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Standing Watch: Baselining Predictable Events That Influence Maritime Operations in the Context of the UN's Sustainable Development Goals

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Abstract: The authors present a practical framework for assessing seasonal events that may influence maritime operations, seeking to tie in discussions about climate change adoption to maritime operational assessments. Most maritime-related research tends to focus on a single event, such as a storm, but maritime systems operate within complex systems that have some predictable patterns. These predictable patterns due to natural events, such as weather and water levels, can influence operations. By contrast, other factors, such as cargo peaks or cultural activities, could also shape maritime systems. The growing focus on adopting human activities to the United Nations' Sustainability Development Goals means that system operations should consider their relationship to these broader goals. By integrating data from emergency management databases and weather information sources with other inputs, the authors, in collaboration with various stakeholder groups, created a matrix of regionally specific predictable events that may occur within a region by time of year that can be linked to the Sustainability Development Goals. The matrix was vetted to verify the information, ensuring that all perspectives were considered. The main findings were that a seasonal event matrix was not just a theoretical tool but a practical reference for examining operational patterns in a river for various uses, such as training, operational planning, and emergency response coordination.

Keywords: maritime; seasonality; natural disasters; risk assessment; maritime operations

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1. Introduction and Problem Statement

Mariners plied rivers, coasts, and oceans for ages, with corresponding risks to themselves, their vessels, and their cargo. Today, the maritime industry can access information about weather and other risks, but things still happen related to weather and climate. Nevertheless, there are new concerns about maritime systems being changed by climate change. While climate change occurs through "natural events", the human response is classified as "sustainability". For example, the United Nations, in seeking to address climate change, developed Seventeen Sustainability Development Goals (SDGs) [1]. While distinct regarding specific reporting elements, these goals contain overlapping elements. For example, using inland waterways to carry freight will reduce emissions compared to transport by rail or truck, leading to the adoption of cleaner and more efficient engines. Both items are included under Goal 9, "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation", and Goal 12, "Responsible consumption and production". Concerns over pollution from maritime accidents are related to Goal 14, which is to conserve and sustainably use the oceans, seas, and marine resources for sustainable development.

Limited frameworks may examine broad sustainability goals to risk management, allowing local assessments to be reported into a broader context of sustainability objectives. Looking at the potential for seasonal events based on predictability, especially regarding waterways and maritime systems, would allow the examination of changing climate activities seasonally to baseline if and how different events shape communities and, thus, their sustainability goals. This paper examines diverse activities, conditions, and events, focusing on seasonality, to provide a baseline for identifying the nature of predictable/known risks at regional and maritime-domain levels. These were developed through a desktop scan to identify known data points with seasonal patterns. Once the information was collected, it was presented to local maritime specialists to consider the merits of a seasonal classification structure. This approach identifies what should be quantified, not necessarily developing a deterministic probability, while providing a framework to discuss shared events to improve operational planning.

This paper has the following structure: a literature review that develops the theoretical framework for focusing on predictable events in the maritime sector to manage operational risks better (the authors also seek to delineate how not all events are "bad", and placing navigation within a context of human activities can provide additional insights into localized activities). The Section 3 discusses the structure used in developing the Seasonal Event Matrix (SEM) (refer to Supplementary Materials) framework through regional and industry definitions, creating a predictable event category, which was then populated using secondary data and desktop scans. The last step was stakeholder validation of the SEM to see if the work was accurate and if it assisted in framing the predictable risks within a region. The results show a regional comparison, in addition to a comparison of the Orleans Parish, Louisiana; Mobile, Alabama; and Warren County, Mississippi to highlight the nature of broad regional patterns and localized events within a region that can vary and should be considered as such.

2. Literature Review

The United Nations developed Seventeen Sustainability Development Goals (SDGs) to address climate change [1]. These seventeen goals address plans to monitor and address how climate change will influence the biosphere and the role of maintaining stewardship goals related to environmental resources, such as fisheries and marine habitat, while sustaining human flourishing, especially in historically improvised areas. While distinct regarding specific reporting elements, these goals overlap among particular groups, for no human activity is isolated from other activities, as highlighted by the Stockholm Resilience Center's wedding cake, where biosphere activities serve as the basis for the second layer of equity and the top layer of economics [2].

Natural disasters are not a minor problem, and climate change is assumed to make these disasters more prevalent and expensive to address [3]. Between 1998 and 2017, disasters from climate or geophysical events killed an estimated 1.3 million people and injured or left 4.4 billion homeless. While most deaths and human losses were from earthquakes and tsunamis, extreme weather events caused 91% of the reported disasters [4]. The Centre for Research on the Epidemiology of Disasters forecasted that these events would only increase over time, leading to more disruptions to human activities such as food production and quality of life. Indirectly, these same changes may influence supporting industries, such as navigation. There is a growing focus on looking at natural disasters in the context of climate security [5]. As such, one SDG focused on climate change, SDG 13, with the goal to "Take urgent action to combat climate change and its impacts". These include reducing human loss from sea level rise and storm events, but other SDG groups also seek to address natural disasters by building more resilient communities (SDG 12).

To assist in this goal, the United Nations developed the SENDAI Framework for Disaster Risk Reduction in 2015 to integrate existing agreements on climate response [6]. The SENDAI Framework seeks to achieve the following outcome: "The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities, and countries". Rather than outline what risks are, the SENDI Framework listed four priorities: Priority 1: "Understanding disaster risk", Priority 2: "Strengthening disaster risk governance to manage disaster risk", Priority 3: "Investing in disaster risk reduction for resilience", and Priority 4: "Enhancing disaster preparedness for effective response and to 'Build Back Better' in recovery, rehabilitation and reconstruction".

There is a need to clarify risks and how these changing conditions may influence specific industries, although most possess robust planning and response capabilities. The challenge is that risks need to be evaluated in the context of awareness and planning, which depends upon agreeing on what risks exist and how to communicate within the respective location. There needs to be more than just listing disasters; this information requires engagement with local groups in planning and responding to these disasters (this engagement with locals supports Sustainability Goal 17, Partnerships for Goals, which focuses on data and institutional sharing). There is a need to reconsider how risks are assessed locally and nationally and, by extension, their effects on other sustainability goals. Therefore, how should local groups compare their activities to SDGs, especially concerning changing weather patterns and local activities?

Regarding ports and navigation, the discussion on climate change tends to center around sea level rise, even in regions as diverse as Australia and Mobile County [7,8]. However, climate change is more than the rise of the sea level. Climate change is expressed in terms of shifting weather patterns [9]. These concerns have been rising sea levels, changing port infrastructure, and water variability for inland navigation. Barros et al. developed a crosswalk between inland navigation and broad sustainable goals; therefore, the focus of this paper will be more narrowly related to sustainability goals and seasonal events [10].

As the relationship between climate change and security/adoption merges, climate change influences the nature of natural disasters, food security, and general community well-being. The problem is that "everyone knows the weather", but as the costs associated with responding to natural and human-caused events increase, there is a growing demand for incorporating risk-based assessments in both the public and private sectors, partially through technology collection but also through better forecasting, big data, and cooperation. One of the challenges Rocha et al. describe through a proposed Coastal Vulnerability Index is that these models and indices are not standardized in their approach to calibrating a coastal baseline [11].

The challenge is that weather patterns are changing. While it is necessary to discuss aggregate rises in the world's temperature, these effects are more apparent in the spring and fall transitional months. In some ways, they change the relationship to human activity, such as the maritime sector [12–14]. These assumptions concerning a "typical" seasonal event may change the relationship to human ecosystems as weather patterns change but are difficult to describe only on an annualized basis.

This effort is one of a limited number of studies that propose looking at waterways monthly, although water levels and operational limitations in Central Europe have been considered on a sub-year basis [15]. While Meißner et al.'s study focused on waterway levels, this study focuses more on examining seasonal events, of which water levels are but one element. Furthermore, other studies have considered changing Arctic conditions, a climate-related seasonal pattern, or sea ice for the Great Lakes, which adds to mariners' exposure to cold weather events while also putting pressure on mitigation strategies [16,17]. The challenge is that maritime disasters focus on singular weather-related events but assume all events contain a human factor element, such as those related to offshore operations [18]. This focus on assessing and mitigating risks, especially in managing vessel operations, has served the industry well. However, some concerns are that changing climate patterns will influence human work patterns and lead to more exposure to natural disasters [19].

Conversely, the changing nature of water levels may also pressure the availability of inland navigation to provide reliable service. As such, changing water levels may lead to a mode shift to other, less environmentally friendly modes [20]. Therefore, while this may be seen as a natural disaster discussion, other operational considerations are not considered "disasters" but will be shaped by changing climate activities on a seasonal basis.

