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# Assessment of global shipping risk caused by maritime piracy

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ABSTRACT

Due to the frequent occurrence of piracy incidents, normal trade, and transportation activities have been hindered. This paper uses the Piracy and Armed Robbery dataset in the Global Integrated Shipping Information System to analyze the types and evolutionary characteristics of shipping risk caused by piracy and the piracy behavior patterns in different seas. This study found that there are three regions with high incidence of piracy in the world, and their gathering centers change dynamically over time. Piracy incidents can be divided into four categories based on the quantitative assessment of shipping risk caused by piracy. Shipping risk caused by piracy shows different evolution characteristics in different seas, affected by factors such as the evolution of national political situations and anti-piracy measures. Based on the qualitative assessment of the shipping risk caused by piracy, the piracy corpus reflects the diverse patterns of piracy in different seas. In the process of pirate attacks, the diversity is mainly manifested in violence and selectivity. In the consequences of pirate attacks, the targets that pirates pay attention to vary significantly in different seas. This research will help to strengthen the dynamic monitoring of shipping risk caused by piracy, and further contribute to the research on maritime transport safety.

## 1. Introduction

It is estimated that approximately 80 % of world trade is carried by sea, with approximately 93,000 merchant ships, 1.25 million seafarers, and nearly 6 billion tons of cargo [1]. The supply chain relying on ocean transportation provides low-cost, efficient, and reliable transportation of commodities and merchandise [2]. The maritime highway of the world economy is supported by a vast infrastructure, including 93,000 merchant ships and 1.25 million sailors sailing to 8000 ports [3]. However, maintaining the safety of ocean shipping is not easy. According to statistics from the International Maritime Organization, there were 578 incidents of piracy and armed robbery in the world in 2011, an average of more than ten per week. The number of piracy incidents has decreased in recent years, but it is also close to 200 per year. In October 2005, a ship named MV Miltzow was attacked by pirates in the port of Marka and was forced to leave the port. The ship was loaded with more than 800 tons of food to aid Somalia [4]. On January 23, 2021, the Liberian-flagged container ship V/S Mozart was attacked by pirates in the Gulf of Guinea, resulting in 1 death and 15 kidnappings [5]. Frequent pirate attacks have brought great insecurity to the smooth development of maritime traffic and trade. To better cope with this maritime instability factor, the research on the spatiotemporal evolution and behavior patterns of pirate attacks became more and

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more important. In this way, the safety of ports, crews, and merchant ships can be further guaranteed.

Pirates are mainly engaged in the plundering of resources and property at sea. However, due to the different locations of the incident, the relevant definitions are different. The International Maritime Bureau (IMB), established in 1981, defines piracy as "an act of boarding a ship to commit theft or any other crime, with the intent or ability to use force to facilitate that act" [6]. However, the International Maritime Organization (IMO) defines piracy as an attack that occurs on the high seas or in areas beyond the jurisdiction recognized by the laws of any country. The biggest difference between the two definitions is where the attack took place. Attacks on ships in the territorial waters or internal waters of coastal states are referred to by the IMO as Armed Robbery. That means, other than acts of piracy, any unlawful act of violence, detention, or any act of plunder or threat committed against a vessel or persons or property on board a vessel for private purposes in the internal waters, archipelagic waters, and territorial waters of a State. The fundamental difference between piracy and armed robbery is the location of the incident. However, most attack data do not distinguish between piracy and armed robbery according to the above definition, so the two can be discussed together [2].

On the global scale, Twyman-Ghoshal and Pierce combined piracy reports from the International Maritime Bureau (IMB) with data on counter-shipping activities from the US National Geospatial Intelligence Agency (NGIA) to provide a more comprehensive assessment of contemporary piracy to determine Changes in pirate tactics, nature, and trends [7]. Förster compiled an overview of global piracy statistics from 2003 to 2013, focusing on the differences in the strategies used by Somali pirates, Gulf of Guinea pirates and Southeast Asian pirates [8]. Helmick used the IMB piracy report to derive the nature and scope of modern piracy and its impact on global supply chains [2]. On the regional scale, Nincic used the piracy Report of the International Maritime Bureau and piracy data from the International Maritime Organisation to derive trends of piracy in Africa from 2001 to 2008, and the high costs of piracy for many countries, including Nigeria, Somalia, Kenya and Tanzania [4]. At the national scale, Bueger put forward six factors that trigger piracy and proposed the experience of promoting maritime security governance based on the case of Somali pirates [9]. Forbes analyzed the effectiveness of naval patrols, unique political and geographic circumstances for military intervention in piracy [10]. Szuma analyzes how modern piracy works and its geopolitical implications, with a case study on Somalia. Hodgkinson discusses global trends in piracy and the transferability of Somalia's anti-piracy measures [11]. Onuoha [12] and Kamal-Deen [13] used the International Maritime Bureau (IMB) piracy report to summarize the dynamics and trends, causes, and anti-piracy measures of piracy in the Gulf of Guinea. Anyimadu discusses the experience of Indian Ocean anti-piracy measures on piracy in the Gulf of Guinea [14]. Using the International Maritime Bureau (IMB) piracy report, Liss identified piracy trends and hotspots in Southeast Asia, as well as effective anti-piracy measures [15]. Using the International Maritime Bureau's (IMB) piracy report, Hribernik analyzed the importance of ReCAAP in anti-piracy activities in Asia and the effectiveness of non-ReCAAP parties' participation in anti-piracy measures.

The above studies on piracy have the following limitations. First, the most salient feature is the lack of synthesis of piracy reports in existing studies [16,17]. That said, most literature lacks a more comprehensive understanding of global piracy. Most studies focus on one or two sea areas, or one or two types of piracy, with only a few studies examining piracy of different natures on a global scale. The reason is intuitive. It is difficult for researchers to browse thousands of piracy incidents of different natures and regions around the world over a certain period and then summarize them. Second, a large number of studies use data on the number of piracy attacks as an important indicator to measure the severity of piracy in a region. However, the amount of piracy is somewhat misleading. In Southeast Asia, for example, local piracy ranges from small-scale opportunistic maritime robbery to sophisticated, organized ship robberies. When a crime is driven by opportunism, the likelihood of failure is greatly increased. It is difficult to compare the intensity of a successful attack to a failed attack. Alternatively, small-scale opportunistic maritime robberies are difficult to quantify compared to complex, organized ship hijackings. Most research centers specializing in armed conflict use the number of deaths as a reliable indicator, rather than the number of attacks [18]. Databases that document political conflicts, such as ACLED and PRIO, also list the death toll as one of the most important areas. This helps to study the extent of piracy. However, as the Greek historian, Plutarch said, the essence of piracy is not war, but merely plunder or monetary gain [8]. A large proportion of piracy does not directly threaten the life of the crew, especially those who want a ransom in return, such as Somali pirates. Therefore, it is not appropriate to directly use the death toll as an indicator to quantify piracy. Risk assessment theory provides an excellent perspective on this conundrum. Risk assessment theory holds that quantitative risk assessment is as important as qualitative risk assessment [19]. For piracy risk assessment, both the quantification of pirate attack risk and the analysis of piracy behavior patterns are indispensable. The question thus becomes, how to identify the variability among a large number of acts of piracy, and then properly quantify the variability and the risks it brings. And, how to extract different piracy patterns and corresponding risk characteristics from the massive corpus.

In this context, this study takes the data of more than 8000 pirate attacks that occurred around the world from January 1, 2006, to December 31, 2021, to conduct quantitative and qualitative assessments of shipping risk caused by piracy based on risk analysis theory and text analysis methods. In the work of quantitative risk assessment, we divide the types of shipping risk caused by pirates and describe the evolution characteristics of shipping risk in different seas over time. In the work of qualitative risk assessment, we analyze the corpus of the process and consequences of piracy respectively and summarize the piracy patterns in different seas.

## 2. Data and methods

### 2.1. Data

The establishment of the Piracy Reporting Centre of the International Maritime Organization made it possible to record piracy incidents [20]. The data used in this study came from the Piracy and Armed Robbery (PAR) dataset in the Global Integrated Shipping Information System (GISIS) of the International Maritime Organization (IMO), which is available at https://gisis.imo.org/Public/PAR/Default.aspx. The PAR dataset covers more than 4000 pieces of pirate attack data that occurred around the world from January 1,

2006, to the present. The incidents of piracy are encoded into many attributes, including the location, date, incident details, and the consequences of the incident. Content, to facilitate statistical analysis of piracy and determine the characteristics and trends of piracy in different regions. In particular, the two attributes of incident details and consequences for crew are crucial to this research. Piracy is a kind of random and selective criminal behavior, and its criminal process and consequences are diverse. For example, in the criminal process, the violent nature of Somali piracy is well known, while Southeast Asian pirates may tend to avoid interaction with the crew [7]. In the process of crime, simple theft is not the same as robbery or even hijacking. To fully identify the differences in the criminal process and criminal consequences of different criminal acts and use them as a basis for measuring the danger of piracy, the use of text-*as*-data methods is necessary. As text-*as*-data methods have become increasingly popular in the social sciences, lexicon-based sentiment analysis techniques have emerged as a popular off-the-shelf tool for the automated extraction of information from political texts [21]. To complete this work, researchers have to access a large number of news reports related to piracy incidents and extract event details and results and encoding. For an average researcher, the above task is difficult. Fortunately, the availability of the Piracy and Armed Robbery dataset has eliminated this problem. This dataset clearly demonstrates incident details and consequences for crew related to piracy incidents, which is crucial for measuring the danger of piracy incidents.

This study extracted information on 4832 piracy incidents worldwide from January 1, 2006, to December 31, 2021, from the PAR dataset. But, as the IMO emphasizes, a large number of the early reports from the 1990s are not well geo-referenced. At the same time, the incident details and consequences for crew information reported earlier are not complete. Therefore, the time range of this study covers from 2006 to 2021 to ensure the validity of the calculation, involving a total of 3836 pieces of valid data. Based on the above data, we use spatial analysis, text analysis, risk analysis, SAGA clustering, and other methods to identify key risk areas for pirate attacks, measure the risk of piracy attacks in different areas, obtain different types of piracy, and analyze piracy patterns in different areas and attack risk characteristics.

### 2.2. Methods

#### 2.2.1. Sentiment analysis

Based on the above risk quantification ideas, it is necessary to quantify the process and consequences intensity of pirate attacks. Sentiment analysis, which identifies and categorizes ideas, attitudes, and emotional expression in texts employing computer analysis [22], has been increasingly widely used in psychology [23–25], journalism and communication [26–29], social conflict [30–32] and other fields in recent years. In this paper, sentiment analysis is used to identify conflict and cooperation information of the piracy incidents based on the descriptive text of "Incident details" and "Consequences for the crew, etc." provided in the PAR data set. Thus, the conflict intensity contained in the incident process and the conflict intensity contained in the incident consequences can be obtained. In the work of sentiment analysis, the corpus provided is first parsed into sentence vectors, and then the sentiment score is calculated by evaluating sentiment to quantify the intensity of the incident. In this study, we use the Syuzhet sentiment dictionary to quantify the intensity of each piracy process and its consequences [33]. The severity of the process and consequences of piracy are referred to in the following paragraphs as risk likelihood and risk consequence, respectively.

