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# Evacuees and Migrants Exhibit Different Migration Systems After the Great East Japan Earthquake and Tsunami

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## Abstract
Research on the destinations of environmentally induced migrants has found simultaneous migration to both nearby and long-distance destinations, most likely caused by the comingling of evacuee and permanent migrant data. Using a unique data set of separate evacuee and migration destinations, we compare and contrast the pre-, peri-, and post-disaster migration systems of permanent migrants and temporary evacuees of the Great East Japan Earthquake and Tsunami. We construct and compare prefecture-to-prefecture migration matrices for Japanese prefectures to investigate the similarity of migration systems. We find evidence supporting the presence of two separate migration systems—one for evacuees, who seem to emphasize short distance migration, and one for more permanent migrants, who emphasize migration to destinations with preexisting ties. Additionally, our results show that permanent migration in the peri- and post-periods is largely identical to the preexisting migration system. Our results demonstrate stability in migration systems concerning migration after a major environmental event.

**Keywords** Great East Japan Earthquake · Migration systems · Fukushima · Hurricane Katrina · Displacement

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## Introduction

Environmentally induced migration and displacement is a key concern of global environmental change (Black et al. 2011; Field et al. 2014; Findlay 2011; Hugo 2011; Mueller et al. 2014), with climate change expected to spur migration and displacement (Gray and Wise 2016; Warner et al. 2009). How this environmentally induced migration differs from more general migration is of key importance to understanding and modeling potential population shifts associated with climate change this century (Rigaud et al. 2018).

Migration in response to environmental stressors oftentimes depends on the type of stressor (Gutmann and Field 2010; Hunter et al. 2013; Thiede and Brown 2013). Previous studies have shown that migration and displacement from rapid-onset environmental events (such as tropical cyclones) lead to a dichotomous spatial concentration of migration toward nearby areas (Curtis et al. 2015; Kayastha and Yadava 1985) and long-distance migration toward far-away areas (Hori et al. 2009). We contend that this dichotomy results from two distinct migration pathways operating simultaneously: an evacuee pathway and a more permanent migration pathway. We define *evacuees* as those who primarily make temporary, short-distance migrations; we define *migrants* as those who primarily leverage preexisting migration networks to make more permanent migration moves. Rectifying this dichotomy will allow for better modeling of environmental migration, but because of data limitations, post-disaster migration studies typically have analyzed evacuees and migrants in a single migration datum.

The Great East Japan Earthquake and Tsunami in March 2011, which ultimately led to the failure of the Fukushima-Daiichi nuclear plant, prompted the Japanese government to capture temporary evacuee migration in a new data ecosystem—the Nationwide Evacuee Information Exchange System—separate from the permanent migration universe. In combination with the official migration statistics, this provides a unique opportunity to parse environmental migration into permanent and temporary classifications. This unique data ecosystem allows us to empirically compare and contrast the migration pathways of permanent migrants and evacuees to address the dichotomous migration pathways observed in literature.

In this study, we focus on the destinations of migrants and evacuees after the Great East Japan Earthquake and Tsunami, and we situate our results within Allan Findlay's six principles governing migration (Findlay 2011). In particular, we take a migration systems approach to answer two fundamental questions about environmental migration. First, did the disaster alter the destinations of out-migrants from the affected region? Second, do evacuees and migrants share migration systems with the pre-disaster migration system and with each other? The parsing of evacuees from migrants in the Japanese data collection system allows for a novel approach in understanding post-disaster migration. Because of our unique data sets, we can distinguish and compare the migration systems of evacuees and migrants in response to an acute natural disaster. Our results show that (1) as expected, the earthquake and tsunami increased the overall migration out of the region, but that (2) the destinations of more permanent migrants closely follows the pre-disaster, embedded migration system and (3) evacuees exhibit markedly different destinations, tending to travel short distances.

## Great East Japan Earthquake and Tsunami

On March 11, 2011, a magnitude 9.0 earthquake occurred off the east coast of Japan—the most powerful earthquake on record in that country and the fourth most powerful in the world since record-keeping began in 1900 (U.S. Geological Survey 2014). This event triggered a tsunami that was, on average, 10m high and up to 40m in height in some places (Sawa et al. 2013), killing 15,871 people and injuring 6,114 more. An additional 2,778 people were still missing and presumed dead up two years after the earthquake (Hasegawa 2013). Financial damages were estimated near \$160 billion (\$US2011), with more than 300,000 residential buildings damaged (International Medical Corps 2011; Takano 2011). The disaster culminated with an accident at the Fukushima-Daiichi nuclear plant where, as of this writing, the long-term implications of the plant's failure are still unknown. Japanese Prime Minister Naoto Kan called it "Japan's worst crisis since the second world war" (Branigan 2011), and the damages make it the second largest natural disaster in Japan's modern history. Within three days of the earthquake, an estimated 468,000+ people sought temporary refuge from the disaster. By December 2011, just eight months after the incident, 92,712 Fukushima residents remained evacuated, 33,943 of whom were still living inside the prefecture (International Medical Corps 2011).

Iwate and Miyagi Prefectures felt the brunt of the earthquake and ensuing tsunami (Fig. 1). Fukushima Prefecture, south of Miyagi, is home to the Fukushima-Daiichi nuclear plant, where the cooling functions of the reactors failed, resulting in a meltdown of the nuclear fuels and leakage of radioactive materials into the local environment (Takano 2011). These three prefectures accounted for approximately 82% of the damaged fishing ports, nearly 91% of the damaged fishing boats, and 84% of the lost aquaculture due to the earthquake and tsunami (Takano 2012). The majority of the casualties and evacuees were also concentrated in these three prefectures (Isoda 2011).

Although much of the migration from the diaspora has been temporary, more permanent changes to Fukushima's migration were felt almost immediately. Prior to the earthquake, the prefecture was already experiencing depopulation (Matanle 2013). However, out-migration from Fukushima increased by 70% between 2010 and 2011, while in-migration fell by 15%. This caused a change in the total net migration from –5,752 persons in 2010 to –31,381 in 2011, more than a fivefold increase in net out-migration in a single year (Statistics Bureau Japan 2011). The disaster caused a Japan-wide diaspora of residents most affected by the tsunami and nuclear plant failure. All Fukushima Prefecture residents within 20km of the plant were instructed to evacuate within four days of the earthquake. Residents between 20km and 30km were advised to voluntarily evacuate (National Research Council 2014).

