), and do not want to return (OR=0.28, 95% CI: 0.15–0.53,  $p < 0.01$ ), compared to returnees. The reciprocity of SC was independently higher among those who do not want to return (OR=3.33, 95% CI: 1.08–10.3,  $p < 0.05$ ), compared to returnees. Compared to the returnees, the non-returnees had a greater reluctant to consume foods from Tomioka or Okuma. Among other groups, the rates were: want to return (OR=2.36, 95% CI: 1.08–5.15,  $p < 0.05$ ), undecided about returning (OR=3.17, 95% CI: 1.61–6.25,  $p < 0.01$ ), and do not want to return (OR=2.55, 95% CI: 1.37–4.75,  $p < 0.01$ ).

Regarding respondents' ages, those who want to return were significantly more likely to be aged  $\geq 65$  (OR=2.09, 95% CI: 1.18–3.70,  $p < 0.05$ ), compared to returnees. Female sex was independently associated with being among those who did not want to return (OR=1.99, 95% CI: 1.26–3.15,  $p < 0.01$ ).

The willingness to acquire information about DTW, the belief that genetic effects will occur because of the FDNPS accident, and HR-QOL of MCS were not independently associated in the model.

## 4 Discussion

In this study, we investigated whether concerns about DTW, SC, HR-QOL, and radiation risk perceptions influenced the ITR of people who lived in the towns near FDNPS on Japan's Pacific coast.

The DTW into the ocean caused serious concerns and negative reactions, despite it being a crucial step for accelerating the reconstruction efforts following the nuclear accident. It is important to note that the first ocean discharge was between August 24 and September 11,

2023 (The Inter-Ministerial Council for Contaminated Water, Treated Water and Decommissioning issues, 2021), about six months before this survey was conducted. This timing could potentially have influenced the responses and perceptions captured in the survey. The event attracted considerable attention, both inside and outside of Japan (Huaxia, 2022). Among respondents, more than half were concerned, and about 70%, wanted to obtain more information about DTW. It is also worth noting that those who were undecided about ITR were the most concerned about DTW, although they were highly willing to acquire information about DTW, compared to other groups. Those who had already returned were less concerned about DTW, compared to other ITR groups. The multinomial logistic regression analysis showed that residents concerned about DTW were more likely to belong to the want to return group. No significant independent relationships were found for residents who were undecided or who did not want to return. The monitoring of seawater treated by the ALPS system, conducted by independent international organizations prior to the commencement of TEPCO's discharge, demonstrated the reliability and safety of the chosen method based on scientific evidence (IAEA, 2023). Following the discharge in November 2023, monitoring results confirmed the absence of tritium and gamma-emitting nuclides at 14 sampling points of seawater. Analyses of fish from the Fukushima coastline also detected no radioactive substances, or showed levels below detection limits. These findings indicate that the marine environment remains safe after the discharge of seawater treated by the ALPS system (Fukushima Prefectural Government, 2023). It is important to track public awareness of the conducted monitoring, as it can influence the level of concern among residents.

Returnees and those who want to return seem to prefer small group or individual consultations, while those who were undecided or did not want to return tended to prefer lecture-type group meetings. Differences in communication preferences may be due to the different information needs and levels

of engagement of different ITR groups. Returnees and those wishing to return may want to participate in smaller, more interactive meetings to discuss and address their specific concerns, while those who are undecided or do not wish to return may want to hear the opinions of others. They wish to participate in larger meetings for a larger meeting to remain anonymous and also not to have to justify their position concerning the risks linked to radiation.

