Study on application of regional ecological risk assessment during the development and utilization of Chu Island

Long Ma1, 2, *, Ying Zhang1, a and Zhizhong Ma1, b
1North Sea Marine Technology and Support Center, State Oceanic Administration, Qingdao, China
2Key Laboratory of Integrated Monitoring and Applied Technologies for Marine Harmful Algal Blooms, State Oceanic Administration, Shanghai, China

*Corresponding author e-mail: malone0305@163.com, azhangyingouc@163.com, b231872581@qq.com

Abstract. Taking natural disaster risk problems in the uninhabited island ecosystem as the main research object and combined with the features of uninhabited island ecosystem, regional ecological risk assessment was carried out with the relative risk model (RRM) taking an example of Chu island. According to “Weihai Chu island protection and utilization planning (2011~2020)”, the study area was divided into three risk areas, which are key protected area, basic facility area and ecological tourism area. Birds, sea cucumbers and their habitat as the receptors for Chu island ecological risk assessment was selected, and combined with the regional sources of risk occurrence probability, the range and intensity, storm surge, drought and cold wave were the main risk sources in the region. The exposure response relationship of "risk source—stress—habitat—ecological end point" in each risk area was analyzed. We pointed out: (1) in the development and utilization process of Chu island, storm surge is the most influential source of risk in the region, and its influence is far higher than drought and cold wave; (2) the island land resources, especially the vegetation, affected by the risk source is the largest, followed by water and the tidal flat; (3) As the two main functional areas in the development and utilization process of Chu island, the relative risk value of basic facility area and ecological tourism area, which is 1.05 and 0.97 respectively, is larger than key protection area, and its relative risk value is 0.5.

1. Introduction
Regional ecological risk assessment is a process that assesses the probability of negative ecological impacts brought by one or multiple stresses on ecosystems at the regional scale [1], including multiple factors such as regional geographic information, multiple risk sources, different receptors, various exposure routes or multiple ecological endpoints [2], which can solve problems such as regional development environmental effects, natural disasters, pollution prevention and sustainable development. Therefore, accurate screening, prediction, analysis, assessment and management of the potential risks existing in regional ecosystems timely are of great practical significance for the maintenance of ecosystem functions and the promotion of sustainable regional economic development.
Taking Chu Island as an example, this paper takes ecological risks as the research object, which are generated by natural disasters as main risk sources. The paper predicts and evaluates the probability of ecological effects caused by these ecological risks. The paper also carries out risk management to prevent or reduce the occurrence of ecological risks. On one hand, the paper provides a scientific basis for risk countermeasures and minimizes the ecological losses. On the other hand, the paper instructs the rational development and utilization of non-resident islands through the comprehensive analysis of natural disaster risks, providing theoretical support for comprehensive and effective management of islands.

Figure 1. Geographical situation of Chu Island

2. Method
Combining with characteristics of ecosystems of non-resident islands, this paper divides the regional ecological risk assessment into four main steps based on relevant theories of ecological risk assessment, namely: problem formation, risk analysis, risk characterization and risk management [3]. The paper also introduces the RRM model [4, 5] to discuss the regional ecological risk assessment of non-resident islands.

Figure 2. Technology roadmap
2.1. Definition, Division and Analysis of Research Areas
The definition of the assessment area is the premise of the regional ecological risk assessment. The time and space range of the assessment area should be defined accurately in accordance with the assessment objective and possible disturbances as well as the ecological endpoints. Chu Island is divided into three risk zones, including the key protected zone, the ecotourism zone and the infrastructure zone. The habitat structure of each zone is mainly realized by the remote sensing image interpretation and the GIS analysis and statistical function. The Chu Island diagram surrounded by a water depth line of 6m can be obtained by overlaying the existing water depth distribution diagram of Chu Island with the registered remote sensing satellite image. Through the remote sensing image classification of the overlaid 6m-water depth line, this paper finally determines the types, areas and distribution ranges of different habitats (see Table 1).

