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Was there an improvement in the years of life lost (YLLs) for non-communicable diseases in the Soma and Minamisoma cities of Fukushima after the 2011 disaster? A longitudinal study

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ABSTRACT

Objectives This study aimed to determine cause-specific years of life lost (YLL) changes between predisaster and postdisaster in disaster-affected municipalities, compared with the national average. We estimated the YLL in Soma and Minamisoma cities (the subject area) in Fukushima, Japan, where the tsunami and the nuclear accident hit in 2011.

Participants We used vital registration records from a national survey conducted between January 2006 and December 2015. We analysed 6369 death data in the predisaster period (2006–2010) and 6258 death data in the postdisaster period (2011–2015).

Methods We incorporated vital statistics data as follows: age-based, sex-based and International Classification of Diseases, 10th Revision-based cause-specific deaths and calculated YLLs by ages 0, 40, 65 and 75 and sex for attributable causes of death for heart diseases, cerebrovascular diseases, pneumonia, all cancers and specific cancers; breast cancer, colorectal cancer, leukaemia, lung cancer, stomach cancer and uterine cancer for predisaster and postdisaster in the subject area.

Results YLL attributed to heart diseases for males showed no decrease and YLL postdisaster was 0.37 years larger than that of the national average at age 0. The difference was −0.17 (95% uncertainty interval: −0.40 to 0.05) years at age 65. It decreased for females; the difference was 0.37 (0.18–0.57) years after the disaster. YLL decrease (that is, difference) in cerebrovascular diseases at age 0 was 0.27 (0.09–0.44) years and 0.18 (0.04–0.32) years; however, the YLLs postdisaster were still 0.24 and 0.25 years larger than those for the national average for males and females, respectively. YLL attributed to cancer did not increase even after the nuclear disaster.

Conclusions We specified the causes of death to be reduced in disaster-affected areas in the future. This study emphasised the importance of understanding how the health situation changed for the whole society of the area from a comprehensive perspective, rather than focusing only on small mortality increases.

Strengths and limitations of this study

- We estimated cause-specific years of life lost of disaster-affected areas as a difference between the predisaster and postdisaster period, compared with the national average.
- The analysis will facilitate prioritisation for local health control policy and better resource allocation and can be useful to assess the performance of the medical (or societal) measures that the municipal, prefectural, or national government emphasised before the disaster.
- Causes of death with a small number could not be examined due to the lower plausibility of the result.
- The appropriate population size could not be fully examined for municipal-level analysis due to scarce previous studies to compare validity of the study.

INTRODUCTION

The Great East Japan Earthquake in March 2011, followed by the tsunami and the nuclear accident, affected people living in the eastern Tohoku area (ie, Iwate, Miyagi and Fukushima prefectures). In the disaster-affected area of Fukushima, residents faced various changes in the medical environment and their lifestyles due to mandatory or voluntary evacuation. Mass evacuation strained essential health services and infrastructure and disrupted social capital and networks due to the disaster.[1]

A comprehensive viewpoint is required to examine the aftermath of a disaster. For example, the National Academy of Sciences mentions in the context of resilience science that it is necessary to focus not only on the negative changes but also on the positive changes that occur after a disaster.[2] This concept is also important in public health. Irrespective of the adverse situation, life expectancy (LE) in Japan has increased even after the big disaster.[3] Years of life lost (YLL), an index of premature mortality, due to major causes of death decreased in 2015 compared with 2010 in Japan,[4 5] and Fukushima prefecture is no exception.[6]

However, it is not clear whether this decrease in YLL occurred in the disaster-affected municipalities in Fukushima. Furthermore, if a YLL decrease did occur, the causes of death which had brought the YLL decrease have not been specified. From a holistic view, our study provides important information to understand change in the health environment, so that local health control policies can be prioritised and resources better allocated in disaster-affected areas. There is no comprehensive analysis on the quantitative magnitude of impact for these health outcomes, although many medical case reports are available that feature disaster-affected areas in Fukushima, and consider populations affected by lifestyle diseases,[7 8] including diabetes mellitus,[9] cardiovascular disease[10] or reports on cancer patient delay,[11 12] elderly people[13 14] or evacuees due to the disaster.[15]

The aim of this study is to determine YLLs at disaster-affected area, by age and sex, to identify the causes of death that could be attributed to it, and to compare them to the Japanese national average. We selected Soma and Minamisoma cities in Fukushima Prefecture (hereinafter referred to as the subject area) for our investigation. The subject area is located around 10–45 km north of the Fukushima Daiichi Nuclear Power Station (online supplemental figure S1) has experienced multiple disasters, such as the tsunami (followed by physical damage) and the nuclear accident (followed by low-level radiation exposure). More than 1000 residents of these cities died from direct injuries caused by the earthquake and the tsunami.[1] A part of the subject areas, and not the entire subject areas were affected. To the best of our knowledge, there is no report on the burden of disease or YLL calculation at the community level (such as city, town, and village) in Japan, regardless of whether the disaster affected the area.

MATERIALS AND METHODS

Definition and rationale for the calculation of LE and YLL

LE is an index of the health status of a cohort. One can calculate LE of a specific cohort over a given period using the life table. The life table consists of the number of the surviving population l, number of deaths d, age-specific mortality rate q and total survival time of population T. From these parameters, a survival curve of the cohort is obtained. Figure 1 shows a conceptual diagram of a survival curve and loss of life years of a population. LE at age x can be obtained by dividing the total survival time of the population T_x (ie, area under the survival curve after age x) by the numbers in the surviving population at age x (l_x).[16]

YLL is defined as the difference of between LE with a risk event and without a risk event. We obtained two survival curves to calculate a YLL; a survival curve without a cause of death, that is depicted from an age-specific number of deaths from the data set which are deaths derived from a specific cause of death (Solid line in figure 1), and a survival curve with all causes of death, that is derived from an age-specific number of deaths from the data set which includes all causes of death (Dashed line in figure 1). YLL can be calculated for any cause of death if the survival curve is obtained. Although YLL estimates are based on hypothetical survival curves, the actual number of deaths were used in the survival curves; thus, the estimates were robust and realistic. Detailed explanation on YLL as a public health index and YLL calculating formula are in online supplemental material.

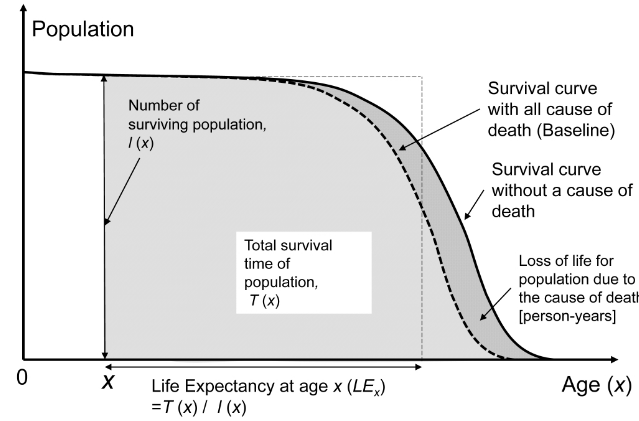

Figure 1 Conceptual diagram of survival curve and loss of life years.

Data

Number of deaths and the population in the subject area

To obtain the survival curves, mortality rates by age (age=0, 1, 2, …, 100+) were required. Mortality rate at age x (q_x), which is an approximate slope of survival curve at age x, is obtained by dividing number of deaths at age x (d_x) by surviving population at age x (l_x). Detailed calculation method of mortality rate q_x is shown in online supplemental material. We obtained the survival curves for males and females separately because it is known that the mortality rates for each age differ between the sexes.

