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Perceptions of risk to compound coastal water events: A case study in eastern North Carolina, USA

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ABSTRACT

It is recognized that compound coastal water events (CCWE) - the combination of rain, river, and ocean flooding - often have increased disastrous consequences as compared to single-form floods due to their physical complexity. However, another potential reason is the lack of adequate understanding and effective response by hazard professionals. In rural eastern North Carolina (ENC), an under-resourced and CCWE-vulnerable region of the US, we survey and interview a focus group of primarily emergency managers and planners about their understanding of CCWE risk and the perceived obstacles in communicating this risk to their constituents. Likely due to recent hurricanes, hazard professionals in ENC are anecdotally aware of the sources and timing of floods in their communities, and the eleven counties represented in the study are quick to share data and experiences with each other. However, they see pluvial flooding outside of hurricanes as a growing problem and disclosed that risk communication to the public is a challenge because of a lack of tools and data to adequately describe CCWE. Finally, our case study participants felt they had a better understanding of CCWE than their state and federal counterparts and wanted to be more involved in response and recovery decision-making.

1. Introduction

Commonly, floods are caused by rainfall, "pluvial", rivers spilling over their banks into the floodplain, "fluvial", and the rise of water bodies onto land due to low atmospheric pressure, winds, and astronomical tides, "coastal". These flood types can happen in isolation or in some combination, often in a storm environment. When floods are attributed to more than one water hazard, they are considered compounded, and recent studies have found that compounded floods are likely to increase on a global scale mostly due to sea level rise and more frequent extreme precipitation [2,8,25].

Eastern North Carolina (ENC) has the geographic and socio-economic necessities for heightened vulnerability to compound flood disasters now and in the future. River systems meander in this region across a flat coastal plain and empty into the second largest estuarine system in the US. De Polt [7] uses the term compound coastal water events (CCWE) and provides quantitative evidence for their prevalence in ENC by demonstrating high interdependence among annual extreme daily precipitation and accompanying river discharge and maximum tide over three coastal watersheds. ENC also contains the barrier islands of the Outer Banks, where tropical cyclone landfall probability is a maximum along the US East Coast. Matthew (2016) and Florence (2018) are two recent landfalling tropical cyclones in ENC that can be considered CCWE [4]. In addition, ENC is primarily rural with a natural resource dependent economy [12]. Among the 11 counties represented in the study, except for Pitt which has a population density of 261 persons per square mile, none of the other counties rise to more than 100 persons per square mile (Table 1). Seven counties are around 50 persons per square mile or less, indicating a vast, mainly rural, and sparsely populated region. Except for Dare, the median household incomes of all the counties are significantly below that of the national median household income of $67,521. The North Carolina Department of Commerce ranks the state's 100 counties into three tiers based on economic well-being, with Tier 1 being the most distressed and Tier 3 as the least

Abbreviations: CCWE, Compound Coastal Water Event.

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distressed. Six participant counties are ranked as Tier 1, and the other five are ranked Tier 2. None of the participant counties fall under Tier 3. The ENC region is thus economically challenged. In terms of housing, Pitt has the highest number of housing units at 80515 units followed by Dare at 34237 units. However, Dare has an occupancy rate of around 46%, much lower than the other counties, indicating a seasonal and transient population. Except for Edgecombe, Martin, and Pitt, all counties are designated as coastal counties, subject to the rules and policies of the Coastal Resources Commission and under the Coastal Area Management Act (CAMA). Nevertheless, individual county exposures differ. Dare is on the Outer Banks (Fig. 1), whereas Bertie, Chowan, Gates, Perquimmans, Washington, and Tyrell are exposed to the Albermarle Sound (Fig. 1). Beaufort is exposed to the Pamlico Sound (Fig. 1). Edgecombe, Martin, and Pitt are located adjacent to the CAMA counties.

While coastal compound flood risk has been assessed in many regions such as Europe [1], the US [17], Taiwan [9], and Mozambique [26], there remains a gap between this scientific understanding and how it is employed by emergency managers and incorporated into hazard planning [3]. Kruczkiewicz et al. [14] state that "multiform flood events remain particularly neglected within the disaster management, humanitarian, and financial sector contexts".

