Early Warning Systems and Evacuation:

Rare and Extreme vs Frequent and Small-Scale Tropical Cyclones in the Philippines and Dominica.

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Abstract

To test the efficacy of early warning systems in prompting residents to take appropriate action ahead of severe hazards, surveys were carried out among affected populations following Super Typhoon Yolanda (2013, Philippines) and Hurricane Maria (2017, Dominica). Both events were rare and extreme but occurred in locations that regularly experience less severe tropical cyclones. We asked if, how and when residents received warnings, what instructions were given, and where and when respondents decided to seek safety. In both examples studied, the residents were aware of the approaching storms, but critical information regarding the severity and potential impacts was either not received in time or not understood fully. This resulted in low levels of evacuation and safety-seeking behaviour. We suggest that planning and public communication need to focus on uncertainty surrounding the severity, impact and multifaceted nature of tropical cyclones and accompanying hazards.

Key words: disaster, risk, resilience, early warning, preparedness, Yolanda, Maria, evacuation, hazard

Introduction

Early warning systems (EWS) provide information ahead of hazardous events to enable pre-emptive action that will reduce the risks faced by those exposed. However, the technical components of EWS alone are insufficient to trigger appropriate response actions in populations ahead of such events, as EWS are inherently social processes (Kelman, et al, 2018). EWS that fails to account for human factors cannot be regarded as effective and complete (Twigg, 2003). To meet the needs of all at risk, one official form of warning alone is often not sufficient, especially in areas subject to multiple hazards (Naylor, Faure Walker and Suppasri, 2018).

Typically, EWS consist of initial warnings from official sources, such as local government authorities and news outlets, and warnings from secondary sources, such as employers and co-workers, families and friends. Online social media sources can straddle the two, relaying both official messages and information arising from community-based reporting and organising. Planning should take into

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account all sources of warning and distribution channels, the warning reception and the reaction times of the public (Lindell, Prater and Peacock, 2005). However, often it is only the official, organised and planned warnings that are considered, ignoring the secondary, unsystematic and diffuse informal systems (Lindell, Prater and Peacock, 2005). The significant role of social networks in determining when evacuation occurs and travel times to safer destinations during hurricanes has been evidenced (Gehlot et. al., 2019). Failing to appreciate informal warning networks underutilises a powerful tool and can lead to overestimation of the time needed to disseminate a message. This can prove critical for rapid-onset events or when changes in location or storm intensity occur (Lindell, Prater and Peacock, 2005), as was the case for Hurricane Maria in 2017.

Warnings may be issued but this does not guarantee receipt, for example hazards occurring during the day can have a higher likelihood of warnings being heard compared to those occurring at night (Mason et al., 2018). Numerous studies have shown that there exists a significantly lower likelihood of seeking safety among those not receiving a warning (Balluz et al., 2000), irrespective of the reason for not hearing the message, e.g. technical failure (Carter et al. 1989), being in transit (Mitchem, 2003), a night event (Schmidlin et al., 1998), or a language and translation issue (Aguirre, 1988). Early attempts to understand evacuation behaviour focussed on the warnings themselves, and it was taken that if a warning was heard and believed, evacuation would naturally result (Mileti et al., 1975). Hazard warning content, source and frequency have therefore long been studied (Drabek, 1986). However, rethinking this assumption has allowed the consideration of specific triggers that may induce safety-seeking behaviour, as well as the way in which warning information is processed by recipients and how individual risk is perceived (Mileti and O'Brien, 1992). Any resultant safety-seeking action following a warning is influenced by sender and receiver characteristics (Sorenson and Vogt-Sorenson, 2006), with people choosing to believe warnings of greatest personal relevance (Dow and Cutter, 1998).

A successful EWS therefore goes beyond functioning as an alarm trigger alone; it needs technology to work effectively, but also the population at risk to be receptive, willing and able to take action. The system requires all of the following: knowledge of the risk, a technical monitoring and warning service, dissemination of meaningful warning messages, and public awareness and preparedness to act (UNDP, 2009; WMO, 2018). Failure of any of these components will lead to a failure to protect lives. Multi-hazard approaches should avoid forcing generalities and instead consider the needs and implications of each hazard through a coordinated 'system of systems' (Basher, 2006).

EWS often fail in the communication and preparedness aspects. In Sulawesi, Indonesia, the 7.4 magnitude earthquake and tsunami of September 2018 demonstrated that, even in a multi-hazard geographical zone well accustomed to such phenomena, high levels of uncertainty among populations remained over how to react safely; public awareness remains relatively low partly as evacuation drills are only sporadically practiced. In Palu, many were unsure how to react to the alert information, with some remaining close to the shoreline even when waves were visibly approaching (Telegraph, 2018). In addition, when public warnings are mixed, inaccurate or absent, usually through power and communications damage, hazard impacts can be underestimated. For example, confusion arose among the public later that year as a tsunami triggered by the Anak Krakatau eruption (and underwater landslide) in Indonesia's Sunda Strait was not forewarned, as current technology does allow the detection of tsunamis not tectonic-related. Moreover, seismometers around the volcano were also apparently damaged during an eruption (The Jakarta Post, 2018)

Insufficient risk knowledge, vulnerability awareness and understanding of uncertainties in warnings among the public is a global issue. This was the case for Hurricane Katrina in New Orleans in August 2005 (Basher, 2006). The same can be said of Typhoon Yolanda in the Philippines in 2013, where storm surge warnings were received extensively, but a widespread lack of understanding of what "storm surge" meant and its dangers led many to ignore evacuation warnings. When Cyclone Nargis struck Myanmar in 2008, the Myanmar Meteorological Service issued warnings but other elements of an effective EWS, such as preparedness to act, were not present (UNISDR, 2018). The Great East Japan Earthquake of 2011 exemplifies when uncertainties in warnings are not sufficiently considered; in some towns (e.g. Taro), residents did not evacuate as the early communications considerably underestimated the tsunami height leading residents to presume the sea wall would protect them (EEFIT, 2011). Warnings with inherent uncertainties must provide sufficient detail so that recipients can make informed decisions, but too much technical information in a warning message can mean the public is less likely to respond (Hiroaki, 1992).

False alarms provide further challenges, as scientific uncertainty in predictions means that an appreciation of probabilities and associated risks must exist among at-risk populations (Atwood and Major, 1998). Typically, decision makers often require near certainty from EWS and although populations can be more likely to believe a warning message if probability information is included (Baker, 1995), some will still fail to take action to protect themselves. There will remain an inherent degree of "risk informed" death and destruction (National Research Council, 2013).

Among natural hazard EWS, those for tropical cyclones perhaps have the greatest potential to save lives due to longer lead times, often of up to a week in advance. Many regions exposed to severe tropical cyclones may also experience regular, smaller events making the hazard a more familiar threat. However, predicting tropical cyclone intensity remains a key challenge, and accurately predicting rapid intensification events such as Hurricane Maria even more so, as so few occur. Late or unforeseen changes in path or intensity, along with associated secondary hazards, can cause complications and confusion within the EWS process.

In light of challenges facing tropical cyclone EWS, the last 15 years have seen significant advances in forecasting and communication systems. Following Hurricane Katrina in 2005, a shift in focus to storm surge prediction and warning began, fuelled by the effects of Hurricanes Ike and Sandy in 2008 and 2012. Recognising the damage caused by storm surge when coastal regions are inundated with flood water, the National Oceanic and Atmospheric Administration's (NOAA) National Hurricane Center (NHC) introduced a storm surge specific element to tropical storm and hurricane warnings along the Atlantic coast of the US in 2014, aimed at allowing roughly 48 hours of advanced warning where storm surge may occur (NOAA, 2018). More recently, the NHC adapted its forecast and communication products in a number of ways ahead of the 2018 Atlantic hurricane season in light of 2017 hurricanes in the Americas and the Caribbean. One such improvement is to issue advisory warnings beyond 48 hours that contain information relevant to all potentially related hazards, including storm surge, inland flooding, tornados, and increased surf (NOAA, 2018).