As a source of the number of deaths, we used vital registration records by age for the subject area (that is, Soma City and Minamisoma City) from January 2006 to December 2015. The data obtained from the vital registration records were aggregated according to the municipalities and these were the original data which were composed of the national vital statistics. The data are usually undisclosed; however, the Ministry of Health, Labour and Welfare (MHLW) approved the secondary use of the records in compliance with the Statistics Act, and provided the data.

The data were provided together with sex, age of death, and cause of death as per the International Classification of Diseases and Health-Related Problems, 10th Revision (ICD-10) for the subject area. We excluded 1091 deaths in 2011 as direct deaths because this study focused on the effects of death other than direct deaths. Direct death was defined according to a previous study.[1] Table 1 shows

Table 1 Age-specific and sex-specific counts of direct and other death in the predisaster and postdisaster period in the subject area

Age at death	Males: Death other than direct death – Predisaster period*	Males: Death other than direct death – Postdisaster period*	Males: Direct death in March 2011	Females: Death other than direct death – Predisaster period*	Females: Death other than direct death – Postdisaster period*	Females: Direct death in March 2011
0–9	16	5	18	12	4	13
10–19	7	6	20	4	5	28
20–29	19	24	20	11	6	17
30–39	35	17	30	24	10	21
40–49	77	51	38	39	18	33
50–59	239	157	71	111	80	68
60–69	464	517	102	181	197	92
70–79	1016	777	130	555	443	154
80–89	1070	1267	88	1229	1249	115
90–99	389	397	7	791	935	24
100+	12	17	0	68	76	2
Population of the subject area	53 430 (in 2010)	49 381 (in 2015)		56 293 (in 2010)	50 647 (in 2015)	

*Predisaster period: 2006–2010, postdisaster period: 2011–2015. The number of deaths is a sum of the deaths over a period of 5 years.

the counts of deaths other than direct death and direct death by age and sex. As a result, we analysed 12 627 data (in the predisaster period: 2006–2010; n=6369 and in the postdisaster period: 2011–2015; n=6258. The proportion of females in these periods was 47.4% and 48.3%, respectively). To investigate the indirect health effects of the disaster, we compared the YLL of postdisaster with predisaster period after excluding direct deaths. We did not identify the nationalities of the deceased persons from the data. The data we used also included residents who had moved outside the subject area, since registration was based on the residents' predisaster addresses.

Population data from 2006 to 2015 were obtained from the Basic Resident Registers, the nationwide resident-registry network maintained by the municipality unit (city/town/village). This included foreigners and evacuees from outside of the subject area. We used population numbers as of 30 September or 1 October for each year for further analyses. We unified data for Soma City and Minamisoma City as one population and averaged the annual population both in the predisaster period (2006–2010) and in the postdisaster period (2011–2015) and obtained the 5-year average and SD for both the populations and crude mortality rates, respectively.

Number of deaths and the Japanese population data

To compare the subject area with the Japanese national average, we obtained vital statistics and population data from the national statistics. Age-based, sex-based and ICD-10-based cause-specific death data were obtained from the Japanese Statistics[17] in 2010 and 2015, respectively. Age-specific and sex-specific population data for the Japanese were obtained from Japanese statistics[18 19] for the years 2010 and 2015, respectively. We chose these years because of the availability of complete data set for the years, that is, cause-specific death data, (living) population, and the extrapolation parameters that were required for the life-table analyses.[16 20] We did not identify the nationalities of the deceased from the data.

Patient and public involvement

Patients and or the public were not involved in this study.

Mortality rate and cause-specific YLL calculation

For the subject area, mortality rates were calculated as 5-year averages (ie, 2006–2010 and 2011–2015) based on the data shown in table 1. The national average was calculated for a single year (2010 and 2015) based on the death data for the Japanese population. The rationale and methodological details of the calculation of mortality rates are shown in online supplemental material.

The method to obtain the mortality rate of ages 1–94 was modified from method described by the MHLW,[16 20] and that of ages 0 and more than 95 was estimated based on method and parameters described by the MHLW.[16 20] LEs were obtained by life table analysis using the age-specific mortality rates for both the subject area and the national average. The YLL was obtained at ages 0, 40, 65 and 75. We focused on the older people aged 65 and 75 as Japan is a super-ageing society; hence, it would be important to distinguish the diseases that occur in for the younger from the diseases that occur in older people.[3]

We analysed the following causes of death: heart diseases (ICD10: I00–59), cerebrovascular diseases (I60–69), pneumonia (J10–19), and all cancers (C00–97). All cancers were specifically analysed for the following

Table 2 Life expectancy at birth (LE_0) based on calculated value and reported value for validation of the calculation method

	Males		Females		
	2010*	2015*	2010*	2015*	Reference
The subject area, calculated*	78.27	79.67	85.00	86.29	This study
The subject area, reported by MHLW†	78.78	80.84	85.97	86.12	[21 22]
National calculated	79.57	80.76	86.04	86.70	This study
National reported by MHLW	79.55	80.75	86.33	86.99	[3]

*For the subject area, the calculated periods were 2006–2010 and 2011–2015 instead of 2010 and 2015, respectively.
†Population-weighted average for Soma and Minamisoma cities.
MHLW, Ministry of Health, Labour and Welfare.

types: breast (C50, females only), colorectal (C18–C20), leukaemia (C90–C95), lung (C33–C34), stomach (C16) and uterine (C53–C55, females only).

Validation of the calculation method at LE at birth (LE_0)

LEs at birth (LE_0s) for the subject area were validated with official values calculated by the MHLW for Soma and Minamisoma cities separately.[21 22] LE_0s were officially reported by the MHLW for the Japanese national using complete life tables[12]; thus, we used these values to validate our estimates of LE_0s. As shown in table 2, our estimates of LE_0 were reasonably comparable for both the national average and the subject area, and small discrepancies were observed with the values obtained from the MHLW. The LE_0 increased after the disaster, which showed the same trend as that for the national average and the subject area.

YLL sensitivity analysis in the subject area

For the subject area, we performed a sensitivity analysis and estimated the uncertainty interval (UI) in addition to the point estimates of the YLLs. Since we observed annual variations in both population and mortality rates in the subject area, we assumed a normal distribution for these variations. In the subject area, which had a thousandth smaller cohort than the whole country, we considered that the annual variation in the population and the number of deaths were not negligible, and that it was better to indicate the YLL accompanied by UIs which were derived from using a 5-year average. The Monte Carlo simulation was conducted using a random number generation based on the 5-year average (2006–2010 and 2011–2015) and the SD for both the populations and crude mortality rates at age 0–94 years. The details of calculation procedure are shown in online supplemental material.

RESULTS

Cause-specific YLL for the subject area and the national average

Attributable YLLs for the subject area and the national average for heart diseases, cerebrovascular diseases, pneumonia and cancer are shown (figure 2A–D). Hereinafter, we refer to YLL at age 0 when we discuss YLL difference on the subject area and national average or at predisaster and postdisaster. Results at ages 40, 65 and 75 are shown in online supplemental figure S2. YLL decreased in the following order: cancer >heart disease >cerebrovascular disease >pneumonia, and this order was common for the subject area and the national average.