Figure 2 shows the geographic distribution of out-migrants from Fukushima, Iwate, and Miyagi Prefectures in 2010 and 2011. Table 1 reports the top five destinations from these prefectures. The Fukushima and Miyagi Prefectures experienced much larger out-migrations between 2010 and 2011, while Iwate experienced a much more modest increase (22,131 in 2010 to 22,199 in 2011). The general destinations are relatively similar between the two periods as well. As Table 1 shows, the top five destinations in 2010 were also the top five destinations in 2011, even if both the magnitude of out-migration and the exact ranking are different.

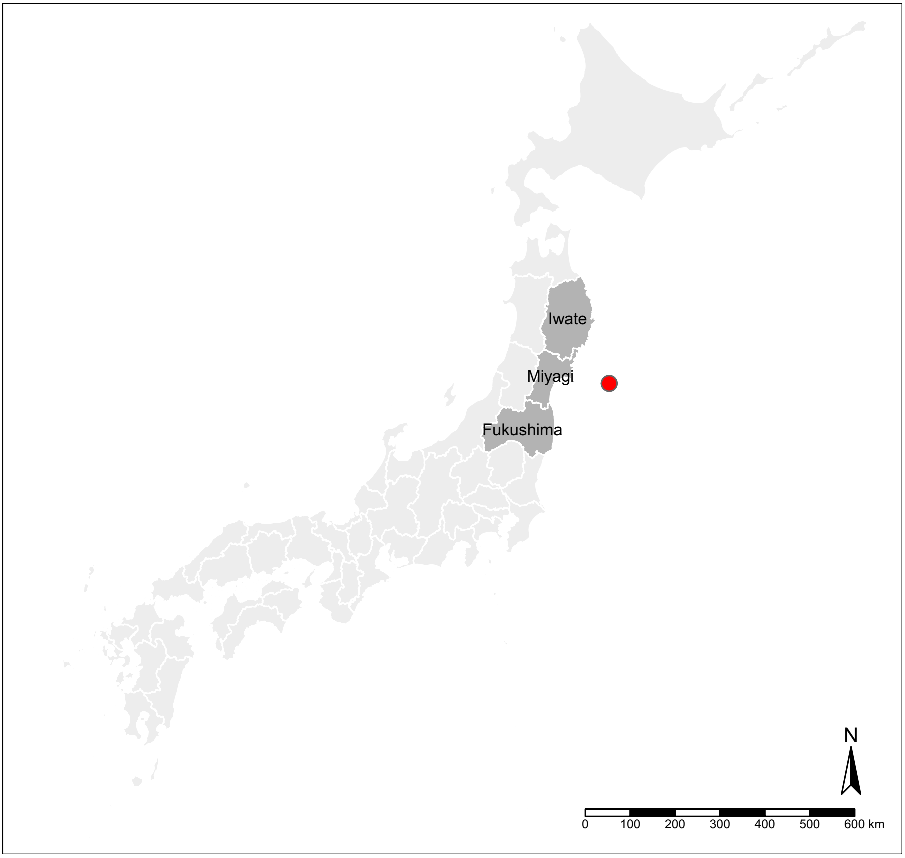


**Fig. 1** Japanese prefectures. The red point is the location of 2011 earthquake. The three most impacted prefectures (Fukushima, Iwate, and Miyagi) are highlighted.

Additionally, Japan created a unique data collection system for processing evacuees from the disaster. These evacuees are captured in a separate data collection system and are not a part of the official migration statistics. By law, all Japanese nationals are required to register their residency. However, many evacuees are unwilling to report their relocation, hoping to return home. The Japanese Ministry of Home Affairs set up a new system following the tsunami and nuclear reactor disaster for evacuees that allows a resident to maintain their residency in their home prefecture while presently living in a different prefecture. Thus, evacuees from Fukushima Prefecture living in a nearby prefecture are still counted as residing in Fukushima in the official population estimates of the Ministry of Home Affairs while appearing in a nationwide evacuee database at their present prefecture. Although these data streams are not antiseptically "clean" from data problems, including double counting, we are confident that they are valid enough to warrant the analysis to which we subject them. We describe the National Evacuee Data System in greater detail in the Data and Methods section.

Separating migrants from evacuees allows us to examine whether the two share a similar migration system. We expect that evacuees will move to destinations near their place of origin, whereas permanent migrants will follow social and human capital

