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Coastal emergency managers' risk perception and decision making for the Tonga distant tsunami

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ABSTRACT

On January 15, 2022, the Hunga-Tonga-Hunga-Ha'apai (Tonga) volcano erupted and triggered a tsunami forecasted to reach North America. This event provided a unique opportunity to investigate risk perception and communication among coastal emergency managers and emergency program coordinators (EMs). In response, this research explores 1) how risk can be communicated most effectively and 2) how risk perceptions associated with "distant" tsunami alerts and warnings affect EMs' willingness to issue emergency alerts. A purposive sample of coastal EMs (n = 21) in the U.S. Pacific Northwest participated in semi-structured interviews. Participants represented Tribal, county, state, and federal agencies in Washington, Oregon, and California. Interview transcripts were deductively coded and thematically analyzed. Participants perceived low risk from the Tonga tsunami but took precautionary measures and alerted the public. Participants described how their actions were driven by community characteristics and the anticipated reactions to messaging among residents. Many reported the need to balance notifying the public and avoiding the negative impacts of their messaging (e.g., "crying wolf," panic, curiosity). The unique nature of the event led to identification of unanticipated facilitators and barriers to decision-making among participants. These findings can inform distant tsunami risk communication and preparedness for coastal communities.

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1. Introduction

The Hunga-Tonga-Hunga-Ha'apai (Tonga) volcanic eruption on January 15, 2022, was the largest recorded globally since Krakatoa erupted in 1883 [1]. Some countries in the Pacific Rim experienced ashfall and a 4.5 m tsunami, and the event resulted in the deaths of four individuals in Tonga and two in Peru [1,2]. The eruption also triggered a "distant" tsunami (i.e., one generated far from

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the coast) for the west coast of the continental United States (U.S.) (Fig. 1) [1]. The last major distant tsunami that affected the region was the tsunami caused by the 2011 Tohoku, Japan, earthquake [3]. While major tsunamis are relatively rare, they can have devastating impacts on humans, including drowning, water and food contamination, damage to infrastructure and shelter, and injury from debris [4]. From the distant tsunami, damage was seen in Peru, Fiji, Hawaii, Chile, California, Japan, Russia, and New Zealand [2]. The Tonga eruption and distant tsunami provided a unique opportunity to explore and glean insights from communications strategies utilized by emergency managers and emergency program coordinators (EMs), especially on the Pacific Northwest (PNW) coast of the U.S. This study explores PNW coastal and state EMs' perceptions of community risk and their alerting behaviors following the Tonga eruption.

The western coastline of the U.S. is subject to dramatic change from tectonic activity, sea level rise, and seasonal factors such as El Niño [6]. The Cascadia Subduction Zone (CSZ), a 1,000 km long fault that stretches from Northern Vancouver Island to Cape Mendocino, California, is particularly important [7]. The CSZ has the capacity to produce a 9.0 magnitude earthquake, which would likely devastate the entire PNW coastline from both the ground shaking and the tsunami it would generate [7]. However, research estimates that the region is likely to experience distant tsunamis from Alaska more frequently (Fig. 2) [8], and all of the region's most damaging tsunamis in the past century were from distant sources [9].

With the looming threats of both near-field (i.e., tsunamis caused by local earthquakes or underwater landslides) and distant tsunamis, emergency managers along the Pacific coast must communicate risk to their communities. Tsunami risk communication can aim to raise awareness, change risk perceptions, or guide or change behavior related to that risk [11]. To these ends, communicators must understand the risk as well as their intended audience [11–14].

Effective risk communication messages include the warning source, specific details about the hazard and its location, protective actions that match the threat level, and where to obtain more information [11,12,15,16]. Providing sufficient information has been shown to be more important than brevity in warning messages [16]. Complete messages that communicate uncertainty can help reduce milling (i.e., information-seeking) behaviors preceding protective action [17]. A case study of those affected by Hurricane Sandy suggested that a community-driven, bidirectional approach to risk communication can help with community preparedness [18]. Furthermore, a scoping review of risk communication literature revealed that targeted messaging to specific audiences is an effective way to ensure message appropriateness [19]. Because communicator strategies are only one side of the risk communication process, research has also examined how intended audiences receive and perceive warning messages.

Risk communication and risk perception are connected, and both influence how risk is understood and managed [20]. How the warning message is received can impact how people perceive the risk and take protective action [20]. Trust in the information source can inform risk perception and measures taken by the public [11,12]. One study involving a literature review and 50 qualitative interviews at four different sites found that during an emergency, people gravitate towards familiar information sources that they trust, such as local weather reporters [14]. Other research suggests that people prefer informal communication sources like family and friends [21–23]. One study involving interviews with 58 Hurricane Katrina evacuees revealed that participants mistrusted authorities and preferred to gather information from trusted family members [24]. Other factors that impact risk perception include direct experience with past hazards, fear, and individual mental models (that is, causal beliefs about the risk) [11,25,26]. These personal factors, along with the inherent uncertainty of risk, variation in media coverage of events, and challenges in understanding probabilities, can lead to misjudgment of the actual risk [26]. This misjudgment can be especially salient on the PNW coast, where near-field tsunami risk dominates natural hazard discussions, but a distant tsunami is more likely [8]. Despite the existence of risk communication brochures describing near-field and distant tsunamis, one survey among 483 people living in Coos Bay, OR, and Crescent City, CA, indicated that respondents were not aware of the difference between the two [27]. Sufficient, clear, community-centered risk communication can help facilitate coastal populations' protective actions [20].

