International Journal of Disaster Risk Reduction 59 (2021) 102244

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: http://www.elsevier.com/locate/ijdrr

# Tsunami preparedness and resilience in the Cascadia Subduction Zone: A multistage model of expected evacuation decisions and mode choice

Chen Chen [a], Michael K. Lindell [b], Haizhong Wang [c,*]

[a] School of Civil and Construction Engineering, Oregon State University, Corvallis, OR, 97331, USA
[b] Affiliate Professor, Department of Urban Design and Planning, University of Washington, Seattle, WA, 98195, USA
[c] Associate Professor, School of Civil and Construction Engineering, Oregon State University, Corvallis, OR, 97331, USA

ARTICLE INFO

*Keywords:*
Disaster
Tsunami evacuation
Cascadia subduction zone
Risk perception

ABSTRACT

Physical scientists have estimated that the Cascadia Subduction Zone (CSZ) has as much as a 25% chance to produce a M9.0 earthquake and tsunami in the next 50 years, but few studies have used survey data to assess household risk perceptions, emergency preparedness, and evacuation intentions. To understand these phenomena, this study conducted a mail-based household questionnaire using the Protective Action Decision Model (PADM) as a guide to collect 483 responses from two coastal communities in the CSZ: Crescent City, CA and Coos Bay, OR. We applied multistage regression models to assess the effects of critical PADM variables. The results showed that three psychological variables (risk perception, perceived hazard knowledge, and evacuation mode efficacy) were associated with some demographic variables and experience variables. Evacuation intention and evacuation mode choice are associated with those psychological variables but not with demographic variables. Contrary to previous studies, location and experience had no direct impact on evacuation intention or mode choice. We also analyzed expected evacuation mode compliance and the potential of using micro-mobility during tsunami response. This study provides empirical evidence of tsunami preparedness and intentions to support interdisciplinary evacuation modeling, tsunami hazard education, community disaster preparedness, and resilience plans.

## 1. Introduction

Recent tsunami events have caused casualties, damage, and social disruption [1,2,3]. Studies of emergency preparedness and intended disaster response should be conducted for communities exposed to near-field tsunami to determine whether people who live in the inundation zone can evacuate successfully [4,5]. Risk area residents and local authorities in these communities need to work together to improve tsunami hazard education and preparedness–especially warning and evacuation systems [5].

Communities in the Cascadia Subduction Zone (CSZ) face the threat of a near-field earthquake and tsunami. As shown in Fig. 1, the CSZ megathrust is a 1000 km dipping fault that runs about 100–160 km off the Pacific coast from Northern California, USA to Northern Vancouver Island, Canada [6,7]. A magnitude 9 (M9) CSZ earthquake can generate significant threats to coastal communities in this region [8]. Although the average rupture probability for the entire CSZ in the next 50 years is 7%–25%, the Southern CSZ margin faces a much higher 85% rupture probability [9]. Such an event will generate a near-field tsunami with waves of 10 m or more that strike most CSZ communities in about 20–40 min [10,11,12,13].

There has been a significant amount of research on this threat, but most studies have concentrated on physical science and structural engineering aspects. By contrast, relatively fewer studies have examined the social science and transportation engineering aspects of tsunami hazard on the CSZ–especially survey data on households' intended evacuation behavior [4,14]. Unlike studies of U.S. hurricane evacuations, which are extensive because of their frequent occurrence [15], studies of U.S. tsunami evacuations appear to be nonexistent because these threats are so rare. In the absence of studies of people's behavior during actual tsunami evacuations, researchers have recently begun to study CSZ residents' tsunami risk perceptions and behavioral intentions [16–18]. Thus, conducting studies of household preparedness and evacuation intentions in Southern CSZ communities can help at-risk residents and local authorities to identify the current gaps in disaster response performances and be better prepared for the next threat.

* Corresponding author.
*E-mail addresses:* chenc4@oregonstate.edu (C. Chen), mlindell@uw.edu (M.K. Lindell), Haizhong.Wang@oregonstate.edu (H. Wang).

https://doi.org/10.1016/j.ijdrr.2021.102244
Received 21 January 2021; Received in revised form 29 March 2021; Accepted 31 March 2021
Available online 16 April 2021

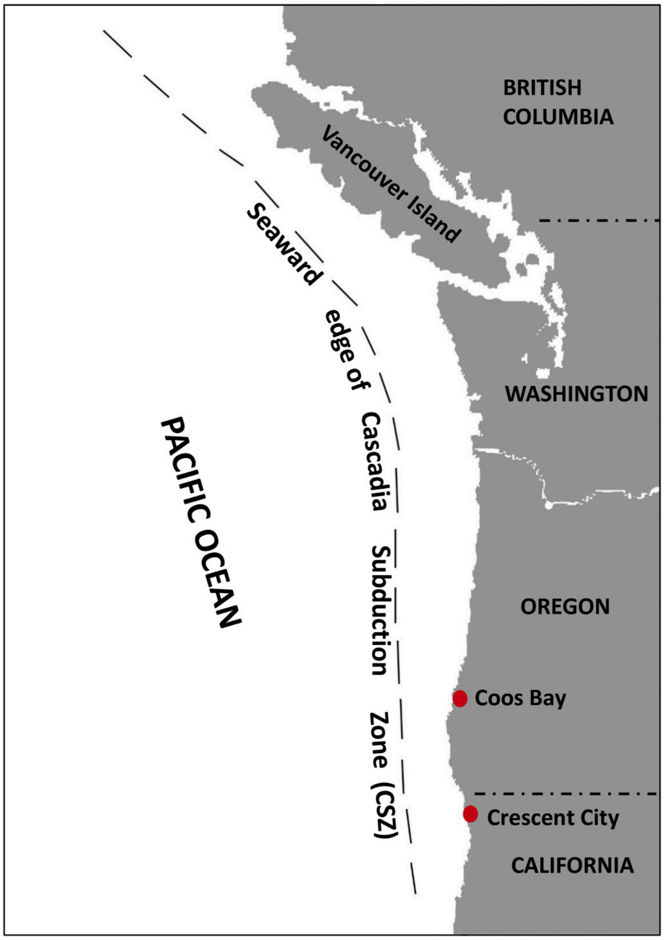


**Fig. 1.** Coos Bay, OR and Crescent City, CA in Cascadia Subduction Zone, revised based on [7].

## 2. Recent research on household response to tsunamis

Recent studies have collected data on people's responses to actual earthquake and tsunami events and hypothetical scenarios throughout the world. Table 1 summarizes some earthquake and tsunami response studies and the corresponding research context for recent actual and hypothetical events.

These studies provide the basic foundation for predicting people's actual behavior when facing a tsunami. In turn, local authorities can use predictions of maladaptive responses to guide hazard education programs and emergency response plans. The findings from this limited number of studies are strengthened by social scientists' finding that there are commonalities in people's protective action decision making process across a wide range of environmental hazards [28,29]. These commonalities are summarized in the Protective Action Decision Model (PADM) [30,29], which describes the process of an individual responding to an environment hazard. The process includes three major sequential components: information, decision, and action. Particularly, the process describes how individuals use environmental and social cues, as well as warning messages, to search for additional information and make protective action decisions. This process depends on receiver characteristics including physical, psychological, economic, and social attributes.

One obvious difference among these studies is that some of them assess the importance of different variables in predicting people's *actual* responses to tsunamis whereas others assess the importance of different variables in predicting people's *intended* responses to hypothetical tsunami scenarios. Nevertheless, there is evidence that evacuation intentions studies produce results that are similar to those of post-event surveys of actual tsunami evacuations. Specifically, Blake et al. [25] found that the 70% of their respondents who actually evacuated in response to a tsunami warning was very similar to the intentions of survey responses from same location in 2015 where 65% said they intended to evacuate [31]. This finding for tsunami evacuation is consistent with hurricane research that has found evacuation intention is significantly correlated with later evacuation [32] and a statistical meta-analysis [33] that found similar results between 38 studies of actual hurricane evacuation and 11 studies of responses to hypothetical hurricane scenarios [15].

**Table 1**
Recent earthquake and tsunami response studies.

| Event type | Study | Event, location, and date | Sample size | Research Focuses |
|---|---|---|---|---|
| Actual | Lindell et al. [19] | M8.1 earthquake and tsunami, American Samoa, 2009 | 262 | Information; Risk perception; Milling time; Preparation; Evacuation decision; Evacuation mode, Evacuation destination |
| Actual | Apatu et al. [20] | M8.1 earthquake and tsunami, American Samoa, 2009 | 211 | Evacuation decision and mode |
| Actual | Wei et al. [21] | M7.1 Christchurch, New Zealand, M9 Hitachi, Japan 2011 | 257 Christchurch; 332 Hitachi | Information; Psychological reaction; Behavior; Evacuation decision |
| Actual | Fraser et al. [22] | M6.6 earthquakes, Wellington, New Zealand, 2013 | 204 | Information; Risk perception; Expected tsunami arrival time; Preparation; Evacuation decision |
| Actual | Yun and Hamada [23] | Tohoku-oki earthquake, Japan, 2011 | 1153 | Information; Milling time; Preparation; Evacuation destination |
| Actual | Urata and Pel [24] | Rikuzentakata, Japan, 2011 | 510 | Risk perception; Evacuation intention; Preparation; Experience; Expected tsunami arrival time |
| Actual | Blake et al. [25] | M7.8 earthquake and tsunami, Aotearoa/New Zealand, 2016 | 245 Petone; 164 Eastbourne | Information; Preparation; Evacuation decision, Evacuation destination |
| Actual | Harnantyari et al. [26] | M7.5 earthquake and tsunami, Sulawesi, Indonesia, 2018 | 200 | Information; Evacuation decision; Evacuation mode; Evacuation destination; Travel time |
| Hypothetical | Arce et al. [27] | Kamakura, Japan, 2016 | 163 | Information; Risk perception; Perceived hazard knowledge; Evacuation intention |
| Hypothetical | Buylova et al. [16] Chen et al. [17] | Seaside, Oregon, USA 2017 | 211 | Risk perception; Perceived hazard knowledge; Self-efficacy, Evacuation intention; Evacuation mode; Travel time; Lead and follow behavior |
| Hypothetical | Lindell et al. [18] | Commencement Bay, Washington; Lincoln City, Oregon; and Eureka, California, USA 2019 | 225 | Risk perception; Perceived hazard knowledge; Warning dissemination; Preparedness; Evacuation intention; Evacuation time and logistics |

### 2.1. Risk perception

According to the PADM, an individual's observation of disaster cues or receipt of warnings triggers an assessment of personal risk that combines the perceived probability, severity, and immediacy of a threat's consequences [16]. Risk perception varies among individuals within a given location. For instance, 47% respondents in Kamakura City, Japan reported that an earthquake and tsunami is likely or very likely to happen in the next 30 years [27]. As a critical component in PADM, risk perception affects an individual's or household's choice of a protective action [29].

Reacting quickly after receiving disaster cues or warnings is critical in surviving a near-field tsunami, so some researchers have analyzed factors impacting people's reactions. When people perceive the risk to be likely, severe, and imminent, they prepare to evacuate [17,14], or take other protective actions [1,34].

Although a substantial amount of evidence supports the impact of risk perception on protective action, the variables influencing risk perception have been reported to vary across studies. For example, Lindell et al. [1] found that tsunami risk perception was affected by some demographic variables, situational factors, and hazard awareness programs. Specifically, expectations of casualties and damage were influenced by household size, community tenure, and home ownership. Consistent with many previous studies of other disasters, other demographic variables had weak and inconsistent correlations with risk perception. People who attended tsunami educational programs thought a tsunami would arrive sooner, but those programs had no apparent impact on tsunami evacuation decisions and outcomes. The authors also suggested that future research should explore reasons why hazard awareness programs did not affect disaster response, as concluded by Baker [35]. A survey study after 2011 Japanese earthquake and tsunami event found that risk perception is determined by the combination of education programs, received information, and demographics [24], and risk perception was found to predict evacuation decision. Buylova et al. [16] separated risk perception into two components–"risk to self" and "risk to other", which were significantly correlated with each other, but differed in their correlations with other variables. For example, self-efficacy, gender, and disability were positively correlated with risk to self but not risk to others. Living in the inundation zone was significantly correlated with both aspects of risk perception.

### 2.2. Perceived hazard knowledge

Hazard knowledge can play an important role in determining risk area residents' responses to an earthquake and tsunami. In many cases, an individual's hazard knowledge will determine what type of protective action to take [29]. For example, although the majority of respondents who evacuated because they knew the 2016 Aotearoa/New Zealand earthquake could cause a tsunami, some respondents were confused about the tsunami risk and waited for officials to warn them [25]. The most immediate source of information about a near-field tsunami threat is the knowledge that long and strong earthquake ground motion is a reliable environmental cue [1]. However, hazard awareness programs to increase coastal residents' knowledge are not always effective. Yun and Hamada [23] found that participation in disaster prevention training showed no clear difference between the survivors (14%) and the dead/missing (16%) in the 2011 Japan earthquake. Information about evacuation routes and evacuation destinations also had no effect on the survival rate.