With respect to heart diseases and cerebrovascular disease, YLLs for the subject area were longer than YLLs for the national average for each age category and both sexes (figure 2A,C and online supplemental figure S2A). The YLLs of cancer for the subject area were shorter than the national average.

Differences in YLL predisaster and postdisaster were calculated (figure 2B,D and online supplemental figure S3A–F). For the national average, a difference was shown as a point-estimate value, and a value of more than 0 indicated postdisaster YLL improvement. For the subject area, a difference was observed with a value with a UI. If the UI did not include 0, there was a significant difference in YLL between predisaster and postdisaster. YLLs decreased after the disaster for both the national average and the subject area. This is commonly observed for males and females; however, the tendency of YLL decrease was different between sexes. Few characteristics were observed to be specific to the subject area. In contrast, statistically significant postdisaster YLL increases were not observed for any of the causes of death.

YLL attributed to heart diseases showed no decrease in males after the disaster (figure 2A) and YLL postdisaster was 0.37 years larger than that of the national average at age 0. The differences were −0.03 (95% UI: −0.28 to 0.23) and −0.17 (−0.40 to 0.05) years at ages 0 and 65, respectively (figure 2B and online supplemental figure S3B). In contrast, for females, it decreased after the disaster (figure 2C). The difference was 0.37 (0.18 to 0.57) years at age 0 (figure 2D), and the differences at ages 40 and 65 were 0.35 (0.16–0.55) and 0.26 (0.09–0.44) years, respectively (online supplemental figure S3D,E). These results showed an apparent improvement for heart diseases in females.

The YLL for cerebrovascular diseases decreased by 0.27 (0.09 to 0.44) years for males (figure 2B) and 0.18 (0.04 to 0.32) years for females (figure 2D), respectively, for the subject area after the disaster. These statistically significant YLL decreases were observed at ages 40, 65 and 75

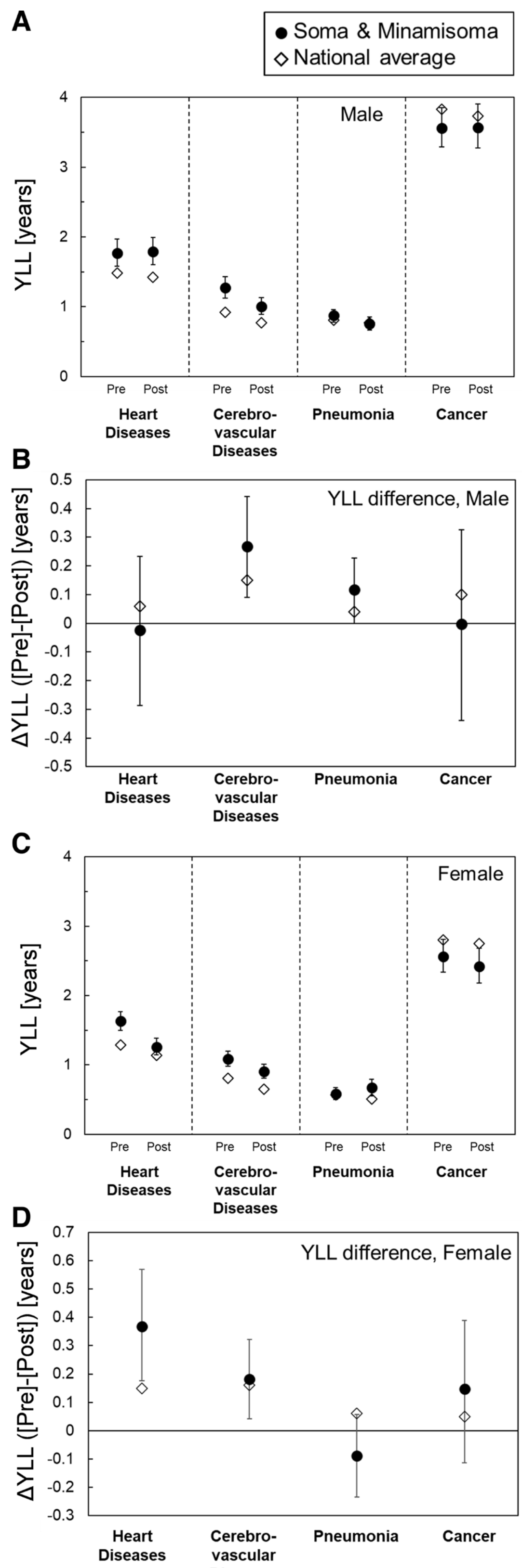

Figure 2 (A–D) YLLs for age 0 due to heart disease, cerebrovascular disease, pneumonia and cancer before and after the disaster. (A) Males; (B) difference of YLL ((predisaster) – (postdisaster)) of males. (C) Females; (D) difference of YLL females. For the subject area (Soma and Minamisoma cities), the error bar indicates the 95% UI of the estimate. YLL, years of life lost.

for both sexes (online supplemental figure S3). However, the YLLs postdisaster for the subject area were still 0.24 and 0.25 years larger than those for the national average for males and females, respectively.

For pneumonia, the YLL in the subject area was comparable to that of the national average. YLL due to pneumonia in males decreased in the postdisaster period (figure 2B) but did not decrease in females (figure 2D).

YLL attributed to cancer was the longest among the four causes of death, even at the age 75. The YLL due to all cancers showed little change after the disaster in both males and females, but YLL in the subject area was less than the national average.

Figure 3 and online supplemental figure S4 show the YLL breakdown for specific cancer types. As for stomach cancer (males) and leukaemia (females), the YLL for the subject area increased than that for the national average found predisaster (figure 3A,C). The YLLs due to lung cancer for both sexes predisaster, and for females postdisaster, were smaller than that for the national average. Although the difference between predisaster and postdisaster was small because of a small number of deaths due to these cancers, significant YLL decreases were observed for stomach cancer (males), breast cancer and leukaemia (females). The YLL differences of those were 0.15 (0.02–0.29) years (figure 3B), and 0.12 (0.00–0.24) and 0.14 (0.07–0.23) years (figure 3D), respectively. The YLL differences between predisaster and postdisaster for breast cancer and leukaemia (females) were larger than those for the national average while YLL decreases in the national average were hardly observed (figure 3D and online supplemental figure S5D–F).

DISCUSSION

We compared the cause-specific YLLs of a disaster-affected area in predisaster and postdisaster periods with that of the national average. Studies have discussed YLL in Fukushima prefecture[6] and age-adjusted mortality rate in the subject area[1 23]; however, our study provided YLL changes by cause of death and sex at the municipal level in a disaster-affected area. The YLL calculation methods used for the subject area and the national average were not identical due to the difference of population size and number of deaths in both cohorts; however, this methodological discrepancy should not have a great effect on the interpretation of the results.

