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Research Article
Design of Visual Simulation and Analysis System of Marine Protected Areas Disasters

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Abstract

Background: According to the vegetation status and special geographical location of China "Island shape" marine protected areas, the visual simulation and analysis system of marine protected areas disasters consisting of forest fire spreading analysis and seawater rising analysis has been designed, based on Geographic Information System (GIS) component development to provide help and support to the disasters prevention and relief. **Methodology:** The combined forest fire model of Wang Zhengfei and Mao Xianmin and calculation and simulation method of Huygens principle have been chosen to simulate the spreading scope of fire. The grid model (Grid) of protected areas and non-source submergence algorithm have been chosen for "Island shape" marine protected areas to simulate seawater rising. **Results:** The results show that the visual simulation and analysis of forest fire spreading can clearly simulate the spreading scope of fire based on specific impact factors and the spreading scope of fire varies by the change of impact factors. The results also show that the visual simulation and analysis of seawater rising can vividly simulate the rising process of seawater level through 3D model of marine protected areas and rising rate of seawater can be calculated by the system through monitoring data. **Conclusion:** In this way, the system can calculate how soon the seawater was reached the warning line and submersed line depending on the rising rate of seawater.

Key words: Marine protected areas, GIS component development, visual, forest fire spreading, seawater rising

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The area of global ocean is about 360 million km^2 and accounts for 71% of the surface of earth. There are a large number of rare creatures and abundant resources in the sea. China is a country with large area of sea in the world. China create marine protected areas to protect the rare and endangered marine species and their habitats as well as the marine natural landscape and historical sites of great scientific, cultural and landscape values[1].

On the one hand, marine protected areas, which have lush vegetation are almost islands and locate in coastal areas. If fire broke out in marine protected areas, it would be very hard to fight. According to this, it is helpful for rescue to clarify the spreading scope of fire as soon as possible. On the other hand, due to the special geographical location of marine protected areas, the rise of seawater by bad weather such as storm tide will cause a serious threat to the protected areas[2]. So, it is significant to know the seawater level, the rising rate of seawater and the time of reaching the warning line. Based on the two points above, this study designs a system to visually and dynamically simulate forest fire spreading and seawater rising by Geographic Information System (GIS) component development to provide help and support for disasters prevention and rescue in marine protected areas.

There have been a number of forest fire spreading models, such as Rothermel model[3], Australian McArthur model[4], Chinese Wang Zhengfei forest fire model, the combined forest fire model of Wang Zhengfei and Mao Xianmin and so on[5]. The calculation and simulation methods of forest fire spreading consist of simulation based on cellular automaton[6], simulation based on Huygens principle[7] and so on. The source submergence algorithm and non-source submergence algorithm are usually used in visual simulation of seawater rising and submerging[8-10]. According to the characteristics of marine protected areas, this study was chosen as appropriate model and algorithm to realize the visual simulation and analysis of marine protected areas disasters by researching the forest fire spreading mechanism and seawater submergence algorithms.

MATERIALS AND METHODS

General condition of study region: The study region is Jinzhou Dabijia mountain national special marine protected areas, which was established on 29th December, 2009. The whole area is 3240 ha, which is divided into the core area, the function undetermined area, the development and utilization area and the protected area. The establishment of the protected area has important significance to protect marine animals and plants resources, geological landscape, cultural landscape, historical sites of the entire region and harmonize the protection of marine environment with the development of resources. The famous Dabijia mountain beauty spot locates inside the region and attracts a large number of tourists every year. In this study, the visual simulation and analysis of disasters is aimed at Dabijia mountain beauty spot. The latest study shows that Dabijia mountain is the most completed and typical attached island of original landscape features.

Logic structure of visual simulation and analysis system: Spatial data and GIS component development have been used to construct the visual simulation and analysis system to simulate the disasters of marine protected areas. The system is programed by C# programing language through Visual Studio, 2008 and SuperMap Objects 6 component packages based on C/S architecture and Net Framework 3.5. The DevComponents.DotNetBar2.dll is used to design UI. The logic structure of system is shown in Fig. 1.