Emergency managers have developed hazard education programs such as tsunami inundation maps and brochures for CSZ communities [36]. However, the effectiveness of those educational programs varies. Arce et al. [27] interviewed tourists in Kamakura City, Japan, about their knowledge of tsunami warning signs. They concluded that many tourists do not even recall having seen these signs. Further, knowledge sometime is difficult or expensive to measure directly. As an alternative to objective tests, perceived hazard knowledge measures how confident people are about their hazard knowledge. Buylova et al. [16] found that perceived hazard knowledge was correlated with demographics such as home ownership, income, disabilities, and preparedness.

### 2.3. Evacuation decision

Evacuation decision, as a critical component of disaster studies, has been documented in previous tsunami research [20,25,17,22,26,1,24]. An individual/household can make decision errors by either starting unnecessary evacuations or failing to initiate necessary ones [37]. It is critical to understand the characteristics of the individuals at risk and the factors that influence evacuation decisions [17].

In many previous tsunami events, the majority of respondents chose to evacuate [20,25,26,1]. As in hurricane studies [35,15], factors influencing evacuation decisions also varied in previous tsunami studies. Evacuation decisions were significantly associated with risk perception, receiving earthquake information, and respondents' locations, but not with their demographic characteristics in the 2011 New Zealand and Japan earthquake and tsunami events [22,21], and the 2009 American Samoa tsunami [20,1]. A survey conducted after two local earthquakes in New Zealand showed that evacuation decisions were not significantly affected by people's expectations that a tsunami would occur, its estimated arrival time, or its expected damage. The event-specific influential variables may be due to variations in perceived shaking intensity, normalisation bias, or warning fatigue [22]. In the 2009 American Samoa tsunami, the majority of respondents evacuated as a consequence of environment cues, social cues, or official warnings, but some searched for further information before evacuating [1].

Similar to the findings from hurricane evacuation research, recent studies of expected response to hypothetical tsunami scenarios have also shown that evacuation decisions are positively correlated with living in the tsunami risk area and risk perception, but negatively correlated with years living in the community [17]. Some studies have found demographic variables, such as gender and age, to affect tsunami evacuation decisions [16] but reviews of the hurricane evacuation literature suggest that these might not replicate [35,15]. A study for residents in Washington State found that people were unsure about what decision to make and how to make response decisions, and the possible reasons were inadequate knowledge and low to moderate level of preparedness [38]. Therefore, it is important for future studies to examine what decision people would make and what factors impact the decision when responding to tsunami threats in CSZ.

### 2.4. Evacuation mode and preparation tasks

Current literature has documented the preparation tasks, evacuation modes, and potential outcomes of tsunami response [20,27,25,17,39,26,1]. Although people tend to evacuate by car when one is available, evacuation mode choice is location- and scenario-dependent. A survey of respondents on the southwest coast of American Samoa showed that the majority of evacuees took cars, even though pedestrian evacuation was feasible [1]. However, the study of American Samoa's capital city, Pago Pago, showed that most residents (74.4%) on the east side of the island evacuated by foot [20]. In the 2016 Aotearoa/New Zealand tsunami, traffic congestion on the South Island was caused by the majority of residents using vehicles to evacuate [25]. There were also other problems such as some residents needing transportation assistance because they lacked access to a vehicle, lacked driving skills, or had a physical disability [25]. Nonetheless, evacuating by vehicle is rare in other communities, with the majority of evacuees evacuating by foot in the 2004 Thailand tsunami [40], the 2011 Kamakura City tsunami [27], and the 2018 Sulawesi tsunami (~ 90%) [26].

Variation in evacuation mode is also found in response to hypothetical scenarios. Half of the respondents intended to evacuate by foot in a hypothetical local tsunami study in Napier, New Zealand [39].

Moreover, the 39% of the respondents from Seaside, OR, U.S. who intended to evacuate by foot is almost the same as by car (38%) [17]. Evacuation mode choice was significantly correlated with self-preparation, physical disability, income, age, gender (female), and previous evacuation experience, but was not significantly related to expected wave arrival time, risk perception, or perceived hazard knowledge [17].

Tsunami research [25,26,1] has frequently documented people's performance of evacuation preparation tasks immediately before departure, including gathering life essentials, packing emergency kits, contacting and gathering family members and friends, obtaining official information, discussing evacuation plans with family or neighbors, gathering pets, helping others, and collecting valuable items. Blake et al. [25] reported that only 7% of their respondents evacuated immediately after the earthquake without taking any preparation actions. These results are consistent with previous findings for flash flood evacuation [14].

### 2.5. Research objectives and questions

Previous literature review sections revealed the need for more studies to support the explanations and predictions of people's protective action decisions when responding to tsunami. Although some studies have analyzed protective decisions in previous tsunami events, studies guided by social science models of evacuation decision making are sparse for CSZ communities. To fill these gaps in the research on tsunami evacuation, this study uses the PADM as a guide to analyze coastal residents' risk perceptions; perceptions of hazard knowledge and evacuation mode efficacy, evacuation intentions, and evacuation mode choice through an evacuation intention questionnaire survey. Specifically, Table 1 and the research reviewed in the preceding sections leads to three research questions:

1. What demographic, location, and tsunami experience variables impact CSZ residents' psychological variables (risk perception, perceived hazard knowledge, and evacuation mode efficacy)?
2. What variables impact CSZ residents' evacuation intentions and evacuation mode choices?
3. Do people intend to follow official recommendations about which evacuation mode to use?

## 3. Methods

### 3.1. Study sites

The city of Seaside OR has been the subject of previous tsunami research, given its high level of vulnerability to this hazard [17,41,42,43]. However, the same cannot be said for other CSZ communities. Fig. 2 shows that the Coos Bay Peninsula, including the cities of Coos Bay and North Bend, is surrounded by bay water on its east, north, and west sides. It is the site of the second largest estuary in Oregon, and the sixth largest on the US west coast [44]. The Coos Bay Peninsula has the largest population of any Oregon coastal community, with a total population of about 26,129 [45]. Although this peninsula has low-lying areas around its periphery, its hilly spine provides ready access to higher ground for safe evacuation destinations. Compared to the Coos Bay Peninsula, Crescent City, CA has a smaller population (6787 according to 2019 Census data), but the offshore bathymetry makes the city susceptible to tsunami impacts. Indeed, the city experienced community damage and life loss in the 1964 Alaska and 2011 Sendai tsunami. Crescent City has a relatively large number of households exposed to tsunami threat but the short distance out of the inundation zone makes successful evacuation possible [43].

These two communities are located in the southern margin of CSZ where the rupture probability is higher and tsunami wave arrival time is shorter than communities in the middle or northern CSZ [11]. Moreover,

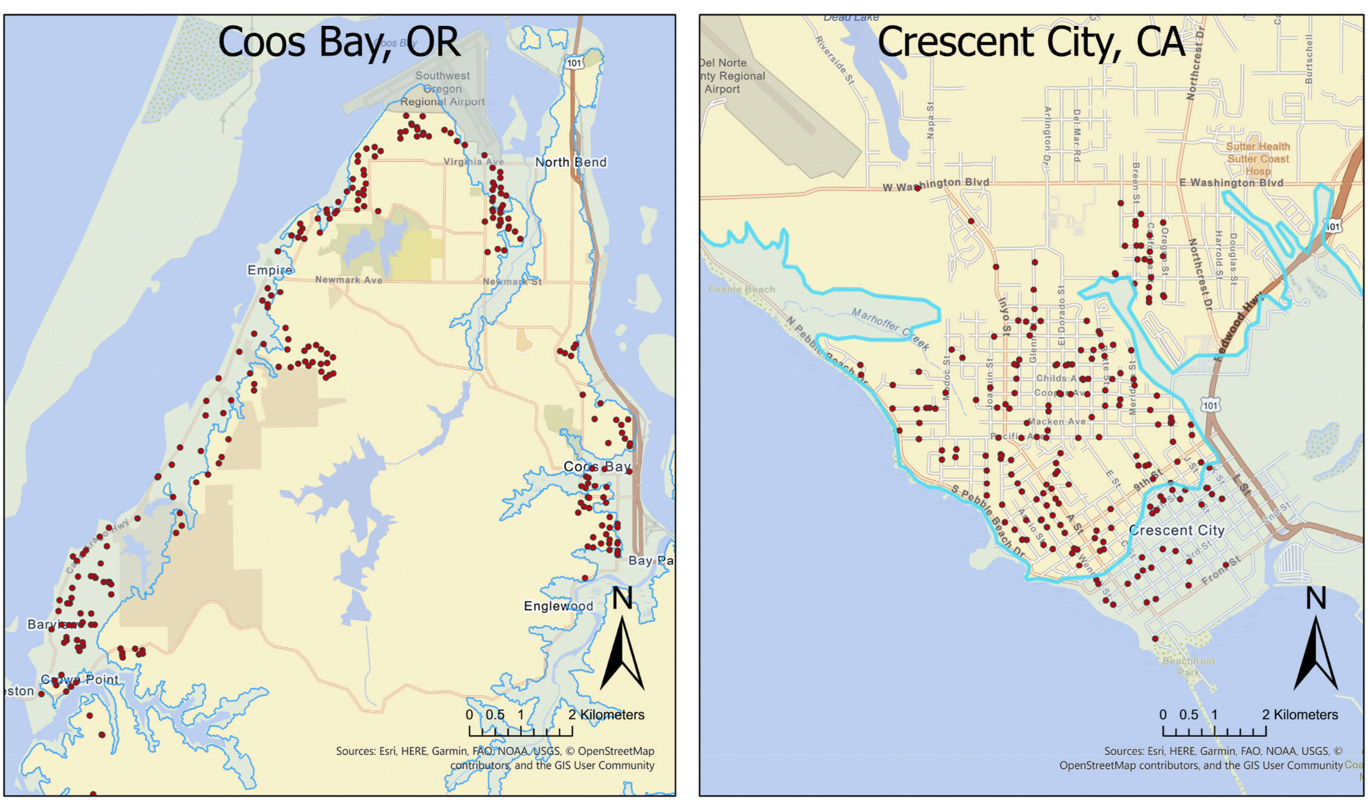


**Fig. 2.** Respondents' locations (red dots) and tsunami inundation areas (blue line) in Coos Bay, OR and Crescent city, CA. Inundation areas are modeled based on the CSZ M9.0 near-field tsunami [46,36].

**Table 2**
Sample and census demographics of study sites [45].

| | Coos Bay | | Crescent City | | Entire U.S. |
|---|---|---|---|---|---|
| | Sample | Census | Sample | Census | Census |
| **Age** | | | | | |
| under 6 | 3.0% | 6.4% | 4.0% | 3.4% | 6.0% |
| 6 to 18 | 12.0% | 21.2% | 16.0% | 13.2% | 22.3% |
| 19-65 | 46.0% | 50.4% | 51.0% | 73.9% | 55.2% |
| above 65 | 39.0% | 22.0% | 29.0% | 9.5% | 16.5% |
| **Gender (female)** | 53.0% | 54.0% | 63.0% | 71.0% | 50.8% |
| **Household Size (Mean)** | 2.13 | 2.36 | 2.16 | 2.16 | 2.63 |
| **Household Monthly Income (median)** | $3666 | $3648 | $3432 | $2607 | $5024 |
| **Education** | | | | | |
| No high school diploma | 4.0% | 13.0% | 4.0% | 33.0% | 22.3% |
| High school graduate or higher | 58.0% | 69.0% | 58.0% | 58.0% | 56.2% |
| Bachelor's degree or higher | 38.0% | 19.0% | 38.0% | 9.0% | 31.5% |
| **Ethnicity (White)** | 91.0% | 83.0% | 88.0% | 51.0% | 76.3% |

these two communities have elevated levels of social vulnerability because, as shown in Table 2, the demographic characteristics of the two communities differ substantially from the U.S. Census averages. Specifically, these two communities have more females, smaller household sizes, and are poorer and less educated than the overall U.S. population. The Census data also show demographic differences between Coos Bay and Crescent City. Crescent City has a smaller proportion of seniors, higher proportion of females, lower proportion of Caucasians, and lower levels of income and education than Coos Bay. Consistent with many previous mail surveys of environmental hazards, the two samples over-represent seniors (age > 65), Caucasians, and the more highly educated. However, sample bias has little effect on correlation coefficients as long as it is not so severe that it substantially attenuates the variances of the variables [47].

