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Shelter crowding and increased incidence of acute respiratory infection in evacuees following the Great Eastern Japan Earthquake and tsunami

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SUMMARY

Although outbreaks of acute respiratory infection (ARI) at shelters are hypothesized to be associated with shelter crowding, no studies have examined this relationship. We conducted a retrospective study by reviewing medical records of evacuees presenting to one of the 37 clinics at the shelters in Ishinomaki city, Japan, during the 3-week period after the Great Eastern Japan Earthquake and tsunami in 2011. On the basis of a locally weighted scatter-plot smoothing technique, we categorized 37 shelters into crowded (mean space $<5{\cdot}5$ m^2/per person) and non-crowded ($\geqslant 5{\cdot}5$ m^2) shelters. Outcomes of interest were the cumulative and daily incidence rate of ARI/10 000 evacuees at each shelter. We found that the crowded shelters had a higher median cumulative incidence rate of ARI [5·4/10 000 person-days, interquartile range (IQR) 0–24·6, $P = 0{\cdot}04$] compared to the non-crowded shelters (3·5/10 000 person-days, IQR 0–8·7) using Mann–Whitney *U* test. Similarly, the crowded shelters had an increased daily incidence rate of ARI of 19·1/10 000 person-days (95% confidence interval 5·9–32·4, $P < 0{\cdot}01$) compared to the non-crowded shelters using quasi-least squares method. In sum, shelter crowding was associated with an increased incidence rate of ARI after the natural disaster.

Key words: Community epidemics, epidemiology, infectious disease control, infectious disease epidemiology, respiratory infections.

INTRODUCTION

Epidemics of acute respiratory infection (ARI) have often been reported at evacuation shelters following natural disasters, imposing significant health burdens on victims of the disaster [1–4]. The Great Eastern Japan Earthquake and tsunami hit the east coast of Japan on 11 March 2011. The initial earthquake and following tsunami resulted in 16 000 deaths, 130 000 collapsed buildings, and 40 000 evacuees at shelters [5]. After this disaster, outbreaks of ARI were reported at two evacuation centres (attack rates 10% and 15%) [6]. The incidence of ARI in patients in a hospital located in the disaster-affected area increased 2·5-fold during the first month compared to the

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incidence during the same period in 2012 [7]. During post-disaster periods, epidemics of ARI at shelters consume the already limited healthcare resources in disaster-affected areas [1, 7].

A better understanding of the factors contributing to ARI outbreaks under emergency conditions is warranted to help public health officials manage the spread of ARI. Of the many potential factors (e.g. cold climate, shelter's capacity to isolate patients with ARI), shelter crowding was deemed to be associated with ARI outbreaks [8–12]. However, to the best of our knowledge, no studies to date have examined this association.

To address the knowledge gap in the literature, we determined whether a lower space per person at the shelter was associated with a higher incidence of ARI during the early period following the Great Eastern Japan Earthquake and tsunami. We also aimed to identify the minimum personal space requirements needed to limit the spread of infection between evacuees.

METHODS

Study design and settings

To evaluate the association between shelter crowding during the early period after the disaster and risk of ARI, we reviewed the medical records of all evacuees who presented to one of the medical clinics at the shelters in Ishinomaki city from 15 March to 4 April 2011 (21-day period). After Ishinomaki city officials began systematically managing shelters on 15 March 2011, several documented cases of ARI occurred during the first 3 weeks following the disaster [2]. This phenomenon was also observed after Hurricane Katrina [13].

Ishinomaki city is located in a coastal area of Miyagi prefecture and was one of the areas most affected by the disaster. Before the disaster, 163 000 people lived in Ishinomaki; the disaster destroyed 12 000 homes, and resulted in 3500 deaths and 450 missing persons [14]. Of the total area of Ishinomaki city, 13% (53 km^2) was flooded by the tsunami [15]. Following the disaster, the affected people voluntarily evacuated to the neighbouring schools, community centres, libraries, and other large buildings (Supplementary Fig. S1) [5]. The infrastructures of these building were well established and maintained during pre-disaster periods by the government or non-governmental agencies.