Our YLL estimates were based on the actual number of deaths in the subject area; thus, the estimates were robust and realistic. Moreover, YLL estimates were more objective than disability-adjusted life-year (DALY) estimates because DALY estimates might require controversial processes of setting parameters, such as severity weights or durations of disability.[24] However, our analysis could not consider health outcomes other than death, such as the deterioration of quality of life (QoL). Another advantage of YLL is its versatile applicability for any age category in the region of interest. Thus, this index would

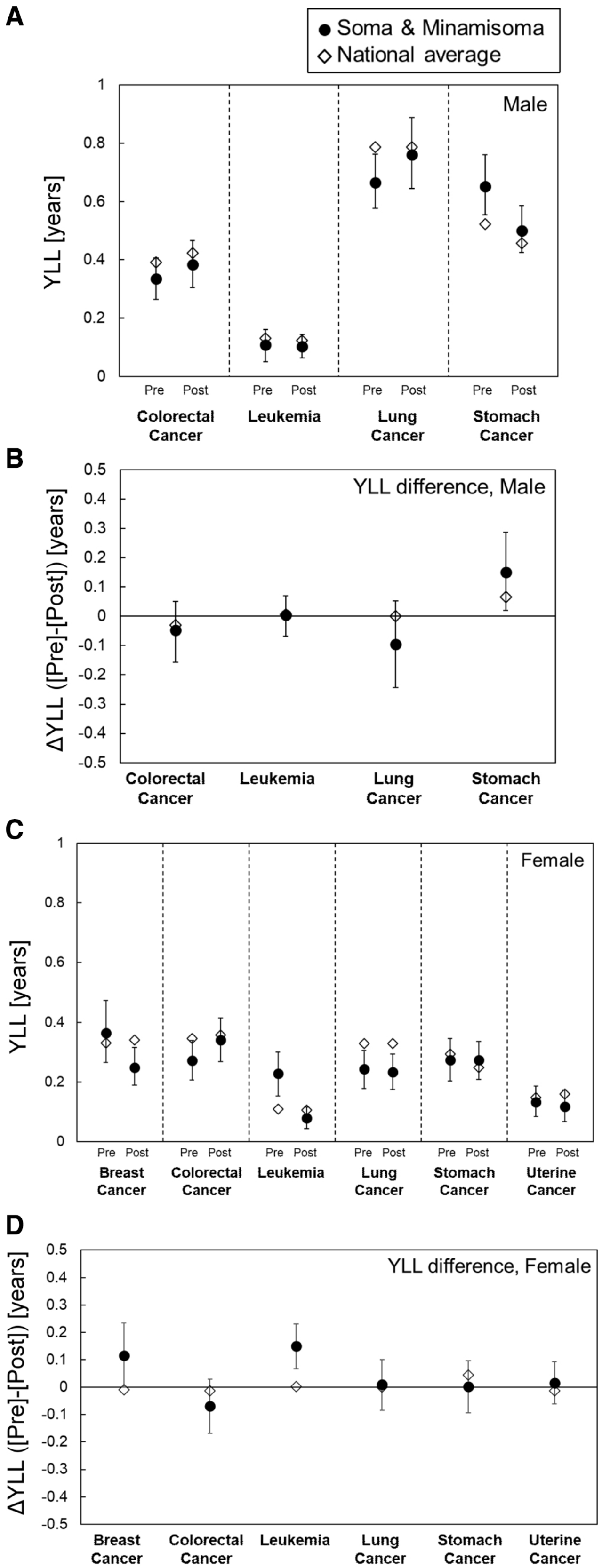

Figure 3 (A–D) YLLs for age 0 due to specific cancers. (A) YLLs of males; (B) Difference of YLL ((predisaster) – (postdisaster)) of males. (C) YLLs of females; (D) difference of YLL females. For the subject area (Soma and Minamisoma cities), the error bar indicates the 95% uncertainty interval (95% UI) of the estimate. YLL, years of life lost.

provide health planners and policy-makers at both the national and specific areas, more refined tools to adapt local public health initiatives to meet the health needs of local populations by age categories.[25]

We focused on four prominent causes of death as follows: heart disease, cerebrovascular disease, pneumonia and all cancers, and four (for males) and six (for females) specific major cancers. The primary finding of our study is that the YLL decreased in the disaster-affected municipalities in Fukushima for the prominent causes. Decrease in YLL was observed for heart diseases (females), cerebrovascular diseases (both sexes), pneumonia (males), breast cancer (females), leukaemia (females) and stomach cancer (males). This tendency was also reported in a previous study in which another public health index, the relative risk of mortality was used in the analysis.[1] The extent of YLL decrease is larger in the subject area than the national average for heart diseases (females at ages 0 and 40), pneumonia (males aged 65 and 75), and breast cancer (females at age 0) and leukaemia (females at age 0).

This study emphasised the importance of understanding how the health situation changed or how YLL has decreased for the whole society in disaster-affected areas, rather than focusing only on small mortality increases caused by radiation exposure, which was at statistically undetectable levels. Importantly, YLL attributed to cancer did not increase even after the nuclear disaster, irrespective of the concern about radiation exposure. The increase in radiation exposure due to nuclear accidents was limited in Fukushima, and cancer incidence related to radiation exposure from the nuclear accident, including thyroid cancer, has not been documented.[26] Furthermore, lifestyle changes due to the disaster did not seem to bring about an apparent increase in death within 5 years since the disaster. This might be because various medical countermeasures were implemented in the subject area. In contrast, an increase in the prevalence of lifestyle diseases has been reported in Fukushima.[27] The appearance of outcomes, such as death, derived from radiation exposure or lifestyle diseases, would be delayed after a long time. In this context, YLL estimates helped express how the health situation changed comprehensively. Residents in the disaster-affected area experienced various kinds of damage, such as physical, medical and mental damage, not only by radiation exposure. Therefore, an evaluation index that includes multiple viewpoints is effective. YLL is suitable at this point, and QoL may be also suitable.

Two reasons can explain the decrease in YLL postdisaster. One is the direct effect of earthquakes, tsunamis and aftermath, which might cause the premature death of people with chronic health problems. However, we observed both an apparent decrease in YLL and little change in YLL in chronic diseases. The extent of YLL changes differed according to the cause of death and by sex. Thus, premature death caused by the earthquake and tsunami for people with chronic health problems would explain only a part of the YLL decrease. For additional analysis, we calculated the YLL postdisaster separately for two periods. One is for 2011, that is, 'disordered period' of just 1year after the disaster and 2012–15, that is, 'recovered period' (online supplemental tables S1A,B). Focusing on the causes of death that had a ±0.3 years difference in YLL between 2011 and 2012–2015, we observed a YLL increase due to heart disease and cancer in males and a YLL decrease due to pneumonia in males. This means that the extent of YLL changes differed by cause of death and sex.

Elongation of LE (or decrease of YLL) is not explained only by elderly people's death because LE is calculated only from age-specific mortality rates. The other aspect to be considered is whether medical intervention or medical measures are in effect. The decrease in YLL could be due to both the medical measures taken before the disaster, which takes time to show an effect, and the measures taken after the disaster. The former is, for example, smoking cessation to prevent cancer or controlling salt intake to prevent cerebrovascular diseases. The latter is, for example, improving cancer screening and medical treatment techniques. This might be partly explained by the reduction of mortality in line with the application of new technologies or improved management of diseases such as all cancers.[28]

There might be many reasons for the decrease in YLL in the subject area. YLL decrease for heart diseases (females) and cerebrovascular disease (both sexes) could be due to improved medical treatment techniques, or the implementation of countermeasures by the municipal or prefectural government. YLL decrease in the cancers (breast cancer (females), leukaemia (females) and stomach cancer (males)) may be partly due to improvements in the municipal mass-screening system of cancers, or changes in the medical care system in the subject area.