This is not to say that maritime researchers have not categorized various risk and disaster events in other settings. Many papers propose risk trees sorted by different phenomena, such as the 4M (Man, Machine, Medium, and Management) approach used by Tao et al., who developed a matrix to examine maritime risks [21]. Their four categories are centered around operational constructs, such as crew (fatigue, negligence, poor training), ship (component failure, navigation problems), channel (dimensions, depth, shoaling), and finally, the environment (fog, rain, and societal events, which includes other vessels). They developed twenty events clustered around five broad categories: crew unsafe acts, ship mechanical failures, harsh channel conditions, adverse weather conditions, and social/economic environments. The groupings were used to develop a static model to assess transportation risks associated with the shipment of spent nuclear fuels in Asia. Other studies have used risk models to examine channel safety, seafarer operations, and collision management [22,23].

For example, Emerson proposed a Waterway Risk Matrix, with four base conditions, Vessel, Traffic, Navigation, and Waterways, to create a Port and Waterway Assessment (PAWSA) framework [24]. The author listed various areas of concern under each condition based on a quality assessment of the current condition. These quality assessments not only include the weather but also human activities, which include conditions in determining their own activity in a waterway, creating a feedback loop between conditions and activities. Over time, these human activities can be assumed to be part of the base or initial condition, especially if these activities indicate a known, predictable relationship to water and weather patterns. When events change the initial conditions, various consequences may occur, creating new base conditions depending on the scope, severity, and duration. Ultimately, each event may generate its consequences, which then may shape the conditions of a port or community for some undesignated time or with unspecific economic costs. In many ways, the Activity, Condition, Event, Consequence (ACEC) methodology provides a framework for looking at events, but these events from their consequences (Figure 1). This approach may help examine events that are difficult to quantify, but as the SDGs include both human and natural events, the feedback loop is appropriate for linking sustainability goals to risk management structures.

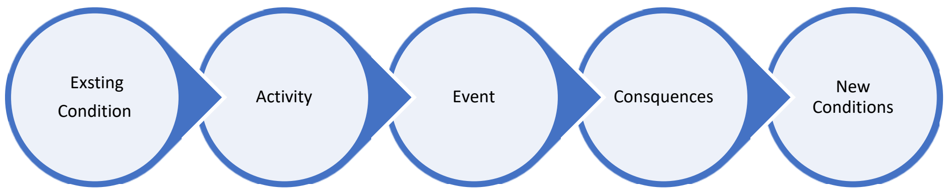

Figure 1. The feedback relationship among activities, conditions, events, and consequences.

One of the challenges is the need to discuss risks, either from a performance metric, as in the case of the SDGs, or to develop risk assessments, as in the case of maritime operations. While most events have a seasonal pattern, these events are not necessarily identified as such. For example, in the National Risk Register, except for volcanos, earthquakes, and tsunamis, the case could be made that the other variables may possess some seasonal element. Other databases, such as the International Disaster Database and the recent Geocoded Disasters extension, do not include a seasonal element but only report annualized data.

Part of this could be based on the taxonomies used in disaster management, which have seasonal and non-seasonal patterns. The PERIL System includes Geophysical, Hydrological, Meteorological, Climatological, Biological, and Extraterrestrial categories [25]. The SENDAI structure outlines the family tree of meteorological, hydrological, geohazards, environmental, chemical, biological, technical, and societal hazards [26]. While not all events are seasonal, their relationship to climate change may be. Also, this broad view of hazards is based on an event with measurable human loss of life or property; navigation-related disruptions may be "too small" for consideration. Focusing on metadata about various data sources, Mazin et al. concluded that no single database covers all information in a manner that may satisfy national/local disaster research needs [27].

Building on Mazin et al.'s criticism of global disaster databases, this study acknowledges a time bias (in this case, annualized, not seasonal, information) and an accounting bias, where risks, especially maritime-related, are quantified concerning exposure. However, people respond to "real events" and plan according to their perceived uses, regardless of the risk taxonomy used. There are practical implications, as Messner et al. developed a methodology to evaluate vulnerability and risk at the Port of San Diego to estimate sea level rise and other related climate change events [28].

There is no way to decouple navigation actions from other human activities, such as fishing, water supply, agriculture, or ecological management. While waterways are essential, these different activities should be treated not as risks but as events, not all of which are "bad" or result in loss of life or property. Cultural events may draw large crowds but are seen as a net positive from a wellness and economic perspective and are a component of the Sustainability Development Goals for supporting communities. Rocha et al. stressed, "It is recommended that coastal risk assessments include an integrated approach that considers the environmental changes, socioeconomic developments, and the interactions between these elements" [11].

In any planning assessment, there is a need to classify what to include before any empirical work occurs, as failing to do so may result in ignoring things that may not be "quantified". It may be essential to consider the timing of predictable events to improve communication within a location. These events should be documented and included in a risk profile as needed. (One could identify four main "realms" related to awareness or response to an event. The first group is emergency responders who plan and respond with "whole-of-community events" to traditional disasters. Secondly, there are localized groups responsible for specific industries, such as industry regulators, that focus on domain awareness and specific activities to mitigate disruptions. Thirdly, there are local businesses that assess risks in the context of their operations, and finally, there are the Supply Chain, or external users, who consider local events in the context of broader operations. Each has specific notification, awareness, and planning needs but also resources and legal obligations in response to an event). The challenge is to agree on events that are likely to happen and to ensure that communications pre-event, during the event, and post-event occur.

The literature review suggests a need for more structure to categorize local actions within the context of national activities and, by extension, events that may be subject to pressures from changing weather patterns; therefore, traditional disaster frameworks must be examined [29]. Many databases/reports will discuss risks and events annually, but not at an operational level. For example, although there are extensive daily reports, nothing is assessed and republished monthly to assist planners, which includes shippers or other stakeholders, and operational decision makers, such as terminal managers, vessel operators, or pilots, related to transportation activities. However, many of these events may exhibit a seasonal pattern. While changing conditions, one would argue such reassessments are critical.

Climate change and the corresponding need for adoption are one component of the Sustainability Development Goals (Climate Change 13). Still, the consequences of changing seasonal weather patterns may influence other SDGs. Conversely, maritime operations treat weather as just one of the many events that may occur (Figure 2). A research gap occurs, as both areas must address seasonality as a planning component. Still, neither framework is suitable for assessing predictable, known events that may appear throughout the year. There are several reasons for this occurrence, but the gap exists, especially as concerns over system resiliency do not necessarily align with sustainability concerns.

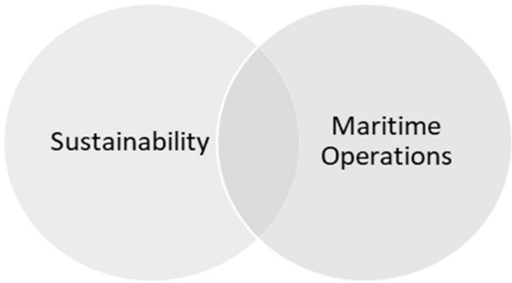

Figure 2. The gap between sustainability and maritime operations.

This gap, represented by the middle-shaded area, recognizes that sustainability goals and maritime operations could benefit from baselining predictable, seasonal events. The development of a Seasonal Event Matrix (SEM), the authors suggest such a framework could provide a starting point for a unified perspective of the predictable events within a specific maritime system that can be linked to some elements of the Sustainability Development Goals.

Here are three research questions:

1. Can a Seasonal Event Matrix (SEM) be developed?
2. What data are available to populate the SEM? How does one collect and classify this information?
3. How could stakeholders validate and use the SEM?

3. Methodology

This research recognizes the importance of supporting communication and feedback and provides a framework for combining publicly available information with local knowledge. Waterways and navigation operate within the context of complex systems. The SEM provides a framework for considering operational and monthly events that may be tied to climate change resiliency goals. In some ways, this basic research looks at developing a framework for understanding the "rhythm" of a port area that can also be used as input in other studies related to navigation sector risk and capacity management.

This paper developed a framework to collect and organize these events to help port managers, operators, and other interested parties identify the essential events in a particular waterway sector. This structure maintains the broad Emergency Management focus of the UN's SDG 13 but expands it to identify specific monitoring and operational needs (this approach would be considered a "preassessment" activity, as related to the guidance document released by the Cybersecurity and Infrastructure Security Agency. In the guidance, there is a framework concerning how to identify a marine system and/or terminal, as well as some resources concerning information related to assessing risks [30]).

The methodological outline is as follows:

1. Define the study area;
2. Develop the activities and conditions to use as the categories to determine what information to include in the Seasonal Event Matrix;
3. Populate the SEM with posted information, initially from national sources but supplemented by desktop scans and local knowledge;
4. Validate the information with various regional stakeholders.