### 3.2. Procedure

In order to have adequate statistical power to detect a moderate correlation (r = 0.20), the required sample size for $\alpha = 0.05$ and $\pi = 0.80$ is n = 194, which we rounded up to a target of 200 completed questionnaires from each community. Assuming a response rate of 20% for a three wave survey, 200/.20 = 1000 households are needed for each community. The Marketing Systems Group provided a sample of 2007 randomly selected households in Coos Bay (1006 households) and Crescent City (1001 households). The random selection process was conducted in each census block group. Most block groups have more than a quarter of their spatial area in the near-field tsunami inundation zone [46,36]. The survey data was collected between May and September 2020. There were 483 (258 from Coos Bay, 225 from Crescent City) respondents who returned a questionnaire, which results in a 29.7% response rate (380 undeliverables).

### 3.3. Measures

Risk perception is measured by 7 items: the estimated likelihood of the earthquake and tsunami, property damage, personal and family injury, work disruption, infrastructure disruption, community damage, and community members injury from the earthquake and tsunami. Factor analysis was used to create a risk perception index based on those variables, shown in Table 3. The preparation task variable is the number of the preparation tasks the respondent expected to perform before evacuating. Those tasks included in the survey were determined based on authors' experience and people's actions in actual tsunami and flash flood events. These are collecting important documents; collecting keys and wallets; contacting loved ones to see if they are safe; waiting for an official evacuation order; packing bags; grabbing an emergency kit; gathering family members; talking with neighbors to see if there is a tsunami warning; checking TV/Internet/social media; and seeing if friends or neighbors are evacuating, then following them.

### 3.4. Analysis

Pearson correlation, ordinary least squares (OLS) regression, and binary logistic regression analyses are employed to examine the relationships between variables and explore the multi-stage process of decision making. Analyses are conducted using SPSS. OLS regression is used when the dependent variable is continuous, whereas binary logistic

**Table 3**
Factor analysis results.

| Factor | Cronbach's α | Total variance explained | Items |
|---|---|---|---|
| Risk perception | 0.80 | 51.8% | The perceived likelihood of an M9 event happening in the next 10 years;<br>Cause major damage to your property;<br>Injure or kill your or your family members;<br>Disrupt your job or work;<br>Disrupt access to lifeline systems;<br>Cause major damage in your community;<br>Injure or kill other community residents. |
| Perceived hazard knowledge | 0.88 | 51.3% | Do you know the difference between local and distant tsunamis?<br>What natural warning signs indicate a tsunami is coming?<br>How soon could a local tsunami arrive after earthquake shaking stops?<br>If your house is located in/out of a tsunami hazard zone?<br>Where your communitys tsunami evacuation shelters/safe zones are?<br>Where your communitys tsunami evacuation routes are?<br>What to do during long, violent earthquake shaking?<br>What to do immediately after long, violent earthquake shaking stops?<br>What to do when there is a warning of a distant tsunami? |
| Bicycle evacuation efficacy | 0.89 | 64.3% | Be able to get you to safety;<br>Be able to get your family members to safety;<br>Be effective in avoiding congestion;<br>Be able to ride off streets when necessary;<br>Be able to carry all the luggage you need during evacuation;<br>Be a transportation mode that you would use to evacuate. |
| Bicycle recovery efficacy | 0.93 | 79.2% | Be effective in obtaining supplies from stores;<br>Be effective in getting you to your families and friends;<br>Be effective in avoiding damaged roads and buildings;<br>Be able to ride off streets when necessary;<br>Be a transportation mode that you would use during the few days. |

regression is used when dependent variable is binary (0/1) [48]. Mean substitution is used to replace the missing data in the regression analysis. In the analyses that follow, there are 595 statistical tests on correlation coefficients and 198 on regression coefficients, so the experiment-wise error rate is a concern [49]. Specifically, the expected number of false positive tests would be $FP = \alpha \times n$, where FP is the number of false positive test results, α is the Type I error rate, and n is the number of statistical tests. If α = .05 and n = 793, then FP = 40. Benjamini and Hochberg [50] [see Glickman et al. [51] for a more recent discussion] advocated that researchers (1) specify a false discovery rate $d$ for the entire study, (2) sort the $p_i$ significance values for the individual tests in ascending order $1 \leq i \leq n$, and (3) classify each $p_i \leq d \times i/n$ as statistically significant. In the present study, Benjamini-Hochberg procedure show that $p_i \leq d \times i/n$ until the variable with the critical value of $p_i =$ .009. Thus all p-values less than 0.01 are classified as statistically significant.

Following Gnanadesikan [52] and Huang et al. [53]; the graphical homogeneity test, shown in Fig. 3, plots the inter-item correlations of variables from Coos Bay responses against those from Crescent City. The cross-plot of 2701 pairs $k \times (k-1)/2 = 73 \times 72/2$ based on original 73 variables from questionnaire) of inter-item correlations result in an approximately linear plot ($r = 0.81$) indicating that the pooled sample is suitable for use in subsequent correlation and regression analyses.

### 3.5. Item analysis

Most of the psychological items were rated on a Likert scale from 1 (= not at all) to 5 (= a very great extent), so factor analysis was conducted to reduce the survey questions into indexes. Principal axis factoring followed by examination of the scree plot was used to determine the number of factors, after which varimax rotation was used to define the factor loadings. Four psychological indexes–risk perception, perceived hazard knowledge, perceived bicycle evacuation efficacy, and perceived bicycle recovery efficacy–were created by averaging all items loading significantly on each factor. Table 3 shows the items defining each factor along with corresponding Cronbach's α and variance explained by a single factor for each psychological variable. Table 4 describes the variables included in the correlation and regression

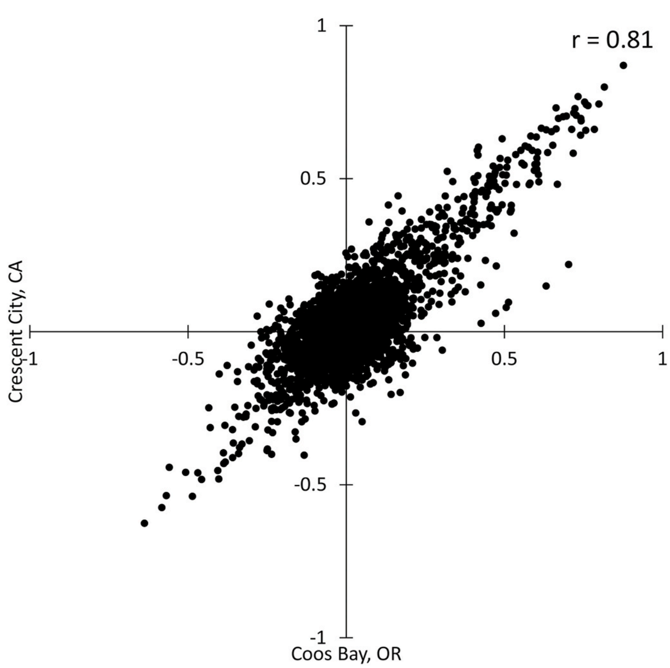


**Fig. 3.** Cross-plot of inter-items Pearson correlations for Coos Bay and Crescent City respondents.

analyses after the factor analysis was completed.

## 4. Results and discussion

The correlation matrix in Table 5 shows that significant correlations are more commonly found between psychological variables and behavior variables (32/77 = 42%) than between demographic variables and psychological variables (19/84 = 23%). Moreover, significant correlations are even less commonly found between behavior variables and demographic variables (15/132 = 11%) or experience/location variables and other variables (11/150 = 7%). As in hurricane research [54, 53], this correlation matrix supports a multi-stage model in which demographic variables predict psychological variables, which in turn predict behavior variables. The results of the regression analyses are presented in Table 6.

### 4.1. Analysis of research question 1: predictors of psychological variables

#### 4.1.1. Risk perception

The results reveal that respondents' overall risk perceptions are similar in Coos Bay and Crescent City. More than 40% of respondents in both communities reported a moderate possibility (3 on the 1–5 scale) that an M9 earthquake and tsunami will happen in the next 10 years. Many other respondents (35% in Coos Bay 37% in Crescent City) rated this event as likely or very likely, whereas only a small percentage said it is unlikely or very unlikely (21% in both cities). This pattern is consistent with previous tsunami risk perception research for Seaside OR [6,7].

The expectation of casualties to both respondents and community members is moderately high (Mean $M = 3.72$) and the rating of infrastructure damage ($M = 4.50$) is even higher–a pattern that is also similar to the findings in the Seaside study [16]. Another notable pattern is that 23% of respondents reported an earthquake/tsunami is very unlikely to disrupt to work, which is possibly due to the high percentage of retirees (39% in Coos Bay and 29% in Crescent City). The regression analysis results in Table 6 show that risk perception is negatively associated with marital status (divorced or widowed).

#### 4.1.2. Perceived hazard knowledge

The average score on each perceived hazard knowledge item (1 = not at all; 5 = very well) shows that people are fairly confident of their knowledge about tsunami in both communities, as shown in Fig. 4. Although most distributions of those items are left-skewed, the majority of respondents are not as confident about their knowledge of the difference between local and distant tsunami or about tsunami arrival time. Although the difference is mentioned in CSZ brochures [36], people may not pay enough attention to differentiating the two types of tsunami if they focus more on the worst case scenario (near field tsunami). People reported higher scores on knowing whether their houses are in the inundation zone than on other questions, which is probably because of the ready availability of this information [36].

Perceived hazard knowledge is positively impacted by evacuation experience, consistent with the findings of Buylova et al. [16]. This association suggests that local authorities can use experiential activities to increase the residents' perceived hazard knowledge, such as practicing evacuation routes by participating in evacuation drills.

#### 4.1.3. Perceived evacuation mode efficacy

Perceived evacuation mode efficacy in this study comprises 5 different transportation modes: walking, bicycle/cargo-bike, e-scooter/e-skateboard, motorcycle/e-bike, and car/truck. Except walking, we classified the alternatives to car/truck as micro-mobility modes. Respondents in both cities were similar in their ratings of each mode's efficacy, as shown in Fig. 5. Respondents reported higher evacuation efficacy for car/truck than the micro-mobility modes. There is a moderate difference between the two cities in ratings of walking efficacy

**Table 4**
Variable description.

| Category | Variable | Explanation | Valid N | Min. | Max. | Mean (numerical) or Percent (binary) | Std. Dev. |
|---|---|---|---|---|---|---|---|
| Behavior Variables | **Preparation tasks** | The number of tasks to do before evacuate | 483 | 0 | 10 | 3.12 | 2.46 |
| | **Preparation time** | Estimated preparation time | 391 | 0 | 180 | 11.85 | 13.55 |
| | **Evacuation intention** | Evacuation intention | 467 | 0 | 1 | 40% | |
| | **Evacuation by car** | Evacuate by car | 413 | 0 | 1 | 75% | |
| | **Evacuation by foot** | Evacuate by foot | 413 | 0 | 1 | 21% | |
| | **Estimated travel time** | Estimated travel time | 373 | 0 | 60 | 8.12 | 8.41 |
| | **Compliance foot** | Compliance to change evacuation mode from car to foot | 450 | 0 | 1 | 50% | |
| | **Compliance micro-mobility** | Compliance to change evacuation mode from car to micro-mobility | 450 | 0 | 1 | 8% | |
| | **Consider micro-mobility** | Consider using micro-mobility in evacuation or recovery phase | 453 | 0 | 1 | 62% | |
| | **Destination inundation** | Whether the evacuation destination is in inundation zone | 423 | 0 | 1 | 6% | |
| | **Evacuation route length** | Evacuation distance | 372 | 47 | 9939 | 2382.79 | 2042.93 |
| Psychological Variables | **Tsunami arrival time** | Estimated tsunami arrival time | 408 | 0 | 300 | 18.27 | 24.48 |
| | **Car efficacy** | Car/truck efficacy | 461 | 1 | 5 | 3.87 | 1.30 |
| | **Foot efficacy** | Walking efficacy | 429 | 1 | 5 | 3.04 | 1.63 |
| | **Bicycle evacuation efficacy** | Bicycle efficacy in evacuation phase | 447 | 1 | 5 | 2.56 | 1.11 |
| | **Bicycle recovery efficacy** | Bicycle efficacy in recovery phase | 452 | 1 | 5 | 2.88 | 1.24 |
| | **Risk perception** | | 469 | 1 | 5 | 3.87 | 0.75 |
| | **Perceived hazard knowledge** | | 468 | 1 | 5 | 3.68 | 0.86 |
| Experience and Location | **Experience micro-mobility** | Heard of, considered, or experienced using Micro-mobility transportation modes | 455 | 1 | 3 | 2.31 | 0.90 |
| | **Experience evacuation** | Prior evacuation experience | 460 | 0 | 1 | 29% | |
| | **Inundation zone** | Home in tsunami inundation zone | 483 | 0 | 1 | 30% | |
| | **Ocean proximity** | Proximity to ocean | 481 | 58 | 2159 | 712.31 | 453.85 |
| | **Home elevation** | Home elevation | 483 | 0 | 72 | 17.66 | 10.57 |
| Demographics | **Own car** | Own car/truck | 464 | 0 | 1 | 95% | |
| | **Own micro-mobility** | Own micro-mobility modes | 464 | 0 | 1 | 47% | |
| | **Age** | | 455 | 18 | 98 | 60.31 | 16.63 |
| | **Female** | Female gender | 454 | 0 | 1 | 58% | |
| | **Household size** | Household size | 483 | 0 | 9 | 2.04 | 1.38 |
| | **Disability** | | 461 | 0 | 1 | 36% | |
| | **Single** | | 455 | 0 | 1 | 26% | |
| | **Married** | | 455 | 0 | 1 | 49% | |
| | **Divorced or widowed** | | 455 | 0 | 1 | 25% | |
| | **Household income** | Monthly Household income | 417 | 1 | 5 | 2.00 | 1.10 |
| | **Education** | Education | 445 | 1 | 7 | 4.38 | 1.80 |
| | **White ethnicity** | White ethnicity | 449 | 0 | 1 | 90% | |

