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Lake restoration from impoldering: impact of land conversion on riparian landscape in Honghu Lake area, Central Yangtze

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Abstract

Impoldering as a type of land conversion can impact both land cover and landscape characteristics. This study characterized the impact of identified lake restoration activities on land uses and riparian landscapes in Honghu Lake area in the Central Yangtze River, China using satellite remote sensing techniques. Landsat TM satellite images for 1987, 1993, and 1998 were classified and analyzed. The land covers were grouped into five types: water body, lacustrine vegetation, floodplain, cropland, and open land. By applying geographic information system (GIS), the spatial patterns of the land cover change over the 11-year period were analyzed. Through overlaying three classification maps generated from the satellite imagery, the percentage of each of the land covers that were converted into other land use types was computed. Patch-related landscape indices were generated to analyze restoration impacts on landscape features. The study indicates that the lake restoration from impoldering greatly changed the land cover and land use types and modified riparian landscapes in a considerably short period of time. Lake and landscape development after the restoration presented clearly two distinct periods, the changing phase and the stabilizing phase. The analysis also suggests that the restoration could affect riparian land type conversion by inundation due to increased water coverage and by land adaptation for changing land uses.

Keywords: Impoldering; Lake restoration; Land cover change; Landscape indices; Remote sensing; Honghu Lake

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1. Introduction

Impoldering is a special type of land conversion that encroaches waters and riparian lands through the building of dikes for cultivation or other agricultural purposes (Schot and Molenaar, 1992). Historically, impoldering was often adopted in China to rapidly increase agricultural production to sustain growing human population (Heilig, 1997). In the central Yangtze River region, perennially or seasonally flooded shallow lakes and marshes, which are typically found in the region, were subjected to extensive impoldering (Shi, 1989). This land reclamation practice was accelerated during the period from the early 1950s through the early 1980s and had made the Jianghan (Hubei Province)-Dongting Lake (Hunan Province) plain in the Central Yangtze, an important area for agricultural production. However, the impoldering activities had resulted in significant negative consequences, both ecologically and economically, including increased flooding and crop losses, as well as declines of lakes and wetlands (Randall et al., 1998). For example, in Hubei Province, the number of the lakes that were larger than 1 km^2 declined to 326 in the early 1980s

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from 1066 in the early 1950s (Wang, 1987). These consequences and the awareness of the importance of wetlands have motivated establishing policies on lake and wetland protection and restoration (Xu, 1999). As a result, state budgets for financing this type of land reclamation ceased approximately two decades ago, promoting effective political and economic measures for lake protection. Under such new policies, China started, from the early 1980s, its lake restoration projects over major lake areas, especially in the central Yangtze River region. As the largest lake in the Jianghan Plain of the Central Yangtze, Honghu Lake was under several major restoration projects in the early and mid 1980s, resulting in tangible changes in the lake itself and riparian landscapes and agricultural resources.

As a reverse process of impoldering, this type of lake restoration, such as opening breaches on dikes, could tremendously shape riparian landscapes in a considerably short period of time. However, there were few studies on this anthropogenic process and its effects on land covers and land uses. It could even be difficult to record such changes at a landscape level based on field observations. Resource managers and environmental researchers are concerned about how the landscape characteristics and land use types were shaped or converted, especially regarding the extents and rates of these changes. This information would help to understand the effects of impoldering-related lake restoration on the agricultural activities adapted for riparian landscape changes and plan future restorations and the lake ecosystem and resource management.

To address these issues, an approach to integrating satellite remote sensing data with landscape metrics was developed. The objectives of the study were to understand the temporal and spatial patterns of land cover changes that happened after the restoration projects and then identify the land use adaptation to the riparian landscape changes.

2. Methods

2.1. Study area

The Honghu Lake watershed comprises of Honghu County and a part of Jianli County, Hubei Province (Fig. 1), with an area of 2463 km^2 (112°34′–114°08′E, 29°33′–30°17′N). The area has a subtropical monsoon climate, with an average annual sunshine of 1987 h, rainfall range of 1100–1300 mm, and annual mean temperature of 16.3 °C (Chen and Xu, 1995). Honghu Lake, originally connecting with Yangtze River, is an