3.1. Define the Study Area

The first step is to define the scope and scale of the domain. Risk managers look at broad events that may result in a loss of life or economic costs but recognize regionalization matters. For example, earthquakes, snow, wildfires, and tsunamis occur worldwide but not in all places. A coastal community may have different flooding events than an inland region. While meta-studies focus on specific events over larger geographies, broad events over vast areas require some limitations to prioritize risk considerations. The focus on a specific location may help eliminate items that may not occur.

This study explores the Central Gulf (the U.S. States of Alabama, Louisiana, and Mississippi). The Gulf Coast is classified as having a subtropical climate [31]. It has hot, humid summers with mild winters. Due to its location between the Gulf of Mexico and the Continental United States, many boundary fronts move through the region, especially in the spring and summer months. The region also experiences hurricanes from late summer into fall.

The Central Gulf is home to some of America's most significant maritime clusters, including six of the Nation's top 15 tonnage ports [32]. Barge and ocean-going vessels move over 2.3 trillion short tons of cargo through the region [33]. The three states have many deepwater and inland ports along significant waterways (Gulf Intercoastal Waterway, Mississippi River, Tennessee–Tombigbee, Black Warrior, and the Red River). According to the U.S. Army Corps of Engineers (USACE), there are over 2600 docks and almost 50 locks [34]. It is in the center of the nation's energy corridor and is the most significant grain export corridor. Still, the region is also home to advanced manufacturing in aviation and transportation. As there is a nexus between counties, where most emergency coordination occurs to waterways, there are 213 counties and parishes in the Central Gulf area, providing some diversity regarding estimating more localized events.

3.2. Define the Risks/Events to Include in the SEM

The next step is to develop a regional event category hierarchy. Once the study area was determined, the SEM requires examining seasonality to predict known risks, based on understanding current conditions and human activities (this paper talks about predictability, defined here as the season during which an event may occur or a general understanding of when an event will occur. It is not defined as a statistical probability, which, for this paper, is a quantified estimation that an event will occur. In some ways, probability may be considered changeable, based on the appropriate timeframe, such as the probability that something will occur over the course of a year, or the probability that an event will occur within the next week, and these are considerably different. Oftentimes, this concept of "annualized" probability may ignore the variation over the year concerning these events). There is no definite structure concerning classifying risks, primarily based on predictable (seasonal) probability, as local information may report similar events but based on different conditions. For example, high-water conditions occur in the spring for inland waterways, while other waterways experience high-water conditions due to rain events. On an annual basis, both would report that high water occurs.

The initial focus is developing an event profile based on nationally available information. In Appendix A Table A1, the National Risk Index, produced by the Federal Emergency Management Agency, lists eighteen natural hazards at the county level [35]. While the model estimates annual risk, for this purpose, the focus is on the events likely to occur over a year; therefore, the annualized information needs to be disaggregated seasonally (other events, such as terrorist attacks or active shooter incidents, but also component failure, such as a pipeline rupture, reflect an uncertainty that may not necessarily have a seasonal element). As expected, some natural hazards, such as avalanches and volcanic activity, are not likely to occur in the study area.

For this paper, eight categories were developed based on their linkages to known, seasonally occurring activities and events (the events are also classified into the predominant Three Es of Sustainability: Economics, Equity, and Environmental. As with any classification structure, differences may exist concerning why things occupy certain categories, but the focus of this paper is tied to both the nature of the event and a perception concerning where the risk notification and communication will start the response process, especially as related to a partial or full closure of a port region). They tend to align with some SDGs, although the linkages could be more specific due to the differences in study focus and classification schemas. Therefore, these represent generalized relationships based on the SDG descriptions (these categories are also aligned with the CEC approach mentioned earlier, as stakeholders focus on the event, including elements of notification and communication, without creating a bias towards immediately discussing consequences).

Ecological: This encompasses events that occur naturally, from migratory animals to other regulations or permits that mitigate the potential for biological risk or environmental degradation. The challenge with this structure is one of definition. Hydro-sociology lists human engagement as related to water resources, but there needs to be a clear distinction concerning how to organize and consider water resource management [36,37]. This can also be applied to other items, such as diseases or pathogens. Also, there is a discussion about changing seasons influencing biological components and pathogens for health risks, such as that proposed by the United Nations Office for Disaster Risk Reduction; therefore, it would be considered a subset of the ecological system [38]. This term also includes the role of ecological stewardship, where restrictions can limit operations to protect ecologically sensitive areas, such as bird rookeries or marine mammals (these elements may often be included in environmental assessment reports). There are several studies linking climate change to ecological changes [39,40]. This category is most tied to the United Nation's Sustainability Goals related to SDG 13, Climate Change.

Cultural: Regionally celebrated events may influence landside or waterway access during their celebration. Culture includes other human activities influencing maritime operations, such as kayaking or fishing tournaments. These are not considered risks in the traditional event-planning framework but have implications for managing crowded spaces if an event should arise. These broad events are tied to SDG 1 (end poverty in all its forms everywhere), SDG 11 (make cities and human settlements inclusive, safe, resilient, and sustainable), and SDG 12 (ensure sustainable consumption and production patterns).

Fluvial: This category includes events determined by water movement, such as river flooding, currents, sediment transport, or other factors that influence the condition of waterways and channels. Some of these, such as flooding, are considered in most disaster management groupings, although they ignore the implications of navigation. Thus, a separate group was created, but it is represented by several studies related to navigation risks to water navigation [41]. These are tied to SDG 13, "Climate Change".

Geotechnical: This category includes events related to land structures, such as landslides or avalanches, could be tied to seasonally related events (based on the National Risk Index, there are no avalanche risks in the region, but there are landslide risks. However, the author was not able to determine a causal relationship between seasonality and landslide events in the region; therefore, these risks were treated as non-seasonal). While usually not associated with navigation risks, landsides, especially in island communities, can have significant disruptions, such as in Southeast Alaska [42,43]. Landslides may be seasonal and driven by precipitation, soil conditions, and temperature. Although forecasting tools have improved, challenges regarding warning and near-time prediction still need to be addressed [44,45]. This is tied more to SDG 13, Climate Change, but not as predictable events.

Maritime: This category includes events related to maritime operations, such as cargo, fishing, recreational boating, ferry operations, or other uses that depend on access to naval activities. These represent the activities that depend upon the condition of the river system and are the most responsive to notifications concerning conditions or possible closures. These activities may be considered "background conditions", although disruptions can affect other users in the same region, thus becoming an event. This maritime category may also include planned military operations or exercises. Again, there are two main areas of research: the assessment of generalized risks [46–48] or more specific risks based on particular cargo types, such as containers [49,50], or regional operations, such as the Arctic [16,51]. Concerns about mitigating peak traffic demand through a terminal, such as in bulk terminals, may exist [52]. It is also not uncommon for vessel operations to be restricted to one-way or daylight-only operations for safety reasons due to various factors.

This can limit "traffic" but does not necessarily close a port or waterway. These activities fall under SDG 9, Industry, Innovation, and Infrastructure.

Metrological: This category includes events shaped by weather conditions, such as wind or hail (for most natural disaster events, these elements list various weather events). Weather patterns are well known, but despite this knowledge, it remains a constant challenge to address perception, storms, temperatures, and other related events or even prepare for an incoming storm system. Nevertheless, the "Weather is the Weather" is linked to SDG 9, Industry, Innovation, and Infrastructure, based on metrological-based damages.

Non-Seasonal Natural Events: Natural events outside of a predictability pattern, such as earthquakes or volcanic activity, may cause significant disruptions when they occur. This goal is tied to SDG 12, community and equity.

Other Events: These events occur but are not predictable, such as an oil spill, active shooter, or space debris in any seasonal structure. The Other Events category provides a placeholder for these events that cannot be categorized but if the occur can influence various events, such as outlined in SDG 14's goals.

Based on the authors' experiences and the literature, these categories were overlaid with a corresponding element regarding closures. For example, the port is closed when some events, such as a hurricane, disrupt the entire port/community area [53]. Other events, such as fireworks, may partially close the river for a few hours, but other facilities are open [54]. Also, Mardi Gras (Carnival) is a significant cultural event, and while navigation continues, there may be localized congestion, leading to traffic delays. Other events, such as termite swarms, are annoying but only sometimes close operations down. Thus, the authors estimated three categories regarding closures: full closure, partial closure/restrictions (waterway or landside), or limited or no restrictions on commercial freight movement. These three categories are based on the authors' own experiences. Only some events shut down an entire port complex, as water-related activities do not mean landside activities cannot occur, or the opposite, where a terminal may be closed, but the waterway and other facilities can still be serviced by marine traffic. There appeared to be no consistent definition of a partial or full/complete closure or disruption (these functions largely reside at the discretion of a harbor master or a "Captain of the Port". For the U.S., the federal "Captain of the Port" is a Coast Guard Officer [55]). However, there are plenty of lists of related risks in the maritime domain; therefore, a table was created to define "closures" (Table 1). In many ways, port closures fall into two distinct categories: events that disrupt the entire community (which includes the port) or events that restrict cargo throughout, either by water or land. When assessing risk, the perception of disruptions and consequences ultimately depends upon the risk tolerance of the affected parties.