(Coos Bay $M = 3.3$, Crescent City $M = 2.7$, $t_{403} = 3.84$, $p < 0.01$), possibly for two reasons (1) topographical differences and (2) educational program differences. Specifically, the hills in the middle of Coos Bay Peninsula enable residents in Coos Bay to walk to safety in a shorter time, whereas the flat area in Crescent City might lead residents to believe they must travel a long distance to safety even though most of the flat area is actually outside the inundation zone. Moreover, the Oregon tsunami education program emphasizes the need for residents to evacuate by foot [36]. Interestingly, the efficacy distribution shows that bicycle/cargo bike, electric-scooter or skateboard, and motorcycle/electric-bike are right-skewed, whereas car/truck is left-skewed and walking has a bimodal distribution because people tend to think it is either very effective or not at all effective to evacuate on foot.

Owning cars is a significantly positive predictor for car efficacy, whereas disability is significantly negative predictor for evacuation by foot. It might seem quite reasonable that people with cars think evacuation by car is more effective than by foot, but they might not realize that this mode would be dangerous if the number of vehicles on the evacuation routes exceeds capacity, causing congestion that is overtaken by the tsunami waves. By contrast, it is much less problematic that people who have household members with disabilities think evacuation by foot is not effective.

To analyze people's attitudes toward using bicycles in evacuation response, bicycle efficacy is further broken down into efficacy within the evacuation phase and efficacy within the recovery phase. When asked how effective bicycles are in these two phases, respondents reported similar average scores for bicycle efficacy in the evacuation phase (Coos Bay $M = 2.53$, Crescent City $M = 2.60$, $t_{442} = -0.60$, $p = 0.54$) and the recovery phase (Coos Bay $M = 2.77$, Crescent City $M = 3.02$, $t_{442} = -2.15$, $p = 0.016$). When comparing bicycle efficacy between the two phases, respondents in the two cities reported significant higher scores in the recovery phase than in the evacuation phase (Bicycle efficacy in evacuation $M = 2.56$, Bicycle efficacy in recovery $M = 2.88$, $t_{889} = -4.05$, $p < 0.01$). As one might expect, people with their own micro-mobility provide higher ratings of efficacy for bicycles in both phases. Consistent with the results for walking efficacy, disability also has a negative sign for bike riding because it is typically not feasible for those with disabilities.

### 4.2. *Analysis of research question 2: predictors of evacuation intentions*

In response to an M9 earthquake and tsunami, 81% of respondents in Coos Bay and 80% in Crescent City intend to evacuate. The high level of evacuation intention is notable because only 41% and 17% of respondents are located within tsunami inundation zone in Coos Bay and

**Table 5**
Pearson Correlation Matrix (Gray shading highlights the patterns of consistent correlations between different types of variables).

| | Variables | Behavior Variables 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Psychological Variables 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Evacuation intention | 1 | | | | | | | | | | | | | | | | | |
| 2 | Preparation tasks | .55* | 1 | | | | | | | | | | | | | | | | |
| 3 | Preparation time | .04 | .40* | 1 | | | | | | | | | | | | | | | |
| 4 | Evacuation by car | .18* | .30* | .15* | 1 | | | | | | | | | | | | | | |
| 5 | Evacuation by foot | -.04 | -.22* | -.14* | -.90* | 1 | | | | | | | | | | | | | |
| 6 | Estimated travel time | .12 | .03 | .23* | -.03 | .05 | 1 | | | | | | | | | | | | |
| 7 | Compliance foot | .07 | -.09 | -.19* | -.39* | .43* | -.03 | 1 | | | | | | | | | | | |
| 8 | Compliance micro-mobility | -.06 | .03 | .13 | -.02 | -.05 | -.02 | -.29* | 1 | | | | | | | | | | |
| 9 | Consider micro-mobility | .08 | .03 | -.06 | -.11 | .12 | -.09 | .14* | .16* | 1 | | | | | | | | | |
| 10 | Destination inundation | .07 | .07 | -.02 | .04 | -.02 | .06 | .01 | -.03 | .02 | 1 | | | | | | | | |
| 11 | Evacuation route length | .02 | .02 | -.02 | -.06 | .08 | -.02 | .11 | -.07 | .04 | -.08 | 1 | | | | | | | |
| 12 | Tsunami arrival time | -.04 | .16* | .31* | .11 | -.09 | .20* | -.07 | .05 | -.08 | .00 | -.03 | 1 | | | | | | |
| 13 | Car Efficacy | .16* | .25* | .11 | .57* | -.54* | -.02 | -.23* | .02 | -.15* | .10 | -.05 | .12 | 1 | | | | | |
| 14 | Foot Efficacy | -.04 | -.13* | -.11 | -.39* | .43* | -.21* | .34* | -.02 | .25* | -.03 | .03 | -.11 | -.35* | 1 | | | | |
| 15 | Bike evacuation efficacy | .10 | .04 | -.11 | -.08 | .05 | -.13 | .16* | .21* | .44* | .02 | -.03 | -.07 | .00 | .37* | 1 | | | |
| 16 | Bicycle recovery efficacy | .14* | .05 | -.15* | -.06 | .05 | -.04 | .11 | .18* | .48* | .00 | .01 | -.09 | -.04 | .24* | .68* | 1 | | |
| 17 | Risk perception | .21* | .03 | -.01 | -.12 | .16* | .12 | .05 | .12* | .13* | .05 | .01 | -.09 | -.19* | .12 | .11 | .18* | 1 | |
| 18 | Perceived hazard knowledge | -.16* | -.19* | -.24* | -.14* | .14* | -.20* | .01 | .02 | .07 | .11 | -.09 | -.15* | -.06 | .21* | .16* | .09 | .11 | 1 |
| 19 | Experience micro-mobility | .03 | .05 | -.09 | -.03 | .00 | -.10 | .04 | .15* | .25* | .03 | -.07 | -.02 | -.01 | .11 | .28* | .24* | .14* | .17* |
| 20 | Experience Evacuation | .07 | .02 | -.06 | .02 | -.03 | -.02 | -.04 | -.02 | -.02 | .11 | .06 | .03 | .06 | -.03 | .03 | -.01 | .00 | .17* |
| 21 | Inundation zone | -.05 | .01 | -.04 | .04 | -.07 | -.04 | -.01 | -.05 | -.02 | .07 | .06 | -.03 | -.02 | .04 | .07 | .02 | -.05 | .02 |
| 22 | Home elevation | .06 | .00 | .04 | -.06 | .06 | -.02 | -.05 | .08 | -.02 | -.10 | -.13 | .02 | -.02 | -.04 | -.06 | -.04 | .08 | .05 |
| 23 | Ocean proximity | .08 | .07 | -.02 | .00 | .00 | .06 | -.03 | .00 | -.07 | -.07 | -.08 | -.02 | .09 | -.11 | -.13* | -.11 | .05 | .02 |
| 24 | Own car | -.02 | .05 | .07 | .35* | -.31* | -.08 | -.17* | .03 | .02 | .06 | -.10 | .05 | .11 | -.02 | .06 | .05 | .04 | .14* |
| 25 | Own micro-mobility | .00 | -.04 | -.04 | -.02 | -.01 | -.13 | -.04 | .28* | .30* | .02 | -.04 | -.10 | -.05 | .08 | .30* | .31* | .13* | .15* |
| 26 | Age | -.09 | -.07 | .06 | -.03 | .01 | .09 | -.09 | -.15* | -.23* | -.08 | -.01 | .03 | -.04 | .02 | -.24* | -.26* | -.10 | -.01 |
| 27 | Female | .06 | .09 | .05 | .00 | .04 | .03 | .13* | -.04 | .02 | .03 | .08 | .09 | .07 | -.08 | -.06 | -.05 | .05 | -.15* |
| 28 | Household size | .00 | .14* | -.05 | .08 | -.11 | -.07 | -.02 | .00 | .10 | .04 | -.02 | -.02 | .02 | -.07 | .04 | .15* | .09 | .08 |
| 29 | Disability family | -.05 | -.01 | .04 | .07 | -.08 | .07 | -.18* | -.04 | -.18* | .03 | .01 | -.03 | .01 | -.19* | -.27* | -.23* | .04 | .03 |
| 30 | Single | .09 | .04 | -.02 | -.01 | .04 | .05 | .03 | .09 | .01 | -.01 | .01 | -.01 | .05 | .00 | .05 | .02 | .05 | -.10 |
| 31 | Married | -.07 | .00 | -.01 | .04 | -.01 | -.04 | .00 | -.06 | .04 | -.03 | .00 | -.03 | -.08 | .05 | -.03 | .01 | .09 | .18* |
| 32 | Divorced or widowed | -.01 | -.04 | .03 | -.04 | -.02 | -.01 | -.03 | -.02 | -.06 | .04 | -.01 | .05 | .04 | -.06 | -.02 | -.04 | -.15* | -.11 |
| 33 | Household income | -.12 | -.07 | -.07 | -.08 | .09 | .00 | .07 | -.04 | .10 | .01 | -.01 | .01 | -.16* | .16* | .11 | .08 | .01 | .16* |
| 34 | Education | -.07 | -.13* | -.02 | -.01 | .04 | -.08 | .16* | .04 | .13* | .01 | -.07 | -.09 | -.10 | .19* | .23* | .12 | .01 | .12 |
| 35 | White ethnicity | -.03 | -.09 | -.04 | .00 | .03 | -.09 | .00 | .04 | -.03 | .01 | -.19* | .06 | -.08 | .05 | .02 | .04 | -.03 | .08 |

| | Variables | Experience and Location 19 | 20 | 21 | 22 | 23 | Demographics 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | Experience micro-mobility | 1 | | | | | | | | | | | | | | | | |
| 20 | Experience Evacuation | .05 | 1 | | | | | | | | | | | | | | | |
| 21 | House inundation | .04 | -.07 | 1 | | | | | | | | | | | | | | |
| 22 | House elevation | .01 | .00 | -.36* | 1 | | | | | | | | | | | | | |
| 23 | Proximity | .00 | .08 | -.38* | .18* | 1 | | | | | | | | | | | | |
| 24 | Own car | .04 | -.03 | .03 | .04 | -.05 | 1 | | | | | | | | | | | |
| 25 | Own micro-mobility | .30* | .01 | .01 | -.02 | -.07 | .06 | 1 | | | | | | | | | | |
| 26 | Age | -.14* | -.02 | .08 | .03 | .00 | -.04 | -.32* | 1 | | | | | | | | | |
| 27 | Female | -.16* | .07 | -.04 | -.06 | .02 | -.14* | -.13* | -.03 | 1 | | | | | | | | |
| 28 | Household size | .08 | .05 | .04 | .02 | -.03 | .13* | .28* | -.32* | -.08 | 1 | | | | | | | |
| 29 | Disability | -.08 | -.04 | .05 | .05 | -.02 | -.06 | -.10 | .23* | .01 | .03 | 1 | | | | | | |
| 30 | Single | .02 | -.01 | -.02 | -.01 | .04 | -.14* | -.07 | -.23* | .01 | -.20* | -.10 | 1 | | | | | |
| 31 | Married | -.01 | -.01 | .04 | -.03 | -.06 | .18* | .15* | -.05 | -.14* | .34* | .07 | -.58* | 1 | | | | |
| 32 | Divorced or widowed | -.01 | .03 | -.02 | .04 | .02 | -.07 | -.10 | .29* | .14* | -.19* | .02 | -.34* | -.57* | 1 | | | |
| 33 | Income | .00 | -.01 | .06 | -.07 | -.10 | .08 | .20* | -.17* | -.16* | .19* | -.16* | -.11 | .33* | -.26* | 1 | | |
| 34 | Education | .06 | -.01 | .06 | -.03 | -.11 | .08 | .15* | -.06 | .00 | -.06 | -.11 | -.07 | .06 | .00 | .38* | 1 | |
| 35 | White ethnicity | .03 | -.11 | .01 | .04 | -.05 | .05 | -.03 | .13* | .03 | -.05 | .04 | -.05 | -.01 | .06 | -.02 | .07 | 1 |

Crescent City, respectively. For those who live inside the inundation zone, 78% expect to evacuate; whereas for those living outside the inundation zone, 82% expect to evacuate, a difference that is not statistically significant ($t_{250} = -1.06$, $p = 0.28$). Although incomplete compliance inside the risk area and shadow evacuation outside the risk area are well established in the evacuation literature [37], the equal level of evacuation intentions inside and outside the tsunami inundation zone is inconsistent with previous findings on evacuation expectations for tsunami [17] and hurricanes [35,15]. The inconsistency may be explained by two possibilities (1) people have inaccurate knowledge whether they are in the tsunami inundation zone and (2) people intend to minimize their risk by evacuating anyway. Given that local residents have high confidence in their knowledge of their location in the inundation zone (Fig. 4), the second reason seems somewhat more likely than the first one. Indeed, the regression analysis results in Table 6 shows that location variables (inundation zone, home elevation, and ocean proximity) are not significantly associated with evacuation expectations.