We hypothesize five potential reasons. First, multiform floods are complex and nonlinear resulting in additional uncertainty compared to floods from a single and easily identifiable source. Thus, emergency practitioners may be reluctant to enter into this paradigm, or if they do, could be faced with information overload and potential inaction [20]. Second, there does not exist an off-the-shelf planning or hazard response tool that adequately communicates compound flood risk (or uncertainty), as current tools focus on a single flood driver such as floodplain or storm surge maps. Raška et al. [22] examined 693 urban hazard vulnerability assessment studies that included cartographic representation, and less than 5% were multi-hazard. Rural studies were too few for a robust review. Third, because of this lack of information in planning and preparedness documents, emergency managers and planners may have insufficient awareness of the overlaps and consequences of CCWE [3]. Fourth, this leads to inadequate communication with the public in understanding what's at stake with compound flooding. Finally, there is often a perceived deficiency in communication across levels of decision making, as compound flood hazards demand a different approach to resilience. Kruczkiewicz [13] cites lack of adequate communication as a primary obstacle in anticipating and responding to compound flood events: "risk assessments must better capture the roles of decision-making dynamics at multiple levels of government and how these dynamics also influence risk reduction and crisis management strategies".

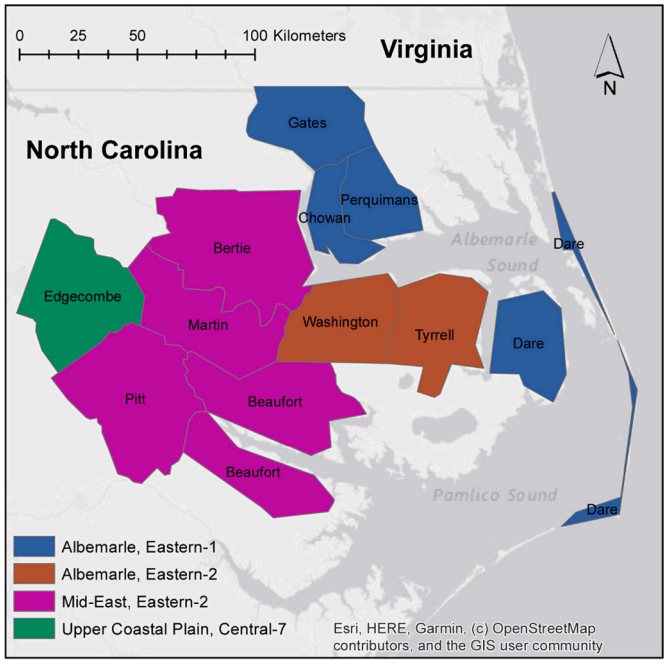

Fig. 1. Counties represented in the 2020 focus group. Color coding gives the combination of Council of Government (Albemarle, Mid-East, or Upper Coastal Plain) and Emergency Management division (Eastern-1, Eastern-2, or Central-7).
(Source: Map created by Scott Curtis using ArcGIS 10.6.1 and ArcGIS online.)

With this background, the current study examines perceptions held by emergency managers and planners in ENC regarding CCWE hazards. We effectively address diagnostic questions 7 and 8 in Bodin et al.'s [3] model to "identify potential weak spots in [compound] emergency response systems": What is the level of awareness among actors concerning the nature, probability and response to compound events?; What is the level of functional fit of the response systems and are organizations and roles properly coordinated? Another motivating factor is that emergency management strategies in rural environments are understudied compared to urban centers, even though rural populations are often socially and economically more vulnerable. At the same time,

Table 1
County economic and demographic data (Source: United States Census - 2020 Decennial Census & American Community Survey, North Carolina Department of Commerce, and North Carolina Department of Environmental Quality).

County	Land Area (sq mi)	Pop Density (Persons Per Sq Mi)	Population 2020	Median Household Income (USD)	Housing Units 2020	Occupied Housing Units (%)	Distress Ranking (NC Tier)	CAMA County
Beaufort	832.74	53.6	44,652	48,051	24,090	80.66	2	Yes
Bertie	699.18	25.7	17,934	35,042	8936	81.29	1	Yes
Chowan	172.66	79.4	13,708	44,050	7131	82.51	1	Yes
Dare	383.23	96.3	36,915	65,420	34,237	46.63	2	Yes
Edgecombe	505.44	96.7	48,900	40,489	23,059	86.60	1	No
Gates	340.61	30.8	10,478	45,871	4767	89.03	2	Yes
Martin	456.41	48.3	22,031	39,909	11,080	86.23	1	No
Perquimans	247.17	52.6	13,005	51,036	6866	81.07	2	Yes
Pitt	652.37	261.0	170,243	49,337	80,515	86.96	2	No
Tyrrell	390.78	8.3	3245	38,250	1999	72.24	1	Yes
Washington	346.51	31.8	11,003	30,941	6039	80.66	1	Yes
North Carolina	**48,623.02**	**214.7**	**10,439,388**	**56,642**	**4,708,710**	**88.33**		

Note: The North Carolina Department of Commerce ranks the state's 100 counties into three tiers based on economic well-being. The most distressed counties are Tier 1 (40), the next as Tier 2 (40), and the least distressed as Tier 3 (20).
CAMA counties are those designated as a coastal county and are subject to the rules and policies of the Coastal Resources Commission which administers the Coastal Area Management Act (CAMA).

rural governments lack the manpower and resources for adequate responses to CCWE, especially as these events are often more spatially extensive and longer lasting than single-form floods.