Although these improvements were observed, YLLs for certain causes of death were longer than the national average, such as heart diseases (males) and cerebrovascular disease (both sexes). As for heart diseases in males at age 65, YLL showed a deterioration tendency after the disaster. Residences in the Tohoku area, including Fukushima Prefecture, have a high prevalence of heart disease and cerebrovascular disease. This may be caused due to local eating habits such as a diet with high salt content and a shortage of exercise due to high motorisation rates, which are common in the Tohoku area. In addition to these conditions, the disaster might worsen the situation in Fukushima. Thus, medical or societal measures to reduce death should be intensively studied. Possible measures would be to improve habits for preventing lifestyle diseases or close societal relationships to strengthen communication among residents.

In future, YLL estimation can be performed for the seashore area (Hamadori) or the entire Fukushima prefecture, where no evacuation area is included, for comparison purposes. The Hamadori includes mandatory evacuation areas, where the whole municipality was relocated to another place due to precautionary protection from high radiation doses. Residences have been experiencing drastic changes in their living status, such as repeated evacuation or living in temporary housing. They might have been facing more challenging conditions than those in the subject area of this study. The high degree of physical inactivity or lack of communication among residents may accelerate this challenging condition. Furthermore, relocation might affect access to hospitals or medical facilities. Our study could not consider these characteristics, and it would be important to compare YLL differences and changes between predisaster and postdisaster in these areas.

This study has some methodological limitations. The first is the uncertainty of the death data. Although death records have a universal, robust definition of the cause of death (ICD-10), they have the possibility of being misclassified and incomplete, particularly in an ageing population.[29] Second, we could not determine whether the populations and numbers of deaths in the data we used were sufficiently large in the subject area. We might discuss the appropriate population size for municipal-level analysis. We excluded causes of death with small numbers, such as suicide, from the analysis due to the lower plausibility of the result, and this might lead to an arbitrary selection of causes of death. The population data we used included the number of residents who moved their registrations outside the subject area, which might bring uncertainty. Furthermore, the reason for the decrease in the YLL may be more complicated and should be looked at in greater detail, taking into consideration effects other than medical, such as perception or behaviour changes on health pursuit after the disaster.

Although some technical limitations remain, this analysis, which clarifies the causes of death that had reduced YLLs and shows the degree of potential improvement of public health in that area, and will facilitate prioritisation for local health control policy and better resource allocation. The results can be useful to assess the performance of the medical (or societal) measures that the municipal, prefectural or national government emphasised before the disaster.

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Contributors Conceptualisation: KO, MM and MT; Data curation: KO, MM and MT; Formal analysis: KO; Funding acquisition: MM and MT; Investigation: KO, MM and

MT; Methodology: KO and MM; Visualisation: KO; Writing (original draft): KO; Writing (review and editing): KO, MM and MT; Guarantor: KO.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Data acquisition and use for this study were approved by the Ethics Board of Fukushima Medical University (approval number: 30272).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request. Data may be obtained from a third party and are not publicly available. The data were obtained from MHLW and are not publicly available, however, data are available on reasonable request to MHLW.

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Supplemental Material

Title

Was there an improvement in the years of life lost (YLLs) for noncommunicable diseases in the Soma and Minamisoma Cities of Fukushima after the 2011 disaster?: A longitudinal study

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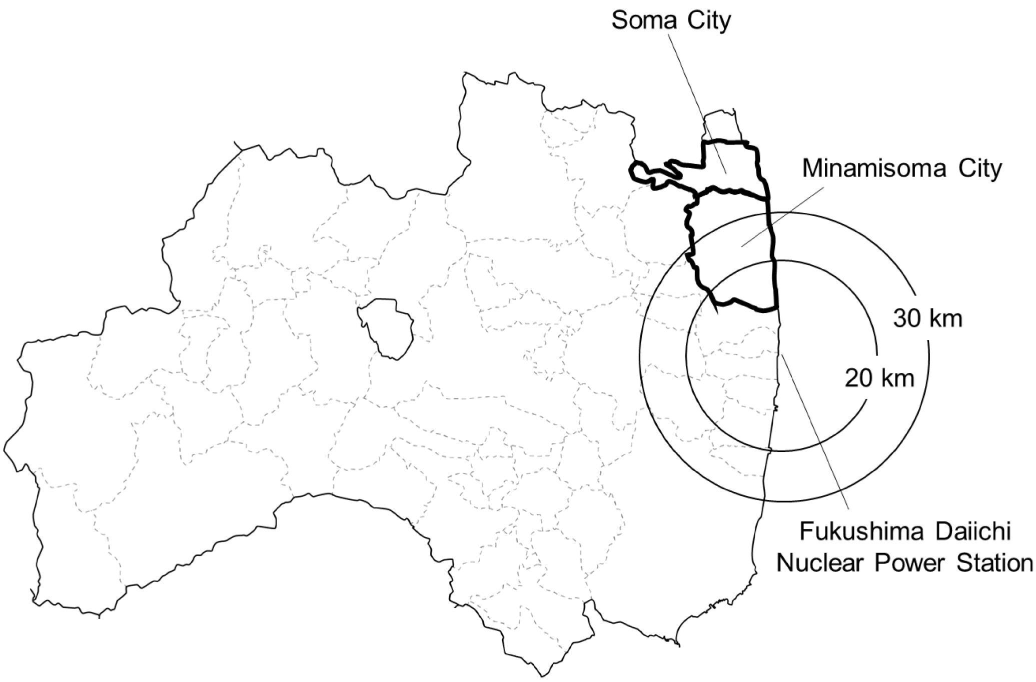

Figure S1. Location of Soma City and Minamisoma City.

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MATERIALS AND METHODS

Rationale of calculation for life expectancy (LE) and years of life lost (YLL)

Life expectancy (LE) is an index of the health status of a cohort, which is calculated from the age-specific mortality of a specific cohort over a given period using the life table method. This measure emphasizes the impact of deaths occurring in younger age groups compared to the relative risk or hazard of mortality.[1] YLL is the difference in LE between a cohort with a specific cause of death and for the cohort in which the cause of death was eliminated. YLL is a population outcome of social health. For example, the Global Burden of Disease studies [2] adopted the YLL as an index of regional health.

LE can be calculated from the age-specific mortality rates (life table analysis). Using the death data and population data, we conducted a life-table analysis for the subject area and the national average of Japan, respectively. The life table consists of the mortality rate, number of surviving population l, number of deaths d, age-specific mortality q, which is obtained by dividing number of deaths by the number of the surviving population, and total survival time of population T.

A conceptual diagram of the YLL is shown in Figure 1. A detailed explanation of the calculation of LE and YLL has been provided elsewhere.[3] Generally, an LE at age x is the value of how long a person survives on average in the population after age x. Survival at age x is described by the mortality rate at age x. LE can be obtained by dividing the total survival time of the population.

$$T_x = \int_x^{\infty} l_t dt \qquad \text{(eq. 1)}$$

Here, T_x [unit: person-years] is the total survival time of the population after age x by the population l_x at age x. LE at age x; e_x [unit: years] is obtained as

$$e_x = \frac{T_x}{l_x} \qquad \text{(eq. 2)}$$

YLL_x was defined as the difference of e_x between a risk event (e_x') and without a risk event (e_x) at age x:

$$YLL_x = e_x - e_x' \quad \text{(eq. 3)}$$

YLL can be estimated for any risk event that causes additional mortality. YLL can be estimated for any population if the survival probabilities are available for the population.

