Ocean and Coastal Management 251 (2024) 107065

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

What is a coastal hazard? Perceptions of critical coastal hazards amongst decision makers in communities across the Great Lakes

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ARTICLE INFO

Keywords:
Risk perception
Great lakes
Coastal communities
Coastal change

ABSTRACT

Coastal hazards are pervasive across the Great Lakes coastline due to highly variable water levels, community utilization of the landscape, and landscape composition. These coastlines are dotted with communities that depend on the lake for socioeconomic stability. Recently, many communities have been tasked with the development of new coastal management policies to combat the record water levels and its impacts to socio-environmental conditions. Many of those tasked with the development of such policies don't, necessarily, have backgrounds in coastal processes. This lack of background knowledge may impact coastal management strategies. Through a workshop activity, in 6 communities, local decision makers were asked to interpret imagery depicting varying coastal hazards. Additionally, participants were asked to rank the hazard based on the impacts seen in the community. Using text mining and statistical analysis, patterns in their interpretation were chronicled. Overall, we found vastly different terminology, understanding, and hazard recognition across the communities.

1. Introduction

Coastal hazards, such as storms, sea level rise, and fluctuating lake levels, are chronic challenges around the world and require targeted management actions and policy decisions (Coelho et al., 2020; Hanson et al., 2002; Williams et al., 2018). Such hazards induce physical changes to the coastline, such as erosion, and can result in loss of vegetation (Christensen et al., 1996; Elias and Meyer, 2003; Radomski and Goeman, 2001), increased inputs of sediments and contaminants into coastal waters (Dugan et al., 2017; Nürnberg and LaZerte, 2004) and impacts to fish and wildlife populations (Brauns et al., 2011; Elias and Meyer, 2003; Helmus and Sass, 2008; Henning and Remsburg, 2009). From a socioeconomic perspective, these changes result in loss of tourism revenue and economic impacts due to failing infrastructure (Mack et al., 2020). For instance, across the Great Lakes of North America, interannual fluctuations in lake level between 2013 and 2020 resulted in emergency declarations, infrastructure damage, increased rates of urban and agriculture runoff, degraded shoreline resources, and closure of historical and cultural heritage sites along the US and Canada shoreline (Meadows et al., 1997; Gallagher et al., 2020).

To address the impacts of coastal hazards long-term strategic coastal management approaches are needed, in both natural and human-altered shorelines, to both monitor landscape change and develop appropriate actions and policies (Norton, 2020). Such management approaches should be based on analyses of modern and historical coastal monitoring data (Coelho et al., 2020). However, to effectively utilize these data to develop effective management approaches decisionmakers must have a robust understanding of coastal changes and processes to accurately assess the vulnerabilities, risks, costs, and implications of coastal hazards. Traditionally, coastal decision makers are defined as anyone in the local realm making decisions that directly or indirectly affect coastal areas (Kellogg et al., 2005). Such decisions can include, but are not limited to engineering changes, ecosystem renourishment, infrastructure repairs, and regulatory decision regarding the development or redevelopment of coastal lands. This definition of coastal decision makers, while accurate, highlights that no background in coastal management, geomorphology, or environmental science is needed, required, or expected. Given this, it is imperative that the knowledge-base of decisionmakers is evaluated to assess their understanding of hazards and associated risks and to determine their capacity to implement proactive, data-driven management actions.

While some coastal issues such as erosion are ubiquitous throughout

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https://doi.org/10.1016/j.ocecoaman.2024.107065
Received 6 July 2023; Received in revised form 9 January 2024; Accepted 14 February 2024
Available online 29 February 2024
0964-5691/

the world, many regional variations exist, further complicating the standardized definition and role of coastal decision makers. In the Great Lakes of North America decadal water level fluctuations (on the order of a meter per decade) can facilitate rapid coastal erosion, resulting in damage to coastal infrastructure and loss of coastal habitat (Meadows et al., 1997; Theuerkauf and Braun, 2021). In the Lake Michigan-Huron basin, between 2013 and 2020, water levels rapidly rose almost 2 m, a greater magnitude than the predicted rise in water level projected for ocean coasts over the next century (Theuerkauf and Braun, 2021; Cazenave and Le Cozannet, 2014). Given the constantly changing water levels and shoreline change there is without a doubt a level of societal learning at work that is feeding into decision makers approaches (Platt, 1994). Coastal hazards are a constant. For instance, in Michigan high water levels from 1985 to 1987 caused roughly $222 million in damage to property bordering the Great Lakes, mostly due to shore erosion and bluff recession (Platt, 1994). Additionally, and more recently, in 2020, the region again experienced high water level and, in the case of Lakes Michigan and Huron, record highs. Erosion along many locations in the Great Lakes during this time led to emergency declarations and requests for federal emergency funds, such as the $50 million per year authorized by the Coastal and Great Lakes Communities Enhancement Act to assist coastal communities affected by high water levels in the 2010s (Kilmer, 2019). Socioeconomic projections from 2019 to 2020 suggest that upwards of $500 million in damage to cities along the Great Lakes could have occurred due solely to the record high lake level (O'Connell, 2020).

Given the demographic of community decision makers, older and long-term residents of a region, there is little doubt of societal learning on the implications of coastal hazards and management/mitigation approaches. Further this learning process is, traditionally, a result of improved perceptions and understand of the hazard and its cost (Platt, 1994). Recent studies, in the Great Lakes, showed that residents are, for the most part, well informed on environmental issues facing the coastal region (Levine et al., 2020). Further, there is also high awareness of the increased severity of climate events and water levels and how it contributes to economic losses for regions (e.g., washed out roads, loss of infrastructure). The Great Lakes region is an ideal location for examining stakeholder perceptions of coastal hazards given the confluence in these coastal areas of high socio-economic importance and high physical risk (e.g., Mack et al., 2020).