Medical teams of the Ishinomaki Area Medical Association (IAMA) began to provide care to the evacuees at the shelters a few days after the disaster. The shelter clinics were operated only when medical teams were present. Although laboratory blood tests and radiography were not available at the shelter clinics, some medical teams performed influenza rapid antigen tests on site.

Inclusion and exclusion criteria

Shelters

We included all previously designated shelters with clinics that were located at public facilities (schools, libraries, community centres) in Ishinomaki city. We excluded from our analysis any shelters for which information about the daily number of evacuees, living space area, number of rooms, availability of heaters, or flood incursion were not recorded.

Participants

We included all patients who presented at a shelter clinic. During the study period, 9969 patients visited one of these clinics. We excluded 1811 patients who did not live within the shelters and 719 patients whose medical records did not include the date of visit or patient's name. Therefore, this study included 7439 (74·6%) patients.

Outcomes and covariates

Outcomes

The primary outcome was cumulative incidence rate of ARI/10 000 evacuees at each shelter during the study period. Cumulative incidence rate was defined as the total number of patients diagnosed with ARI at each shelter for the first time during the study period divided by the sum of the daily number of evacuees at each shelter during the same period.

The secondary outcome was daily incidence rate of ARI/10 000 evacuees at each shelter. The daily incidence rate of ARI was defined by the daily number of patients who were newly diagnosed with ARI for the first time during the study period divided by the daily number of evacuees at the shelter on the same day.

The definition of ARI is given in Figure 1. The case definition for ARI may include infection of the upper and lower respiratory system. The second case definition is designed to detect patients with upper respiratory infection (e.g. pharyngitis and influenza). We were unable to establish the clinical case definition including lower respiratory infection based on the

Definition of acute respiratory infection (ARI)

Case definition

1. Fever (100°F [37.8°C] or greater) and diagnosis of respiratory infection (e.g., pneumonia, bronchiolitis, influenza, and pharyngitis) made by physicians in charge of the clinic.

OR

2. In case the medical records did not contain diagnosis, but included patient symptoms, fever (100°F [37.8°C] or greater) and the presence of at least two of the following signs or symptoms: (1) nonproductive cough; (2) nasal discharge or sneezing; (3) sore throat, hoarseness, or dysphagia; and (4) nasal congestion.

OR

3. Positive results of rapid antigen detection tests for influenza.

Fig. 1. The definition of acute respiratory infection

physical findings and symptoms; the respiratory rate, physical findings on chest examination, and pulse oximetry were not routinely recorded and radiography was not available at the shelter clinics. This definition of ARI did not include patients without fever and negative results of rapid antigen detection tests for influenza because other respiratory tract illness (e.g. hay fever, asthma, heart failure) can also cause respiratory symptoms such as cough [11, 16]. The fever cut-off value was derived from the U.S. Outpatient Influenza-like Illness Surveillance Network criteria [17]. Body temperature was measured only when patients visited the shelter clinic. This definition was not known to the physicians in charge during the disaster relief activities.

Risk factors of ARI

The extent of ARI incidence at shelters is considered to be affected by crowdedness of shelters, isolation of patients with ARI, air temperature, and cases of near-drowning [8–10, 12]. As an indicator of crowdedness of shelters, space per person was used and defined as the living space area at shelters divided by the number of evacuees per day. As an indicator of isolation, the number of rooms at the shelter was used. These were classified into four categories according to quartiles: very low (1–3 rooms), low (4–8 rooms), median (9–21 rooms), and high (>22 rooms) at each shelter. The number of rooms was fixed at each shelter during the study period. Spaces divided by cardboard were not regarded as rooms. As an indicator of air temperature, availability of heaters at the shelter was used. A flooded shelter was defined as those shelters that experienced flood incursion.

Methods of measurements

Using a standardized data collection form, patients' data (i.e. patients' demographics, physicians' diagnosis, symptoms, and disposition) were extracted from paper-based medical records by four research assistants who were medical file clerks and blinded for the study hypothesis. The abstractors received a 1-hour lecture from the principal investigator. The information about daily number of evacuees was provided by Ishinomaki city officials. The information about living space area at shelter, number of rooms at shelter, availability of heaters, and flood incursion was obtained from the shelter records.

Statistical analysis

To determine the linear trend between the mean space per person during the study period at each shelter and

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the cumulative incidence rate of ARI at shelters, we conducted simple linear regression analysis with the Huber–White heteroscedasticity-robust sandwich variance estimator.