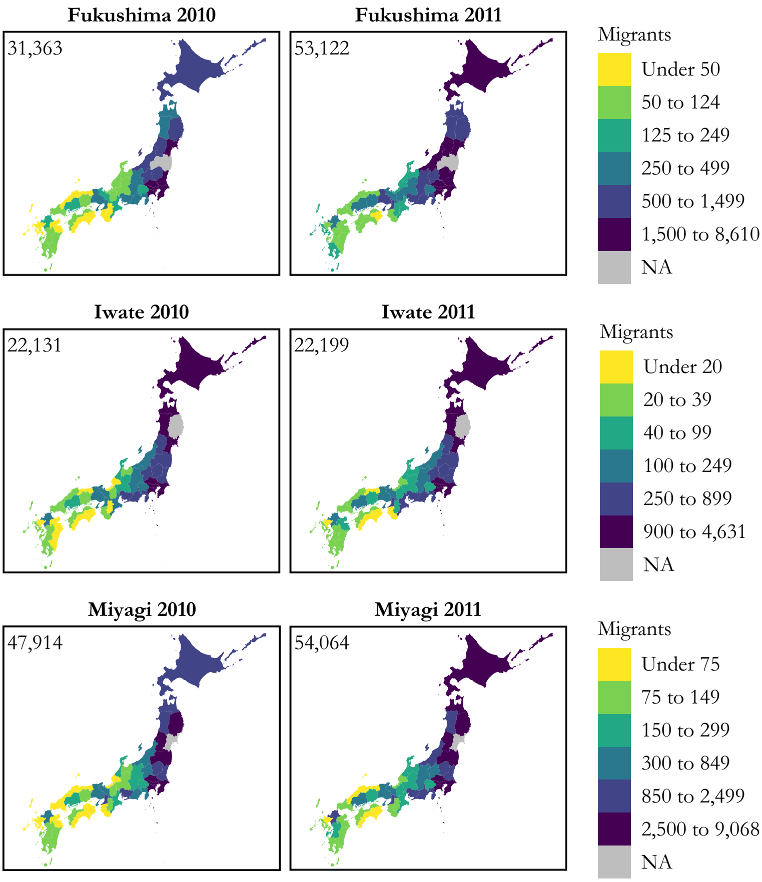


**Fig. 2** Out-migration from Fukushima, Iwate, and Miyagi Prefectures, 2010 and 2011. We report the total number of out-migrants in the corner of each panel for each prefecture-year.

pathways. Our analysis compares the permanent migration system with the evacuee system of Fukushima residents. The permanent migration system data come from official Japanese government counts. To capture the evacuee migration system, we take the number and locations of evacuees from Fukushima Prefecture in June 2011 from Takashi Oda's *Grasping the Fukushima Displacement and Diaspora* (2011) and compare them with the 2004–2016 permanent migration data from the Statistics Bureau of Japan.

## Environmental Migration

When examining environmental migration, the effect that an environmental pressure has on a migration system largely depends on the type of pressure. Droughts, tropical cyclones, and tsunamis all affect a migration system differently. For instance, droughts might generate migrants but generally do not generate evacuees, whereas tropical cyclones and tsunamis can generate both. Similar research on the displacement of populations from flooding in India has found that displacements tend to be localized,

**Table 1** Top five destinations for Fukushima, Iwate, and Miyagi Prefectures

| Origin | Destination | Migrants 2010 | Migrants 2011 |
|---|---|---|---|
| Fukushima | Tokyo | 6,386 | 8,610 |
| | Miyagi | 5,099 | 7,133 |
| | Saitama | 2,688 | 4,727 |
| | Kanagawa | 3,103 | 4,611 |
| | Chiba | 2,275 | 3,164 |
| Iwate | Miyagi | 4,631 | 4,213 |
| | Tokyo | 3,734 | 3,726 |
| | Kanagawa | 1,974 | 1,968 |
| | Aomori | 1,980 | 1,929 |
| | Saitama | 1,501 | 1,711 |
| Miyagi | Tokyo | 8,407 | 9,068 |
| | Kanagawa | 4,347 | 4,698 |
| | Iwate | 3,654 | 4,603 |
| | Saitama | 4,023 | 4,120 |
| | Fukushima | 4,191 | 3,491 |

*Note:* We show the numeric top five destinations in 2010 and 2011. For all three prefectures, the top five contain the same destination prefectures in 2010 and 2011, although the exact ordering might be slightly different.

with migration along short distances in search of safer areas (Kayastha and Yadava 1985). Studies on Hurricane Katrina's impact on the Gulf Coast of the United States found similarly large out-flows to nearby areas with some migration to distant locations (Curtis et al. 2015; Frey et al. 2007; Hori et al. 2009; Stone et al. 2012). These studies examined the geography of displacement, but they provided little or no temporal comparison with the pre-event migration system and did not distinguish evacuees from migrants.

Allan Findlay's (2011) six principles governing migration provide key insights for understanding both evacuees and migrants.[1] These six principles can be summarized into three main findings: (1) potential migrants prefer to stay in their current residence, often called the *immobility paradox*; (2) if people do move, they tend to move short distances; and (3) human capital and preexisting ties play a large role in determining destinations. We anticipate that evacuees tend to migrate short distances, whereas permanent migrants will leverage human capital and preexisting ties in their location decisions.

Gutmann and Field (2010) developed a useful framework for understanding environmental effects on migration and have identified four types of environmental factors that influence migration: (1) environmental calamities, such as floods,

[1] Findlay's six principles are (1) most migrants want to stay in their current place of residence; (2) people tend to move over short distances rather than longer distances; (3) people do not always move to the most attractive destination but live/work nearer rather than farther; (4) attraction to destinations can be interpreted as increased income or returns to human capital; (5) destination selection is shaped by preexisting social and cultural connections; and (6) destinations can be viewed as attractive because of the social and cultural capital they offer.

hurricanes, and earthquakes; (2) environmental hardships, such as drought or short periods of favorable weather; (3) environmental amenities, such as warmth, sun, or proximity to mountains and water; and (4) environmental barriers, such as heat, air conditioning, and irrigation. This framework for environmental migration can be used to place historically significant environmental events of the twentieth century into analytically useful categories. The list of environmental events or impacts is long and wide—for example, the American Dust Bowl of the 1930s, with migration from U.S. Midwest to California (McLeman and Smit 2006); air conditioning, making the U.S. Sun Belt a more attractive destination (Borts and Stein 1964; Graves 1980); and Hurricane Katrina, with its large population displacement (Fussell and Elliott 2009).

These typologies—combined with Findlay's six principles—provide a robust framework for organizing research on environmental migration, yet previous research on environmental migration has been dominated by "who?" and "what?" questions. For example, many studies have focused on who moves (Hori et al. 2009; Rivera and Miller 2007) and who returns (Groen and Polivka 2010; Stringfield 2010; Thiede and Brown 2013). Much of the literature has overlooked questions surrounding migrant destinations, leading to a gap in knowledge about how environmental events affect migration systems and patterns over time. The Great East Japan Earthquake and Tsunami is an environmental calamity, as identified by Gutmann and Field (2010), with a data ecosystem that allows us to apply Findlay's (2011) six principles to two distinct populations in order to examine the similarities and differences in the destinations of evacuees and migrants. Based on Findlay's framework, we expect that migrants will emphasize principles 4–6 regarding social capital and preexisting ties but that evacuees will emphasize principles 2 and 3 regarding short-distance moves.