The Sendai Framework for Disaster Risk Reduction 2015-2030 issued the global challenge to substantially increase access to Multi-Hazard Early Warning Systems (MHEWS) as well as disaster risk information and assessments by 2030. The need for MHEWS emanates in part from the fact that single hazards such as tropical cyclones are often accompanied by secondary hazards such as storm surge, associated hazards such as heavy rains, and cascading hazards such as coastal inundation and flooding. All of which can lead to the disruption of water and sanitation systems, power supplies, roads, housing, national infrastructure, supply chains and agriculture. As a commitment to the Sendai framework, and specifically the need to improve MHEWS in Small Island Developing States (SIDS) and Least Developed Countries (LDCs), the Climate Risk and Early Warning Systems (CREWS) initiative was established in 2015 with the aim of enhancing integrated MHEWS to "generate and communicate effective impact-based early warnings, and risk information for hazardous events" (CREWS, 2018).

Technical elements of EWS can be simulated in scenarios but understanding real-life public response requires real events (National Research Council, 2013). This is because what people say they would do and what they actually do in an emergency can be very different, and evacuation plans have often been based on behaviour informed by the former (Nelson et al., 1988). Studies following real events have shown that the following key factors are needed to provoke protective and effective action (Mileti et al., 2006):

- *Education about the warning system is needed before an event (*King, 2000; Parr, 1998; Liu et al., 1996, *discuss public awareness of warning systems for their efficacy)*
- *Alerting needs to attract attention (Lachman et al,1961; Lindell and Ronald, 1987, find the frequency and pervasiveness of warning messages can prompt safety-seeking action)*
- *People seek social confirmation of warnings before taking protective action*
- *Messages should contain information that is important to the population (Baker, 1979; Goldsteen and Schoor, 1982, show that personalising warning messages increases the likelihood of a response)*
- *Responders should consider the demographics of affected populations when preparing warning messages*
- *Access for those with disabilities must be considered when developing alert of warning systems*
- *Alerting and warning is a process, not a single act (National Research Council, 2013; Gladwin and Peacock, 2001; Golden and Adams, 2000, acknowledge the complexities of EWS, recognising the importance of accounting for messiness in decision-making processes).*

In this paper, we analyse EWS and public responses during two extreme tropical cyclone events: Typhoon Yolanda in the Philippines (2013), and Hurricane Maria in Dominica (2017). Both events occurred on islands experiencing frequent, low-to-moderate intensity tropical cyclones (Category 2-3). However, these events were unusual in that they were extremely high intensity (Category 5) and featured elements that led many residents to underestimate the risk. During Yolanda, many did not understand the storm surge risk due to a lack of experience of storm surge and understanding of its meaning (Faure Walker and Alexander, 2014). In the case of Hurricane Maria, increased risk arose from the very rapid escalation from Category 1 to Category 5 within a 15-hour period as it made landfall on Dominica. This was not predicted by forecasters at the NHC and not communicated fully to the public when radio communications across the island failed.

Background to the Study Location

Located in the Pacific along the typhoon belt, the Philippines experiences an average of 20 typhoons per year, five of which are destructive (ADRC, 2008). Its location and physical environment make it vulnerable to storm surge, tsunami, sea level rises, flooding and landslides (ADRC, 2008). Tacloban city, densely populated and home to over 200,000 inhabitants (Philippines Statistics Authority, 2013) bore the brunt of Yolanda's 195mph sustained winds. The city lies at the tip of a funnel-shaped bay in the Leyte Gulf which channelled the storm surge towards the city, amplifying its height and speed and leading to an estimated 90% destruction rate (Mercy Corps, 2013). Yolanda, the 13th named storm and most powerful of 2013, became the strongest typhoon to make landfall in Filipino history and one of the strongest on global records, despite occurring after the official end date of the typhoon season (World Vision, 2018). Yolanda affected more than 14 million people across 44 provinces, displaced 4.1 million people, killed more than 6,000 people, left 1,800 people missing, disrupted 5.9 million people's livelihoods, damaged approximately 1.1 million houses and destroyed 33 million coconut trees (DEC, 2015; World Vision, 2018).

In the Caribbean, the North Atlantic hurricane season brings an average of 10 named storms per year, with an average of six making it to hurricane strength, and 2.5 becoming major hurricanes (Category 3 or higher) (NOAA, 2017). Maria's sustained maximum winds were 90mph as of 5am Atlantic time on Monday 18th September, putting it at the high end of a Category 1 hurricane. However, in approximately 15 hours, winds rose to 160mph, almost 50mph higher than forecast the previous night, accelerating Maria to a Category 5 and catching many residents off guard (NHC, 2019; NOAA, 2017).

Methods

The results for this paper were drawn from structured oral questionnaires of residents conducted house-to-house following two case studies: Typhoon Yolanda in the Philippines and hurricane Maria in Dominica. Time at the end of the survey was given to allow for further comment and more qualitative detail.

In the Philippines, data were collected in two separate fieldwork campaigns. The first, in March 2014, four months after Typhoon Yolanda, surveyed 160 households across 12 coastal Barangays (districts) of Tacloban, Palo and Tanauan in the province of Leyte, Eastern Visayas (Figure 1, Table 1) (Faure Walker and Alexander, 2014). The second survey was undertaken in September 2016, three years after Yolanda. It visited a different set of 155 households in the same Barangays. Both data sets, totalling 315 responses, were used to analyse overall evacuation decisions, and evacuation decisions made by the levels of home damage experienced and the cause of home damage e.g. wind, water or both. In addition, the 155 responses from the 2016 data set were used to analyse the sources through which warnings were heard, when the initial warnings were heard, the evacuation instructions received, and the evacuation decisions made by housing materials used.

In Dominica, data were collected in October 2017, three weeks following Hurricane Maria. A total of 177 respondents from nine separate locations around the island were sampled (Figure 1, Table 1), representing towns and cities island wide. These questionnaires were similar to the 2016 Philippines survey, with minor alterations to adjust for local context.

Table 1: Locations surveyed during the three fieldwork campaigns.

Tropical cyclone	When survey conducted	Survey locations within country	No. of households surveyed
Typhoon Yolanda (Haiyan), Philippines, Nov 2013	2014 (four months post-disaster) and 2016 (3 years post-disaster)	Leyte island: 1. Barangay 70 (Tacloban) 2. Barangay 69 (Tacloban) 3. Barangay 68 (Tacloban) 4. Barangay 60A (Tacloban) 5. Barangay 58 (Tacloban) 6. Pawing (Palo) 7. San Fernando (Palo) 8. Cogon (Palo) 9. San Joaquin (Palo) 10. Santa Cruz (Tanauan) 11. Santa Nino (Tanauan) 12. Bislig (Tanauan)	160 (in 2014) and 155 (in 2016), totalling 315 **Both data sets used for:** 1. Evacuation decisions **2016 data set only used for:** 1. Warning sources 2. When warnings heard 3. Evacuation advice received via warnings 4. Evacuation decision by housing materials used
Hurricane Maria, Dominica, Sept 2017	2017 (4 weeks post-disaster)	Island wide: 1. Salybia (St David) 2. Portsmouth (St John) 3. Marigot (St Andrew) 4. Rosalie (St David) 5. Calibishie (St Andrew) 6. Roseau (St George) 7. Canefield + Mahaut (St Paul) 8. Grand Bay (St Patrick) 9. Soufriere (St Mark)	177

