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# Why did so few refugees return to the Fukushima fallout-impacted region after remediation? An interdisciplinary case study from Iitate village, Japan

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## ABSTRACT

Large volumes of radionuclides were deposited on the soils in North-eastern Japan after the accident at the Fukushima Dai-ichi nuclear Power Plant (FDNPP) in March 2011. The village of Iitate, with a population of 6544 inhabitants in early 2011, was located in the main radioactive plume. Its population was evacuated between 2011 and 2017, when the town reopened after decontamination was completed in some cultivated and residential areas. This situation is unprecedented in history. Even around Chernobyl, access to the most contaminated area has remained forbidden until today. This manuscript compiles measurements of radiation dose rates and sediment radioactive contamination, socio-economic statistics, and reports the results of interviews conducted among refugees since 2011. Despite this reopening, which was presented as desirable by the authorities, less than ten percent of the original population - almost all of them over 70 years old - had returned to live in the village by January 2022. An analysis of the evolution of the population shows that it is now declining again. When the village was evacuated in 2011, most of the families that used to live with three generations under the same roof were often separated. The majority of the inhabitants took refuge in neighbouring municipalities, and many lived in temporary housing sites with a strong feeling of promiscuity. This study shows the difficulty for the majority of villagers who had never heard of Becquerels before the accident in 2011 to return to a very different environment with forests remaining contaminated and major landscape transformations having occurred after several years of abandonment and through the remediation process itself. Before 2011, forests and cropland were the main land uses in the village, and the local authorities promoted a model of eco-village. While decontamination has been effective in limiting the dispersion of radionuclides across the landscape, it did not affect the large stock of radionuclides stored in forests that cover ~80% of the surface area. Moreover, the lack of facilities and public services remains problematic for an elderly population that has a limited mobility to travel to nearby towns to find the necessities of everyday life. This study provides a benchmark for comparison with the evolution of the seven other municipalities located nearby FDNPP that are being reopened to settlement. This research, which shows the situation after a remediation tentative, will provide a unique reference in post-accident management.

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## 1. Introduction

The Great Tohoku earthquake that occurred on March 11, 2011 triggered a massive tsunami and an unprecedented nuclear accident at the Fukushima Dai-ichi Nuclear Power Plant (FDNPP). Large volumes of radionuclides have deposited on soils and formed a radioactive pollution plume extending up to 70 km to the northwest of the FDNPP [1]. Among the radioactive substances released during the accident [2], the main post-accident concerns are related to the deposition of cesium-134 ( $^{134}\text{Cs}$ ) and cesium-137 ( $^{137}\text{Cs}$ ), which were emitted in abundance and which are characterized by relatively long half-lives (2 and 30 years, respectively), causing their potential long term persistence in the environment. The environmental contamination in the region located to the northwest of the FDNPP has generated lively debates on the potential solutions to implement to protect the populations living in this area [3,4].

In the main radioactive pollution plume of the Fukushima Prefecture, the Iitate Village (飯館村) represents an area of particular interest (Fig. 1). This municipality has been classified since 2011 as a “Restricted Residence zone” until its reopening in 2017, after the completion of the remediation work planned by the authorities on some cultivated and residential areas [6]. However, the Nagadoro district (186 ha, 280 inhabitants before 2011), located in the southernmost part of the village, is an exception, as it is located in a zone where initial radiocesium levels exceeded  $100 \text{ kBq kg}^{-1}$ . Nagadoro district remain characterized as a “Difficult-to-Return Zone” (Fig. 1). This zone comprises one of the six “Special Zones of Reconstruction and Revitalization” (SZRR) of 186 ha, set up in the Difficult-to-Return Zone, which is scheduled to be fully reopened by 2023. Following the revision of the Act for Special Measure for the Reconstruction and Revitalization of Fukushima (May 2017) the Japanese national government designated six SZRR (see Fig. 1): Futaba Town in Sept. 2017 (555 ha), Okuma Town in Nov. 2017 (860 ha), Namie Town in Dec. 2017 (661 ha), Tomioka Town in March 2018 (390 ha), Iitate Village in Apr. 2018 (186 ha), and Katsurao Village in May 2018 (95 ha, reopened on 12<sup>th</sup> June 2022, with 4 households - i.e. 8 inhabitants, all over 70 years old).

Numerous studies have investigated the fate of the radioactive contamination in the environment, including in the soil (Yasunari et al., 2011), in sediment transiting the rivers [7–9], in the vegetation (Kato et al., 2012) or the social and political issues in this municipality [10,11]; Munro, 2013). The originality of the current interdisciplinary approach consists in complementing all this research with the results of the authors’ field surveys carried out since the FDNPP accident (2011–2022). During all this period, we followed step by step the inhabitants and the different management policies for promoting their return in order to analyze its consequences for the local population (economic, social and health consequences, including psychological effects).

In this context, several arguments plead in favor of the choice of Iitate Village as a research area. First, the administrative boundaries of the village coincide with the divide lines of two catchments, which are those areas of land where precipitations collect and drain into a common outlet. Accordingly, upper sections of the Niida and the Mano Rivers drain the land of Iitate (Fig. 1). Those situations where geomorphological and administrative units share the same borders are not so frequent, and their coincidence therefore provides an ideal framework to investigate both social and environmental research questions.

Second, the completion of the remediation works in Iitate village in 2017 corresponds to an unprecedented situation in history to date. As a comparison, the authorities of the Soviet Union took the decision to restrict the access to the most contaminated area located around the Chernobyl Nuclear Power Plant after the accident that took place in 1986, and this decision has been maintained for several decades until today [12,13].

Third, as mentioned earlier, this municipality was a “Restricted Residence Zone” (RRZ) across the entire village (230 km<sup>2</sup>) between 2011 and 2017. In the RRZ, the annual integrated doses were comprised between 20 and 50 mSv, entry and business operations were only partially permitted and staying overnight was prohibited. These restrictions were applied during six years before the ban was lifted in April 2017. In contrast, the other municipalities exposed to the main radioactive fallout were either fully reopened to the population (e.g. Minami-Soma), or they remained closed both day and night as they were referred to as the “Difficult-to-Return Zone” (e.g. Namie Town; Fig. 1). The surface remaining classified as such covers 337 km<sup>2</sup> (as of April 2022). As the government plans to reopen the whole area from 2023 onwards, the current interdisciplinary evaluation is therefore particularly timely. The analyses related to the psychology of risk and the associated evaluations in terms of cognition, emotion and action underlie the social component of this work [14]. The disintegration of ideal life models and the loss of reference points associated with the loss of material goods and social link also underpinned our approach.