Table 1. Listing of different types of port closures.

Closure	Implications for Operations	Implications for Community
No Closure	Events may cause minor annoyances, but within routine operations, there is always a risk of escalation if something "happens."	Community is unaffected.
Partial Closure	A segment of a waterway or an inland corridor (rail, barge, or pipeline is inoperative) or operating with restrictions that limit total capacity. There needs to be a discussion on duration or significance, as the focus is on serviceability. It may be worded as "Open, but with Restrictions".	The community may experience delays or losses due to the closure of landside facilities, or community activities may limit regional services.
Full Closure	The port is closed to all maritime traffic until the area is deemed clear to resume operations.	The community becomes inoperable, such as in the aftermath of a significant natural disaster.

These categories influence what events should be added to the SEM structure. Including cultural or environmental regulations, which are not necessarily risks, became a vital engagement point for local stakeholders. The anticipation was that local stakeholders could have considered these events as risks, but they did not understand how these influenced their business operations over the year.

3.3. Develop and Populate the SEM Model

The third step is to populate the matrix based on readily accessible databases, focusing initially on weather events, to be supplemented with the other data elements (including activities) through a desktop scan. Two primary data sources were considered, ranging from national to local information, each requiring a different data collection/integration approach. Still, a basic regional framework was developed before any events were included. The work was put into Excel, expecting that users would not require additional software to use the SEM, nor was there assumed to be a prohibitive learning curve for users who wish to modify the current information (the SEM summarizes the raw data into an Excel Pivot Table that users can manipulate. The columns reflect months when an event will likely happen if it did occur, while events that have no discernable month are listed as non-seasonal. A “notes column” allows users to retain information on particular activities not included in the pivot table. The structure was deemed the easiest to maintain/revise and did not require additional software).

3.3.1. National Risks

The initial integration step was linking the National Risk Index with the U.S. Army Corps Master Docks Plus database. This data provided a framework for integrating a baseline of information on navigation systems, such as waterways, docks, locks, and dams, and where commercial navigation occurs with annualized risks. The National Risk Index included all counties and parishes in the region, but only the county and the events were included for this purpose. Finally, areas identified as coastal zones were determined based on the respective State coastal zone plan [56].

Weather is reported on a monthly matrix at a location, with record temperatures and precipitation posted [57]. The NOAA Storm Database was used to examine these elements and develop a seasonal estimate for each county/parish in the study area, as it reports information monthly and at a county level. However, there are some concerns about using the data as a quantitative source [58]. For some elements, the actual County FIPS reported events occurring in different counties/parishes, such as coastal flooding in Northern Louisiana, or an event is reported at the discretion of the local weather service station. Therefore, the data can provide a good proxy of regional activities despite some coverage gaps. Still, the information provided a starting point for examining seasonal weather events at a county level across the region.

The monthly summary for the three states during 2006–2022 shows that most of these events follow a seasonal pattern (Appendix A Table A2). Spring into summer is when most storm-related episodes and events occur, but intense storms and tornados happen year-round. Some elements were dropped from the metrological category, such as seiches, which were so infrequently reported that how to validate their occurrence needed to be clarified. Also, drought is an accumulated lack of rain that can affect water levels and span multiple months [59]. Finally, the authors could not find a consistent regional database that reported river stages monthly at a county level; therefore, they estimated these based on generalized knowledge (there are several data sources on water conditions, such as the National Weather Service on flood conditions [60,61]. For example, the Mobile District of the U.S. Army Corps of Engineers lists many resources related to monitoring water to support navigation [62]. Other databases, such as the Marine Cadastre, were also consulted, especially for sea level rise and storm surge review [63]). The National Risk Index items were thus disaggregated by month to develop the national-level weather-related SEM. Still, some elements, such as earthquakes, remain in the database but are listed as non-seasonal. Most of the more “significant events” are included in the various UN disaster frameworks and are linked to the Sustainability Development Goals.

3.3.2. Localized Events

The authors conducted a desktop scan to supplement the national data with local information and identified additional seasonal risks. For example, fog is an issue for regional navigation, but it was not listed for Louisiana in the Storms database [64]. Other known events that may influence operations were added. These are listed in Table 2 and came from various sources, such as local emergency responders and discussions with stakeholders (Table 2 serves as a repository for additional events that may be added to the SEM model to maintain a log of the source of the event. In many ways, one could argue this is a systematic literature review, especially if expanded to include environmental reporting based on permitting and other activities. It is assumed that the SEM will never be "finished" for any region). It should be noted that other regions will have different elements within their broad categories, and that the results presented here are tailored to the specific study region. Other regions will exhibit different weather patterns or cultural events; therefore, while the framework is transferable, the results may not be appliable.

Table 2. Review of other categories/events in the region that are not reported in the National Risk Index (source: authors).

Category	Event	Notes and Source	Seasonality
Ecological	Flighted Spongy Moth Complex	Vessels arriving from East Asia must be inspected for egg masses to prevent damage [65,66].	May to October
Ecological	Termite Swarms	Terminates can cause considerable damage, but often that damage is observed after the "swarm" occurs. The swarms are very annoying to workers doing work outside at night. The swarms occur along and south of the I-10 corridor [67].	May
Ecological	Wildfire	Wildfires occur throughout the region, but swamp fires can lead to heavy smoke. A swamp fire combined with heavy fog led to a significant traffic incident in the greater New Orleans area [68–70].	Typically, from fall into Spring, although they may occur year-round
Cultural	Christmas Bonfires	Bonfires are lit along the river to "guide Poppa Noel" to visit Children on Christmas Eve. There is localized congestion [71].	Christmas
Cultural	Fireworks	Fireworks occur in downtown New Orleans, but other ports can have closures due to fireworks. The Coast Guard provides notifications through the Federal Register [72].	The Mississippi River by Jackson Square is closed for fireworks on the 4th of July and New Year's Eve.
Cultural	Mardi Gras	Carnival Season begins on January 6 and extends to Mardi Gras (Fat Tuesday). While the navigation and transportation systems continue to operate, traffic is heavy by parade routes, and hotel space is also limited [73–75].	January–March
Cultural	Unauthorized Fires	Fires are set in unauthorized areas, leading to fires at various piers along the river (Interview with Fireboat Captain).	December–March
Maritime Operations	Saltwater Silt Construction	Occasionally, low-water periods allow saltwater to come up the Mississippi River, which can damage drinking water access. The Corps of Engineers is responsible for mitigating this, typically by building a saltwater dam in the river [76]. This is not done every year but as conditions dictate.	June–October, depending on conditions
Fluvial	Low Water	The Mississippi River drains the Central U.S.; water levels are predicated on snow melt and precipitation events. Traditionally, the fall is the low-water period. Other waterways may be influenced by coastal or rain events. The Tennessee Tombigbee Waterway watershed is also relatively large, but numerous rivers are more driven by rain and tidal movements than systemwide precipitation [77–79].	Fall

Table 2. *Cont.*

Category	Event	Notes and Source	Seasonality
Fluvial	High Water	Traditionally, spring is the high-water period in the Mississippi River. Other waterways may be influenced by coastal or rain events.	Spring
Fluvial	Lock Inspections	The Corps is responsible for locks and dams on federal waterways. Usually, locks are inspected during low-water conditions [80].	Low-water periods—the elements listed here are placeholders, as USACE notifies partiers concerning any expected/ unplanned facility closures/closures.
Maritime	Inbound Containers	Containerized inbound shipments arrive in anticipation of the holiday shopping season [81].	The holiday rush typically occurs in August and ends in the first week of December.
Maritime	Ferry	The LA Department of Transportation operates several ferry services in Louisiana. However, there are execution ferries to Ship Island in Mississippi and a ferry in Alabama [82–84].	Year-round, except for the Ship Island Ferry, which runs from March to October
Maritime	Grain Shipments	Mississippi River is one of the nation's grain export corridors. Shipments by barge and train arrive at the end of the harvest and are shipped out of the port [81].	September–February
Maritime	Offshore Construction	Port Fourchon, the most extensive offshore service port, seeks a drop in traffic in the fall and winter due to changing conditions.	April to September
Maritime	Vessel Cruise	Ocean-going Vessel Cruise [85,86].	Year-round in New Orleans, but seasonal in Mobile
Maritime	Dinner Cruises	Local dinner and excursion vessels [87,88].	The New Orleans Steamboat Company and the Creole Queen run two services
Maritime	River Cruises	Inland Shallow draft vessels [89].	Year-round south of St. Louis
Maritime	Military Cargo	Ports dedicated to supporting Military operations [90].	Year-round
Metrological	Marine Fog	Marine Fog is caused by warm air moving over colder water, resulting in advection fog [91–93].	Typically, fog starts in late fall and ends in early spring.