To address gaps in the knowledge surrounding distant tsunami risk perception and communication, we describe EM experiences with tsunami risk communication when physical ground shaking is absent, as well as how EMs' perception of the risk from a distant tsunami informs their willingness and motivation to issue an alert. This paper elucidates gaps in existing practice and can inform the implementation of tsunami preparedness and response programs.

2. Methods

We conducted, deductively coded, and thematically analyzed 21 semi-structured key informant interviews with 24 coastal emergency management practitioners in the U.S. states of California, Oregon, and Washington.[4] The University of Washington Human Subjects Division determined this study to be human subjects research that qualifies for exempt status on June 7, 2022 (STUDY00015778).

2.1. Participant recruitment

We used purposive sampling [28] to identify emergency management practitioners with professional responsibility for areas along the CSZ. Participants worked for city, county, state, federal, and Tribal government agencies and had a role in communications surrounding the Tonga tsunami event.

[4] While participants were recruited for one-on-one interviews, two interviews included more than one participant. The participant in Interview 15 brought in a colleague briefly to provide context. The participant in Interview 21 brought in two colleagues; one individual had more specific information on hazard communication and the other was present for situational awareness. All additional participants gave their consent for the interview and recording.

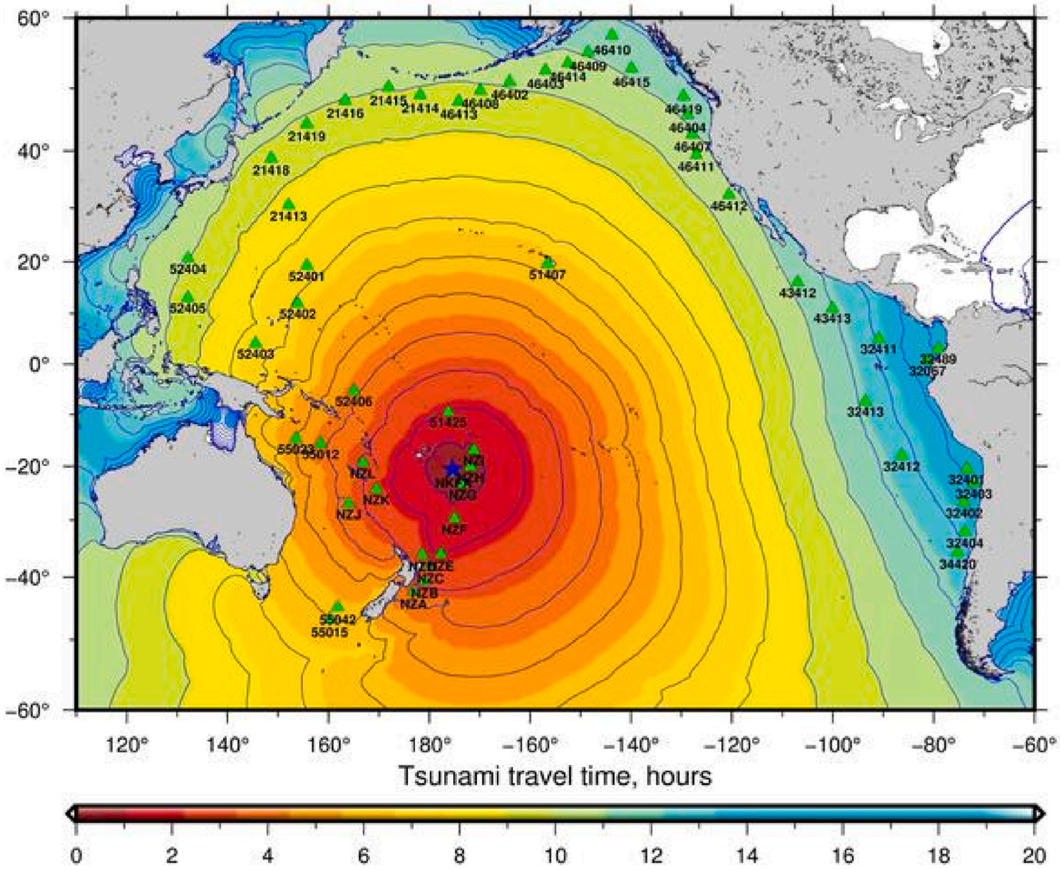

Fig. 1. Predicted tsunami travel time.
Caption: Illustration of the predicted time in hours for the tsunami waves to reach various coastlines. The green triangles indicate Deep-ocean Assessment and Reporting of Tsunamis (DART) buoys that detect tsunami wave movement.[3]
Source: Pacific Coastal and Marine Science Center [5].

The researchers initially identified participants and gathered their contact information through public emergency management web pages. Members of the research team then requested participation through a standardized recruitment email that detailed the purpose of the study and the reasoning for the prospective participants' inclusion. Additional participants were recruited based on interviewee suggestions, and their contact information was obtained directly from interviewees or from their jurisdictions' public web pages.