The current research compiles the qualitative and quantitative results of field monitoring surveys, official document analyses and residents’ interviews conducted in Iitate Village between 2011 and 2022. The main objective of this study is to provide an interdisciplinary benchmark scientific assessment of the situation, after the evacuation order has been lifted, as other municipalities will undergo the same transition in 2023. To this end, data obtained by the means of ethnographic and sociological analysis methods will be combined with those generated by environmental science specialists in order to understand why so few refugees returned to their hometown after the reopening of their village.

## 2. Materials and methods

As all the municipalities affected by the nuclear disaster, the village of Iitate was confronted to a composite and complex situation. Interdisciplinarity is therefore essential to develop adapted tools for understanding the situation and avoid the risks of pitfalls that may be caused by individual approaches. This is why this research proposes and assumes a multidisciplinary approach allowing a complete understanding of the situation.

### 2.1. Eco-geographical presentation of the study site

Iitate Village (230.13 km<sup>2</sup>) is located in the eastern part of the Fukushima Prefecture in the middle of the *Abukumakōchi* mountains reaching 918 m at *Mount Hanatsukaya*, which is the highest point of the village. Forests are the main land use in the area and

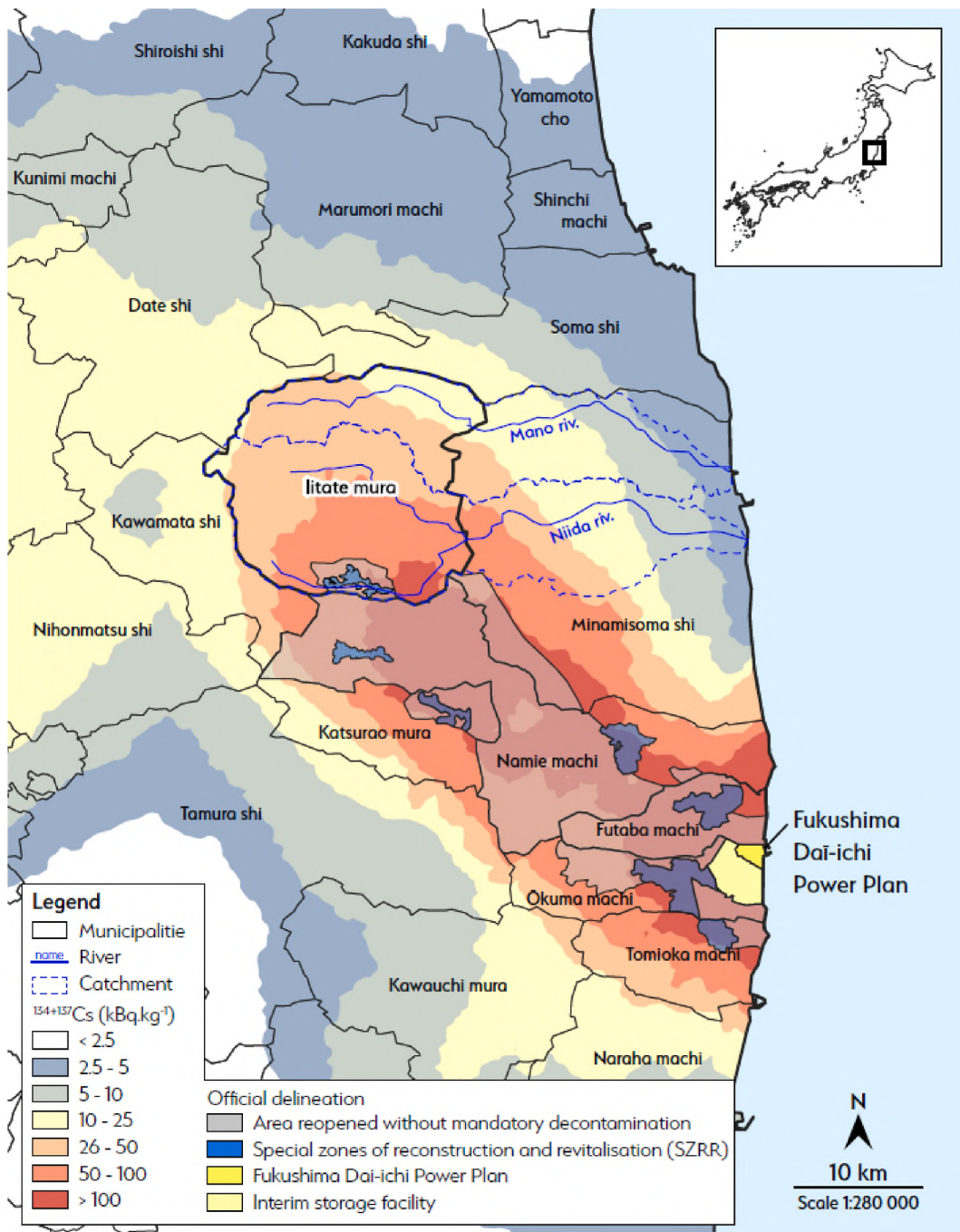


Fig. 1. Location of the Litate Village municipality, in the main radioactive pollution plume of Fukushima Prefecture, in Northeastern Japan, and the main rivers (i.e., Mano and Niida Rivers) draining the village. Background radiocesium ( $^{134}\text{Cs} + ^{137}\text{Cs}$ ) contamination map in topsoil (upper 5-cm layer) derived from Chartin et al. [5] and decay-corrected to 14 June 2011. Official delineation of the main zones defined by the Japanese authorities as of April 2022.

provide a rich habitat for a mix of broadleaf and coniferous trees including beeches, oaks, maple, keyaki, harigiri and firs. According to public data from the Japanese Meteorological Agency, monthly temperatures vary from an average of  $-6\text{ }^{\circ}\text{C}$  in winter to  $+28\text{ }^{\circ}\text{C}$  summer (1991–2020) while the mean annual precipitation reaches  $\sim 1400\text{ mm}$  [15]. Heavy rainfall is concentrated between July and October, with 82% of the annual erosivity supplied during these months, and with the occurrence of an average of 2 tropical storms or typhoons on average each year [16].

The village was particularly exposed to the radioactive fallout transported by the winds from the FDNPP on March 14, 2011, and the occurrence of rain and snowfall on the night of 14–15 March led to significant radionuclide deposition on the local soils and vegetation [17]. Radioactivity levels are strongly variable across the municipality, from  $\sim 10\text{ kBq kg}^{-1}$  of  $^{134+137}\text{Cs}$  in the northern part of

the village to more than 100 kBq kg<sup>-1</sup> of <sup>134</sup>+<sup>137</sup>Cs in topsoil (upper 5-cm layer) of the southernmost part, in Nagadoro district (Fig. 1) [5].