Migration systems theory (MST) is a branch of migration research that uses all origin-destination combinations as the object of study as opposed to any single origin-destination pair (DeWaard et al. 2012; Fawcett 1989; Massey et al. 1994). A systems approach posits that when one place experiences a change, the effect is manifested throughout the system. Migration decisions—not just decisions to migrate, but also location decisions—are often driven by the presence or absence of human capital as well as macro factors, such as labor force, economic vitality, anticipated increases in living standards, and both natural and economic amenities (Fawcett 1989; Haug 2008; Lee 1966; Pandit 1997; Thiede and Brown 2013). This network of human capital embedded within the migration system tends to drive locational decision-making in the aftermath of environmental events (Findlay 2011; Gray and Bilsborrow 2013; Hugo 2008, 2011; McLeman 2013; Schultz and Elliott 2013).

MST has been explicitly tied to environmental migration in recent years (Curtis et al. 2015; DeWaard et al. 2012; Fawcett 1989), with research examining both the stability of such systems (DeWaard et al. 2012) and altered systems (Curtis et al. 2015; Fussell et al. 2014). We build on this previous research and employ MST to explore the stability of the Japanese migration system in the wake of a catastrophic event. In this study, we are not necessarily concerned with *who* moved and why, or *who* returned and why, but rather *where* people moved and whether permanent migrants and evacuees share migration systems.

## Data and Methods

### Data

We describe the migration systems in Japan using two primary migration data sources. Concerning permanent migration, we use the Statistics Bureau of the Ministry of Internal Affairs and Communication's (MIC) annual series of origin-destination matrices of prefecture-to-prefecture migration. Residents of Japan must register all changes of residence to their municipal governments for purposes of governance. It is from this population registry that the Statistics Bureau produces its annual series of internal migration. Concerning more temporary evacuee migration, we use data from the Nationwide Evacuee Information Exchange System that was created in the aftermath of the earthquake and tsunami.

#### Nationwide Evacuee Information Exchange System

In response to the earthquake and tsunami and to support rehabilitation of evacuees, the MIC, prefecture governments, and local municipalities collaborated to produce a Nationwide Evacuee Information Exchange System on April 12, 2011 (Suzuki and Kaneko 2013). By June 2011, more than 1,700 municipalities were participating in this exchange. The purpose of the system is to allow participating governments to track and locate former residents. Evacuees voluntarily report their current residence at their current municipal government (Oda 2011; Umeda 2013). The information is then passed to their home municipality and to the Reconstruction Agency, which presently publishes the number of evacuees with the cooperation of local governments. Evacuee data, by their nature, are variable across time and difficult to collect (Hasegawa 2013). Despite this limitation, the data in the evacuee exchange system provide the most rigorous and complete information on the locations of evacuees available, although they surely do not capture every evacuee because there is no legal obligation to participate. These data are the official number of evacuees from the Japanese government.

Individual prefecture governments are largely responsible for disaster relief; most of the governmental response to the disaster is shared between the national government, the 47 prefecture governments, and the 1,700 municipalities (Aoki 2016), and participation by prefectures and municipalities is voluntary (Umeda 2013). Even evacuee participation in the exchange system is voluntary. However, there are numerous reasons why evacuees might participate. In August 2011, Japan passed a law enabling certain administrative services of displaced evacuees to be covered by the government in which they currently reside (Umeda 2013). Evacuees are eligible for these administrative services, in addition to financial grants, special loans, tax relief, unemployment benefits, emergency housing, relief from administrative obligations, access to relief donations, and monetary compensation (Umeda 2013).

Evacuees might relocate to a different prefecture and participate in the evacuee system *without* registering a change of address in their home prefecture. This is particularly true for Fukushima evacuees because their displacement is at least partially caused by the human-induced disaster. In other words, if evacuees change their registered address, it might be considered that they voluntarily relocated themselves regardless of the accident and could be ineligible for benefits. By registering with the nationwide evacuee database, the registered evacuees can maintain their home address, receive municipal service from the new location municipality, and receive postal mail documents concerning their public support and services.

Official numbers published by the Reconstruction Agency show that more than 250,000 people from Iwate, Miyagi, and Fukushima Prefectures participated in the evacuee system in December 2011, but only 69,000 of these evacuees were displaced outside their home prefectures. Most people relocated within their home prefecture. By June 2018, the total number of evacuees inside these prefectures had fallen to 11,000, and 36,000 people were still listed as evacuees outside their home prefecture in part because of the availability of permanent recovery apartments in the affected prefectures.[2] Figure 3 shows the total number of persons in the evacuee system who were displaced outside their home prefecture for the three most impacted prefectures between 2011 and 2019.

The Reconstruction Agency publishes three primary pieces of information. First, it publishes the total number of evacuees present in each prefecture, although not the origin prefecture of these evacuees. Second, it publishes the type of accommodations in which evacuees shelter. The four facility types are (1) public shelters, such as public halls or schools; (2) hotels; (3) relatives/acquaintances; and (4) public/temporary housing, including hospitals. In December 2011, nearly 95% of evacuees were in public/temporary housing; by June 2019, evacuees were nearly evenly split between public/temporary housing and relatives/acquaintances. Third, the agency publishes the number of evacuees located outside the three most impacted prefectures.

The Reconstruction Agency publishes total counts of evacuees but not the number of evacuees broken down by origin and destination prefecture. However, individual municipalities have access to the locations of their own displaced residents for administrative purposes. We use data published by Takashi Oda (2011) on the location of evacuees from Fukushima Prefecture for June 2011 as reported to Fukushima Prefecture via the evacuee information system. The availability of evacuee data for only Fukushima Prefecture precludes an analysis of evacuees from Iwate and Miyagi Prefectures, although evacuees from Iwate and Miyagi who relocated outside their home prefecture total just 15% of the evacuees outside of their home prefecture. The lack of socioeconomic data on evacuees also precludes an analysis of the socioeconomic characteristics of evacuees.