#### 2.2.2. Risk analysis

In order to more reasonably quantify the shipping risk caused by different types of pirate attacks, we introduce risk analysis theory. Risk analysis theory states that risk is a function of the likelihood of a given threat source using a particular potential vulnerability and the impact that adverse event has on an organization [19]. Generally, risk measures are quantified using risk likelihood and risk consequence [34–37]. Mapping risk likelihood and risk consequences to a risk matrix or risk map for assessing risks and prioritizing them to address a wide variety of issues, including terrorism risk analysis [38], project risk management [39], climate change risk management [40], enterprise risk management [41] and other fields. Risk can be any smoothly increasing function of risk likelihood and risk consequence. In practice, the product of the above two is often used in discussions of the quantitative risk concept that accompanies risk matrices [36], as shown in formula (1).

$$\text{Risk} = \text{likelihood} \times \text{consequence} \tag{1}$$

In the case of pirate attacks, both the process and consequences of the attack pose a threat to ships, crews, and cargo at sea. During the attack process, violence such as firing and kidnapping is the main source of risk. The consequences of an attack, including loss of property, demand for ransom, or casualties, also indicate risk. Therefore, in this study, the risk of piracy incidents considers both the procedural risk and the consequential risk of piracy, which are respectively referred to as risk likelihood and risk consequence in this study. The risk of piracy is expressed by the product of risk likelihood and risk consequence, which is based on the sentiment analysis method and risk analysis theory.

The risk consequences of piracy incidents can be obtained from the sentiment analysis results of the corpus in the "Consequences for crew etc" field in the PAR database. The acquisition of the risk likelihood of a piracy incident requires further processing. Since the information provided by "Incident details" in the PAR database includes both the incident process and the incident consequences, it is necessary to further process according to the number of piracy sentence vectors and the average sentiment score of the sentences. In this way, the conflict intensity of the incident process can be obtained, which is called risk likelihood in this study.

$$L_k^{(i)} = \frac{D_k^{(i)} * N_k^{(i)} - C_k^{(i)} * n_k^{(i)}}{N_k^{(i)} - n_k^{(i)}} \tag{2}$$

In the formula (2), $L_k^{(i)}$ represents the risk likelihood caused by piracy incident $i$ in sea area $k$. The division of the spatial boundaries of the world's oceans and seas comes from the Flanders Marine Institute [42], which was defined by the International Hydrographic Organization (IHO) in S-23 publication: Limits of oceans and seas [43]. $D_k^{(i)}$ represents the whole process risk caused by piracy incident $i$ in sea area $k$, which is obtained from the average sentiment score of the corpus in the field "Incident details". $N_k^{(i)}$ represents the number of sentence vectors describing the whole process of piracy incident $i$ in sea area $k$, that is, the number of sentence vectors contained in the corpus in the field "Incident details". $C_k^{(i)}$ represents the risk consequence of piracy incident $i$ in sea area $k$, which is obtained from the average sentiment score of the corpus in the field "Consequences for crew etc". $n_k^{(i)}$ represents the number of sentence vectors describing the result of the piracy incident $i$ in sea area $k$, that is, the number of sentence vectors contained in the corpus in the field "Consequences for crew, etc".

On the above basis, the two calculated risk values are further normalized to facilitate subsequent calculation and analysis, as shown in formulas (3) and (4).

$$L_k^{'(i)} = \frac{L_k^{(i)} - L_{min}}{L_{max} - L_{min}} \tag{3}$$

$$C_k^{'(i)} = \frac{C_k^{(i)} - C_{min}}{C_{max} - C_{min}} \tag{4}$$

In the formula (3) and formula (4), $L_k^{'(i)}$ represents the normalized risk likelihood of piracy incident $i$ in sea area $k$, and $L_{min}$ and $L_{max}$ are the minimum and maximum value of the risk likelihood, respectively. $C_k^{'(i)}$ represents the normalized risk consequences of piracy incident $i$ in sea area $k$, and $C_{min}$ and $C_{max}$ are the minimum and maximum value of risk consequences, respectively.

Therefore, the shipping risk arising from a piracy incident can be calculated as:

$$R_k^{(i)} = L_k^{'(i)} * C_k^{'(i)} \tag{5}$$

In the formula: $R_k^{(i)}$ represents the shipping risk caused by piracy incident $i$ in sea area $k$. $L_k^{'(i)}$ represents the risk likelihood caused by piracy incident $i$ in sea area $k$. $C_k^{'(i)}$ represents the risk consequence caused by piracy incident $i$ in sea area $k$. The value ranges of $L_k^{'(i)}$ and $C_k^{'(i)}$ are both [0,1]. The larger the value of $L_k^{'(i)}$ and $C_k^{'(i)}$, the higher the conflict intensity of the corresponding text, indicating a more serious risk.

Based on the risk analysis theory and sentiment analysis method, the risk likelihood $L_k^{'(i)}$ and risk consequence $C_k^{'(i)}$ of each piracy incident are obtained. According to formula (5), the shipping risk corresponding to each piracy can be obtained. Then, according to formula (6), the shipping risk caused by piracy in a certain sea area can be obtained. $R_k(\mathrm{t}) = \frac{\sum_{i=1}^{n} L_k^{'(i)}(\mathrm{t}) * C_k^{'(i)}(t)}{n(t)}$ (6)

In formula (6), $R_k(\mathrm{t})$ represents the shipping risk caused by all piracy incidents in the sea area $k$ in the chosen time window, which is year here. $L_k^{'(i)}(\mathrm{t})$ represents the risk likelihood caused by piracy incident $i$ in sea area $k$. $C_k^{'(i)}(t)$ represents the risk consequences caused by piracy incident $i$ in sea area $k$. $n$ represents the number of piracy incidents in sea area $k$. In this way, the importance of some incidents similar to the type of petty theft on the coast of Indonesia from the 1990s to around 2005 is reduced, while the importance of kidnapping, injury, and other incidents is enlarged.

### 2.2.3. Clustering based on simulated annealing algorithm and genetic algorithm

Clustering is a useful unsupervised data mining technique that can efficiently divide a large number of samples into $K$ groups (clusters) [44]. There have been a massive amount of piracy attacks worldwide, and the corresponding risk likelihood and risk consequences vary. The cluster analysis method can effectively classify pirate attacks according to the risk likelihood and risk consequences, so as to further analyze the characteristics and differences of shipping risk in different seas. However, in this study, there is no clear boundary between points in the data results of the risk likelihood and risk consequences of pirate attacks, and it has a certain randomness. For such features, the common clustering methods based on local search optimization algorithms such as K-means and K-medoids are prone to converge to the local minimum point under the local search algorithm [45], which affects the correct classification of piracy incidents.

Genetic Algorithms (GA) search in complex, large-scale, and multimodal environments and provide near-optimal solutions to the objective function or fitness function of an optimization problem [46,47]. Simulated annealing (SA) seeks to find the least-cost solution to large optimization problems by minimizing the associated energy [48]. Global optimization of K-medoids clustering algorithms using genetic algorithms and simulated annealing algorithms has been demonstrated on different synthetic and real life data sets [49]. Therefore, this study adopts the clustering method based on simulated annealing algorithm and genetic algorithm (SAGA) to cluster the risk likelihood and risk consequence data of all piracy incidents in the world and obtains the classification of piracy incidents.

### 2.2.4. Word cloud analysis

As a maritime crime, the criminal process of piracy incidents is complex, highly uncertain, and highly subjective. At the same time,

affected by the differentiated geographical environment, piracy incidents in different regions emerge with different characteristics of criminal behavior, which is difficult to classify with a unified standard. The introduction of text-*as*-data methods is helpful to better analyze the regional, phased, and subjective characteristics of piracy. A word cloud is an image composed of words used in a specific text or topic. The size of each word in the word cloud corresponds to the frequency that the word appears in the text. Word clouds is helpful to learn about the number and types of topics appearing in the text, which can be used as an important perspective for conducting deeper analysis [50–52]. Word cloud is an intuitive text visualization method, which has been applied in the analysis of text data in fields such as public health [53], social media [54,55], and educational philosophy [56]. We analyze text in R based on the text mining package [57]. Then, it is feasible to visualize the keywords as a word cloud, based on the wordcloud package in R [58].

### 2.2.5. Topic modeling

In this study, the consequences of piracy incidents are complex. The piracy corpus demonstrates that pirates attack targets and attack methods vary in different seas. This study used the LDA topic modeling method to extract topics from the piracy incident consequence corpus, in order to obtain the behavior patterns of pirates in different seas in the event consequence.

Latent Dirichlet allocation (LDA) is a generative probabilistic model of corpus. LDA presents a method for discovering latent structures in large-scale semantic information [59]. LDA has been widely applied to text modeling issues with proven reliability [60]. Through LDA, a document can be represented as a random mixture of several topics, where each topic contains a representative set of vocabulary [61].

The steps of LDA are as follows. For a certain number of topics $K$, a randomly generated document is obtained by setting different $\alpha$ and $\beta$. The document with the highest similarity to the original document among the n documents corresponds to the best $\alpha$ and $\beta$, and the best model. $\alpha$ and $\beta$ obey the Dirichlet distribution. $\alpha$ randomly generates a multinomial distribution $\theta$ of documents corresponding to topics, and $\theta$ randomly generates a topic $z$. $\beta$ randomly generates a multinomial distribution $\varphi$ of the words corresponding to the topic. Combine $z$ and $\varphi$ to get the word $w$. Based on such a loop, a document is generated, which contains $M$ words. Finally, $n$ documents under $k$ topics are generated. This model was trained using Gibbs sampling. Gibbs sampling probability distribution $p(D|\alpha,\beta)$ is shown in formula (7). The number of topics $k$ in it is determined according to the method of maximizing the log-likelihood value.

$$p(D|\alpha,\beta)=\prod_{d=1}^{M}\int P(\theta_d|\alpha)\left(\prod_{n=1}^{N_d}\sum_{z_{d_n}}P(z_{d_n}|\theta_d)P(w_{d_n}|z_{d_n},\beta)\right)\mathrm{d}\theta_d \tag{7}$$

### 2.2.6. Kernel density analysis

Kernel density analysis can be used to calculate the density of point features in the surrounding neighborhood, and is commonly used in fields such as measuring building density and obtaining crime reports. As a form of crime, piracy is also suitable for detecting its spatial distribution using kernel density analysis. In kernel density analysis, points closer to the center of the grid search are given more weight, and points farther from the center of the grid are given less weight [62]. A larger search radius produces a smoother and more generalized density raster. The smaller the search radius, the more detailed the generated raster will be.