We classified the evacuation shelters into two groups (crowded and non-crowded shelters) according to the United Nations High Commissioner for Refugees (UNHCR) minimum shelter standards of required personal space. The UNHCR recommends different minimum standards for floor space in cold climates – 4·5–5·5 m^2/person [11]. To identify an optimal cut-off value from these candidate values, we examined the possible nonlinear relationship between the mean space per person at each shelter and cumulative incidence rate of ARI by using a locally weighted scatterplot smoothing (LOESS) technique (smoothing parameter 0·6). This technique is designed to produce a smooth fit to data that have nonlinear relationships [18]. We excluded one shelter as an outlier from this analysis because the shelter had a mean space of 36·1 m^2/person. Then, we chose 5·5 m^2/person as an optimal cut-off value based on the shape of the LOESS curve, because the difference of the cumulative incidence rate of ARI between two groups of shelters classified by <5·5 or ⩾5·5 m^2/person appeared to be the largest.

Between the crowded and non-crowded shelters, we first compared the cumulative incidence rate of ARI using Mann–Whitney *U* test. Then, to assess the association between the crowdedness at shelters and daily ARI incidence rate with adjusting for confounders, we fitted the regression model using quasi-least squares (QLS) method with a Gaussian distribution and the Markov working correlation structures, along with the Huber–White heteroscedasticity-robust sandwich variance estimator. QLS is used to estimate correlation parameters within the framework of the generalized estimating equations (GEE), with the Markov working correlation structures. The distribution of the daily incidence rate of ARI did not fit the gamma and Poison distributions. Because the daily incidence rate of ARI was measured repeatedly at unequal intervals at each shelter, Markov working correlation structures were used to account for the autocorrelation of the units with unequal time intervals [19]. Although we obtained medical records for the shelter clinics, we were not able to obtain the data of the evacuees who did not visit the clinics. Therefore, we developed a population-averaged GEE model. We constructed this model to assess the range of difference in daily incidence rate of ARI at crowded shelters compared to non-crowded shelters with other covariates: number of rooms at shelters, availability of heaters, and flooded shelters.

In the sensitivity analysis, we repeated this model with a different definition of crowded shelters (<4·5 m^2/person space). $P < 0·05$ was considered statistically significant. All analyses were conducted with Stata v. 12·1 (Stata Corp LP, USA).

Ethical considerations

The study protocol accorded with the guidelines for epidemiological studies issued by the Ministry of Health, Labour and Welfare of Japan [20]. The Institutional Review Board of Fukui University approved the study with waiver of informed consent for this chart review study.

RESULTS

During the study period, 44 shelters with medical clinics were established at public facilities. Seven shelters were excluded due to missing information; therefore, 37 (84%) shelters were included in the study. Of eligible patients, 418 (5·6%) were diagnosed with ARI.

The mean space per person at each shelter had no significant linear association with the cumulative incidence rate of ARI [−0·4/10 000 person-days, 95% confidence interval (CI) −0·1 to <0·1, $P = 0·23$].

Based on the shape of the LOESS curve, we selected 5·5 m^2/person as the optimal cut-off value (Fig. 2), and classified the shelters into two categories: 21 (56·8%) shelters were categorized as crowded shelters (mean space <5·5 m^2/person) and 16 (43·2%) were non-crowded shelters (mean space ⩾5·5 m^2/person). Characteristics of shelters and patients are listed in Table 1. The overall median daily number of evacuees at the 37 shelters was 11 871 [interquartile range (IQR) 9653– 17 689]. Mean space per person was 3·8 m^2 [standard deviation (s.d.) = 1·1 m^2] at crowded shelters and 9·1 m^2 (s.d. = 7·4 m^2) at non-crowded shelters.

The crowded shelters had a higher median cumulative incidence rate of ARI (5·4/10 000 person-days, IQR 0–24·6) compared to the non-crowded shelters (3·5/10 000 person-days, IQR 0–8·7, $P = 0·04$).