Most displacement was localized within the prefecture (Ishikawa 2012; Koyama et al. 2014), likely because of local government responses. Some people evacuated via institutional transportation provided by the local government, whereas others evacuated using their own means of transportation (Crimella and Dagnan 2011). Local governments relocated some evacuees using lottery methods and group allocation (Koyama et al. 2014), and destination prefectures voluntarily provided unoccupied public housing to evacuees (Umeda 2013). Between 60% and 70% of local governments in Japan provided some form of aid to those displaced by the disaster (Inui 2016). Every prefecture in Japan received some evacuees (Fig. 3).

[2] http://www.reconstruction.go.jp/topics/main-cat2/sub-cat2-1/201907_hinansha_suii.pdf.

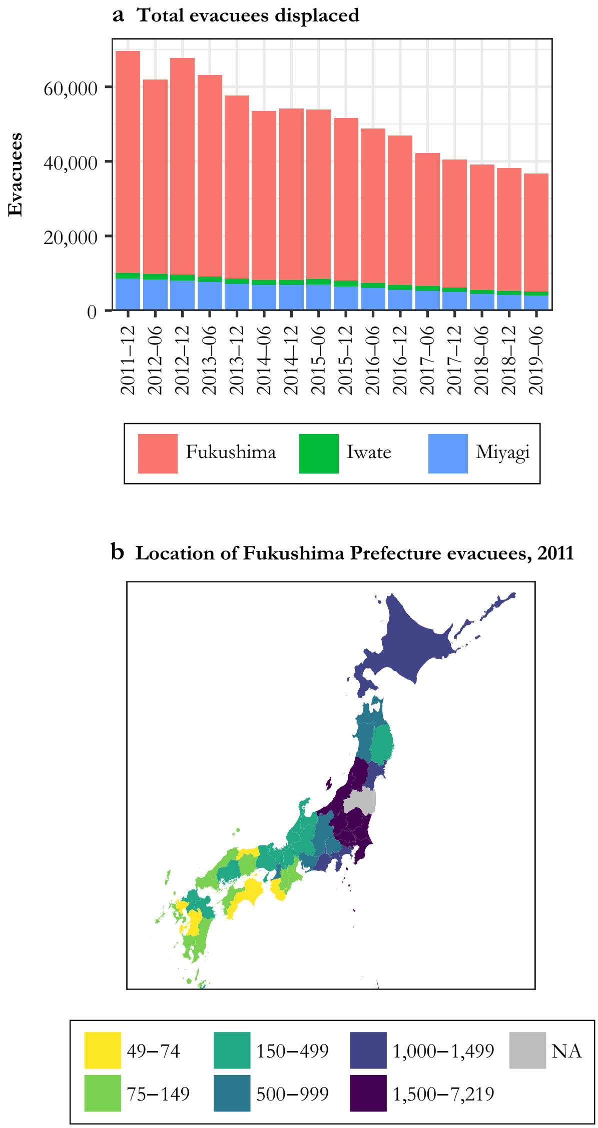


**Fig. 3** Total evacuees displaced outside their home prefecture originating from the three most impacted prefectures over time (panel a) and the locations of Fukushima Prefecture evacuees in 2011 (panel b). In panel a, we report the total number of evacuees from the Nationwide Evacuee Information Exchange System for Fukushima, Iwate, and Miyagi Prefectures who were displaced outside their home prefecture. In panel b, we report the locations of evacuees from Fukushima Prefecture in June 2011.

The vast majority of evacuations and the governmental responses were voluntary and highly varied. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reported that 95,100 residents evacuated from either the mandatory evacuation zone of <20km from the plant or the voluntary evacuation zone between 20km and 30km of the plant (UNSCEAR 2014). Of the 18 identified compulsory evacuation scenarios, only the 6,900 residents of Futaba

Town in Fukushima Prefecture were forced to evacuate to a destination outside their home prefecture, to the Saitama Super Arena in Saitama Prefecture (UNSCEAR 2014). Thus, less than 10% of those who evacuated from Fukushima Prefecture to another prefecture were compelled to a particular destination outside their home prefecture.

Because of this largely decentralized governmental response and the voluntary nature of the response, the extent to which individual municipalities shaped destinations is largely unknown. Some people were forced to evacuate, and others evacuated voluntarily; some people were evacuated to specific locations, and others had more freedom in destination location. Approximately 100,000 of 450,000+ evacuees were compulsory evacuees, and, as stated earlier, approximately 10% of those who evacuated outside their home prefecture were steered to a particular location. Given that both the decision to evacuate and the destination were largely voluntary, it seems unlikely that evacuee data reflect where the government chose to resettle people rather than the migration decisions of the evacuees themselves. It is the confluence of preferences, kin networks, social capital, and governmental responses that shaped destination decisions.

Thus, two avenues of reporting are available for those displaced by the earthquake and tsunami. First, residents choosing to permanently relocate would be listed in the official prefecture-to-prefecture migration data, and residents choosing to resettle in their home prefecture at a later date would be listed in the Evacuee Exchange System. There is certain to be some overlap between the two groups. However, based on the reports from the Reconstruction Agency, this overlap appears minimal, which allows for a unique decomposition of environmental flows between permanent migrants and evacuees. This distinction between permanent migrants and evacuees may recede over time if evacuees settle in place.

## Characterizing Migration

To assess permanent migration, we focus on the year preceding (2010), the year of the disaster (2011), and the years immediately after the earthquake and tsunami (2012 and 2013). In terms of evacuees, we compare the 2010 migration system before the earthquake with the diaspora of evacuees from Fukushima Prefecture in the post-disaster period (2012).

We characterize the migration system of Japan as several matrices representing the total prefecture-to-prefecture migration as a proportion of total flows out of any given prefecture. We use the proportionality of the flows—expressed as $M_{i,j}/M_i$, the ratio of the migrants from prefecture $i$ to $j$ to the total number of out migrants from prefecture $i$—to investigate the similarity in the migration systems.

