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 co-mingling of evacuee and permanent migrant data. Using a unique dataset of separate evacuee and migration destinations, we compare and contrast the pre– (2010), peri– (2011), and post– (2012-2013) 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 and one for more permanent migrants – where evacuees seem to emphasize short distance migration while more permanent migrants emphasize migration to destinations with pre-existing ties. Additionally, our results show that permanent migration in the peri– and post-periods is largely identical to the pre-existing 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

1 Introduction

Environmentally induced migration and displacement is a key concern of global environmental change (Black et al. 2011, Findlay 2011, Hugo 2011, Mueller et al. 2014, Field et al. 2014), with climate change expected to spur migration and displacement (Warner et al. 2009, Gray & Wise 2016). 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 & Field 2010, Hunter et al. 2013, Thiede & Brown 2013). Previous studies have shown migration and displacement from rapid-onset environmental events (such as tropical cyclones) leads to a dichotomous spatial concentration of migration toward nearby areas (Curtis et al. 2015, Kayastha & 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 and we define more permanent migrants as those who primarily leverage preexisting migration networks to make more permanent migrations. Rectifying this dichotomy will allow for better modeling of environmental migration but, due to data limitations, post-disaster migration studies typically analyze evacuees and migrants in a single migration datum.

The Great East Japan Earthquake and Tsunami in March 2011, which ultimately lead to the failure of the Fukushima-Daiichi nuclear plant, prompted the Japanese government to capture both permanent and temporary migration in two separate migration data universes, providing 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 paper, 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? and 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. Due to 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 in the region, but (2) the destinations of more permanent migration closely follows the pre-disaster, embedded migration system and (3) evacuees exhibit markedly different destinations, tending to travel short distances.

2 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 (USGS 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 of 2011, just eight months after the incident, 92,712 Fukushima residents remained evacuated, 33,943 of whom were still living inside the prefecture, according to the International Medical Corps' Fukushima Prefecture Data Sheet (2011).

Iwate and Miyagi prefectures felt the brunt of the earthquake and ensuing tsunami

(**Figure 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 five-fold 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 fallout. All Fukushima Prefecture residents within 20km of the plant and most residents within 30km were forced to evacuate.

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. Both Fukushima and Miyagi prefectures experience much larger out-migrations between 2010 and 2011, while Iwate experiences a much more modest increase (22,131 in 2010 to 22,199 in 2011). The general destinations are relatively similar between the two time 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.

Additionally, Japan created a unique data collection system for processing both evacuees and more permanent migrants 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