The Great Lakes are often seen as highly resilient, maybe even more so than ocean coasts, but the high variability in management and conservation approaches, socioeconomic demographics, local level management of the coastline, and land use/cover results in two key circumstances. First, while the Great Lakes shoreline is vast the local scale land use/cover dynamics are critically important and the impacts of shoreline management one region will have cascading impacts to other areas, including natural vegetation. Second, the cost to manage both human altered and natural coastlines is high meaning that strategic decisions need to be made quickly but such decisions will have long lasting implications. Currently, responses to the physical, ecological, and economic changes induced by coastal hazards are mostly reactive decisions by states and municipalities with approaches that are not typically regionally coordinated. Ironically, in many coastal communities including those facing the greatest loss from coastal change, little coastal management planning is underway (Berke and Lyles, 2013; Burby, 2006; Norton et al., 2018; Norton and Welsh, 2018). A better understanding by these communities of hazards and risks in general would be an important step towards developing proactive management strategies that promote coastal resilience. Ultimately there is no perfect management approach but with such cascading implications for socioeconomic condition and environmental health it is important to assess the perspective and perceptions of those making key decisions.

This study looks to evaluate the knowledge base of coastal decision makers with the goal of understanding their knowledge gaps, and how information might assist in coastal decision-making and management efforts. As previously stated, there is no one perfect management option for the entire Great Lakes coastline. In fact, there are a wide variety of management and conservation approaches that can be put in place. Therefore, through this work, we look to understand the benchmark understanding of decision makers to key coastal hazards in the Great Lakes. To achieve this objective, there are two overarching objectives to this paper. First, we look to evaluate community decision makers' understanding of coastal hazards. With this information we can gauge the breadth of community knowledge of coastal processes and identify which hazards they deem most critical to their community. Second, we access spatial patterns of decision makers risk perceptions as it pertains to coastal hazards. Additionally, the second objective looked at how perceptions trended within different community asset types.

2. Study area

Combined, the Great Lakes account for 4530 miles of the coast and 21% of the world's freshwater (NOAA, 2022). Coastal communities along the shores of Lakes Michigan, Huron, and Superior are the focus sites for this study. All of these sites experience coastal changes at varying magnitudes related to fluctuating lake levels and storms. Great Lakes water levels fluctuate on interannual timescales in response to changes to precipitation and evaporation (Fry et al., 2020). For example, in Lakes Michigan-Huron, water levels were at or below long-term averages for an extended period of time from 2000 to 2013. In 2014, following several years with high precipitation and a winter of high ice cover (low evaporation), lake level began to rapidly rise (Gronewold et al., 2016). Monthly water level records were reached throughout most of 2020 and then began lake level began to slowly recede. High water levels produced dramatic erosion along the lakeshore, resulting in damage to infrastructure, loss of coastal habitat, and flooding of wetlands and low-lying coastal lands (Meadows et al., 1997; Theuerkauf and Braun, 2021; Wilcox and Nichols, 2008).

Six coastal communities along the Michigan shores of the Great Lakes of North America were specifically examined in this study (Fig. 1). The communities differ in their size, socioeconomic condition, length of coastline, location within Michigan (Upper or Lower Peninsula), and the Great Lake they are situated on. These communities were selected for analysis based on this diversity (Mack et al., 2020; Theuerkauf and Braun, 2021). The six communities include: Iosco County, Chikaming Township, South Haven, Manistique, Manistee, and Marquette (Table 1; Fig. 1). The latter 4 communities were studied at the city level though

Fig. 1. Pilot citizen science communities across the Michigan Great Lakes shoreline. Six communities are monitoring and imaging their coastline in partnership with this project: Marquette, Manistique, Manistee, South Haven, Chikaming, and Iosco County.

Table 1
Profile for the 6 communities studied including Iosco County, South Haven, Manistee, Chikaming Township, Marquette, and Manistique.

Community	Great Lake	Location
Iosco	Lake Huron	Lower Peninsula
South Haven	Lake Michigan	Lower Peninsula
Chikaming	Lake Michigan	Lower Peninsula
Manistee	Lake Michigan	Lower Peninsula
Marquette	Lake Superior	Upper Peninsula
Manistique	Lake Michigan	Upper Peninsula

members from the greater township were also took part in this study. Iosco is on the coastline of Lake Huron. South Haven, Chikaming, Manistique, and Manistee are all on the coastline of Lake Michigan. Marquette is on the coastline of Lake Superior.

Iosco County is located along the western shore of Lake Huron and is composed of several townships, the largest of which is Tawas City. Generally, the shoreline areas within this county are low-lying and subject to flooding and erosion during high lake levels. As a result, the townships/county has hardened many portions of the shoreline and installed jetties. Tourism is a large source of revenue for the county; therefore, large stretches of the beach have not been hardened to encourage use.

Chikaming Township, located near the MI border on the southern portion of Lake Michigan, is a community that has taken drastic measures to combat high water induced erosion. This community of roughly 3000 people (U.S. Census Bureau, 2020) banned hard armoring along the Lake Michigan in 2021 (Ellison, 2021). Chikaming Township was the first Great Lakes community to codify such an ordinance. North of Chikaming, the next community studied is South Haven, Michigan a city on the eastern side of Lake Michigan. This popular tourist destination has been greatly impacted by beach erosion and the threat of infrastructure loss from high water levels. The community is heavily invested in the development of long-term coastal management planning and has worked cooperatively with engineering firms and academic groups. As of 2019, the township had a year-round population of just under 5000 and a median property value of $214,000 (Data USA, n.d.). Further north along Lake Michigan is the community of Manistee. This township, of roughly 6100 people (2019) has taken measures similar to South Haven by working cooperatively with local engineering firms to mitigate the impact of coastal hazards through managed retreat, armoring, and beach renourishment (Data USA, n.d.).

Two communities with different socioeconomic conditions and approaches to coastal management from the upper peninsula of Michigan were included in the study, Marquette and Manistique townships. Marquette, located on Lake Superior, has a population of roughly 21,000 people, as of 2019 (Data USA, n,d.). Community managers and even residents have taken on the issue of coastal hazard impacts. This includes participation in a National Science Foundation workshop series, to study the history of the coastline in the area including ways to protect it both now and in the future. Lastly, Manistique, MI is the last and smallest community of the six communities with about 3000 people (Data USA n.d.). Impacts of high water levels on Lake Michigan have damaged boardwalks and other coastlines structures.