The system is logically divided into support layer, control layer and application layer. In support layer, the SDB and SDD databases are used to store the spatial data and the corresponding attributes, such as 3D model, remote sensing image and so on. Analysis models database store the algorithms and models, which are used in the system. Control layer is used to output the results by responding to users' commands. In this layer, the interfaces and controls of SuperMap Objects 6 component packages are used to design

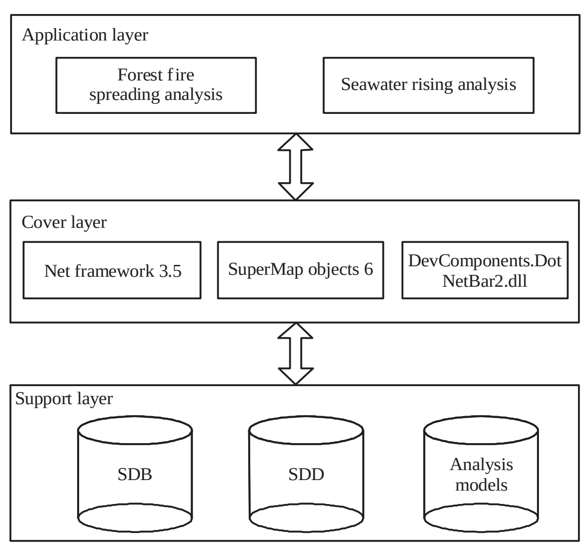

Fig. 1: Logic structure of the system

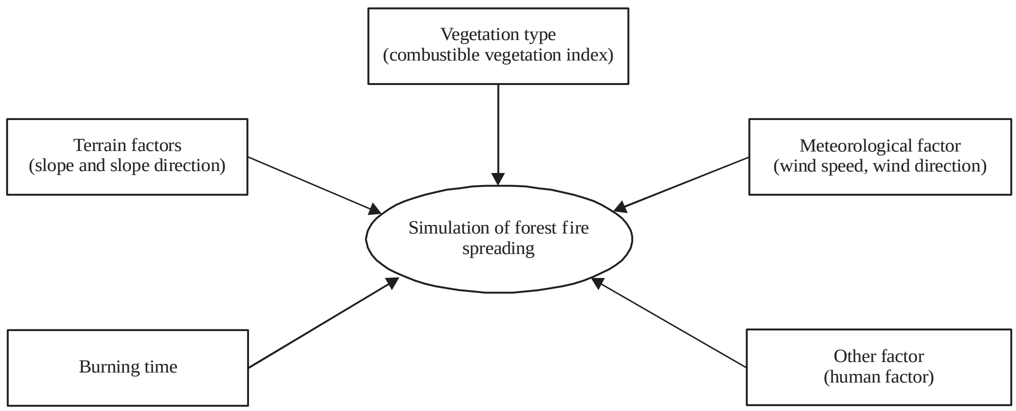

Fig. 2: Impact factors of forest fire spreading

Table 1: Combustible vegetation indexes

Combustible vegetation index	Meadow	Artificial forest	Pine
K_s	1.0	0.7	0.6

and develop the system functions and realize the connection and access to databases. The DevComponents.DotNetBar2.dll is used to design beautiful and easy-to-use UI. Application layer (function layer), which is used to realize human-machine interaction and complete visual simulation and analysis.

Model and algorithm for forest fire spreading: In order to simulate the forest fire spreading scope of special time and condition in marine protected areas, the location of fire and impact factors should be known and the forest fire spreading model and calculation and simulation method should be properly chosen.

Impact factors of forest fire spreading: The forest fire spreading is a complex process and affected by many factors[11], such as vegetation type (combustible vegetation index), terrain factors (slope and slope direction), meteorological factors (wind speed, wind direction, wind scale, temperature and relative humidity), burning time and other factors (human factors and others), as shown in Fig. 2. In the simulative process of forest fire spreading, the values of every impact factor should be accurately gained and the final scope is calculated by the system.

Selection of forest fire spreading model and calculation and simulation method: According to the terrain and vegetation characteristics of study region, the combined forest fire model of Wang Zhengfei and Mao Xianmin has been finally chosen in the perspective of applicability and the calculation and simulation method of Huygens principle has been finally chosen by reason of improving efficiency and saving memory.