In both normal and crisis times, people turn to social networks for information and support. In addition, social capital contributes to resilience and the faster recovery of individuals after natural disasters (Uekusa *et al.*, 2022; Staněk *et al.*, 2021). In our study, 50.9% of returnee residents rated their levels of community trust and attachment as high or middle, and they had higher levels of social cohesion, even in affected areas. Interestingly, high perceived levels of reciprocity, even among those not wanting to return (86.8%), presented a complex picture, suggesting positive connections in their current communities (to where they had evacuated). Previous studies of social cohesion and place attachment have shown that evacuees had weak ties to their former places of residence, despite maintaining strong ties to neighborhood associations before the disaster (Matsumoto, 2018). This underscores the significance of factors like work responsibilities, family presence, and property ownership in influencing evacuees' decisions to return (Do, 2020). It is also important to consider the effect of age. Older people with strong ties to the community were more likely to return, while younger people were more likely to look for opportunities elsewhere (Gagné, 2020). Civic participation did not show statistical significance between returnees and evacuees in our analyses. It has been suggested that disaster recovery efforts may need to move beyond traditional forms of community participation to include diverse populations (Bodas *et al.*, 2022). The lack of social networks, support, and trust after the Fukushima accident led to stress, suffering, and depression among many people in Japan. Social capital plays an important role in overcoming these difficulties and improving health and well-being (Murakami *et al.*, 2019). However, there were also negative impacts, such as disagreements over safety, compensation, or reconstruction plans; hence, social cohesion was disrupted, which made it difficult to rebuild trust and community spirit (Villalonga-Olives *et al.*, 2017). The level of people's trust in industry, the government, and citizen groups is determined by factors such as openness and honesty, concern and care, competence, people's concern with risks, and shared values. In particular, it has been suggested that an organization's sense of openness is not attained merely by the disclosure of information, but also by bi-directional communication with the public (Maeda *et al.*, 2002; Ando *et al.*, 2023). Overall, social capital plays a complex and multifaceted role in ITR decisions. Restoring social trust and self-worth among affected people is crucial to the recovery process, requiring their inclusion in decision-making processes. This involves respecting survivors' preferences and cultural values, and engaging all stakeholders, including authorities, professionals, NGOs, the media, and local leaders (Thu Zar *et al.*, 2023).

The study clarified that more than half of those who have already returned assessed their mental state as "good," while more than half of those who did not want to return rated it as

"bad." Although the PCS of HR-QOL showed no statistical significance, psychological distress among evacuees is an acute problem that needs to be addressed, and social support remains a pressing need for people affected by the consequences of any nuclear accident (Yamaguchi *et al.*, 2017).

There were disturbing differences between risk perception and ITR. Although 74.3% of the returnees thought the possibility of genetic effects would not occur due to the accident, only 48.4% of those undecided about ITR felt the same. In particular, those who were undecided or who did not want to return tended to overestimate radiation health risks. In general, the interaction of a risk factor with social, institutional, and cultural processes can strengthen or weaken society's response to it (Panchenko, 2001). In Tomioka town, for example, reconstruction began with the residents' opinions in mind, which was very important for their level of trust and further reconstruction (Yamakawa *et al.*, 2017).

Interestingly, the returnees had low levels of reluctance to consume local foods in Tomioka or Okuma, compared to the non-returnees. The reason for this may be that food monitoring centers were established in both towns. At these centers, residents can measure radiation levels and decide if a food is safe to consume. The centers are also staffed by specialists, and residents can get advice not only on nutrition but also in a broader sense (Tomioka Town office; NEA, 2020). This is consistent with a previous study that emphasized the role of familiarity and trust in overcoming food safety problems after disasters (Uchida *et al.*, 2015). However, approximately half of all respondents remain reluctant to consume local foods. Objective risk, subjective perception, and individual decision-making are marked by complex interactions. This suggests the need to emphasize continued efforts to build trust in food monitoring systems and the information residents receive.

A study of people living near an operating nuclear power plant in China found that women have a relatively high perception of risk. They are also sensitive to environmental risks and tend to experience increased levels of stress and anxiety (Sung *et al.*, 2022). The differences in responsibilities and priorities between men and women may reflect the ITR differences in these groups. To provide security for their children, mothers often leave their jobs and other parts of life behind, while their husbands remain at the evacuation site and continue working. This has led to a distorted gendered distribution of population and labor (Shimizu, 2022). The development of gender-sensitive tools for information provision, counseling, and dialogue methods is essential, especially for mothers. In addition, the influence of women leaders in supporting these efforts is noteworthy.

The immediate response to the nuclear accident at the FDNPS included a series of measures aimed at safeguarding public health, such as evacuation, iodine prophylaxis, and regulating the distribution of contaminated food and water. Evacuation orders were executed in stages, covering areas at different radii around the plant. Subsequent decontamination efforts were extensive, encompassing residential areas, agricultural lands, and forests; however, despite these concerted efforts, indicators of population return remain low, both in Okuma and Tomioka, where evacuation orders began to be lifted in 2019 and 2017, respectively, prompting reflection on the efficacy of decontamination measures and the

challenges residents face in rebuilding their lives in these towns. In comparison, in Kawauchi village, where the return began in 2012, about one year after the accident, the rate of return exceeded 80%.