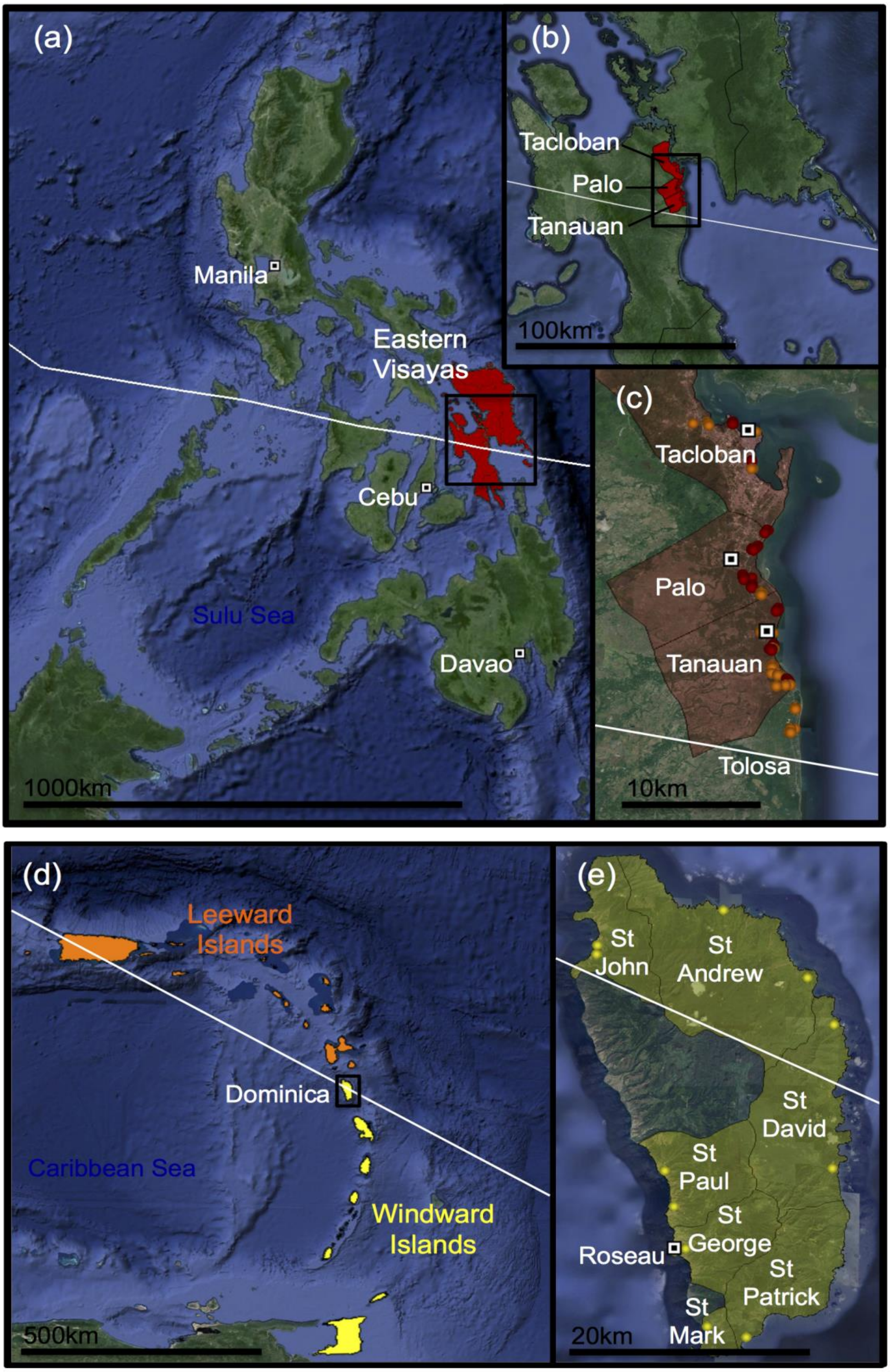

Figure 1: Location maps showing the path of (a) Super Typhoon Yolanda through the Philippines, (b) specifically through Leyte Island, and (c) locations of households surveyed; also (d) Hurricane Maria

through the Caribbean, and (e) specifically through the island of Dominica. Images were produced in Google Earth.

Statistical significance of relationships between whether safety seeking behaviour occurred and warning timing, number of warnings received, and construction quality, were conducted using Welch's t-tests at significance levels 0.01, 0.05 and 0.1.

Surveys were accompanied by informal interviews with local authority figures in each location, who provided contextual understanding by helping identify specific, area-related challenges. These interviews further helped with ranking employment types appropriately for the region, with the results checked by locally sourced translators (Philippines) and on-the-ground partners (Dominica).

Survey participants and interviewees were advised about the nature of the research and the intention to use the findings from the questionnaires for publication within academic literature and for evidence-based advice to policy makers. Preliminary findings have been shared with government and military partners of a UK-based Disaster response NGO closely tied with the Philippines and the Caribbean.

The limitations of this study primarily lie in the ability of the respondents in 2016 to accurately recall information from shortly after the typhoon. This is particularly the case regarding warnings received, evacuation practices and assistance received relative to sources and time frames. It was possible to some degree however, to corroborate details of earlier memories through the 2014 data set, to identify general trends that appear consistent in the areas surveyed.

Results

All but one of the respondents in the Philippines received a warning prior to Yolanda, while in Dominica all respondents received a warning. The most common warning source for Yolanda was the television, while for Maria it was the radio. These warnings were received with more than a day's notice by 71% and 46% of respondents for Yolanda and Maria respectively. However, 78% and 82% of those surveyed either remained at home throughout, or evacuated during or after the storm for Yolanda and Maria respectively. For Yolanda, some families decided to separate creating gender-specific changes in vulnerability while for Maria all families stayed together. Most respondents in the Philippines had experienced intense typhoons in the past, but 96% reported they had never experienced anything resembling Yolanda in their lifetimes. Similarly, 96% of respondents in

Dominica reported never having experienced a hurricane of Maria's scale, with 47% unable to name another hurricane of similar strength or nature.