The trend of the daily incidence rate of ARI/10 000 evacuees at crowded and non-crowded shelters is described in Figure 3. The daily incidence rate of ARI at crowded shelters peaked at approximately 2 weeks after the disaster, while the daily incidence

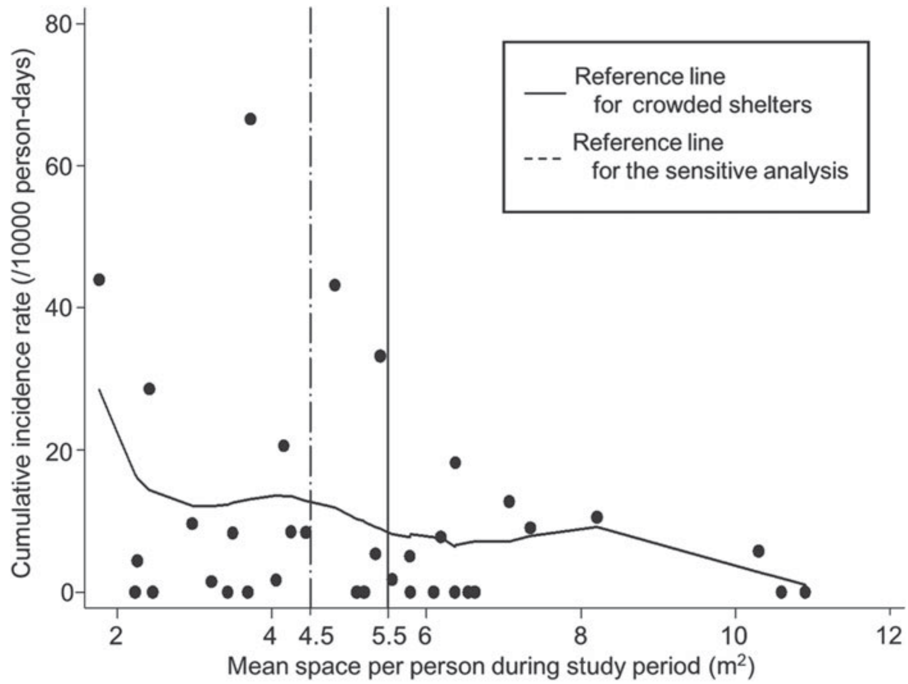

Fig. 2. Relationship between mean space per person at each shelter during the study period and cumulative incidence rate of acute respiratory infection

Table 1. *Shelter and patient characteristics*

	Total shelters	Crowded shelters	Non-crowded shelters	*P* value
Shelter characteristics				
Number of shelters, *n* (%)	37	21 (56·8)	16 (43·2)	
Number of evacuees per day, median (IQR)	11 871 (9653– 17 689)	8127 (6646– 12 187)	3792 (3007–5502)	<0·01
Mean space per evacuee, m^2 (S.D.)	6·1 (5·6)	3·8 (1·1)	9·1 (7·4)	<0·01
Number of rooms at shelters, median (IQR)	8 (4–21)	8 (4·5–21·5)	6 (1–10·6)	0·09
Post-disaster days to beginning to utilize heater, *n* (IQR)	2·0 (0–6·5)	3·0 (0–7·5)	0 (0–5·8)	0·24
Number of flooded shelters, *n* (%)	13 (35·1)	7 (33·3)	6 (37·5)	0·31
Patients' characteristics				
Total patients with ARI during the study period, *n*	418	364	54	
Age (yr), median (IQR)	32·0 (12·0–62·0)	32·0 (13·0–61·0)	33·0 (9·0–64·0)	0·23
Female, *n* (%)	212 (50·7)	184 (50·5)	28 (51·9)	0·31
Transferred to hospital for ARI, *n* (%)	5 (1·2)	4 (1·1)	1 (1·9)	0·31

ARI, Acute respiratory infection; IQR, interquartile range; S.D., standard deviation.
Crowded shelters: mean space <5·5 m^2/person at shelter; non-crowded shelters: mean space ⩾5·5 m^2/person at shelter.

rate of ARI at non-crowded shelters was relatively stable during the study period. Similar to the finding of the cumulative incidence rate, crowded shelters had an increased daily incidence rate of ARI (adjusted difference 19·1/10 000 person-days, 95% CI 5·9–32·4, $P = 0·01$, Table 2) compared to non-crowded shelters.