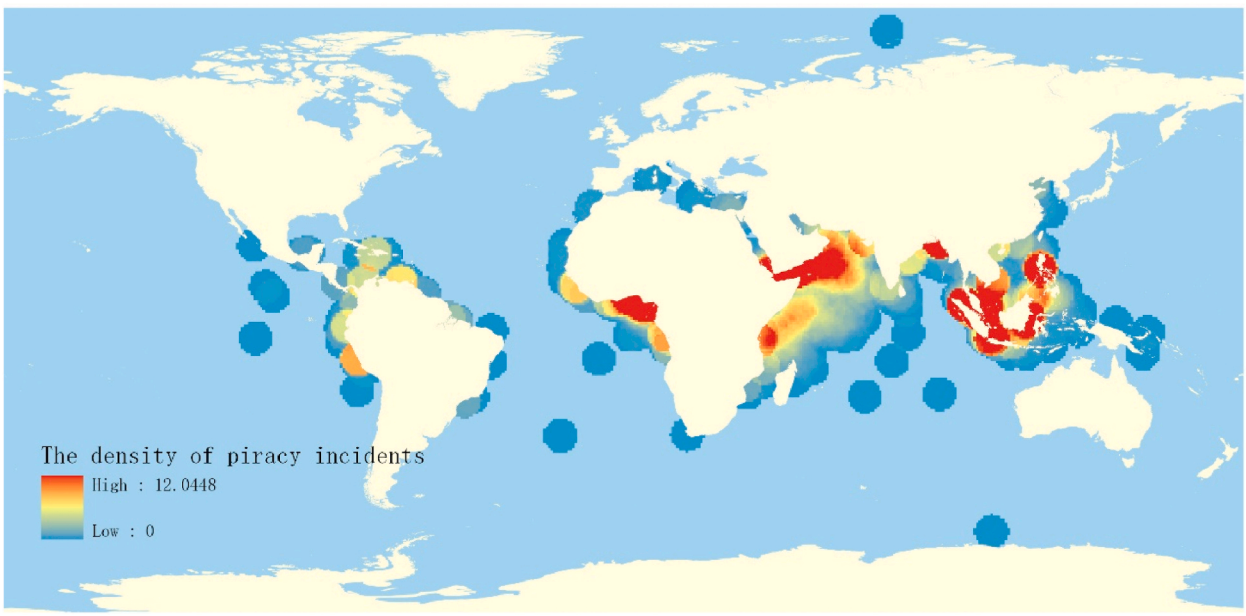


**Fig. 1.** Global pirate attack density map, 2006–2021.

#### 2.2.7. Point density analysis

Point density analysis can also be used to calculate the density of point elements around each output grid pixel. The larger the radius parameter value, the higher the generalization degree of the generated density grid. The smaller the value, the more detailed the resulting grid displays.

## 3. Results

### 3.1. The overall geographical pattern of global pirate attacks

#### 3.1.1. Spatial evolution characteristics of global pirate attacks

In order to intuitively find out the spatial agglomeration direction of global pirate attacks, with the help of the spatial analysis technology of ArcGIS 10.7 software, the Point Density method is used to generate a density map of pirate attacks from 2006 to 2021, as shown in Fig. 1.

On a global scale, pirate incidents have occurred in major shipping areas around the world, but they are mainly concentrated in a few areas and are clustered. There are mainly three high-value areas, namely the Gulf of Guinea, the Gulf of Aden and the Western Indian Ocean, and Southeast Asia. These three areas have the highest density of pirate incidents, forming three significant clusters of pirate incidents.

At the sea area scale, the aggregation characteristics of pirate incidents in different sea areas are also different. Pirate incidents in some waters are concentrated in certain coastal waters. For example, pirate incidents in the Indian Ocean are mainly concentrated on the side near Tanzania, Nairobi, and Somalia. Pirate attacks in the South China Sea are concentrated on the side near Malaysia and Singapore. Pirate attacks in the Bay of Bengal are more concentrated in Bangladesh. In other sea areas, pirate attacks are distributed in high density and densely throughout the sea area, such as the Arabian Sea, the Gulf of Aden, and the Gulf of Guinea. There are also some sea areas where pirate attacks are spread in low density, such as the Caribbean Sea.

*3.1.1.1(1). Piracy in the gulf of Guinea.* The Gulf of Guinea is the bay extending from Cape Lopez, Gabon to Cape Palmas, Liberia. Coastal Gulf countries include Angola, Benin, Cameroon, Côte d'Ivoire, Democratic Republic of Congo, Republic of Congo, Guinea, Equatorial Guinea, Guinea-Bissau, Gabon, Nigeria, Ghana, Sao Tome and Principe, Togo, and Sierra Leone, which line an entire coastline of about 6000 km [63]. The Gulf of Guinea is an important gateway for these coastal countries to the world, and they depend on it for the exchange of goods and services. Therefore, the security of the ports and waters of the Gulf of Guinea is crucial to the trade and shipping of the above coastal countries and even landlocked countries such as Mali and Burkina Faso, and it is a key international shipping hub.

The main oil producing countries in the Gulf of Guinea region are Nigeria, Angola, Equatorial Guinea, Cameroon, the Republic of Congo, and Gabon [64]. Nigeria and Angola are Africa's largest and second largest oil producers, respectively, according to the U.S. Energy Information Administration. From a geostrategic point of view, the Gulf of Guinea covers oil-producing and potential oil-producing countries along the coasts of western, central, and southern Africa, reflecting its maritime geopolitical importance. In addition, the Gulf of Guinea is also very rich in fishery resources. Taking Nigeria as an example, fishing is the second highest non-oil exporting industry in Nigeria [4] and is vital to the Nigerian economy. Energy trade and fisheries all depend on a safe shipping environment [65].

The safe flow of goods and services on this route is threatened by the disturbingly rapid growth of piracy in the Gulf of Guinea [4]. In the oil economy, international oil companies such as Shell, ExxonMobil, Total, Chevron, and Eni with operations in Gabon, Equatorial Guinea, and Nigeria are particularly at risk of experiencing sporadic but highly disruptive piracy in their supply chains. In addition to crew capture and ransom payments, oil companies face the risk of time delays and increased costs. In terms of fishery economy, piracy in the Gulf of Guinea has reduced the scale of the local fishery economy, threatening the huge value of fishery exports [66]. Piracy also hinders the inflow of foreign investment needed to develop the economy [67]. As a result, trade and transportation throughout the Gulf of Guinea region have been disrupted, the oil and fishing economies have shrunk, and piracy has also threatened African economic growth [68].

*3.1.1.2(2). Piracy in the Gulf of Aden and the Western Indian Ocean.* Here we discuss another group of piracy - piracy in the Gulf of Aden and the Western Indian Ocean. Their active range is centered on the Gulf of Aden and extends to the open seas of the vast western Indian Ocean. Trade and transportation in the Gulf of Aden have been going on for thousands of years. The Gulf of Aden is an important passage connecting the Suez Canal with the Arabian Sea, and more than 20,000 ships pass through the Gulf of Aden every year. Crude oil from the Persian Gulf, which accounts for 9 % of the world's seaborne oil trade, passes through the Gulf of Aden into the Suez Canal and eventually reaches North America and Europe. The same route is also required for goods, consumer goods, etc., to travel from Asia to Europe and America. Therefore, the security of the Gulf of Aden is critical to global trade and supply chains.

Pirate attacks have had many negative impacts on shipping in the Gulf of Aden and the Western Indian Ocean. Piracy directly causes disruption or even interruption of transportation. This phenomenon is particularly prominent in the Gulf of Aden and the western Indian Ocean. More piracy occurs on the high seas, and pirate attacks directly threaten the safety of people and cargo on board. Once attacked, ships are forced to take measures such as speeding up and changing course to avoid the attack. If pirates board the ship, the consequences will be even more disastrous. According to the Suez Canal Authority, traffic on the canal has dropped by 50 % since the surge in piracy [69]. Disruptions in transport further resulted in trade losses. According to the World Bank, the loss of trade

disruption caused by piracy in the waters off Somalia is approximately US$18 billion [70]. The intrusion of pirates on ships also had a deeper impact. For countries such as Kenya and Tanzania, which are also affected by Somali pirates, fuel shortages, inflation, and food shortages cannot be ignored. In order to reduce the huge economic and time cost of tanker kidnappings, some companies have chosen to cancel oil shipments to East Africa, which will lead to fuel shortages and higher prices. Pirate attacks drive up regional shipping insurance premiums, which are often passed on to consumers, leading to domestic inflation. From 2005 to 2009, ships chartered by the UN World Food Programme to transport aid supplies to Mombasa, Kenya repeatedly attacked by pirates [4]. Mombasa is an important humanitarian aid distribution center in the region, and the attack on these ships has hindered the delivery of aid to Kenya, Somalia, Uganda, and other countries, and millions of people are threatened with starvation.

In recent years, with the joint efforts of multinational navies and the International Chamber of Shipping, piracy in the Gulf of Aden and the western Indian Ocean has been largely contained. However, due to the poverty and instability of Somalia, there is still reason to believe that Somali pirates may reappear [71]. Therefore, it is still necessary to analyze and understand the process characteristics and consequences of piracy in the Gulf of Aden and the Western Indian Ocean.

*3.1.1.3(3). Piracy in Southeast Asia.* Southeast Asia is another global hub for piracy. This is inseparable from the busy traffic and trade in Southeast Asia. According to the World Shipping Council (WSC) data, in the past five years, Asian ports have occupied the top nine among the ten busiest container ports in the world. With the increasing importance of Asia in the world economy, the security issues of Asian waters are becoming more and more important. Among them, the location of Indonesia is particularly important. Located between the Pacific and Indian Oceans, Indonesia provides a central meeting point for global shipping through the Strait of Malacca [72]. More than 60,000 vessels with over 300 gross tonnages pass through the region each year, including large numbers of tankers from the Middle East to China, Japan, and other destinations [73].

Indonesia has thousands of islands and about 8 million square kilometers of sea area [72], which gave birth to thousands of recognized ethnic groups, as well as a variety of ethnic cultures and rich tourism resources. But at the same time, the rather long coastline also brings risks for pirates. After the 1997–1998 Asian financial crisis, unprecedented poverty prompted more and more locals to turn to pirates to earn a living. The security of this sea area is related to the smooth development of trade between Asia and the world.

According to statistics from James Warren of the Asia Research Institute at the National University of Singapore, piracy in Southeast Asia costs the world $25 billion annually [3]. The proliferation of piracy has brought high insurance premiums for merchant ships, which will be directly or indirectly calculated into the cost of goods, affecting the import and export of goods. In addition, many industries are directly or indirectly negatively affected by piracy. Due to frequent attacks on oil and gas tankers, Indonesia's natural resource exports have been affected [74]. Due to the hijacking of raw materials and equipment, piracy has also implicated the local handicraft industry, which is a very important source of non-oil foreign exchange earnings for the country [75].

### *3.1.2. Time evolution characteristics of global pirate attacks*

In order to explore the temporal evolution characteristics of pirate attacks, the number of pirate attacks that occurred every year around the world was counted, as shown in Fig. 2.