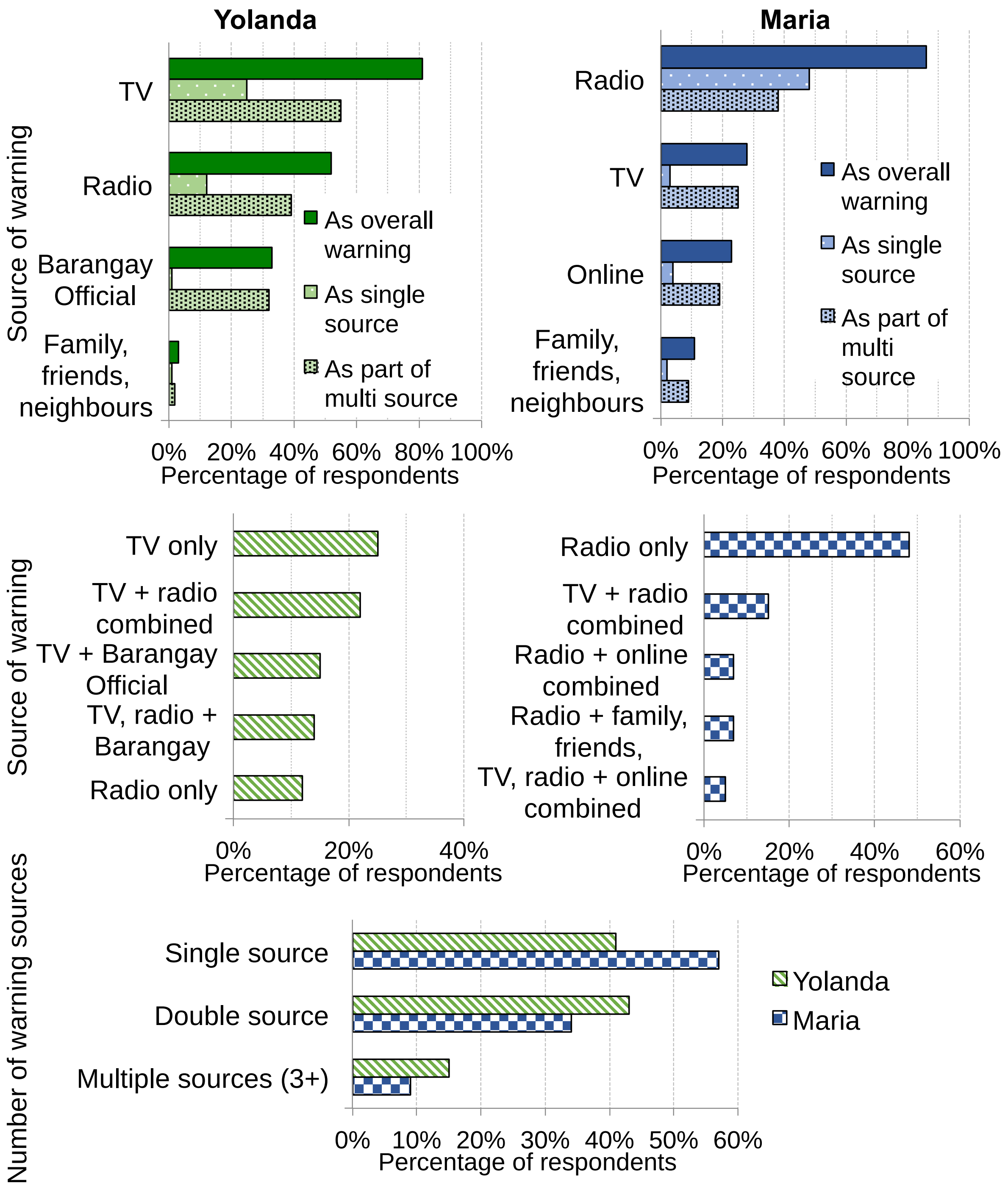

Figure 2: The most frequently cited warning sources for (left) Yolanda and (right) Maria. (Top) Individual sources separated by whether they were received as a single source or as one of multiple sources (two or more sources). (Middle) The five most common combinations of warning sources received. (Bottom) The relative percentages of single, double, and multiple sources (three or more sources).

In both case studies, the most prevalent warning type reached a high number of respondents, but not all (Figure 2). For Yolanda, 81% of respondents heard a warning through the television, with this being the most commonly reported single source (reaching 25% respondents) and element of a multi-source warning (reaching 55% respondents). For Maria, the most common warning mechanism was the radio, reaching 86% of respondents (48% as a single source and 38% as part of a multisource warning), but the radio network faltered when Maria made landfall. Warning types received not included in figure 2 include the police, online sources, the military, and national disaster committees in the Philippines, local councils, WhatsApp groups, employers, religious groups and Disaster Committees in Dominica, but each of these reached less than 2% of respondents. The five most common warning combinations received were notably more common than the next in each case study (radio and barangay officials with 3% for Yolanda and online sources alone with 4% for Maria). More respondents in Dominica were reliant on only one type of warning (57%) than in the Philippines (41%). A total of 58% and 43% of respondents received two or more warnings in the Philippines and Dominica respectively.

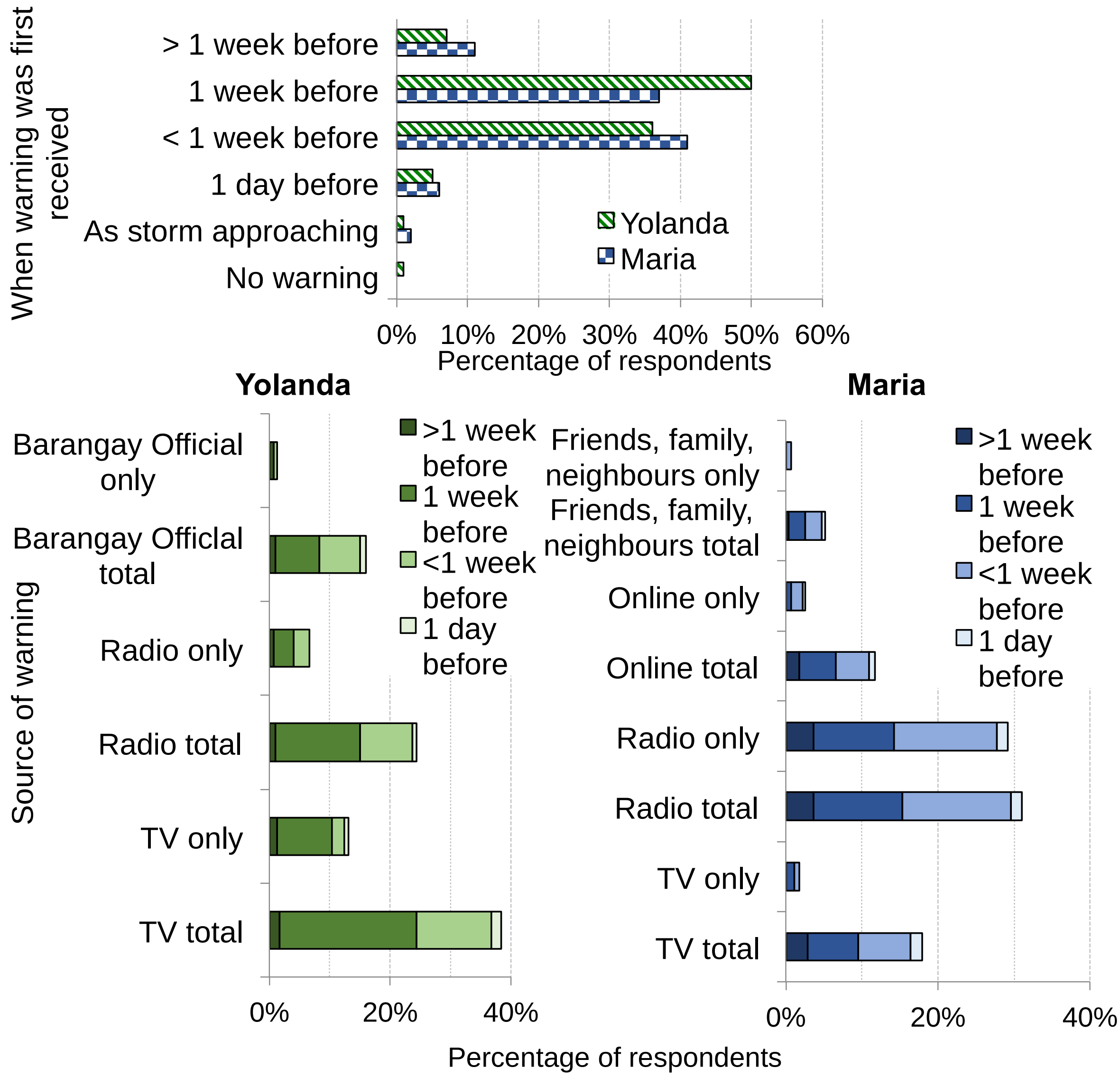

Figure 3: Times when respondents first heard a warning message. The bottom panel shows results separated by the most common warning types for (left) Yolanda and (right) Maria.

Warnings in both case studies were heard by a majority of people in enough time to be able to react in some capacity. All but one respondent heard a warning for Yolanda and all of the respondents heard a warning for Maria. Almost all respondents received a warning at least one day ahead of landfall (98% and 95% respondents for Yolanda and Maria respectively). A total of 57% in the Philippines and 48% in Dominica received a warning a week or more in advance, the majority being afforded two to three days of advanced warning (Figure 3). There is no clear distinction between the relative timings of when different types of warnings were first heard (Figure 3).