Combined model:

$$R = R_o\, K_s\, K_w\, K_\phi = R_o\, K_s\, e^{0.1783v\cos\theta}\, e^{3.533\,(\tan\phi)^{1.2}} \quad (1)$$

where, R_o is the initial spreading rate (m min^{-1}), K_s is the combustible vegetation index, K_w is the wind correction coefficient, K_ϕ is the terrain correction coefficient, v is the wind speed, (m sec^{-1}), θ is the angle between wind direction and slope, (°) and ϕ is the slope angle (°).

The R_o is the most basic factor and best index when fire breaks out. The other parameters are used to revise it gradually. This study uses indoor initial velocity formula under the condition of no wind:

$$R = 0.0299T+0.047W+0.009\,(100-H)\,-0.304 \quad (2)$$

where, T is the daily maximum temperature (°C), W is the wind scale at noon (level), H is the daily minimum relative humidity (%).

The K_s represents the combustible vegetation index and is a correction factor, which is used to describe the degree of combustible vegetation and whether the combustible vegetation are easy to satisfy the burning configuration pattern. On the basis of Professor Zheng Huanneng's study results[12], the combustible vegetation in study region can be divided into three grades, such as meadow, artificial forest and pine. The corresponding indexes are shown in Table 1.

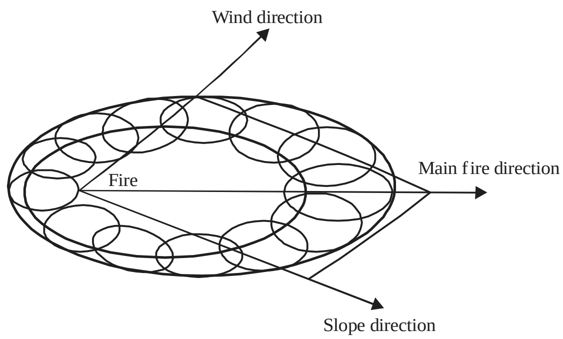

Fig. 3: Calculation and simulation method based on Huygens principle

The calculation and simulation method based on Huygens principle is a kind of method also based on wave propagation theory. At regular intervals, the ellipse parameter and spreading rate spreading from source points on the boundary of fire to the unburned zone are calculated and finally a series of small elliptical burned areas have been formed. The outside envelopes of the elliptical burned zones merge vectorially to form the fire scope of next moment. The algorithm has been designed through the study of ellipse model[13]. The boundary control point at certain moment is regarded as an independent fire source and its spreading scope is an ellipse. The wind vector and slope vector jointly determine the fire direction and the spreading rate is calculated by forest fire spreading model combined with slope, wind speed and so on. Figure 3 shows the specific principle. The fire source locates in the focus of the ellipse and the wind vector and slope vector merge the main fire direction. The control points on the ellipse form small burned areas.

DEM and algorithm for seawater rising: Seawater rising threatens the safety of marine protected areas and the surrounding areas. If seawater level exceeded a certain value, it would submerge the whole marine protected areas. The suitable Digital Elevation Model (DEM) and submergence algorithm should be chosen to calculate and simulate the changing process of seawater level in order to clarify the submersed scope.

Selection of DEM: The DEM is the basic data for hydrological analysis, which contains catchment areas analysis, drainage network analysis, rainfall analysis, flood calculation and submergence analysis and so on. There are various types of DEM. The Triangulated Irregular Network (TIN) model and grid model (Gird) are widely used[14]. Due to Grid runs significantly faster than TIN in program and has the

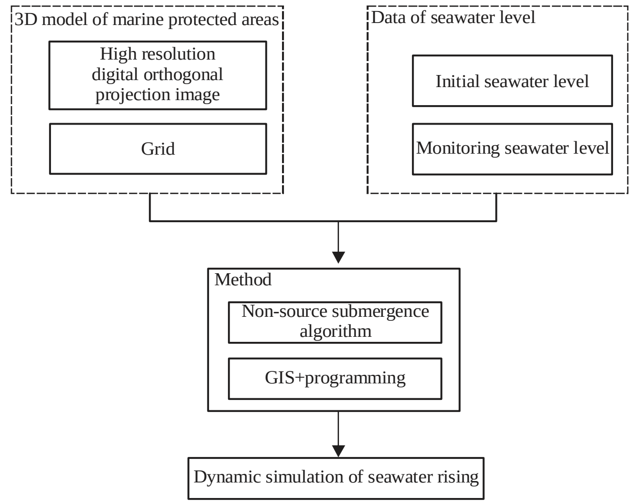

Fig. 4: Simulation process of seawater rising

characteristics of simple structure, less memory occupation and convenient calculation, this study chooses Grid of marine protected areas to simulate and analyze seawater rising. The high resolution digital orthogonal projection image of marine protected areas is overlaid with Grid to generate a vivid 3D model for the simulation of seawater rising.