3. Data

The 6 aforementioned communities are all part of a citizen science program entitled Interdisciplinary Citizen-based Coastal Remote Sensing for Adaptive Management (IC-CREAM). The program looks to empower coastal communities by developing and supporting a network of citizen scientists focused on documenting coastal change using imagery. The data for this study were collected as part of community workshops conducted late 2019 and 2020. These workshops consisted of 5–20 community stakeholders (i.e., decision makers such as city planners, mayors, commissioners, etc.) involved in coastal management and planning. Each workshop consisted of focus groups, talks on coastal changes, and collaborative activities between the academic research team and the community stakeholders. The ice-breaker component of these workshops is the entire basis for the data analyzed in this article. During this ice-breaker activity, conducted using Qualtrics, each attendee (aka respondent) was shown a series of images of coastal hazards around the Great Lakes from locations purposefully outside of the communities of interest (Fig. 2). The images were either printed large (3 × 5) or the participants could zoom into their computer screens to look through the image. Respondents were asked to name or describe the coastal hazard, no preference or leading voice was given as to how they analyzed the images. Additionally, no description of the images was provided at the start of the activity, prior to providing responses. Next, respondents were asked to rank the images in terms of community impact, with a one corresponding to the most impact and an eight, the least impact. It is important to note that there is no perfect answer to these survey questions. Through this project we are looking for alignment in terminology, description, and overall perspective on the coastal hazard and its resulting landscape impacts.

All images included in this survey were collected and interpreted by a coastal geomorphologist in order to accurately portray the coastal hazard and keywords associated with the events. Image 1 represents a coastline damaged by erosion (Fig. 2). Across the Great Lakes storms and high-water levels are the primary driver of coastal erosion (Theuerkauf and Braun, 2021). With such events the sediment is put in suspension and move either offshore or down shore to other regions, resulting in a net loss of coastline. There are a wide range of mitigation strategies that can be employed, if the community chooses so, to combat erosion issues. Across the Great Lakes both hard and soft armoring are common, though there is great debate on the legal implications such coastline engineering. In image 1 the community attempted to mitigate the hazard by armoring the shoreline with a concrete cube revetment. However, as seen this protection effort has failed during a period of high-water level, also seen in the image. Image 2 depicts a calm day at a bluff site along Lake Michigan where several nearshore sandbars are present. Image 3 highlights erosion and infrastructure damage again resulting high lake level. This image explicitly and clearly highlights infrastructure damage, a problem consistently seen across the Great Lakes in the recent time of high-water level. With this type of coastal hazard, one would also see loss of beach and overall change in the sediment load across the area. Image 4 represents a common coastal phenomenon across the Great Lakes, winter shore ice, which can both protect the shoreline from erosion and cause more erosion depending on the setting. Shore ice is critical to the Great Lakes shoreline as it protects the coast from extreme shore event. However, the onset, melt, and duration on ice cover is changing. Within the ice sediment is suspended. Image 5 is a wide, low-elevation beach that appears to be minimally vulnerable to coastal hazards. However, this flat beach is susceptible to ponding of water that can lead high bacterial concentrations from shorebirds. Image 6 shows the results of a storm along the coastline. The lack of beach and debris highlights the impact of storm hazards. Similar to Image 6, Image 7 shows a site being impacted from a coastal storm along Lake Michigan. In this case, a wetland is eroding and being inundated with water, which is changing its ecological functioning. Lastly, Image 8 shows beach and bluff erosion and loss of vegetation (trees) due to high water, which can be augmented by upland runoff into streams that dump into the Great Lakes. These streams can either promote erosion through scour as they enter the basin or contribute sediment that helps to build beaches.

4. Methods

Using only data from the aforementioned ice breaker activity both text mining and pattern analysis were conducted within R (R Core Team, 2014); figures were produced using the package ggplot2 (Pedersen et al, n.d.). Prior to text mining and pattern analysis, the ice breaker data were cleaned within R, using the tm and SnowballC packages (Bouchet-Valat,

Fig. 2. Coastal hazard images utilized during the workshop activity.

2020; Feinerer et al., 2023). First, by image, the responses were merged into a corporal collection of documents or phrases containing natural text. From there the tm_map function was used to remove symbols, number, punctuation, and common words (e.g. cause, the, and, is, have, are, was, be, of) from each response entry. The resulting text is not in sentence format but rather the key words within each response.

After the data were cleaned, analysis began with simple frequency counts. Using this simple statistic, the common terms or words utilized by the respondents were tallied by image. The frequency counts were conducted by community and across all communities. Terms or words used more than twice were preserved in the analysis. In addition to the frequency analysis, word clouds were constructed using the wordcloud packages in R (Fellows, 2018). The word cloud represents the extreme of thought, terminology, and understanding of coastal hazards. For instance, in many instance “Don’t know” was a common term; whereas, others would use specific terminology for an event. The word clouds also highlight the frequency in term utilization by the respondents. We conducted an analysis of summary statistics to understand the hazard images ranked as most impactful to each community, as indicated by the mode function in R.

To understand recurring themes in the icebreaker data, we categorized responses into four mutually exclusive groups using bins that are based on the capital asset guiding decision-making processes defined in the existing literature (Bunting et al., 2013; Carney, 1998). The first category represents natural capital assets that are linked to increased coastal vulnerability. The second category contains infrastructure capital which refers to necessary basic services (Bunting et al., 2013). The third asset group contains human-oriented capital assets. Examples of these assets include clean drinking water, infrastructure or efforts designed to prevent vector borne diseases, and infrastructure or efforts to increase public safety. The fourth asset group contains all remaining assets not otherwise classified in the other three categories. This category was developed because of some responses being unclear. For instance, several respondents, under various images, wrote “failed mitigation”.