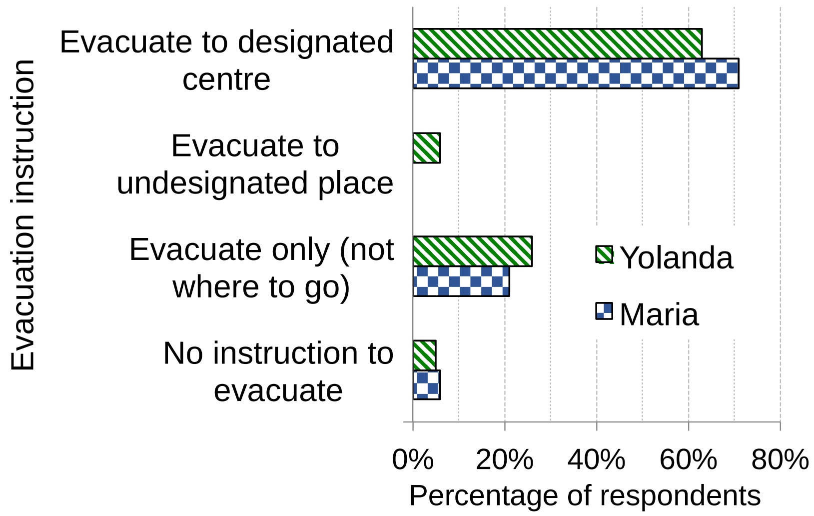

Figure 4: Evacuation instructions accompanying warnings heard by respondents.

An instruction to evacuate, with or without further information as to where to go, reached 95% and 92% of the surveyed population for Yolanda and Maria respectively, with 63% and 71% receiving an instruction to evacuate to a designated storm shelter (Figure 4).

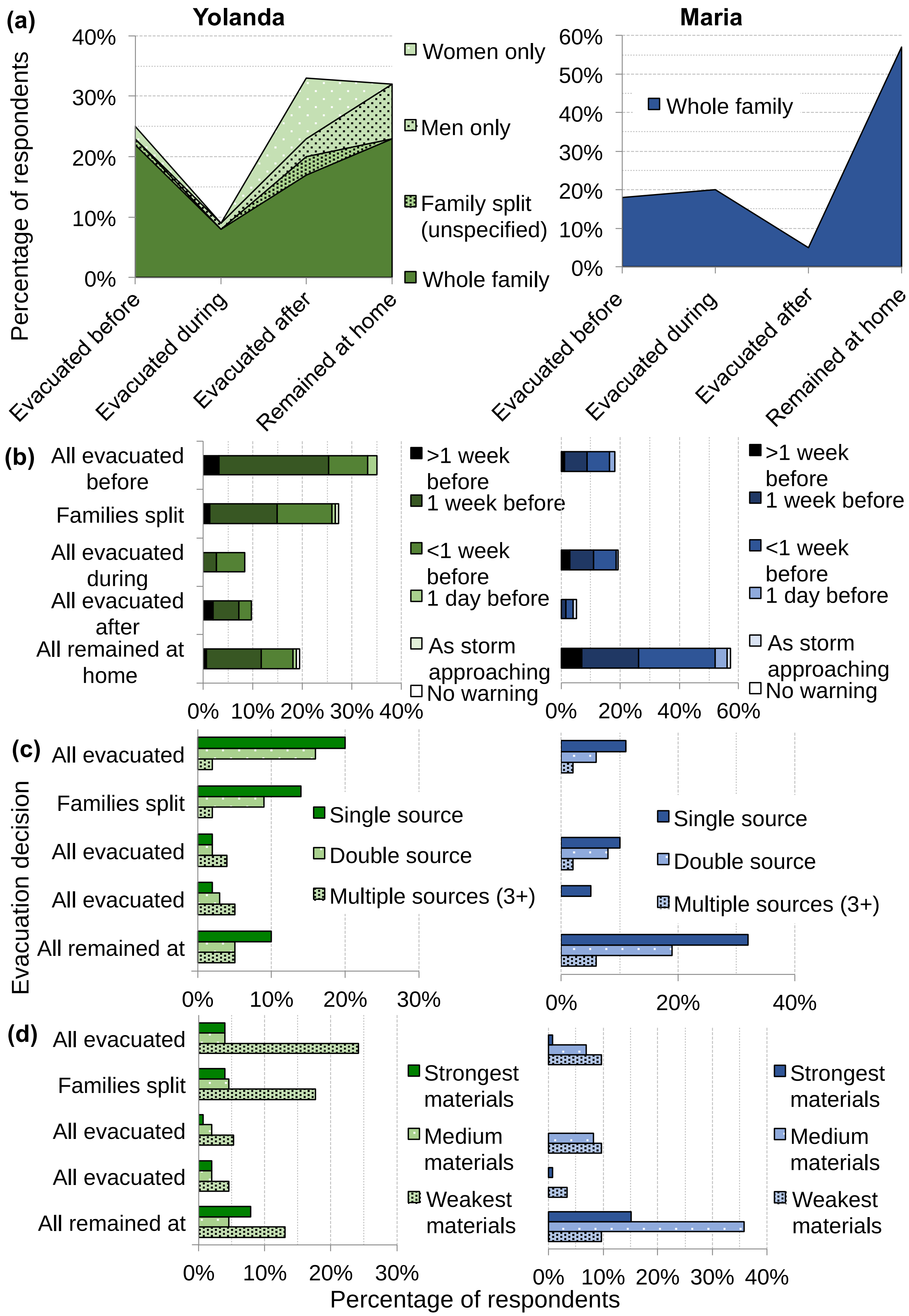

Figure 5: Evacuation decisions for (left) Yolanda and (right) Maria taken by (a) who evacuated (for

Maria all are grouped together), (b) the time when warnings were first heard, (c) the warning source type, and (d) building vulnerability determined by housing material.

Assuming that the safest action was to evacuate the home before the arrival of the storm, 78% and 82% of those surveyed did not seek the safest option in response to Yolanda and Maria respectively, as they either remained at home throughout or evacuated during or after the storm. The warnings received prompted 23% and 9% of respondents to evacuate before and during Yolanda in the Philippines respectively, and 18% and 20% of respondents to evacuate before and during Maria in Dominica.

Gender-based vulnerabilities relating to evacuation decisions were discernible for Yolanda, but not Maria (Figure 5a). Following a warning for Yolanda, families remaining together was the most popular choice across all evacuation timing decisions (including remaining at home). When families did chose to split, male and female specific heightened vulnerability accounted for 13% and 10% respectively of actions among those surveyed, with the majority choice for men alone being to remain at home throughout (9%) while for women acting alone it was to evacuate after the typhoon had passed (10%). Response actions to warnings for Maria saw households acting together (staying at home being the most frequent decision (57% respondents)).

Some 64% and 81% of respondents given at least one day of advanced warning did not evacuate before the Yolanda and Maria, making a decision that increased their vulnerability. Comparing families that evacuated together before the storm arrived to those that did not for both Yolanda and Maria, at least one day of warning was more likely to promote evacuation at the 0.01 significance level. However, this relationship does not hold with statistical significance at the 0.1 significance level if comparing when at least some family members evacuated before to those not, for Yolanda. A total of 40% of the respondents that heard first warnings roughly one week before Yolanda evacuated before the storm's arrival, however 25% of this group decided to split their families, evacuating some and leaving others behind (Figure 5b). For Yolanda, a total of 33% of those who had lead times of less than one week, (two to three days), decided to split their families. In Dominica, only 9% of those hearing a warning around one week before Maria decided to evacuate before the storm, although families always moved together. A total of 11% and 26% hearing a warning a week or more prior evacuated during the storm and remained and home throughout.

The respondent hearing their first warning as Yolanda approached decided to split their family. Half of the four households that received a warning for hurricane Maria as it approached remained at home throughout and the other half evacuated once it had passed (Figure 5b). The only respondent reported to have heard no warning for Yolanda remained at home throughout the typhoon.

Whether the efficacy of warnings to promote safety-seeking action was influenced by the number of types of warning received is explored in figure 5c. For Yolanda, double source warnings had the relatively highest success rate when compared with single source or multiple (3+) sources. Comparing a single source to at least two sources, or single and double relative to multiple sources, we found a statistically significant difference at the 0.05 (but not 0.01) and 0.01 significance levels respectively. For Maria, no statistically significant pattern appears to have emerged based on the numbers of warning sources relative to evacuation decisions, tested by comparing the means at the 0.1 significance level. However, it should be noted that those remaining at home may be likely to receive more types of warnings than those who evacuate.