Selection of submergence algorithm: When Grid is used to calculate the submersed scope, source submergence algorithm and non-source submergence algorithm are usually chosen. The source submergence algorithm needs to be considered with connectivity, while non-source submergence algorithm needn't[15]. Due to marine protected areas are mostly islands and this study studies the impact of seawater rising on marine protected areas, non-source submergence algorithm is finally chosen for "island shape" marine protected areas with high efficiency. It was compared by grid elevation values of Grid with seawater level by non-source submergence algorithm and classify the grids bellowing the seawater level into submersed scope[16].

By comparing seawater levels of a period of time, the rising rate of seawater can be calculated and then the time of reaching the warning line and submersed line can be calculated. The 3D model is used to simulate the seawater rising dynamically. The simulation process of seawater rising is shown in Fig. 4.

RESULTS

Visual simulation and analysis of forest fire spreading: The specific process of visual simulation and analysis of forest fire spreading in marine protected areas is that: Based on the combined forest fire model of Wang Zhengfei and Mao Xianmin and the calculation and simulation method of Huygens principle, the program simulates the spreading scope of certain time through the location of fire and impact factors. The high resolution digital orthogonal projection image of marine protected areas is used to display the scope vividly. The impact factors selected in this study consist of burning time, combustible vegetation index, wind speed, wind direction, daily maximum temperature, wind scale at noon, daily minimum relative humidity, slope and slope direction. The slope and slope direction are gained by DEM of marine protected areas and the others are gained by field measurement.

Compare and analyze the simulation of forest fire spreading by controlling impact factors:

- When the location of fire, combustible vegetation index, wind speed, wind direction and daily maximum temperature, wind scale at noon and daily minimum relative humidity are equal and burning time is diverse, the spreading scopes are shown in Fig. 5

The red scopes in Fig. 5 are the spreading scopes of forest fire. The picture above is the scope of 60 min and the picture below is the scope of 80 min. When burning time is diverse and the other impact factors are equal, the spreading scopes are different. The burning time is longer, the spreading scope is bigger.

- When the location of fire, combustible vegetation index, wind speed, burning time, daily maximum temperature, wind scale at noon, daily minimum relative humidity are equal and wind direction is diverse, the spreading scopes are shown in Fig. 6

The picture above is the scope of 20° and the picture below is the scope of 80°. When wind direction is diverse and the other impact factors are equal, the spreading scopes are different.