We would anticipate changes in the number of migrants after a disaster of this magnitude, but we are instead interested in seeing the changes in the structure of the migration system. A set of matrices covering the period 2004–2016 represents the pre-disaster migration system ($\mathbf{M}(2004), \ldots, \mathbf{M}(2010)$), the peri-disaster migration system ($\mathbf{M}(2011)$), and the post-disaster migration system ($\mathbf{M}(2012), \ldots, \mathbf{M}(2016)$). We also construct a matrix for the evacuees $\mathbf{M}(E)$, using data from the Nationwide Evacuee Information Exchange System on evacuees in February 2012. These matrices take the general form shown in Eqs. (1) and (2).

$$\mathbf{M}(t) = \begin{Bmatrix} \frac{M_{i,i}}{m_i} & \cdots & \frac{m_{i,j}}{m_i} \\ \vdots & \ddots & \vdots \\ \frac{M_{j,i}}{m_j} & \cdots & \frac{m_{j,j}}{m_j} \end{Bmatrix}, \tag{1}$$

$$\mathbf{M}(E) = \begin{Bmatrix} \frac{e_{F,i}}{e_F} & \cdots & \frac{e_{F,j}}{e_F} \end{Bmatrix}, \tag{2}$$

where $t$ is the set of periods $t \in \{2004, \ldots, 2016\}$; $F$ in $\mathbf{M}(E)$ refers to Fukushima Prefecture; and $i$ through $j$ refer to the set of 47 Japanese prefectures $\in \{Aichi, \ldots, Yamanashi\}$.

These matrices have no "net" migrants and represent the complete picture of prefecture-to-prefecture out-migration. The sum of any given row in the matrix will equal 1.0, representing the total probability distribution of flows from any given prefecture to any given prefecture.

## Calculating Migration System Differences

Although the magnitudes of the flows can and should be different pre- and post-disaster, our tests determine whether the overall structure of the flows to each prefecture changed in the post-disaster period. For instance, 4.7% of all out-migrants from Fukushima Prefecture (1,470 of 31,363 out-migrants) went to Tochigi Prefecture in 2010, compared with 4.8% in 2011 (2,542 of 53,122). Despite a 73% increase in the number of migrants from Fukushima to Tochigi, the proportion of out-migrants remained virtually unchanged. We are interested in whether the migration systems between the periods $\mathbf{M}$(2011, 2012, 2013, $E$) differ significantly from $\mathbf{M}$(2010), not necessarily in the absolute changes in both in- and out-flows.

By converting the origin-destination matrices into matrices of probability distributions (i.e., the probability of moving from prefecture $i$ to prefecture $j$), we can use statistical distance metrics to quantify the similarity between two probability distributions. We use the Hellinger distance metric (Hellinger 1909; Pardo 2005) to quantify the similarity and dissimilarity for each prefecture between periods. Hellinger distance, $H(P, Q)$, describes the distance between two discrete probability distributions, $P = (p_i, \ldots, p_k)$ and $Q = (q_i, \ldots, q_k)$.

The Hellinger distance has several useful qualities as a distance metric. First, the distance value always lies between 0 and 1, where $H = 0$ means distributions are identical. Second, it fulfills the four conditions required for a distance measure to be a metric as opposed to a divergence (such as the Kullback-Leibler Divergence) (Pardo 2005): it must be nonnegative; if $p$ and $q$ are the same, then the distance must be 0; $H(P, Q) = H(Q, P)$, implying symmetry; and it must obey the triangle inequality law.

The general Hellinger distance equation is defined in Eq. (3).

$$H(P, Q) = \sqrt{1 - \sum_{i=1}^{N} \sqrt{p_i \cdot q_i}}, \tag{3}$$

where probability distribution $P$ is the set of probabilities of migrating from prefecture $i$ to prefectures $i$ to $j$ in period $t$, and probability distribution $Q$ refers to the period $t + 1$. By calculating $H$ between each period, we generate the distribution of $H$ to test for significance.

We calculate $H$ between each consecutive period for 2004–2015 and calculate a standard $z$ score ($z = (x_i - \mu) / \sigma$), where $\mu$ is the mean of $H$ over all prefecture-periods. We also calculate $H$ for the distribution of $Fukushima_{2010}$ and $Evacuees_{2011}$ to measure the distance between the preexisting migration system in Fukushima and that of the evacuees. Because the Hellinger distance is bounded by 0 and 1, we report significance based on a log-normal distribution.

### Reproducible Research

All data and code necessary to reproduce the reported results are licensed under the CC-BY-4.0 license and are publicly available in a replication repository (https://osf.io/jvund/?view_only=3982ed9f1ea64c8cbb6c27b2683c9a79). The analyses were performed in R (R Core Team 2018), primarily using the *philentropy* package (Drost 2018) for the Hellinger distance.

## Results

### Statistical Distance

Figure 4 reports the results of the Hellinger distances comparing the annual differences between 2004 and 2015 out-migration from each prefecture. The differences between any given origin prefecture are relatively small for permanent out-migration ($\mathbf{M}(t)$), with Yamagata Prefecture exhibiting the greatest difference among any yearly comparison ($H$ = .11308) and Tokyo exhibiting the smallest difference ($H$ = .00731). The mean Hellinger distance is .03542, with a standard deviation of .01892.

Table 2 reports the prefecture-years exhibiting different Hellinger distances between two years with positively significant different distances ($\alpha \leq .05$).

### Did the Disaster Alter the Destinations of Out-Migrants From the Affected Region?

In short, we find that the disaster did not alter destinations of out-migrants. Table 3 shows the Hellinger distances and their significance for Fukushima, Iwate, and Miyagi Prefectures for the peri-disaster migration system. Only Miyagi Prefecture exhibits a significant difference between the pre-disaster migration system and peri-disaster systems. Both Fukushima and Iwate Prefectures exhibit nonsignificant differences.

Of the impacted prefectures, Fukushima Prefecture, which had such a well-documented increase in the out-migration and is traditionally the focal point of the migration effect, had the least dissimilar peri-disaster migration system—a mere 3.7% different from the pre-disaster migration.