On a global scale, the overall piracy incidents have shown a characteristic of first rising linearly, then gradually decreasing and tending to be stable since 2006. Specifically, the number of pirate attacks in the world increased rapidly for six consecutive years between 2006 and 2011, from about 100 in 2006 to about 500 in 2011. From 2012 to 2015, the number of pirate attacks showed a relatively sharp decline, stabilizing at around 270 per year. Between 2016 and 2021, the number of pirate attacks further declined to around 180 per year.

In order to clarify the focus of pirate attacks in different years, the number of pirate attacks in each key sea area every year is counted, as shown in Fig. 3. According to the characteristics of the number of pirate attacks in different sea areas, the sea areas with high incidence of pirate attacks in different time stages are different. Accordingly, the time evolution of pirate attacks can be divided into five stages: 2006–2009, 2010–2012, 2013–2015, and 2016–2021.

In order to explore the evolution characteristics of the distribution pattern of pirate attacks in the time dimension, this study uses the kernel density method to analyze the hot spots of pirate attacks at different stages, as shown in Fig. 4. On the global scale, the agglomeration center is a unique location where pirates gather polarized under specific geographical environments and socio-economic conditions, which is an abstract geographical entity. In the concrete spatial dimension of the region, the distribution of

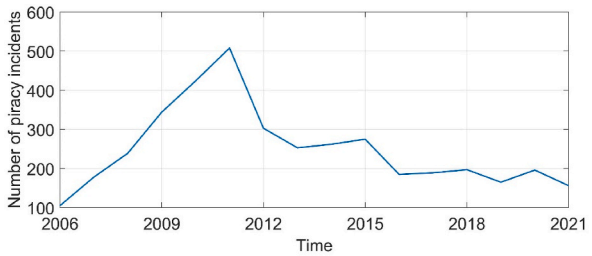


**Fig. 2.** Proportion of pirate attacks in global maritime space from 2006 to 2021.

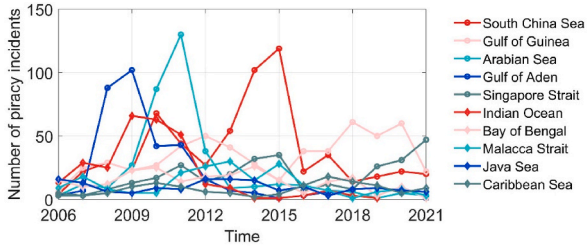


**Fig. 3.** Number of pirate attacks in global key marine from 2006 to 2021.

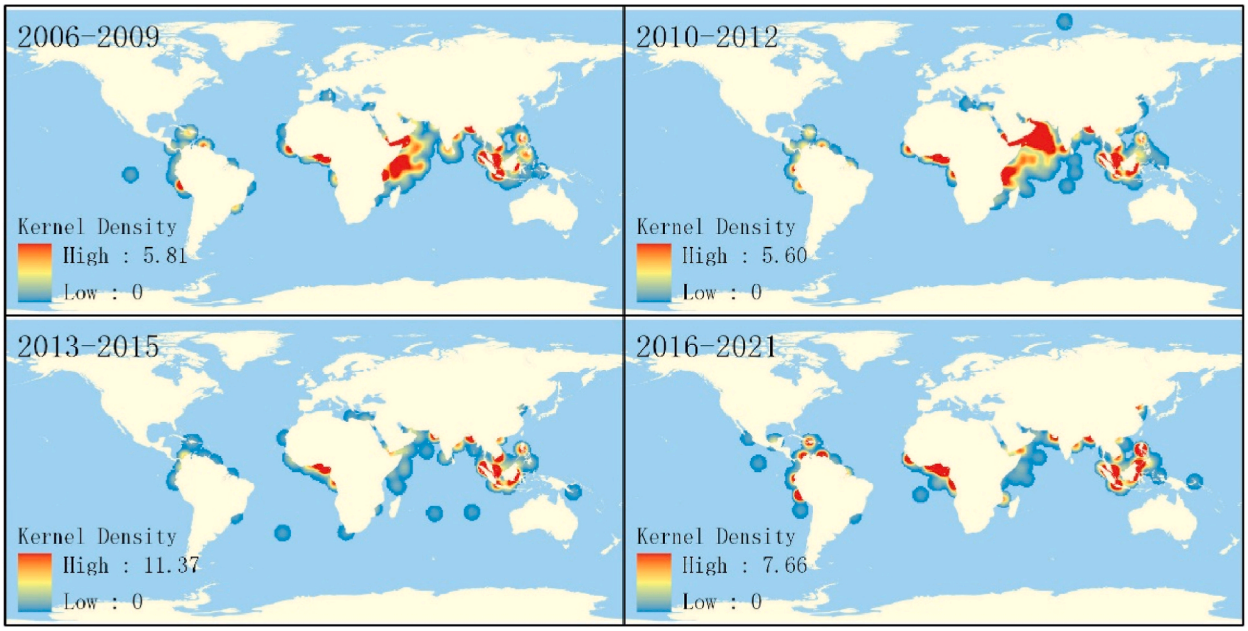


**Fig. 4.** Kernel density distribution of pirate attacks in global key marine from 2006 to 2021.

piracy attacks consists of cores of different classes, which is derived from calculations based on the kernel density method. In general, the key sea areas where pirate attacks gathered at different time stages showed the characteristics of the gathering center moving westward, northward and then eastward, with the core sea area shrinking. In terms of the maximum of kernel density, the maximum from 2013 to 2015 was 11.37, which was significantly higher than other stages.

The first stage is from 2006 to 2009. The gathering centers of pirate attacks at this stage were the Gulf of Aden and the Western Indian Ocean. Correspondingly, the main core of pirate attacks covered the coastal waters of Somalia, Kenya, and Tanzania. The secondary core covered the South China Sea, the Strait of Malacca, and the Java Sea. In addition, the secondary core includes the Ganges delta offshore in the Bay of Bengal, the Gulf of Guinea, the offshore Conakry port in Guinea, and the Pisco Bay in Peru.

The second stage was 2010–2012. At this stage, the gathering centers of pirate attacks were still dominated by the Gulf of Aden and the Western Indian Ocean, but the sea area involved was significantly expanded. The main core shifted to the northeast, with the Arabian Sea, Gulf of Aden and Red Sea becoming the main core of global pirate attacks. And the secondary core covered the Gulf of Guinea, the coasts of Tanzania and Kenya, as well as the South China Sea, the Strait of Malacca, the Java Sea and the Makassar Strait.

The third stage is from 2013 to 2015. At this stage, the areas of core of pirate attacks around the world shrank significantly, and the dominating gathering center were Maritime Southeast Asia and the Gulf of Guinea. The main core of this stage mainly covered the South China Sea, the Strait of Malacca, the Java Sea and the Strait of Makassar. The secondary core included the Gulf of Guinea, the offshore waters of the port of Pointe-Noire in the Congo, the Gulf of Khambhat in the Arabian Sea, and the offshore waters of the Ganges Delta in the Bay of Bengal.

The fourth stage is from 2016 to 2021. The gathering centers of piracy incidents at this stage were still Maritime Southeast Asia and the Gulf of Guinea. It is worth noting that the piracy in the Gulf of Guinea has formed a relatively obvious spillover, which is manifested in the significant expansion of piracy in the Gulf area. At the same time, the coverage area of the main core in Southeast Asia has increased, and there is a trend of eastward expansion. At this stage, the main core covered the South China Sea, Malacca Strait, Java Sea, Makassar Strait, Celebes Sea, Sulu Sea. The secondary core includes the Gulf of Guinea, the Port of Pointe-Noire in the Congo, the Caribbean Sea, the Gulf of Pisco in Peru, the Gulf of Guayaquil in Ecuador, and the coastal Ganges Delta in the Bay of Bengal.

### 3.2. Quantitative assessment of global shipping risk caused by piracy

#### 3.2.1. Classification of shipping risk caused by piracy

It is generally believed that the more frequent pirate attacks occur in a sea area, the greater the shipping risk caused by pirate attacks. However, when we extend the research scale to the world, the intensity of piracy attacks between different seas is difficult to compare, and the resulting shipping risk varies.

Modern pirates operate in a variety of ways, with varying levels of violence and targets. In terms of action, Nigerian pirates in the Gulf of Guinea tend to use lethal violence, while Somali pirates in the Gulf of Aden tend not to use lethal violence against their crews [76]. In terms of goals, unlike most other regions of the world, Somali pirates hijack ships with the purpose of using hostages in exchange for ransom income [77]. The captured crew members will still be released safely in most cases, corresponding to a relatively safe and peaceful resolution of the incident.

Under the background of different behaviors and goals of pirates, the likelihood and consequences of shipping risk caused by piracy is also different. In order to clarify the corresponding relationship between risk likelihood and risk consequence, the normalized risk likelihood and risk consequence of all piracy incidents in various sea areas around the world are mapped to obtain a risk map. Then, the clustering algorithm based on genetic algorithm and simulated annealing algorithm is used to classify all piracy incidents in the world according to the risk characteristics, and the classification of piracy incidents is obtained as shown in Fig. 5.

As shown in Fig. 5, based on the clustering method based on genetic algorithm and simulated annealing algorithm, piracy incidents are divided into four types: severe risk consequence incidents, severe risk likelihood and moderate risk consequence incidents, mild risk likelihood and moderate risk consequence incidents, and mild risk consequence incidents, which are labeled as *a*, *b*, *c*, and *d* respectively in Fig. 5. Among them, type *a* incidents are shown in red in Fig. 5, which corresponds to severe risk consequences, a total of 427 times. Type *b* incidents are shown in yellow in Fig. 5, which correspond to severe risk likelihood and moderate risk consequences, totaling 727 incidents. Type *c* incidents are shown in green in Fig. 5, which correspond to mild risk likelihood and moderate risk consequence, with a total of 1236 occurrences. Type *d* events are shown in blue in Fig. 5, which correspond to mild risk consequences, with a total of 1446 incidents.

The kernel density analysis tool was used to explore the distribution characteristics of different types of pirate attacks, as shown in Fig. 6. From the perspective of spatial distribution, the types of risks in different seas are different, and the corresponding ways and consequences of piracy are also different. Severe risk consequence piracy is mainly distributed along the coast of the Gulf of Guinea and in narrow waterways in Southeast Asia. Piracy with severe risk likelihood and moderate risk consequences is widespread in the vast open seas of the Gulf of Aden and the Western Indian Ocean. Piracy with mild risk likelihood and moderate risk consequence is mainly distributed in the Gulf of Guinea and Southeast Asia, with a larger amount and higher density than the former two types of piracy. Mild risk consequence piracy has similar characteristics to the former type of piracy.

#### 3.2.2. Risk evolution characteristics of piracy incidents

Based on Equation (5), the time-dependent changes in shipping risk caused by piracy in the Gulf of Guinea, in the Gulf of Aden and the Western Indian Ocean, and in Southeast Asia are obtained, as shown in Fig. 7. It can be seen that the evolution characteristics of shipping risk caused by piracy in these three major areas varies.