2.2. Data collection

A semi-structured interview guide, informed by the Protective Action Decision Model (PADM), was used for data collection (see supplementary material). The PADM explains the characteristics of and informational processes surrounding a threat that motivate individual protective action decisions in the context of environmental and social variables [29]. The modified PADM includes three core perception categories: threat perceptions, protective action perceptions, and stakeholder perceptions [30]. We piloted the guide with two participants at a state-level emergency management office. We made minor alterations in the language of the questions (e.g., disseminate *and/or elevate* tsunami alerts) and added probes suggested by the pilot interviewees. Pilot interview data were included in the analysis.

All interviews were conducted in English and involved one interviewer and one note-taker, with the exception of one interview that was conducted by the interviewer alone, without a separate note-taker. Interviews were conducted over Zoom and lasted from 45 to 60 min. Each interview was recorded with the consent of all participants. Recordings were professionally transcribed and reviewed for accuracy by a local study assistant.

Member checking was used for interview validation, data accuracy, and collaborative research purposes [28]. Members of the research team (MK, CJ, and AM) prepared a summary of each interview and sent it to participants for feedback. Participants provided written feedback through comments and tracked changes on these documents, and their input was incorporated into the summaries.

[3] This figure represents only water waves traveling all the way from Tonga, and does not include representation of the faster waves generated by the atmospheric Lamb wave in the Tonga event, which were > 1 m in some places in the Pacific [53].

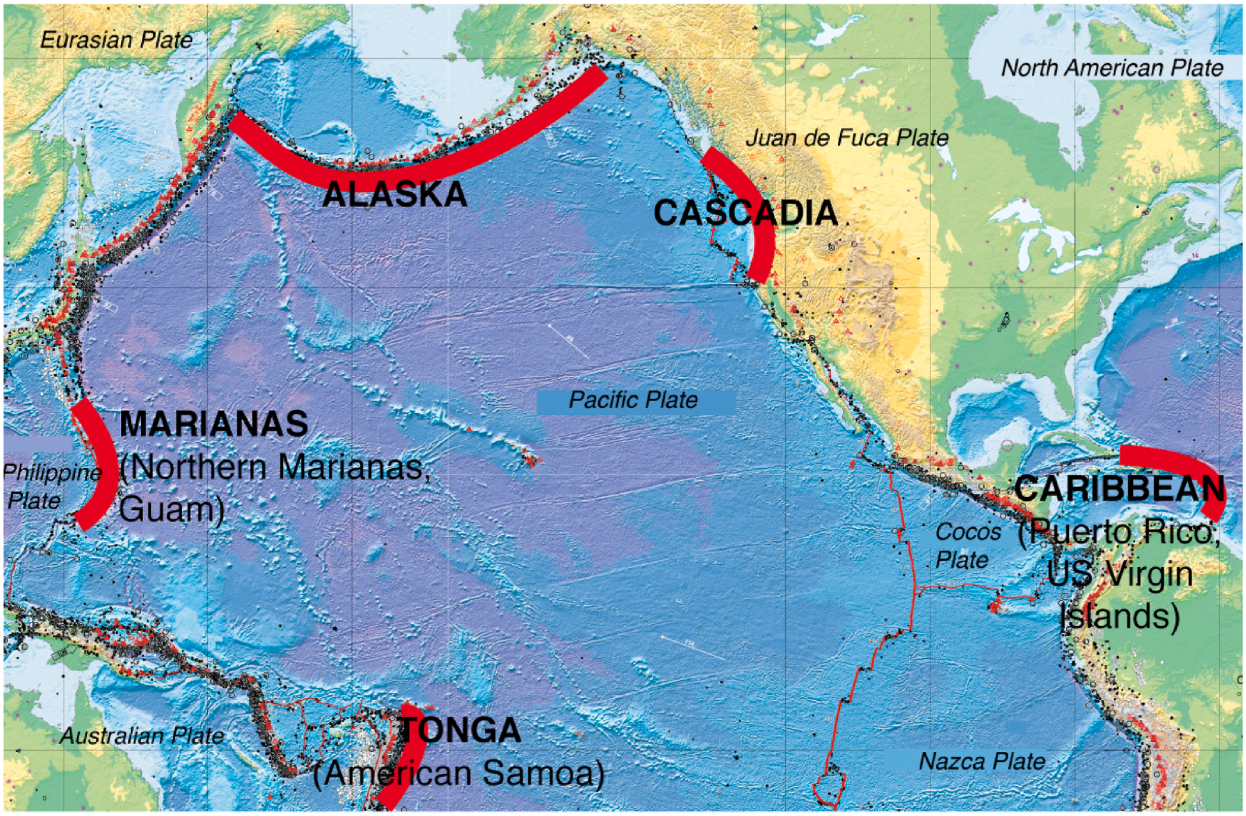

Fig. 2. Pacific ocean subduction zones.
Caption: The red zones on this map indicate subduction zones in the Pacific Ocean basin.
Source: Earthquake Science Center, United States Geological Survey [10].