## 2.2. Methodology for demographic, cultural and socio-economic characteristics of the village

Official archives, documents and statistics from the Fukushima Prefecture and the municipality of Iitate Village were analyzed and associated with the local residents' narrative (which will be referred later in the text) in order to reconstruct the cultural situation and the socio-economic activities in the village, both before and after the nuclear accident. The demographic evolution of the population was also characterized based on national local official data (e.g. official population census of Japan). The cost of the remediation strategies and the evolution of the local budget and the aids granted to the refugees were also estimated, when available, based on official sources.

## 2.3. Method of assessment of environmental contamination with radionuclides

Annual fieldwork surveys were conducted between November 2011 and November 2020 along the main rivers draining Iitate Village. During the field campaigns, radiation dose rates were systematically measured in the field using a radiometer (LB123 D-H10, Berthold Technologies) in recently deposited riverine sediment. The corresponding dose rates from the soils were calculated based on data provided by the MEXT decay-corrected to the sampling date [18,19]. Only the results of three surveys (November 2011, May 2013 and November 2017) are provided in the current study to illustrate the evolution of dose rates and their spatial patterns across the municipality between 2011 and 2017, when the village was reopened to the inhabitants.

## 2.4. Interviews of local residents and municipal authorities

Interviews of ~50 local stakeholders were conducted on various occasions between 2011 and 2021. Among the residents, four types of inhabitants were interviewed: (1) people who have returned to live in Iitate, (2) refugees who continued to live in temporary housing in nearby municipalities when it remained operational, (3) refugees in other regions/municipalities, and (4) refugees who continue to work during daytime in Iitate. Specialists in charge of educational, agricultural and social affairs were also interviewed at the town hall. Extracts from these open-ended interviews will be provided throughout the text. The results of surveys organized by local newspapers and researchers are also reported.

## 2.5. Mapping the evolution of land use

To complement land use information made available by the Japan Aerospace Exploration Agency [20], we carried out a systematic screening of the aerial photos available on Google Map in 2022 following their UTM grid based on the geodetic within the boundaries of Iitate Village. The specific objective was to highlight the evolution of specific land cover features that are not captured by routine land cover mapping and which are the main visible changes in the landscape in terms of land use since the nuclear accident (i.e. contaminated waste disposal areas and solar panel fields). These zones were delineated and the corresponding surface areas were also calculated.

## 2.6. Limitations of findings

In addition to the environmental consequences, the accident at the Fukushima Dai-ichi nuclear power plant has been a catalyst for demographic processes that were often already initiated before 2011, i.e. depopulation of the rural municipalities. Therefore, efforts to revitalize the region have limited consequences for the time being, although it is difficult to assess whether this trend is due to the contamination of the territory only (which undoubtedly accelerated and amplified the process) or whether it would have been similar over the long term even in the absence of nuclear accident. Nevertheless, drastic policies have been implemented, notably regarding the reuse of waste from decontamination and, consequently, the reduction of the number of sites for storing contaminated soil bags. It is therefore necessary to continue to monitor the situation over the long term in order to capture the demographic trend.

# 3. Results and discussion

## 3.1. Cultural and socio-economic characteristics of the village

The village, which is subdivided in 20 districts, is mainly covered with forests (81.9% of the surface area, with 47% of these forests being owned by the Japanese State) and cropland (16.2%). The rest of the land was mainly occupied by pasture and vegetable fields, with scattered settlement areas across the landscape (Fig. 2). The local population with a majority of farmers amounted to 6211 inhabitants before the FDNPP accident, which corresponds to a very low density (26 inh. km<sup>-2</sup> vs. 343 inh. km<sup>-2</sup> in 2010 at the scale of Japan). In 2010, paddy fields occupied more than half of the cropland, the rest being cultivated with tobacco, vegetables and flowers. Grassland covered 1.97 km<sup>2</sup> (0.8%) for cattle (black *wagyu* cows) and horse breeding, with a total of ~2000 heads of cattle in 2010 [21]. Another significant economic activity in Iitate was the production of timber. However, to meet their needs, most farmers had sideline activities (e.g. production of traditional *bento*'s, of blueberry jam and pastries, maintenance of forest in the mountains ...)

This situation radically changed after the accident, when the village re-opened. From the 25.4 km<sup>2</sup> surface area cultivated before the accident, only 1.6% were exploited in 2020 (rice, buckwheat, flowers). Local experiments are being conducted to test the cultivation of rice and vegetables, among other crops, on limited surfaces (typically 0.01 or 0.02 km<sup>2</sup>). Timber cannot be produced anymore as it would be too contaminated, and the production of wood pellets for heating installations is prohibited [22].

Despite its small size, the village had a rather diverse cultural and recreational life until March 2011. Listed among the "most beautiful villages of Japan", Iitate's lush countryside attracted students in its agricultural school. Fishermen caught carps and black

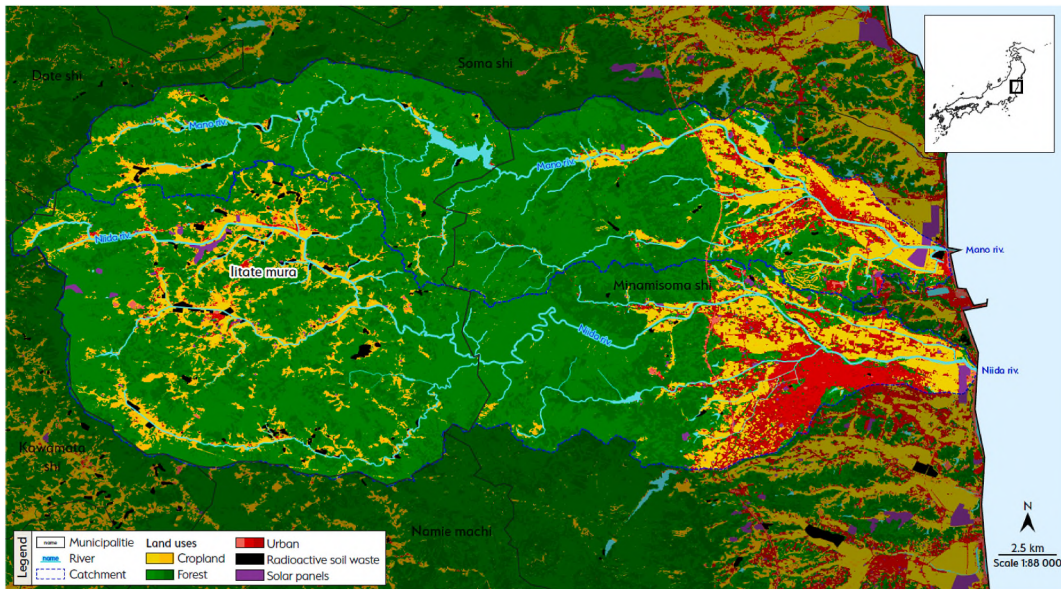


Fig. 2. Land uses and specific land cover features (i.e., solar panel fields, waste storage zones) after data from the Japan Aerospace Exploration Agency [20] for the situation observed over the period 2018–2020 and aerial images available on Google Earth (April 2022, this study).

basses in the rivers or in the Mano Dam Reservoir. Iitate is also rooted in the collective imagination of Japanese citizens, as it is referred to in Tatsuyuki Takanô’s famous song “*Furusato*” (Hometown). In addition to these specificities, those ancestral traditions found in the countryside across Japan, like the gathering of *sansai* (literally “mountain vegetables”) were widespread in the village.