For Yolanda and Maria, safety-seeking behaviour (with at least some of the household evacuating before the storm) was found to be related to housing construction, and those in weaker housing were more likely to evacuate. This relationship was displayed at the 0.01 significance level for both Yolanda and Maria when comparing weakest construction to medium and strong, and when comparing weaker and medium to strong (Figure 5d). In the Philippines, the strongest housing consisted of concrete walls with a variation of roofing materials ranging from reinforced CGI sheeting to wood and tarpaulins. These houses generally sustained less severe damage than other housing types. The medium strength buildings consisted of “hardflex” (fibre cement board) walls with a variation of roofing materials ranging from reinforced CGI sheeting to wood and tarpaulins. The weakest form of housing was customarily built using wood (both plywood and traditional wood such as coconut, bamboo and woven “amakan” strips) for the walls and a variation of roofing materials ranging from CGI sheeting to wood and tarpaulins. These houses were mostly completely destroyed. The majority of our surveyed population lived in homes built from the weakest materials (Figure 5d). In Dominica, the strongest forms of housing comprised concrete walls and concrete roofs, which were mostly flat, remained intact and protected inhabitants well. Medium strength homes consisted of concrete walls with a galvanised iron roof. The weakest forms of housing were built with wooden walls and a galvanised iron roof. The majority of homes with galvanised iron roofing from both medium and weak housing categories lost their roofs to the wind.

Overall, we found that many of the results were comparable in the two case studies, allowing us to discuss these findings in the context of rare, extreme hazards in regions that experience more frequent, less severe events.

Discussion

Lack of awareness or experience of hazards and associated risks can be a cause of EWS failure, however do these problems exist in regions that are accustomed to regular hazards causing mild to moderate damage and usually necessitate fewer evacuations? While exposure to regular hazards may appear to encourage populations to be more responsive to warning messages, the regularity itself may hinder the efficacy of warnings for more irregular, extreme events. Mixed opinion over hazard experience and the likelihood of responding to warnings persists, with research showing hazard familiarity can both help (Anderson, 1969; Gruntfest, 1997) and obstruct (Ketteridge and Fordham, 1998; Kilpatrick, 1957) message receipt and induced action. This reasoning may explain response actions taken by respondents ahead of Yolanda and Maria, believing both would be of "normal" level storm intensity and therefore usual preparedness measures to be sufficient. Important to note is that due to failures in both warning systems, people were prepared for a familiar situation, but were unknowingly about to face an unfamiliar one.

We recognise that for an EWS to be effective, the dissemination of meaningful warnings to at-risk populations is needed, as well as preparedness to act (Hoffman and Muttarak, 2017). If warning and alerting is a process and not a single act, we need to evaluate what the EWS process entails, how it differs depending on location, hazard and experience, and what that requires for accurately informing people throughout a disaster as well as spurring the best immediate action to protect lives.

A key requirement of an EWS is that warnings reach intended recipients with sufficient time to react; this element is reliant on technology and dissemination systems working. In our case studies, 99% and 95% of the surveyed population in the Philippines and Dominica received an initial warning at least one day or more in advance of the typhoon and hurricane respectively, allowing sufficient time for evacuation. (We note such figures are from survivors and we do not have complete information regarding the deceased, in some instances we were able to hear anecdotally that those who stayed behind did receive a warning.) However, the EWS were not effective enough in prompting the desired safety-seeking action in most cases.

As effective EWS should be sensitive to the daily pressures, beliefs and expectations of at-risk populations, the media through which warnings are passed, and the meaning of the messages contained within warnings should be familiar and appropriate (National Research Council, 2013). EWS are often designed to seize attention and are repeated in order to consolidate messages and provoke action (National Research Council, 2013). Although our findings show that the technology behind the EWS worked in both case studies, with official warnings generally coming from ubiquitous and familiar sources (television and radio), Dominican radio network failures prior to Maria's arrival proved critical to lower awareness levels. Populations relying on this media source for late information updates were left largely uninformed of the new, heightened level of risk as Maria strengthened rapidly just prior to landfall. This was a major flaw, considering radio alone was by far the most frequently cited source of warning and information. Other sources of information that remained functional, such as internet coverage, assisted in filling information gaps, as respondents reported turning to online sources when radios ceased broadcasting. However, far fewer residents used this source. The need for redundancy in all elements of a warning system has long been acknowledged, and the radio network collapse in Dominica emphasised the need for providing viable back-ups (Gruntfest and Huber, 1989). This lends credence to the generally accepted principle that the more channels used for disseminating warnings, the greater the chance target populations will receive a message (National Research Council, 2013), as was demonstrated for the 2011 Great East Japan Earthquake and Tsunami (Naylor, Faure Walker and Suppasri, 2018). No single official warning system can meet the needs of society as a whole, as idiosyncratic social and personal considerations must be taken into account. Our findings showed that only around half of respondents (58% in the Philippines and 43% in Dominica) received two or more warning types, meaning there was still a relatively high reliance on one warning system.

In addition to the need of multiple warning types to ensure warnings are received, it has been suggested that the public is more likely to respond to warning messages if the they are delivered over multiple channels (Baron, Etzel and Sanderson, 1988). However, we did not find noteworthy differences in response action to multiple versus single source warnings in our case studies (Figure 5c).

As well as official systems, unofficial social networks play a central role in the diffusion of information, and research into relationships as determinants of collective behaviour has shown that strong social ties increase both a person's likelihood of hearing a warning message (Aguirre et al., 1991) and their likelihood of responding to it (Aguirre et al., 1998). Respondents in both our case studies confirmed that people routinely seek social verification of warnings from family, friends and neighbours. In Dominica, that extended to a reliance on family overseas in other Caribbean islands such as Anguilla and Guadeloupe, as well as those based in the US, for added information. These extra warnings provided updates that both appeared to complement the official Dominican warnings and provide vital additional information when people struggled to receive local updates closer to landfall. However, the process of “milling” (National Research Council, 2013), where information is corroborated among groups and views of communal risks and possible responses are discussed, can influence decisions to both evacuate or ignore warnings based on the shared judgement that they are or are not in excessive danger. Group perception building, dynamics and influences can therefore be very powerful. In the Philippines, one respondent wanted to evacuate before the typhoon, but as family members decided unanimously to remain at home, she remained with them. Social confirmation can also produce a time lag between when the warning is received and when safety-seeking action is taken, and so allowance in lead times should be given for such processes. The use of social media can help in expediting milling, if it is widely accessible, but can also rapidly spread false and dangerous information. In both the Philippines and Dominica, we found that although smart phones and internet access were ubiquitous, few people appeared to rely on online and social media-based sources for critical information and warning advice.

A successful EWS must be understood to trigger appropriate action, noting that appropriate action can include remaining at home. Many typhoon warning messages in the Philippines generated confusion when referring to an accompanying storm surge, and subsequent advice to people living close to water was to evacuate as a priority. However, 100% of the approximately 85% respondents asked about their understanding of the term “storm surge”, had not understood the term before Yolanda. If “tsunami” or “tidal wave” had been used, along with numerous equivalent local terms, most said they would have understood the risk and evacuated. This represents a catastrophic EWS failure; it was the storm surge, over the wind and torrential rainfall, that proved most deadly, damaging and destroying at least 90% of structures (note the majority of Tacloban’s populated area lies less than 5 metres above sea level, and there were no coastal defences to prevent inundation). Likewise in Dominica, although warnings were received, there was some confusion when referring to the geographical location of the island and the hurricane’s predicted path. Anecdotally, a number of respondents explained that hurricane warnings broadcast mixed and often unclear messages as to Maria’s expected path and landfall location. Dominicans correctly believe themselves to be part of the Windward Islands (southern islands in the Lesser Antilles, located to the east of the Caribbean Sea, see Figure 1) but some pre-Maria news reports suggested the hurricane would hit the Leeward

Islands, leading people to believe that they would remain largely unaffected. Consistency in messaging across all forms of official warning is key, and can be critical in keeping informal networks, which play a central role in risk perception and decision making, from deviating from the facts and advice issued by official sources.