The last element of the analysis conducted with the responses from the icebreaker workshop activity looked at awareness of shoreline protection. In addition to capital asset categorization, activity responses were also categorized related to mentions of shoreline protection efforts. This three-class system is straightforward with code 0 representing responses that did not mention shoreline protection at all, code 1 representing responses were the term protection was stated explicitly, and code 2 representing responses related to, but not specifically saying protection. Examples of code 1 responses include terms such as "shoreline projection project" and "failed coastal protection". Examples of code 2 responses include "structure to stop erosion" and "boulders installed". While this analysis does not definitively give insight into decision makers' understanding of shoreline protection it designed to highlight two important aspects of community knowledge. One, the analysis highlights the breadth of shoreline protection terminology used across and within the communities. Two, it highlights viewpoints about different shoreline protection options.

5. Results

5.1. Word frequency

Fig. 3 depicts word clouds for the 6 different icebreaker activities conducted, one for each community. In the majority of these clouds, erosion appears most frequently and is often the largest word, indicating high frequency of use. Aside from this term however, there was otherwise great diversity in the terms used by respondents to describe hazards during the ice breaker activity.

For image 1 the terms shoreline (n = 11), erosion (n = 10), protection (n = 6), and armoring (n = 6) where mentioned most frequently by respondents. Collectively, these terms represent approximately 57% of the key words related to image 1. Other terms including concrete (8.6%), blocks (6.9%), revetment (8.6%), and hardened were also frequently seen in the responses. All of these terms accurately interpret the mitigation strategy (revetments) employed for the hazard presented in the image. Unfortunately, no respondents identified the hazard presented by the image, high water level, as indicated by the fact that this phrase did not make the top 5 in the word frequency analysis. Meaning that the hazard impact was well noted but not the hazard itself. For image 2, bluff (n = 6), infrastructure (n = 5), loss (n = 5), water (n = 5), and erosion (n = 5) were the most noted, representing 66% of the keyword answers. All these terms are spot on with what information presented in the image, showing a strong understanding of the hazard. Twenty-eight responses (30.7%) mentioned the term erosion in response to image 3. Beyond erosion, infrastructure (n = 16, 17.6%), road (n = 9, 9.9%), damage (n = 8, 8.9%), water (n = 6, 6.6%), and beach (n = 6, 6.6%) were the most frequently used terms. Again, the actual hazard depicted is rarely mentioned, high water level. Interestingly, all the terms are related to the impacts of the hazard presented in the image. For image 4, the hazard itself was mentioned 30 times by respondents (46.9%), ice. The other terms from respondents included shelf (n = 6, 9.4%), shoreline (n = 5, 7.8%), sand (n = 4, 6.25), and erosion (n = 4, 6.25%). Image 5, a large beach which at times, represents a health hazard, did not have a single respondent use the word health, disease, or any such related term. Instead, the most common words were beach (n = 10, 20.8%), sand (n = 8, 16.6%), hazard (n = 5, 10.4%), see (n = 5, 10.4%), and water (n = 5, 10.4%). The term see was common in the phrase "I don't see a hazard" or "I see nothing here". For image 6, erosion (n = 10, 14.3%), debris (n = 9, 12.9%), loss (n = 9, 12.9%), and beach (n = 7, 10%) were highly mentioned. What is unique about image 6 responses is the diversity in respondent text patterns. For the other images, words appearing at the bottom of the top ten list had a frequency of 3 or less. This was not the case with image six where the frequency at the bottom of the list was five for water. Erosion (n = 14, 21.5%) was the most common response for image 7, followed by debris (n = 8, 12.3%), water (n = 8, 12.3%), and loss (n = 7, 10.8%). Not only was water mentioned 8 times, but high (n = 6) was frequent as well, highlighting the term "high water" amongst responses. Lastly, for image 8, erosion was mentioned 22 times (32.4%), followed by water (n = 11, 16.2%), loss (n = 8, 11.8%), bluff (n = 5, 7.4%), high (n = 5, 7.4%), and trees (n = 5.7.4%). While bluff was a common word within responses failure was not.