Even though Miyagi Prefecture's difference is significant, it is significant only within the universe of annual distances. In other words, Miyagi Prefecture's peri-

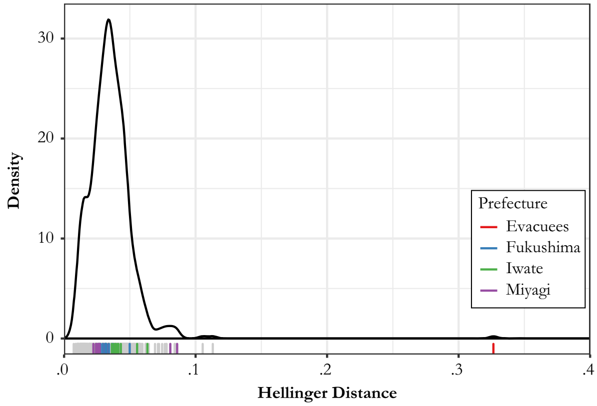


**Fig. 4** Distribution of yearly Hellinger distances for all years. A Hellinger distance of 0 indicates an identical probability distribution. Fukushima, Iwate, and Miyagi Prefectures along with evacuees are highlighted along the bottom. Evacuees represent a considerable outlier.

disaster migration system is only 8.5% dissimilar from the pre-disaster migration system. Although it is significant compared with other annual changes, the actual *magnitude* of difference is relatively minor. Additionally, if we examine the peri- and post-disaster migration systems with the pre-disaster migration systems for Fukushima, Iwate, and Miyagi, we again find very little dissimilarity when compared with the preexisting migration system (Table 4). None of the Hellinger distances approach the level of dissimilarity as the evacuees' system. The magnitude of the *H*-distance for the evacuee system is almost three times larger than the greatest pairwise distance computed. These results suggest that permanent migrants continued to leverage the preexisting migration system during and after the disaster and that the evacuee migration system differs substantially from the preexisting migration system.

**Table 2** Hellinger distances significant at $\alpha$ = .05

| Prefecture | *P*, *Q* | *H*(*P*, *Q*) | *z* Score | *p* Value |
|---|---|---|---|---|
| Evacuees | 2010, Evacuees | .326466 | 5.14563 | .000000 |
| Yamagata | 2010, 2011 | .113084 | 2.79505 | .005189 |
| Yamanashi | 2008, 2009 | .105390 | 2.63882 | .008319 |
| Miyagi | 2010, 2011 | .085971 | 2.18731 | .028720 |
| Kochi | 2010, 2011 | .085481 | 2.17462 | .029658 |
| Niigata | 2010, 2011 | .084214 | 2.14150 | .032233 |
| Yamanashi | 2009, 2010 | .084033 | 2.13675 | .032618 |
| Kochi | 2009, 2010 | .080804 | 2.04987 | .040377 |
| Miyagi | 2011, 2012 | .080791 | 2.04951 | .040413 |
| Yamagata | 2011, 2012 | .077995 | 1.97142 | .048676 |

*Note:* We report only positive and statistically significant differences because we are interested in the probability distributions that are most significantly different.

**Table 3** Hellinger distances and significance for Fukushima, Iwate, and Miyagi out-migrations between 2010 and 2011

| Prefecture | *P*, *Q* | *H*(*P*, *Q*) | *z* Score | *p* Value |
|---|---|---|---|---|
| Miyagi | 2010, 2011 | .085971 | 2.187308 | .028720 |
| Iwate | 2010, 2011 | .055544 | 1.218800 | .222920 |
| Fukushima | 2010, 2011 | .037334 | 0.338009 | .735356 |

## Do Evacuees and Migrants Share Migration Systems With the Pre-Disaster Migration System and With Each Other?

As evidenced by Tables 3 and 4, permanent migrants in the peri- and post-disaster periods seem to share the pre-disaster migration systems. However, this is in stark contrast to the evacuees' migration system (Fig. 4), which is significantly dissimilar to the preexisting migration system ($z$ score = 5.14563).

What about the evacuees' migration system is different from the preexisting migration system? The Hellinger distance results demonstrate a clear schism between the migration pathways of permanent migrants and the migration pathways of evacuees. These result cannot tell us how the systems differ, however. Figure 5 presents the changes in the spatial extent of the migration systems between out-migrants and evacuees by examining the percentage of the emigrants and evacuees from Fukushima to the six prefectures immediately adjacent (Gumma, Ibaraki, Miyagi, Niigata, Tochigi, and Yamagata). Over the 2010–2013 period, between 33.6% and 35.9% of people who emigrated from Fukushima went to nearby prefectures. This stands in stark contrast to the 46.1% of the evacuees who relocated to surrounding prefectures, suggesting that evacuees tended to move to nearer locations in larger numbers than typical out-migrants.

**Table 4** Hellinger distances for Fukushima, Iwate, and Miyagi Prefectures for the peri- and post-disaster migration systems

| Prefecture | *P*, *Q* | *H*(*P*, *Q*) |
|---|---|---|
| Fukushima | 2010, 2011 | .037334 |
| | 2010, 2012 | .045702 |
| | 2010, 2013 | .055841 |
| Iwate | 2010, 2011 | .055544 |
| | 2010, 2012 | .047369 |
| | 2010, 2013 | .044689 |
| Miyagi | 2010, 2011 | .085971 |
| | 2010, 2012 | .046067 |
| | 2010, 2013 | .046190 |

## Discussion

Population displacement is expected to be a growing issue in the twenty-first century. The environmental migration literature has generally focused on the characteristics of migrants rather than their destinations. Where displaced persons migrate has important policy implications. For instance, global environmental change over the coming century could lead to mass migrations (Black et al. 2011; Feng et al. 2010), and knowing the potential destinations of future environmental migrants is paramount to understanding the total demographic implications of a world with increasing population displacement from environmental phenomena. Knowing who and from where someone might migrate is only two-thirds of the migration equation. This study provides an additional step toward filling the final third of the migration equation: *where* someone might migrate.