Warning timings as well as accuracy are important for EWS credibility, especially in locations where lower-level hazards occur relatively frequently and more extreme hazards are rare but possible. While longer lead times have been found to increase the chances of people responding to a warning message (Hammer and Schmidlin, 2002), issuing warnings too early can mean that relatively high scientific uncertainty remains, and populations do not yet perceive the warning with enough urgency to act. Issued too late however, and a warning leaves little time to safely react (Glantz, 2003). A sweet spot where greater lead times can be achieved but still before the point where false alarm probability increases must be found (Rogers and Tsirkunov, 2010). Ahead of Maria, Dominica faced several challenges. First, warnings for Hurricane Irma two weeks prior, the first Category 5 hurricane of the 2017 Atlantic hurricane season and the first Category 5 hurricane to strike the Caribbean Leeward Islands on record, had left the population sceptical that Maria would pose as significant a risk as forecast because little or no effect from Irma was realised in Dominica. A number of interviewees reported feeling prepared for Irma's arrival (stockpiled goods, strengthened weaknesses in housing, considered evacuation) before landfall. In Maria's case however, even with lead times of up to a week, many underestimated the levels of preparation needed and a sense of cry wolf was felt. Second, Maria proved unpredictable in its later stages, rapidly intensifying shortly before landfall leaving many without time to protect themselves adequately. Coupled with communication infrastructure damage, warning transmissions of the newly intensified storm failed, just when they were most critically needed. Hurricane models performed poorly in anticipating Maria's rapid intensification (Pasch, Penny and Berg, 2018), and although warnings may be understood elementally, increased understanding of uncertainties and potential changes would help in making better informed and time-sensitive decisions.

Recipients of a *meaningful* warning system need information on which to base an evacuation decision. Instructions to evacuate were almost always received in the Philippines and in Dominica (95% and 92% of respondents respectively), although not all evacuation messages were the same. Some warning messages advised leaving only if homes were vulnerable by location, building material and building strength, and therefore required people to exercise subjective judgement over levels of personal risk. Only 22% and 18% of respondents left their homes before Yolanda and Maria, the majority choosing to either remain at home throughout the storm or to evacuate during or after the storm when their homes had been damaged or destroyed and they needed shelter. These examples demonstrate that informed decisions can only be made if both sufficient information is shared and a sufficient level of risk understanding among respondents exists prior to warning.

EWS recipients also need to know where to evacuate to, and designated shelters must be perceived as accessible with tolerable conditions. Following the Great East Japan Earthquake and Tsunami, some residents cited a lack of awareness of evacuation shelter locations as causing delay to their evacuation (Naylor, Faure Walker and Suppasri, 2018). Preceding Yolanda, we found that mixed messages were broadcast depending on location, with some populations being urged to evacuate to higher ground or stronger buildings, not to an evacuation centre. While the majority of warning messages did instruct people to evacuate to emergency shelters, concerns that they were overcrowded, unsafe and subject to damage, prevented many from seeking this option. One respondent evacuated pre-storm but immediately returned home as the shelter was overcrowded and chaotic. A number of shelters were severely damaged, including the Tacloban City Convention Centre (locally known as the Astrodome), which served as the city's primary evacuation centre but suffered severe damage itself, trapping and killing over 300 people (GMA News, 2013). In the Philippines, many residents could not rebuild their homes for up to and beyond a year, with some still living in temporary housing three years later. Shelter dwelling was not feasible or even possible for such an extended length of time beyond the emergency phase. In Dominica, 93% of respondents were warned to leave their homes but again, not all evacuation messages were the same. The majority of warnings advised relocation to evacuation centres, however the notion of dedicated storm shelters appeared less prominent here. Anecdotally, respondents explained that many of the shelters routinely used were not set up to support enough people safely and adequately, especially for extended periods of time. Privacy and protection, particularly for women and children, were named issues, and for when larger, more destructive events occur that mean greater numbers of people would use them for longer. Respondents advocated for the development of shelters to enable the pre-positioning of essential supplies such as food, water, tarpaulins and hygiene products that would encourage shelter use correctly.

The level of response that makes a warning message successful varies. So, what comprises an *appropriate* response? This changes depending on the extremity of the hazard and its anticipated impacts. Is awareness of an approaching hazard and knowledge of its potential impacts far enough in advance sufficient for an EWS to have fulfilled its purpose? Or must an EWS prompt specific behaviour change, such as supply preparation or evacuation? When human, infrastructural or financial resources are limited, it can become necessary to decide what traits of EWS are desirable versus what are essential (Glantz, 2003). When hazards range in intensity and when populations are accustomed to more frequent, milder events with minor, if any cascading or secondary hazards, we see from the Philippines and Dominica that warnings must change in order to both accurately inform and prompt appropriate safety-seeking behaviour. Experience may dictate that evacuation is not necessary on most occasions, and so triggering behaviour that may be very different to the customary response, and on fewer occasions when hazards are more severe, presents a technical, social and operational challenge. Perceptions of reality may not align with actual reality (Glantz, 2003), and if inaccurate perceptions are the basis for decision and action, as we have seen among respondents in the Philippines and the Caribbean, vulnerability can be heightened.

Less attention has been paid to the human response to warnings, regarding risk and subsequent decision-making (Thomalla et al., 2009). Previous case studies have shown that if a person fears their home being looted, they are less likely to respond to a warning (Aguirre, 1991). In the Philippines, the fear of burglary, loss of possessions and depletion of assets was frequently reported as the principal reason for at least a male member of the household choosing to remain at home. Populations residing in low-quality housing may be more likely to comply with warning messages (Aguirre, 1991), however EWS must grapple with complexities brought about by those living on or below poverty lines, like our cohort of respondents. If no other option exists than to build on ineligible land in dangerous locations, vulnerability will persist in the face of even the most inclusive of EWS. Furthermore, if sources of livelihoods are attached to the home, such as livestock and small businesses as we witnessed in this study, protection of those must be considered if people are going to be expected to leave them behind.

Warnings must also take into account varying perspectives on what comprises a cause of risk (Powell and Jiggins, 2003), and that those outside and inside of any given risk situation may measure and determine risk in very different ways (Twigg, 2003; Salter, 1996). Our respondents were required to make an assessment, quickly, in the face of their daily pressures, and to weigh up the cost-benefit conundrum of leaving their most valuable possessions and future insurances (e.g. shop stock and farm animals) to be almost certainly lost. Moreover, responses to warnings in potentially hazardous situations are not always rational (Buchanan-Smith and Davies, 1995; Thomalla and Schmuck, 2004), and therefore implementing EWS cannot always follow logical processes (Hamza, 2006).

Overall, the EWS in our two case studies failed to prompt the desired safety seeking behaviour due to a number of both "foreground" and "background" components (Figure 6) at several stages (Table 2) within the systems that were simply insufficient.