3.3.3. Stakeholder Engagement

The last step was to solicit stakeholder review. The authors identified stakeholders to review this, which included various federal agencies (U.S. Army Corps of Engineers, the U.S. Coast Guard, and the National Oceanic and Atmospheric Administration), the region's ports, several trade associations, and other local maritime stakeholders. It was stressed that this work is more exploratory and not a specific guidance or recommendation.

4. Results

The goal is to develop a single monthly matrix for all users to understand their expectations concerning access and usage of the waterways. Therefore, the first question is, does seasonality matter? While the region experiences hot, humid summers and mild winters, there are changes due to metrological events. Also, different events occur throughout the area due to water levels and cultural activities.

The second question is whether the matrix presents the information in an easy-to-understand format. The balance remains on capturing this knowledge while not penalizing the lack of exactness nor diminishing the ability to communicate the seasonal nature of a waterway system to inexperienced staff or non-maritime stakeholders interested in understanding regional risks. Thus, the monthly matrix is designed for non-specialists but should also be relevant to the maritime operator (the SEM's lowest geography level is at the county level; therefore, the counties could be linked to various visualization software packages. This also aligns with traditional port regions or boundaries, but in the U.S., is often the lead administrative agency, in partnership with city agencies, for local emergency operations).

Figure 3 shows the final table of the screenshot of the SEM for the states of Alabama, Louisiana, and Mississippi from the Excel database. As expected, meteorological events occur in every county/parish, but from an event matrix, 101 counties or parishes have navigation activities as reported by the USACE [34]. The Months of April and October were highlighted to assist the reader in comparing the difference in seasonal patterns.

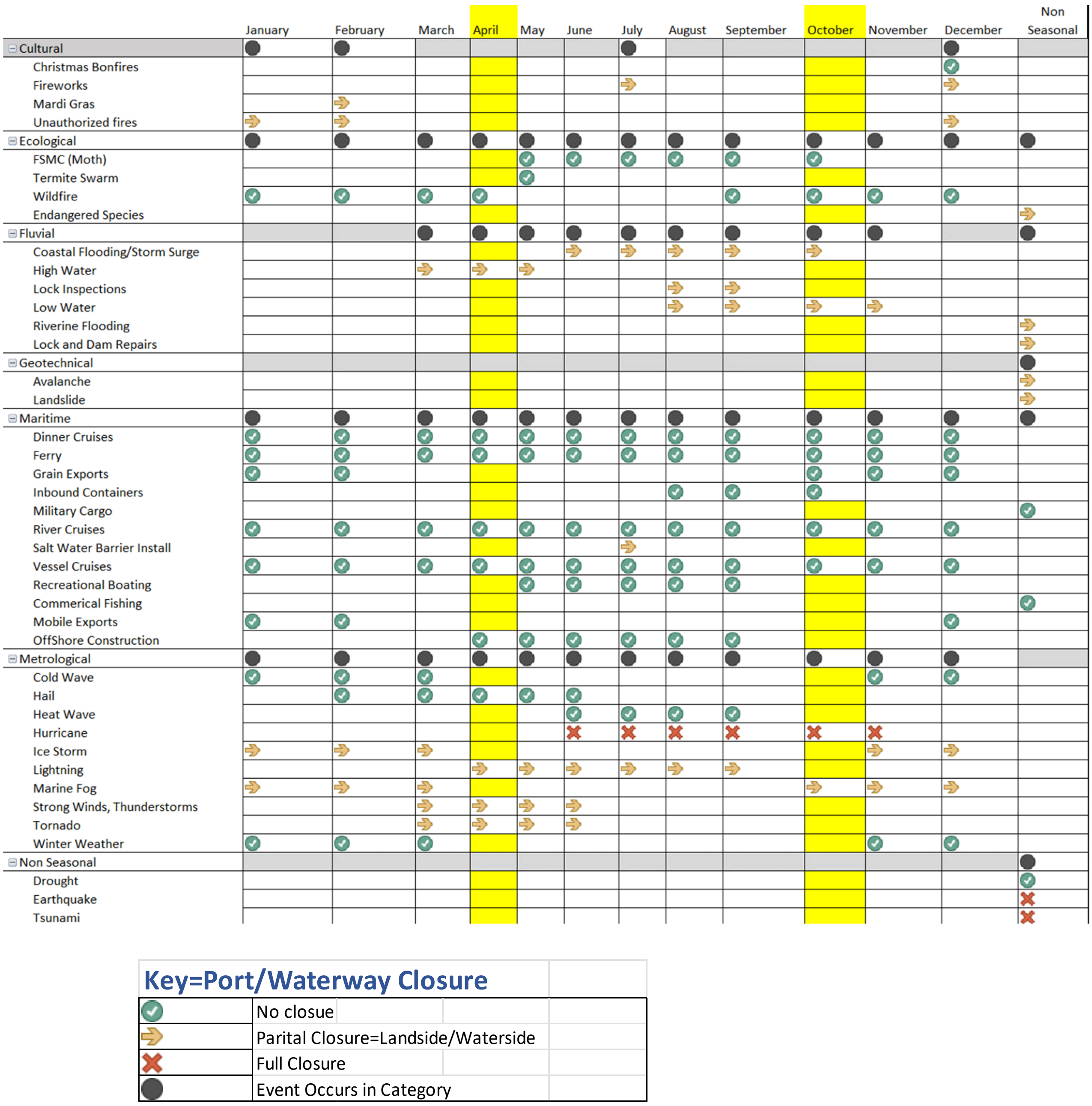

Figure 3. The regional seasonal event matrix for Alabama, Louisiana, and Mississippi.

To test the usefulness of this SEM methodology, the authors recognized the need to evaluate the differences among the three port areas. Three different counties/parishes were considered: Orleans Parish, Louisiana; Warren County, Mississippi; and Mobile, Alabama. Orleans Parish ranks as one of the U.S.'s top tonnage ports. It handles a mix of breakbulk (steel, rubber, metals, and coffee), project cargo, containers, and bulk products through 140 publicly and privately owned docks and terminals [34]. According to the U.S. Census, there were over 380,000 residents in 2020. Warren County is located roughly 300 miles upstream along the Mississippi River, home of the Port of Vicksburg, with a population of 44,700 [94]. The port handles a mix of bulk and break-bulk products, such as metals, alumina ores, wood pallets, grains, and fertilizer, through the 36 docks reported in the county. Mobile County's maritime community is critical to the regional economy, with over two hundred docks and 183,000 people. Meanwhile, the port of Mobile receives containerized, break-bulk, and bulk cargo operations facilities and other facilities at Chickasaw and private operations throughout Mobile County. Figure 4 highlights the study area [95].