Before 2011, the village’s project was to set-up a “eco-village” model. The local authorities promoted the installation of several experimental farms in charge of developing original environmental-friendly farming practices. Among these institutions, *Iitate Farm* was managed by Mr. Nobuyoshi Itô who accepted this position when he was 67 in 2010, just one year before the FDNPP. After the accident, this farm was transformed into a site devoted to radioactivity measurements and decontamination experiments. During 7 years, he carried out very diverse radionuclide measurements in a variety of environmental samples including butterflies [23], honey, tree barks, branches and leaves, or even rice. He received more than 800 visitors until the farm closed down in July 2018. “All the green that you see here is cesium-green. You cannot find a single spot free of contamination”, he said.

### 3.2. Reconstruction of events during the accidental phase

Despite the detection of high radiation dose rates (up to  $45 \mu\text{Sv h}^{-1}$ ) in the region by the SPEEDI (*System for Prediction of Environmental Emergency Dose Information*) system between March 11–15 [24], which the government had not access to at the time of the accident, the evacuation of the population of Iitate Village began on April 22, 2011 after the changes in the delineation of the restricted zone. Initially, a 20-km radius zone centered on the FDNPP was evacuated before being extended to a 30-km radius zone and, finally, adjusted to the exact shape of the radioactive plume extending to the northwest of the region (Fig. 1). Most villagers actually evacuated the village later, in June 2011. The measurement of radiation dose rates as high as  $20 \mu\text{Sv h}^{-1}$  (i.e.  $\sim 175 \text{ mSv yr}^{-1}$ ) in the vicinity of the houses during Spring in 2011 supported the decision to evacuate [25]. This evacuation was a rather chaotic experience for the villagers, as they received a series of conflicting orders and information [26]. The temporary housing sites were only ready to welcome them by August 2011, and they had to find provisional solutions staying at relatives or in *ryokans*. To this confused management, during which the inhabitants were shuffled from one place to another, we must add the pain of the loss, certainly of their former living place, but also of the animals that shared their lives until then. Furthermore, the requirement for the families to kill their cows or their horses when leaving the village has been reported as a traumatic experience by many local families.

### 3.3. Demographic evolution

Following a cycle of depopulation similar to that observed in the countrysides of other developed countries around the world, the decline in population is not recent in Iitate Village, as the population decreased from 9385 inhabitants in 1970–6211 early in 2011 (Fig. 3). Nevertheless, the way of life had remained very traditional. In most families, three generations lived under the same roof, with a mean of 3.6 persons per household, as 1700 households lived in Iitate. After the residence restrictions issued in April 2011, families were often separated, as the size of the temporary housing residences available was generally not sufficient to accommodate the entire family. Therefore, the number of households increased by 77%, to 3008 units and the number of person by family decreased to 1.8 persons per family.

Of the 2476 households that migrated to other places located in the Fukushima Prefecture (82.3%) in December 2016 (i.e. three months before the original date for withdrawal of evacuation subsidies), 467 were living in temporary accommodation, 100 were living in public housing, 935 were housed in the private rental sector (with rent paid by the Japanese authorities) and 911 households

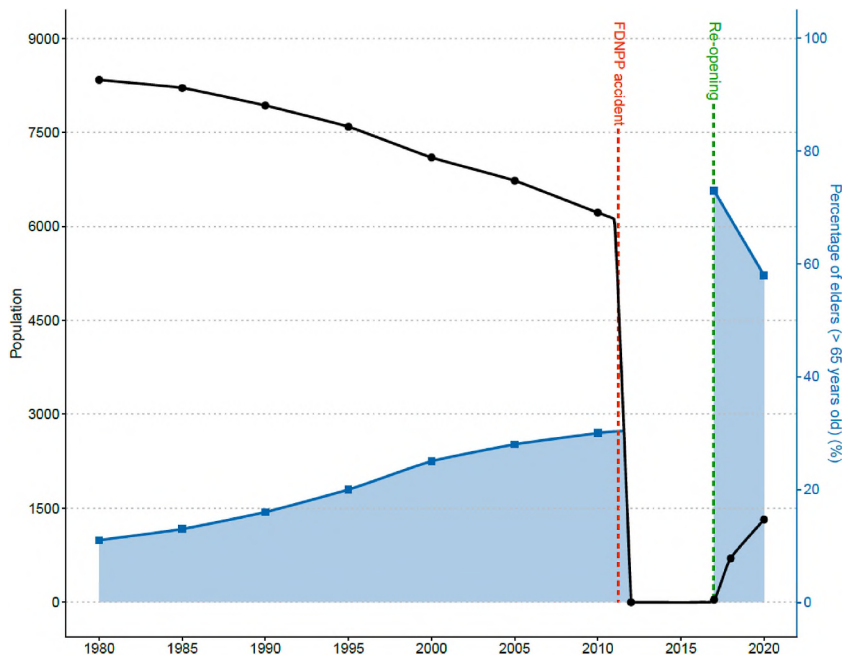


Fig. 3. Evolution of the population and the proportion of elderly population (> 65 years old) in Iitate Village, from 1980 to 2020. Data available from the Japanese Ministry of Internal Affairs and Communications.

acquired a new house. Of the remaining households, 63 left no trace, lived in retirement homes or returned to the village. A further 182 households moved outside of the Fukushima Prefecture. These data illustrate the familial disruption induced by the small size of housing available to the refugees. “With the very low population density in the village, the houses were very distant from each other. Imagine the stress and the containment feeling experienced by those people who moved to small-sized temporary housing or flats. You have windows onto your neighbor and you hear everything in the house next door ... The situation was untenable for most of us”, explained a refugee in Date. Many households consist of only one elderly person, and an increased mortality was observed in this group. In 2017, when the village was reopened to the residents, the population had dropped to 41. Early in 2018, slightly over 10% of the initial population, i.e. 700 individuals, had returned to the village (Fig. 3). In 2022, the population increased to 1476 individuals divided into 774 households, i.e. less than two people per household, which indicates a major transformation in the way people lived together, since the majority of the returnees found themselves alone at home.