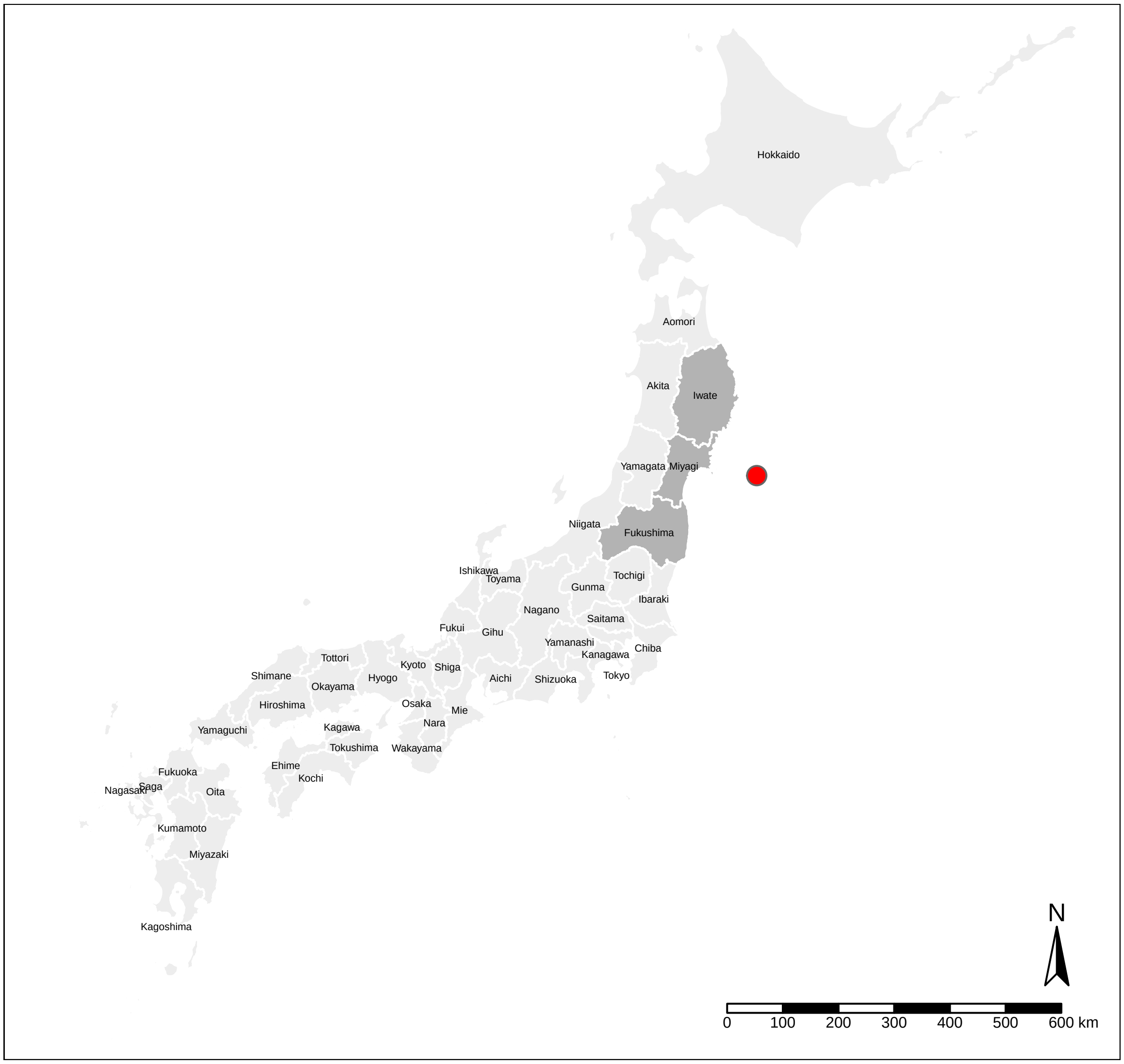

Figure 1: **Japanese Prefectures.** The red point is the location of 2011 earthquake. The three most impacted prefectures (Fukushima, Iwate, and Miyagi) are highlighted.