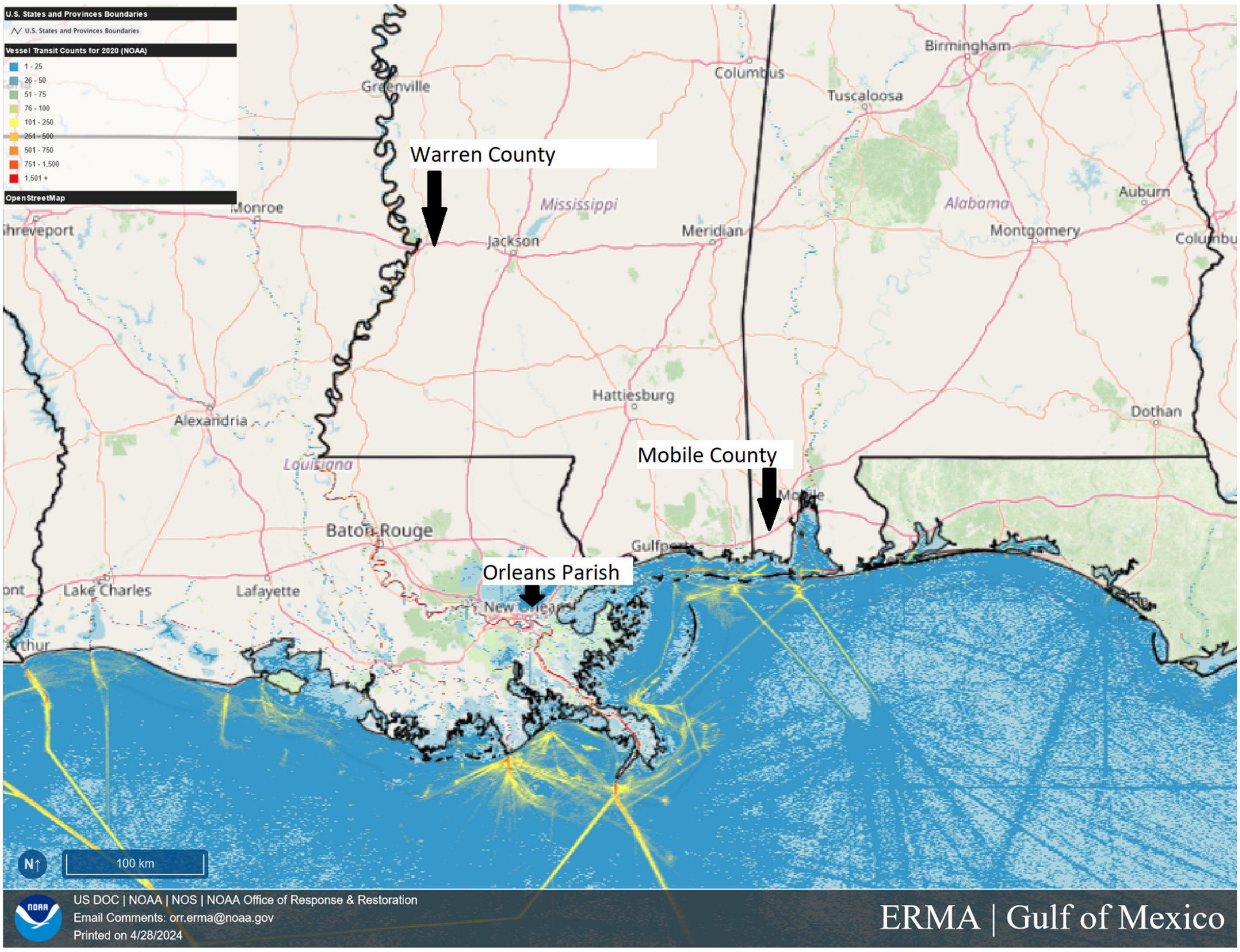

Figure 4. Location of the study area, with Orleans Parish, Warren County, and Mobile County highlighted.

All three regions handle barge services, but both Orleans Parish and Mobile County service ocean-going vessels. As such, Orleans Parish and Mobile are exposed to coastal activities and events specific to deep-sea navigation. Warren County, located further north, experiences the same broad regional weather events but different marine-related risks due to its navigation sector and infrastructure (as one of the authors lives in the greater New Orleans Area, there is a bias towards more information on the lower Mississippi River than in other regions). Figures 5–7 show the SEM results for New Orleans, Warren County, and Mobile County. Again, the months of April and October were highlighted to show seasonal variability.

Event Occurance	January	February	March	April	May	June	July	August	September	October	November	December	Non Seasonal
⊟ Cultural	●	●					●					●	
Fireworks							→					→	
Mardi Gras		→											
Unauthorized fires	→	→										→	
⊟ Ecological	●	●	●	●	●	●	●	●	●	●	●	●	
FSMC (Moth)					✓	✓	✓	✓	✓	✓			
Termite Swarm					✓								
Wildfire	✓	✓	✓	✓					✓	✓	✓	✓	
⊟ Fluvial			●	●	●	●	●	●	●	●	●		●
Coastal Flooding/Storm Surge						→	→	→	→	→			
High Water			→	→	→								
Lock Inspections								→	→				
Low Water								→	→	→	→		
Riverine Flooding													→
⊟ Geotechnical													●
Avalanche													→
Landslide													→
⊟ Maritime	●	●	●	●	●	●	●	●	●	●	●	●	
Dinner Cruises	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Ferry	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
River Cruises	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Vessel Cruises	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Recreational Boating					✓	✓	✓	✓	✓				
⊟ Metrological	●	●	●	●	●	●	●	●	●	●	●	●	
Cold Wave	✓	✓	✓								✓	✓	
Hail		✓	✓	✓	✓	✓							
Heat Wave						✓	✓	✓	✓				
Hurricane						✗	✗	✗	✗	✗	✗		
Ice Storm	→	→	→								→	→	
Lightning				→	→	→	→	→	→				
Marine Fog	→	→	→							→	→	→	
Strong Winds, Thunderstorms			→	→	→	→							
Tornado			→	→	→	→							
Winter Weather	✓	✓	✓								✓	✓	
⊟ Non Seasonal													●
Drought													✓
Earthquake													✗
Tsunami													✗
Volcano													✗

Key=Port/Waterway Closure	
✓	No closue
→	Parital Closure=Landside/Waterside
✗	Full Closure
●	Event Occurs in Category

Figure 5. Seasonal event matrix for the Orleans Parish, screen capture of excel database (April and October are highlighted to reflect seasonal variation).

Event Occurance	January	February	March	April	May	June	July	August	September	October	November	December	Non Seasonal
⊟ Ecological	●	●	●	●					●	●	●	●	
Wildfire	✓	✓	✓	✓					✓	✓	✓	✓	
⊟ Fluvial			●	●	●			●	●	●	●		●
High Water			➔	➔	➔								
Low Water								➔	➔	➔	➔		
Riverine Flooding													➔
⊟ Geotechnical													●
Avalanche													➔
Landslide													➔
⊟ Maritime	●	●	●	●	●	●	●	●	●	●	●	●	
River Cruises	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Recreational Boating					✓	✓	✓	✓	✓				
⊟ Metrological	●	●	●	●	●	●	●	●	●	●	●	●	
Cold Wave	✓	✓	✓								✓	✓	
Hail		✓	✓	✓	✓	✓							
Heat Wave						✓	✓	✓	✓				
Hurricane						✗	✗	✗	✗	✗	✗		
Ice Storm	➔	➔	➔								➔	➔	
Lightning				➔	➔	➔	➔	➔	➔				
Strong Winds, Thunderstorms			➔	➔	➔	➔							
Tornado			➔	➔	➔	➔							
Winter Weather	✓	✓	✓								✓	✓	
⊟ Non Seasonal													●
Drought													✓
Earthquake													✗
Tsunami													✗
Volcano													✗

Key=Port/Waterway Closure	
✓	No closue
➔	Parital Closure=Landside/Waterside
✗	Full Closure
●	Event Occurs in Category

Figure 6. Seasonal event matrix for Warren County, Mississippi, screen capture of excel database. Warren County, initial SEM. (April and October are highlighted to reflect seasonal variation).

If one made a cursory comparison between April and October (the highlighted areas), one can see different seasonal patterns. April is typically a high-water season in the Mississippi, but the region experiences seasonal thunderstorms. In October, while there is hurricane season and potential marine fog, there are fewer seasonal thunderstorms. The cargo mix is different; the grain season starts when grain moves down the Mississippi River by barge. The U.S. Army Corps conducts most of its "in-water" inspections and repairs during low-water periods. These tables were shown to the respective regional stakeholders for validation.

Warren County, Mississippi, has fewer natural disaster risks due to its inland location. As with the Orleans Parish, it experiences similar metrological events, such as thunderstorms and winds, but there are no coastal-related risks. However, as Warren County sits along the Mississippi River, its maritime community does respond to the exact change in seasonal water levels, and its docks and terminals are constructed to manage the changes in water levels. Moreover, like the Orleans Parish, some changes occur when one compares April and October, primarily due to water levels and other potential national disasters (the highlighted months).

Like Orleans Parish, Mobile County experiences many of the same coastal and cultural events. However, the Mobile River and its tributaries, which drain into a large coastal estuary, mitigate some of the fluvial pressures of the Mississippi River, as it is still a managed (leveed) river through Orleans Parish.