Among the initial residents of Iitate, 4934 persons divided into 2032 households sought refuge within the Fukushima Prefecture, with a vast majority in the City of Fukushima itself (3174 persons, 64.3% of the refugees; Fig. 4a). Only 297 persons divided into 156 households took refuge outside of the Prefecture, mainly in the region of Tokyo (Fig. 4b). In total, 90% of the initial population lived out of the village during 7 years and, among them, 546 persons distributed across 288 households planned to return to Iitate by March 1, 2018. For these persons who sought to come back to the village, their household composition (mean: 1.8 persons) suggests that they almost exclusively correspond to couples without children.

Another question to investigate was the number of fatalities recorded during the 2011–2017 period, coinciding with the evacuation. In the Fukushima Prefecture, it was shown that more people died indirectly from the consequences (over a long period of time) than from these disasters themselves (i.e. the earthquake and the tsunami of March 2011). From the 4040 inhabitants of the Prefecture who lost life for reasons attributed to the catastrophe, according to the local newspaper, 1605 (39.7%) passed away following the natural disasters, while 2211 (54.7%) died from “stress or difficulties associated with the evacuation” [27]. On March 3, 2018, the headline of the local newspaper *Fukushima Minpō*’s frontpage was as follows: “at the heart of the shelter, more than 2211 fatalities directly resulting from stress”. However, we must point out that the controversies are still extremely tense on questions relating to the health consequences of the nuclear accident. For instance, one of the villagers of Iitate who agreed to answer our questions died of thyroid cancer in October 2021. Although a formal link is difficult to establish, we cannot fully exclude that there is a link between these cancers and the early exposition to radiation. The health commission in charge of evaluating the thyroid cancers that have developed in the region is under great pressure to interpret the results, which are likely showing an increase in the number of thyroid cancers in the sample of 370,000 children under the age of 18 (although the age limit also raises questions) at the time of the accident, i.e. 301 children in May 2022. Nevertheless, the health commission concludes, despite the anger of the inhabitants and other epidemiologists who were not part of the commission, that these cancers are the result of over-diagnosis due to the increased sophistication of medical equipment and a screening effect caused by systematic testing. This question therefore remains widely debated.

Another health effect that should not be neglected as it represents a factor explaining the increase in deaths, exceeding that associated with the natural mortality of an ageing population, although it is difficult to assess quantitatively, is depression and its consequences: alcoholism, overall physical inactivity, malnutrition (some isolated elderly people stop feeding themselves), suicide, etc. For

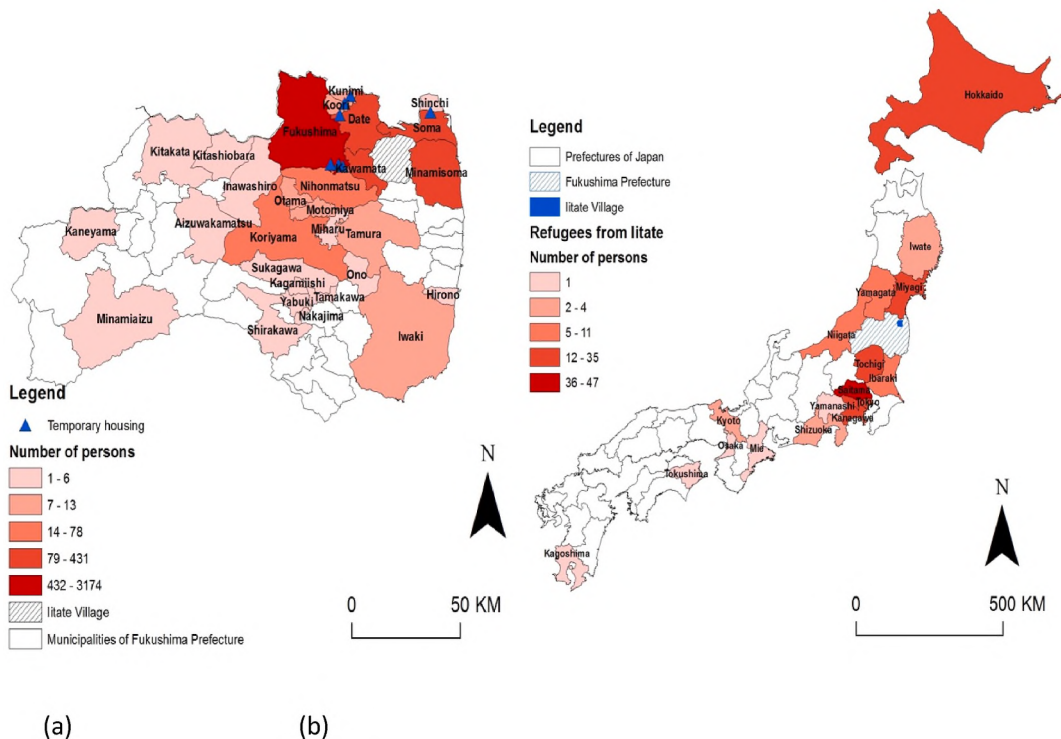


Fig. 4. Number and location of refugees originating from Iitate Village (a) in the Fukushima Prefecture and (b) elsewhere across Japan as of March 1, 2018. The location of the 9 temporary housing sites in the vicinity of Iitate Village is provided by the green triangle symbols in (a).

many villagers who had spent their entire lives in the countryside, it was difficult to adjust to urban living conditions for those who had to move to the city. Their new living environment were sometimes fatal to them.

### 3.4. Accommodation

The lifting of the compensatory allowances in April 2017 encouraged most of the elderly persons with low incomes to return to the small deserted village. Among the 4934 persons who sought refuge in the Fukushima Prefecture, 384 of them, distributed across 233 households, were accommodated in nine temporary housing sites that were definitively closed in March 2019. Although 363 persons (174 households; 8%) were relocated in public housing and 1053 persons (550 households) were resettled in private housing with the rent being supported by the government, nearly half of them (3119 persons spread across 1060 households; 49%) were hosted by relatives. Fifteen isolated elderly individuals lived in retirement homes. This raises the question of the meaning of “home”.