![Figure 3. Analysis of Geographical Features in Chu Island](image)

| Type      | The Key protected zone (m²) | The Ecotourism zone (m²) | The Infrastructure zone (m²) |
|-----------|-----------------------------|--------------------------|------------------------------|
| Vegetation| 73927.64                    | 56036.96                 | 23272.65                     |
| Tidal flat| 18366.58                    | 19751.40                 | 9129.43                      |
| Water     | 51814.36                    | 54586.61                 | 20503.48                     |
| Total     | 144108.58                   | 130374.97                | 52905.56                     |

2.2. Analysis of Receptors
Receptors refer to risk takers, which should be selected considering the following three points: (1) the importance in the ecosystem; (2) the sensitivity to the effects of risk factors; and (3) related species, populations, communities and ecosystems can all be used as risk receptors. In this paper, birds, stichopus and their habitats are used as the receptors for the ecological risk assessment of Chu Island.

2.3. Analysis of Risk Sources
This paper carries out a comprehensive analysis of the historical data of Chu Island and determines that storm surge, drought and cold wave as the main risk sources in the region in accordance with the probability, intensity and range of each risk source. The frequency statistics of each risk source are shown in Table 2.
Table 2. Statistics of Frequency of Major Natural Disasters in Chu Island

|                      | Larger Level (%) | Major Level (%) | Super Level (%) | Total Probability (%) |
|----------------------|------------------|-----------------|-----------------|-----------------------|
| Drought              | 22.0             | 14.0            | 12.0            | 48.0                  |
| Cold Wave            | 56.0             | 20.0            | 16.0            | 82.0                  |
| Storm surge          | 18.0             | 12.0            | 8.0             | 38.0                  |

2.4. Analysis of Ecological Endpoints
The ecological endpoint refers to the damage that the risk receptor may suffer under the influence of the risk source with uncertainty, as well as the damage of the regional ecosystem structure and function caused by it [6]. In Chu Island, the possible ecological endpoints include the reduction in the bird populations, the decrease in the species and yield of stichopus, as well as the degradation of related habitats.

3. Results and Discussion

3.1. Exposure and Hazard Analysis

3.1.1. Exposure Analysis. Through the field investigation of Chu Island and the analysis of the exposure relationship between risk sources, habitat types and ecological endpoints, this paper forms a diagram of contact exposure routes from risk sources to ecological endpoints (see Figure 2). To better describe the degree of actions on the receptors from the pressure sources in risk zones, this paper introduces the concept of “pressure density” and “habitat abundance” [7] to set the ration of the intensity of various risk sources or habitats in risk zones to the maximum intensity of the risk source or the habitat in this zone as its density or abundance.

![Figure 4](source)

The area of Chu Island is 17.0 hm², which is a small scale. Therefore, the impact of natural disasters can be regarded as the same, that is, the affected area and the intensity distribution are consistent. The formula for the pressure density [7] is:

\[ P_k = \sum P_{mn} \] (1)
In the formula, $P_k$ refers to the comprehensive risk probability of the $k$ risk zone. $P_{mn}$ refers to the probability of $m$-type $n$-level ecological risk in the $k$ risk zone, $\beta_m$ refers to the weight of the $m$-type risk source.

This paper uses the analytic hierarchy process to establish the structural model combining with the historical statistics and relevant data for risk analyses in the region. Finally, it determines the relative weights of the three main risk sources of Chu Island as follows: the weight of drought is 0.31, the weight of storm surge is 0.50, and the weight of cold wave is 0.19. Therefore, this paper finally obtains the pressure density of each risk zone in Chu Island, as shown in Table 3.