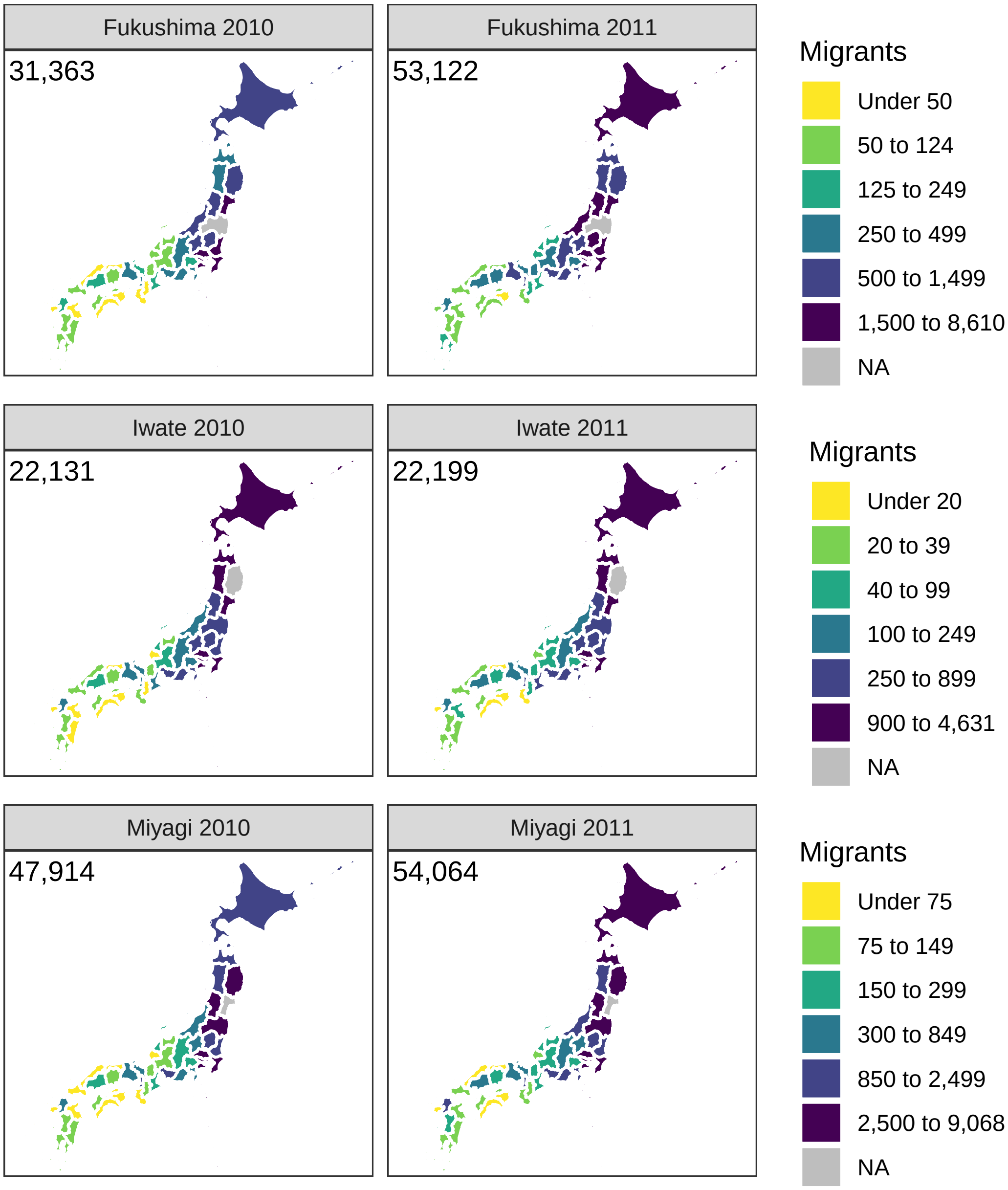

Figure 2: **Out-migration from Fukushima, Iwate, and Miyagi prefectures, 2010 and 2011.** We report the total number of out-migrants in the corner of each panel for each prefecture-year. Fukushima and Miyagi prefectures exhibit larger out-migration in 2011 compared to 2010 while Iwate Prefecture does not.

Table 1: **Top 5 destinations for Fukushima, Iwate, and Miyagi Prefectures.** 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 while the exact ordering might be slightly different.

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

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. We describe the National Evacuee Data System in greater detail in the **Data and Methds** 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 pathways. Our analysis compares the permanent migration system to 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 2010 and 2011 permanent migration data from the Statistics Bureau of Japan.

3 Environmental Migration

When examining environmental migration, the effect an environmental pressure has on a migration system largely depends on the type of environmental 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 finds that displacements tend to be localized, with migration along short-distances in search of safer areas (Kayastha & Yadava 1985). Studies on Hurricane Katrina's impact on the Gulf Coast of the United States find similarly large out-flows to nearby areas with some migration to distant locations (Frey et al. 2007, Hori et al. 2009, Stone et al. 2012, Curtis et al. 2015). While these studies examine the geography of displacement, they provide little or no temporal comparison to the pre-event migration system nor do they 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: A) Potential migrants prefer to stay in their current residence, often called the immobility paradox, B) If people do move, they tend to move short distances, and C) human capital and existing ties play a large role in determining destinations. We anticipate that evacuees tend to migrate short distances while permanent migrants will leverage human capital and existing ties in their location decisions.

Gutman 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, 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, irrigation, etc. This framework for environmental migration can be used to place historically significant environmental events of the 20th century into analytically useful categories. The list of environmental events or impacts is both long and wide and includes the American dust bowl of the 1930s (Adamo 2009), air conditioning (Glaeser & Tobio 2007), and Hurricane Katrina (Fussell & Elliott 2009), for instance. These typologies – combined with Findlay's six principles – provide a robust framework for organizing research on environmental migration, yet previous research on environmental migration is dominated by "who?" and "what?" questions. For example, many studies have focused on who moves (Hori et al. 2009, Rivera & Miller 2007) and who returns (Groen & Polivka 2010, Stringfield 2010, Thiede & 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

[1]Findlay's six principles: 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 attrative destination but live/work nearer rater than farther.

4. Attraction to destinations can be interpreted as increased income or returns to 'human capital.'

5. Destination selection is shaped by pre-existing social and cultural connections.

6. Destinations can be viewed as attractive because of the 'social' and 'cultural capital' they offer.

over time.