Data for the study was collected through a focus group workshop held in early 2020 [5], described in section 2. The results of this paper, section 3, focus on the perception of flood risk and obstacles to communication and regional cooperation in ENC. A discussion and conclusion are given in section 4.

2. Materials and methods

Data was collected from a full day focus group workshop conducted in February 2020 at the East Carolina University campus in Greenville, North Carolina. The workshop took place 2-weeks before the COVID-19 shutdown came into effect across the state of North Carolina. As a result, the COVID-19 pandemic did not impact data collection. Workshop participants included emergency managers, planners, elected officials, and other public officials (e.g., county manager, public services director, floodplain manager) from the ENC region. In all, 41 participants represented jurisdictions under three Regional Planning Councils (Mid-East Commission, Albemarle Commission, and Upper Coastal Plain) and three divisions of Emergency Management (Eastern-1, Eastern-2, and Central-7). This leads to four jurisdictional clusters in our study area (Fig. 1) with the potential for disparate operational priorities and communication gaps. Participants were divided into fourteen groups: seven in the morning session divided by geography and seven in the afternoon divided by profession. A breakdown of the participants is provided in Table 2.

Focus group tables generally consisted of 6–7 participants, a facilitator and a recorder. The facilitator asked a pre-determined set of questions of each group, and recorders took handwritten notes to document key points. All sessions were audio recorded, and the recordings were transcribed into text documents with most transcriptions covering 20 plus pages of discussion. The text documents were then uploaded into NVivo, a qualitative analysis software, for coding.

Two cycles of qualitative coding were completed. Descriptive coding technique was used for the first cycle of coding in NVivo. Descriptive coding "summarizes in a word or short phrase the basic topic of a passage" ([23], p.70). More than 100 codes were derived inductively through an iterative process during this first cycle of qualitative analysis. Of these, 11 codes were related to CCWE risks and 22 were related to the local response. The second cycle coding used a pattern coding technique and was completed in MS Word. The process of identifying themes from codes (based on the first cycle descriptive coding), also known as thematic analysis, "is a method for identifying, analyzing, organizing, describing, and reporting themes found within a data set" [19]. The themes that emerged during the second cycle pattern coding are the key study findings.

Prior to the workshop an anonymous survey was administered to all registered participants. The survey, which included multiple choice and open-ended questions, was meant to generate a baseline understanding of the perception of current and future risks from floods in ENC and their economic and health impacts. Initial definitions were given to distinguish flood type as either *rain-caused*: storm water, flash flooding, ponding, and pluvial; *ocean-caused*: high tide flooding, king tide, storm surge, coastal; or *river-caused*: floodplain flooding, overtopping banks, fluvial. The eighteen questions and response choices used in this study are outlined in Fig. 2. A final.

question on flood response and recovery was also included in the analysis: "Select ALL the resources you typically use during a flood event in regards to response and recovery in your community/county/region". Choices were: personal experience, technical expertise within your local office, direct communications with others outside your local office, flood histories, operating manuals or other static materials, websites or software, field-based tools, and other. Twenty four (59%) of the 41 participants completed the anonymous survey, so there may be some discrepancy between the survey responses and the outcomes of the focus group discussion.

The study findings from the 2020 focus group interviews were presented to the ENC community during a second focus group workshop conducted in February 2022. Sharing the research results with our study participants was in line with our objective to co-produce knowledge and enable transparency in the research process. Feedback from the participants was overwhelmingly in agreement with our findings, thus strengthening its validity and rigor.

Table 2
Breakdown of focus group participants according to profession and gender.

	Planner	Emergency Management	Elected Official	Other Official	Private Entity
Female	6	2	4	4	–
Male	7	8	–	7	3
Total	13	10	4	11	3

3. Results

3.1. Perceptions of compound flood risks in ENC

For the study area, every source of flooding was thought to be very frequent or constant and very damaging for at least some of the participants (Table 3). Surprise was the lowest concern from the pre-workshop survey, which likely arises from their own personal experiences with flooding (explored further in the next sub-section). For example, one focus group participant noted:

We flood in stages. It's gonna flood in the ditches, and then its gonna flood in the creeks, and then its gonna flood in the swamps, and then its gonna flood in the river finally. So, you can predict, for what you can predict, that it's not gonna flood the roads today, but tomorrow the roads are gonna flood.