**Table 3. Pressure Density under the Action of Pressure Sources in Chu Island**

| Risk sources   | Basis for calculating pressure density                                  | Pressure density |
|----------------|------------------------------------------------------------------------|-----------------|
| Drought        | Depending on the probability and intensity of the pressure source       | 0.149           |
| Storm surge    |                                                                        | 0.190           |
| Cold wave      |                                                                        | 0.156           |

Combining with the remote sensing image interpretation data of different habitats in each risk zone of Chu Island, this paper calculates the habitat abundance of each risk Zone of Chu Island (see Table 4).

**Table 4. Habitat Abundance of Risk zones in Chu Island**

| Habitat       | Basis for calculating habitat abundance                  | Habitat Abundance |
|---------------|----------------------------------------------------------|-------------------|
|               | The Key protected zone                                    | The Infrastructure zone | The Ecotourism zone |
| Tidal flat    | The ratio of the percentage of habitat area to the percentage of maximum in the region | 0.74       | 0.88       | 1             |
| Vegetation    | 1                                                       | 0.84       | 0.86       |               |
| Water         | 0.86                                                    | 1           | 0.93       |               |

For each risk zone, the exposure, response route and extent of the whole process of “risk source – pressure characterization – habitat type – ecological endpoint” are not the same. The quantified intensity and coefficient are shown in the following table.

**Table 5. Relative strength and coefficient of exposure and response path**

| Relative strength | Coefficient | Description                                      |
|-------------------|-------------|--------------------------------------------------|
| Exposure and Response path | Lower       | 0                                                | Path does not exist. |
|                    | Low         | 0.3                                              | Path exists and exposure or response is low. |
|                    | Medium      | 0.5                                              | Path exists and exposure or response is medium. |
|                    | High        | 0.7                                              | Path exists and exposure or response is high. |
|                    | Higher      | 1.0                                              | Path exists and exposure or response is higher. |

For the different habitat types of Chu Island, the exposure coefficient of different risk sources is determined by the exposure degree of the habitat in the region. The same type of risk source have different exposure degree in different risk zones. The difference is regulated by the regional pressure density of this risk source [8].
Table 6. Risk Exposure Coefficient for the Development and Utilization of Chu Island

| Risk source Habitat | Drought | Storm merge | Cold wave |
|---------------------|---------|-------------|-----------|
| Tidal flat          | B 0.3   | A,B 0.5     | B 0.5     |
| Vegetation          | B,A 0.7 | A,B 0.7     | B 0.7     |
| Water               | -- 0    | A,B 0.7     | B 0.3     |

Tips: A —— Habitat destruction, B —— Environmental disturbance

The response coefficient represents the different response degree of the ecological endpoint to the risk source, which is mainly determined by the closeness between the population of different species and the habitat in this region.

Table 7. Risk Response Coefficient for Development and Utilization of Chu Island

| Risk zones                  | Habitat | Birds | Sea cucumber |
|-----------------------------|---------|-------|--------------|
| The Key protected zone      | Tidal flat | F,R | 0.3 | -- | 0 |
| Vegetation                  | F,R,B | 0.3 | -- | 0 |
| Water                       | F | 0.3 | R,B | 0.3 |
| The Infrastructure zone     | Tidal flat | F,R | 0.5 | -- | 0 |
| Vegetation                  | F,R,B | 0.7 | -- | 0 |
| Water                       | F | 0.3 | R,B | 0.7 |
| The Ecotourism zone         | Tidal flat | F,R | 0.7 | -- | 0 |
| Vegetation                  | F,R,B | 0.7 | -- | 0 |
| Water                       | F | 0.3 | R,B | 0.7 |

Tips: F —— Foraging, R —— Habitat, B —— Reproduction

3.1.2. Hazard Analysis. Drought disasters will hinder the growth and development of vegetations and aquatic organisms in the wetlands, which in turn can affect the habitat of bird receptors. Storm surge will not only destroy the structure and habitat types of the wetlands but also accelerate coastal erosion processes [9]. Strong winds and cool weather brought by cold wave and strong cold air will also have certain impacts on the land creatures in the island and the surrounding water bodies.