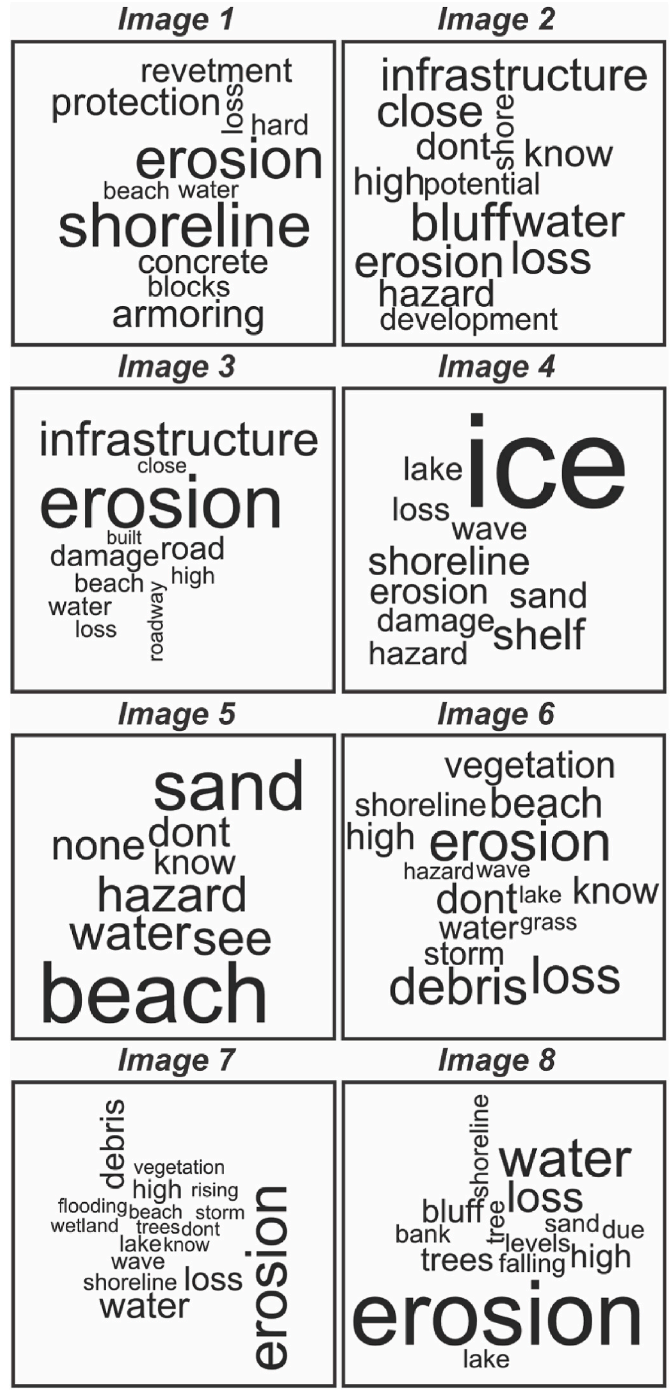

Fig. 3. Word clouds highlighting the common terms, across all communities, for each of the 8 images analyzed by decision makers. The words shown above were those commonly given by survey respondents as they defined/conducted image interpretation on each image.

5.2. Image rank

Table 2 presents the mode of the ranking of images in terms of community impacts. Rank 1 indicates the most image of greatest concern/impact while rank 8 indicates the least concern/impact. More specifically, as we look in Table 2 in the Rank 1 column, overall, the most common number one ranked image was image 1, this is seen Iosco County and Chikaming Township as well. However, in Marquette and Manistique image 3 was most commonly ranked number 1 in terms of greatest concern. Here, it is important to note that an image can receive

Table 2
Mode rankings of images across and by communities. Rankings highlight what decision makes perceived as the biggest threat to their community. NA refers to instances where there is not one common rank.

Communities	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7	Rank 8
All Communities	1	7	1	4	8	7	7	5
Iosco	1	8	1	4	8	6	8	3
South Haven	2	3	1	4	7	5	4	6
Chikaming	1	3	2	4	8	7	7	3
Manistee	2	7	1	5	8	NA	3	NA
Marquette	3	1	8	8	7	4	2	5
Manistique	3	8	1	4	8	6	7	6

the same ranking twice since the mode of the ranking was used in this portion of the analysis (i.e. a community could rank two different images commonly, the same number of times).

Across all communities, image 1, armoring failure, was perceived as the biggest threat to communities. Specifically, 2 communities (Iosco and Chikaming) ranked this as the biggest coastal concern of those listed. Image 7 was ranked second as the biggest perceived threat across all communities. This image, which shows coastal habitat degradation, including erosion, is a pervasive problem across multiple Great Lakes coastlines. Therefore, it is logical that decision makers would be concerned about this hazard. In Iosco the only images that concerned decision makers were images 1, 4, and 8. All these images are associated with degradation or erosion. Iosco officials have been very focused on finding policy options to address loss of structures and properties, especially those that are private, to erosion, such as through the installation of hard shoreline armoring. Surprisingly, image 2 was ranked one most commonly in two communities, South Haven and Manistee, this choice might seem odd given the picture shows a clear day with little extreme event damage. However, respondent who choose image 2 as the most highly ranked commented that the picture highlights: “development close to the edge of the bluff”, “very high water and construction on a bluff”, and “man-made structures developed that resulted in removing vegetation that is holding slopes together”. The ranking within all the other communities do not depict a focus by community members, indicating multiple shoreline hazards of concern.

While mode shows us the most frequent image per ranking a similar median analysis highlights the middle rank per image. Table 3 highlights the median ranking of each image across the different communities and collectively for the whole study area. Overall, there are two striking conclusions from this analysis. First, we see that images 1 and 2 ranked consistently high across almost all communities. Secondly, we see that our two communities in the upper peninsula of MI were the only ones to highly rank image 3 which depicts large infrastructure damage. This is surprising because multiple of the communities included in this study had seen substantial damage related to high water, even regarding infrastructure. However, these are also areas (e.g., Chikaming, South Haven, and Manistee) that had large erosion issues at the same time.

5.3. Capital assets analysis

The capital asset analysis groups responses by the community assets they are associated with. For instance, if the hazard is described as “failed revetment, a bad financial investment.” This indicates that there is a financial burden or impact to financial capital. In some instance, responses could be categorized into multiple asset type. Therefore, Fig. 4 shows the pattern of responses highlighting if a single asset or multiple assets were mentioned. The order of the assets listed indicates which was listed first(see Fig. 4)

Image 1 responses fell primarily into the infrastructure (n = 35) and natural (n = 10) assets categories (Fig. 4). Marquette and Chikaming had the highest number of infrastructure asset type responses. The natural asset responses came primarily from Iosco (n = 3) and Manistique (n = 4). All respondents agreed that the image did depict a coastal hazard, therefore none list “I don’t know” or “No Hazard”.

21% of the respondents indicated that image 2 did not depict a hazard. Those that disagreed with this responded in ways associated with infrastructure (n = 13) or natural (n = 15) assets. Similarly, to image 1 there were no community clusters within these two asset groups. This lack of clusters is ideal as it shows similar thinking by decision makers across the communities.

Image 3 showed similar patterns to the previous two images, with most responses falling under the infrastructure and natural capital assets (Fig. 4). Additionally, these responses occurred across all communities and were not clustered. However, unlike the previous images (1 and 2), 9 responses were classified as both natural and infrastructure. These include responses such as “First, beach erosion. Second, infrastructure damaged” and “High water, wind causing erosion, infrastructure damage”. Given the combination of answers by respondents there was no choice but to classify they together in a separate class.

Image 4 responses were overwhelmingly classified in the natural asset class (n = 41; Fig. 4). Overall, 75.9% of the responses were in the class, only 5 were related to infrastructure and 4 were classified as no hazard. Of those responses classified as natural assets, 24.4% were from Marquette, 17% were from Manistique, Manistee, and Chikaming. Iosco (14.6%) and South Haven (9.8%) had the lowest number of responses deemed natural assets.

