Chapter 2

Long-Term Mass Displacements—The Main Demographic Consequence of Nuclear Disasters?

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Abstract Human history has witnessed several major disasters that have affected the economic, social and environmental conditions of their respective regions. The nuclear disaster of Chernobyl (1986, Ukraine, that time the Soviet Union) and Fukushima (2011, Japan) appears to be the most significant disasters in terms of negative outcomes produced for their population over a long time. Despite this, the analysis of the socio-economic outcomes of these disasters has attracted much less scientific attention than health or radiation-related issues (UNDP 2002a; Lehman and Wadsworth 2009, 2011). Although nuclear accidents are deemed to be rare events, the Fukushima disaster occurred only 25 years after Chernobyl. These disasters highlighted the need for a detailed long-term socio-economic analysis of these accidents to acquire sufficient knowledge to be applied when considering new construction sites for nuclear power facilities (Lehman and Wadsworth 2011). This chapter focuses on the problem of permanent resettlement resulting from nuclear disasters and its effects on regional demographic trajectories and spatial shifts. Based on the results of this study we argue that mass displacement after a nuclear disaster rather than the radiation itself has a much more significant impact on deteriorating health, natural reproduction and economic performance of the affected population. Furthermore, given the differences in radio-ecological conditions, reconstruction policy and the time framework, Fukushima may demonstrate demographic consequences that are different from the Chernobyl case.

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D. Karácsonyi et al. (eds.), *The Demography of Disasters*,
https://doi.org/10.1007/978-3-030-49920-4_2

Keywords Chernobyl · Fukushima · Radiation exposure · Mass displacement · Spatial-demographic consequences · Urbanisation

2.1 Introduction

Human history has witnessed several major disasters that have affected the economic, social and environmental conditions of their respective regions. The nuclear disaster of Chernobyl (1986, Ukraine, that time the Soviet Union) and Fukushima (2011, Japan) appears to be the most significant disasters in terms of negative outcomes produced for their population over a long time. Despite this, the analysis of the socio-economic outcomes of these disasters has attracted much less scientific attention than health or radiation-related issues (UNDP 2002a; Lehman and Wadsworth 2009, 2011). Although nuclear accidents are deemed to be rare events, the Fukushima disaster occurred only 25 years after Chernobyl. These disasters highlighted the need for a detailed long-term socio-economic analysis of these accidents to acquire sufficient knowledge to be applied when considering new construction sites for nuclear power facilities (Lehman and Wadsworth 2011). This chapter focuses on the problem of permanent resettlement resulting from nuclear disasters and its effects on regional demographic trajectories and spatial shifts, while Chap. 11 studies the community involvement during and after evacuation and resettlement process in two nuclear disaster cases.

At first glance, Chernobyl and Fukushima may not be comparable, given the tremendous difference in their socio-economic conditions. The geographic, cultural and socio-economic distances can hardly be greater between any two points on Earth than between Japan during the 2010s and the Soviet Union during the 1980s. However, according to Oliver-Smith (2013), geographically and culturally distanced societies present analogous issues during similar disaster events. For instance, Chernobyl and Fukushima both deployed similar policies to manage mass population displacements. An initial emergency evacuation was followed by organised or spontaneous resettlement of the vulnerable population to avoid further radiation risks. The radiation threat should be considered as both a rapid-onset disaster because of the urgent need of evacuation and a slow-onset disaster because of its long-lasting effect, making a return difficult or even impossible over time.

The Chernobyl and Fukushima disasters illustrate how long-term emergency mass displacement triggers demographic shifts. They are not the largest evacuations in human history; however, they are among the largest permanent resettlements in peacetime caused by a previously unforeseen, unplanned situation.

Geographically detailed data is necessary to understand spatial turbulences caused by mass displacement after the Fukushima and Chernobyl disasters. In this study, data series spanning over three decades was used to provide insights into long-term population shifts after Chernobyl based on census populations. In the Fukushima case, mobile phone location data was used alongside the census data in spatially fine-scale to interpret population changes. This provides short-term but spatially and structurally detailed data about the effect of mass displacement. This detail is used to explore the difference between de facto and de jure populations which could be significant during the post-disaster evacuation phases. Thus, the findings derived by analysing the two data sets can complement each other.

The core analysis used Geographic Information Systems (GIS) based on detailed spatial units that included the territories of Belarus, Ukraine, nine western provinces of Russia and the Tohoku area located on the northern part of Honshu the main island of Japan.

2.2 Spatial Demography Impact of Mass Displacements

Relocation or resettlement of disaster-stricken populations is a common strategy applied within disaster mitigation policy (Oliver-Smith 1996). Generally speaking, displacement is the impact of a disaster which results from the vulnerability of people to shocks or stresses, compelling them to relocate just for survival (Lavell and Ginnetti 2013). Migration has always been one of the most important survival strategies adopted by people facing natural hazards or human-caused disasters (Hugo 2008).

Along with the demographic loss (death tolls and injuries) caused directly during the disaster event, it could be argued that population displacement can be viewed as the other demographic consequence of a disaster. Mass displacement also has direct effects such as death, injury, disease (Robinson 2003) and could cause social insecurity and disrupted life prospects. Displacement, the demographic and social impacts of which are oftentimes underestimated, can be an even more significant consequence of a disaster than the direct death toll.

A large number of studies on the health and natural reproduction consequences of Chernobyl mostly explained the demographic losses resulting exclusively from radiation. However, they often neglected the impact of mass displacement itself. In the 30-year period after the Chernobyl disaster, the number of indirect victims (deaths caused by cancer, cardiovascular diseases, etc.) is still widely debated (TORCH 2006, 2016; Peplow 2006 or see Greenpeace 2006) because the linkage between radiation and cancer cannot be proven due to its stochastic occurrence within the population (see WHO 2006, 2016; IAEA-WHO-UNDP 2005; IAEA 2006). The only two exceptions are the increase of thyroid cancer cases among those who were young and adolescent during the disaster (4000 cases by 2002 according to IAEA 2006; OECD 2002) and leukaemia that occurred after 1990 among former on-site emergency clean-up workers (*likvidator*s) (Hatch et al. 2005; Balonov et al. 2010; European Commission 2011).

Despite there being a large number of health studies, science still lacks full, final and objective information about the medical and biological consequences of Chernobyl (UNDP 2002b; Hatch et al. 2005; Baverstock and Wiliams 2006 and others). Studies investigating health issues resulting from nuclear disasters are limited as a result of the lapse between initial exposure and the presentation of symptoms. This lapse can be as long as 10–20 years after the accident (Lehmann and Wadsworth 2011). Extreme variations in individual exposure causing tragic outcomes are impossible to follow up over long periods of time when analysing large populations. Considering also that the screening effect inflates health statistics when populations in the affected area experience intense health control that identifies illnesses which would otherwise never be explored (UNDP 2002a). It is estimated that the indirect death toll varies from 4,000 (Peplow 2006; IAEA 2006) to 60,000 (TORCH 2006).

Studies on natural population reproduction trends often did not prove a mathematical correlation with radiation exposure after Chernobyl (IAEA 2006). According to Linge et al. (1997), the birth and death rates during 1986–1996 were similar to those in non-affected areas. However, their investigations were based on the populations of larger regions, potentially cloaking extreme local variations. Other studies (see Omelianets et al. 1988, 2016; Lakiza-Sachuk et al. 1994; Voloshin et al. 1996; Rolevich et al. 1996) claim radiation exposure temporarily decreased birth rates immediately after the accident in the affected areas. However, this decrease can be explained by the disinclination to bear children during the uncertain life prospects that eventuated post-Chernobyl resettlement (Abbott et al. 2006). It can also be explained by the fear of the effect of radiation exposure during pregnancy instead of the presence of radiation effect itself (Jaworowski 2010). This view is supported by Lehmann and Wadsworth (2011), who states that contamination levels have little or no influence on fertility, marriage behaviour and education performance. This is further illustrated by a lack of statistical correlation between radiation exposure and chromosome aberrations or birth defects (OECD 2002; Baverstock and Williams 2006). According to the research by Rolevich et al. (1996), Libanova (2007), and Mesle and Poniakina (2012), there is higher mortality among people living in the affected areas. However, the increase in mortality cannot be explained by the radiation alone (Shestopalov et al. 1996). The increase of psychological problems caused by the social disruption during the resettlement presented significant health consequences (Brenot et al. 2000; Balonov et al. 2010). Furthermore, as younger generations migrate out of the disaster area (Voloshin et al. 1996; Omelianets et al. 2016), a statistical consequence is an increase in mortality simply because of the shift in age structures towards aging.

Although approaches cited in the previous paragraph often appear opposing, it is very important to stress that even if the results are biased that the majority of scientists agree that the Chernobyl disaster as a whole played a significant role in the deteriorating natural reproduction during the 1990s. Natural reproduction decline was also related to general socio-economic decay during and after the collapse of the Soviet Union, such as growing poverty and unemployment, increasing alcoholism and poorer medical services (Ioffe 2007; Baranovski 2010; Marples 1993, 1996 and others). As such, it is hard to distinguish the two separate effects.

Out of the health and natural reproduction studies, only a few research focuses on wider demographic consequences. Lehmann and Wadsworth (2011) underline the lower market performance of those who were exposed to higher radiation. This effect however is based on the self-assessment of their own health condition as poor, not directly from the radiation. These people also have lower mobility. Abbott et al. (2006) approached the socio-economic effect of Chernobyl through the view of risk and uncertainty when analysing poor economic circumstances. The most significant documentation on Chernobyl-related social and economic issues has been launched by UNDP (2002a as well as 2002b, c), calling for the need of a new developmental approach. According to this document, a holistic approach integrating health, radio-ecology and economic aspects is needed to fully understand Chernobyl.