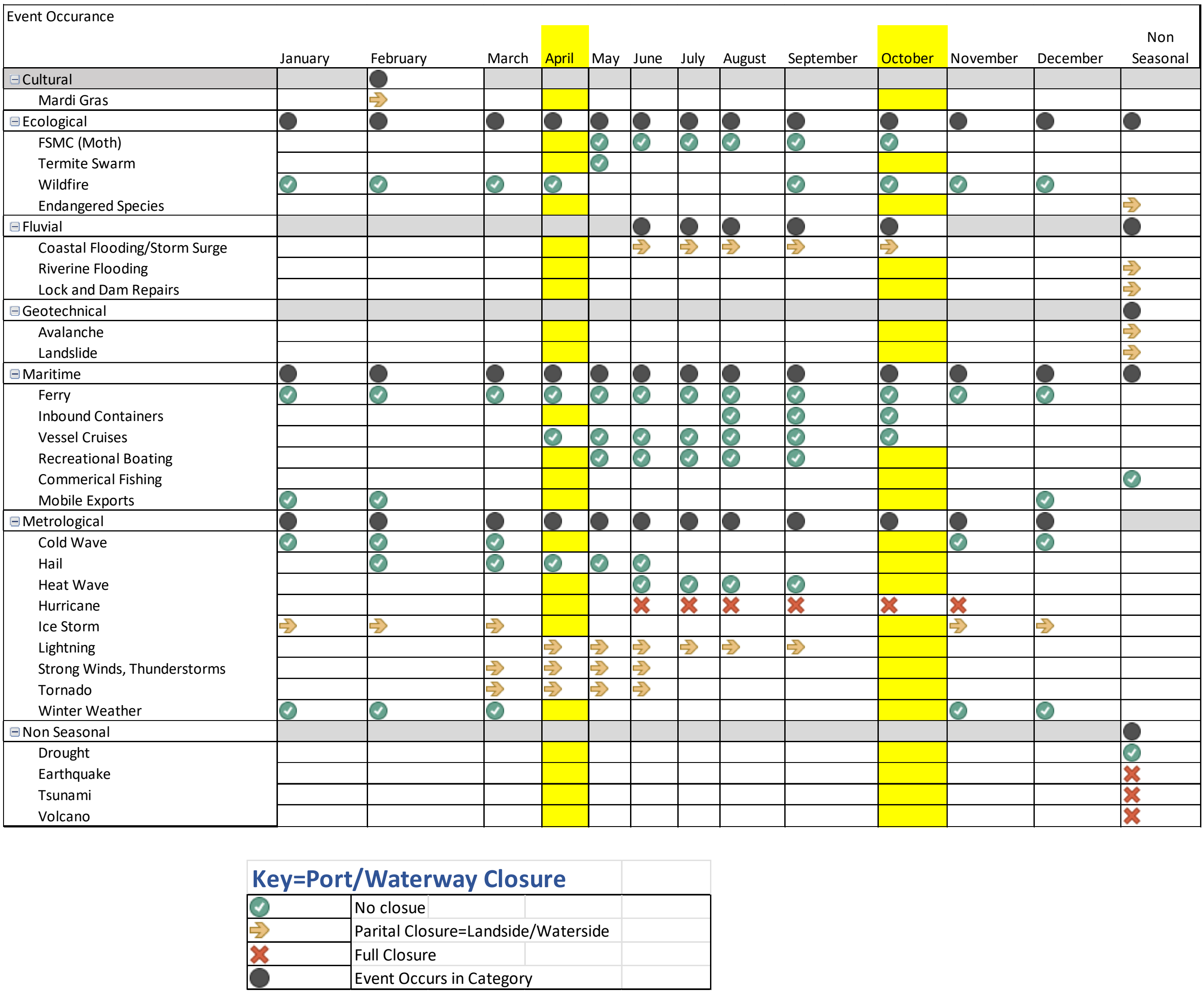

Figure 7. Seasonal event matrix for Mobile, Alabama, screen capture of excel database. (April and October are highlighted to reflect seasonal variation).

Stakeholder Review

SEM outputs were shared with regional stakeholders. Initially, many stakeholders struggled with the concept that not all events were catastrophic; therefore, there was a question asking why include these at all. This led to discussions concerning consequences, reporting, and risk awareness. Once briefed on the SEM structure and the need for broad categories, most recognized the value of organizing awareness of seasonal events (discussions with trade associations, pilots, weather service forecasters, ports, and federal agencies were conducted throughout 2023 and early 2024. It was stressed that their feedback was not "an official" support of this SEM by themselves or their organizations). They also recognized its usefulness in "framing" activities, which may become events, which are often not considered at a national level but are important locally. There were concerns over maintaining such a table, as well as how to share the information with other stakeholders. The general viewpoint of federal officials was practical, especially in training unfamiliar staff. By contrast, the non-federal officials saw the SEM as helpful in engaging non-local ship agents and beneficial cargo owners. Both groups appreciated having a framework for looking at regional events beyond their traditional planning calendars that incorporated other elements considered "external" to their specific operations and, by extension, some of the relationships identified in the SDG structure.

One theme that emerged was the consideration of the SEM as a planning tool incorporating nationalized information on seasonal events supplemented by localized knowledge. The potential for cascading and unrelated events exists, in addition to quantifying small events, which may be treated as simply the cost of doing business. For example, heavy fog may result in a vessel remaining at the dock, resulting in additional fees for dockage. There is no significant loss if no one moves, but moving in heavy fog conditions can lead to damage/loss to vessels, docks, or staff. The tragedy is that some other elements, especially smaller events, are only considered when a failure occurs.

The focus on identifying what elements could be included is worthwhile, especially as most risk assessments do not include predictability or "foreknowledge" of an event's occurrence in their protocols due to a focus on consequences. Knowing the event is as important as its consequences, especially when addressing events in the broader discussion of multipurpose sustainability goals.

5. Discussion

The SEM represents a framework for assessment. However, the research identified challenges concerning various stakeholders' adoption of this framework. Three areas for additional discussion could focus on the framework's purpose, data elements and collection, and finally, the SEM's use.

Firstly, risks and uncertainties must be considered for items related to the SEM's purpose. Knowing what to evaluate is as essential as the monitoring itself. The adage "forewarned is forearmed" is relevant when mitigating risks. For example, as SDGs are reported with annual data and include estimated deaths at a country level, the SDGs may not be appropriate for looking at localized events, which can have economic consequences but maybe change due to shifting weather patterns. The development of a seasonal element, while not necessarily based on quantifiable measures, would better illustrate the differences of predictable events among different regions to identify events to SDGs and to monitor if these shifts are occurring. Using the SEM model lies in its simplicity, where robust climatological data can be integrated with other, less qualitative data to form a basic structure to consider seasonally determined events at a localized level. However, that simplistic structure may also create a problem, as local experts may not see the importance of categorizing these activities and their translation into events although local emergency planning is included in the SDG structure. Still, without such a framework, it could be suspect to some degree of cognitive bias from both non-local and local stakeholders.

Related to elements and collection, not all data elements come from publicly available information, nor is the information available even in published sources. For example, how does one quantify events like Mardi Gras or Christmas fires along the waterfront? Some ecological events could be gleaned from other documents related to environmental impact assessments, planning, or statutory documentation required to secure specific permits, especially related to marine habitats and migratory animals. When the focus is on collecting information on known things that may occur, non-statistical information may be underreported. However, other data concerns may be related to the potential release of confidential data, influencing how people participate in such a process and their comfort with releasing that information. Finally, it is common for people to focus on the various activities (but ignore the methodology) that is the basis of the SEM framework.

Related to application, if SEM estimates are developed across broad regions, in this case, the Central Gulf, they could be expanded to more significant areas, such as at a national level. However, that may also require a reexamination of the metrological data used in this report to better align risks at a local level. But, the SEM could provide a basis for more scenario-based risk frameworks, which can alleviate component-based risk estimations [96]. Regarding climate change, the assumptions of seasonal stationary may be in error, especially without a common baseline of activities and conditions. In this regard, the SEM model may help link broader discussions about climate adoption and resiliency to operational concerns. Incidentally, such information can assist in developing better algorithms for "smart" maritime operations/ports, which may not be able to optimize without quantifying local variations or for the management of multimodal corridors to optimize sustainability goals, especially as related to potential disruptions.

Furthermore, the SEM may be extended to other industries. Several studies on airport conditions suggest such a framework may be beneficial when examining regional airport networks. Each discussed weather conditions, but there has yet to be an attempt to classify them into a single matrix that accounted for the totality of delays mentioned by Kulesa [97–100]. Weather conditions influence highway and rail transportation or can be "multimodal", for example, when planning an emergency response for an island state where airports and ocean ports may be affected, although in a different manner, by predictable events.

The SEM provides a structure to link these groups to discuss these unique structures, but at best, it will remain a small part of any specific dialogue, as the rest of the SENDAI report highlights as necessary. As simple as this sounds, the information is not easily accessible or summarized in a manner that can be used to develop such a matrix. The SEM aims to communicate, especially in discussions concerning events across diverse stakeholders. Such communication could also be extended to discussions concerning insurance, especially seasonal-related insurance claims ranging from general claims concerning catastrophic events to vessel transits [101–103]. In this regard, the SEM could include more discussions on notifications and consequences related to specific events.

Finally, the SEM is not a risk assessment tool. Traditionally, risk assessments focus on quantifying risks, of which the SEM framework could quantify either a single event or multiple events. Additional work should seek to understand how the SEM framework could be used to develop a regional risk matrix, which includes discussions on duration, severity, or other consequences, but also with pre-event and post-event communications. These discussions could build upon activities and conditions and how stakeholders perceive risks for the same event. Furthermore, the SEM could be used to validate response-planning activities to see if there may be some "unknown" occurrence that may shape an incident command or risk mitigation.

In closing, using the SEM to organize predictable risks may be criticized as too simplistic or not contributing to primary research, or the consequences and risk profiles may not be estimated for each event. Several studies cited suggest that the data/research standardization gap remains problematic. By assessing published information and calibrating that information with stakeholders, the SEM can assist in managing awareness, in this case, for the maritime system in the Central Gulf. With the potential for simultaneous events, the SEM may fill that knowledge gap and assist in addressing SDG 17 of improving collaboration, especially if there were improved meteorological and other climate-related information formulated for the SEM structure.