Unemployment and poverty levels in Indonesia were unprecedented after the 1997–1998 Asian financial crisis. In 1998, the economic recession led to the overthrow of President Suharto, and political unrest in some areas intensified [75,78]. Coupled with the depletion of local fishery resources, many opportunists and employees of organized crime gangs have turned to piracy [15]. Originally, pirate raids were simple—climbing on ships at night or when the crew was not looking, stealing belongings, and disappearing in the shortest time possible, known as “hit-and-run robberies”. This tends not to cause major physical conflict. However, with the increase in piracy and the increased involvement of criminal gangs, piracy in Southeast Asia has also undergone structural changes. Examples of corrupt customs officials, port employees, or crew members leaking ship and cargo manifest information to pirates abound [79], and pirates have also expanded their targets from shipboard goods to merchant ships including palm oil, timber, and even oil tankers. With

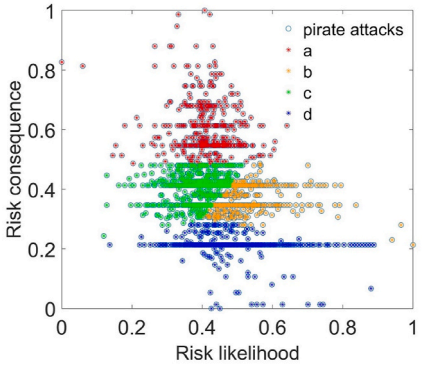


**Fig. 5.** Risk likelihood and risk consequence of all piracy incidents around the world, and the classification of piracy incidents.

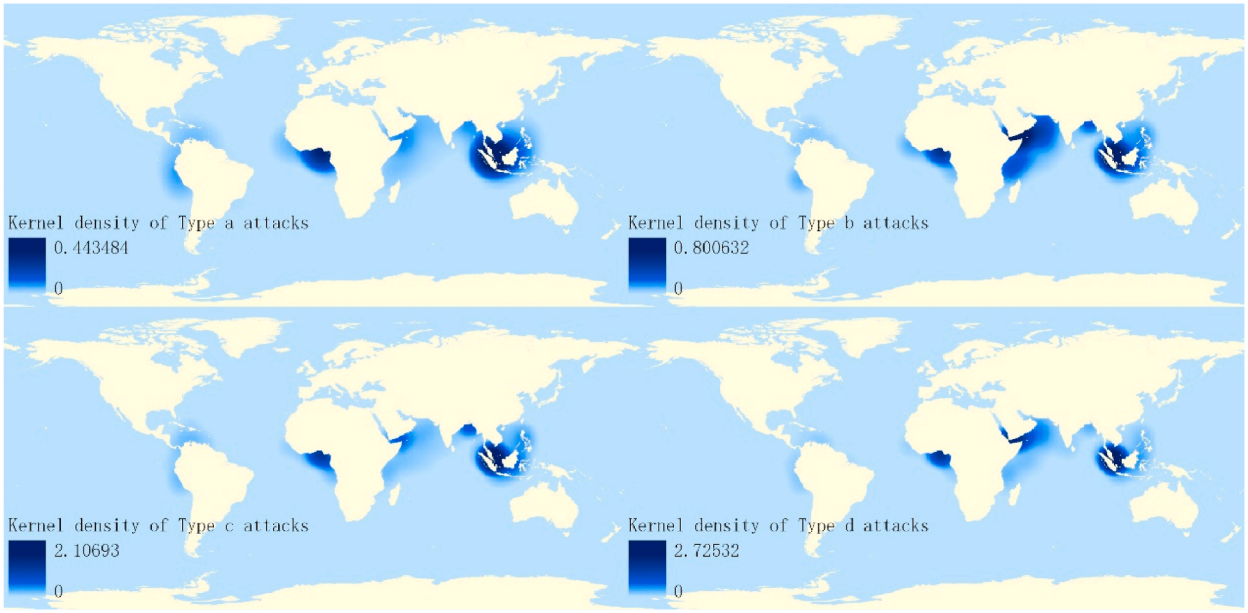


**Fig. 6.** Global kernel density distribution of different types of pirate attacks, 2006–2021.

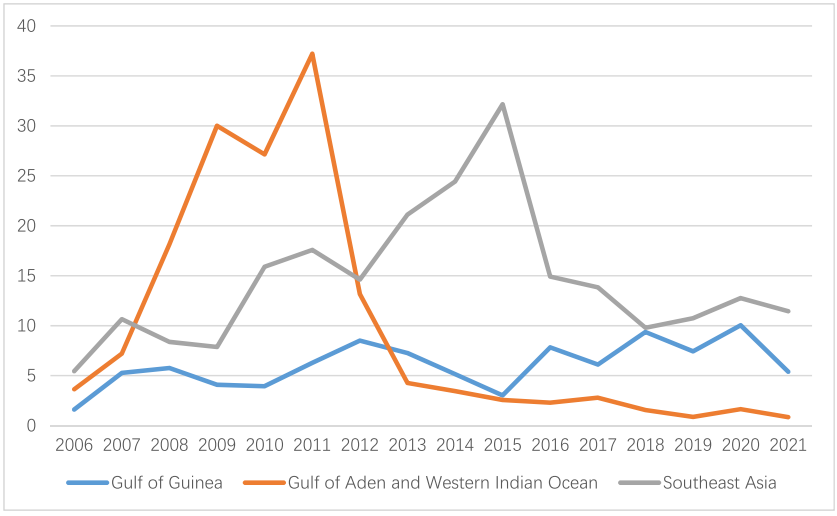


**Fig. 7.** Shipping risk due to piracy over time in the Gulf of Guinea, Gulf of Aden and Western Indian Ocean, Southeast Asia.

high criminal returns, the risks posed by piracy increase dramatically. As shown in Fig. 8, for most of the years from 2006 to 2021, the risk from mild risk consequence incidents (labeled as Type *d* attacks) did not change much. However, there was a sharp increase in three other types of risk, particularly Type c attacks (mild risk likelihood and moderate risk consequence incidents) and Type b attacks (severe risk likelihood and moderate risk consequence incidents). This was highlighted in 2019 when three other types of piracy risk exceeded 10 times the risk posed by mild risk consequence incidents.

From 1998 to mid-2000s, pirates in Southeast Asia became more and more active in the Strait of Malacca. In late June 2004, Indonesia, Malaysia and Singapore launched the "MALSINDO" trilateral naval patrol operation. In April 2006, The Malacca Strait Patrols (MSP) were jointly established by the countries along the Strait of Malacca. From 2008 to 2009, piracy in the Straits of Malacca was thus effectively controlled. At the same time, 2008 and 2009 were the two most frequent years of piracy in Somalia, and the international community's attention to pirates in Southeast Asia waned. However, the original pirates did not return to the community. They migrated to farther waters, including the South China Sea and the Singapore Strait, and continued to engage in vicious activities such as robbery and kidnapping. From 2010 to 2015, the risk of piracy attacks in Southeast Asia rose slowly amid fluctuations. Nowhere else in the world have shipping risk in one area increased for such a long period of time, and this is a very important signal of insecurity in Southeast Asian waters. However, piracy was not effectively controlled. More and more dangerous acts of piracy emerged.

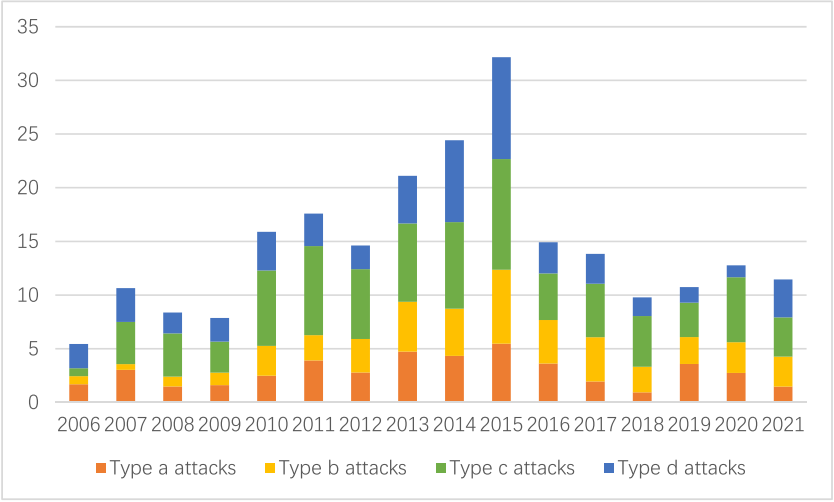


**Fig. 8.** Stacked bar chart of different types of shipping risk caused by piracy incidents in Southeast Asia.

After 2016, piracy in Southeast Asia declined and stabilized, roughly equivalent to about three-quarters of the risk posed by pirate incidents in the Gulf of Guinea. But it's important to note that this risk has slightly increased in 2020 and 2021. According to the Indonesian National Police Headquarters (Polri), crime rates across Indonesia have risen by 11.8 % during the Covid-19 pandemic, which reflects the direct impact of poverty on crime. Poverty is also the most important factor triggering Indonesian fishermen to turn to piracy. In the era of epidemic, the export and domestic sales of the fishery are hindered, which will further increase the instability in Southeast Asian waters.

Piracy first emerged in Somalia in 1991, when instability in Somalia increased due to the Somali insurgency and civil war, resulting in insecurity and economic chaos [80]. It can be seen from Fig. 8 that shipping risk due to piracy in the Gulf of Aden and the Western Indian Ocean was on the rise from 2006 to 2009. At this stage, naval anti-piracy measures are very limited. Somali pirates have launched numerous attacks in coastal waters, driven by lucrative returns. In the early stages of piracy, shipping companies paid more ransoms [81] and then transferred losses to insurance to reduce time losses. This approach further motivated Somali pirates to hijack ships. From 2008 to 2009, the rapid escalation of piracy aroused the international community's further attention to piracy. From 2008 to 2009, Combined Task Force 150, Combined Task Force 151, and the European Union's Operation Atalanta carried out a large number of anti-piracy operations. Piracy in the Gulf of Aden experienced a cliff-like decline after 2010 [82], with more pirates turning to the high seas. According to rational choice theory, offenders will try to satisfy their needs in the simplest and least risky way. When criminals spend more time and energy chasing their prey, their motives for crime have not fundamentally changed. Therefore, the shipping risk caused by piracy incidents declined briefly in 2010 and rose again in 2011, as shown in Fig. 8. After 2012, the shipping risk caused by Somali pirates decreased and leveled off year by year, as shown in Fig. 8. The reasons are mainly in two aspects. First, international efforts have greatly increased the security of the sea area, including the technical guidance of the BMP, the escort patrols of the navy, and foreign maritime assistance. Second, Somalia's domestic efforts for security and stability cannot be ignored. In August 2012, The Federal Government of Somalia was established, the first permanent central government since Somalia's civil war began in 1991. The political situation in Somalia has since become stable [83–85], and the risk of piracy has gradually disappeared. There is, however, the possibility that some former pirates are simply dormant, reintegrating into their communities, waiting for the withdrawal of international forces, the relaxation of shipping company defenses, or a chaotic economic environment [8]. Therefore, Somali piracy and the risks it poses still require continued attention.