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, amenities, both natural and economic, and so forth (Fawcett 1989, Haug 2008, Lee 1966, Pandit 1997, Thiede & 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 & Bilsborrow 2013, Hugo 2008, 2011, McLeman 2013, Schultz & 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) as well as 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. We are not necessarily concerned with *who* moved and why, nor *who* returned and why, but rather *where* people moved and whether permanent migrants and evacuees share migration systems.

4 Data and Methods

4.1 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.

4.1.1 Nationwide Evacuee Information Exchange System

In response to the earthquake and tsunami and to support rehabilitation of evacuees, the Ministry of Internal Affairs and Communication (MIC), prefecture governments, and local municipalities collaborated to produce a Nationwide Evacuee Information Exchange System on April 12, 2011 (Suzuki & Kaneko 2013). By June of 2011, over 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 (Umeda 2013, Oda 2011). 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.

Individual prefecture governments are largely responsible for disaster relief, making most of the governmental response to the disaster shared between the national government, the 47 prefecture governments, and the 1700 municipalities (Aoki 2016) and voluntary in nature (Umeda 2013). Even evacuee participation in the exchange system is voluntary and not compulsory. 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.

Most displacement was localized within the prefecture (Koyama et al. 2014, Ishikawa 2012) likely due to local government responses. Some people evacuated via institutional transportation provided by the local government while others evacuated using their own means of transportation (Crimella & Dagnan 2011). Local governments relocated some evacuees using lottery methods and group allocation (Koyama et al. 2014) and destination

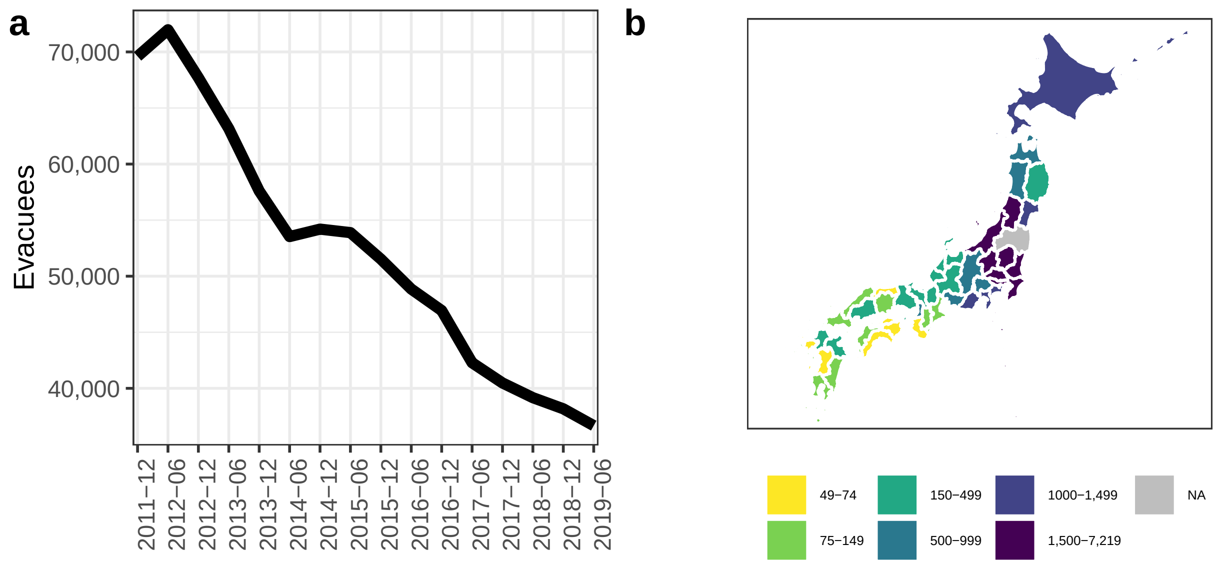

Figure 3: **Total Evacuees over time and the locations of Fukushima Prefecture evacuees** (a) We report the total number of evacuees from the National Evacuee Exchange System for the period 2011 to 2019 for Fukushima, Iwate, and Miyagi prefectures who were displaced outside of their home prefecture. (b) We report the locations of evacuees from Fukushima Prefecture in June 2011.

prefectures voluntarily provided unoccupied public housing to evacuees (Umeda 2013). Every prefecture in Japan received some evacuees (**??**). The vast majority of evacuations and the governmental responses were voluntary and highly varied. Due to this largely decentralized governmental response and the voluntary nature of the response, the extent to which individual municipalities shaped destinations is largely unknown. Since the evacuations were largely voluntary, it seems unlikely that evacuee data reflects where the government chose to resettle people rather than the migration decisions of evacuees themselves.