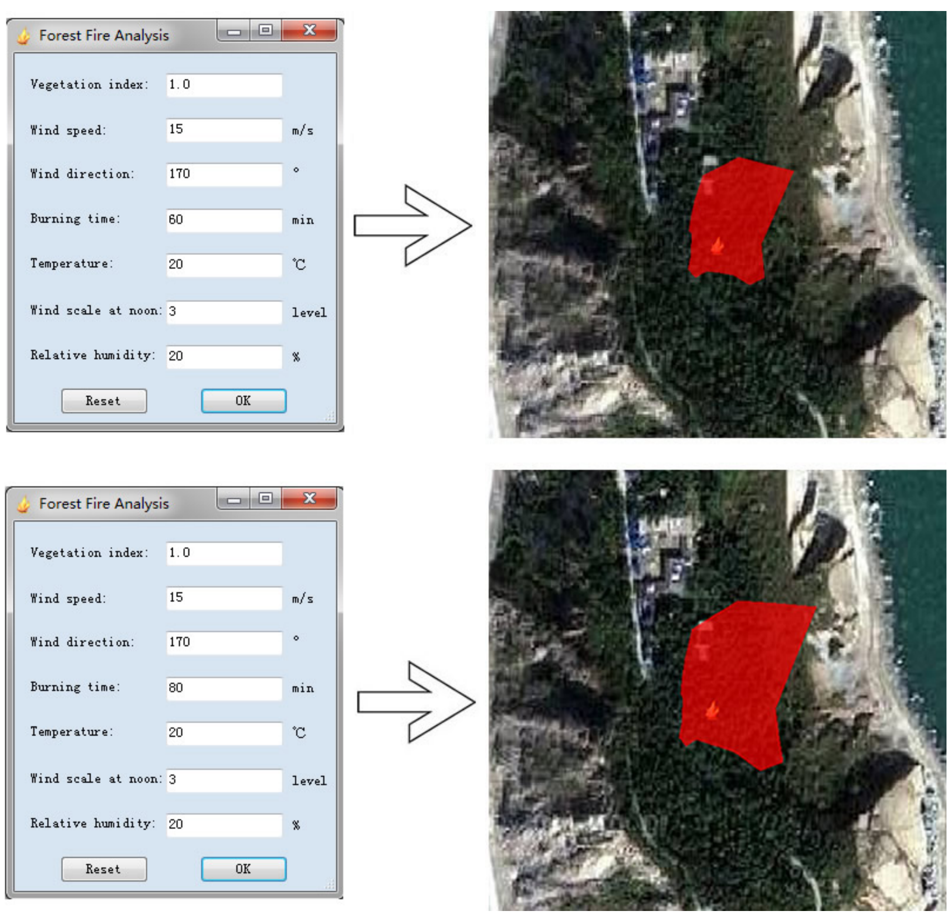

Fig. 5: First picture of forest fire analysis

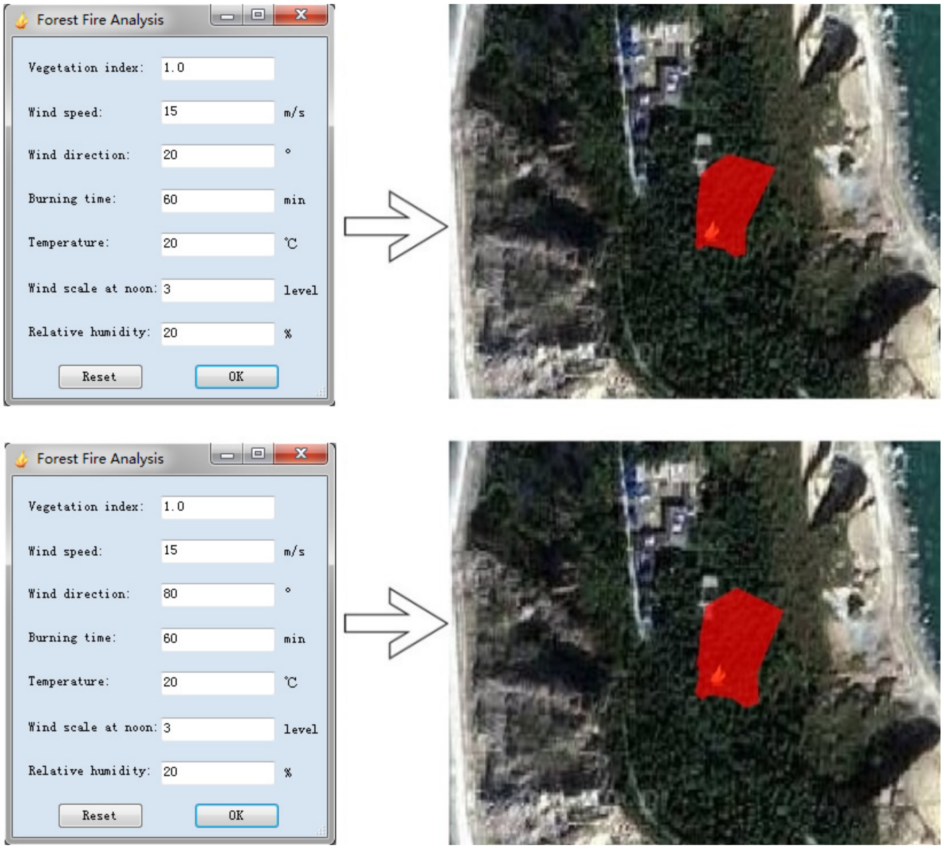

Fig. 6: Second picture of forest fire analysis

Table 2: Seawater level rising information

Seawater level an hour ago (mm)	Current seawater level (mm)	Seawater rising rate (mm min^{-1})	Warning line (mm)	Submersed line (mm)	Time of reaching warning line (min)	Time of reaching submersed line (min)
20500	25000	75	50000	78000	333.3	706.7