Dissatisfied with the inequality and environmental pollution caused by oil production in the Nigerian Delta, members of the Movement for the Emancipation of the Niger Delta (MEND) frequently attack oil facilities in the Niger Delta, starting from onshore oil pipelines and expanding to offshore oil platforms [86]. By 2006, MEND members had made piracy their main activity [87]. Unemployment in Nigeria has prompted more people to participate in illegal activities in the Niger Delta [88]. Piracy in the Gulf of Guinea is different from Somali pirates, which are effectively curbed by naval escort patrols and private armed security. Pirates in the Gulf of Guinea region have a sophisticated oil theft network that includes facilitators, operations and security personnel, local and foreign transporters, buyers and sellers, and corrupt members of the security forces. Additionally, the Private Contracted Armed Security Personnel (PCASP) is banned in the territorial waters of Nigeria, Togo, and Benin, further reducing the ability of ships to defend themselves. The above factors contribute to the high success rate of pirate attacks in the Gulf of Guinea. As a result, from 2006 to 2012, shipping risk arising from piracy in the Gulf of Guinea region showed an increase in volatility, as shown in Fig. 8. During this time, shipping risk temporarily fell by about a quarter in 2009 and 2010, as most MEND militants received amnesty. On June 26, 2009, Nigerian President Umaru Yar'Adua announced a general amnesty and unconditional pardon for militants in the Niger Delta, with the grace period ending on October 4. On October 25, 2009, MEND declared a unilateral truce and accepted the government's reintegration proposal. However, on January 30, 2010, MEND called off the unilateral truce and threatened an all-out onslaught on the oil industry, which corresponds to the continued rise in the risk of piracy incidents from 2010 to 2012 in Fig. 8. Since 2013, anti-piracy

efforts in the Gulf of Guinea have begun to increase. On June 25, 2013, 25 countries from West and Central Africa signed the Yaoundé Code of Conduct, the first broadest and most ambitious regional initiative to combat piracy in the Gulf of Guinea. However, this anti-piracy operation had little success. Shipping risk in the Gulf of Guinea only experienced a brief decline in 2013, 2014, and 2015, as shown in Fig. 8. The risk of shipping caused by piracy incidents in the Gulf of Guinea increased again in 2016, approaching that in Southeast Asia, although far more piracy took place in Southeast Asia during the same period.

### 3.3. Qualitative assessment of global shipping risk caused by piracy

#### 3.3.1. Risk likelihood analysis

*3.3.1.1. (1) Piracy in the gulf of Guinea.* As can be seen from Fig. 6, there are four types of piracy incidents in the Gulf of Guinea. The characteristics of severe risk consequences of piracy are prominent, and three other types of piracy incidents are also included. The process and consequences of pirate attacks in this area are particularly violent. First, a textual analysis of the risk process is performed. According to the incident details of the Gulf of Guinea piracy incident, the frequency distribution of words is counted, and the corresponding word cloud map is formed on this basis, as shown in Fig. 9. By analyzing the high-frequency words reflected in the word cloud map, the risk likelihood characteristics of piracy in the Gulf of Guinea can be obtained.

Violence is the most prominent features of piracy incidents in the Gulf of Guinea. The high frequency of "arm" and "gun" corresponds to the high level of weapons and equipment of pirates in the Gulf of Guinea. "fire", "attack", and "kidnap" appeared frequently, which corresponded to the prominent violent characteristics of pirates in the Gulf of Guinea. AK-47s, machine guns, bazookas, grenades, and knives were commonly used in raids [13], enabling Gulf of Guinea pirates to use firepower to stop ships in transit and hijack ships and threaten crews after boarding. On January 5, 2020, the Ambika, a dredger belonging to a Lagos gas development company, was attacked. Four security guards were killed and two wounded after intense firefights. Pirates in the Gulf of Guinea are known for their violence [64], not only during boarding but also after boarding. They often carried out high levels of violence against the crew, including beatings and torture [89], as well as kidnappings. Under the high-intensity violent behavior, the crew increases their cooperation with the pirates' illegal behavior out of fear, so that the pirate's attack target can be quickly achieved. Due to high levels of violence and clear targeting of high-value goods, Gulf of Guinea pirates achieve their goals faster. The average duration of hostage-taking by pirates in the Gulf of Guinea is ten days, while in the Gulf of Aden it is six months [64]. Improving maritime security capabilities can be beneficial for controlling violence. On February 28, 2019, two speedboats carrying 16 armed men pursued and opened fire on an offshore supply vessel while it was sailing about 30 nautical miles southwest of Bonny Island, Nigeria. Nigerian escort security boats intervened to repel the attack. For a long time, the responsibility of the Gulf of Guinea countries for coastal security was far from commensurate with their maritime jurisdiction and interests in the Gulf of Guinea [90]. As a result, impunity for piracy in the Gulf of Guinea has contributed to an increase in piracy. On June 25, 2013, the establishment of the Yaoundé Code of Conduct laid a good regional foundation for preventing and combating piracy in the Gulf of Guinea. On June 24, 2019, Nigeria introduced the Suppression of Piracy and Other Maritime Offences Act, becoming the first country in the region to pass an anti-piracy law.

Apparent selectivity is also a prominent feature of piracy in the Gulf of Guinea. The high frequency of "tanker" shows that piracy in the Gulf of Guinea is most common in oil tankers in terms of vessel types. The main targets of pirate attacks in the Gulf of Guinea are


**Fig. 9.** Word cloud map of incident details of piracy incidents in Gulf of Guinea.

ships linked to the oil industry. In the Gulf of Guinea, piracy is closely linked to oil theft [88]. Pirates use a transnational mafia to obtain vital information on tankers, including vessel name, route, cargo value, and insurance coverage [91]. Pirates form oil theft networks in collaboration with facilitators, operations and security personnel, local and foreign transport, buyers and sellers, and corrupt members of the security forces [92]. They then steal oil through a sophisticated organization and sell it to the black market or other ships for huge profits [89,93]. The Gulf of Guinea pirates have thus become the most profitable pirate organization in the world [94]. In 2009, statistics from Royal Dutch Shell showed that 100,000 barrels of crude oil were stolen in Nigeria every day and the weapons and ammunition that could sustain a 1500-person fighting force for two months after the sale. In 2022, data from the Nigerian National Petroleum Corporation showed that 250,000 barrels of crude oil were stolen per day in Nigeria. Benefiting from considerable financial support, the level of weapons and equipment of pirate groups has always been maintained at a high level. On January 18, 2014, the Liberian-flagged oil tanker MT Kerala went missing. It was found eight days later nearly 3000 km north of the coast of Warri, Nigeria, with 13,000 metric tons of refined oil on board. The Kiribati-flagged vessel MT Hai Soon 6 was boarded and hijacked by 10 heavily armed pirates about 46 nautical miles off the coast of Ghana on July 26, 2014. The pirates fled in a speedboat after all the crude on board was pumped into a barge. When it was discovered that the hijacked ship had no oil, things became easier. On March 3, 2014, the Nigerian platform supply ship Prince Joseph 1 was hijacked by a group of armed pirates. All crew members were released safely when the pirates found there was no fuel on board and ensured their own safety. It is important to note that when international oil prices plummet, such as in 2015 and 2020, the resale of oil is no longer a lucrative source of income. At this time, the Gulf of Guinea pirates will turn more to kidnapping crew members for ransom. On November 27, 2015, pirates opened fire on the Cyprus-flagged cargo ship Szafir, forcing it to the anchor before it could be boarded and looted. The crew has since been held hostage for ransom.

The high frequency of “anchor” and “port” indicates that piracy in the Gulf of Guinea region occurs most frequently when ships are anchored in the port. At the same time, it also reflects the high concentration of piracy near the port in the Gulf of Guinea. This is consistent with what has been observed in existing studies, namely that piracy in the Gulf of Guinea usually occurs in jurisdictional waters, not far from the coast [95], with attacks on ships at anchor or in port [64]. A typical case is that on February 4, 2015, the Greek tanker Kalamos carrying 2 million barrels of crude oil was attacked at the Qua Iboe oil terminal in southeastern Nigeria, resulting in the death of one person and three kidnappings.

*3.3.1.2. (2) Piracy in the Gulf of Aden and the Western Indian Ocean.* From Fig. 6, it is easy to obtain that the Gulf of Aden and the Western Indian Ocean have prominent features of severe risk likelihood and moderate risk consequence incidents, and also involve mild risk consequence incidents. The process risk and consequence risk of pirate attacks are relatively low, and the intensity of piracy is weaker than that in the Gulf of Guinea on the whole. However, from the perspective of spatial scope, the location of pirate attacks is more extended to the wide open sea, with the coast of the Horn of Africa as the core, radiating south to the coasts of East African countries such as Kenya and Tanzania, and north to the Arabian Sea.

The word frequency statistics of the incident details of piracy in the Gulf of Aden and the Western Indian Ocean are performed, and a word cloud graph is drawn on this basis, as shown in Fig. 10. The characteristics of Somali piracy can be obtained by analyzing the word cloud map.


**Fig. 10.** Word cloud map of incident details of piracy in the Gulf of Aden and western Indian Ocean.

In terms of spatial clustering characteristics, the pirate behaviors in the Gulf of Aden and the West Indian Ocean region are not concentrated in a certain port or coast but widely distributed in the wide open seas of the Gulf of Aden and the West Indian Ocean region, which is different from the spatial distribution characteristics of the pirate behaviors in the Gulf of Guinea and Southeast Asia. It's a bit odd that such a pattern of behavior requires more time and greater distance. In criminology, Rational choice theory holds that offenders will try to achieve their goals in the simplest and least risky way [82,96], which applies to piracy in the Gulf of Guinea and Southeast Asia. But clearly, the behavior of Somali pirates cannot be explained by rational choice theory. The reason lies in the following aspects. First, a large number of naval anti-piracy activities have a prominent deterrent effect on Somali pirates. From 2008 to 2009, Combined Task Force 150, Combined Task Force 151, and the European Union's Operation Atalanta carried out a large number of anti-piracy operations. The frequent occurrence of "warship" in the corpus also confirms this. As more and more naval forces are devoted to combating Somali pirates, the geographic scope of Somali piracy far exceeds the original 200 nautical miles [10], and they have to sail farther to seek more targets. This brings more time cost and distance cost. Second, in order to avoid pirate attacks, shipping companies will adopt methods recommended by Best Management Practices to adjust shipping routes to stay away from dangerous waters. As of 2011, there has been a trend in the way of circumnavigating the Cape of Good Hope [97], which has led pirates to search further offshore. In 2012, the average successful attack occurred 746 km off the coast of Somalia [98]. This explains why words like "port" are absent in the word cloud, and "underway" has become a high frequency word.