2.3. Analysis

2.3.1. Coding

We used a flexible deductive coding process with *a priori* codes from the PADM to analyze the data. We used NVivo software (Release 1, 2022) to manage and code the data. One researcher developed initial codes (AM) and code definitions after familiarization with the data. After codebook development, AM and CJ independently co-coded the first 10 % of transcripts (n = 2). Transcripts were coded at the paragraph level to retain context. The researchers reconvened to discuss and resolve any differences in code application. AM and CJ each coded half of the remaining transcripts. Several related codes were combined to form higher-level code categories.

2.3.2. Thematic analysis

AM queried data for each code in NVivo and took written notes describing both common and disparate narratives among participants within each code. If ideas from two or more codes related to one another or overlapped, the codes were combined to build cohesive themes from the data. The themes were reviewed and verified by the other coder (CJ). Within each theme, we determined the proportion of participants who expressed the ideas presented. This proportion is indicated in the results as “few” (<25 %), “some” (25–49 %), “many” (50–75 %), or “most” (>75 %).

3. Results

3.1. Participant characteristics

Participants represented emergency management offices within governmental agencies in Washington (n = 16), Oregon (n = 5), and California (n = 3). Most came from county-level (n = 11) jurisdictions, with some from state (n = 7), Tribal (n = 2), federal (n = 2), and city (n = 1) agencies.

3.2. Overview

All participants or their organizations issued some level of alert regarding the Tonga tsunami to either the public or their partners. See Fig. 3 for the pathways of communication as described by participants. Participants described experiencing some initial confusion

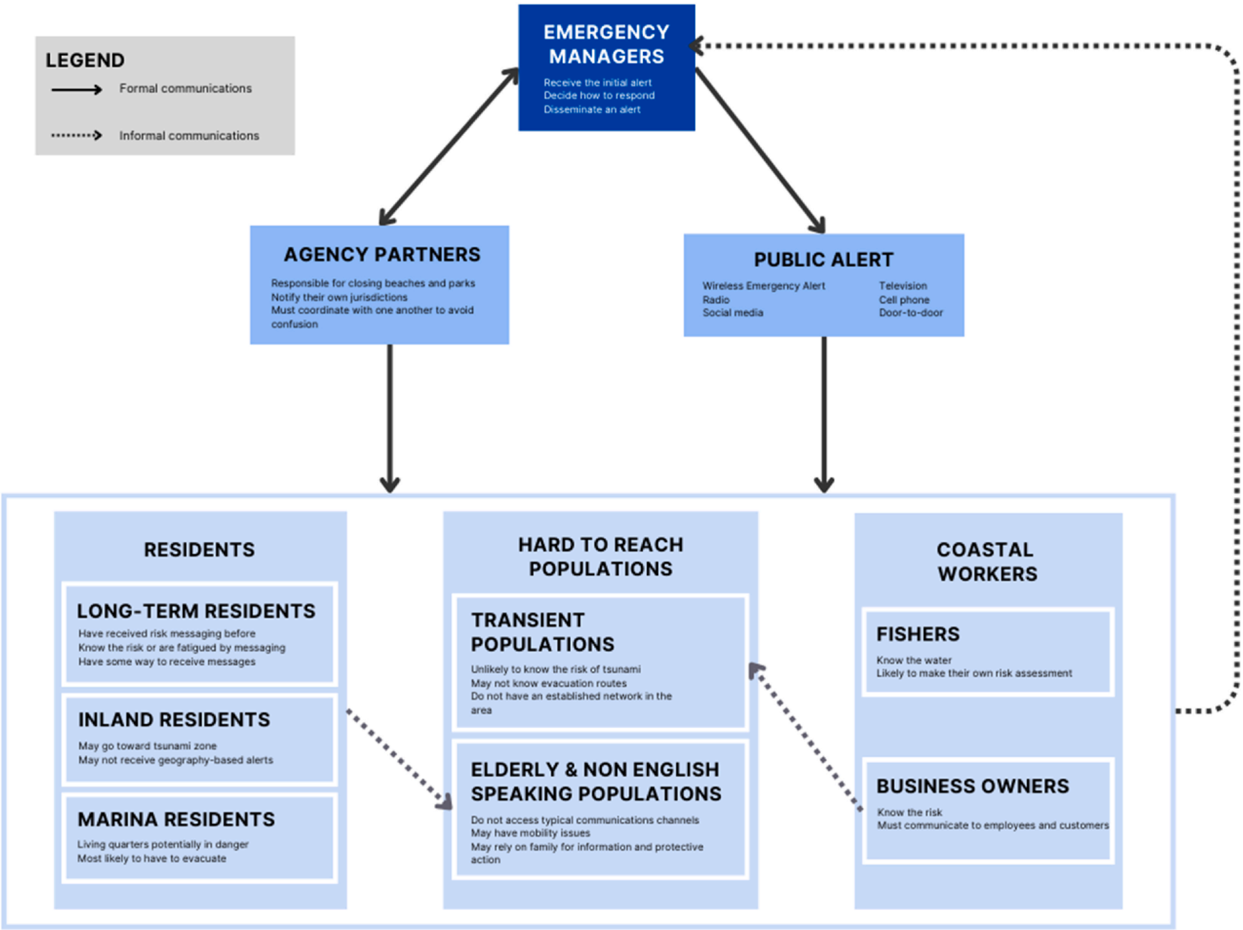

Fig. 3. Emergency alert pathways.