However, there was a fairly large difference in the situational awareness of the flood types. Interestingly, pluvial flooding was seen as much more unexpected compared to coastal flooding, with fluvial flooding in between (Table 3). One reason for this finding may be that individually storm surge and riverine flooding are fairly well predicted at large lead times and these floods cover large areas, whereas intense precipitation occurs on much smaller time and space scales making it difficult to predict. In the focus groups, one participant praised the local National Weather Service office's ability to provide river forecasts:

Weather Service does an outstanding job; it's gotten better and better every year…We have such a great working relationship with the National Weather Service out of Newport. We can pick up the phone, we are on first-name basis with them…they can put us with their river forecast folks, and we get excellent information, just from a phone call. And they'll push stuff out to us as we need it or as we ask for it. So yeah, we've come to rely on that river forecast quite a bit.

Focus group participants agreed with the survey results that rain related flood events were the most surprising. In particular, concentrated areas of precipitation outside of established flood zones catches them off-guard. According to multiple participants, "the only surprise ones we see are related to that rain flooding" and "when we get a heavier than expected rainfall." One person explained further:

We had a major rain, what, three weeks ago, and our towns were flooded. Water was coming over our roads, and it was unexpected because it was supposed to be just a regular rainstorm coming through and it flooded. We can't handle those three-to-four inches within an hour-and-a-half because we're so flat and so low… it [the water] has nowhere to go.

Fluvial flooding was seen as most damaging, with 14 survey respondents indicating it was very or extremely damaging. This is not surprising considering several of the counties are inland and this area was devastated by fluvial flooding produced by Hurricanes Floyd (1999) and more recently Matthew (2016). The combination of the frequent rain events (average score of 3.375) and damaging riverine events

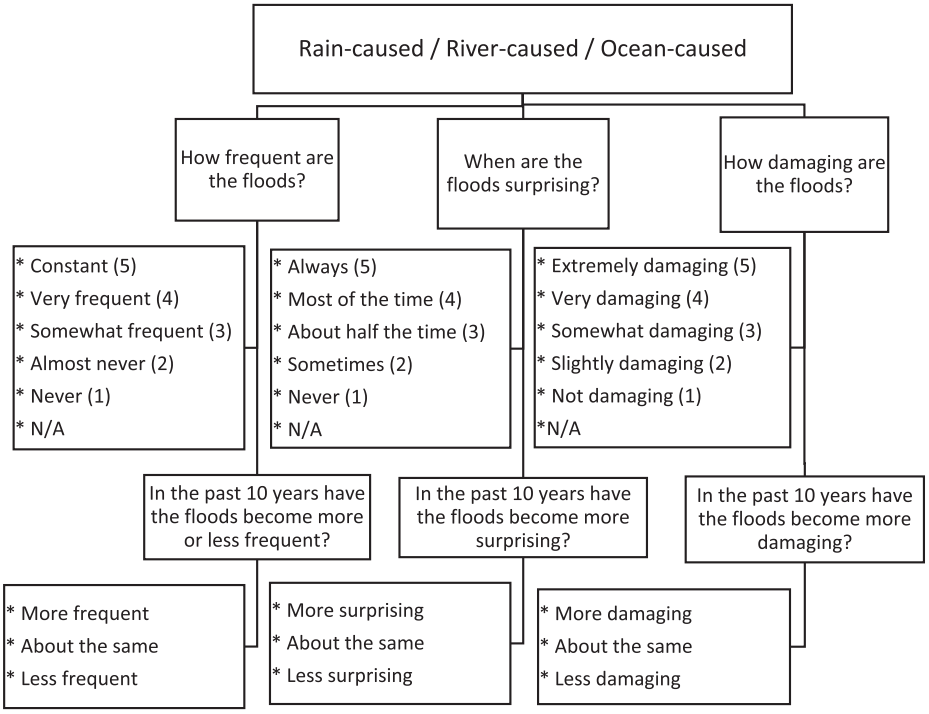

Fig. 2. Flow chart of survey questions related to perception of rain-caused, river-caused, and ocean-caused flood frequency, surprise, and damage and how they've been changing over time.

Table 3
Data on perception of flood frequency, surprise, and damage by flood type from the 200 pre-focus group survey. Numbers 1–5 correspond from low to high perceived risk (see Fig. 2), and N/A is not applicable. Counts and percentages of responses are given (N/A is excluded in percentages). Avg is the weighted average response score.