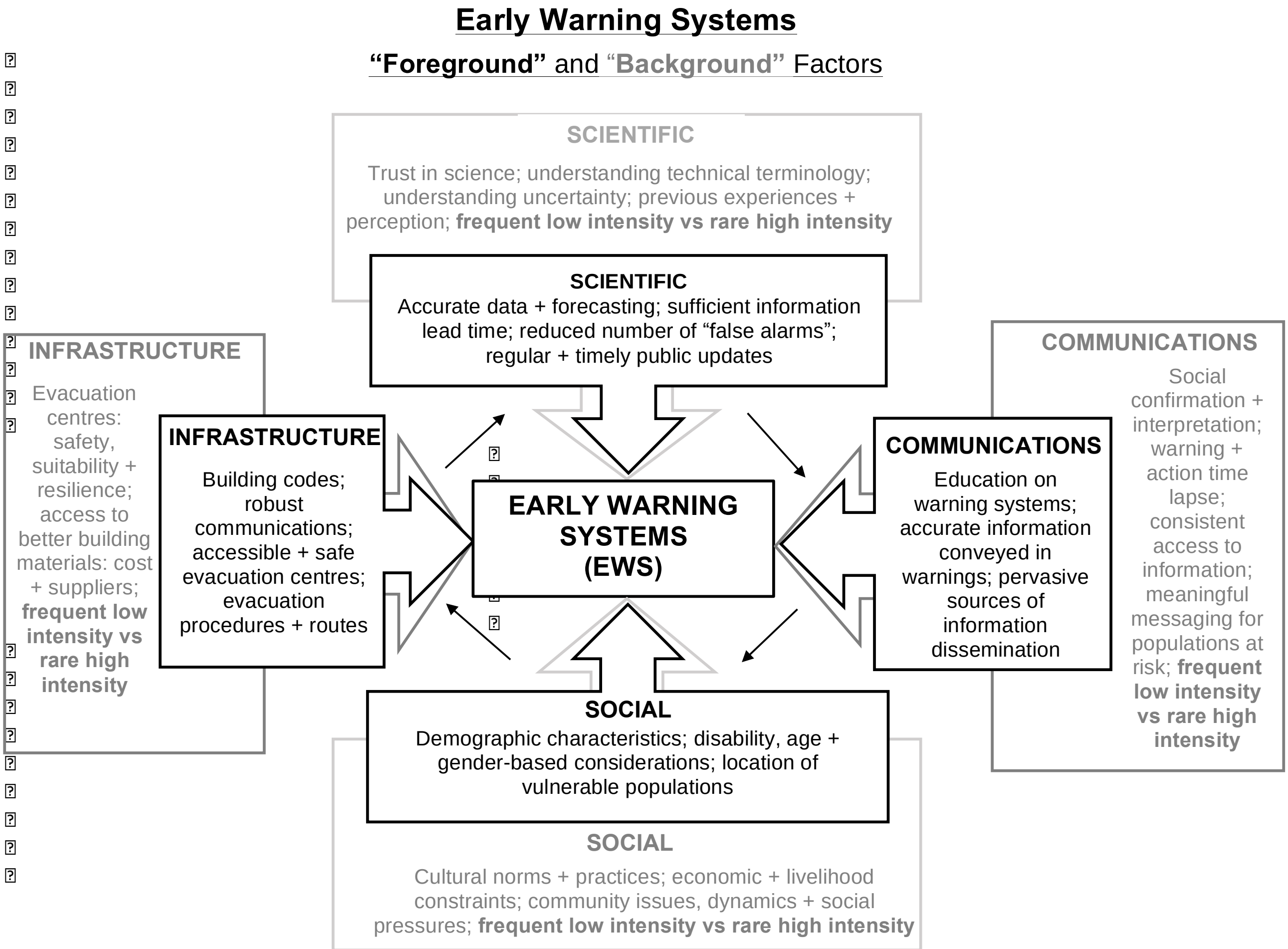

Figure 6: The four overarching components of an effective EWS. The inner components in black state the "foreground", outwardly recognised elements of each. The grey components highlight the "background", less outwardly appreciated factors and influences in each.

Table 2: "Foreground" and "Background" components of EWS that, in the case of Yolanda and Maria, have been identified as points of weakness.

EWS COMPONENT(S) CATEGORY	"FOREGROUND" POINT OF FAILURE	"BACKGROUND" POINT OF FAILURE
COMMUNICATIONS SOCIAL	*People seek social confirmation of warnings before taking protective action.*	*In the Philippines people often gathered at the houses of neighbours, when deemed stronger and safer (made from materials such as concrete), based on collective decision making. Occasionally respondents reported staying at home if their families decided not to evacuate, despite wanting to evacuate themselves.*

SCIENTIFIC COMMUNICATIONS	*Messages should contain information that is important to the population.*	*In the Philippines people did not receive comprehendible information regarding the storm surge. As an unfamiliar term to the receiving population, this led to people underestimating risk and heightening vulnerability.* *Very low-income people in the Philippines were often living in the worst housing in the most dangerous locations. Warning messages must account for the distinct needs and considerations of such populations, considering their often heightened vulnerability due to housing location, materials, disinclination to abandon property and assets and potentially reduced capability to rebuild, recover and adequately protect against further shocks.* *In Dominica people did not get accurate enough information in the crucial moments before the storm hit. Hurricane Maria escalated to Category 5 strength very rapidly and very late. Conflicting information was given shortly before landfall and then communications infrastructure failed, leaving large numbers without updated information on the hurricane's path and higher intensity.* *In Dominica people did not fully appreciate the dangers of living close to rivers and ravines; many of these swelled, burst their banks and flowed rapidly through the inland settlements. Many houses on the banks of these ravines were completely washed away and fatalities occurred. Warnings did not consistently highlight the heightened risk for those living close to water. Those who did receive this warning often did not take it seriously enough to evacuate.*
SOCIAL	*Responders should consider the demographics of affected populations when preparing warning messages, including social pressures, constraints within communities and cultural factors influencing behaviour*	*In the Philippines, many men remained at home to both protect the home from looting and to continue looking after livestock they did not wish to leave unattended.*

SOCIAL INFRASTRUCTURE	*Access for those with disabilities must be considered when developing warning systems.*	*In the Philippines, some respondents reported not going to or remaining at evacuation centres due to feeling unsafe, overcrowding, unsuitability, access issues or damage to the shelter buildings (post disaster).*
SCIENTIFIC COMMUNICATIONS SOCIAL INFRASTRUCTURE	*Alerting and warning is a process, not a single act*	*People often had not experienced an extreme event in their lifetime. Expectations and responses to warnings of the impending storm were based on knowledge and experience of lower grade strength storms and impacts.*

Conclusions

We found that Early Warning Systems following recent large events in the Philippines and Dominica exposed a significant weakness: although the warnings were almost unanimously received by respondents, the severity of the events were not fully understood and therefore appropriate preparatory, safety-seeking actions were not widely taken. In the Philippines, many residents did not understand the term “storm surge”, while in Dominica the rapid upgrade to a hurricane of Category 5 strength created confusing messaging and gaps in effective communications. We argue that experiencing more regular, lower intensity storms has in many ways made populations more vulnerable to the rarer, higher-intensity storms in these case studies.

We consider the following elements to be critical to an effective EWS, so that sufficient protective action can be taken before an event:

1. Before an early warning, residents must recognise potential hazards and risks faced so that warnings can be placed in context and acted upon appropriately. This includes understanding uncertainties in warnings, heightened risk in extreme cases, and all terminology used in EWS communications.
2. Warnings messages and hazard ramifications must be comprehensively through personalisation, or the EWS will not trigger enough of the required action.
3. The social circumstances and physical abilities of residents must be better observed when considering shelter reach and inclusivity e.g. socio-economic status, family dynamics, livelihoods, shelter safety/appropriateness.
4. Warnings must be varied enough to compel safer choices ahead of extreme events, particularly in locations subject to more regular, smaller-scale hazards. These must be accompanied by wider support efforts to improve infrastructure and emergency response preparation, particularly in housing, transport, personal finance and communications.

The solution is not an overarching, one-size-fits-all-hazards, approach to EWS. Consideration of varying strata of societies must be made to account for inherent vulnerabilities and entrenched social, economic and institutional inequality, as well as disparities in lifestyles and needs. One example being that multiple sources of warning are required in order to reach everyone, as demonstrated when even the most common sources did not reach all respondents (television 81% for Yolanda, radio 86% for Maria). Advancing science and increasing technical capabilities augmenting EWS must offer information that is personal, meaningful and comprehendible through robust communications networks on which people can rely consistently throughout a disaster. There is an evident need to account for varying experiences of hazards, and to distinguish between warnings transmitted for more frequent, lower-intensity events and those occurring less frequently but with higher-intensity, greater risk and more disastrous impacts.

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