Figure 5 and 6 show that every impact factor can generate great impact on the simulation results. So, the accurate measured values of the day should be inputted to ensure the accuracy of the simulation results. The spreading direction, trend and scope of forest fire can be obtained by visual simulation and analysis of forest fire spreading. Therefore, the firefighters can make plans in time by the information to minimize the loss caused by the fire.

Visual simulation and analysis of seawater rising: The rising rate of seawater can be calculated by comparing the current seawater level with the seawater level an hour ago of the monitoring data from observation station. So, the time of reaching the warning line and submersed line can be calculated. On the basis of the calculated results, the changing process of seawater level is simulated dynamically through 3D model. So, the seawater rising condition and the position of seawater reaching can be clearly observed, which can provide basis for prevention and rescue. Take certain monitoring data for example. The monitoring data and results calculated by visual simulation and analysis system through monitoring data are shown in Table 2. This study takes the 25000, 30000 and 35000 mm seawater levels for example, as shown in Fig. 7.

The changing process of seawater level and the position of seawater reaching can be seen by the 3D model in Fig. 7. Therefore, the grid model (Grid) and non-source submergence algorithm are suitable for is "Island shape" marine protected areas to simulate seawater rising. In this way, the visual simulation and analysis of seawater rising can come true by the system automatically.

Fig. 7: Changing process of seawater level

DISCUSSION

Rothermel model is a semi-empirical model, which requires numerous parameters and most of them need be acquired through experiments. There is no access to acquire the parameters in most parts of China. Australian McArthur model is adapted to grassland and eucalyptus forest in Australia with severe regional restriction, so it is not suitable for the study[17]. The combined forest fire model of Wang Zhengfei and Mao Xianmin is based on the forest fire experimental analysis in Greater Higgnan Mountains of China. The parameters of the model could be acquired easily and the model is convenient and practical[18].

By field survey of research region, the region is hill and the vegetation is similar to that used in the combined forest fire model of Wang Zhengfei and Mao Xianmin. So, the model is suitable for the study region.

Because the study region is an island, the change of seawater level is the first factor to be considered. Due to the non-source submergence algorithm is more efficient than source submergence algorithm[19], it is more suitable for the rapid calculation of seawater level change and disaster emergency in study region when the seawater is rising.

For China, "Island shape" marine protected areas, simulation and prediction of disasters is an important way to reduce staff and economic losses. The algorithms chosen in this study have applicability for "Island shape" marine protected areas. By means of GIS component development, making full use of spatial data and visually simulating the mechanism and changing process of disasters has become an important means, for example, the surge vulnerability of landslides can be visually analyzed by GIS[20].

This study puts forward the forest fire spreading analysis and seawater rising analysis methods for China "Island shape" marine protected areas and there is less study which considers the both cases at the same time. As a result of the vegetation status and special geographical location of "Island shape" marine protected areas, the two kinds of disasters are easy to happen. So, the both cases should be considered at the same time.

CONCLUSION

The visual simulation and analysis system of marine protected areas disasters can simulate the development tendency of disasters to provide help and support for disasters emergency. The study conclusions are as follows:

- This study chooses the combined forest fire model of Wang Zhengfei and Mao Xianmin and the calculation and simulation method of Huygens principle to realize the visual simulation and analysis of forest fire spreading in marine protected areas by GIS component development. The simulation results show that the spreading scope can be simulated within a certain period of time through the location of fire and the values of impact factors. When the values of impact factors change, the spreading scope will change
- Grid and high resolution digital orthogonal projection image are used to make the vivid 3D model of marine protected areas. The visual simulation and analysis of seawater rising is realized by non-source submergence algorithm. The simulation results show that the 3D model can simulate the changing process of seawater level vividly and the rising rate of seawater can be calculated by monitoring data. Therefore, the time of reaching the warning line and submersed line can be calculated

ACKNOWLEDGMENTS

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