regarding the origin of the tsunami and the fact that it was an "advisory" rather than a "warning."[5] However, most participants had hazard communication plans in place and alerted their communities of the potential hazard. Participants described tsunamis as rare but devastating events, and their threat perception was informed primarily by their prior knowledge and experience. They noted several factors they considered in deciding whether to issue an alert, including identifying and reaching the right populations for alert reception, ensuring clarity of message, and collaborating with counterparts in other jurisdictions for consistent messaging. The distance of the tsunami's origin from the coastline of the PNW created a window of uncertainty and frustration for participants but also provided time to evaluate alert options and determine which to pursue. The lack of environmental cues (i.e., signals, such as ground shaking) associated with the tsunami origin, coupled with the original federal warning messages' lack of detail, confused the predecision process (i.e., exposure, attention, comprehension) for some participants. While the PADM posits that situational facilitators and barriers inform only the behavioral response, our results indicate that they influenced several stages of the decision-making process. We found four key themes from our analysis:

1. EMs perceived the tsunami to be low-threat, but they disseminated a precautionary alert
2. EMs' decisions to take action were driven by anticipated community reactions
3. EMs consider their communities' characteristics when selecting the appropriate mode(s) of communication
4. The nature of the event introduced impediments and facilitators to the information flow and decision-making for EMs

Participants described both formal (solid arrows) and informal (dotted arrows) communications regarding tsunami risk. Alerts were targeted towards agency partners, who may have a two-way dialogue with the EMs, and the public, who may contact EMs or those in their office to ask questions and gain clarification of the alert. The participants also described informal discussions among the public, such as hotel staff/owners to tourists or younger residents sharing information with their elderly family members.

[5] The U.S. Tsunami Warning System utilizes four alert levels for potential hazards, coupled with recommended public actions: information statement (no action), watch (be prepared to act), advisory (stay away from beaches), and warning (move to high ground or inland) [33].

3.3. Theme 1: EMs perceived the tsunami to be low-threat, but they disseminated a precautionary alert

Some participants described tsunamis as rare events but said that they can be damaging and deadly when they do occur. According to Participant 20: *"And tsunamis is* [sic] *just one more hazard. However, it's a low occurrence event, but it tends to be a high consequence event."* Some used the limited information they had from the initial alert and subsequent updates and, after monitoring the situation and often after discussing with colleagues, determined that the risk of potential damage from the Tonga tsunami exceeded the threshold of risk to inform the public. Participant 11 referred to their standard operating procedures: *"So, for us, we've kind of had a standard protocol in that if it endangers life and property and it's something that is significantly impacting the citizens, then we will alert. It's kind of a-- I don't want to say case-by-case basis, but it has to meet certain levels."* Though they did not anticipate a large wave or major destruction, a few participants stated that they would rather issue an alert and disturb their community than not issue an alert and have the community experience a damaging or harmful wave. According to Participant 15, *"It would just seem more on the prudent side that we evacuate because of the size of the wave that was expected, but it didn't occur."* Many of the participants prioritized their alerting only for those near the coast, but some communicated more broadly in the event that residents traveled to the coast that day, such as Participant 14: *"And then we decided, for those people who might be planning on going down to the water, we just give a full-county alert advising people to stay away from the water."*

3.4. Theme 2: EMs' decisions to take action were driven by anticipated community reactions

The majority of participants described a conscious, delicate balance of three key considerations in deciding whether to issue an alert, to whom it should be issued, and what information should be included. Some participants discussed these details with their agencies' primary decision-makers or counterparts in neighboring jurisdictions.

3.4.1. Notification vs. panic

A few participants were concerned that an alert would cause panic, which might result in an overwhelming number of 911 calls or unnecessary evacuations. This question was posited by Participant 18: *"Are we just going to spark up a bunch of interest from the general public to want to call 911 and ask a bunch of questions, or are we actually warning the public of imminent danger?"* Few participants reported the need to be careful in the language they used in their alerts, especially because the lead time for the tsunami was significantly longer than it would be for an alert triggered by a local source. Reaching the wrong populations or disseminating an alert too widely could lead people to evacuate when they did not need to. Participant 6 was concerned about the potential harm caused by a panic: *"The panic would undoubtedly have more mortality and morbidity than the event probably would…[P]utting that information out is a balancing act."*

3.4.2. Notification vs. alert fatigue

Some participants were concerned about over-burdening their communities with alerts, which might render future alerts less effective. Participant 11 stated, *"So for emergency managers, we kind of walk this fine line between over-alerting and under-alerting. And it is something that is always a challenge."* Similarly, Participant 7 stated, *"If you fatigue people with too much messaging, they're just going to ignore it. If you don't do it often enough, folks oftentimes aren't quite sure how to react to it."* Some participants wanted to err on the side of caution and send out the alert but did not want to "cry wolf" as they thought that might cause people to distrust future alerts. If communities repeatedly receive alerts for risks that never materialize, participants reported concerns that those communities may grow fatigued and, therefore, less responsive to future alerts. Participant 21 described how this could impact communities in California: *"And people, especially in the state of California, they're starting to grow kind of fatigued over the alerts that we start to see with all the weather events, with all of the different things that are out there."* The participants noted, however, that it is their responsibility to notify the public of threats, and this balance is not unique to the Tonga tsunami.