Based on the literature, we argue that the main direct negative demographic impact of Chernobyl was not the number of deaths or illnesses, not even the psychological consequences (see Rumyantseva et al. 1996; Lochard 1996; Brenot et al. 2000 or Jaworowski 2010) but the urgent need for the resettlement of ten-hundred thousands of people because of the long-term radiation threat. This resettlement resulted in the distortion of everyday life and changed natural reproduction due to post-disaster uncertainty and social insecurity. Post-Chernobyl and post-Fukushima displacement caused much more significant demographic shifts than the radiation itself. Thus, the effect of permanent mass displacement should be the focus when explaining demographic outcomes.

Permanent resettlements resulting from disasters are relatively rare events hence less discussed in the general disaster literature (Oliver-Smith 2013) despite having a long-term demographic impact. Flooding, earthquakes and volcano eruption can cause large evacuations but rarely long-term displacements. However, long-term demographic shifts can be caused by temporary resettlement during or following a natural hazard event as well as it discussed in Chaps. 5 and 6. If a displacement caused by natural hazards becomes permanent, this indicates failed remediation policies (Oliver-Smith 2013). Yet there is no clear distinction between temporary (short-term) and permanent (long-term) displacement in the literature. As previously identified, such a distinction can often be policy induced. In Fukushima, policy documents refer to evacuees as temporarily displaced people to maintain hope for a return and to keep communities together (see Chap. 11). A displacement can last for years, even for life and still, it is described as “temporary”.

Furthermore, mass displacement in practice often does not solve the problem caused by the disaster itself but generates new challenges (Robinson 2003). In many cases, the resettlement results in a secondary disaster (Oliver-Smith 2013), which will further produce serious consequences in a badly planned or unplanned resettlement (Cernea 2004). At a new location, an appropriate settlement design, housing, services and an economic base need to be built to enable people to revitalise itself and achieve adequate levels of resilience (Oliver-Smith 2009). These challenges caused by mass displacement should also be considered as integral parts of the Chernobyl and Fukushima disasters. We argue that the lack of a holistic view led to an overemphasis of health risks by radiation which neglected the effect of the main consequence of nuclear disasters: permanent mass displacement and the uncertainties and disturbances caused by it.

2.3 Changing Region and Shifting People by Nuclear Disaster

Nuclear radiation levels significantly determine evacuation and resettlement policies rather than an understanding of the key findings from the literature summarised in the previous section whereby radiation exposure itself has a minor effect directly on general demographic trends. The radiation is not a homogenous phenomenon, it has changing levels, composition and characteristics over time, and thus, the evacuation and resettlement measures follow this change to cope with the changing radiation threat. Based on this, certain radiation phases can be distinguished over time which results in an adjustment of resettlement policies following the disaster. Thus, the level of radiation and change in population trends are strongly interrelated through the resettlement policies rather than through health consequences. There are important differences between Fukushima and Chernobyl in terms of the composition of emitted isotopes resulting in the slightly different evacuation and resettlement policies. In the following section, these different and changing characteristics of radiation will be presented to better understand evacuation and resettlement measures in the two cases.

2.3.1 The Chernobyl Case

In 1986, at the Chernobyl nuclear power station, the operation failure and poor engineering design that led to an explosion in Unit 4 within the reactor core[1] which damaged the shielding, released 3–4% (5–6 tonnes) of fragmented nuclear fuel[2] into the surrounding environment and was followed by a ten-day graphite fire. The accident caused a release of fission products into the environment, which was the

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[1] A runaway nuclear chain reaction caused a steam blast within the reactor vessel that was followed by a larger chemical explosion seconds later either by hydrogen–air or carbon-monoxide–air ignition. The magnitude of the reactor core explosion and resulting release of fuel was unprecedented in the history of nuclear accidents, e.g. in Fukushima, in Three Mile Island or Windscale.

[2] The reactor that exploded in Chernobyl used low-enriched uranium-oxide fuel with 2% ^{235}U and 98% ^{238}U. The spent fuel still consists of ~96% ^{238}U as well as <1% ^{235}U, ^{236}U and ~1% transmuted isotopes such as ^{239}Pu, ^{240}Pu and other trans-uranium elements, which emit alpha radiation (high energy ^{4}He nuclei) when decaying. These isotopes are harmful when inhaled (causing lung cancer) or ingested in small quantities, but human skin stops alpha radiation.

On the other hand, during normal reactor operation, most of the fissile isotopes (82% of ^{235}U, 62–73% of ^{239}Pu and 72% of ^{241}Pu), representing ~2 to 3% of the total fuel mass, will undergo fission when capturing a neutron instead of transmutation, producing short and medium half-life products such as ^{131}I (beta emitter), ^{90}Sr (beta emitter) and ^{137}Cs (beta and gamma emitter, a decay product of very short-lived ^{137}Xe). Although the total amount of such material released was less than 0.5 kg for ^{131}I and less than 25 kg for ^{137}Cs, it represents a significant danger because beta radiation (emission of high energy electrons or positrons) and especially gamma radiation (high energy photons) can penetrate human tissue, making it hazardous even without actual intake of the isotope.

principal source of high initial effective doses[3] in large areas that extended outside of the Soviet Union. However, the isotopes with a short half-life[4] rapidly decay (UNDP 2002b), such as ^{131}I (Iodine-131) which was found to be the root cause of increased thyroid cancer cases after the disaster. One year after the accident, the total effective dose levels dropped to 2% of what it had been at the time of the accident, and after two years, it had fallen to 1% (IAEA 2006). Among those isotopes that remained over long time,[5] the largest area (Table 2.1) was polluted by ^{137}Cs (Caesium-137), which is the predominant source of the remaining dose levels causing a health risk since the third year after the disaster.[6]

After the Chernobyl disaster, two solutions—or their combination—were employed to mitigate the effects on the local population: radiological decontamination and the resettlement of people to non-contaminated areas. Establishing new homes for resettlement seemed clearly more expensive but was also the much safer solution (Tykhyi 1998).

The most severely contaminated area was the surroundings of the power plant with a radius of 30 km, the so-called "Exclusion Zone" including the plant itself, as well Pripyat city with 50 thousand people (1986), Chernobyl town and several villages. The total population of this area (116 thousand people) (Table 2.1) was evacuated during 1986–1987 (UNSCEAR 2000; IAEA 2006) mostly to large cities such as Kiev, Minsk, Chernihiv, Zhytomyr (Lehmann and Wadsworth 2011), was their communities quickly dissolved (Voloshin et al. 1996; IOM 1997). Many of them were settled later in Slavutich, a town established in 1988 for evacuees from Pripyat (Voloshin et al. 1996; Mesle and Poniakina 2012). The "Exclusion Zone" remained closed even until today. It is only opened in special cases such as for a very small number elderly and voluntary repatriates (*samosyoli*) (Lochard 1996).

The concentric zoning was adjusted in 1988 based on the survey results of ^{137}Cs surface activity levels[7] (Fig. 2.1). At the same time, the definition of "Contaminated Area" (^{137}Cs activity is above 37 kBq/m^2),[8] as well as an additional "Resettlement

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[3] Effective dose is measured in Sieverts (Sv) defined as the total amount of energy from ionizing radiation absorbed by the human body, measured in J/kg.

[4] Half-life of these released isotopes: ^{132}Te 78 h, ^{133}Xe 5 days, ^{131}I 8 days. This means that half of the initial amount of each isotope present will have decayed over this time. E.g. ^{131}I 100% on day 1, 50% on day 8, 25% on day 16, 12.5% on day 24 and so on.

[5] ^{137}Cs has a half-life of 30 years, ^{90}Sr 29 years, ^{239}Pu 24 thousand years and ^{240}Pu 6.5 thousand years.

[6] ^{137}Cs is highly soluble in water. Thus, its salts are more easily integrated into parts of the food chain and easily adsorbed in human soft tissues (particularly the cardiovascular system). Its biological half-life is only 2 months; thus, it is rapidly excreted on intake. Unlike ^{137}Cs, ^{90}Sr has a biological half-life of 20 years and absorbed into the bones. This prolonged exposure caused leukaemia amongst clean-up workers in the evacuation zone (Balonov et al. 2010).

[7] Activity, given in becquerels (Bq) or curies (Ci), is a measure of the total number of nuclear decays per second occurring in a certain quantity of radioactive substance. Activity by weight of radioactive material can be expressed as Bq/g, and average surface activity level can be expressed as kBq/m^2 or Ci/km^2. $1 \text{ Ci} = 3.7 \times 10^{10}$ Bq.