In terms of boarding methods, Somali pirates adopted accelerated pursuit, fire deterrence, and other methods to threaten the sailing ships and boarded them. This is because shipping companies often speed up their ships to pass through dangerous waters in order to ensure their own safety. In this case, the pirates will further accelerate and take measures such as fire deterrence to board the ship. Somali pirates active on the high seas have thus developed unique prey capture characteristics. High-frequency words such as "speed" and "chase" are typical, highlighting the characteristics of Somali pirates' attacks on cargo ships sailing in the waters, including faster speed, more boarding-related efforts, and more chase time. High-frequency words for boarding methods also include "skiff" and "mother ship". Skiff is the main means of transport used by Somali pirates before boarding. However, the duration of small boats sailing on the high seas is limited, so mothership is necessary, often consisting of hijacked fishing vessels and merchant ships [10]. Somali pirates use "mothership" to effectively reduce the defenses of passing ships, and gain more time and longer sailing distances offshore.

Similar to but different from the Gulf of Guinea, more sophisticated weapons and relatively weak violence are also prominent features of Somali pirates. The high frequency of "arm", "gun", "rocket", "grenade" and "weapon" corresponds to the perfection of the equipment of Somali pirates. Rocket propelled grenades (RPGs) and guns are often carried at the same time. Rocket propelled grenades (RPGs) are used to slow down a moving cargo ship for boarding, and guns are used to threaten and control the crew once on board. High-frequency words such as "fire", "attack", "hijack", and "shot" reflect the violent nature of Somali pirates. It should be noted that the violent nature of the Somali piracy process serves the purpose of kidnapping, and then the ransom is their ultimate goal, which will be highlighted in the risk consequences. Therefore, although Somali pirates act violently, they will not cause serious hostage casualties, which may affect the exchange of ransom. As observed by Madsen et al. attacks in West Africa tend to be more violent than those by Somali pirates [99]. Kidnapping peaked in late 2010 when nearly 700 crew members were taken aboard 30 merchant ships off the coast of Somalia [2].

Piracy in the Gulf of Aden and the Western Indian Ocean has a lower probability of success than that in the Gulf of Guinea, suggesting a higher randomness in attacks. From the high frequency of words such as "attempt", "away" and "abandon", it can be seen that failed attacks often occur. As Förster observed in 2016, only about one in five attacks by Somali pirates in 2011 and 2012 were successful [8]. The reason lies in the following three aspects. First, unlike Gulf of Guinea pirates, Somali pirates do not have accurate sources of information on merchant ships, so their attacks are more random. Randomness also means that the probability of failure is higher. They tend to launch a large number of raids, expecting some of them to be successful and garner high returns [8]. The average earnings per pirate for a successful attack exceeds two years' salary [100]. Secondly, as can be seen from the boarding method of Somali pirates just discussed, Somali piracy incidents are often achieved by pursuing a moving merchant ship and successfully boarding the ship. This way of boarding is more difficult than raiding a ship that is anchored in a port. The target ship may take measures such as changing course and going full speed to avoid pirates, which brings a greater possibility of failure to piracy. Third, the continuous improvement of security measures has strengthened the protection of merchant ships, including the cruising of multi-national joint warships and the setting up of security teams. Correspondingly, words such as "security team", "warship", and "coalition" appear frequently in the corpus. The effective deterrence of piracy by naval power has just been discussed. On the other hand, compared to crew members, security teams often have richer capabilities to deal with armed attacks and can effectively deter and resist pirates. A typical case of failed boarding is this: "Four armed pirates in a boat approached the ship underway. The security team on board the ship fired warning shots in the air. Pirates abandoned attempted boarding". As observed by Giampaolo and Foster in 2011, approximately one in ten ships employ security personnel to pass through the Gulf of Aden [97]. And this measure is ineffective in the Gulf of Guinea. The use of Privately contracted armed security personnel (PCASP) is prohibited in the territorial waters of Nigeria, Togo, Benin, and other countries, and guards can only be obtained from the local army.

*3.3.1.3. (3) Piracy in Southeast Asia.* It can be seen from Fig. 6 that piracy incidents in Southeast Asia involve four types of risks, and incidents with severe risk consequences are also included. This seems to be at odds with our conventional wisdom - between the 1990s and the mid-2000s, Indonesian pirates seemed to carry knives and carry out hit-and-run robberies [15]. However, after 2010, things changed. As shown in Table 1, by examining the word frequencies of tools commonly used by pirates in Southeast Asia in the corpus, it can be found that the frequency of gun tools is almost a quarter of that of knives, which is often accompanied by greater violence. As

Rosenberg observed in 2009, More attackers are armed, more crew members are injured, and more vessels are being hijacked [3].

According to the incident details of piracy in Southeast Asia, the word frequency is counted and the word cloud graph is drawn, as shown in Fig. 11. By analyzing the high-frequency word list and word cloud map, the overall characteristics of piracy in Southeast Asia can be obtained.

Piracy in Southeast Asia has both the characteristics of Nigerian pirates and Somali pirates in terms of spatial characteristics. Both ships moored in ports and ships sailing in the sea are their targets. The frequent occurrence of words like "anchor", "port", "underway" etc. Illustrates this point. The appearance of "anchor" and "port" is easy to understand. The depletion of fish, or the dumping of discarded products, impoverishes small-boat fishermen and their families [101]. Some of these poor fishermen choose to petty theft of moored boats near the harbour. Once noticed by the crew, the pirates would flee with the loot or give up the loot. This also explains why the word "escape" appears so many times. Such behavior was common before 2007. After 2007, piracy in the Malacca Strait gradually decreased while piracy in the Singapore Strait and the South China Sea increased. According to rational choice theory, we know that if piracy is spread farther out, there must be some driving force that makes them have to search further afield. This is because, after 2007, the anti-piracy measures in the Straits of Malacca have been effective, resulting in a spatial shift in piracy in Southeast Asia. In this context, "underway" has become a more important keyword. Pirates need to chase ships in motion with a view to boarding and committing robbery and theft.

Besides "escape", another important action word in the piracy corpus in Southeast Asia is "stolen". Unlike the pirates in the Gulf of Guinea or the Somali pirates with a clear purpose, the goals of pirates in Southeast Asia are more complex. The first is the theft of parts and supplies on board. The high frequency of "engine spare" and "store" reflects this. As a typical example, on February 1, 2012, a Chemical Tanker named Siteam Neptun was hijacked at Batam Outer Anchorage during the night. Pirates boarded the ship and stole the ship's stores. The second is the theft of oil tankers, which is the reason for the high frequency of "tanker". On the evening of July 4, 2014, an oil tanker named Moresby 9 was attacked by nine pirates about 34 nautical miles from the Anambas Islands in Indonesia. The pirates forced the first officer to pilot the vessel, while the rest of the crew was tied up and locked in the engine control room. Moresby 9 was then sailed to an unknown location where part of the gas oil was transferred to another tanker. After the transfer, the pirates left the ship [15]. The third type is the attack on tugboats and barges, which is illustrated by the high frequency of "tug" and "barge". This is caused by the characteristics of the tugs and barges themselves. Freeboard and speed determine how easy it is for pirates to board a sailing ship. Vessels with lower freeboards and speeds below 15 knots are more likely to be boarded by pirates. Such vessels are known in the industry as "low and slow" [2]. Tugboats and barges have low freeboard and speeds of around 8 to 10 knots, so they have become the focus of pirate attacks. On June 9, 2013, a tugboat carrying a barge from Thailand to Indonesia was attacked. Six armed robbers climbed aboard in Malaysian waters and forced the crew to pump oil from a tugboat into a fishing boat. The perpetrators then tied up the crew, stole their belongings and other valuables, and fled in a white speedboat [15].

### 3.3.2. *Risk consequence analysis*

Another component of risk is risk consequences. Using the LDA topic model, the topic mining is carried out on the event consequences of piracy incidents in the Gulf of Guinea, the Gulf of Aden and the Western Indian Ocean, and Southeast Asia. On this basis, the prominent features of piracy in each region are extracted, and the corresponding high-frequency words for each topic in the corresponding region and the associated probability of each topic are obtained. The number of topics $K$ in it is determined according to the method of maximizing the log-likelihood value. Fig. 12, Fig. 13, and Fig. 14 show the topic distribution of the risk consequences of piracy incidents in the Gulf of Guinea, the Gulf of Aden and the Western Indian Ocean, and Southeast Asia. From Figs. 12, Figure 13, and Fig. 14, it can be seen that the themes of piracy, especially in the same area, show strong similarity. In this context, the topic assignment probabilities of piracy corpora form relatively concentrated features. The topics with the highest topic assignment probability of the piracy corpus in each region are extracted, as shown in Table 2.

The risk consequences of piracy in the three key sea areas have certain similarities, but there are also clear differences. The similarity is that the word "stolen" appears in the high-frequency words of the key themes of risk consequences in all three regions, but the order is different. The stealing behavior of pirates in Southeast Asia is the most prominent, slightly weaker in the Gulf of Guinea, and the weakest in the Somali waters. The stealing targets of pirates in Southeast Asia and the Gulf of Guinea are also different, which

**Table 1**
Weapons and frequency of weapons of piracy in Southeast Asia.

| word | frequency |
|---|---|
| knife | 567 |
| gun | 119 |
| pistol | 21 |
| machet | 17 |
| firearm | 10 |
| crowbar | 10 |
| parang | 9 |
| stick | 8 |
| rifle | 5 |
| handgun | 4 |
| gunshot | 3 |


**Fig. 11.** Word cloud of incident details of piracy in Southeast Asia.

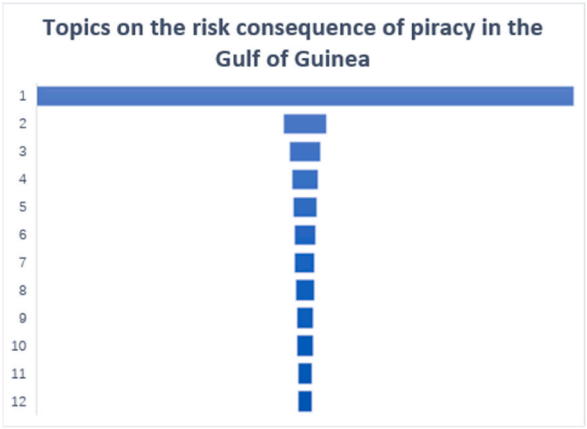


**Fig. 12.** Topics on the risk consequences of piracy in the Gulf of Guinea.


**Fig. 13.** Topics on the risk consequences of piracy in the Gulf of Aden and western Indian Ocean.

often determines the severity of the risk consequences. Pirates in Southeast Asia tend to steal various items from ships, especially personal items. Correspondingly, words such as "personal", "stores", "property", and "belongings" occupy important and numerous positions in high-frequency words. The targets of pirates in the Gulf of Guinea are mainly full-loaded oil tankers or ships with valuable

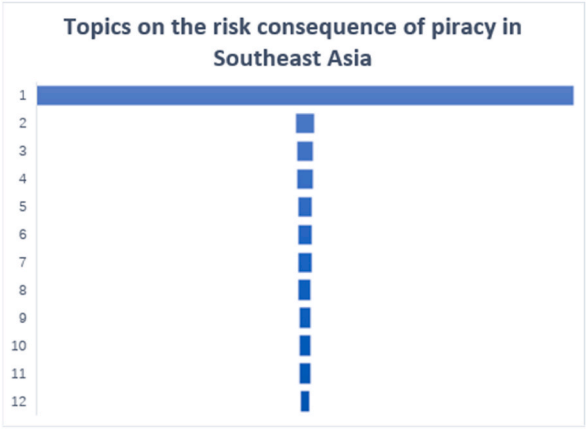


**Fig. 14.** Topics on the risk consequences of piracy in Southeast Asia.

**Table 2**
High frequency words with each topic for piracy risk consequences in key waters.

| Topic Proportion | Region | Top Words | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 69.0 % | Gulf of guinea | ship | stolen | members | pirates | kidnapped | stores | the | tanker | fired | injured |
| 79.5 % | Gulf of Aden and western Indian Ocean | ship | pirates | fired | upon | hijacked | hostage | members | taken | the | stolen |
| 79.3 % | Southeast Asia | stolen | ship | the | stores | property | injured | personal | robbers | belongings | engine |

cargo [89], and the high-frequency word "tanker" is a typical representative. For Somali pirates, who are often active in the Indian Ocean and Gulf of Aden, "stolen" also appears in high-frequency words in key themes, but the extremely low frequency of words shows that theft of goods is not their main goal. Firefights and kidnappings are their preferred tasks, and negotiating a ransom is their main goal.