3.4.3. Notification vs. curiosity

Many participants described balancing the need for people to know of the hazard against the tendency for some people to go to the beach to watch the tsunami. Participant 18 described alert dissemination as a *"double-edged sword,"* where the message may reach those who do not fully understand the risk, sparking curiosity. Participant 14 highlighted the importance of public safety: *"You send a message, and we knew a certain amount of the population would then go to the beach to try to see what was going on. But at the same time, you need people to have the information so that they can keep themselves safe."* This issue was further complicated by the fact that the tsunami waves were predicted to be relatively small, so there was a greater potential for people to take the risk and watch the waves from the beaches. Participant 11 noted that behavior may have been different depending on the warning type: *"So for some of our residents, when you hear that there's going to be a foot difference in whatever it is now, it doesn't alarm them too much. Unfortunately, I feel like we would have gotten a different reaction if it was a warning."* Though the public's behavior was identified as a concern for participants, some acknowledged that they ultimately cannot control people's behavior.

3.5. Theme 3: EMs consider their communities' characteristics when selecting the appropriate mode(s) of communication

3.5.1. Multiple communication strategies

Most of the participants used multiple mechanisms for their tsunami alerting. In particular, they used wireless emergency alerts (WEA), social media messaging, radio, and even door-to-door evacuation notifications for smaller, high-risk communities. Some participants emphasized the importance of using more than one strategy in order to 1) reach enough people and 2) ensure that there are redundancies so that residents can validate the initial message they receive. Participant 9 stated, *"So we're trying to hit as many different channels and different media as possible and with clear messaging to be able to alert as many people as possible."* Participant 16 also spoke of the need for multiple strategies: *"… [Y]ou really need to have redundancy for people to keep hearing it and get that 'Oh yeah, that means it's [the Office of Emergency Management].'"* For example, if someone sees a social media alert, they can go to the emergency management website to confirm that information. Participant 14 recognized a change in how people receive information: *"… I think this is part of a new culture. But we have to do a variety of messaging to get the word out because there are a lot of people out there who do not listen to the radios, do not watch TV."* The participants noted that having these multi-pronged strategies in place is useful to ensure that their communities have the information they need to take action.

3.5.2. Targeted communications

In conjunction with multiple communication strategies, some participants described the importance of using targeted efforts to reach at-risk populations that may not use typical communication channels. They reported that it was helpful to have communication and outreach processes already in place so messages could go out quickly. These efforts involved ensuring that members of the community were signed up for notifications and knew what to do when they received one. As described by Participant 19: *"The dynamics behind having a system is imperative that you really understand it and you maximize its technology, but you also have to train your public how to use the technology to their best advantage."* In Participant 16's jurisdiction, the fire department took a targeted approach to reach those in the marina and *"… went up and down the docks and notified all the people living on the boats. And radio broadcast went out to boats. And pretty much the harbor cleared out …"* The participants noted that they may not reach everyone but hoped that the community's social network would fill any gaps in communication. This was pertinent for Participant 7: *"So the messaging I've done for my elders' group is, have two to three people within your immediate circle of influence that you know you can trust during an emergency…come get you and assist you out the door."* However, transient and tourist populations remain populations of concern for a few participants, as they have not established a network in the area and would likely not receive a message through opt-in alert systems. Participant 20 noted, *"If you say tsunami, to people that live on the coast, most of them are very aware of it… But it's also the transient or the tourist population that we have to be concerned with as well."*

3.6. Theme 4: the nature of the event introduced impediments and facilitators to the information flow and decision-making for EMs

3.6.1. Impediment: language of information received

Many of the participants were frustrated and/or confused when they received the National Weather Service (NWS)/National Oceanic and Atmospheric Administration (NOAA) notification about the Tonga eruption and tsunami because it was characterized as an "advisory." It was unclear to the participants how to proceed because the term "advisory" indicates that an event may not require evacuation. A few participants noted their hesitancy to disseminate evacuation orders when they received the notification and wished that their information sources, namely NWS/NOAA, were clearer with their language. Participant 20 posed several questions: *"The biggest thing we struggle with is getting good information. If they're putting out a tsunami advisory, is it actually occurring?...did it impact Hawaii? Did it start impacting the Alaska tide gauge and tsunami buoys? That type of information is really critical to us."* However, Participant 19 did not experience such confusion, and they noted that their plans clearly outlined what to do: *"Well, we have an emergency operations plan, and in there, it talks about how we will make decisions if the subject is in harm's way. I mean, it really is kind of just bread and butter."* Most participants look to NWS/NOAA for guidance, but this guidance was not consistently available during the Tonga event. However, the participants did acknowledge that the fact the tsunami was generated by a volcanic eruption rather than an earthquake may have contributed to the lack of clarity in the initial notification, as stated by Participant 10: *"And nature is going to do that. It's going to find a way to sneak around our radar because no matter how many ways we come up with, I think nature and the universe is a little more-- I think it's smarter than we are. And it's not going to sit in our box."*