[8] Staying in an area where ^{137}Cs activity is 37 kBq/m^2 is equivalent to receiving an effective dose of 0.25 μSv per hour (the human body absorbs ~0.25×10^{-6} J energy per kg every hour from beta

Table 2.1 Zoning in Chernobyl, compared to Fukushima (Based on IAEA 2006; UNDP 2002a)

Level of contamination (1986/2011)	Zoning in Chernobyl	Size of affected territory by Chernobyl (1986)	Population living in Chernobyl affected area (thousand people) (1986/2010)	Size of affected territory by Fukushima (2011)
$Cs^{137} > 37$ kBq/m^2 $Cs^{137} > 1$ Ci/km^2 or >0.25 μSV/h	Contaminated Area/zone of radiation monitoring	191,560 km^2 total, 57,900 km^2 in Russia 46,500 km^2 in Belarus 41,900 km^2 in Ukraine 45,260 km^2 in other countries	6000/5000	
$Cs^{137} > 185$ kBq/m^2 $Cs^{137} > 5$ Ci/km^2 or >1 μSV/h	Zone of voluntary/guaranteed resettlement	29,000 km^2 total, 16,000 km^2 in Belarus 8,000 km^2 in Russia 5,000 km^2 in Ukraine		1,700 km^2
$Cs^{137} > 555$ kBq/m^2 $Cs^{137} > 15$ Ci/km^2 or >4 μSV/h	Zone of (mandatory/obligatory) resettlement	6,400 km^2 in Belarus 2,440 km^2 in Russia 1,500 km^2 in Ukraine	400/200	
Various levels	Exclusion zone	2,230 km^2 in Ukraine 2,162 km^2 in Belarus	116/0	Initially 600 km^2, reduced to 207 km^2 (2018)

Zone" (^{137}Cs activity above 555 kBq/m^2) was established (UNSCEAR 2000; IAEA 2006). The latter was subject to further obligatory evacuation and resettlement. The general position was that in the mainly rural areas where healthy foodstuffs could no longer be produced in agriculture, it was futile to compel the local population to stay. Decontamination efforts were suspended in those areas where the local population

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and gamma-decay). This effective dose over one day is equivalent to one dental X-ray check (which is ~5 μSv), or eating 2.5 bananas every hour (0.1 μSv) (Banana contains naturally occurring ^{40} K). During a standard air flight, the average dose is 2–4 μSv/h, while during a flight by Concorde, it was 9–10 μSv/h.

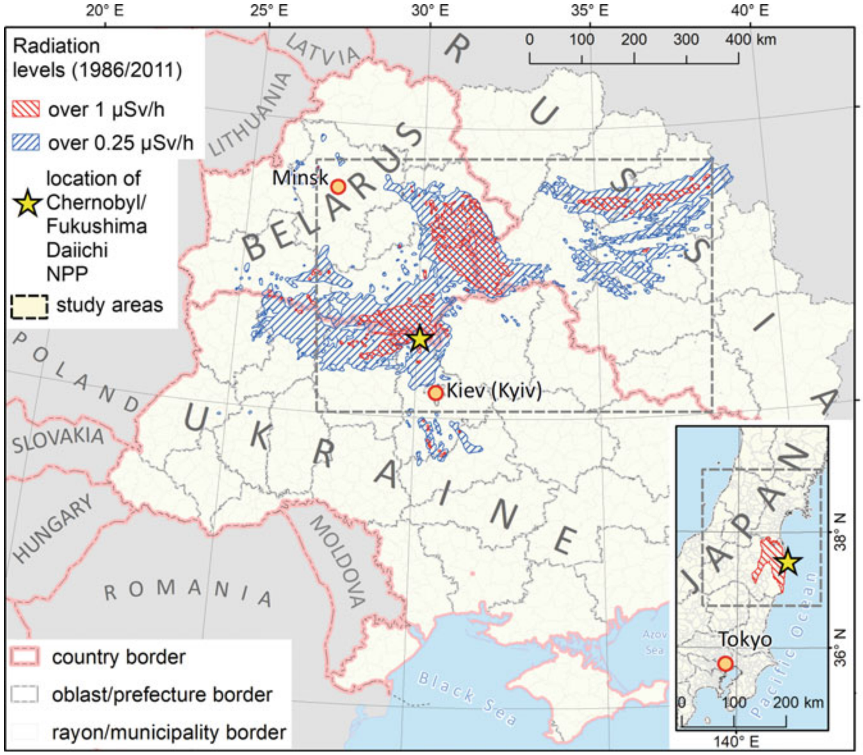

Fig. 2.1 Affected areas by Chernobyl and Fukushima disasters (Author and cartography by Karácsonyi, ^{137}Cs contamination data by USCEAR 2000)

would receive a 70-year ("lifetime") extra effective dose[9] of at least 350 mSv (milli-Sievert) (Malko 1998), and residents of these areas, 220 thousand people, were also resettled to non-contaminated areas at the very beginning of the 1990s (UNSCEAR 2000; IAEA 2006). The 350 mSv concept became the subject of sharp criticism (Malko 1998) given the impossibility of determining the dosage for each person leading to questioning the calculations made for the resident population as a whole. This inevitably caused mistrust among people.

Majority of subsequent resettlements happened in Belarus, until 1996, when these measures were finalised there. This second wave was followed by a more moderate one during the late 1990s only in Ukraine by the resettlement of additional 50 thousand people until 2005 when the process was officially ended there as well (IAEA 2006).

There are no exact records available on the total number of people that moved in the three affected countries, the numbers vary between 300 and 500 thousand which

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[9] The average daily global background dose on the Earth's surface is 100 µSv which means, people who exposed 350 mSv extra dose throughout their lifetime, they exposed to at least ~10% higher background radiation caused by Chernobyl.

Table 2.2 Estimated number of people affected by post-Chernobyl resettlement/evacuation by country and by time frame (Based on UNDP 2002a; UN 2002; IOM 1997; UNSCEAR 2000; IAEA 2006; Lehmann 2011)

Resettled/evacuated	The entire time period (1986–2005)	1986–1987	1990–1996	1996–2005
By country	163,000 Ukraine (UNDP) 135,000 Belarus (UNDP) 52,000 Russia (UNDP)	24,000 Belarus (IOM) (the rest in Ukraine)	131,000 Belarus (IOM) 52,000 Russia (UNDP) (the rest in Ukraine)	50,000 Ukraine (IAEA)
Ukraine, Belarus, Russia total	326,000 (IAEA) 350,000 (UNDP) 492,000 (UN)	115,000 (UNSCEAR/IEA) 120,000 (Lehmann)	220,000 (UNSCEAR/IEA)	

includes voluntary resettlement as well (326,000—IAEA 2006; 350,000—UNDP 2002a; IAEA-WHO-UNDP 2005; 492,000—UN 2002) (Table 2.2). Outside the "Resettlement Zone", in areas with ^{137}Cs activity levels between 185 and 555 kBq/m^2, people were free to decide to stay or to leave. A legal act provided dwellings for those displaced. In these areas, economic restrictions, such as in agriculture, were coupled with increased health and food control.

It was reported that around 5–6 million people (IAEA-WHO-UNDP 2005; Balonov et al. 2010) lived in "Contaminated Areas" as of 2005, and still 200 thousand (IAEA 2006; Balonov et al. 2010) resided in the "Resettlement Zone". We estimate that by 2010, approximately 5 million people still lived in areas where radiation exposure exceeded 0.25 μSv/h (^{137}Cs activity over 37 kBq/m^2) in 1986 (Table 2.1). As a result of the natural isotope decay and purification processes, the exposure significantly decreased from 1986 which allowed the zoning to be readjusted (IOM 1997; UNDP 2002b). The only exception is the closer area surrounding the accident site in the "Exclusion Zone". It was polluted by ^{241}Pu which has a relative short half-life and decaying into ^{241}Am, a much more radio-toxic isotope.[10]

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[10] ^{241}Pu (a beta emitter) has a relatively short half-life (14 years), but its decay product ^{241}Am (an alpha and gamma emitter, half-life: 400 years) is much more radio-toxic. In contrast to other isotopes, there will be a natural increase in ^{241}Am activity over time. By 2058, the ^{241}Am activity will surpass the cumulative activity of all trans-uranium isotopes (UNDP 2002b) and reach its maximum concentration a hundred years after the accident (IAEA 2006). Because of its longer half-life, it will surpass the activity of ^{137}Cs 300 years after the accident, significantly slowing the natural purification within the "Exclusion Zone".

2.3.2 *Fukushima—The Accident, Zoning, Regulation, Consequences*

On 11 March 2011, the Great East Japan Earthquake (moment magnitude of 9.0) and subsequent huge tsunami hit the two nuclear power plants (Fukushima I and II or Fukushima Daiichi and Daini) in Fukushima Prefecture. According to the official government report (NAIIC 2012), all nuclear reactors stopped safely after the earthquake. However, soon after the earthquake water from the tsunami wave, which was higher than 14 m, flowed into the nuclear power plants over the seawall. At the Fukushima I nuclear power plant, four out of six nuclear reactors lost their cooling functions because all the emergency backup generators were destroyed or drained by the huge tsunami. Three nuclear reactors then experienced a nuclear meltdown, and hydrogen–air chemical explosions occurred outside the reactor vessel.

Due to the accident, a large amount of fission products, mainly ^{131}I, ^{134}Cs and ^{137}Cs, were released into the ocean and the atmosphere. The total amount of radioactive materials released was estimated to be 770,000 TBq by the Nuclear and Industrial Safety Agency and 570,000 TBq by the Nuclear Safety Commission (TEPCO 2011). Steinhauser et al. (2014) reported around 5,300,000 TBq in case of Chernobyl and 520,000 TBq in case of Fukushima. These numbers mean that the long-lasting effect of Fukushima is significantly lower than Chernobyl; however, the threat during the accident was almost on a similar scale. In particular, radioactive materials spreading in a north-western direction from the nuclear power plant made a huge geographic area highly contaminated. During the evening of 11th March, the Japanese government declared a nuclear emergency. On the same day, an evacuation order was initially issued to the area within a 3 km radius of the power plant, but this was increased to a 30 km radius until 15th March. Group evacuations of residents were carried out by municipality offices on the morning of 12th March. At the same time, many residents who could drive cars evacuated individually.

After the nuclear accident, government organisations started to measure accurate aerial radiation levels with aeroplanes, helicopters and cars. Also, radiation levels were monitored continuously by at least 1600 monitoring posts installed across Fukushima Prefecture. The geographical extent of the highly contaminated area in Fukushima is limited compared to the Chernobyl case (Imanaka 2016; Steinhauser et al. 2014). However, ^{137}Cs is expected to remain for a long time (Fig. 2.1).