The lack of privacy and the life in crowded environments were associated with the economic dependence imposed by this type of community housing, with the need for this majority of farmers to purchase all their food products and necessities, without the possibility to produce or cultivate them in the vicinity of their new residence. On June 5, 2012, the regional newspaper *Seikei Tohoku* released the results of a survey conducted among 1539 inhabitants from Iitate. Only 39.8% of the interviewed agreed to reply (576 persons). Among the respondents, 445 (85.7%) were between 70 and 79 years of age, and 70% were men [28]. This questionnaire is extremely enlightening of the stressful situation to which the inhabitants were confronted. Question 17 asked the refugees which type of relationships they had with their family. 85.6% of them replied that their links had deteriorated after the catastrophe. Question 18 addressed the medication use, and 65.1% (375 persons) of the respondents stated that their drug consumption significantly increased. This questionnaire also provided information on the refugees’ plans to return to the village as of May 2012: 49.1% of the respondents declared that they did not plan to come back, whereas 21.6% of them wanted to go home after the general decrease of the radiation dose rates in the village below 1 mSv yr<sup>-1</sup>. This is crucial because, as previously stated, Iitate is a rural village, more than 75% of which is covered by forests that cannot be decontaminated. Without decontamination, it will be necessary to wait several more decades before radioactivity levels become acceptable again. Furthermore, the risk of contamination run-off from the forest to the decontaminated farmland persists, and dealing with this risk may require repeated decontamination campaigns in already remediated areas or the application of potassium fertilizers to prevent the plants from fixing the residual radiocesium. In addition, when the villagers were asked why they would not return to the village if they were allowed to do so, 82.7% of the respondents replied that they were not satisfied with the remediation works; 74% thought that they could not trust the reassuring message of the authorities; and 67.5% argued that they would not agree to return if it was impossible for them to restart an agricultural activity. In 2012, 63% of the respondents thought that it would not be possible for them to return to their homes even after decontamination. Furthermore, 57% of the interviewed estimated that it was not necessary to spend such a high budget on remediation (estimated to 300 billion yens or 2 billion US dollars when the survey was conducted in 2012). Despite this dominant opinion expressed as early as in 2012, Iitate was se-

lected to be a model municipality for re-opening, and an ambitious decontamination program was carried out in the village at an unprecedented scale [22].

### 3.5. Effectiveness of decontamination

Radiation doses measured on decontaminated soils measured on multiple occasions across Iitate Village varied between 0.3 and 0.4  $\mu\text{Sv h}^{-1}$  (i.e. 2.6–3.5  $\text{mSv yr}^{-1}$ ), which remains higher although of a similar magnitude than the mean annual dose due to the exposition to cosmic rays in Fukushima Prefecture comprised between 0.20 and 0.50  $\text{mSv yr}^{-1}$  or the total annual dose (including exposition to  $^{210}\text{Po}$  from fish products,  $^{222}\text{Rn}$  in houses, etc.) estimated to a mean of  $\sim 2 \text{ mSv yr}^{-1}$  [29]. Most decontamination works conducted in the village concentrated on the cropland in general, and on the paddy fields in particular, with the removal of the 5-cm top-soil layer concentrating the radionuclides (as demonstrated by Lepage et al. [30] for several soil profiles including five soil cores collected in Iitate). This generated very large quantities of decontamination waste (with storage sites across the landscape covering up to 2.6  $\text{km}^2$ ; Fig. 2), which the authorities plan to recycle in civil and road works for those material containing less than 8000  $\text{Bq kg}^{-1}$  of  $^{137}\text{Cs}$ , while the threshold value was fixed to 100  $\text{Bq kg}^{-1}$  before the FDNPP accident. The multiple campaigns of decontamination works could not fully remove the radioactive fallout deposited after the FDNPP accident. A monitoring campaign conducted in eight village houses in August 2017 showed that radioactive dose rates comprised between 0.15 and 0.4  $\mu\text{Sv h}^{-1}$  were found indoor on the floor, while those measured nearby the ceiling varied between 0.2 and 0.8  $\mu\text{Sv h}^{-1}$ . A previous campaign conducted in 2014 showed significantly higher rates, reaching up to 2  $\mu\text{Sv h}^{-1}$ . Whether this decrease is sufficient to allow the return the population remains debated by several groups of experts [31,32].

Furthermore, outside of the houses, the measured rates were higher than those measured indoor, with a mean of 0.6  $\mu\text{Sv h}^{-1}$  at the ground level [33]. The houses surrounded by the forest are exposed to the radiation of the woodland that could not be decontaminated, which is rather paradoxical for people who lived in harmony with nature in a village such as Iitate. In June 2017, measurements made on sap of the trees located nearby houses in Iitate showed that they contained 71.6  $\text{kBq kg}^{-1}$  of  $^{137}\text{Cs}$  in oaks and 19.6  $\text{kBq kg}^{-1}$  in cherry trees. In the area monitored, some estimations calculated that it will take a further 50 years before the mean radioactive dose rate drops below 1  $\text{mSv.yr}^{-1}$  [31], which is the mean annual rate internationally recognized as acceptable for the population in addition to the exposition to natural sources [34]. However, this threshold was increased to 20  $\text{mSv yr}^{-1}$  in the post-accident situation in the area located around the FDNPP, in accordance with the recommendations made by ICRP (International Commission on Radiological Protection).

### 3.6. Radionuclide redistribution in the landscape

The frequent occurrence of heavy rainfall in the region leads to episodes of extensive soil erosion and to the redistribution of sediment contaminated by radionuclides that strongly bind to soil particles across the landscape, mainly through the river network [35,36]. The radioactive contamination of the sediment transiting the Mano and Niida Rivers during floods has been systematically monitored since the accident (Fig. 5). The measurements clearly showed that, despite variations in the contamination levels from one campaign to the next, a very strong decrease (90%) of the  $^{137}\text{Cs}$  levels was observed throughout time. In 2017, the radiation dose rates emitted by the flood deposits in the river remained lower than 3  $\text{mSv yr}^{-1}$ , while it exceeded 7.6  $\text{mSv yr}^{-1}$  at most sites in 2011 and 2013. This very rapid and strong decrease is mainly attributed to the export of contaminated material during typhoons [7,37] as well as to the decontamination works [38,39]. The effectiveness of the clean-up efforts to decrease the contamination levels in the rivers is mainly explained because they were concentrated on cropland and paddy fields that were shown to provide the main source exposed to soil erosion in the region [40]. In contrast, forests provide a lower although continuous source of matter and radionuclides to the rivers [41], and the difficulty to decontaminate forested areas will likely make them the main perennial source of radioactivity to the rivers during the next several decades in this region. This different behaviour is well illustrated on the map corresponding to the situation of November 2017 (Fig. 5), with the measurement of low radiation ( $< 3 \text{ mSv yr}^{-1}$ ) in soils under decontaminated cropland and in inhabited areas, although higher rates may be found in nearby forests (exceeding 15  $\text{mSv yr}^{-1}$  in the southern part of Iitate Village). This is likely one of the main reasons justifying the reluctance of many inhabitants to return, as residential areas remain surrounded by contaminated forests, where no remediation action is scheduled.