Official numbers published by the Reconstruction Agency show that more than 250k people from Iwate, Miyagi, and Fukushima prefectures participated in the evacuee system in December of 2011 but only 69k of these evacuees were displaced outside of their home prefectures. By June of 2018, the total number of evacuees inside these prefectures had fallen to 11k while 36k people were still listed as evacuees outside their home prefecture[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.

Evacuee data, by its nature, is variable across time and difficult to collect (Hasegawa 2013). Despite this limitation, the data in the evacuee exchange system is the most rigorous and complete information on the locations of evacuees available, though it surely does not capture every evacuee since there is no legal obligation to participate. These data are the official number of evacuees from the Japanese government.

The Reconstruction Agency publishes three primary pieces of information. (1) They publish the total number of evacuees present in each prefecture, but not the origin prefecture of these evacuees. (2) They publish the type accomodations in which evacuees shelter. There are four facility types: (a) public shelters such as public halls or schools, (b) hotels, (c) relatives/acquaintances, and (d) public/temporary housing including hospitals. In December of 2011, nearly 95% of evacuees were in public/temporary housing but by June 2019, evacuees were nearly evenly split between public/temporary housing and relatives/acquaintances. Finally, (3) they publish the number of evacuees located outside of the three most impacted prefectures.

[2] `http://www.reconstruction.go.jp/topics/main-cat2/sub-cat2-1/201907_hinansha_suii.pdf`, retrieved August 2019.

The Reconstruction Agency publishes total counts of evacuees, but not 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, though evacuees from Iwate and Miyagi who relocated outside of their home prefecture total just 15% of the evacuees outside of their home prefecture. The lack of socio-economic data on evacuees also precludes an analysis of the socio-economic characteristics of evacuees.

Thus two avenues of reporting are available for those displaced by the earthquake and tsunami: if a resident chooses to permanently relocate, they would be listed in the official prefecture-to-prefecture migration data, if a resident chooses to resettle in their home prefecture at a later date, they would be listed in the Evacuee Exchange System. This allows for a unique decomposition of environmental flows between permanent migrants and evacuees.

4.2 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 to 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. Unlike Fussell, Curtis, and DeWaard's systems work on New Orleans after Hurricanes Katrina and Rita (2014), we do not control for population size since any change in population in any prefecture will exogenously alter a migration rate, ie the changes in the migration system should be examined independently of other population dynamics such as mortality and fertility. Rather, we use the proportionality of the flows, expressed as $\frac{M_{i,j}}{M_i}$, 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 are rather interested in seeing the changes in the structure of the migration system. A set of matrices covering the period 2004-2016 represent the pre-disaster migration system ($M(2004), ..., M(2010)$), the peri-disaster migration system ($M(2011)$), and the post-disaster migration system ($M(2012), ..., M(2016)$). We also construct a matrix for the evacuees $M(e)$ (utilizing data from the Evacuee Information Exchange System on evacuees in February of 2012). These matrices take the following general form as shown in Eq. 1 and 2.

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

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

where:

t is the set of time periods $t \in \{2004, ..., 2016\}$

F in $M(E)$ refers to Fukushima Prefecture.

i through j refer to the set of 47 Japanese prefectures $\in \{Aichi, ..., Yamanashi\}$

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.

4.3 Calculating Migration System Differences

While 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, in 2010 4.7% of all out-migrants from Fukushima Prefecture went to Tochigi Prefecture (1,470 of 31,363 out-migrants) and 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 time periods M(2011, 2012, 2013, e) differs significantly from 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 (ie 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 utilize the Hellinger distance metric (Hellinger 1909, Pardo 2018) to quantify the similarity and dissimilarity for each prefecture between time periods. Hellinger distance, $H(P,Q)$, describes the distance between two discrete probability distributions $P = (p_i, ...p_k)$ and $Q = (q_i, ..., q_k)$.

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. And 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 2018): it must be non-negative; if p and q are the same then the distance must be zero; $H(P,Q) = H(Q,P)$, 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 time period t and probability distribution Q refers to the time period $t+1$. By calculating H between each time period, we generate the distribution of H to test for significance.

We calculate H between each consecutive time period for 2004-2015 and calculate a standard z-score ($z = (x_i - \mu)/\sigma$) where μ 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 pre-existing migration system in Fukushima and that of the Evacuees. Since the Hellinger distance is bounded by 0 and 1, we report significance based on a log-normal distribution.