3.6.2. Impediment: period of uncertainty

Another impediment to making alerting decisions for some participants was the delay in information disseminated by NWS/NOAA as well as state-level agencies due to the distance of the tsunami origin. Participant 17 indicated that quicker detection of tsunamis through technological advancements would alleviate this frustration: *"If I could wave a wand and change one thing, it would be that time of unknown. We got to detect tsunamis earlier. We've just got to."* In order to provide clear, actionable messages to the public, the participants reported needing adequate information about wave height, timing, and location. However, due to technological constraints, participants had to either wait for more information before taking action or use what limited information they had to issue alerts stating what they knew. A few participants noted that the length of the event was longer than for a locally generated tsunami, which complicated the timing of issuing their alerts. Participant 19 stated, *"… once we realized it was going to be a really, really long event until the cancellation came through, it sort of changes your understanding about what our response is going to be."* This factor also impacted their emergency activation procedures, as the emergency management offices would need to be activated for much longer than they would for a near-field tsunami.

3.6.3. Time to make a decision

While the distance of tsunami origin was an impediment for some, it served as a facilitator for a few. The resulting delay gave participants sufficient time to decide on when and how to issue an alert. Participant 13 stated, *"I mean, we knew it was quite a distance away. And the lucky thing is, is that gave us some time."* Participant 15 echoed that idea: *"So we had plenty of time, probably a couple of hours to decide what we were going to do if we needed to."* These EMs discussed options with colleagues or milled for additional information. For Participant 10, *"… the time that it was going to take for it to get here was going to be something that worked in our favor because we would be getting more and more updates as the event progressed. And we had the luxury of sitting down and looking at this slowly."* The delay also gave at least one EM time to issue door-to-door evacuation notices for a low-lying area on the coast.

4. Discussion

We aimed to understand how emergency management practitioners' experiences with and perceptions of the Tonga distant tsunami impacted their decision to alert the public. Participants described facilitators and impediments to gathering information, crafting alert messages, and disseminating information to the right audiences for the distant tsunami. Participants relied on their perceptions of community needs and potential reactions to inform the modes of communication they used and the content of their messages. While the PADM posits that situational facilitators and barriers specifically inform behavioral response, our results indicate that, in this case, they influenced several stages of the decision-making process, including contextual factors, pre-decisional processes, and threat and stakeholder perceptions.

4.1. "Normal" tsunamis

The participants described the Tonga tsunami as atypical, largely because its origin was a volcanic eruption. The distance of the tsunami source was also perceived as an impediment to participants' decision-making. While the northwest coast of the U.S. is at risk of a major tsunami from a CSZ megaquake, historical records indicate that the region primarily experiences tsunamis from distant sources, such as the Alaska-Aleutian Subduction Zone, where earthquakes occur approximately every 75 years [8,31]. As residents along the coast receive educational information about earthquakes and tsunamis, they may expect ground shaking or other environmental cues to warn them of a tsunami (however, even environmental cues may not spark an evacuation [32]). The emphasis on ground shaking as a precursor, coupled with the absence of codified distant tsunami plans, indicates a gap in distant tsunami preparedness among some local jurisdictions. According to some participants, this gap can lead to delays in public warning messages for incoming tsunamis from distant or non-seismic events.

4.2. Precautionary behavior

Participants showed precautionary behavior whereby they expected little damage from the distant tsunami but still chose to issue alerts in alignment with the U.S. Tsunami Warning Center's recommended actions for an "advisory." [33] As shown in connection with the Camp Fire of 2018, delays in emergency notifications can lead to delayed or reduced community evacuations, which may result in increased morbidity and mortality from the hazard [34]. Mileti and Sorensen (1987) describe a balance between the costs and benefits of taking precautionary measures [35]. The decision is informed by risk perception of the hazard, personal characteristics, and external incentives [35]. The accuracy of an individual's risk estimate and their knowledge of the precautionary decision's effectiveness can affect the outcome of their decision [35]. For participants in our study, the cost of potential damage or injury caused by the Tonga tsunami was generally perceived to be greater than the cost of issuing an alert. The participants may also have had external incentives to take precautions, such as occupational pressures. Due to the uncertainty of the event and lack of information, the participants had to rely on intuition, opening up the potential for misjudgment of risk [26]. As described in the PADM, the participants carefully weighed their own perceptions of the threat and protective action, as well as their perceptions of how their community would perceive both the threat and protective action when deciding whether to send an alert. Ultimately, for these participants, the importance of notifying the public superseded their own low-threat perceptions of the tsunami.

4.3. Panic

Study participants expressed concern about the possibility that a tsunami alert could cause public panic. However, past studies have determined that panic as an immediate reaction to an emergency is highly unusual [15,36,37]. People tend to cooperate despite their fear, and social order may break down only when there is no possibility of safety [36]. It is possible that the literature and our participants define "panic" differently. The participants give examples of behaviors such as calling 911 for more information or evacuating and causing traffic jams. The literature on panic, however, defines it as acting out of self-interest with a loss of behavioral control [37]. The "panicking" described by participants may align more with milling and protective action behaviors as described in the PADM [30]. While potentially frustrating, our findings suggest that these behaviors can be anticipated and thus planned for. Prior research suggests that communicators should not withhold information out of concern for potential panic [16]. As insufficient information has been shown to increase milling behavior and delay protective action [38–41], our findings suggest that increased EM training is warranted on the nature and drivers of milling and panic and how sufficient, clear risk communication can reduce such delays by helping residents decide for themselves how to respond.