Image 5 responses were, for the most part, classified as natural (n = 14) or no hazard (n = 19). Of those classified in the natural asset class 42.8% were from the Marquette community. Contrary to this, Chikaming did not have any response deemed natural assets. The reverse community pattern is seen in responses classified as no hazard. Marquette Township, one of our largest workshop groups did not have any responses in the vein of no hazard. Whereas all of the Chikaming respondents interpreted this image as not a hazard. This response by Chikaming accounts for 42.1% of the no hazard responses. On a different note, three responses were classified as human assets, the only time this

Table 3
Median ranking of each image across the different communities.

Communities	Image 1	Image 2	Image 3	Image 4	Image 5	Image 6	Image 7	Image 8
All Communities	2	3	4	4	6	6	6	5
Iosco	2.5	3	6	4	6	5	5.5	6
South Haven	2	1	3	3	6	6	5	5
Chikaming	1	3	7	4	4	6	6	5
Manistee	3	2	7	3	5	4.5	2	5
Marquette	2	6.5	1	6	8	4	5	4
Manistique	3	3	1	4.5	3.5	5	4	5

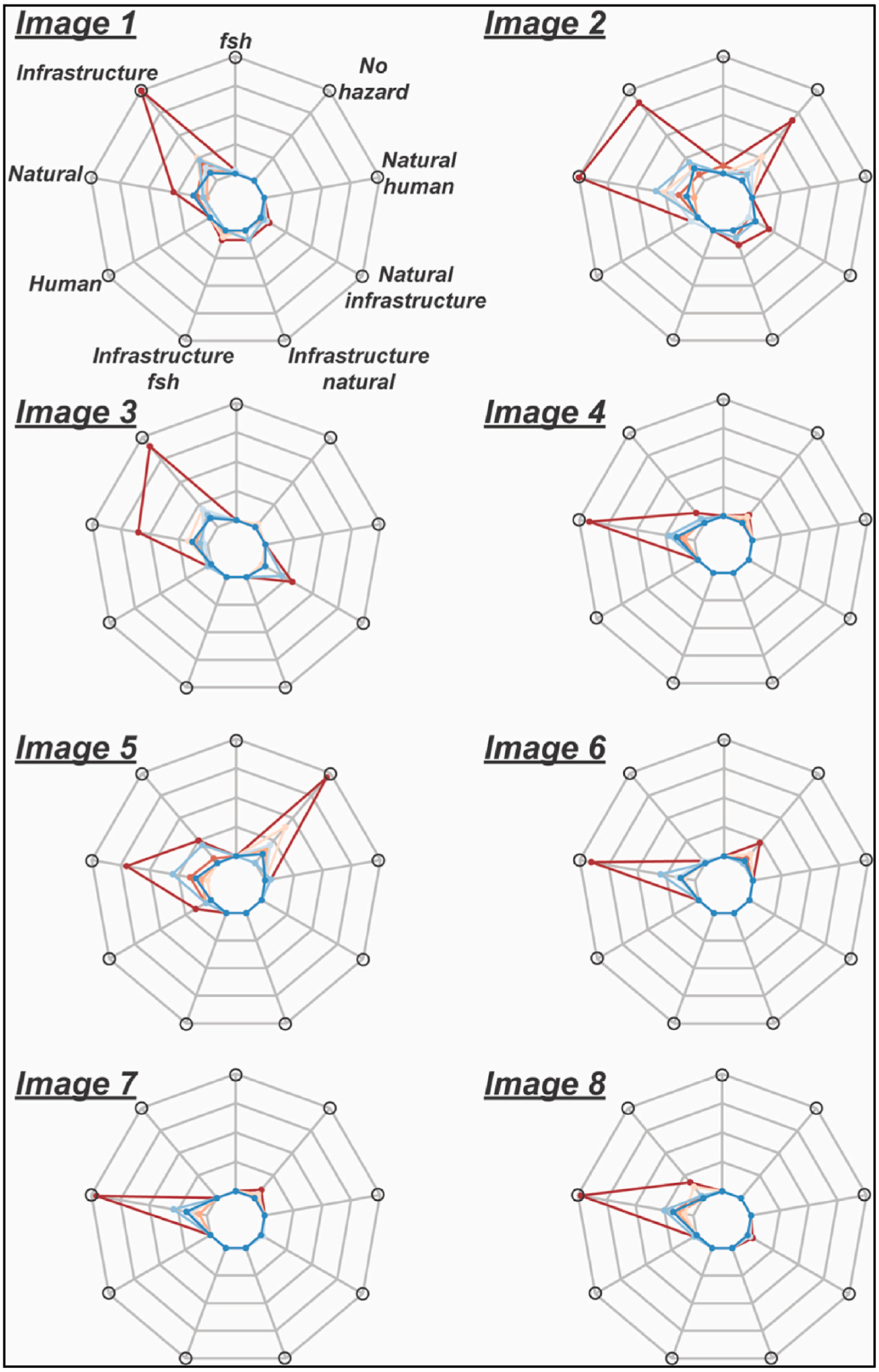

Fig. 4. Radar diagrams highlighting the capital asset for which the decision makers interpretation response falls into. FSH = financial, social, human. Natural = natural asset. Human = human asset. Infrastructure = infrastructure asset. No hazard = respondent indicate the image included no coastal hazard. In cases where two asset types are listed the respondent answer indicate both.

class was utilized in this study.

Image 6 responses fell into one of three categories: infrastructure (n = 1), natural (n = 36), and no hazard (n = 9). Like image 5, Marquette respondents had the most responses classified as pertaining to natural assets (n = 12 or 33.3%). Also like the previous image, Chikaming respondents had the highest number of no hazard responses.

Forty-three responses to image 7 were classified as pertaining to natural assets, 13 of which came from Marquette. The other communities were fairly uniform in their responses classified as natural asset (n ranging from 6 to 8). Four responses indicated that a coastal hazard was not depicted in the image. Lastly, image 8 exhibited the same repose diversity seen in image 1–3. Responses were classified as infrastructure (n = 7), natural (n = 39), human (n = 1), and natural/infrastructure (n = 2). Of those classified as pertaining to natural assets, 10 were from Marquette, and 7 were from three communities (Iosco, Manistee, and Manistique).