Environmental migration has been a major topic of migration scholars and demographers (Gray and Bilsborrow 2013; Hunter et al. 2015; Nawrotzki et al. 2015). Rapid-onset environmental events, such as tropical cyclones, are typically studied to understand environmental migration (Fussell et al. 2014; Lu et al. 2016), with Hurricane Katrina garnering tremendous attention (Curtis et al. 2015; Fussell and Elliott 2009; Groen and Polivka 2010; Stone et al. 2012). However, many of these studies were limited to vague directional geographies, such as *rural to urban* (Gray and Bilsborrow 2013) or *to nearby cities* (Mallick and Vogt 2014). Vagaries such as these make it difficult for governments to predict and plan for migration. Still, these studies inform our understanding of future climate-related migration—migration that could increasingly be due to more slow-onset environmental changes, such as drought or extreme heat.

The manifestation of environmental migration is largely dependent on the type of environmental pressure (Gutmann and Field 2010). Both rapid-onset and slow-onset environmental events can produce permanent migration, but only rapid-onset events are likely to trigger evacuee migration. If our understanding of how future climate-rated migration might unfold comes from environmental events where permanent migrants and evacuees are analyzed together and future climate change migration is linked to

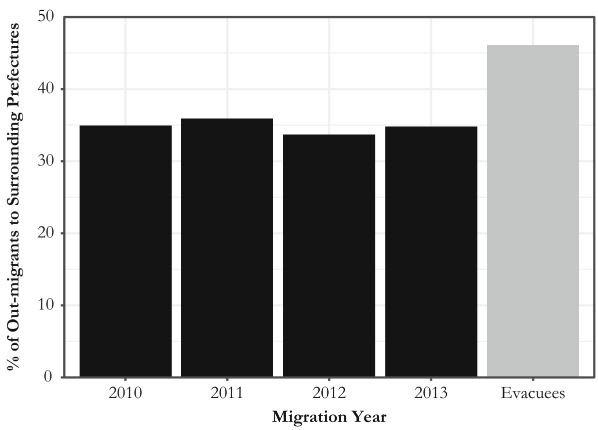


**Fig. 5** Percentage of Fukushima out-migrants and evacuees to the six immediately adjacent prefectures.

slow-onset environmental change (Call et al. 2017; Feng et al. 2010; Hunter et al. 2013), then governments responsible for managing this migration could be misinformed. Although the Great East Japan Earthquake and Tsunami did not result from climate change, our work helps clarify which parts of a migration system are more predictable in response to an environmental event due to separate analysis of migrants and evacuees.

We find that the migratory responses to the Great East Japan Earthquake and subsequent events manifest in two separate and distinct systems: one for permanent migrants and one for evacuees. We also find relatively little change in the spatiotemporal structure of the migration system. The proportions and destinations of migrants were relatively unaltered in the aftermath of the earthquake and tsunami. These two systems—evacuation and migration—each exemplify different aspects of Findlay's six principles. Evacuees' migration seems to emphasize short-distance moves, whereas permanent migrants seem to follow preexisting human and social capital connections. Although our data set does not include any measure of human capital, the stability of the migration system—even in the face of such a catastrophic event—and prior research (e.g., Randell 2018) suggest that permanent migrants leverage human and social capital connections present in the pre–environmental displacement migration system. Consequently, the migration system of permanent migrants after an environmental event are likely to reflect the migration systems exhibited prior to the event.

Evacuees on the other hand, exhibit a markedly different migration system from the preexisting migration system, and unlike more permanent migrants, are more likely to migrate to nearby destinations in greater numbers. Our results suggest that the differences between permanent migrants and evacuees could be the intentionality to return. Evacuees who suddenly had to give up their home may not be ready for distant relocation. For evacuees who were deeply rooted in their home community, it may have been difficult to move far away from their center of social capital and thus moved to nearby "safe" locations, possibly with the intent to return home. Return migrants after Hurricane Katrina tended to be from low-damage areas (Fussell et al. 2010; Groen and Polivka 2010) as well. Those who made more permanent migrations perhaps may have less intent to return to their home prefecture or could have come from more damaged areas in the Tohoku region.

There are some limitations to this analysis. First, the official number of evacuees is still in continual flux, even eight years after the disaster, and is subject to administrative problems (Ishikawa 2012). The extent to which these administrative problems have infected the migration data is unknown. Similar issues plagued the U.S. Internal Revenue Service (IRS) data in the immediate aftermath of Hurricane Katrina (Johnson et al. 2008), prompting skepticism around disaster-related administrative data (Curtis et al. 2015; Groen and Polivka 2010). Additionally, although we document nearly a 550% increase in net negative migration from Fukushima Prefecture after the disaster, the total number of negative net migrants (–31,381 net migrants in 2011) is approximately one-half of the known number of evacuees displaced outside the prefecture (59,494 in December 2011). How many of these evacuees have been included in the official migration statistics is unknown, and this study examines only the universe of migrants pre- and post-disaster captured in the Japanese government data.

Finally, the Japanese relocation policy could have steered evacuees to short-distance moves. Some residents voluntarily evacuated, others were compelled to evacuate, and those with stronger social capital had more destination options to leverage than those with weaker social capital. Thus, the distribution of destinations for evacuees may depend in part on the nature of the evacuation event: voluntary versus involuntary decision to migrate, voluntary versus involuntary housing decision, and so on. Those who have limited social capital and were forced to evacuate from the irradiated zone might have tended to evacuate to the nearest place with available housing, exhibiting different destinations from those who involuntarily evacuated but who possessed stronger social capital. There is a distinct possibility that our origin-destination evacuee data are selected with bias and forms of bias that we simply cannot describe or account for in the evacuee data.

Despite these limitations, our research provides a robust examination of two concurrent migration systems and contributes to the environmental migration literature. There is growing interest in projecting migration responses to environmental events (Curtis and Schneider 2011; Davis et al. 2018; Hassani-Mahmooei and Parris 2012; Hauer 2017; Lu et al. 2016; Rigaud et al. 2018), and our method, data, and results offer important empirical grounding to further those efforts.

**Authors' Contributions** All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Mathew E. Hauer. The first draft of the manuscript was written by Mathew E. Hauer and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

**Data Availability** All data and code necessary to reproduce the reported results are publicly available in a replication repository (https://osf.io/jvund/?view_only=3982ed9f1ea64c8cbb6c27b2683c9a79).

## Compliance With Ethical Standards

**Conflict of Interest** The authors declare that they have no conflict of interest.

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