As Table 6 and Fig. 6 indicate, evacuation intention is significantly associated with psychological variables (i.e., risk perception, perceived hazard knowledge, and car efficacy), but not with demographic variables and experience variables. This relationship in tsunami evacuation is consistent with the decision making process in PADM [29], other tsunami studies [17,22,34], and hurricane studies [35,15], where evacuation decision making is directly affected by psychological variables, but only indirectly by demographic variables [54,53].

The result that risk perception is positively related to evacuation intention is consistent with the findings from the Seaside evacuation expectations study [17] and from actual tsunami evacuations [22,34,24,21]. However, the negative association of perceived hazard knowledge with evacuation intention is inconsistent with the findings from the Seaside study. By contrast, the positive association between perceived car efficacy and evacuation intention is broadly consistent with the findings from the Seaside study, which found that self-efficacy is a positive predictor for evacuation intention. Even though car efficacy is a

**Table 6**
Regression analysis.

| Dependent Variables (Linear regression) | Risk perception | | | Perceived hazard knowledge | | | Car efficacy | | | Foot efficacy | | | Bike evacuation efficacy | | | Bicycle recovery efficacy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Independent Variables | B | S.E. | std. B | B | S.E. | std. B | B | S.E. | std. B | B | S.E. | std. B | B | S.E. | std. B | B | S.E. | std. B |
| Experience micro-mobility | .12 | .04 | .15 | .11 | .05 | .11 | -.03 | .07 | -.02 | .16 | .09 | .09 | .20 | .06 | .16 | **.17*** | .06 | .13 |
| Experience evacuation | -.06 | .08 | -.04 | **.33*** | .09 | .18 | .19 | .13 | .07 | -.17 | .16 | -.05 | .07 | .11 | .03 | -.10 | .12 | -.04 |
| Inundation zone | -.03 | .09 | -.02 | .04 | .10 | .02 | .06 | .15 | .02 | -.05 | .18 | -.02 | .05 | .12 | .02 | -.10 | .13 | -.04 |
| Home elevation | .01 | .00 | .10 | .00 | .00 | .04 | -.00 | .01 | -.04 | -.00 | .01 | -.01 | .00 | .00 | .00 | -.00 | .01 | -.01 |
| Ocean proximity | .00 | .00 | .04 | .00 | .00 | .04 | .00 | .00 | .09 | -.00 | .00 | -.10 | -.00 | .00 | -.09 | -.00 | .00 | -.10 |
| Own car | .02 | .17 | .01 | .34 | .18 | .09 | **.75*** | .29 | .13 | -.40 | .34 | -.06 | .05 | .22 | .01 | .10 | .26 | .02 |
| Own micro-mobility | .11 | .08 | .07 | .14 | .09 | .08 | -.05 | .14 | -.02 | .07 | .16 | .02 | **.43*** | .11 | .20 | **.47*** | .12 | .19 |
| Age | -.00 | .00 | -.01 | .00 | .00 | .03 | -.00 | .00 | -.05 | .01 | .01 | .07 | -.01 | .00 | -.13 | -.01 | .00 | -.12 |
| Female gender | .18 | .07 | .12 | -.16 | .08 | -.10 | .20 | .13 | .08 | -.22 | .15 | -.07 | -.04 | .10 | -.02 | -.02 | .11 | -.01 |
| Household size | .02 | .03 | .04 | -.04 | .03 | -.06 | .03 | .05 | .03 | -.11 | .06 | -.10 | -.04 | .04 | -.05 | .06 | .05 | .07 |
| Family member with disability | .08 | .08 | .05 | .09 | .08 | .05 | -.02 | .13 | -.01 | **-.52*** | .16 | -.16 | **-.43*** | .10 | -.19 | **-.51*** | .12 | -.20 |
| Single | .03 | .09 | .02 | -.23 | .10 | -.12 | .10 | .16 | .04 | .02 | .19 | .01 | .09 | .13 | .04 | .04 | .14 | .01 |
| Divorced/widowed | **-.25*** | .09 | -.15 | -.23 | .10 | -.12 | .10 | .16 | .03 | -.14 | .19 | -.04 | .14 | .13 | .06 | .13 | .14 | .05 |
| Income | -.02 | .04 | -.03 | .07 | .04 | .09 | -.16 | .07 | -.13 | .11 | .08 | .07 | -.03 | .05 | -.02 | -.05 | .06 | -.04 |
| Education | .00 | .02 | .01 | .02 | .02 | .03 | -.03 | .04 | -.04 | .09 | .04 | .11 | .10 | .03 | .16 | .04 | .03 | .06 |
| White ethnicity | -.18 | .12 | -.07 | .27 | .13 | .10 | -.24 | .20 | -.06 | .06 | .24 | .01 | .11 | .16 | .03 | .26 | .18 | .06 |
| Constant | **3.52*** | .33 | | **2.64*** | 0.36 | | **3.73*** | 0.56 | | **3.01*** | 0.69 | | **2.36*** | 0.44 | | **2.77*** | 0.50 | |
| Model Statistics | F(16,415) = 2.41, p < 0.00<br>R2 = 0.09 | | | F(16,415) = 4.05, p < 0.00<br>R2 = 0.14 | | | F(16,452) = 1.89, p < 0.05<br>R2 = 0.07 | | | F(16,415) = 3.00, p < 0.00<br>R2 = 0.10 | | | F(16,415) = 7.98, p < 0.00<br>R2 = 0.24 | | | F(16,415) = 6.45, p < 0.00<br>R2 = 0.20 | | |

| Dependent Variables (Binary logistic regression) | Evacuation intention | | | | | Evacuate by car | | | | | Evacuate by foot | | | | | Compliance car to foot | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Independent Variables | B | S.E. | exp (B) | std.B | std. exp (B) | B | S.E. | exp (B) | std. B | std. exp (B) | B | S.E. | exp (B) | std.B | std. exp (B) | B | S.E. | exp (B) | std.B | std.Exp (B) |
| Tsunami arrival time | -.01 | .01 | .99 | -.27 | .76 | .01 | .02 | 1.01 | .28 | 1.32 | .00 | .02 | 1.00 | .00 | 1.00 | .01 | .02 | 1.01 | .07 | 1.07 |
| Car efficacy | **.45*** | .12 | 1.57 | .57 | 1.77 | **1.16*** | .16 | 3.17 | 1.47 | 4.33 | **-.99*** | .16 | .37 | −1.26 | .28 | **-.28*** | .1 | .76 | -.36 | .70 |
| Foot efficacy | .03 | .10 | 1.03 | .04 | 1.04 | **-.48*** | .14 | .62 | -.73 | .48 | **.73*** | .16 | 2.07 | 1.12 | 3.06 | **.37*** | .09 | 1.44 | .55 | 1.74 |
| Bike evacuation efficacy | .20 | .20 | 1.23 | .22 | 1.25 | -.20 | .24 | .82 | -.22 | .80 | -.08 | .25 | .93 | -.08 | .92 | .17 | .16 | 1.18 | .180 | 1.20 |
| Bicycle recovery efficacy | .19 | .16 | 1.21 | .23 | 1.26 | .02 | .21 | 1.02 | .03 | 1.03 | .07 | .22 | 1.07 | .08 | 1.09 | -.03 | .13 | .97 | -.04 | .96 |
| Risk perception | **.86*** | .20 | 2.37 | .64 | 1.89 | -.27 | .27 | .76 | -.2 | .82 | .34 | .29 | 1.4 | .25 | 1.29 | .05 | .17 | 1.05 | .06 | 1.06 |
| Perceived hazard knowledge | **-.63*** | .19 | .53 | -.53 | .59 | **-.72*** | .24 | .49 | -.61 | .54 | .57 | .25 | 1.78 | .48 | 1.62 | -.09 | .15 | .92 | -.08 | .92 |
| Experience micro-mobility | .01 | .17 | 1.01 | .01 | 1.01 | .17 | .22 | 1.19 | .15 | 1.16 | -.32 | .24 | .73 | -.28 | .76 | .11 | .14 | 1.11 | .09 | 1.09 |
| Experience evacuation | .52 | .32 | 1.68 | .24 | 1.27 | .25 | .40 | 1.28 | .11 | 1.12 | -.42 | .44 | .65 | -.19 | .82 | -.26 | .26 | .77 | -.12 | .88 |
| Inundation zone | .04 | .33 | 1.04 | .02 | 1.02 | .13 | .43 | 1.14 | .06 | 1.06 | -.49 | .45 | .61 | -.23 | .80 | -.09 | .28 | .91 | -.04 | .96 |
| Home elevation | .02 | .02 | 1.02 | .18 | 1.2 | -.01 | .02 | .99 | -.14 | .87 | .00 | .02 | 1.00 | .05 | 1.05 | -.01 | .01 | .99 | -.07 | .93 |
| Ocean proximity | .00 | .00 | 1.00 | .17 | 1.19 | .00 | .00 | 1.00 | .02 | 1.02 | -.00 | .00 | 1.00 | -.07 | .93 | -.00 | .00 | 1.00 | -.02 | .98 |
| Own car | -.26 | .72 | .77 | -.06 | .94 | **4.46*** | .92 | 86.55 | .99 | 2.69 | **−3.71*** | .79 | .02 | -.82 | .44 | **−1.99*** | .70 | .14 | -.45 | .64 |
| Own micro-mobility | -.25 | .33 | .78 | -.12 | .88 | -.15 | .40 | .86 | -.07 | .93 | -.13 | .42 | .88 | -.06 | .94 | -.68 | .27 | .51 | -.34 | .71 |
| Age | -.01 | .01 | .99 | -.16 | .85 | -.01 | .01 | .99 | -.10 | .91 | -.01 | .01 | .99 | -.10 | .90 | -.01 | .01 | .99 | -.16 | .85 |
| Female gender | .07 | .29 | 1.07 | .03 | 1.03 | -.10 | .38 | .91 | -.05 | .95 | .38 | .42 | 1.46 | .19 | 1.20 | **.64*** | .25 | 1.91 | .31 | 1.37 |
| Household size | -.05 | .12 | .95 | -.07 | .93 | .09 | .16 | 1.09 | .12 | 1.13 | -.29 | .19 | .75 | -.39 | .67 | .09 | .10 | 1.09 | .12 | 1.13 |
| Family member with disability | -.14 | .31 | .87 | -.07 | .94 | .38 | .40 | 1.46 | .18 | 1.20 | -.33 | .42 | .72 | -.16 | .85 | -.59 | .26 | .55 | -.28 | .76 |
| Single | .16 | .43 | 1.18 | .07 | 1.07 | .65 | .54 | 1.92 | .29 | 1.33 | -.29 | .58 | .75 | -.13 | .88 | .06 | .34 | 1.06 | .03 | 1.03 |
| Divorced/widowed | .09 | .36 | 1.10 | .05 | 1.05 | .48 | .49 | 1.61 | .24 | 1.27 | .12 | .53 | 1.13 | .06 | 1.06 | .21 | .31 | 1.23 | .1 0 | 1.11 |
| Income | -.16 | .14 | .85 | -.16 | .85 | -.08 | .20 | .92 | -.09 | .92 | .03 | .21 | 1.03 | .03 | 1.03 | -.08 | .13 | .92 | -.08 | .93 |
| Education | -.08 | .08 | .92 | -.15 | .86 | .10 | .10 | 1.11 | .18 | 1.20 | -.05 | .11 | .95 | -.09 | .91 | .15 | .07 | 1.16 | .26 | 1.30 |
| White ethnicity | -.012 | .52 | .99 | -.00 | 1.00 | .39 | .59 | 1.48 | .12 | 1.13 | .00 | .64 | 1.00 | .00 | 1.00 | -.029 | .388 | .972 | -.02 | .98 |
| Constant | −1.01 | 1.70 | | | | −2.63 | 2.05 | | | | 1.51 | 2.19 | | | | 1.62 | 1.42 | | | |
| Model Statistics | (−)2 Log likelihood = 353<br>Cox & Snell R Square = 0.16<br>Nagelkerke R Square = 0.25<br>Correctly predict = 81.7% | | | | | (−)2 Log likelihood = 231<br>Cox & Snell R Square = 0.40<br>Nagelkerke R Square = 0.60<br>Correctly predict = 86.7% | | | | | (−)2 Log likelihood = 208<br>Cox & Snell R Square = 0.39<br>Nagelkerke R Square = 0.60<br>Correctly predict = 89.1% | | | | | (−)2 Log likelihood = 477<br>Cox & Snell R Square = 0.21<br>Nagelkerke R Square = 0.28<br>Correctly predict = 69.3% | | | | |

*Significant at 0.01 Level.