5.4. Awareness of shoreline protection mechanisms

Shoreline protection can take on a number of different forms depending on the hazard impacting the landscape. The last portion of the analysis involved an analysis of shoreline protection mechanisms, as indicated by mentions in the icebreaker activity data. Understanding shoreline protection mechanisms and approaches is important to effective management. The analysis of shoreline protection awareness looks to highlight terminology and breadth of awareness of protection measures.

Fig. 5 depicts the diversity in responses across images and communities in terms of protection awareness. For image 1, only 8 people specifically mentioned protection, but 35 people alluded to it in their answers. These respondents were spread across several communities: Iosco (12.5%), South Haven (25%), Manistee (37.5%), and Marquette (25%). No one in Chikaming or Manistique responded in such a manner. Responses that alluded to protection (code 2) occurred in every community; Chikaming Township had the highest number of responses (31.4%), followed by Marquette (22.8%).

Image 1, by far, had the most responses coded as 1 and 2; indicating some mention of protection. The other images were, for the most part was coded 0, though images 5, 6, and 8 had small percentages coded 2. These results indicate that protection was synonymous with either (1) armoring (likely hard armoring) or (2) erosion and high-water level across our communities. Both interpretations are logical conclusions given the common response of the term “protection” in image 1 which depicts failed hard armoring in a high-water scenario, and the lesser use of the word in other images that still show high water and erosion but no or lesser armoring. Beyond these hazards communities were not highlighting protection measures to mitigate the hazards impacts. For image 2 no one mentioned protection across any county, which makes sense because there are no protection measures in place in the image (Code 1). Further, only 1 person, in South Haven alluded to protection in their response. Meaning that 60 respondents did not, when describing or naming the hazard, include aspects related to shoreline protection. Similarly, for image 3 all 61 respondents answers were classified as Code 0. Image 4 had zero responses coded as 1, i.e. protection explicitly stated, and only 3 coded as 2 (protection alluded too). The three responses coded 2 there not in the same community with South Haven, Chikaming, and Marquette each having one response coded in this fashion. For image 5, 56 were coded 0, no responses were coded 1, and 5 were coded 2. Like image 4 these code 2 responses occurred across multiple communities. Image 6 has 60 responses coded 0 and 1 response coded 2. The one code 2 response was from Manistee. Image 7 still has the majority coded 0, 60 responses. However, one response was coded a 1 indicating the respondent outright mentioned shoreline protection. Lastly, for image 8, 53 responses were coded 0, and 8 where coded 2. Unlike the other image, where there was diversity of codes across the community, this image shows a different pattern. Seven (87.5%) of the 8 code 2 responses were from Chikaming Township for image 8. The first such clustering seen in this analysis.

6. Discussion

The goal of this study was to assess community decision makers’ understanding of coastal hazards and associated mitigation strategies using data from community workshops for 6 communities located along the Great Lakes within the state of Michigan. Overall, this assessment revealed little awareness of coastal hazards other than erosion and those related to high-water level. These patterns of awareness are likely due to rising lake levels across the Great Lakes since 2013, which was occurring during the time of this survey (2020–2021). The word association portion of the analysis also revealed few linkages of mitigation strategies with the hazard images, indicating little awareness of mitigation strategies other than those associated with erosion and high-water level. Importantly, through this analysis we see that “shoreline protection” is generally understood amongst coastal communities as it pertains to

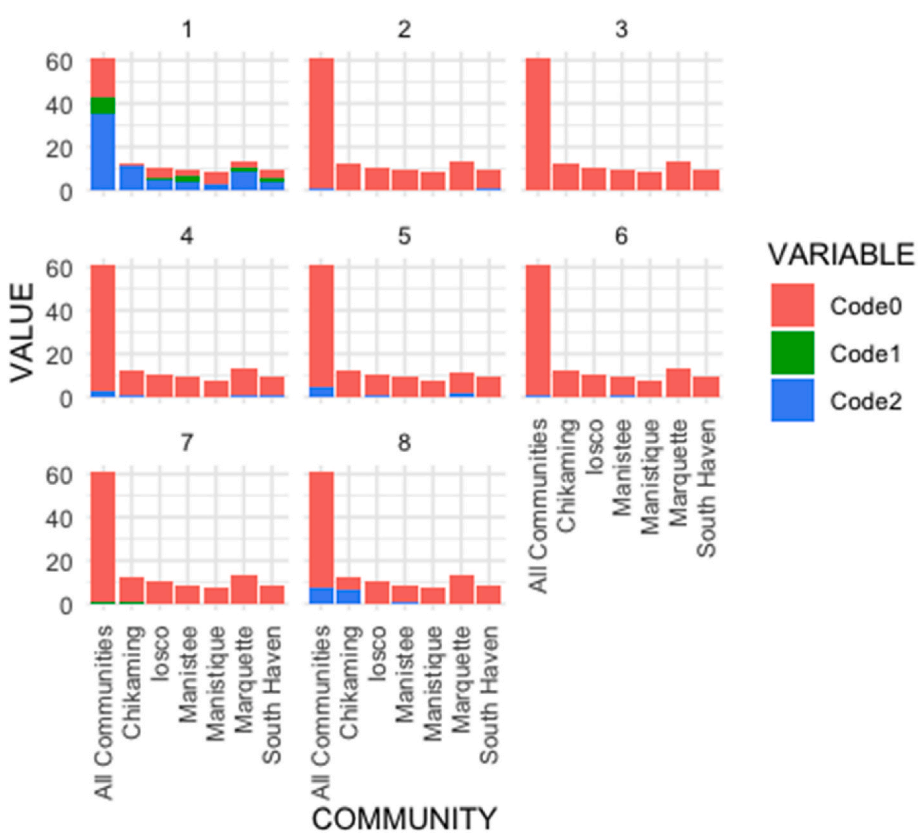

Fig. 5. Bar graph depicting if the respondents image interpretation response included aspects of shoreline protection. Code 0 = no response or respondent did not answer. Code 1 = the word protection is explicitly mentioned in the response. Code 2 = aspects of shore protection are mentioned.