Mortality rate

We obtained the mortality rate of patients aged 1–94 years using the following concept. Based on the basics of human demographics that normalized the mortality rate of age, which is the ratio of the number of deaths at the age of *x* in an arbitrary year to the number of population (survivals) at the age of *x* in the middle of the year. In the formula,

$$q_x = \frac{d_x}{l_x + \frac{d_x}{2}} \qquad \text{(eq. 4)}$$

where q_x is the mortality rate at age *x*. If death occurs at a constant rate, the number of population at age *x* at the beginning of the observation period should be $l_x + d_x/2$. For the right side of (eq.4), divide both the numerator and denominator by l_x and replace d_x/l_x as m_x.

$$\frac{d_x}{l_x + \frac{d_x}{2}} = \frac{\frac{d_x}{N_x}}{\frac{l_x}{l_x} + \frac{d_x}{2 \times l_x}} \quad \text{(eq. 5)}$$

$$q_x = \frac{m_x}{1 + \frac{m_x}{2}} \qquad \text{(eq. 6)}$$

where q_x is the mortality rate at age *x*, *and* m_x is the crude mortality rate at age *x*. Thus, we calculated q_x using (eq. 6) for further analyses. We calculated mortality rates at age *x* with risk events (q_x') in the same way using cause-specific death data.

The mortality rates at age 0 were adopted as national values for 2010 and 2015, respectively. Both were reported by the MHLW.[4,5] The birth data of the subject area did not include details on the month of birth or death for babies at age 0. Generally, the baby cohort has a large change in mortality over a short period of time. Thus, monthly life table data should be used for these analyses, but we could not do so due to limited data availability at age 0. Therefore, we adopted national data to calculate q_0 for the subject area. Although this assumption for the age 0 might cause a discrepancy in YLL because YLL weighs heavily on younger age, we assumed the discrepancy was negligible by using the national data instead of data of the subject area. At ages over 95 years, we used the force of mortality instead of q_x. This assumption is commonly used for national averages and subject areas. The force of mortality was based on Gompertz–Makeham coefficients obtained from the MHLW [6,7] because of the large annual variability of *q* in this age range because the number of deaths for the population is small. This assumption on mortality rates for the elderly, such as for an age over 95 years, has little effect on the calculated results of LE.

Methodological details of sensitivity analysis on YLL in the subject area

We performed a sensitivity analysis for the subject area. The Monte Carlo simulation was conducted using a random number generation based on the 5-year-average and standard deviation for both the populations and crude mortality rates at age 0–94 years before the calculation of the mortality rates. The uncertainty interval (UI) was estimated according to the following procedure:

Oracle Crystal Ball ver.11.1 was used for the Monte Carlo simulation. We used two-sided truncated normal distributions for crude mortality rates to avoid a random selection of crude mortality rates of less than 0. Thus, the distributions were set as symmetrical, around the average, with the lower limit being 0 and the upper limit being two times the average. The Excel add-in "NTTRUNCNORMINV" function in NtRand Ver 3.3.0 [8] was combined with the Monte Carlo simulation. Sampling was performed according to the Latin hypercube method, and the number of trials was set to 10000 times. Random numbers were generated for all the causes of death and for each specific cause of death, separately, and the calculation of YLL was conducted at each trial. At age 0 and at ages over 95 years, we assumed no distribution for the force of mortalities.

We performed an additional Monte Carlo simulation with the condition that the mortality rate q was less than 0 (no truncated option) for validation. We confirmed that the change in the median was approximately 3% for the absolute value of YLL and the truncated assumption rendered the median change into both higher and lower values. Although the range of the UIs was broadened, it was confirmed that the conditions with and without the truncated option did not affect the results significantly.

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YLL and its difference at ages 40, 65 and 75

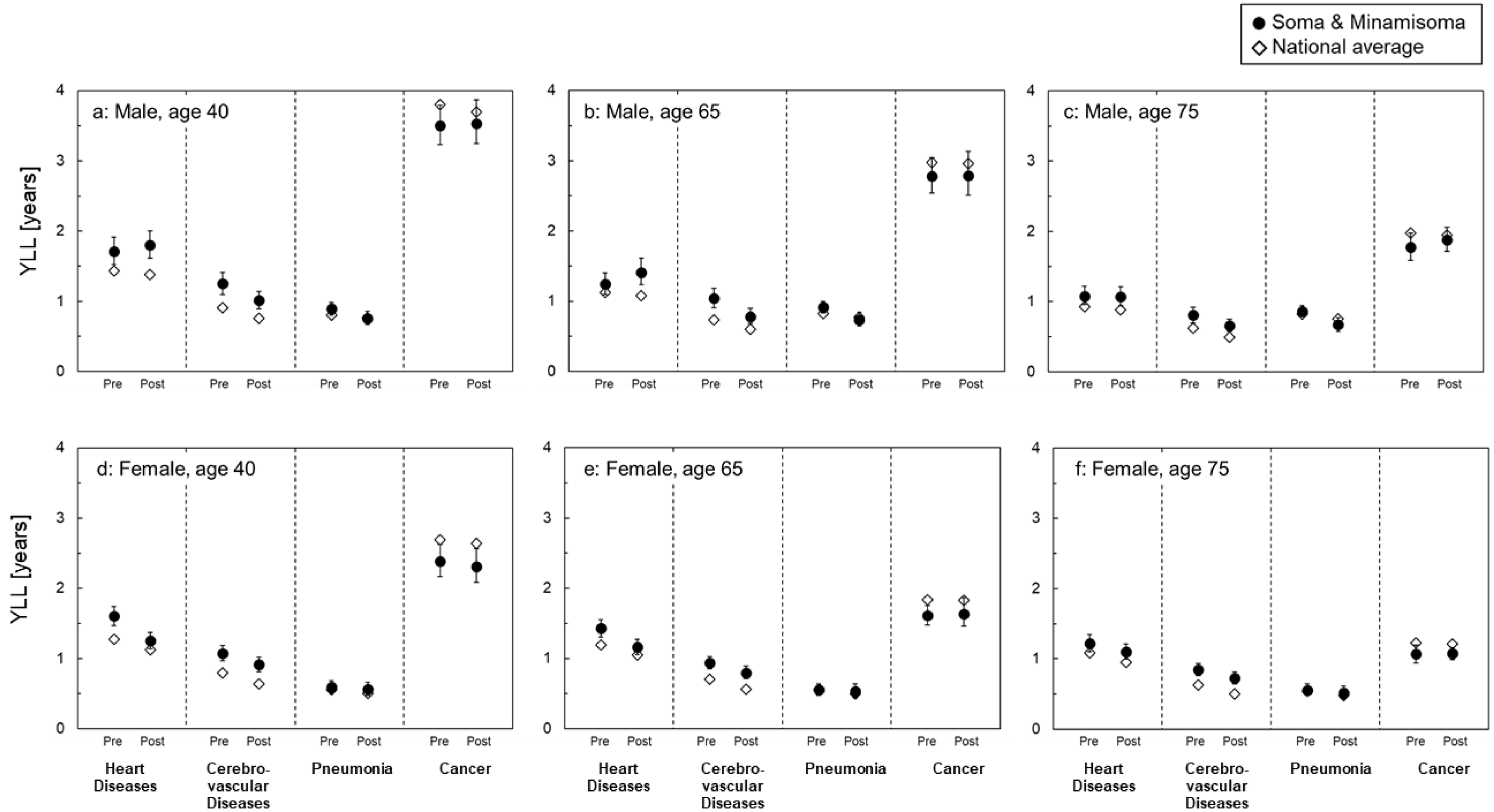

Figure S2a-f. YLLs due to heart diseases, cerebrovascular diseases, pneumonia, and cancer before and after the disaster of ages 40, 65 and 75 (a–c: Males, d-f: Females). For the subject area (Soma and Minamisoma cities), the error bar indicates the 95% uncertainty interval (95% UI) of the estimate.