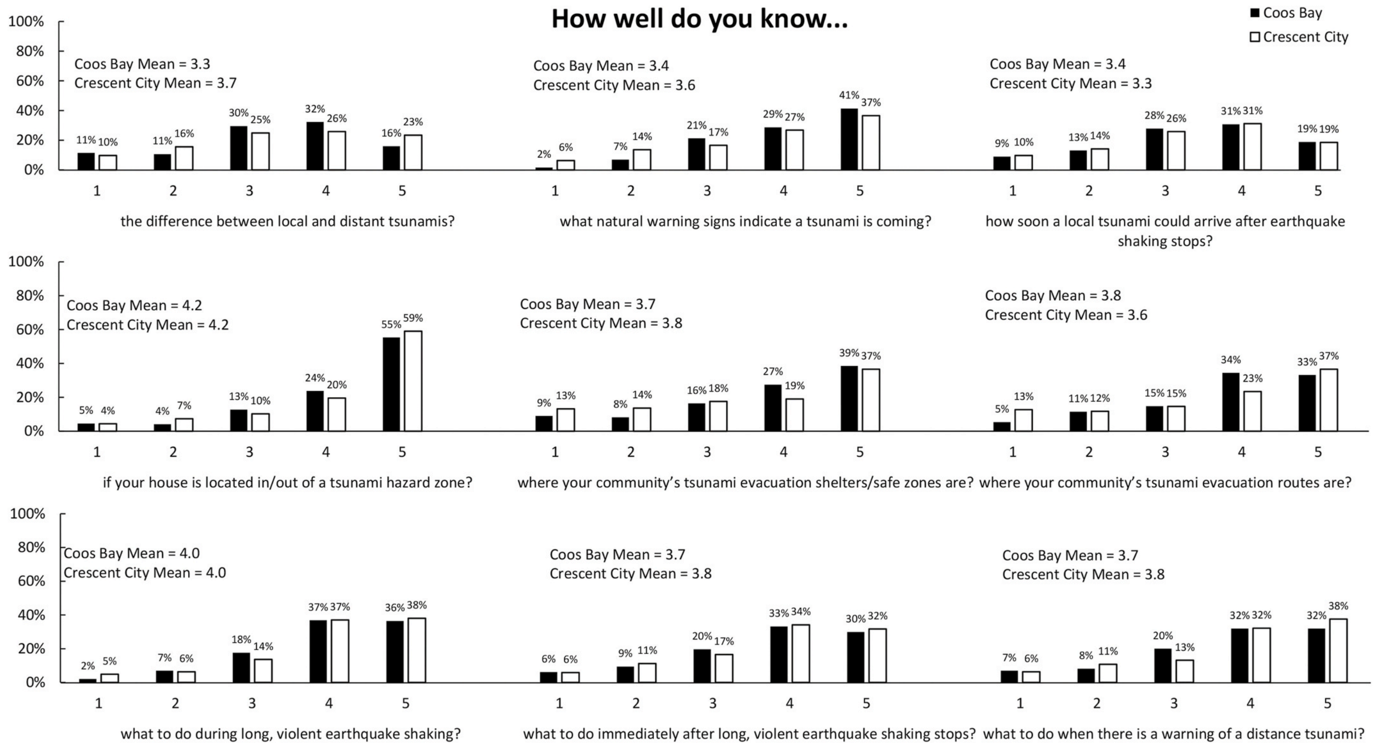


**Fig. 4.** Perceived knowledge for earthquake and tsunami.

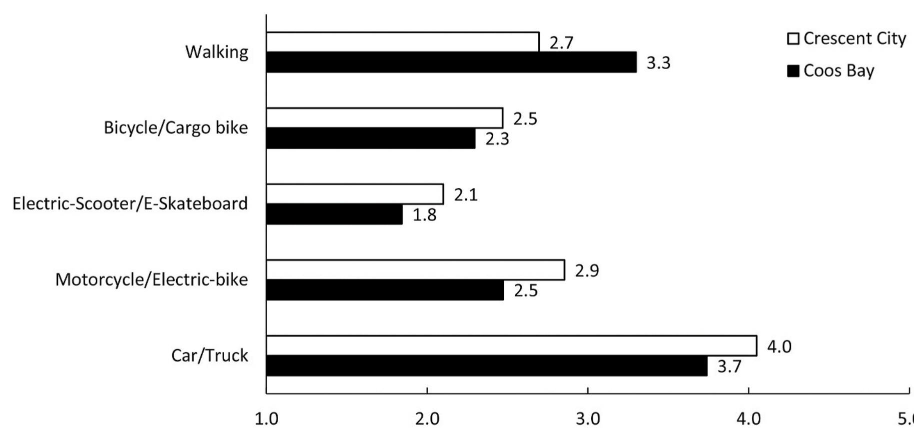


**Fig. 5.** Transportation mode efficacy for evacuation mean score.

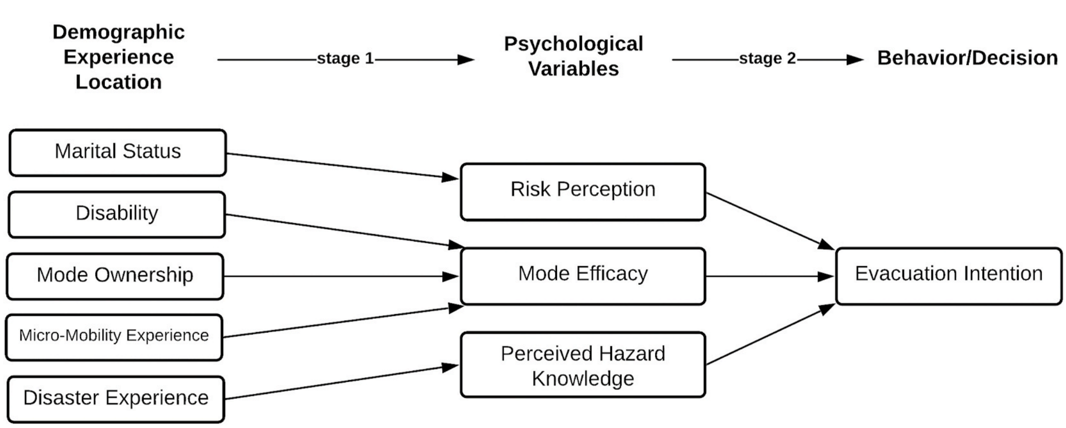


**Fig. 6.** Multistage regression model for evacuation intention.

measure of response efficacy, and thus is theoretically different from self-efficacy, the two concepts are similar in assessing respondents' beliefs about their ability to successfully evacuate from an oncoming tsunami.

Location variables have previously been found to be significant predictors for evacuation decisions [20] and intentions [17], but not in Coos Bay and Crescent City. One possible explanation is that the location variables determine residents' risk perceptions which, in turn, predict evacuation, but Table 5 shows that this is not the case. Another explanation is that almost all of the residents in these two communities–even those who are outside the tsunami inundation zone–believe they are too close to the ocean to be safe from tsunami inundation. Indeed, this explanation is consistent with the extremely high level of shadow evacuation in a number of major disasters such as Hurricane Rita [37].

For those who intend to evacuate (Coos Bay n = 206, Crescent City n = 155), Fig. 7 documents the preparation tasks that they expect to perform before evacuation. More than half of them stated they would gather family members, grab emergency kits, collect keys and wallets, and collect important documents before evacuation. More residents in Crescent City would choose to check media and wait for an official warning than in Coos Bay. This milling behavior is likely to be problematic when there is a short wave arrival time triggered by a CSZ earthquake and tsunami (i.e., roughly 20 and 25 min for Coos Bay and Crescent City, respectively). Given that an immediate evacuation is critical for a local tsunami, official tsunami evacuation brochures instruct residents that they do not have time to wait for an official warning or check social media. Although respondents vary in the preparation tasks they plan to perform before evacuation, the total number of those tasks is similar in the two cities (Coos Bay $M = 3.0$, Crescent City $M = 3.2$, $t_{434} = -0.83$, $p = 0.41$).

### 4.3. Analysis of research question 3: evacuation mode

The majority of respondents reported that they would evacuate by car (70% in Coos Bay, 74% in Crescent City), but some would rather evacuate by foot (27% in Coos Bay, 13% in Crescent City). Very few chose micro-mobility modes, as is shown in Fig. 9 (a). This evacuation mode split is consistent with the expectation that a vehicle is the major daily transportation mode for residents in the two communities. The preference for vehicular evacuation is similar to people's behavior in the 2016 Aotearoa/New Zealand tsunami [25] and in the 2009 American Samoa event [1]. However, it is quite different from the majority of residents who evacuated by foot in the 2004 Thailand tsunami (75%) [40], in the 2011 Kamakura City tsunami (71%) [27], and in the 2018 Sulawesi tsunami (90%) [26]. The difference indicates evacuation mode choice is event- and community-dependent, especially the percentage of the community that has ready access to cars. The findings from Coos Bay and Crescent City are different from those in the Seaside study, even though all three communities are located in the CSZ. Specifically, compared with findings from this study, Chen et al. [17] reported that fewer respondents intended to evacuate by car (38%) and more intended to evacuate by foot (39%), whereas a similarly small percentage expected to evacuate by micro-mobility (6%).

The slightly higher number of respondents who expect to evacuate by car in Crescent City may be partially due to the longer travel distances to safer locations than in Coos Bay. The hilly spine in Coos Bay Peninsula provides people a larger area to evacuate within the community, whereas residents in Crescent City may evacuate to other adjacent towns along Highway 101 due to relatively smaller evacuation area. Many respondents who experienced the 2011 tsunami evacuation left comments indicating that they experienced heavy traffic congestion on Highway 101 North, and they would consider other egress routes or other modes if possible. Indeed, Highway 101 is the major road inland from the ocean in Crescent City. The tsunami inundation zone in Fig. 2 shows that a part of Highway 101 is located within the evacuation zone, so congestion could slow the evacuation and increase the risk of some evacuees being overtaken by the tsunami in low-lying locations on the highway.

Consistent between correlation analysis and regression analysis, evacuation mode choice is significantly associated with mode ownership and two psychological variables (i.e., mode efficacy perception and perceived hazard knowledge), but not with demographic variables. This finding mostly supports the second stage of the multi-stage regression model in which only psychological variables directly predict behaviors, as shown in Fig. 8. More broadly, it is consistent with the PADM if mode ownership is considered to be one of the resources associated with personal characteristics [30]. Residents with higher perceived hazard knowledge are more likely to evacuate by foot, when controlling for other variables, a finding that is inconsistent with the Seaside study [17]. As one might expect, people tend to choose one mode when they own that mode and think it is more effective than the others.