4.4 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 located at `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.

5 Results

5.1 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 ($M(t)$), with Yamagata Prefecture exhibiting the greatest difference among any yearly comparison (H = 0.11308) and Tokyo-to exhibiting the smallest difference (H = 0.00731). The mean Hellinger distance is 0.03542 with a standard deviation of 0.01892.

Table 2 reports the Prefecture-Years exhibiting different Hellinger distances between two years with positively significant different distances (α<=0.05).

5.2 Did the disaster alter the destinations of out-migrants from the affected region?

In short: no. **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 non-significant 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 – just a mere 3.7% different from the pre-disaster migration.

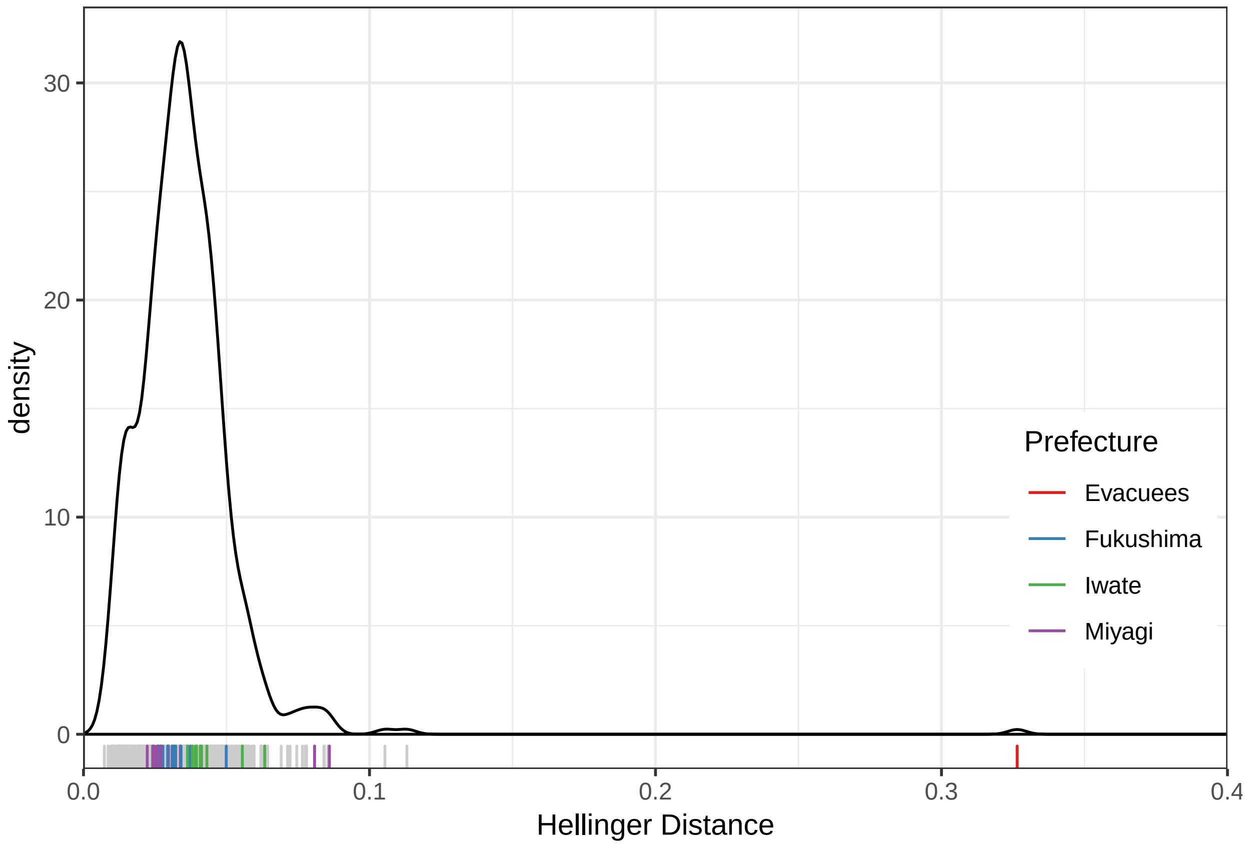

Figure 4: **Distribution of yearly Hellinger distances for all years.** A Hellinger distance of 0 indicates an identical probability distribution. Fukushima, Iwate, and Miyagi prefectures along with Evacuees are highlighted along the bottom. Evacuees represent a considerable outlier.