4.4. False alarms & crying wolf

Some participants wanted to avoid "crying wolf" when issuing alerts, as they perceived that false alarms could degrade trust among message recipients. However, it has been shown that false alerts have little impact on public perceptions as long as the information source is clear about why there was a false alert and how to return to regular activities [42–44]. One study on tornado false alarms did find that areas with higher proportions of false alarms had more casualties from tornadoes; however, the study only looked at casualty data and not people's perceptions of alerts [45]. In addition, the researchers described a trade-off between early warnings and accuracy, where alerts issued more quickly may lose accuracy [45]. One study of individuals who experienced a flood noted that some felt that they received the evacuation orders too late, so they sheltered in place [46]. Our study participants understood that the unique nature of the non-seismic tsunami reduced NOAA's ability to make reliable tsunami forecasts. While this indicates a need for more robust tsunami detection beyond seismically-generated events, in the interim, NOAA and EMs can work together to navigate the limitations of the current warning systems and ensure that EMs can interpret and act on NOAA warning messages. Furthermore, communicators can work to create clearer expectations around updating public alerts as events unfold and forecasts increase in accuracy.

As NOAA natural hazard risk communication guidance shows, communication materials should be monitored and revised based on public response to the messages [47].

4.5. Inappropriate evacuation behavior

Many participants mentioned seeing or hearing about individuals going to the water to watch the tsunami. While evidence is limited for this type of behavior, one study using focus groups, interviews, and surveys among Italian villagers who experienced a flash flood found that 18 % of respondents went to see what was happening to verify the danger [48]. Another study surveyed New Zealand residents after tsunami warnings were initiated from the 2010 Chilean earthquake. Three of the twenty study participants reported going towards the tsunami hazard areas [49]. There was no evacuation order, and the tsunami occurred at low tide, similar to the distant tsunami from the 2022 Tonga eruption. The authors described this sight-seeking behavior as a form of milling in which the individuals were motivated to confirm the reports they received [49]. However, the participants in our study attributed the sight-seeking to curiosity or general interest; the true motivation of residents who went to observe the tsunami is unknown. This issue warrants further study as it can impede both warning and evacuation efforts [49].

4.6. Alert/warning fatigue

The participants' geography played a role in their concerns regarding the effects of the alerts, particularly for those in regions that already receive a large volume of hazard warnings. Alert inundation has been shown to produce cognitive overload and can reduce the recipient's ability to recollect the information within an individual alert [50,51]. A mixed methods study involving 83 interviews followed by a survey of 330 residents in Australia who experienced a flood showed that some individuals took the event less seriously due to warning fatigue [46]. They decided to shelter in place rather than evacuate as instructed [46]. Given that coastal regions in the U.S. face several different types of natural hazards, it is possible that residents can become overwhelmed by alerts. As the region is facing more intense and complex hazards due to climate change [52], coastal EMs may face increasing alert fatigue among their residents and must anticipate this in their hazard communications planning.

4.7. Limitations

The generalizability of our study is limited due to its geographic focus in the U.S. Pacific Northwest, with both near-field and distant tsunami risk compounded by an uneven distribution of participants across the states represented in the sampling frame. We interviewed more individuals from Washington than from Oregon and California. In addition, we had limited representation from Tribal government officials. Future research may explore the risk perceptions and decision-making of Tribal EMs for tsunami hazards. Finally, there may have been issues related to recall, as some interviews took place one year after the event, and a few participants were not active in their EM capacity at the time of the tsunami. Some, but not all, of these participants had written records of the event activities.

5. Conclusion

The January 2022 Tonga volcanic event and subsequent tsunami underscored the vital role that clear, timely, and accurate risk communication plays in effective disaster preparation and response, especially from atypical events originating from non-seismic triggers such as volcanoes. This study highlights the need for robust warning systems for distant tsunamis from the federal to the local level, as well as integrated planning to support interoperability and operationalization of communications. It likewise emphasizes that the unfamiliarity of rare events can delay alert dissemination and subsequent protective action adoption among coastal residents. EMs and their partners must comprehend the complexities of the geological processes contributing to such events and how to communicate these with the general public. As the distant tsunami was a mild event for the U.S. West Coast, EMs can also consider counterfactuals (i.e., alternative scenarios with more severe outcomes) in plans and in drills. Future research might also consider exploring counterfactual scenarios in discussions with decision-makers. Conveying the seriousness of potential future hazards while reducing warning fatigue from the public requires a nuanced and well-informed approach. Lessons drawn from this study can be instrumental in shaping strategies for future earthquake and tsunami warnings.

CRediT authorship contribution statement

Ashley Moore: Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Cassandra Jean:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Matias Korfmacher:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Jamie Vickery:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Ann Bostrom:** Writing – review & editing, Funding acquisition, Conceptualization. **Nicole A. Errett:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

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.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2024.104560.

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