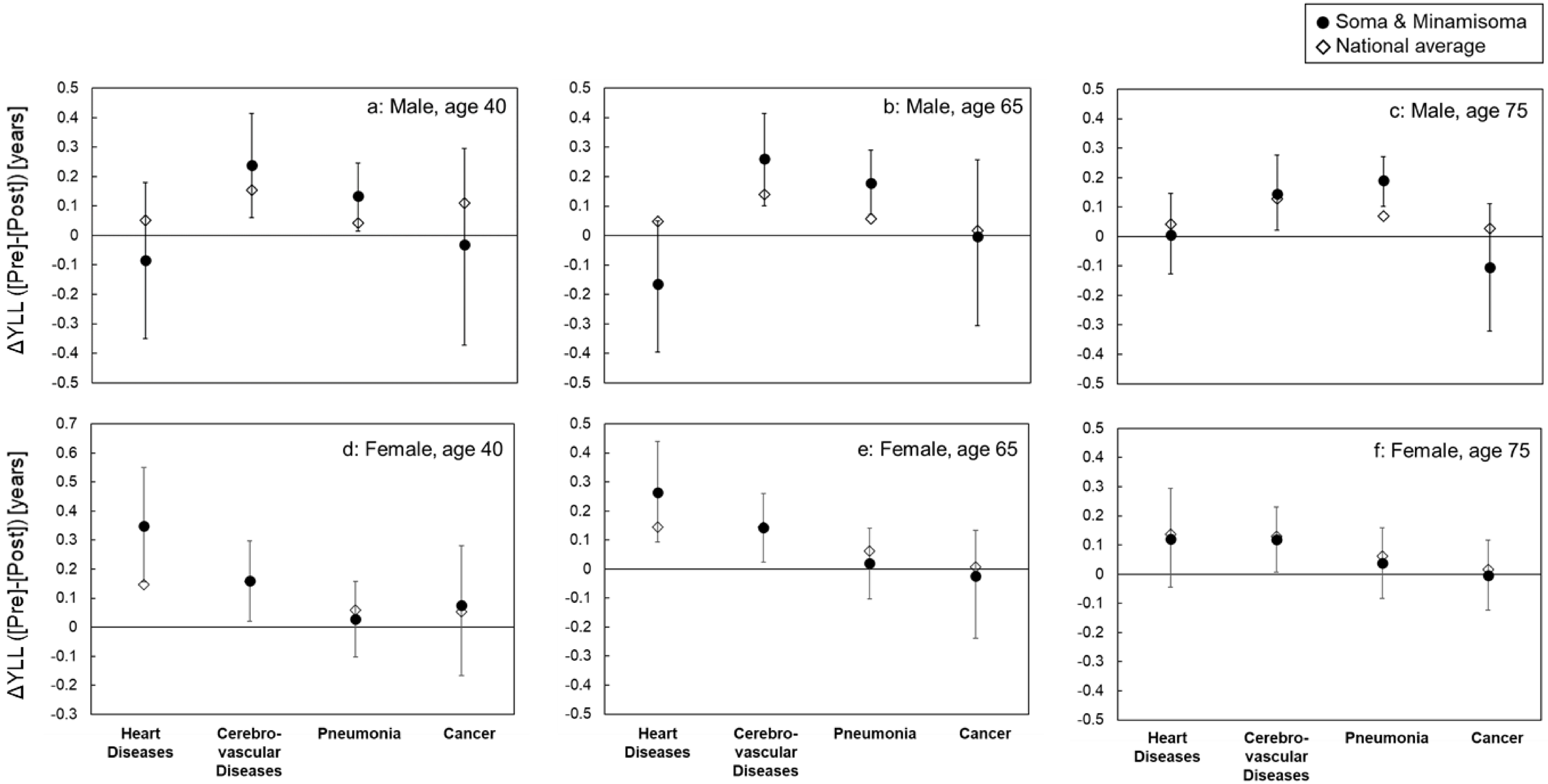

Figure S3a-f. Differences between YLL pre-disaster and YLL post-disaster due to heart diseases, cerebrovascular diseases, pneumonia, and cancer at ages 40, 65 and 75 (a –c: Males, d–f: Females). For the subject area (Soma and Minamisoma cities), the error bar indicates the 95% UI of the estimate.