Flood Characteristic	Flood Type	5	4	3	2	1	N/A	Avg
Frequency	RAIN	1 (4.2%)	8 (33.3%)	14 (58.3%)	1 (4.2%)	0 (0.0%)	0	3.375
	RIVER	1 (4.8%)	3 (14.3%)	14 (66.7%)	2 (9.5%)	1 (4.8%)	3	3.048
	OCEAN	1 (6.7%)	2 (13.3%)	8 (53.3%)	1 (6.7%)	3 (20.0%)	9	2.800
Surprise	RAIN	1 (4.2%)	6 (25.0%)	4 (16.7%)	13 (54.2%)	0 (0.0%)	0	2.792
	RIVER	0 (0.0%)	2 (9.5%)	0 (0.0%)	14 (66.7%)	5 (23.8%)	3	1.952
	OCEAN	0 (0.0%)	0 (0.0%)	2 (14.3%)	4 (28.6%)	8 (57.1%)	10	1.571
Damage	RAIN	0 (0.0%)	6 (25.0%)	11 (45.8%)	6 (25.0%)	1 (4.2%)	0	2.917
	RIVER	5 (25.0%)	9 (45.0%)	2 (10.0%)	1 (5.0%)	3 (15.0%)	4	3.600
	OCEAN	2 (15.4%)	5 (38.5%)	4 (30.8%)	1 (7.7%)	1 (7.7%)	9	3.462

(average score of 3.600) was considered the most impactful flooding by the focus group participants. One person put it simply, "it's [the] rain and river." Another elaborated:

I think more damaging from the aspect that they occur more, so it's causing damage more frequently, not necessarily causing more damage in one particular event. But because it's compounding each time it happens, I think it's definitely more damaging from that perspective.

The 2020 pre-focus group survey also asked about perceived changes in the risk of flooding over the past 10 years (Table 4). At least 30% of respondents believed that all flood types are becoming more frequent and severe. The focus group discussion was consistent with this result, with a recurring theme that flood hazards are mostly growing in frequency and severity. As one person noted:

I think the intensity and the occurrence have both increased over the last twenty years. Used to, we dealt with flooding during a hurricane event most of the time and now you're getting a lot of localized flooding from a six-inch rain in the middle of the summer, which used to [be] unheard of.

Interestingly, more participants believed pluvial flooding was becoming more frequent, surprising, and damaging than fluvial or coastal flooding, and no one thought rainfall flooding was becoming less frequent or damaging (Table 4). According to the focus group participants, flooding happens even after moderate rain events when soils are saturated from localized rainfall, thunderstorm bursts, or tremendous excessive rainfall in a specific area. Stormwater drainage problems, due to flat topography that does not drain, presence of swamps, low elevation, higher water table, location with respect to the sound, sinking soil, and high winds also contribute to flood inundation.

Participants agreed that the risk of flooding was high to very high, that the flood events were coming one on top of another, and the nature of the risk was changing. One participant explained that "in seventeen years, we've had four one-hundred [and] five-hundred year floods" and that "people can't afford to fix their houses because, hey here comes

Table 4
Data on perception of trends in flood frequency, surprise, and damage by flood type (see Fig. 2). Counts and percentages are given.

Flood Trend (10 years)	Flood Type	More	About the Same	Less
Frequent	RAIN	19 (79.2%)	5 (20.8%)	0 (0.0%)
	RIVER	11 (55.0%)	8 (40.0%)	1 (5.0%)
	OCEAN	7 (58.3%)	4 (33.3%)	1 (8.3%)
Surprising	RAIN	6 (26.1%)	9 (39.1%)	8 (34.8%)
	RIVER	2 (10.5%)	10 (52.6%)	7 (36.8%)
	OCEAN	0 (0.0%)	10 (83.3%)	2 (16.7%)
Damaging	RAIN	12 (50.0%)	12 (50.0%)	0 (0.0%)
	RIVER	8 (40.0%)	9 (45.0%)	3 (15.0%)
	OCEAN	4 (30.8%)	8 (61.5%)	1 (7.7%)

September about to bring another one for us." Another participant added, "I have seen over time…that the risk is starting to change, that it's not just what's in that mapped floodplain. We are running into a lot of.

localized flooding from a lot of outdated infrastructure and continual development." Participants added that storms were occurring outside of hurricane events and that there was an increase in heavy rainfall that was leading to localized floods and flooding in stages due to "a combination of a lot of things that we have either overlooked, chose to ignore, and didn't understand."

The survey did not ask about the compounding nature of the three flood types, but that was drawn out in the focus group discussion. Participants relayed that during hurricanes, riverine flooding can happen for an extended period and cause more damage as the wind pushes the water up the river, which when combined with rain and storm surge can cut off access to critical facilities such as shelters and hospitals. A participant explained, "when we see coastal flooding, the water's coming in and going out…when the wind shifts during the storm. When we see riverine flooding, like in Greenville, it sat for weeks." Such a situation is exacerbated when there are stormwater issues and changes in drainage patterns resulting in flood waters that cannot be pumped out. The river flooding then "causes canal flooding, which causes agricultural flooding, which causes impoundment flooding." A participant told us that "coastal issues come in those points where you have the riverine flooding and the storm surge coming and converging" and that "it is all coming from either the sound, or it's localized flooding in these lower areas that'll flood during heavy rainstorms, and we have no outlet for that water."