In April 2012, since the nuclear reactors were confirmed to be cooled down, the evacuation areas were reorganised into three based on their annual radiation dose as of March 2012: (1) areas where it is expected that the residents will have difficulty returning for a long time (above 50 mSv/year), (2) areas in which the residents are not permitted to live (20 mSv-50 mSv/year) and (3) areas for which the evacuation order is ready to be lifted (below 20 mSv/year). The Japanese government accepted the 20 mSv/year rule during rehabilitation period according to recommendations by ICRP Publication 111 (ICRP 2009) in comparison with the 5 mSv/year (or 350 mSv during 70 years) rule introduced after Chernobyl. Inside the evacuation areas, the total population was 81,291 people over an area of 1150 km^2. Among the population, 24,814 people resided within the highest contaminated area (above 50 mSv/year), whose size is 337 km^2 (Team in Charge of Assisting the Lives of Disaster Victims, Cabinet Office 2013). In 2015, the evacuation order was lifted for some parts of the evacuation areas, but five municipalities remain completely within evacuation areas and another three are partially included. In all the evacuation areas, previous residents are not allowed to stay overnight without special permission. In the highest contaminated area, all entrance roads to the area are blocked, and previous residents are currently not permitted to enter.

In the area affected by Fukushima disaster, large-scale decontamination is now underway (Ministry of Environment 2017). In fact, owing to natural degradation and decontamination work since the disaster, some parts of the evacuation areas meet the criteria for the order being lifted; the annual air dose has dropped to a level below 20 mSv per year, infrastructure and basic amenities such as supermarkets, hospitals and post offices can be reconstructed, and close consultation with municipalities achieved (Nuclear Emergency Response Headquarters 2015). In areas where the evacuation order was lifted, previous residents are permitted to return. On the other hand, in areas with the highest contamination levels, it was expected that residents would not be permitted to enter for a long time. The Japanese government, however, revised their legislation in an attempt to encourage residents to return there in five years or so by selecting prioritised sites for intensive decontamination and reconstruction which is named "reconstruction base".

2.4 Data and Methods

This research analysed and mapped population census data related to the Chernobyl (1979–2010) and Fukushima (2005–2015) affected regions. Demographic trends in the Chernobyl affected area at district (*raion*) level were derived from population censuses extending three decades following the disaster. In conjunction with the final two censuses under the Soviet Union (1979, 1989),[11] the censuses from the successor states were also used noting their time and methodological deviation. These included Belarus in 1999 and 2009, Ukraine in 2001 and Russia in 2002 and 2012. To further Ukraine's 2001 census data, the 2010 registered resident population number and composition data were included because there was no further census held in Ukraine after 2001 and until the publication of this chapter.

This investigation used a consolidated spatial system that included 846 units based on district-level (*rayon*) data. This data was free of administrative boundary changes that covered the entire territory of Ukraine and Belarus, as well as nine western regions (*oblast*s) of Russia (Fig. 2.1). This wider territory included the evacuation areas as well the evacuee receiving sites, where the post-Chernobyl evacuation and resettlement could have a fundamental impact upon the demographic processes. For an exact determination of the impact of the disaster, the share of ^{137}Cs contaminated

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[11] The Soviet Union dissolved in 1991.

area within the area of each spatial units (districts) was taken into account and ArcGIS was utilised for calculations. The radiation level data was provided by UNSCEAR (2000).

As evacuation is still underway in the Fukushima-affected area, understanding displacement after the accident is a difficult task. Resident registration and questionnaire surveys of evacuees are important data sources. However, at the time of writing this chapter, the former provides information on registered residents only. Response rates to the latter are now around 50–60%, and the tabulated data published is inadequate for demographic analysis. Recently, the results of the Japanese population census 2015 were released. The census form, which asked about demographic characteristics as well as locations of residence five years ago, provides information on migration from highly contaminated areas. The geographic unit for this study is the municipality level (*Shi-Cho-Son*).

As a shortcoming of the census data, the data can only capture night-time populations who have resided in their current place continuously for at least three months. Although evacuation areas are lifted every year and temporal visitors increase after that, we cannot understand such changes in the ambient population by utilising census data. In Japan, as a new form of dataset, ambient population datasets based on 70 million mobile phone users' locations, named "mobile spatial statistics", are released at the 500 m grid cell level. The technical details of the dataset are explained in Terada et al. (2013) and Oyabu et al. (2013). The ambient population datasets we have shown the average of the hourly population in June 2015 and June 2016. Since the ambient population before the accident is not available, the census population in 2010 at the same 500 m grid cell level was used in combination to understand the geographical distributions of population change from 2010 to 2015.

2.5 Demographic Impacts on Regional Scale

2.5.1 Chernobyl Disaster—Shifts of Three Decades

The population of Polesye region, where Chernobyl disaster occurred, has been decreasing since 1970 (Khomra 1989), first to a moderate extent, then at a higher rate since 1986. The data series spanning three decades since the disaster reveals that the consequences of the Chernobyl accident are reflected most characteristically by the demographic trends of the 1990s even though evacuation measures can be reached back to the 1980s (Fig. 2.2). This is partly because during the census in 1989, three years after the disaster, many people still stayed in the evacuation zone and received permanent housing in the following years after that.

The annual population growth of Ukraine amounted barely to 200,000 in the 1980s. Such a wave of resettlement mobilising 100,000 in 1986–87 and additional 100,000 during the following ten years thoroughly reshaped the total population pattern in large part of the country. In Belarus, the population increased in the 1980s by

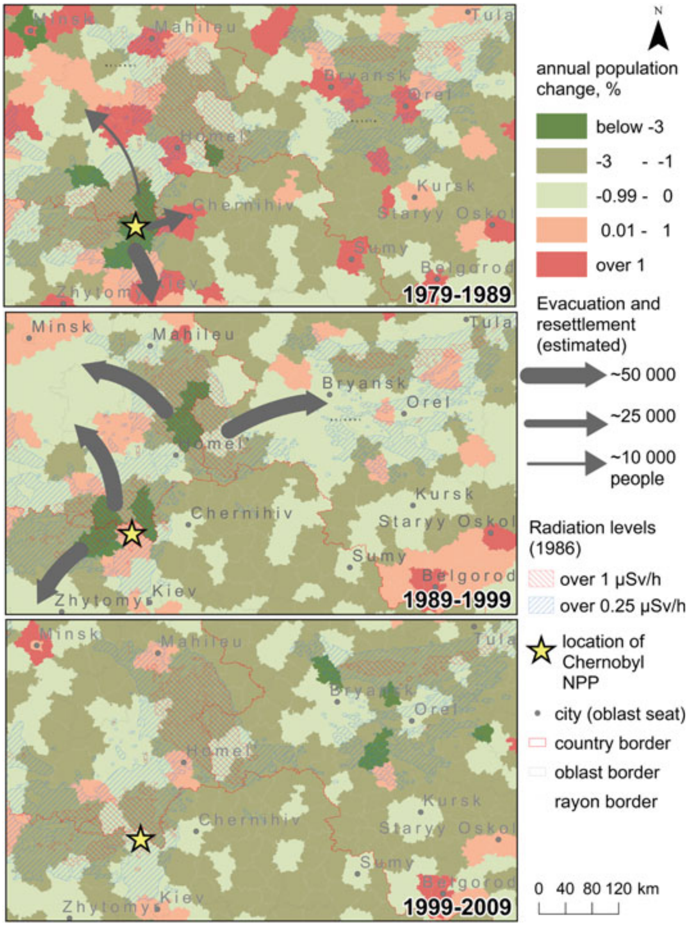

Fig. 2.2 Average annual population change by rayons (Author and cartography by Karácsonyi, calculation based on 1979, 1989 Soviet, 2001 Ukrainian, 1999, 2009 Belarusian and 2002, 2010 Russian census populations as well as de jure population in Ukraine by 2010)

around 30,000 people each year, while in consequence of the Chernobyl disaster, 25–30,000 people were resettled in 1986–87, followed by additional 100,000–130,000 during the 1990s in a country with a population of barely 10 million. The effect was even more dramatic because the evacuation affected around 1–1.6% of the country's total population. The corresponding figure was 0.4% in Ukraine and 0.04% in Russia. Even in 2010, Belarus had the highest share of population living in contaminated areas (Tables 2.3and 2.4). No other country has experienced the impact of a nuclear accident to the same degree. Given the large number of people who were resettled, the recipient regions—in particular the major towns and their environs—saw a relatively more favourable demographic trend in the 1990s.

Table 2.3 People living in administrative units in 2010, where radiation dose was higher than 0.25 μSv/h during Chernobyl (in 1986) and Fukushima (in 2011) disasters

Country	Population of affected administrative units (2010)	Area of affected administrative units (km^2)
Belarus	2,388,700 (34.4%)	60,463 (46.3%)
Japan[a]	1,875,210 (27%)	9,812 (7.5%)
Ukraine	1,407,811 (20.2%)	33,860 (25.9%)
Russia	1,281,781 (18.4%)	26,400 (20.2%)
Total	6,973,502 (100%)	130,535 (100%)

[a] Before the disaster, they became affected one year later

Table 2.4 Share of population and area of administrative divisions in selected countries in 2010, where radioactive contamination was higher than 0.25 μSv/h after Chernobyl (in 1986) and Fukushima (in 2011)

	Country	Administrative division level	From total population of the country (%)	From total area of the country (%)
1	Belarus	District	25.1	29.1
2	Ukraine	District	3.1	5.6
3	Japan[a]	Municipality	1.5	2.6
4	Russia	District	0.9	0.2

[a] Before the disaster, they became affected one year later

When reviewing the entire affected area within the three countries, a general dependence of the population change on the proportion of areas of radioactive contamination was only apparent in the 1990s (Table 2.5). The internal population change of entire Ukraine and Belarus was strongly under the influence of the resettlement measures rather than by natural change or other types of internal migration between 1989 and 2001. In Russia, the depopulation of affected areas was less significant. Because of dissolution of the Soviet Union, a large number of ethnic Russian political refugees from other republics arrived and resettled into these areas counterbalancing the out migration caused by the disaster (Veselkova et al. 1994).