As indicated in Fig. 9(b), many residents expect to comply with an official evacuation mode recommendation. In Coos Bay and Crescent City, 40% of respondents who plan to evacuate by car are willing to evacuate by foot and 7% are willing to change to micro-mobility modes. That explains the percent increase in using other modes and decrease in using car/truck from Fig. 9(a)–(b). Given that 39% (Coos Bay) and 28% (Crescent City) of the respondents are senior citizens and 36% of them have at least one family member with disabilities in their household, it is not surprising that many (~ 50%) respondents still would use a vehicle to evacuate. Correlation analysis indicates having a family member with disabilities has a significant negative impact on mode compliance ($r = -$

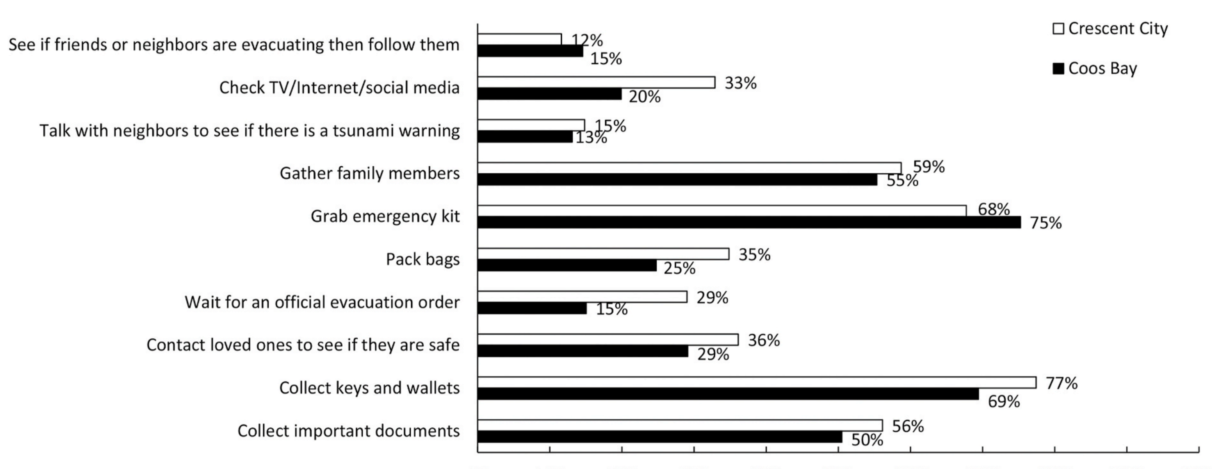


**Fig. 7.** Preparation tasks before evacuation.

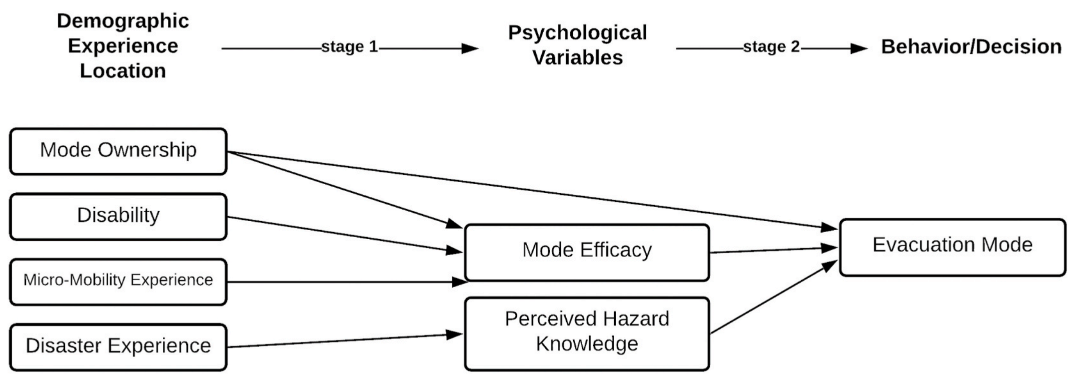


**Fig. 8.** Multistage regression model for evacuation mode.

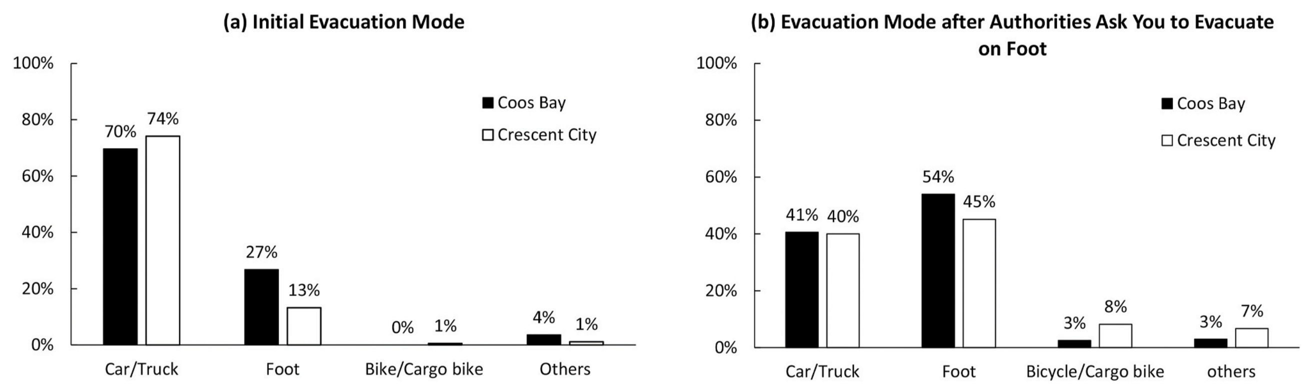


**Fig. 9.** Evacuation mode choice in coos bay, OR and crescent cit, CA, the U.S.

0.18, $p < 0.01$). In the regression analysis, compliance with a recommendation to evacuate on foot is also significantly associated with owning a vehicle (−), walking efficacy (+), car efficacy (−), and female gender (+). This finding suggests that local emergency managers can seek other means to reduce potential congestion besides an official advisory. Carpooling with a neighbor [17] might be effective for people with disabilities but would depend on the additional amount of time to perform this additional preparation task before departing.

## 5. Conclusion

Physical scientists have confirmed the earthquake and tsunami threat in the CSZ, but social scientists and transportation engineers have not done enough research on people's perceptions and intended responses to the tsunami threat [4]. This study contributes to bridging that gap by conducting a mail-based household questionnaire of random samples in two communities at the southern end of the CSZ. Using the PADM as a guide to questionnaire design, this study captured impact factors in two stages of evacuation decision-making process: (1) the impact of demographics, experience, and location on psychological variables; and (2) the impact of psychological variables on evacuation intentions. The analysis of this multistage model of the survey data indicates that, for the first stage, risk perception, perceived hazard knowledge, and perceived mode efficacy are significantly influenced by some demographic variables and experience variables. For the second stage, evacuation intention is significantly associated with the psychological variables–i.e., risk perception, perceived hazard knowledge, and perceived mode efficacy–but not the demographic variables. This two stage model is consistent with research in hurricane evacuation [54,53]. However, the location and experience variables do not directly affect evacuation intentions in Coos Bay and Crescent City, which is inconsistent with some studies for hurricanes [15] and the Seaside tsunami study [16]. This suggests that the effects of location and experience factors are situation- and community-dependent. Although we assume this can be attributed to the topographical features of the two selected communities, future research should test this explanation.

This study also made a significant contribution to the understanding of tsunami evacuation mode intentions. The majority of residents intend to choose a vehicle as their evacuation mode but are willing to change to other modes in response to officials' recommendations to evacuate on foot. Nonetheless, many residents would not comply because of family members with disabilities who could not walk to safety. Like another tsunami evacuation expectations study in CSZ, we found that expected mode choice is significantly related to perceived hazard knowledge when controlling for mode ownership and perceived mode efficacy [17]. Similar to mode choice in other actual and hypothetical evacuation studies, we found expected mode choice varies by community. This study, furthermore, examined the potential of using micro-mobility as tsunami evacuation modes. The results suggest that, even though only a small percent of people intend to use micro-mobility modes to evacuate, people with micro-mobility experience or who own micro-mobility report higher efficacy of those modes. One limitation to this finding is that evacuation mode efficacy is measured when respondents assume they have access to those modes, so they could respond differently when they actually have access. However, the variables "experience with micro-mobility" and "owned micro-mobility" can account for this variance and reduce the potential bias of this concern. Future studies should also examine the effectiveness of using micro-mobility modes in different evacuations or in different communities. Indeed, the use of bicycles and cargo bikes was significant during the recovery phase after the 2018 Mexico City Earthquake [55], but more scientific analysis is needed to examine this potential.

In summary, results from these two coastal communities provide empirical evidence about people's perceptions, evacuation intentions, and expected mode choices when responding to tsunami threat. However, further research is needed to develop a more thorough understanding of this topic in other communities. Apart from improving hazard education and disaster preparedness, such research can inform interdisciplinary evacuation models and simulations.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgement

The authors would like to acknowledge the funding support from the National Science Foundation through grants CMMI # 1563618, # 1826407, and # 1826455. Any opinions, findings, and conclusion or recommendations expressed in this research are those of the authors and do not necessarily reflect the view of the funding agency. We are also thankful to Ziyan Feng, Charles Koll, and Mohammad Rayeedul for their contributions to data collection. This project was approved by the Oregon State University Human Research Protection Program (HRPP) and Institutional Review Board (IRB) and follows the regulations to protect participants, with projects reference number 0489.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2021.102244.

## References

[1] M.K. Lindell, C.S. Prater, C.E. Gregg, E.J. Apatu, S.-K. Huang, H.C. Wu, Jun, Households' immediate responses to the 2009 American Samoa earthquake and tsunami, Int. J. Disaster Risk Reduct. 12 (2015) 328–340. https://linkinghub.elsevier.com/retrieve/pii/S2212420915000266.

[2] N. Mori, T. Takahashi, T. Yasuda, H. Yanagisawa, Apr, Survey of 2011 Tohoku earthquake tsunami inundation and run-up, Geophys. Res. Lett. 38 (7) (2011) http://doi.wiley.com/10.1029/2011GL049210.

[3] S. Sassa, T. Takagawa, Jan, Liquefied gravity flow-induced tsunami: first evidence and comparison from the 2018 Indonesia Sulawesi earthquake and tsunami disasters, Landslides 16 (1) (2019) 195–200. http://link.springer.com/10.1007/s10346-018-1114-x.

[4] M.K. Lindell, C.S. Prater, May, Tsunami preparedness on the Oregon and Washington coast: recommendations for research, Nat. Hazards Rev. 11 (2) (2010) 69–81. http://ascelibrary.org/doi/10.1061/%28ASCE%291527-6988%282010%2911%3A2%2869%29.

[5] National Research Council, Tsunami Warning and Preparedness: an Assessment of the U.S. Tsunami Program and the Nation's Preparedness Efforts, The National Academies Press, Washington, DC, 2011. https://www.nap.edu/catalog/12628/tsunami-warning-and-preparedness-an-assessment-of-the-us-tsunami.

[6] A.R. Nelson, H.M. Kelsey, R.C. Witter, May, Great earthquakes of variable magnitude at the Cascadia subduction zone, Quat. Res. 65 (3) (2006) 354–365. https://www.cambridge.org/core/product/identifier/S0033589400027526/type/journal_article.

[7] W. Thatcher, Silent slip on the Cascadia subduction interface, Science 292 (5521) (2001) 1495–1496.

[8] N. Wood, J. Peters, R. Wilson, J. Sherba, K. Henry, Nov, Variations in community evacuation potential related to average return periods in probabilistic tsunami hazard analysis, Int. J. Disaster Risk Reduct. 50 (2020) 101871. https://linkinghub.elsevier.com/retrieve/pii/S221242092031373X.

[9] C. Goldfinger, C.H. Nelson, A.E. Morey, J.E. Johnson, J.R. Patton, E.B. Karabanov, J. Gutierrez-Pastor, A.T. Eriksson, E. Gracia, G. Dunhill, R.J. Enkin, A. Dallimore, T. Vallier, Turbidite Event historyMethods and Implications for Holocene Paleoseismicity of the Cascadia Subduction Zone. Report 1661F, Reston, VA, 2012. http://pubs.er.usgs.gov/publication/pp1661F.

[10] G.R. Priest, L.L. Stimely, N.J. Wood, I.P. Madin, R.J. Watzig, Jan, Beat-the-wave evacuation mapping for tsunami hazards in Seaside, Oregon, USA, Nat. Hazards 80 (2) (2016) 1031–1056. http://link.springer.com/10.1007/s11069-015-2011-4.

[11] G.R. Priest, Y. Zhang, R.C. Witter, K. Wang, C. Goldfinger, L. Stimely, Jun, Tsunami impact to Washington and northern Oregon from segment ruptures on the southern Cascadia subduction zone, Nat. Hazards 72 (2) (2014) 849–870. http://link.springer.com/10.1007/s11069-014-1041-7.

[12] B. Uslu, J.C. Borrero, L.A. Dengler, C.E. Synolakis, Oct, Tsunami inundation at crescent city, California generated by earthquakes along the Cascadia subduction zone, Geophys. Res. Lett. 34 (20) (2007) L20601, http://doi.wiley.com/10.1029/2007GL030188.