It is crucial to acknowledge certain limitations of the present study, such as potential survey biases and the complexity of the decision-making process, which cannot be fully captured solely through quantitative metrics. Future research could benefit from a more detailed exploration of residents' narratives, including qualitative methodologies, to unravel the intricate interplay of emotions, experiences, and economic and social dynamics following a nuclear catastrophe.

A detailed analysis of the study provides valuable insights into the multifaceted challenges faced by Okuma and Tomioka residents in the aftermath of the nuclear disaster at the FDNPS. The low population return rate, intertwined with risk perception, concerns about environmental safety, and the role of social capital, paints a complex picture of recovery and rehabilitation efforts. Understanding these factors is crucial for policymakers and stakeholders seeking to support affected communities and develop targeted initiatives for the long-term recovery of the Fukushima region. As the world grapples with the consequences of nuclear disasters, the lessons learned from Fukushima underscore the importance of disaster preparedness, having a clear action plan, building trusting communities, and cultivating thought leaders.

The limitations of this study include potential response biases, a small sample size, and a cross-sectional design that restricted causal inferences. Also, the social capital assessment was limited in scope. While the study included measures of civic participation, social cohesion, and reciprocity to assess social capital, the scale may not have captured the full complexity of residents' social networks and community connections. Additional dimensions of social capital, such as network density, trust level, social norms, the commons, and bridging ties could provide a more comprehensive understanding of community resilience and recovery (Aldrich *et al.*, 2015; Onyx *et al.*, 2000). Addressing these limitations requires careful consideration of alternative methodologies, such as longitudinal studies, mixed-method approaches, and inclusive sampling strategies, to enhance the validity, reliability, and generalizability of future research on residents' post-disaster experiences and intentions to return to Tomioka and Okuma. Despite these limitations, the study contributes valuable insights into the challenges faced by coastal residents, emphasizing the need for targeted recovery initiatives and ongoing research.

In conclusion, our study revealed that 57.7% of respondents were concerned about DTW, and 67.2% had a willingness to acquire information about it. Those desiring to return demonstrated the highest concern about DTW compared to other ITR groups. Further, returnees had stronger SC of social cohesion, better health assessments, and lower risk perceptions regarding the genetic effects and consumption of local foods, compared to non-returnees. Residents of areas affected by the FDNPS accident remain concerned about various issues regarding radiation. Considerations regarding the issue of returning to areas affected by a nuclear power plant accident should be included in the future recommendations of the ICRP (Bourguignon 2022, Clement *et al.*, 2021, 2022). It is

important to continue efforts to assess the specific concerns of former and relocating new residents and to provide them with appropriate support.

## Acknowledgments

We would like to thank all study participants and staff members of Tomioka and Okuma towns, Fukushima Prefecture, Japan.

## Funding

This work was supported by the Research on the Health Effects of Radiation program organized by Japan's Ministry of the Environment.

## Conflicts of interest

The authors declare that they have no conflict of interest.

## Data availability statement

The research data associated with this article are included within the article.

## Author contribution statement

A. Zabirowa: Writing original draft, H. Matsunaga, M. Orita, A. Zabirowa: Conceptualization, Methodology, Y. Kashiwazaki, X. Xiao: Visualization, Investigation, T. Schneider: Writing-Reviewing and Editing., N. Takamura: Supervision, Writing-Reviewing and Editing.

## Ethics approval

All processes in this study were reviewed and approved by the Ethics Committee of Nagasaki University Graduate School of Biomedical Sciences (No. 21082702).

## Informed consent

Written informed consent was obtained from all participants.

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**Cite this article as:** Zabirowa A, Matsunaga H, Orita M, Kashiwazaki Y, Xiao X, Schneider T, Takamura N. 2025. Impact of the discharge of treated water on residents' intention to return to areas near the TEPCO Fukushima Daiichi Nuclear Power Station a decade after the accident. *Radioprotection* 60(1): 99–108. <https://doi.org/10.1051/radiopro/2024036>



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