From the 2000s, a significant correlation between population change and the share of contaminated areas could not be found. Demographic "waves" of resettlement calmed down by the 2000s, and even returning migration to the former places could be detected. The population of several small towns that lay in the contaminated areas in Belarus but had been cleaned–up (Naroŭlia, Brahin and Chojniki) began to grow once more (Table 2.6). In these towns that have undergone complex rehabilitation, people receive significant state assistance as well as apartments built with governmental funding. In such small towns, the presence of young families with small children is striking. For this reason, in the contaminated areas, the population is becoming urbanised more rapidly than elsewhere. These areas have become

Table 2.5 Correlation between share of contaminated surface (>1 μSv/h) of admin. districts and selected demographic indicators

Area of investigation	Number of administrative raions	Population change 1989–2000	Population change 2000–2010	Urban population change 2000–2010	Rural population change 2000–2010	Change of urbanisation level 2000–2010	Population density 2010	Rural population density 2010
In the total area	846	−0.23	−0.15	0.19	−0.12	0.28	−0.30	−0.41
In Belarus	119	−0.88	−0.13	0.31	−0.27	0.52	−0.37	−0.49
In Russia[a]	177	−0.21	−0.08	0.06	−0.09	0.05	−0.24	−0.05
In Ukraine[a]	239	−0.74	−0.35	0.15	−0.46	0.64	−0.31	−0.67

[a] Only those districts are considered where contaminated spot over 1 μSv/h is present or located closer than 200 km to the closest such contaminated spot

Table 2.6 Change of total population of some towns in contaminated area

Country	City	Total population, 1989 (persons)	Total population, 2000 (persons)	Total population, 2010 (persons)	Change between 1989 and 2000 (%)	Change between 2000 and 2010 (%)
Ukraine	Ovruch	19,121	17,031	16,792	−11	−1
	Ivankiv	10,282	10,563	9,768	3	−8
	Poliske	13,786	0	0	−100	0
Belarus	Lelchitsi	8,600	9,700	8,900	13	−8
	Hoyniki	17,100	15,000	13,100	−12	−13
	Brahin	5,900	3,400	3,954	−42	16
	Naroulya	11,000	7,200	8,400	−35	17
	Vetka	11,000	7,700	8,200	−30	6
	Elsk	9,600	10,400	9,600	8	−8
	Chechersk	9,700	7,400	7,700	−24	4
	Petrikov[a]	11,800	11,200	10,200	−5	−9
	Turov[a]	15,300	17,100	16,700	12	−2
Russia	Novozubkov	44,845	43,038	41,745	−4	−3
	Starodub	18,906	18,643	18,445	−1	−1

[a] Outside the contaminated area

Belarus's "most rapidly urbanising" regions (Table 2.5). The ratio of urban population is on the increase in Ukraine as well, but it is also a result of its close location to the Kyiv agglomeration.

Chernobyl did not change the direction of regional population dynamics. The decline in population would be significant even without Chernobyl; however, it did accelerate the process. The population density was low even before the disaster, and the evacuations merely accentuated this state of affairs. Natural population reproduction data (crude birth and crude death ratio) around 2010 does not reflect any correlation with higher radiation levels any more, suggesting the decline in the birth rate was only temporary after the disaster and connected with the uncertainties because of resettlement. The disaster did, however, fundamentally alter the urbanisation processes and the network of villages. Smaller villages in remote areas disappeared in significant numbers, whereas small towns and minor urban centres became relatively more "stable".

The negative demographic processes of the Polesye combined with the disaster-caused outmigration and resettlement poked a huge hole in the demographic space of the region, which is especially spectacular in the changing population density within rural areas. Even the districts outside the evacuated zone became the most sparsely populated areas of Belarus and Ukraine (Fig. 2.3).

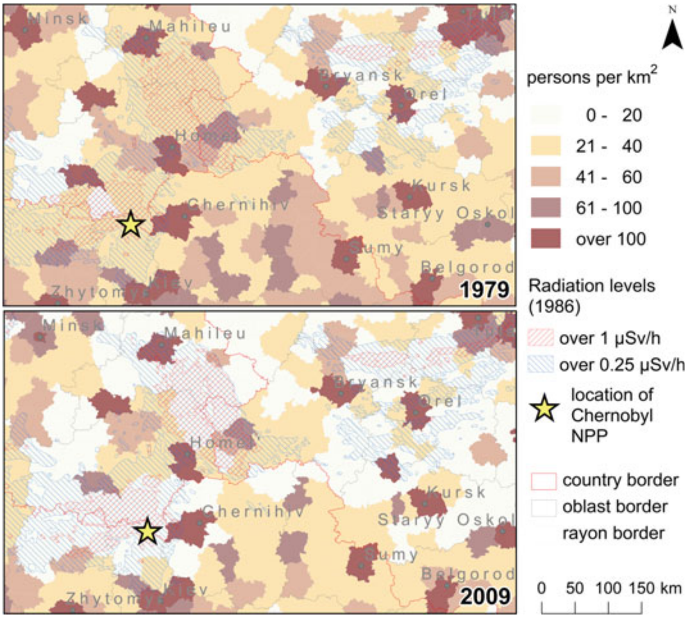

Fig. 2.3 Population density by rayons (Author and cartography by Karácsonyi, calculation based on 1979 Soviet, 2009 Belarusian, 2010 Russian census populations as well as de jure population in Ukraine by 2009)

2.5.2 *Fukushima—Recent Demographic Processes*

Regional population structure changed fundamentally after the construction of the nuclear power plants in the coastal area of Fukushima Prefecture. According to a case study conducted in Tomioka Town by Kajita (2014), residents consisted of three groups: (1) people who lived in the area originally, before the construction of the nuclear power plant, (2) "newcomers" who migrated there to work for construction and electric industries and had already settled for a long term and (3) short-term stayers who were sent by TEPCO and other related companies. Overall, the total population increased in the 1970s when people migrated for work. However, during the 1990–2000s, it gradually decreased again or levelled off. Along with such population decline, the elderly ratio (people aged 65 years and over) went up to around 20–30% in 2010.

The nuclear accident had almost irreversible impacts on regional population structure. As we explained above, group evacuation was organised by municipality offices, and evacuees temporally stayed at city halls, schools and hotels in nearby major cities such as Iwaki, Fukushima, Koriyama and Nihonmatsu. An exception is Futaba, which chose Saitama Prefecture, located around 200 kms away to the south. Understandably, some people outside the evacuation areas escaped farther, stayed at their friends' or relatives' houses temporarily and after that found new houses by themselves.

According to official statistics, the total number of evacuees including both ordered and voluntary evacuations reached the maximum number (164,000 people) in May 2012 and 79,000 people remained evacuated as of February 2017 (Asahi 2017a).

In Japan, there are two types of temporal houses provided for evacuees by municipality: prefabricated houses specially constructed after the accident and existing rented houses that municipalities leased. The maximum number of house units provided was 16,800 in 2013 for the former type and 25,554 in 2012 for the latter type (Fukushima Prefecture 2017). Evacuees from the same municipality were arranged to stay in the same prefabricated house complex to maintain the original community and human network (Fig. 2.4). As the map suggests, most of them are located in major cities where infrastructures are provided and daily necessities are easily purchased. In contrast, the detail spatial distribution of households staying in rented houses is not publicly reported, but it can be assumed to be more dispersed and close to major cities based on the locations of housing supply before the accident.

The Japanese population census 2015 provides insights about where people were displaced after the accident (Fig. 2.5). Table 2.7 provides the proportion of evacuees who live outside or inside Fukushima Prefecture by five municipalities which lost their population almost completely after the accident. For those who stay in the prefecture, the proportions of current residences in four major cities are presented. Analysing the proportions disaggregated by age group, we found that the younger they are, the more they are likely to leave Fukushima Prefecture. Around 30–40% of people aged below 40 years old choose to find new residence outside Fukushima Prefecture, for example, Tokyo Metropolitan Area and Sendai in Miyagi Prefecture. Young people can choose a new place which is distant from their home municipality because they have less economic and social capital which keeps them staying in an area closer to their previous residence (Isoda 2015).

As far as those who remain in Fukushima Prefecture are concerned, people are likely to select the nearest major city. For example, in the case of Iitate Village, 60–70% of residents among those who remain in Fukushima Prefecture chose Fukushima city located 35 kms away. Around 40% of residents from Tomioka selected Iwaki. These results partly reflect the fact that about 55,239 people still lived in temporary houses at the end of September 2015 (Fukushima Prefecture 2017), when the Japanese population census was carried out. The figures in Table 2.7 partially include people already resettled. According to questionnaire surveys conducted by the Reconstruction Agency (2016) in 2015–2016, around 30–40% of affected families bought a new house and settled in a new community. Furthermore, based on the number of recipients of special provisions for housing acquisition, 85% of them seem to have found a newly owned house in Fukushima Prefecture (Asahi 2016). The locations of new houses are likely to be in major cities because land prices in places such as Fukushima City, Iwaki City have increased or at least levelled off.