### 3.7. The population's perception upon return

A survey conducted by Professor Itonaga's team in December 2017 [42] among 52 households composed of 195 persons helped to identify the main trends regarding the inhabitants' intentions upon their potential return to the village. Among the respondents, 11% planned to come back to comply with the recommendation of the authorities, and 18% reported to be forced to return because of financial difficulties associated with the subsidy removal. A further 20% of the interviewed chose not to return despite financial problems, and 47% had not decided yet.

The residents who decided to return to their homes in Iitate (17 households) were also interviewed on their residential options: 25% of them were able to renovate their house, 25% wanted to keep it in its current state, and 12% did not plan to renovate it because of a lack of physical or financial means. However, most buildings in Japan are constructed with natural and therefore perishable materials (wood, straw, etc.) The subtropical climate to which Japan is exposed results in hot and humid conditions in summer, which may significantly damage the buildings requiring frequent renovations. Many of these buildings that remained vacant during seven years were in a dilapidated state. Furthermore, the animals including wild boars, rodents and monkeys had reconquered these inhabited areas. Accordingly, the households who did not plan to rehabilitate their house (37%) will likely live in uncertain and unstable conditions.

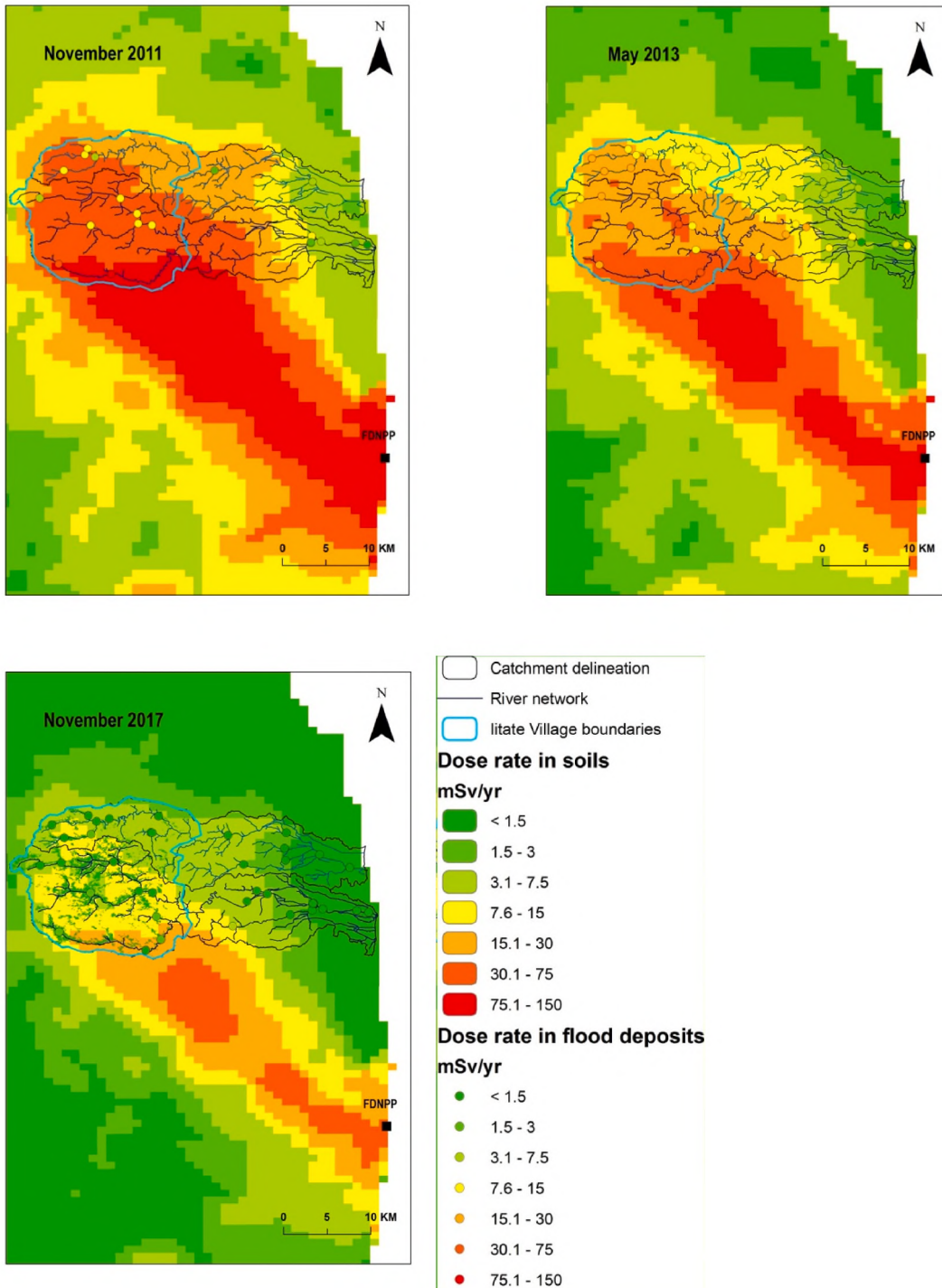


Fig. 5. Evolution of radioactive dose rates measured in soils (background map) and in flood sediment deposits (coloured dots) in the rivers of Iitate Village in November 2011, May 2013 and November 2017.

The main reason (69%) why the inhabitants refused to return to the village is that they will not have the opportunity to live with their children and grand-children anymore, as they do not plan to come back. By July 2018, only 27 children (between 6 and 15 years of age) attended school in Iitate, while they were ~400 children before the accident. In 2021, this number has fallen further to 23 pupils. The town hall officers having children that were interviewed in the framework of the current research did not live in the village and their children did not attend school in Iitate, which underlines the complexity of the situation, including for the municipal officers. Many parents and grand-parents underlined the difficulty to move children and force them to change to another school more

than seven years after they left the village. Furthermore, this trend, far from being reversed, has only become more pronounced. The government offers financial support to those willing to develop a business in the sector, but the incentives are clearly not considered to be sufficient.

A non-negligible proportion of villagers justified their decision not to return through the rejection of living in a place where the mountains and the forests remain contaminated (64%). This is an important point in a village where 74% of the surface area is occupied by forests. A similar percentage of persons (65%) was reluctant to return because of the expansion of wild terrains and animals in the village. Another problem was the lack of shops, health facilities and other infrastructures for 62% of the respondents who decided not to come back. Furthermore, 53% of the people estimated that the ambient radioactivity levels remained too high, 51% mentioned the difficulties to maintain an agricultural activity and 51% were worried about the potential future health impacts of living in the village. Among the interviewed who refused to return, a significant proportion of people (47%) decided not to come back because of the (contaminated) waste disposal frecon bags strewn across the village. A considerable number of these bags have been removed to the three storage centres near the power plant, but many of them were still many scattered across agricultural landscapes. In 2022, 2.1 km<sup>2</sup> of land remained occupied by these big bags in the village of Iitate (Fig. 2). Other minor reasons (mentioned by less than 40% of the respondents) for not returning were the impossibility to consume mushrooms and other products from the mountains, the absence of neighbours and the weakening of community relationships.