erosion and high-water level. However, there is a strong tendency for respondents to associate protection with engineered approaches, such as hard armoring. Further, but in support of the narrative that respondents understand shoreline protection in this context, the capital assets analysis revealed that the impact on infrastructure and the natural environment were more likely to be mentioned than were impacts on the financial, social and health aspects of coastal communities. With that in mind, it is important to note that while communities may have had similar rankings, especially regarding erosion and associated management strategies, there could be different reasons for those rankings. For instance, results show that both Iosco County and Chikaming township rated failed armoring (image 1) as the biggest threat to the community, but these two communities have a very different management history related to coastal hazards. Iosco county relies heavily on armoring of the shoreline whereas Chikaming township has banned armoring. Thus, this study is just a glimpse of the larger understanding and perception of coastal hazards and does not speak to the specific communities and their differing management histories.

These results are concerning from a coastal planning and management perspective as lake levels are starting to falling and almost to average condition (per US Army Corps of Engineers website), meaning other hazards will become pressing soon. For example, bluff failures can continue to occur even during falling lake levels and some studies even indicate that peak bluff recession occurs after peak lake level (Krueger et al., 2020). Additionally, overall system recovery (i.e. beach and foredune) is expected during falling lake levels but erosive and impactful storm events continue to make the region vulnerable (Theuerkauf and Braun, 2021). Decision makers also did not appear to be aware of a perhaps pervasive health issue along Great Lakes shorelines: water ponding that can become concentrated with bacteria from shorebirds feces. The Great Lakes are not the first to see such ponding water effects. Ming-He et al., 2007 found that isolated ponded water, as seen in one of our workshop images, had significantly higher fecal indicator bacterial than adjacent flowing water. Across freshwater adjacent public beaches such sand contamination is often overlooked, but activities in this area present a health risk to sensitive populations (Alm et al., 2003; Nevers et al., 2014 highlighted that within the Great Lakes, research has led to the widespread discoveries of such bacteria in natural habitats including soils and beach sand. Additionally, Nevers et al., 2014, shows that many beach managers along the Great Lakes have actively incorporated such bacterial findings into their monitoring. Through this study, however, it does appear that some communities were more aware of some hazard and mitigation strategies than others. In the case of standing, ponding water there was a lesser awareness of its implications. These results suggest that interaction between community decision makers and coastal scientists is necessary to understand hazards beyond erosion and the appropriate responses to these hazards.

That said, there are some limitations that are important to note about this analysis. First, this work represents a sample of six Michigan communities. These communities were carefully selected because of the diversity of challenges confronting each. However, the experiences of communities on Great Lakes not analyzed in this study may impact overall perceptions of hazards and associated mitigation strategies. For example, communities along the coast of Lake Erie may be acutely aware of issues related to uncontrolled algal blooms because of this prominent issue for this Great Lake in past years (Smith et al., 2015). Second, the community assets analysis conducted as part of this study was developed as an offshoot of traditional risk perception analysis (see Bunting et al., 2013). Unlike with traditional risk perception analysis, based on capital assets, this study narrowed the definition and scope of assets included given the context of the workshop. Third, the workshops associated with this project began as the COVID-19 pandemic began. Therefore, the first workshop, in Marquette, MI, was conducted in person and the activity was done with people walking around a conference room examining images while completing the Qualtrics questions. For all the other workshops the workshops were completed via Zoom. For this ice breaker zoom participants were given as much time as needed to answer the questions just like the people that completed the activity in person.

To understand, broad scale Great Lakes-wide, awareness of decision makers understanding of coastal hazards several things would need to occur. First, a similar study would need to take place across all Great Lakes communities. This is feasible given that we already converted the activity to a virtual presence. Additionally, it would be ideal to work with the coastal zone management programs within the region to pinpoint communities that need further assistance in their understanding of coastal hazards. That said, overall, the largest hazards and risks facing the coastal regions where understand well by the coastal decision makers.

7. Conclusion

To avoid miscommunication, misuse of funds, and/or reliance on traditionally unsuccessful management or policies it is essential to foster, both within and across communities, a broader collaborative relationship between decision makers and scientific researchers. Such relationships have been idealized in numerous publications (e.g. Aceman, 2005; Liu et al., 2008) however have rarely become operational in the long term across coastal environments such as the Great Lakes. Capacity remains the largest barrier for data-driven management as communities are not typically able to use the data directly and researchers typically lack the time, interest, or incentive to translate data and information into more useable formats. Therefore, while modern coastal science could greatly improve management, most decision-making is occurring in the absence of data because there is not a clear pathway from science to practitioner. A combination of rapidly changing environmental, climatic, and social conditions and anthropogenic stressors are confronting coastal managers/decision makers leading to a variety of challenges in the Great Lakes. A collaborative atmosphere will foster increased and/or better data collections, development of science based but real-world monitoring approaches, and minimize communication gaps overall helping to mitigate such stressors and, potentially, leading to better coastal management and planning regarding hazard events.

Funding

This research was funded by the National Science Foundation (Award Number: 1939979) project entitled: *CoPe EAGER: Development of a Drone-Based Coastal Change Monitoring Program through Citizen Science Partnership and Capacity Building.*

CRediT authorship contribution statement

Erin L. Bunting: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Ethan J. Theuerkauf:** Methodology, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

Acknowledgements

This research was funded by a grant National Science Foundation Coastlines and People program (award number: 1939979). Multiple people and organizations made this publication possible, and the authors wish to express their gratitude, especially to Robert Goodwin from Remote Sensing and GIS Research and Outreach Services (RS&GIS) at

Michigan State University for helping with program onset, application development, and during workshops. Additionally, we thank the reviewers for their time and effort put into the manuscript review.

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