The sudden population increase caused by mass displacement unintentionally led to several complaints among residents in receiving municipalities. For example, local newspapers reported that traffic jams became more frequent, the queues in hospitals were longer, and housing rent increased. It should also be noted that junior and high school students evacuated from Fukushima-affected areas experienced bullying

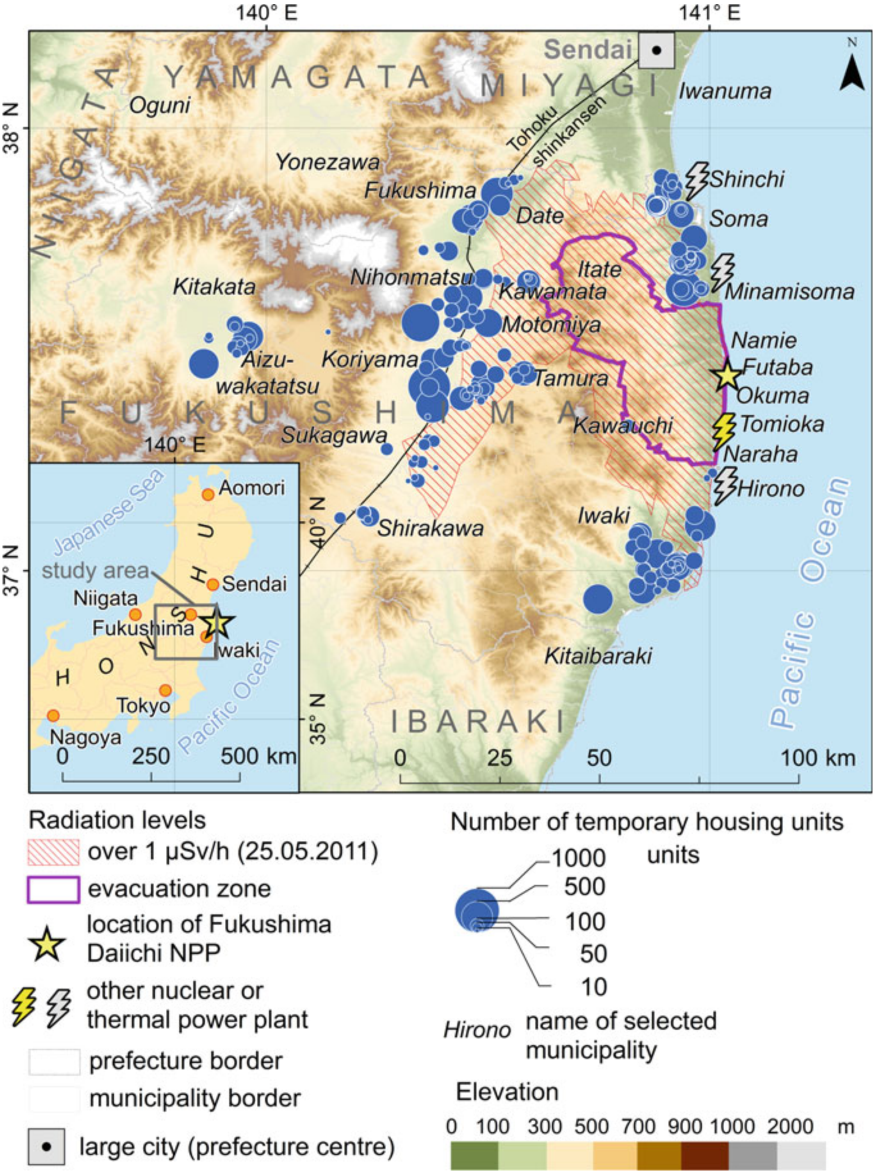

Fig. 2.4 Locations of temporary housing complexes in Fukushima Prefecture (Author Hanaoka, cartography by Hanaoka and Karácsonyi, data from www.pref.fukushima.lg.jp/sec/41065d/juutakutaisaku001.html)

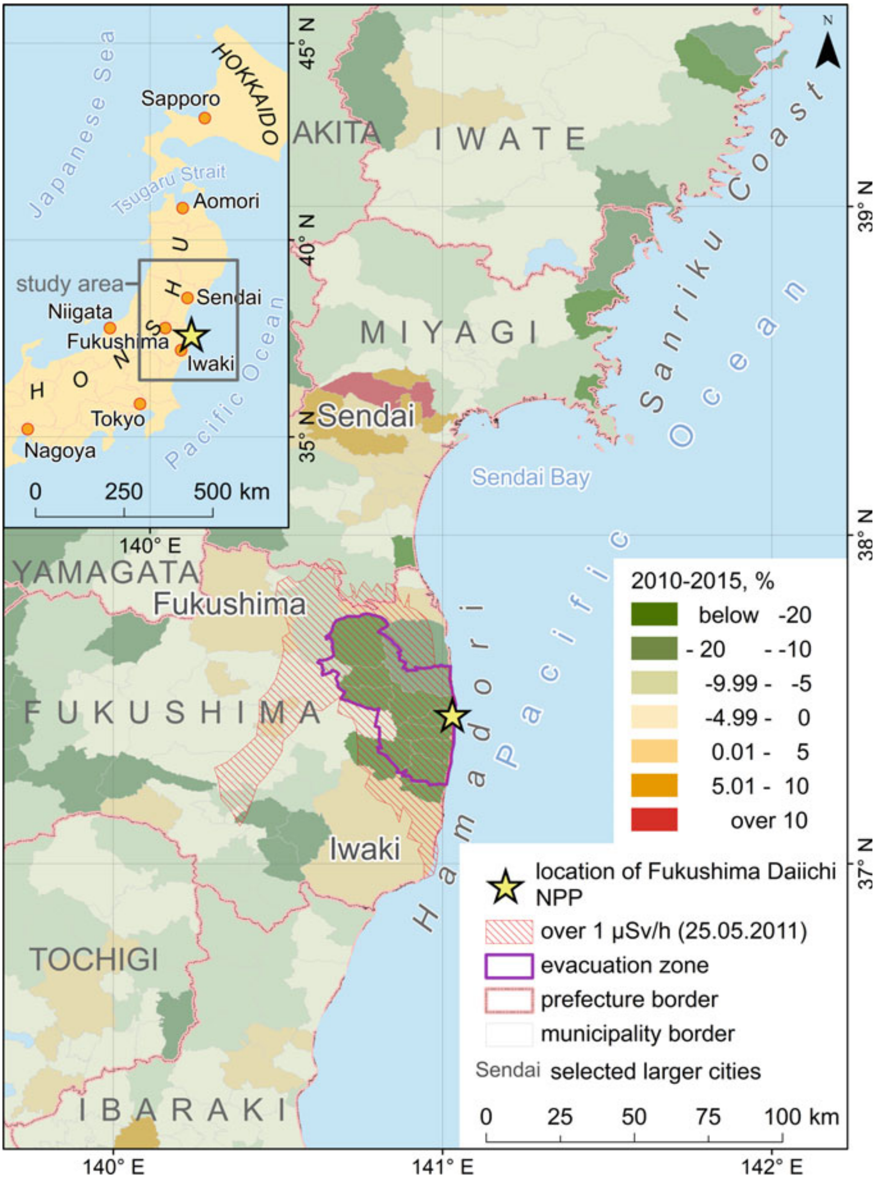

Fig. 2.5 Total population change by municipalities (Author and cartography by Karácsonyi, calculation based on 2010, 2015 Japanese census populations)

Table 2.7 Proportions of internal migrants by destination (based on 2010, 2015 Japanese census populations)

Destination	Unit	Current age group (years old)								
		5–14	15–29	30–39	40–49	50–59	60–69	70–79	80+	5+
From Tomioka Town										
Outside Fukushima Pref	%	**31.9**	**35.7**	**30.4**	**28.7**	23.6	23.1	19.2	20.2	26.9
Inside Fukushima Pref	%	68.1	64.3	69.6	71.3	**76.4**	**76.9**	**80.8**	**79.8**	73.1
Iwaki City (43 km)	%	38.6	36.9	40.3	39.7	**46.4**	**41.9**	**42.7**	**43.7**	41.3
Koriyama City (77 km)	%	13.3	14.9	13.5	16.0	16.8	**20.3**	**25.1**	**23.1**	17.6
Fukushima City (95 km)	%	**3.3**	2.4	**4.3**	2.0	1.8	2.4	1.6	**3.5**	2.6
Aizuwakamatsu City (124 km)	%	**2.0**	0.9	**1.6**	**1.4**	0.8	0.4	0.5	0.6	1.0
Total	N	1,137	1,842	1,564	1,795	1,888	2,029	1,255	1,121	12,631
From Okuma Town										
Outside Fukushima Pref	%	**31.5**	**33.2**	**32.0**	**28.7**	20.8	23.3	16.8	20.5	26.4
Inside Fukushima Pref	%	68.5	66.8	68.0	71.3	**79.2**	**76.7**	**83.2**	**79.5**	73.6
Iwaki City (50 km)	%	36.7	37.6	36.4	37.3	**45.4**	**42.1**	**43.4**	**41.7**	40.0
Koriyama City (68 km)	%	7.2	**8.4**	**8.4**	7.3	**8.7**	**8.9**	**8.6**	**8.8**	8.3
Fukushima City (95 km)	%	2.0	2.0	2.1	**3.1**	**3.3**	2.0	1.1	**2.8**	2.3
Aizuwakamatsu City (116 km)	%	**13.1**	10.7	9.1	**13.5**	11.2	**14.3**	**20.4**	**16.1**	13.1
Total	N	1,105	1,363	1,273	1,227	1,378	1,480	852	782	9,460
From Futaba Town										
Outside Fukushima Pref	%	**52.6**	**49.6**	**48.8**	**41.6**	32.9	39.2	30.4	34.3	40.7
Inside Fukushima Pref	%	47.4	50.4	51.2	58.4	**67.1**	**60.8**	**69.6**	**65.7**	59.3
Iwaki City (58 km)	%	27.0	25.5	26.0	**29.8**	**36.0**	27.6	**31.6**	**32.3**	29.5