### 3.8. Main reactions and difficulties of the refugees

Several citizens defended their rights in court, like the family of Mr. Okubo, a 102-year-old man who killed himself when he received the order to evacuate his hometown of Iitate. In February 2018, the Fukushima District Court ordered the company that operated the FDNPP (Tokyo Electric Power Company Holdings Inc.), to pay compensation for the pain caused by this suicide. Other villagers organized themselves in associations (e.g. *Iitate Network*, *Resurrection of Fukushima*) to measure the radioactivity in the environment surrounding them or to provide services and assistance to the community. During the evacuation, they rented fields in the vicinity of their temporary buildings to maintain collective agricultural activities.

Among the refugees interviewed, many mentioned the impossibility for them to move to another village in the countryside. Those who were born in Iitate know “where the water flows and where the wind blows”. Often, the husband native of Iitate convinced his wife to return to the village. “The most difficult is not to be able to touch the vegetation around” said the wife of a farmer, native from Nihonmatsu, who followed her husband when returning to Iitate although she would have preferred to continue living elsewhere.

Despite the difficulties to restart those economic activities related to the exploitation of land and forest resources, several inhabitants came up with original solutions. Collective greenhouses were installed, with soil imported from the Fukushima City with “only 100 Bq kg<sup>-1</sup> of <sup>137</sup>Cs” to cultivate safe leaf vegetables. In experimental fields, the cultivation of tobacco or sorghum is tested. The cultivation of flowers – and those from Iitate were formerly renowned in the entire region – is also envisaged, as “we do not eat flowers” said a farmer who has now retired. Restarting an activity is easier for those few people working in the economic sectors that do not necessarily directly depend on the local land resources, like that family that reopened a noodle (*udon*) restaurant, the village's only restaurant in 2018.

Practical difficulties are also associated with the old age of those people who returned, who fear to lose their mobility when they will not be able to drive anymore. The previous staff refused to return to work at the only retirement home of the village (*Iitate Home*), and medical consultations are only possible at a dispensary during a few hours two days per week. The previous villagers of Iitate are often stigmatized by other citizens, as they are supposed to “have received plenty of public money without doing anything”. However, as a resident who returned to the village mentioned, “living in a safe landscape cannot be bought with money”.

### 3.9. Main reactions of the municipality

The village hall officers are confronted by the accelerating age profile of the resident population. Although ~3000 persons commuted every day to work in Iitate by July 2018, almost all the 750 inhabitants who stayed day and night in the village were older than 65. Most farmers sold their agricultural equipment and many of them were too old and did not have the physical means anymore to maintain their diverse farming activities associating cultivation and cattle breeding. Some landlords devoted their fields to the installation of solar panels (Fig. 2) with the authorization of the village hall to convert land to this end. Others have rented their land to the municipality for the same use as Mr Masao Uchibori, the governor of Fukushima Prefecture is focused on making it [green] energy self-sufficient by 2028 so solar panels are very popular in the area and an increasing surface area is devoted to them. In 2022, 0.9 km<sup>2</sup> of land in Iitate was covered by solar panels. However, the municipality does not want to further extent the surface covered with solar panels and would like to achieve the recovery of farming activities in Iitate instead, with the support of the agricultural municipal department.

Before the accident, the budget of the municipality was 36 million USD. To support the reopening of the village, the Japanese central government attributed an additional budget of 180 million USD to the municipality in 2017, and 90 million in 2018. This likely demonstrates the major role played by Mr. Norio Kanno, who has been the mayor of the village for two decades, for reopening the village to the inhabitants. The local authorities mainly spent the budget granted by the Japanese government through the renovation of the village party hall that may accommodate more than 200 guests, the construction of a new town hall building to accommodate the municipal services, multi-sport competition areas, a new school and a shopping mall (*madeikan*) where local food products and necessities can be bought. Until 2022 a device was also available to measure the radioactivity in food products. Two convenience stores reopened in the village, even if they close early on evenings. One of them had to close due to lack of customers. Indeed, despite these massive public investments, very few economic activities had restarted in the village by 2022 and the population is declining

despite government proposals to fund people to repopulate the area. Only 192 individuals (or 97 households) responded to this call in January 2022.

#### 4. Conclusions

Despite the significant decrease of radioactive dose rates in soils, vegetation and rivers observed between 2011 and 2017, radionuclides in general, and radiocesium in particular, are still found in some parts of the environment of Iitate. In addition, the residents were suddenly confronted with a situation that was truly unknown to them until 2011. They are either on the lookout of the slightest Becquerel or, on the contrary, they do not want to hear about it anymore. It is difficult for them to know on which values to rely, in a context where the rules and the thresholds have been revised several times. Furthermore, despite the considerable financial effort to decontaminate the cultivated land and rebuild the municipal infrastructures, the resumption of economic activities remains a real challenge as the village strongly relied on its natural resources with the dominance of those activities associated with agriculture and forestry before the accident. The lifting of the evacuation order in the contaminated areas of the Fukushima Prefecture threw the population in great disarray. The inhabitants had been confronted to difficult choices during the last 10 years. This excessive stress that sometimes led people to commit suicide may be attributed to the difficulties associated with the prolonged life in temporary housing facilities, to the enforced nature of the return, or the disillusionment following the resettlement. Those families who lived with three generations under the same roof, with the younger taking care of their elderly parents, were dislocated, and the elder are often actually left alone without family or close neighbor. There is no evidence of a mass return of refugees to their home villages, despite the cutting of shelter subsidies and payment for return. These measures do not seem to provide sufficient incentives to boost the repopulation of the region. The current development does not seem to show any drastic growth. Five years after the reopening of the village, less than 20% of the population has returned, which does not appear very promising less than one year before the planned reopening of the difficult-to-return zone. The interdisciplinary analysis of this case study allows us to highlight the complexity of the obstacles encountered by a reopening policy that advocates a tendency to learn how to “live with radioactivity” by only responding point by point to the individual problems encountered without considering the whole picture. Furthermore, the decontamination of the cultivated land, while allowing most returnees to restart their activity, will not allow them to exploit and enjoy the forests as they did before, as they still represent a potential perennial source of radioactive contamination for the years to come.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Data availability

Data will be made available on request.

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