However, CCWEs are not restricted to hurricanes alone. One participant noted, "the storm we had three weeks ago was worse than the hurricane last October." Another participant said:

Over nine inches of rain, we know we're gonna have problems…once the rain falls, they have issues with it getting to the river, and once it gets to the river then the river swells. And then if we're in the middle of a hurricane and we've got coastal surge going on, then our river can't flush out. So, all three of them really tie into what the issues are for everybody in the county.

In summary, heavy rainfall is perceived as the primary cause of floods in ENC. Ocean flooding is also a concern albeit mainly at the coast where wind driven tides flood the Albemarle and Pamlico Sounds (see Fig. 1). The compounding impacts of CCWEs, especially a combination of fluvial and pluvial driven events that increase and magnify damages to property and infrastructure, can be difficult to evaluate separately. Our findings indicate that ENC communities prepare for and respond to the cumulative impacts of CCWEs in two main ways – through an emphasis on communication and by relying on a high degree of regional cooperation. At the same time, ENC communities face several barriers in both these areas.

3.2. Challenges to communication and cooperation

Here we examine challenges related to 1) assessing CCWE risk, 2) communicating that risk to the public, and 3) working across jurisdictional boundaries.

In terms of the resources that participants access during a flood event, the vast majority rely on personal experience, technical expertise within the office and direct communications outside the office (Table 5). Focus group participants said that professional networks, crowdsourcing to map flood extent, vulnerable population registry, the National Weather Service (NWS), data from the rain gauges of local farmers and the forest service, were the main sources of hazard information.

for ENC. Interestingly, less than half of those surveyed rely on web sites and field-based tools. Several respondents mentioned accessing online weather information, but the most popular website is NC FIMAN (Flood Inundation Mapping Network, flood.nc.gov). FIMAN provides real-time data on stream elevation, rainfall, and weather parameters from over 550 gauges across North Carolina. FIMAN also models and maps inundation around gauges in flood stage. This is likely an advantage over flood histories or static flood maps, which often do not adequately represent CCWEs.

Several focus group participants did not favor static flood maps because areas outside designated zones are increasingly flooding and that the "line on the map doesn't really mean much…[as] outside that line you could still get flooded just as easily as inside that line." A participant from the Outer Banks area expressed frustration:

The new FEMA flood maps, which for the Outer Banks, the models they use to create those maps are – by their own admission – absurd. They are pulling out 80% of the properties in Duck, 79% to be technical – that are in an "A" flood zone, are being pulled out of it and put in an "X" zone with no elevation or pilings or anything. It just doesn't make a lick of sense.

One participant noted that despite the resources available, there is a lack of useful information at the local scale, partly because there is not the manpower to collect and track data during an emergency.

There's a huge lack in data. So much of what we go through on the response side, it's hard to justify on the planning side because we don't have trackable data. It doesn't exist. In those response situations, there's no one there that has the time or knowledge to be able to track that.

Participants emphasized that it was critical to send out accurate information to the wider public as information overload or incorrect information can lead to a loss of trust. One obstacle to communication is "competing forecasts" from news channels that are "there for ratings" and "are trying to sell a storm" while the local staff "are trying to prepare for a storm." Multiple participants stressed that information must be tailored to a community's needs, or they risked losing credibility within the community.

Emergency management staff put in considerable effort to maintain relationships within and beyond their community. They see the need to have a relationship with the media and with community ambassadors, religious faith-based communities, reverends, and pastors as key to effective communication with their community. As one participant noted:

Table 5
Counts and percentages (n = 24) of answers to the pre-focus group survey question: "Select ALL the resources you typically use during a flood event in regards to response and recovery in your community/county/region". Multiple answers were allowed.

Personal experience	21 (87.5%)
Technical expertise within your local office	21 (87.5%)
Direct communications with those outside	20 (83.3%)
Flood histories	14 (58.3%)
Operating manuals / static materials	14 (58.3%)
Web-sites	11 (45.8%)
Field-based tools	6 (25.0%)
Other	4 (16.6%)

Talking about…relationships – your community ambassadors. Our religious faith-based community, in Bertie County there's 220-some churches there. If you can nail down and get those reverends and pastors in there, and tell them what you want [the community] to hear, and get their buy-in, you've won the battle.