6. Conclusions

Concerns over climate change have led to the adoption of 17 Sustainability Goals by the United Nations. During the same period, there has been an increased focus on understanding disaster-related events, especially regarding the maritime sector. Understanding the nature of risks, which range from catastrophic events to manageable "annoyances", may not necessarily consider the predictability of the possible timing of an event, which presents a challenge for planners and emergency responders. The purpose of the SEM is to raise planning awareness about effectively addressing risks and uncertainties. It is crucial to identify what needs evaluation, as well as to recognize the importance of being forewarned to mitigate risks effectively. While most Sustainable Development Goals (SDGs) are reported annually with country-level data, they may not capture localized events that can have significant economic consequences. Despite its qualitative nature, introducing a seasonal element could better illustrate regional differences in predictable events and their alignment with SDGs. There is no framework that looks at seasonal patterns; therefore, risk assessments may be biased due to this data gap.

As with most industries, navigation encounters predictable, seasonal elements, ranging from storms, changing water levels, regulatory restrictions, and diverse cargo seasons. While these seasonal events are known, they are not baselined into a single framework despite the available data and localized knowledge. This paper attempted to fill that gap by developing the Seasonal Event Matrix to integrate the awareness of locally predictable events with other natural events and to link navigation risk to the United Nations' Sustainability Development Goals. The SEM Framework could capture events or provide the starting point for a localized risk assessment, especially as not all events can be quantified, but it must include local participation, something that may be lacking from a traditional topline, national data collection, or risk assessment approach. As the SEM framework does not aim to encompass all possible events or provide precise localized probabilities for risk assessment, recognizing the inherent limitations in quantifying every conceivable scenario is necessary. However, the framework for examining published data, joined with specialized local knowledge, which is verified by stakeholders, can be transferred to other regions.

This paper developed and tested a framework to provide a basis for communicating predictable risks within a maritime system. The structure allows events to be collected, ranging from disasters to ongoing maintenance and regulatory activities to minor events, without any judgment concerning their duration or severity. The comparison among Mobile County, Warren County, Mississippi, and Orleans Parish, Louisiana showed how local knowledge gaps exist outside published resources.

The Seasonal Event Matrix demonstrates the feasibility of such a framework, albeit with the understanding that it should complement other sources of information. Regional variations in seasonality within broader geographical zones, such as the Central Gulf Region, highlight the necessity of flexibility in applying this framework. While not every event may qualify as a "disaster", the SEM allows for the improved communication of well-known occurrences, including hurricanes, water level fluctuations, and cultural events. By aligning navigation risk management with the UN's Sustainability Goals, this framework serves as a vital tool in fostering international collaboration towards a more sustainable and resilient maritime sector.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16093820/s1, and it was posted on https://www.preprints.org/manuscript/202403.1522/v1/download/supplementary (accessed on 25 April 2024).

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Appendix A

Table A1. List of hazards in the National Risk Index; source: National Risk Index [35].

Hazard Type	Definition in National Registry
Avalanche	An Avalanche is a mass of snow traveling down a mountainside in swift motion.
Coastal Flooding	Coastal Flooding is when water inundates or covers normally dry coastal land due to high or rising tides or storm surges.
Cold Wave	A Cold Wave is a rapid fall in temperature within 24 h and extreme low temperatures for an extended period. The temperatures classified as a Cold Wave are dependent on the location and defined by the local NWS weather forecast office.
Drought	A Drought is a deficiency of precipitation over an extended period of time, resulting in a water shortage.
Earthquake	An Earthquake is a shaking of the earth's surface by energy waves emitted by slow-moving tectonic plates overcoming friction with one another underneath the earth's surface.
Hail	Hail is a form of precipitation that occurs during thunderstorms when raindrops, in extremely cold areas of the atmosphere, freeze into balls of ice before falling towards the earth's surface.
Heat Wave	A Heat Wave is a period of abnormally and uncomfortably hot and unusually humid weather typically lasting two or more days with temperatures outside the historical averages for a given area. The temperatures classified as a Heat Wave are dependent on the location and defined by the local NWS weather forecast office.
Hurricane	A Hurricane is a tropical cyclone or localized, low-pressure weather system that has organized thunderstorms but no front (a boundary separating two air masses of different densities) and maximum sustained winds of at least 74 miles per hour (mph). Hurricane data also include tropical storms for which wind speeds range from 39 to 74 mph.
Ice Storm	An Ice Storm is a freezing rain situation (rain that freezes on surface contact) with significant ice accumulations of 0.25 inches or greater.
Landslide	A Landslide is the movement of a mass of rock, debris, or earth down a slope.
Lightning	Lightning is a visible electrical discharge or spark of electricity in the atmosphere between clouds, the air, and/or the ground, often produced by a thunderstorm.
Riverine Flooding	Riverine Flooding is when streams and rivers exceed the capacity of their natural or constructed channels to accommodate water flow, and water overflows the banks, spilling into adjacent low-lying, dry land.
Strong Wind	Strong Wind consists of damaging winds, often originating from thunderstorms, and are classified as exceeding 58 mph.
Tornado	A Tornado is a narrow, violently rotating column of air that extends from the base of a thunderstorm to the ground and is visible only if it forms a condensation funnel comprising water droplets, dust, and debris.
Tsunami	A Tsunami is a wave or series of waves generated by an earthquake, landslide, volcanic eruption, or even a large meteor hitting the ocean and causing a rise or mounding of water at the ocean surface. A Tsunami can travel across the open ocean at about 500 mph and slow down to about 30 mph as it approaches land, causing it to grow significantly in height.
Volcanic Activity	Volcanic Activity occurs via vents that act as a conduit between the Earth's surface and inner layers and erupt gas, molten rock, and volcanic ash when gas pressure and buoyancy drive molten rock upward and through zones of weakness in the Earth's crust.
Wildfire	A Wildfire is an unplanned fire burning in natural or wildland areas, such as forest, shrub lands, grasslands, or prairies.
Winter Weather	Winter Weather consists of winter storm events in which the main types of precipitation are snow, sleet, or freezing rain.

Table A2. Summary of weather events for Alabama, Louisiana, and Mississippi, 2006–2022, based on weather events; source: NOAA Storms Database.

Row	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Astronomical Low Tide	6	4	6	4						3	4	5	32
Coastal Flood		1	8	10	16	6	3	1	1	17	2	1	66
Cold/Wind Chill	146	34			1		3	2				52	238
Debris Flow	1		1	1				1	2		1		7
Dense Fog	3		1	1				1		2	3	5	16
Drought	77	95	81	122	131	154	148	133	153	162	185	196	1637
Dust Devil					1	3	1	1	1	1			8
Excessive Heat						40	46	106	17				209
Extreme Cold/Wind Chill	53	6	1	3	3		4	2	3	3	1	35	114
Flash Flood	131	148	171	181	176	158	172	162	181	132	81	151	1844
Flood	34	63	56	62	64	55	41	37	29	34	32	44	551
Freezing Fog	5											11	16
Frost/Freeze			11	53						11	11		86
Funnel Cloud	16	10	50	57	38	24	23	21	23	20	23	13	318
Hail	128	192	209	210	203	185	168	151	72	109	114	140	1881
Heat	3	3	2	3	6	93	187	202	40	3	6		548
Heavy Rain	14	8	31	28	23	33	41	43	21	14	8	17	281
Heavy Snow	133	149	49								2	99	432
High Surf						1	1	1	2	2	1		8
High Wind	38	18	20	56	5	2	3	1	55	27	16	35	276
Hurricane							2	52	5	25			84
Hurricane (Typhoon)							49	107	132	63			351
Ice Storm	111	92	2									27	232
Lightning	17	21	48	67	67	99	114	111	32	20	10	20	626
Rip Current			1	4	4	2	3	5	2	1			22
Seiche					2						3		5
Sleet	64	35	37										136
Storm Surge/Tide						28	17	31	36	25	1	3	141
Strong Wind	47	54	87	76	23	41	24	32	46	39	26	61	556
Thunderstorm Wind	201	203	211	211	209	210	210	205	151	188	198	197	2394
Tornado	126	150	164	197	151	67	46	70	100	117	160	150	1498
Tropical Depression					11		3	84	18	12	33		161
Tropical Storm					5	59	118	183	146	131	18		660
Waterspout			2			1	2	5	1				11
Wildfire		1	3	3		3	1	3	5	5	1		25
Winter Storm	145	134	40									94	413
Winter Weather	187	128	90	9							26	135	575
Total	**1686**	**1549**	**1382**	**1358**	**1139**	**1264**	**1430**	**1753**	**1274**	**1166**	**966**	**1491**	**16,458**

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