Table 2: **Hellinger distances significant at α=0.05.** We only report positive, significant differences as here we are interested in the probability distributions that are most significantly different. Concerning permanent migration associated with the Earthquake and Tsunami, only Miyagi Prefecture in 2011 and 2012 is significantly different. Evacuees exhibit a probability distribution very different from the pre-existing migration system.

Prefecture	P, Q	H(P, Q)	z-score	p-val
Evacuees	2010, Evacuees	0.326466	5.14563	0.000000
Yamagata	2010, 2011	0.113084	2.79505	0.005189
Yamanashi	2008, 2009	0.105390	2.63882	0.008319
Miyagi	2010, 2011	0.085971	2.18731	0.028720
Kochi	2010, 2011	0.085481	2.17462	0.029658
Niigata	2010, 2011	0.084214	2.14150	0.032233
Yamanashi	2009, 2010	0.084033	2.13675	0.032618
Kochi	2009, 2010	0.080804	2.04987	0.040377
Miyagi	2011, 2012	0.080791	2.04951	0.040413
Yamagata	2011, 2012	0.077995	1.97142	0.048676

Even though Miyagi Prefecture's difference is significant, it is only significant within the universe of annual distances. In other words, Miyagi Prefecture's peri-disaster migration system is only 8.5% dissimilar from the pre-disaster migration system. While it is significant compared to 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 to the pre-existing migration system (**Table 4**). None of the Hellinger distances approach the level of dissimilarity as the Evacuees system. These results suggest that permanent migrants continued to leverage the pre-existing migration system during and after the disaster.

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-val
Miyagi	2010, 2011	0.085971	2.187308	0.028720
Iwate	2010, 2011	0.055544	1.218800	0.222920
Fukushima	2010, 2011	0.037334	0.338009	0.735356

5.3 Do evacuees and migrants share migration systems with the pre-disaster migration system and with each other?

As evidenced by **Table 3** and **Table 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 (**Figure 4**) which is significantly dissimilar to the pre-existing migration system (z-score = 5.14563).

What about the Evacuees migration system is different from the pre-existing 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 percent 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.

6 Discussion

Population displacement is expected to be a growing issue in the 21st century. The environmental migration literature has generally focused on the characteristics of migrants, rather