[13] R.C. Witter, Y. Zhang, K. Wang, G.R. Priest, C. Goldfinger, L.L. Stimely, J. T. English, P.A. Ferro, Simulating Tsunami Inundation at Bandon, Coos County, Oregon, Using Hypothetical Cascadia and Alaska Earthquake Scenarios. Tech. Rep. Special Paper 43, Oregon Department of Geology and Mineral Industries, 2011. https://www.oregongeology.org/tsuclearinghouse/resources/sp-43/SP-43_onscreen144dpi.pdf.

[14] M.K. Lindell, A. Bostrom, J. Goltz, C.S. Prater, Social Science Evaluation of Tsunami Evacuation Products, Part 1: Assessment of Textual, Graphical, and Numerical Features. Tech. Rep, Environmental Hazards Research Institute, Seattle, WA, 2019.

[15] S.-K. Huang, M.K. Lindell, C.S. Prater, Oct, Who leaves and who stays? A review and statistical meta-analysis of hurricane evacuation studies, Environ. Behav. 48 (8) (2016) 991–1029. http://journals.sagepub.com/doi/10.1177/0013916515578485.

[16] A. Buylova, C. Chen, L.A. Cramer, H. Wang, D.T. Cox, Apr, Household risk perceptions and evacuation intentions in earthquake and tsunami in a Cascadia Subduction Zone, Int. J. Disaster Risk Reduct. 44 (2020) 101442. https://linkinghub.elsevier.com/retrieve/pii/S2212420919310040.

[17] C. Chen, A. Buylova, C. Chand, H. Wang, L.A. Cramer, D.T. Cox, Jun, Households intended evacuation transportation behavior in response to earthquake and tsunami hazard in a Cascadia subduction zone city, Transport. Res. Rec.: J. Transport. Res. Board 2674 (7) (2020). http://journals.sagepub.com/doi/10.1177/0361198120920873.

[18] M.K. Lindell, C.S. Prater, D.H. House, Social Science Evaluation of Tsunami Evacuation Products, Part 2: Survey Results. Tech. Rep, Environmental Hazards Research Institute, Seattle WA, 2019.

[19] M.K. Lindell, S. Arlikatti, S.-K. Huang, Mar. 2019a. Immediate behavioral response to the June 17, 2013 flash floods in Uttarakhand, North India, Int. J. Disaster Risk Reduct. 34 (2016) 129–146. https://linkinghub.elsevier.com/retrieve/pii/S2212420918309919.

[20] E.J. Apatu, C.E. Gregg, N.J. Wood, L. Wang, Oct, Household evacuation characteristics in American Samoa during the 2009 Samoa Islands tsunami, Disasters 40 (4) (2016) 779–798, http://doi.wiley.com/10.1111/disa.12170.

[21] H.-L. Wei, H.-C. Wu, M.K. Lindell, C.S. Prater, H. Shiroshita, D.M. Johnston, J. S. Becker, Oct, Assessment of households responses to the tsunami threat: a comparative study of Japan and New Zealand, Int. J. Disaster Risk Reduct. 25 (2017) 274–282. https://linkinghub.elsevier.com/retrieve/pii/S2212420917302455.

[22] S.A. Fraser, E.E. Doyle, K.C. Wright, S.H. Potter, J. McClure, D.M. Johnston, G. S. Leonard, M.A. Coomer, J.S. Becker, S. Johal, Jun, Tsunami response behaviour during and following two local-source earthquakes in Wellington, New Zealand, Int. J. Disaster Risk Reduct. 16 (2016) 123–133. https://linkinghub.elsevier.com/retrieve/pii/S2212420916300760.

[23] N.Y. Yun, M. Hamada, Evacuation behavior and fatality rate during the 2011 tohoku-oki earthquake and tsunami, Earthq. Spectra 31 (3) (Aug. 2015) 1237–1265. http://journals.sagepub.com/doi/10.1193/082013EQS234M.

[24] J. Urata, A.J. Pel, May, People's risk recognition preceding evacuation and its role in demand modeling and planning: people's risk recognition preceding evacuation, Risk Anal. 38 (5) (2018) 889–905, http://doi.wiley.com/10.1111/risa.12931.

[25] D. Blake, D. Johnston, G. Leonard, L. McLaren, J. Becker, Jul, A citizen science initiative to understand community response to the kaikura earthquake and tsunami warning in petone and eastbourne, wellington, Aotearoa/New Zealand, Bull. Seismol. Soc. Am. 108 (3B) (2018) 1807–1817. https://pubs.geoscienceworld.org/ssa/bssa/article/108/3B/1807/530729/A-Citizen-Science-Initiative-to-Understand.

[26] A.S. Harnantyari, T. Takabatake, M. Esteban, P. Valenzuela, Y. Nishida, T. Shibayama, H. Achiari, A.G. Rusli Marzuki, M.F.H. Marzuki, R. Arnguiz, T. O. Kyaw, Feb, Tsunami awareness and evacuation behaviour during the 2018 Sulawesi Earthquake tsunami, Int. J. Disaster Risk Reduct. 43 (2020) 101389. https://linkinghub.elsevier.com/retrieve/pii/S2212420919312154.

[27] R.S.C. Arce, M. Onuki, M. Esteban, T. Shibayama, Risk awareness and intended tsunami evacuation behaviour of international tourists in Kamakura City, Japan, Int. J. Disaster Risk Reduct. 23 (Aug. 2017) 178–192. https://linkinghub.elsevier.com/retrieve/pii/S2212420916307968.

[28] T.E. Drabek, The Human Side of Disaster, CRC Press, 2013, p. 433.

[29] M.K. Lindell, R.W. Perry, Apr, The protective action decision model: theoretical modifications and additional evidence: the protective action decision model, Risk Anal. 32 (4) (2012) 616–632, http://doi.wiley.com/10.1111/j.1539-6924.2011.01647.x.

[30] M.K. Lindell, Communicating imminent risk, in: H. Rodrguez, W. Donner, J. Trainor (Eds.), Handbook of Disaster Research. Handbooks of Sociology and Social Research, second ed., Springer, New York, 2018, pp. 449–477.

[31] A. Dhellemmes, G. Leonard, D.M. Johnston, GNS Science (N.Z.). Tsunami Awareness and Preparedness on the East Coast of New Zealand's North Island, OCLC, 2016, p. 951655272.

[32] J.E. Kang, M.K. Lindell, C.S. Prater, Apr, Hurricane evacuation expectations and actual behavior in hurricane lili, J. Appl. Soc. Psychol. 37 (4) (2007) 887–903, http://doi.wiley.com/10.1111/j.1559-1816.2007.00191.x.

[33] A.P. Field, R. Gillett, How to do a metaanalysis.pdf, Br. J. Math. Stat. Psychol. 63 (2010) 665–694.

[34] M.K. Lindell, C.S. Prater, H.C. Wu, S.-K. Huang, D.M. Johnston, J.S. Becker, H. Shiroshita, Jan, Immediate behavioural responses to earthquakes in Christchurch, New Zealand, and Hitachi, Japan, Disasters 40 (1) (2016) 85–111, http://doi.wiley.com/10.1111/disa.12133.

[35] E.J. Baker, Hurricane evacuation behavior, Int. J. Mass Emergencies Disasters 9 (2) (1991) 287–310. https://training.fema.gov/emiweb/downloads/ijems/articles/hurricane%20evacuation%20behavior.pdf.

[36] DOGAMI, Larger-Extent Evacuation Brochures. Tech. rep., State of Oregon Department of Geology and Mineral Industries, 2020. https://www.oregongeology.org/tsuclearinghouse/pubs-evacbro.htm.

[37] M.K. Lindell, P. Murray-Tuite, B. Wolshon, E.J. Baker, Large-Scale Evacuation: the Analysis, Modeling, and Management of Emergency Relocation from Harzardous Areas, Routledge, 2019, p. 22.

[38] D. Johnston, D. Paton, G.L. Crawford, K. Ronan, B. Houghton, P. Burgelt, Measuring tsunami preparedness in coastal Washington, United States, Nat. Hazards 35 (2005) 173–184.

[39] S. Fraser, G. Leonard, D.M. Johnston, GNS Science (N.Z.). Intended evacuation behaviour in a local earthquake and tsunami at Napier, New Zealand, OCLC, 2013, p. 861302515.

[40] C.E. Gregg, B.F. Houghton, D. Paton, R. Lachman, J. Lachman, D.M. Johnston, S. Wongbusarakum, Jun, Natural warning signs of tsunamis: human sensory experience and response to the 2004 great sumatra earthquake and tsunami in Thailand, Earthq. Spectra 22 (3_suppl) (2006) 671–691. http://journals.sagepub.com/doi/10.1193/1.2206791.

[41] D. Connor, Outreach Assessment: How to Implement an Effective Tsunami Preparedness Outreach Program. Tech. rep., State of Oregon Department of Geology and Mineral Industries Open File Report OFR 0-05-10, Portland OR: Nature of the Northwest Information Center, 2005. https://www.oregongeology.org/pubs/ofr/O-05-10_onscreen.pdf.

[42] H. Wang, A. Mostafizi, L.A. Cramer, D. Cox, H. Park, An agent-based model of a multimodal near-field tsunami evacuation: decision-making and life safety, Transport. Res. C Emerg. Technol. 64 (Mar. 2016) 86–100. https://linkinghub.elsevier.com/retrieve/pii/S0968090X15004106.

[43] N.J. Wood, J. Jones, S. Spielman, M.C. Schmidtlein, Apr, Community clusters of tsunami vulnerability in the US Pacific Northwest, Proc. Natl. Acad. Sci. Unit. States Am. 112 (17) (2015) 5354–5359. http://www.pnas.org/lookup/doi/10.1073/pnas.1420309112.

[44] CLW, Geographic Features of the Coos Estuary and Lower Coos Watershed. Tech. rep., the Communities, Lands & Waterways Data Source, 2015. http://www.partnershipforcoastalwatersheds.org/wordpress/wp-content/uploads/2015/08/FINAL-Geographic-Features-Data-Summary.pdf.

[45] United State Census Bureau, QuickFacts: United States; Crescent City City, California; North Bend City, Oregon; Coos Bay City, Oregon. Tech. Rep, 2020. https://www.census.gov/quickfacts/fact/table/US,crescentcitycitycalifornia,northbendcityoregon,coosbaycityoregon/PST045219.

[46] County of Del Norte, Tsunami Inundation Map for Emergency Planning Crescent City Quadrangle. Tech. Rep, 2009. https://www.conservation.ca.gov/cgs/documents/tsunami/maps/Tsunami_Inundation_CrescentCity_Quad_DelNorte.pdf.

[47] M.K. Lindell, R.W. Perry, Jul, Household adjustment to earthquake hazard: a review of research, Environ. Behav. 32 (4) (2000) 461–501. http://journals.sagepub.com/doi/10.1177/00139160021972621.

[48] W.H. Greene, Econometric Analysis, seventh ed., Prentice Hall, Boston, oCLC, 2012 ocn692292382.

[49] R.L. Ott, M. Longnecker, An Introduction to Statistical Methods & Data Analysis, seventh ed., Duxbury, Pacific Grove CA, 2016.

[50] Y. Benjamini, Y. Hochberg, Jan, Controlling the false discovery rate: a practical and powerful approach to multiple testing, J. Roy. Stat. Soc. B 57 (1) (1995) 289–300, http://doi.wiley.com/10.1111/j.2517-6161.1995.tb02031.x.

[51] M.E. Glickman, S.R. Rao, M.R. Schultz, False discovery rate control is a recommended alternative to Bonferroni-type adjustments in health studies, J. Clin. Epidemiol. 67 (8) (Aug. 2014) 850–857. https://linkinghub.elsevier.com/retrieve/pii/S0895435614001127.

[52] R. Gnanadesikan, Methods for Statistical Data Analysis of Multivariate Observations, second ed. Edition, Wiley, New York, 1997. https://onlinelibrary-wiley-com.ezproxy.proxy.library.oregonstate.edu/doi/book/10.1002/9781118032671.

[53] S.-K. Huang, M.K. Lindell, C.S. Prater, H.-C. Wu, L.K. Siebeneck, Household evacuation decision making in response to hurricane ike, Nat. Hazards Rev. 13 (4) (Nov. 2012) 283–296. http://ascelibrary.org/doi/10.1061/%28ASCE%29NH.1527-6996.0000074.

[54] S.-K. Huang, M.K. Lindell, C.S. Prater, Multistage model of hurricane evacuation decision: empirical study of hurricanes katrina and Rita, Nat. Hazards Rev. 18 (3) (Aug. 2017), 05016008. http://ascelibrary.org/doi/10.1061/%28ASCE%29NH.1527-6996.0000237.

[55] M. Pskowski, How Mexico City Cyclists Are Using Bicycles to Aid Earthquake Victims, Sep. 2017. https://cyclingtips.com/2017/09/mexico-city-cyclists-using-bicycles-aid-earthquake-victims/.