In the sensitivity analysis using a different definition of crowded shelters, i.e. shelters with a space of <4·5 m^2/person had a non-significantly increased daily incidence rate (10·4/10 000 person-days, 95% CI –7·6 to 28·4, $P = 0·26$) compared to shelters with a space of ⩾4·5 m^2/person.

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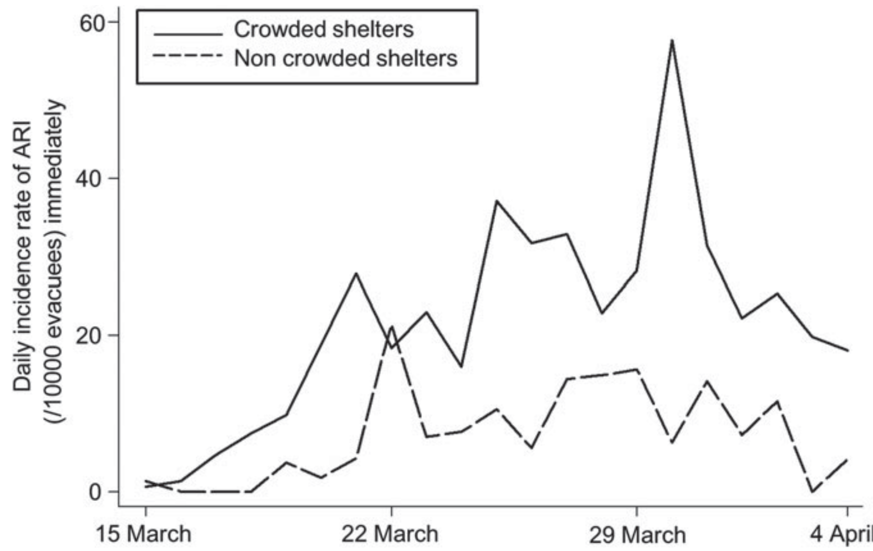

Fig. 3. Trend of daily incidence rate of acute respiratory infection (ARI)/10000 evacuees at crowded and non-crowded shelters.

Table 2. *Difference in daily incidence rate of ARI/10 000 evacuees*

Characteristics	Difference in daily incidence rate/10 000 evacuees	95% CI	*P* value
Non-crowded shelter	Reference	—	—
Crowded shelter	19·1	5·9 to 32·4	0·01
Number of rooms at shelter			
Very low (1–3 rooms)	Reference	—	—
Low (4–8 rooms)	−9·7	−33·7 to 14·1	0·42
Median (9–21 rooms)	−17·7	−41·5 to 6·1	0·15
High (>22 rooms)	−5·8	−28·5 to 16·9	0·62
Availability of heaters	3·4	−8·2 to 15·2	0·58
Flooded shelter	7·2	−9·9 to 24·2	0·83

ARI, Acute respiratory infection; CI, confidence interval.
Non-crowded shelter: mean space $\geqslant 5{\cdot}5\ m^2$/person at shelter during the study period; crowded shelter: mean space $<5{\cdot}5\ m^2$/person at shelter during the study period.

DISCUSSION

In this retrospective study of the evacuees presenting at one of the 37 medical clinics at the evacuation shelters during the first 3 weeks after the Great Eastern Japan Earthquake and tsunami in 2011, we found that a lower space per person at the shelter was associated with a higher incidence of ARI. More specifically, we also found that the shelters with $<5{\cdot}5\ m^2$/person space had significantly higher cumulative and daily incidence rates of ARI for evacuees.

Outbreaks of ARI in the evacuees at large emergency shelters are considered to be associated with crowdedness at shelters; however, the association had not yet been proved empirically [21]. In an area affected by the South Asia earthquake in 2005, ARI was the most common infectious disease, accounting for 30% of total patients [22]. Similarly, ARI was also a prevailing infectious disease after the earthquake and tsunami in Indonesia in 2005 and the earthquake in Iran in 2003 (62% of total patients in Indonesia and 79% in Iran) [3, 4]. Despite its public health importance, crowdedness at shelters was not measured in the previous studies.