Social media is a key aspect of communicating with the community but has its drawbacks as the elderly population is not accustomed to using the technology. The most common communication methods used are through cell phone alerts, public meetings, website updates, social media such as Facebook and Twitter, TV and radio stations, newspaper notices, alert notification system with voluntary sign-up, reverse 911, Hyper Reach system, orange dot signs on highways, targeting the younger generation to reach out to older family members, mobilizing county fire departments to get information out to households, and sending out emergency vehicles (e.g., police) when there is no internet or other capabilities. Participants elaborated on some strategies they use:

*[We have an] aging and lower-educated community. So, they don't have the tools, the resources, or the knowledge to sign up for these things [*e.g.*, opt into reverse 911]. We did a vulnerable population registry starting last year, and we targeted it towards the younger generation to sign their older family members up with it. We didn't even target the older, because most of them, while they may have a smartphone, they can look at Facebook, and that's about the extent of what they know they can do.*

Communities lack the education to understand information and often harbor misconceptions about actuarial terms. Not surprisingly, there is a reluctance to evacuate during flood events. A participant told us that "it's a whole culture. It's a whole mindset. I am not leaving here honey. And you can get over yourself," which combines with complacency, "been there, done that. I've seen it, I ain't worried about it." Local governments also face challenges trying to educate a fluctuating population as "they move in…[and] out. They don't all know when they move in that they moved into a place that is not designated as a special flood hazard area, but it has had flooding in the past." Another participant responded:

It's also education. I don't think we've done a real good job in a lot of respects of that…That component is sort of missing. Education, a lot of times, it can prevent something, or at least minimize events if somebody is educated enough to know what to respond, and how to respond.

ENC communities actively partner with neighboring counties as a strategy to share resources for emergency preparedness and response. A large majority (83.3%) of survey respondents work with professionals outside of their office (Table 5). The communities are co-dependent and provide technical assistance to one another. The Northeast North Carolina Disaster Assistance Working Group (NE NC DAWG) is an example of a high degree of regional cooperation in the ENC region. The NE NC DAWG is a 13-member group of counties located in the northeast region of the state (Bertie, Chowan, Dare, Gates, Martin, Perquimans, Tyrrell, and Washington Counties were represented in our workshop).The group conducts planning and training exercises together, maintains strong working relations among professional staff, carries out unified decision-making on issues such as stormwater and a regional pet shelter, and has prior agreements in place to assist one another during disaster events. A participant explained:

We are in a thirteen-county group… the DAWGs. It don't matter what they have, we don't even have to go through the state to call them in to bring us materials…. I got an area coordinator I can call right now and tell him I need something, and I can guarantee within thirty minutes they're gonna find it. And I mean, that's from a flood vehicle to a helicopter…I mean, they're gonna find something and have it in my hands very shortly.

Other counties have followed suit by establishing smaller units of cooperation such as the five-county group of Martin, Washington, Tyrell, Hyde, and Bertie (all but Hyde county was represented in the workshop, see Fig. 1). One participant told us:

Five counties, as a matter of fact - Martin, Washington, Tyrell, Hyde, and Bertie – we were working together just as a planning commission. So, we did our planning together, we did our training together, we did our educational pieces together, to ensure that the citizens within all five county districts were aware of what was actually going on.

Participants also described the close working relationships among towns within a county, often necessary given the limited resources of individual jurisdictions. As one explained:

With the exception of Washington, the rest of us are all tiny little towns. So, we don't have the resources and the manpower, and maybe the expertise. But the county has been very supportive, so we have a really good relationship…So, the jurisdictional boundaries don't seem to be an issue, because we're all part of Beaufort County.

Participants emphasized that communication was key to these close cooperative relations, explaining that "they are not afraid to communicate…they might not like something, but they'll talk…they don't get mad, they just work through it…because it is not what you want, it's what's best for the people." Another added:

All the municipalities have a member in the county, and they all sit together on the Dare County control group. And they make a unified decision of when to call it, watch the forecast, deal with the hurricane center, and the weather data they collect and then make a decision [on] when to require mandatory evacuations.

In contrast, relationships with state and federal level units lack adequate communication, creating barriers to appropriate responses to CCWEs. Participants acknowledged that "it's all about building relationships in advance," yet find that "it is increasingly difficult to communicate with the state." For instance, communication or information disseminated by state-level agencies "ends up to the elected official." A participant explained:

Most of our town managers do a pretty good job of paying attention. The elected officials, ours is a wonderful mayor, but he doesn't have an office. He works full-time. He checks his mail sometimes. So…a lot of times it's just not getting to the people who need it.