3.2. Risk Characterization

The calculation formula of RRM model is:

$$RS = \sum \left\{ S_{km} \times \frac{1}{H_{kn}} \times X_{mn} \times E_{np} \right\}$$  \hspace{1cm} (2)$$

In the formula above, $RS$ represents the relative risk value of this zone; $k$ is the label of the risk zone; $m$ is the label of the risk source type; $n$ is the label of the habitat type; $p$ is the label of the ecological endpoint type; $S_{km}$ is the density level of the risk source in the risk zone; $H_{kn}$ is the abundance level of the habitat in the risk zone; $X_{mn}$ is the exposure coefficient of the exposure route of “risk source – pressure gauge – habitat type”; $E_{np}$ is the response coefficient of the response route of “habitat type – ecological endpoint”. The risk evaluation results for different subjects can be obtained through the formula above.
(1) Risk assessment for potential risks of different pressure source types

Figure 5. Relative risk value of risk zones under different pressure source types

Figure 5 clearly shows the relative risk values of three different risk zones in Chu Island affected by different risk sources. The assessment results show that storm surge has the greatest impact on the risk zones of Chu Island, followed by cold wave and drought. Among the three different risk zones, the infrastructure zone and the ecotourism zone are affected by various risk sources similarly, which are relatively large. The key protected zone is the least affected, which is almost 1/2 lower than the former two zones. Therefore, from the division principle of the risk zones, it can be known that the key protected zone protects the island tree species and vegetations, rock reefs and ecosystems in this zone, while the infrastructure zone and the eco-tourism zone are exposed to relatively high risks.

(2) Risk assessment for potential risks of different habitat types

Figure 6 shows the relative risk values of three different risk zones in Chu Island affected by different habitat types. The assessment results show that as the main land resource and habitat type in the island, the relative risk of vegetations is the largest among the three risk zones, followed by water bodies and tidal flats. For the same habitat type, the relative risk values of the infrastructure zone and the ecotourism zone are higher than that of the key protected zone.

Figure 6. Relative risk value of different habitat types in risk zones

(3) Risk assessment for potential risks of different risk zones

The assignments are marked in the figure through the GIS means. The three risk zones are divided into three different risk levels, including low risk zone 0~0.5, medium risk zone 0.5~1.0, and high risk zone greater than 1.0. On this basis, among the three risk zones of Chu Island, the key protected zone belongs to the low-risk zone; the ecotourism zone belongs to the medium risk zone; the infrastructure zone belongs to the high risk zone. As two important functional zones developed and utilized by Chu Island, the infrastructure zone and the ecotourism zone suffer from relatively high risks generated by the natural factors while the key protected zone suffers from relatively small risks.
4. Conclusion

Taking Chu Island as an example, this paper takes the natural disaster risk problems in the non-resident island ecosystem as the research object, and uses the relative risk model (RRM) to carry out the regional ecological risk comprehensive assessment on the non-resident island ecosystem. It is found that during the development and utilization of Chu Island, storm surge will have great impacts on this zone as the main risk source. Island land resources, especially vegetations, are most affected by risk sources. The offshore precious marine resources are also greatly affected by storm surge and cold wave; in the planning, the development of the infrastructure zone and the ecotourism zone is relatively strong. Their relative risks of natural disasters are also large. Therefore, it is recommended that risk management should be strengthened from the following two aspects.

(1) Establish the monitoring, early warning and forecasting, emergency response systems of marine disasters, such as storm surge and cold wave [10]. Further improve the disaster emergency response and disposal capabilities, improve the prediction and monitoring capabilities of the ecological environment in non-resident islands, providing Chu Island with scientific basis for its rational development and utilization.

(2) Prepare the Chu Island Development and Utilization Plan in strict accordance with the Chu Island Protection and Utilization Plan. Carry out the spatial layout of the island construction project scientifically and rationally. Strictly control the island development area and development mode to achieve the purposes of legal, scientific and effective utilization of Chu Island.

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