(continued)

Table 2.7 (continued)

Destination	Unit	Current age group (years old)								
		5–14	15–29	30–39	40–49	50–59	60–69	70–79	80+	5+
Koriyama City (73 km)	%	6.6	8.8	8.7	9.0	**10.8**	**11.1**	**13.4**	8.9	9.8
Fukushima City (85 km)	%	1.7	3.1	3.3	2.9	**6.2**	**6.4**	**7.8**	**7.7**	5.1
Aizuwakamatsu City (120 km)	%	**1.9**	1.0	1.1	**2.0**	0.6	0.5	**1.4**	**1.6**	1.2
Total	N	534	718	642	652	776	996	629	685	5,632
From Namie Town										
Outside Fukushima Pref	%	**40.0**	**38.8**	**36.5**	**30.9**	23.6	23.9	20.5	22.1	28.8
Inside Fukushima Pref	%	60.0	61.2	63.5	69.1	**76.4**	**76.1**	**79.5**	**77.9**	71.2
Iwaki City (63 km)	%	**14.1**	13.0	**15.5**	**14.4**	**17.3**	13.8	10.7	12.3	14.0
Koriyama City (75 km)	%	**7.7**	7.2	**7.9**	6.9	**8.1**	7.2	6.0	6.9	7.3
Fukushima City (79 km)	%	12.7	14.5	11.6	**17.0**	**18.3**	**17.2**	**22.9**	**20.2**	17.0
Aizuwakamatsu City (126 km)	%	**2.9**	1.0	**2.7**	**1.4**	0.5	0.8	1.2	1.3	1.3
Total	N	1,499	2,207	1,868	1,936	2,567	2,973	1,994	1,864	16,908
From Iitate Village										
Outside Fukushima Pref	%	**12.4**	**12.7**	**9.4**	**7.3**	3.4	3.0	3.7	4.8	6.6
Inside Fukushima Pref	%	87.6	87.3	90.6	92.7	**96.6**	**97.0**	**96.3**	**95.2**	93.4
Iwaki City (101 km)	%	0.0	**0.6**	0.2	0.2	0.5	0.2	0.2	0.0	0.3
Koriyama City (64 km)	%	0.7	2.0	**0.9**	0.7	**1.1**	0.5	0.9	0.6	0.9
Fukushima City (35 km)	%	**69.3**	**68.1**	60.5	**65.6**	58.5	62.0	**62.8**	57.0	62.4
Aizuwakamatsu City (104 km)	%	**1.4**	**0.6**	**1.2**	0.2	0.0	0.0	0.0	0.0	0.3
Total	N	476	624	469	477	754	838	575	691	4,904

Values above the average (= age group: 5+) are presented in bold
Distance in brackets is based on the shortest path between two municipal offices calculated by Google Maps

concerning the nuclear accident at school. In this way, resettlement after the nuclear accident, unfortunately, has been accompanied by various hardships in the new environment for evacuees. Figure 2.6 shows those municipatities where evacuees were

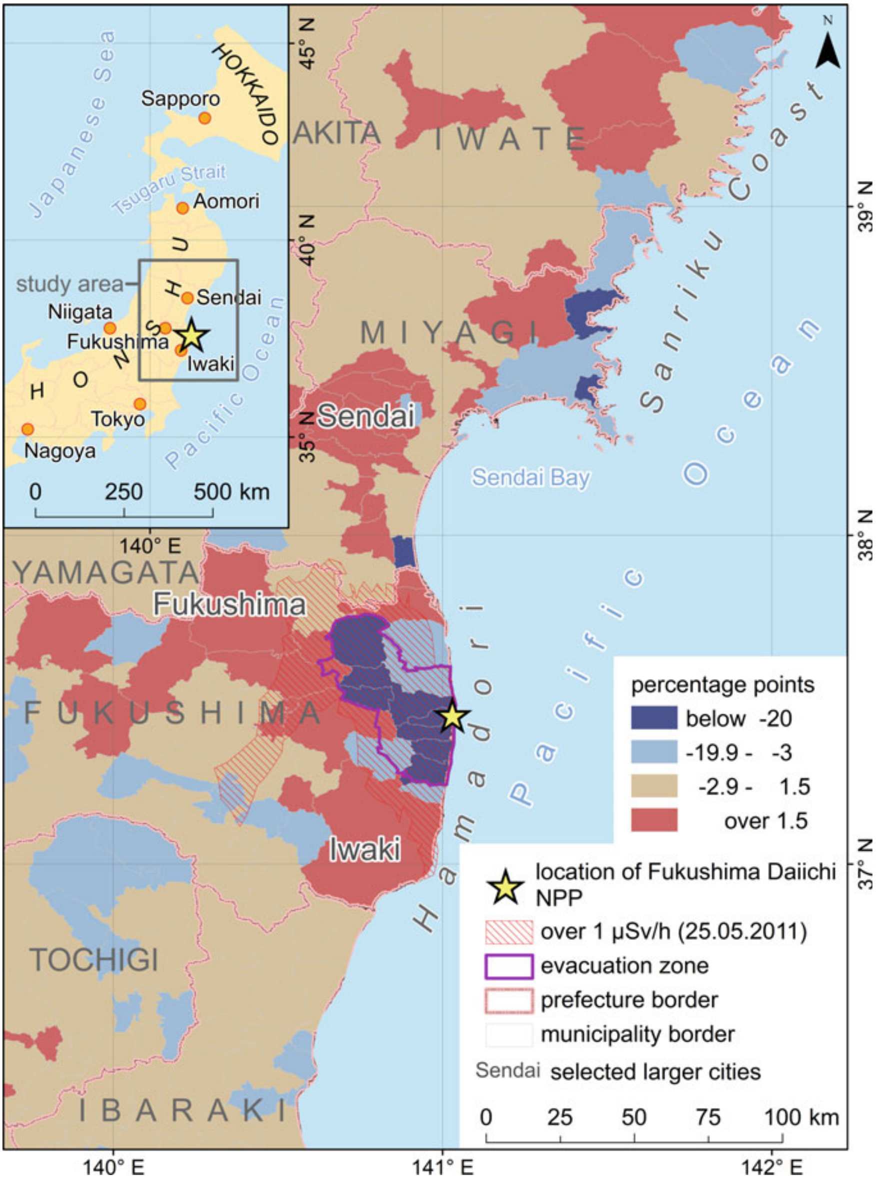

Fig. 2.6 Changing population dynamics after 2011 (Difference between population change of 2005–2010 and 2010–2015) (Author and cartography by Karácsonyi, calculation based on 2005, 2010, 2015 Japanese census populations)

hosted (red colour), changing the demographic trends between 2010 and 2015 in these settlements.

In Fukushima, affected municipalities are planning several resettlement sites outside evacuation areas, but they seem to be temporal, not permanent resettlements. This is because firstly, some evacuees' wish to return to their hometowns, and secondly, permanent resettlement sites managed by the affected municipality in the receiving municipality are practically difficult under the current Japanese local government system. There are several issues to solve, such as whether dual resident registration can be admitted or not and how to share taxes and public services among municipalities (Tsunoda 2015). Therefore, in principle, affected municipalities are making every effort to enable residents to return to their homes through decontamination. The evacuation order has already been lifted for some evacuation areas, and radiation levels dropped as a result of the natural degradation and decontamination. In the spring of 2017, the evacuation order excepting the highest contaminated area was lifted for the majority of evacuation areas in Iitate Village, Kawamata Town, Namie Town and Tomioka Town. Approximately, 32,000 people lived there before the accident (Asahi 2017b). The total evacuation areas being lifted until April 2017 was 70% of the initial evacuation areas issued immediately after the accident. Yet, many people decided not to return. They not only worried about the radiation level, but basic amenities (e.g. shops, hospitals) and employment opportunities are limited. For example, in Naraha Town, the evacuation order was lifted for all evacuation areas, which covered 80% of the municipality. According to official town records (Naraha Town 2016), only 781 people, which is equivalent to 10.6% of the total population before the accident, have returned. Among them, the proportion of people aged 65 years and over reached 53% (the elderly ratio in 2010 was 24%).

Young people resettled outside Fukushima Prefecture, while many of the migrants who returned are elderly people. This trend accompanies geographical separations of generations in rural areas where young families and their parents traditionally lived together. In addition, since the 1970s, nuclear industries had attracted many migrants from the outside. Many of the first generations reached or are reaching the age of retirement (65 years old). Thus, it is a difficult question whether such people who migrated from the outside previously and settled for a long time will choose to return again. Pre-disaster population structure characterised by a mixture of rural and industrialised areas makes the estimation of future demographic trends difficult in Fukushima-affected areas.