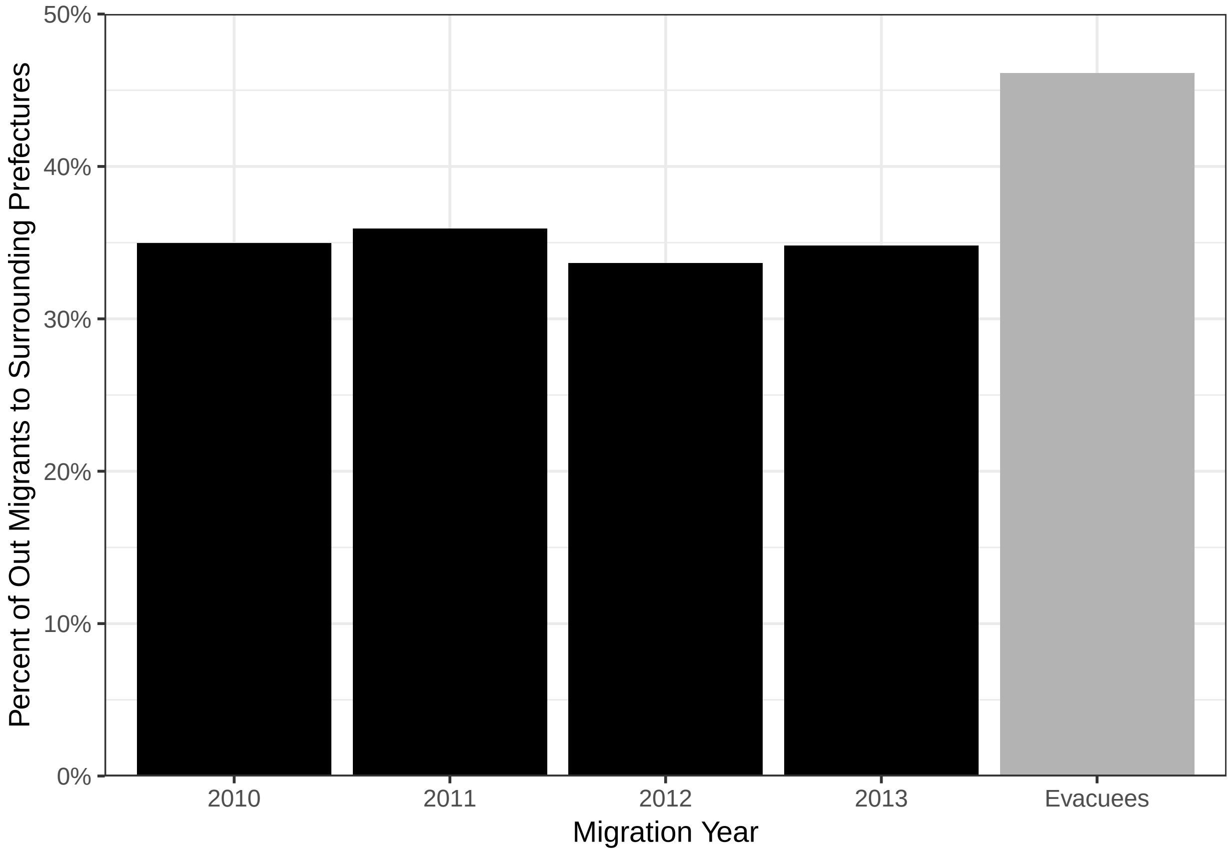

Figure 5: **Percentage of Fukushima out migrants and Evacuees to the six immediately adjacent prefectures.** Out-migration to the six adjacent (Gumma, Ibaraki, Miyagi, Niigata, Tochigi, and Yamagata) prefectures is largely stable for the period 2010-2013 (approximately 35% of out-migrants went to the adjacent prefectures). There is a considerable spike in the % of Evacuees who went to the adjacent prefectures (approximately 45%), further suggesting the presence of different migration systems for permanent migrants and evacuees.

Table 4: **Hellinger distances for Fukushima, Iwate, and Miyagi prefectures for the peri- and post-disaster migration systems.** We show the similarity between the pre-existing migration system and the peri- and post-disaster migration systems. All of these distances are relatively small, with only Miyagi (2010, 2011) demonstrating a significant difference. These results suggest permanent migrants in the most impacted prefectures continued to leverage the pre-existing migration system during and after the disaster.

Prefecture	P, Q	H(P, Q)
Fukushima	2010, 2011	0.037334
	2010, 2012	0.045702
	2010, 2013	0.055841
Iwate	2010, 2011	0.055544
	2010, 2012	0.047369
	2010, 2013	0.044689
Miyagi	2010, 2011	0.085971
	2010, 2012	0.046067
	2010, 2013	0.046190

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: to *where* someone might migrate.

Environmental migration has been a major topic of migration scholars and demographers (Nawrotzki et al. 2015, Gray & Bilsborrow 2013, Hunter et al. 2015). Rapid-onset environmental events, such as tropical cyclones, are typically studied to understand environmental migrantion (Fussell et al. 2014, Lu et al. 2016), with Hurricane Katrina garnering tremendous attention (Stone et al. 2012, Fussell & Elliott 2009, Groen & Polivka 2010, Curtis et al. 2015). However, many of these studies are limited to vague directional geographies such as ‘rural to urban’ (Gray & Bilsborrow 2013) or ‘to nearby cities’ (Mallick & Vogt 2014). Vagaries such as these make it difficult for governments to predict and plan for migration. But 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 depend upon the type of environmental pressure (Gutmann & 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 slow-onset environmental change (Hunter et al. 2013, Feng et al. 2010, Call et al. 2017), then governments responsible for managing this migration could be misinformed. While 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 spatio-temporal 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, while the permanent migrants seem to follow pre-existing human and social capital connections. Although our dataset 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 (eg Randell (2018)) suggests 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 pre-existing migration system and, unlike more permanent migrants, were more likely to migrate to nearby destinations in greater numbers. 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.

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 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 & Polivka 2010). Additionally, the Japanese relocation policy could have steered evacuees to short-distance moves. The extent to which government policy shaped destinations is unknown, though presumed to be minimal. Finally, while we document nearly a 550% increase in net negative migration from Fukushima Prefecture after the disaster, the total number of negative net migrants pales in comparison to the known number of displaced evacuees. 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.

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 & Schneider 2011, Rigaud et al. 2018, Hauer 2017, Hassani-Mahmooei & Parris 2012, Lu et al. 2016, Davis et al. 2018), and our method, data, and results offer important empirical grounding to further those efforts.

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