In other respects, piracy in the three regions presents a clearer difference in risk consequences. According to the parts of speech of high frequency words, we can distinguish the goals of pirates and the means used to achieve them. The combination of the two creates risk consequences. The first is the goal of piracy, represented by the nouns in the high-frequency words. The word "stores" appears in a similar position in the high-frequency vocabulary in the Gulf of Guinea and Southeast Asia, but not in the high-frequency vocabulary in the Gulf of Aden and the Western Indian Ocean. The reason is the same as just mentioned, the main goal of Somali pirates is the high ransom, so they are not interested in the items on board. The word "tanker" appeared in high-frequency words in the Gulf of Guinea, underscoring that they were targeting high-value crude oil. According to UNODC statistics, pirate attacks in the three Gulf countries of Benin, Nigeria, and Togo all involved oil tankers in 2011 and 2012 [102]. The presence of "hostage" in the high-frequency vocabulary of Somali pirates further highlights their goals. Interestingly, the word "engine" appears in high frequency vocabulary in Southeast Asia. Ship engine spare parts, as well as the various items on the ship just mentioned, are more favored by pirates in Southeast Asia. Then there are the verbs in the high frequency list, which show what means pirates generally use to achieve their goals. "fired", "kidnapped", and "hijacked" appear in similar positions in the high-frequency vocabulary of the Gulf of Guinea region and the Gulf of Aden and Western Indian Ocean regions. Pirates often use this method to transmit fear to the crews in order to obtain valuable goods in the shortest time, or to control hostages and ships. However, in the high-frequency vocabulary in Southeast Asia, such words are missing. In addition, the appearance of "fired" also reflects the relatively high level of weapons and equipment of pirates in the corresponding regions. Compared with Nigerian pirates and Somali pirates, Indonesian pirates in Southeast Asia have a lower level of equipment and are not easy to take the initiative in attacks. But in recent years, this situation has gradually changed, and cases of kidnapping crew members and reselling oil have occurred from time to time. "Injured" is similar to the verbs just mentioned. However, the word does not appear in the high-frequency vocabulary of Somali pirates. This reflects less violence by Somali pirates against crew members. This corresponds to the goals of Somali pirates. They need to keep the crew safe in exchange for a hefty ransom. As Lehr observed, Somali pirates usually do not use violence against crew members unless the crew resists them [76]. "Injured" is representative of the consequences of attacks by pirates in the Gulf of Guinea, as crews on ships are seen by pirates as an obstacle to hijacking the vessel, which often results in more injuries and even death. As a typical example, in 2011 and 2012, attacks in Nigerian waters resulted in the injury of 39 sailors and the death of 4 [8].

## 4. Conclusion and discussion

Piracy has brought enormous challenges to international trade and national economic stability. Normal socio-economic activities

such as cargo shipping, cruise navigation, and fishing vessel operations are disrupted. The change of piracy behavior pattern and active area brings new problems to the risk assessment caused by piracy. The text analysis method provides a new idea for the analysis of piracy patterns. In this study, we developed a new shipping risk measure by using text analytics to quantify the process and consequences of piracy. We found that (1) from a spatial point of view, the high-incidence areas of piracy include the Gulf of Guinea, the Gulf of Aden and the Western Indian Ocean, and Southeast Asia, which are the main shipping risk areas caused by piracy in the world. (2) From the perspective of time evolution, the gathering centers of piracy are not static on a global scale. Since 2006, the gathering centers of piracy in the Gulf of Aden and the Western Indian Ocean tend to disappear. The gathering centers of piracy in Maritime Southeast Asia shrunk slightly. And the piracy gathering centers in the Gulf of Guinea have expanded significantly. At the same time, the core sea area involved in pirate attacks is also shrinking and expanding within the region. For example, the core sea area of the Strait of Malacca shrinks while the area of the Singapore Strait and the South China Sea expands, due to the effective anti-piracy measures in the Strait of Malacca. Piracy in the same sea area also has obvious characteristics of emergence and decline, and Somalia is a typical example. (2) according to the risk likelihood and risk consequence, piracy incidents can be divided into four categories: severe risk consequence incidents, severe risk likelihood and moderate risk consequence incidents, mild risk likelihood and moderate risk consequence incidents, and mild risk consequence incidents. (3) The global distribution of different types of piracy varies. Piracy incidents with severe risk consequences are mainly distributed along the coast of the Gulf of Guinea and in narrow waterways in Southeast Asia, which indicates that piracy in this area has caused serious casualties and losses. Piracy incidents with severe risk likelihood and moderate risk consequence incidents have a wider distribution in the Gulf of Aden and the Western Indian Ocean, which corresponds to more intense conflicts in the risk process. (4) Shipping risk caused by piracy in different seas has different evolutionary characteristics. Shipping risk arising from piracy in Southeast Asia has experienced a decade of volatility and plateaued after 2016. The shipping risk caused by Somali pirates began to rise from 2006 until 2009, fluctuated at a high level from 2009 to 2011, and then declined rapidly and stabilized. Shipping risk arising from piracy in the Gulf of Guinea region showed a volatile rise from 2006 to 2012. Risks declined briefly from 2013 to 2015 due to joint regional anti-piracy measures and remained stable after rising in 2016. (5) The behavior characteristics of the risk process of piracy in different seas are diverse, and the violence and selectivity of the Gulf of Guinea are prominent. Compared with the Gulf of Guinea, piracy in the Gulf of Aden and the western Indian Ocean is scattered, well-armed, less violent, and less likely to succeed. Piracy in Southeast Asia has a variety of theft targets and backward weapons, but the level of equipment has improved in recent years. (6) The risk consequences of different seas are significantly different. Somali pirates focus more on high ransoms, Gulf of Guinea pirates focus on high-value crude oil, and Southeast Asian pirates focus more on supplies and personal belongings on board.

According to the above research results, this study can provide relevant suggestions for global piracy control and prevention. (1) Piracy in the Gulf of Guinea has become more active in recent years and the resulting shipping risk remains high, which is the focus of future piracy prevention and control. Regional piracy security measures against piracy need to be further strengthened, under the guidance of the Yaounde Code of Conduct and the Gulf of Guinea Inter-regional Network. (2) Severe risk consequence piracy incidents are distributed along the coast of the Gulf of Guinea and in narrow waterways in Southeast Asia, where stronger security measures are required to protect the lives of crew. (3) Piracy incidents with severe risk likelihood and moderate risk consequence are widely distributed in the Gulf of Aden and the Western Indian Ocean. For this type of piracy, more predictable measures are necessary to prevent pirates from boarding vessels by firing, chasing, etc., thus ensuring maritime security more effectively. (4) Although piracy in Southeast Asia is less violent and less likely to succeed, the massive number of incidents still deserves attention. Especially in the context of global economic slowdown in the post-COVID-19 era, the country of origin of piracy should promote resident equality and income growth, ease conflicts among marginalized groups in society and marginal areas, and prevent piracy at the source.

This study also has significant limitations, mainly in the availability of data. A considerable percentage of pirate attacks go unreported, around fifty percent, due to concerns about increased premiums, pirate retaliation, and time-consuming investigations [103]. At the same time, this problem also exists in other crime-related data. The British Crime Survey shows that only 49 % of personal robberies are reported to the police [104]. It is necessary to advocate shipping companies to form a correct pirate attack reporting model. Only in this way can the research data on pirate attacks be further enriched and the characteristics and trends of piracy can be more accurately grasped. In addition, this study is insufficient for work on multi-agent games involved in piracy. Piracy affects a wide range of entities. In addition to crews, international naval forces, governments of coastal countries, coastal maritime security agencies, private military security agencies, insurance companies, ocean carriers and other entities that participate in and benefit from global trade have all been involved in the huge losses of piracy. However, there is insufficient discussion on the cooperation between different entities in anti-piracy and the confrontation with piracy, which is not conducive to the discussion of piracy prevention and control strategies. At present, evolutionary game theory is helpful to the research on the interaction mechanism of multi-agent behavioral strategy selection in the field of maritime management [105], which needs to be further applied in follow-up research.

Starting from the corpus of piracy, this paper uses text analysis, risk assessment theory, rational choice theory, and other interdisciplinary theories and methods to quantitatively depict and analyze piracy in different seas, and further excavate and explore the rich information in the corpus of piracy. In particular, the evolution curve of shipping risk caused by piracy deserves further discussion and research, which is helpful for us to grasp the evolution trend of shipping risk caused by piracy more accurately. For example, the shipping risk caused by piracy in Southeast Asia has fluctuated upwards for ten consecutive years, which is an important and dangerous signal that should not be ignored. If necessary, the time resolution of the pirate risk evolution curve can be reduced to one month or one week, so as to realize dynamic monitoring of piracy risk. In addition, the close relationship between piracy and political instability is also worthy of attention. As mentioned in this study, piracy in a region is often greatly influenced by the political instability of a country, such as Somalia and Indonesia. Piracy in Somalia began with violent political upheaval and culminated at the beginning of a hopeful democratic process. Therefore, in further research in the future, the factors of political instability, and even the

regional geopolitical background, need to be further analyzed and emphasized. In addition, piracy was bred in a complex geographical environment, affected by various factors such as political instability, economic backwardness, and energy price fluctuations. In the existing research on maritime management, FMEA and AcciMap-BN have performed well in the quantitative analysis of the causes of maritime accidents [106, 107]. In the next step of research, it is necessary to learn from the above methods to fully explore the causes of piracy.

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## Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## CRediT authorship contribution statement

**Zhaoyang He:** Writing – original draft, Software, Methodology, Data curation. **Chengjin Wang:** Project administration, Funding acquisition, Conceptualization. **Jianbo Gao:** Validation, Formal analysis. **Yongshun Xie:** Validation, Supervision.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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