Participants also pointed to the lack of coordination and communication between FEMA and state-level units that exacerbates the challenge of coordinating at the county or regional level. The lack of coordination and communication was attributed to high staff turnover at the state level and at FEMA. The constant turnover brings in new staff frequently and "everyone has to be retrained." In turn, this results in an inconsistent and fragmented flow of communication, difficulty communicating with state-level agencies, and missed deadlines at the state level that creates delays and confusion around reimbursements from the federal government. Participants expressed that "there is no real continuity at the state level" and it all "goes back to our legislative people" because "they don't know. They are just putting money out." The problem also exists at the federal level as one participant added that for FEMA: "You get assigned someone and then in three months you get another person and you have to start all over." Another put it plainly that "it is as confusing as it can be because nobody knows who's doing what, where, and the different programs don't talk to each other." Another participant gave an example:

Take Beaufort County as an example, who has been through multiple recovery efforts, has staff that knows more about hurricanes and recovery than a large number of the folks who are working in Raleigh right now. Part of the problem is that every time that we have a storm, we have a whole new cast of characters that are in play, and they've gotta learn…And every time we get this whole new cast of characters, they think they know more than we know. And they don't.

In summary, ENC communities rely on robust local communication and community relationships and a high degree of regional cooperation as strategies for effective response. This is in line with previous work showing that rural communities are especially at risk and struggle with scarce resources but have adaptive capacities due to strong social capital based on long-standing relationships. Yet, economic challenges in rural communities undercut the benefits of higher social capital [6,10,11,21].

4. Discussion and conclusion

This study examined the cognitive capacities of two primary actors in the realm of compound hazards: planners and emergency managers. We examined whether hazard professionals are aware of their risk to compound hazards and can they identify obstacles to communication and emergency response. Compound hazards can be temporally and spatially extensive stretching the capacity of resources and manpower, especially in rural environments, which makes cooperation and collective action critical [3]. However, "traditionally, emergency managers have confined their activities to developing emergency response plans and coordinating the initial response to disasters" ([18], p.29), while mitigation falls under planning. The divide weakens resilience.

Our case study area of Eastern North Carolina, USA is both primarily rural and has an elevated risk of the combination of pluvial, fluvial, and coastal flooding, referred to as Compound Coastal Water Events (CCWE). Quantitative and qualitative data were collected from surveys and focus group interviews with planners, emergency managers, and other public officials to assess the perceptions of CCWE risk. Thus, our data captures the unique needs and challenges of rural coastal communities. However, as a place-based study, we caution that it is not designed to represent areas outside of this specific context. Thus, future research is encouraged.

Participants recognized that their counties are at the nexus of flooding from the sounds and ocean, rivers upstream and excessive rainfall and this poses a challenge to effective flood hazard management. Consequently, CCWE is an established perspective among hazard professionals. Pluvial flooding is perceived as most problematic because it is difficult to forecast and prepare for, can affect the entire study area, and is increasing in frequency. Thus, the sensitivity to compound flooding primarily arises from extreme rainfall. Climate change was not given as the cause for the perceived trends, rather the majority saw it as a consequence of degraded storm water infrastructure and poor land management. In fact, participants believed that more flood gauges, improved stormwater models, and updated engineering standards on infrastructure would make their communities more resilient to CCWE in the future. These and other mitigation options are explored further in a companion study [16].

The literature presents many obstacles to communication and cooperation related to compound flooding. The complexity and uncertainty of CCWE and the lack of maps and other tools for adequately describing these compound risks makes it difficult to express the importance of this hazard to the public. This was confirmed in our case study. For example, the likely reason that less than half of hazard professionals in ENC use web-based and field-based tools is because they are not tailored to CCWE. We found that communication obstacles in ENC were overcome by maintaining relationships to garner trust. Education was also recognized as a key, albeit challenging, task, especially as new people move into the area. One interesting result that agrees with the literature (e.g., [15,24]) was that both hazard professionals and the populace they serve rely on past experiences as their primary resource for flood preparation. This is somewhat concerning as previous flood events may not resemble future ones, which may be more compounded in nature, as suggested by the climate literature. However, counties and municipalities are quick to share flood experiences and data, despite arbitrary top-down organizational boundaries, which may improve their resilience. This is necessary as rural communities lack resources compared to their urban counterparts. The communication stream that needs the most attention is between governance levels – local government and state and federal agencies. This is partly due to turnover and the hazard and planning practitioners not being part of the decision-making process.

In conclusion, the hazard management and planning communities in ENC are fully aware of their risk to CCWE. However, they are seeking improvements in rainfall forecasting, CCWE visualization, infrastructure, land management, workforce development, and relationships with community groups, the media, and state and federal agencies to enhance their resilience to this growing flood hazard.

CRediT authorship contribution statement

Scott Curtis: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Visualization. **Anuradha Mukherji:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – review & editing. **Jamie Kruse:** Conceptualization, Investigation, Writing – review & editing. **Jennifer Helgeson:** Conceptualization, Investigation, Writing – review & editing. **Ausmita Ghosh:** Conceptualization, Writing – review & editing. **Nelson Adeniji:** Visualization.

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.

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