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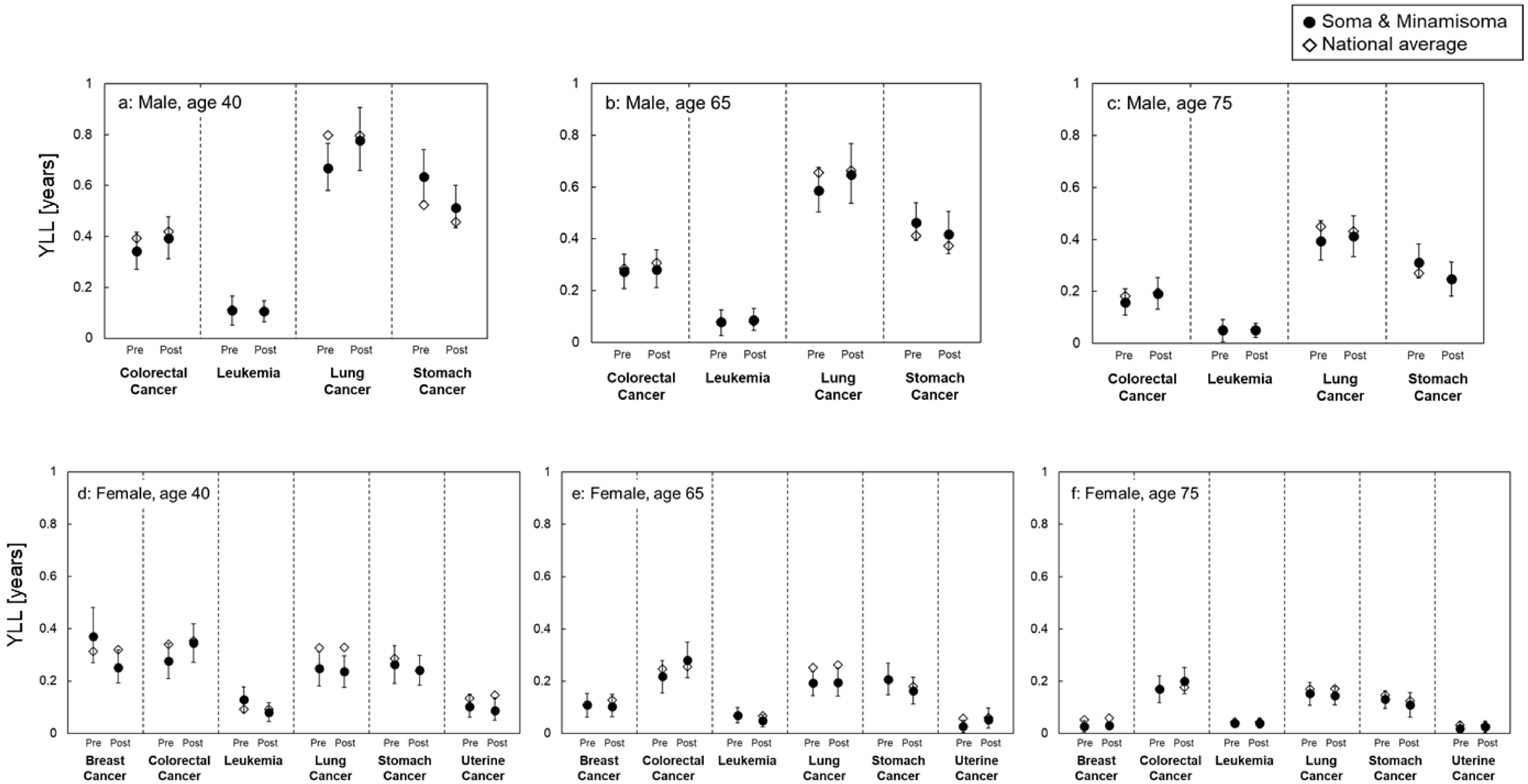
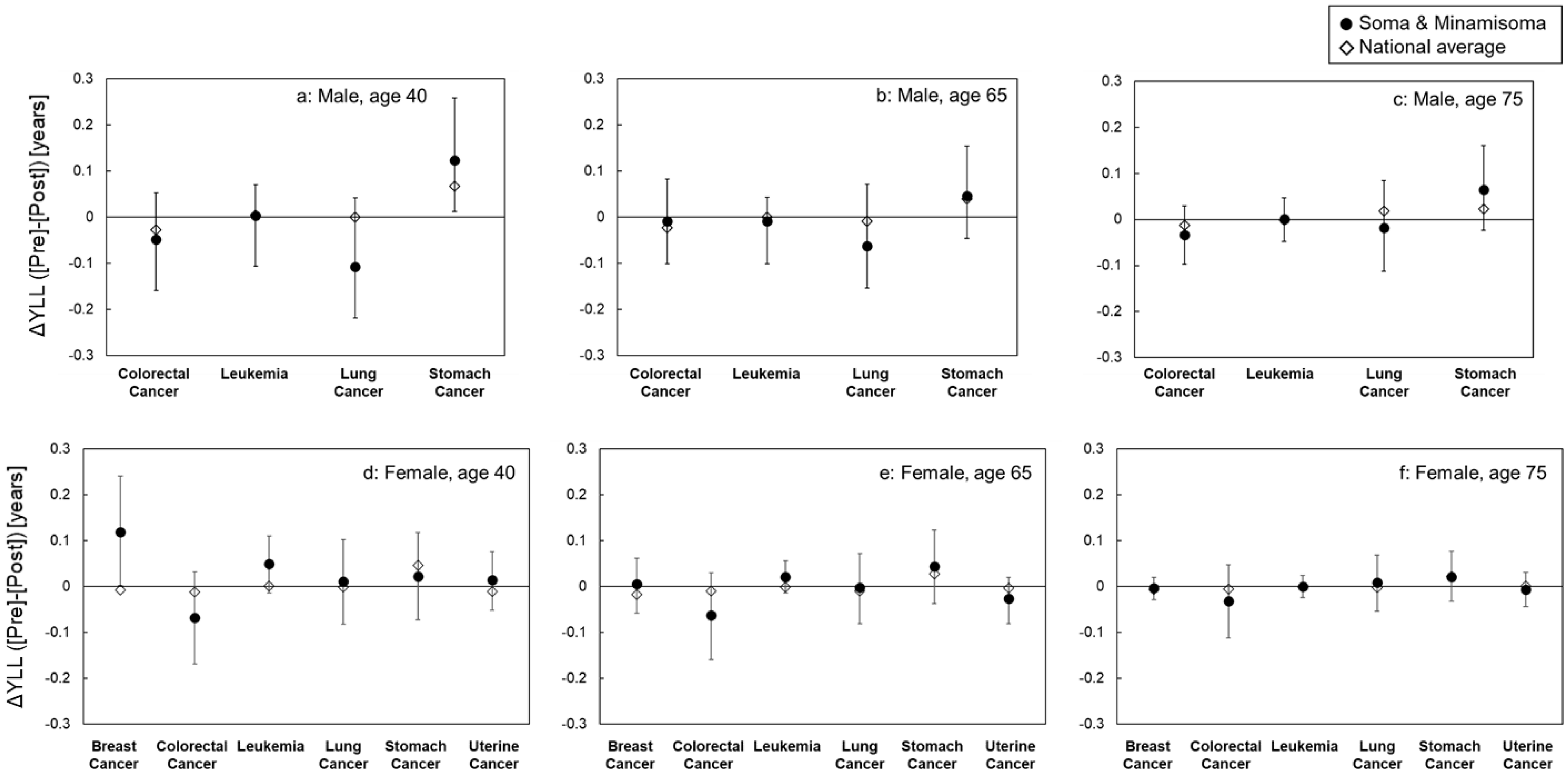


Figure S4a-f. YLLs due to specific cancers before and after the disaster at ages 40, 65 and 75 (a–c: Males; colorectal cancer, leukemia, lung cancer, and stomach cancer. d-f: Females, breast cancer, colorectal cancer, leukemia, lung cancer, stomach cancer and uterine cancer.). For the subject area (Soma and Minamisoma cities), the error bar indicates the 95% uncertainty interval (95% UI) of the estimate.



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139 Figure S5a-f. Differences between YLL pre-disaster and YLL post-disaster due to specific cancers at ages 40, 65 and 75 (a –c: Males, d–f:
140 Females). For the subject area (Soma and Minamisoma cities), the error bar indicates the 95% UI of the estimate.

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YLL at the year of the disaster (2011) and after the year of the disaster (2012–2015)

We calculated the YLL post-disaster separately for two periods, i.e. 2011 and 2012–2015 (Tables S1a and S1b). For YLL in 2011, we used population data and death records for a single year (2011) and calculated the values. Similar to that for YLL in 2012–2015, we used population data and death records for the four years and calculated the values. The UI of the estimation was not calculated. The mortality rate at age 0 followed the national values in 2015, both reported by the MHLW.[5] For ages over 95 years, we used the force of mortality instead of q_x. The force of mortality was based on the Gompertz–Makeham coefficients obtained from the MHLW.[7]

Table S1a. YLL at the year of the disaster (2011) and after the year of the disaster (2012–2015) [years]: Males

	Age 0 years		Age 40 years		Age 65 years		Age 75 years	
	2011	2012–2015	2011	2012–2015	2011	2012–2015	2011	2012–2015
Heart diseases	1.53	1.86	1.57	1.86	1.37	1.41	1.00	1.10
Cerebrovascular diseases	1.08	0.98	1.05	1.00	0.84	0.76	0.77	0.64
Pneumonia	1.05	0.69	1.08	0.69	1.02	0.67	0.90	0.61
Cancer	3.24	3.62	3.19	3.60	2.26	2.90	1.65	1.95

Table S1b. YLL at the year of the disaster (2011) and after the year of the disaster (2012–2015) [years]: Females

	Age 0 years		Age 40 years		Age 65 years		Age 75 years	
	2011	2012–2015	2011	2012–2015	2011	2012–2015	2011	2012–2015
Heart diseases	1.33	1.24	1.33	1.22	1.28	1.12	1.22	1.06
Cerebrovascular diseases	0.87	0.91	0.88	0.92	0.68	0.82	0.70	0.73
Pneumonia	0.61	0.68	0.62	0.54	0.60	0.51	0.62	0.48
Cancer	2.26	2.44	2.11	2.34	1.43	1.67	0.86	1.13

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