To the best of our knowledge, this study is the first to demonstrate the association between shelter crowdedness and increased incidence rate of ARI. Based on our findings, $5{\cdot}5\ m^2$/person space may serve as a threshold for the required space at shelters to prevent ARI epidemics in the evacuation shelters. To set an international standard, the UNHCR published guidelines for the minimum living space at shelters [11]. Indeed, the UNHCR recommends a minimum space of 4·5–5·5 m^2/person in cold climates because the risk of ARI is deemed to increase in a cold climate [8, 11]. Our findings lend a significant support to this UNHCR standard for the minimum living space in light of the prevision of ARI outbreaks in shelters.

Natural disasters occur abruptly, but the disease burden in the post-disaster periods is often predictable. Our findings would be beneficial for emergency evacuation planning to reduce incidence of ARI at shelters. Within the next 30 years, another large catastrophic natural disaster called the 'Nankai Megathrust Earthquakes' is predicted to occur in Japan [23]. Estimated damages of this disaster are 9000– 85 000 deaths and 5 million evacuees [23]. To accommodate a large number of evacuees, the local governments have established evacuation planning with the required space per person at evacuation shelters to be 2·54 m^2/evacuee on average [24]. Based on our findings, this minimum required space for evacuees would result in a high incidence of ARI. However, if the threshold of 5·5 m^2/evacuee suggested by our study could be implemented, an estimated 20 000 ARIs would be prevented within 3 weeks after the disaster. Our data strongly suggest that evacuation planning should consider the perspective of infectious disease management, and prepare adequate space for each evacuee. Otherwise, the current evacuation planning could place additional significant burdens on already stressed healthcare systems in affected areas.

Limitations

Our study has several limitations. First, our study might have underestimated the incidence rate of ARI due to the following reasons. We excluded patients who were suspected to have reinfection with ARI; however, reinfection with the same agent within a month after the initial infection is typically low and most patients with reinfection are asymptomatic [25]. Thus, the true number of infections may not have been counted. Additionally, we excluded patients who had respiratory symptoms with fever <37·8 °C at medical examination. These patients might have experienced a higher fever during times the IAMA teams were unavailable. Second, we were unable to identify evacuees who were newly arrived at shelters, which could cause the number of persons at risk to be less accurate. However, these evacuees were probably rare because they typically moved to unaffected areas rather than to the shelters. Third, as with any observational studies, the observed associations do not necessarily prove causality and might by confounded by unmeasured factors, such as the use of personal sterilization, nutrition status, and availability of healthcare education [8]. Fourth, our study did not collect the patients' socioeconomic status. The schools, community centres, and libraries were used as shelters to accommodate neighbourhood residents without charging a fee in the setting of a disaster. These shelters were designed to preserve social ties in communities. It is possible that shelters contained populations of residents that were not socioeconomically diverse; however, it is unlikely that the socioeconomic factors affect the exposure of interest (i.e. personal space in the shelter), thereby not serving as a confounder. Fifth, the population characteristics might have affected the incidence of ARI. Unfortunately, in this post-disaster setting, we were not able to collect detailed patients' characteristics of the evacuees at each shelter. Sixth, in the setting of the disaster relief activity, it was logistically difficult to ensure complete ascertainment, although these medical records were strictly stored in the Japanese Red Cross Ishinomaki Hospital, the headquarters of IAMA. Therefore, we believe the number of missing records is few. Finally, unfortunately, we do not have data on the population who did not present at shelter clinics; we obtained the daily number of evacuees at each shelter because the city officers collected the number of evacuees to estimate daily requirements such as food and water. Therefore, it is unclear if our inferences are generalizable to the entire population. Further, although the proportion of cigarette smoking and immunization coverage (pneumococcal vaccine: 7% of the people aged $\geqslant$65 years in Japan, and influenza vaccine: 35% of the total population in Japan) was unavailable in our target population, the observed relationships are likely present [26–28].

CONCLUSION

In this retrospective study of shelter clinics after the Great Eastern Japan Earthquake and tsunami, we found that crowded shelters during the early post-disaster period had an increased incidence rate of ARI compared to non-crowded shelters. Our findings may aid healthcare authorities in formulating optimal shelter planning that will allot enough emergency housing space to prevent ARI outbreaks after disasters.

SUPPLEMENTARY MATERIAL

For supplementary material accompanying this paper visit http://dx.doi.org/10.1017/S0950268815001715

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DECLARATION OF INTEREST

None.

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