Using spatial mobile statistics, we mapped the average of hourly population per 500 m grid cell in June 2016 and compared it to 2010 population census data to analyse the changes (Fig. 2.7). Comparing the two maps, we found that the geographic distribution of grid cells with high population density almost remained the same outside the evacuation areas between two time periods, while inside, they disappeared almost completely. In particular, there is no peak in population density distribution in the town centre proximity to railway stations, implying that densely populated residential areas no longer exist after the accident. However, there are several grid cells with somewhat higher population density in areas close to the nuclear power plant in Okuma Town and Tomioka Town. This population distribution does not well

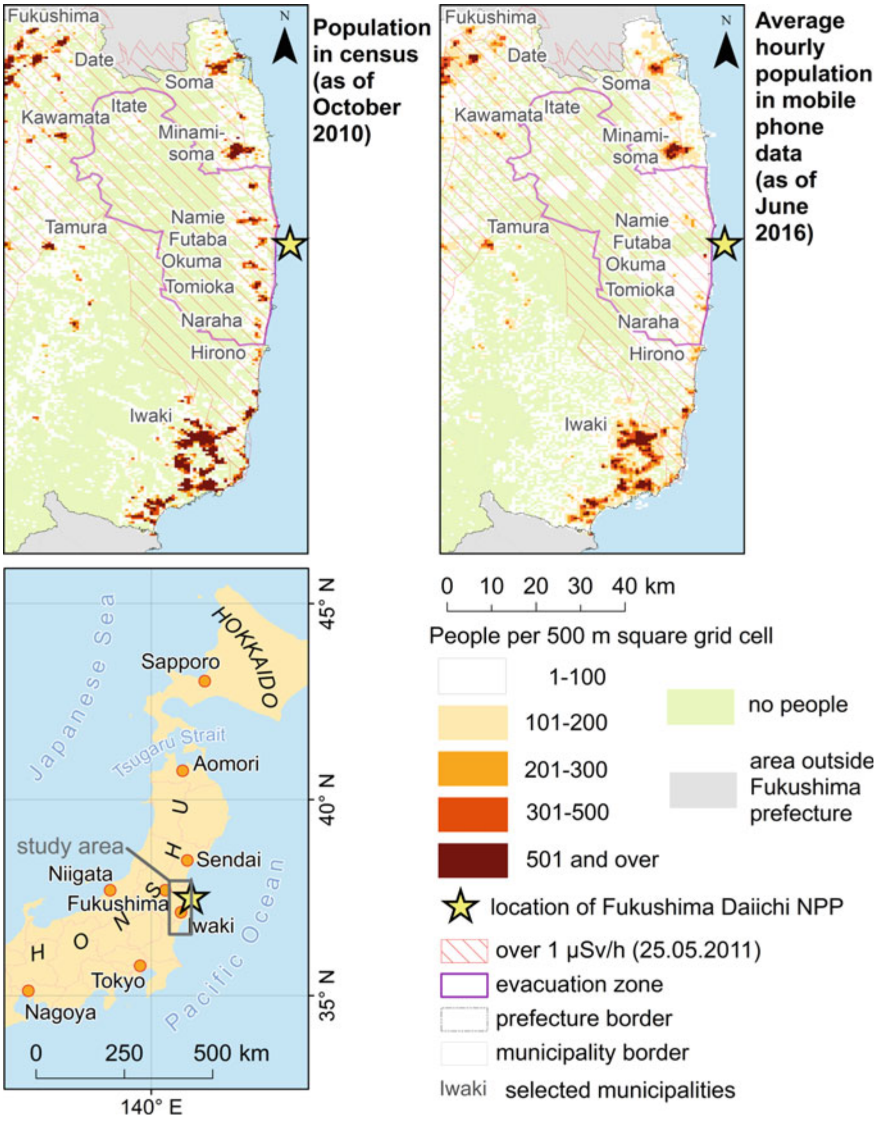

Fig. 2.7 Population distributions in census and mobile phone data (Author Hanaoka cartography by Hanaoka and Karácsonyi)

overlap with the census one, suggesting that most of the people are temporal visitors such as engineering and technical workers at nuclear power plants.

Eighty percent of the area of Naraha Town, located within the 20 km radius from the nuclear power plant, was previously included in the evacuation areas. As we discussed above, the evacuation order was lifted for these areas in September 2015, and the total number of grid cells with population density above 100 people also increased from 32 grid cells in June 2015 to 41 grid cells in June 2016, among 472 grid cells across Naraha Town. This result may suggest that people already returned in these areas or people can enter them more frequently than before, perhaps in preparation for returning. The Japanese population census is conducted every five years, and it is not able to capture such temporal dynamics of population changes. Using mobile spatial statistics will help to continuously monitor and explore the reconstruction progress after the evacuation areas are lifted.

2.6 Discussion and Recommendations

The mass displacement after a nuclear disaster, rather than the radiation itself has a much more significant impact on deteriorating health, natural reproduction and economic performance of the affected population. Based on the literature and the results of this study, these consequences can be summarised as follows:

(1) In both Fukushima and Chernobyl cases, the regional impact of the accident resulted in a dramatic loss of population in the contaminated areas and accelerated the concentration of populations in adjacent major cities through evacuation. Evacuated communities were traumatised and destroyed, facing challenges that result from not having any spatial or social attachment in the recipient areas (see also Chap. 11). The receiving communities faced population growth and a radically changed composition by the arriving evacuees, whose integration often ended up in social segregation and marginalisation.

(2) A strong spatial shift towards urbanisation can also be observed because urban centres provide a better chance for socio-economic recovery and re-integration (job opportunities, more extensive social network) for the evacuees, even for former rural residents (Voloshin et al. 1996; IOM 1997). Carson et al. (Chap. 5) emphasise that other types of disasters can also increase urbanisation because urban areas providing people more opportunities to cope with the consequences.

(3) Large migration shifts are significant during the first 5–10 years after the disaster, when a large number of evacuated population are on the move, often staying temporarily at one location and going through multiple migration steps until settling down. The population trends can take a totally different direction for this decade in certain areas. This challenges the local housing market, service sector and government policy. Later, these shifts are less and less significant. Some of the people remain, but the majority of the people (mostly young families) start a new life mostly in urban areas out of the affected region.

(4) After a decade, however, positive migration balance has been observed in certain areas of the affected region, mainly resulting from clean-up workers, scientists or even tourists and settlers along with the returning elderly. High variation in short-term population numbers can be registered in the regions with extremely low population density caused by the disaster.

Population immigration trends are influenced by employment opportunities. Sectors vulnerable to radiation such as agriculture, fishing, food industry are in decline (IOM 1997; UNDP 2002b), while others requiring a lesser sized or a rotating labour force, such as forestry or nuclear waste storage facilities are maintained. New jobs in health care, engineering, science and construction are also represented.

(5) The returning migration or remaining in place is more common in the case of elderly people. Firstly because they have a higher attachment to the place and because of their age, they are less flexible to start a new life somewhere else. Their expected lifelong exposure is also much lower than for the adolescent population. Therefore, they are more likely to accept the risks associated with living in these polluted areas. In-migration to contaminated areas can also be observed in Belarus recently. However, this results from government policy to attract new settlers, rather than the return of the elderly population.

Unlike the Chernobyl case, in Fukushima, permanent resettlement sites outside the affected area were not organised, and instead, extensive decontamination work and higher accepted radiation thresholds make evacuees legally able to return their original homes within six years or so after the nuclear accident. This was also possible because of lower level of Cs^{137} contamination and lack of high risk trans-uranium elements. Not to mention that according to some experts (see Hjelmgaard 2016), after the ^{131}I and ^{137}Cs phases (IOM 1997), a third phase related to ^{241}Pu–^{241}Am decay has begun in Chernobyl with health consequences yet to be realised and understood. Given the differences in radio-ecological conditions, reconstruction policy and the time framework, Fukushima may demonstrate demographic consequences that are different from the Chernobyl case. In contrast, the return rate is very low which causes a large drop in population density similarly to Chernobyl.

According to World Nuclear Association (2018), nuclear accidents have a low and decreasing probability. Even though previously unforeseen circumstances always could cause accidents in the nuclear industry (Labaudiniere 2012), bring forth the need for evacuation or even permanent displacement of large populations. There are certain points that should be considered when developing resettlement and redevelopment policy for possible future disaster-stricken regions based on the consequences of past displacements. Most of the following points were not considered in post-Chernobyl but were followed in post-Fukushima mass displacement showing a clear policy improvement and better situation-adapted decision-making.

(1) A well-planned short-term evacuation is necessary during the rapid-onset phase ("^{131}I phase") of the disaster when a high number of temporary or permanent housing, as well as financial and social aid, is needed to cope with the consequences. This is the most significant challenge within 1–2 years following the disaster. Chernobyl, and to some extent Fukushima, evacuation measures failed during this phase.

(2) A clear distinction between temporary and permanent displacement as well as planning and straightforward communication of community futures accordingly is strongly required during the slow-onset phase ("^{137}Cs-phase" from 2

to 50 years onwards following the disaster). The permanent mass displacement should be seen only as the ultimate solution to cope with the consequences of a nuclear disaster. It can cause much larger and longer demography shifts than the distortion caused by a low-level radiation exposure resulting in health problems. People should be provided with reliable information about the threat and assistance if they decide to move. On the other hand, people should be allowed to take the risk if they decide to do so, but compensation is necessary.

(3) The intent to move, stay or return is strongly age-specific, and the return migration should be supported accordingly. Infrastructure redevelopment should be planned in accordance with the demographic shift towards aging populations such as more senior homes, hospitals rather than nursery. Low return rates, falling population density and shifting settlement system towards population concentration and urbanisation are also common consequences. Thus, infrastructure regeneration, reconstruction (roads, railway links) should target these areas.

In summary, the most significant lesson from this study is that a poorly planned mass displacement can cause a larger economic loss than the disaster itself. There were clear differences between the management of Chernobyl and Fukushima disasters in this regard. The post-Chernobyl policies that drove population displacement lacked previous experiences on effect of radiation on human health in large populations. The administrative rigidity of the zoning and lack of financial sources for infrastructure-reconstruction and redevelopment (see also Chap. 11) accelerated further the total population and economic loss in Chernobyl. The knowledge and experience derived from the Chernobyl case helped the decision-making in Fukushima. Townships were opened up for returners in recent years in the Fukushima disaster area is possible because of the lower level of radiation and lack of emitted trans-uranium isotopes. The long-lasting existence of Chernobyl zone contributed significantly to the false view to explain all demographic consequences by the invisible radiation threat presented in and around the "death zone". This delivered a negative image of the entire area, making regional redevelopment even more difficult.

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