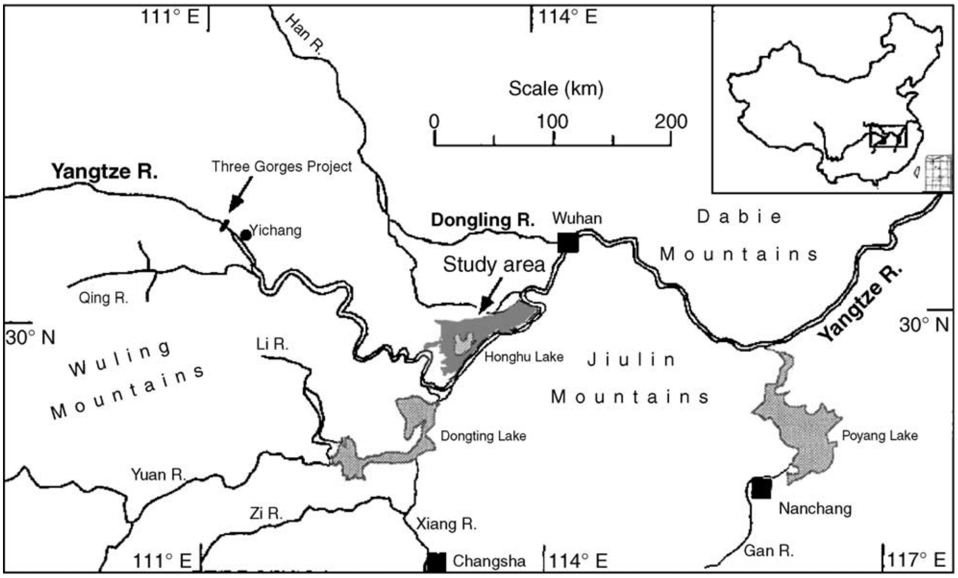

Fig. 1. Sketch map of the study area.

obstruction lake originated from Yangtze River and East Jingjiang River. The lake area has been subject to flood damage over thousands of years, and flooding control projects did not make significant progress until 1950s (Cai and Xia, 1993). The building of dikes in 1955 and establishing of a large throttle dam in 1958 blocked the connection of Honghu Lake to East Jingjiang River and Yangtze River and mitigated flooding damages (Yu et al., 1993). The established irrigation system also facilitated impoldering in this area, and as a consequence, Honghu Lake has decreased in size greatly during the period from the early 1950s through the early 1980s (Wang and Dou, 1998). As a result, Honghu Lake became a closed lake with reduced capacities in serving multiple functions, such as water storage, irrigation, fisheries, and navigation.

2.2. Data and methods

The image processing software IDRISI (Clark University, USA) was used to classify the land cover types with a data set of a three-band RGB combination (Bands 3–5) of Landsat Thematic Mapper (TM) imagery. In order to minimize possible interpretation errors, all the images were acquired around September and October (26 September 1987; 12 October 1993; 26 October 1998, respectively). The 1987 and 1998 images were geo-referenced to that of 1993, which was geometrically corrected first. The images of three dates were then classified using the maximum likelihood method (Jensen, 1996). The land covers were grouped into five types: water body, lacustrine vegetation, floodplain, cropland, and open land (Table 1 and Fig. 2). An initial field survey was conducted before TM imageries were interpreted.

In order to determine the accuracy of the image classification, the stratified random sampling method (Jensen, 1996) was used to generate reference points. For each of classified images, 210 reference points were obtained. Those points that fell outside the study area or on the border between different land covers were eliminated. The accuracy of three classified products were assessed by verifying general land cover delineation using topographic maps and vegetation maps, or based on field survey information and interviewing with local residents. The resulting overall classification accuracy was 83, 86, and 84% for the three images, respectively.

Spatial analysis was carried out to describe patterns of land cover changes over time and to measure the rate of changes. Based on this information, two land cover type transformation layers (1987–1993) and (1993–1998) were then generated and analyzed using IDRISI GIS's Crosstabulation function.

Patch characteristics can be used to describe landscape features (Forman, 1995). Thus, several patch-related landscape indices were generated and analyzed across the study area based on classified image data. The classification maps were exported to the Grid Module of ArcInfo GIS program (ArcInfo is the product of ESRI Inc.), and each patch area and its perimeter were derived for all the land cover types of the three classification maps (1987, 1993, and 1998). The patch-related landscape indices listed below were computed using FRAGSTATS algorithms (McGarigal and Marks, 1995).

Mean patch size (MPS) can serve as a habitat fragmentation index at the landscape level, because a patch type with a smaller MPS might be considered more fragmented (Turner, 1990).

$$\mathrm{MPS} = \frac{0.0001\sum_{j=1}^{n} a_{ij}}{n_i} \qquad (1)$$

where i is the ith land cover type, j the jth patch of the ith land cover type, a_{ij} the jth patch area (ha) of

Table 1
Descriptions for land cover types in the study area

Land cover category	General description
Water body	Areas that include river, lake, channel, and ponds used to culture fish and freshwater crab
Lacustrine vegetation	Wetland vegetation, in some cases mixed with natural and artificial forests and shrubs
Floodplain	Areas carrying a large volume of water during rainy season but covered by sand and different sizes of gravel and stones during dry seasons
Cropland	Areas allotted to dry fields, paddy fields, and lotus cultivation
Open land	Areas that include barren lands and remaining open land near homesteads

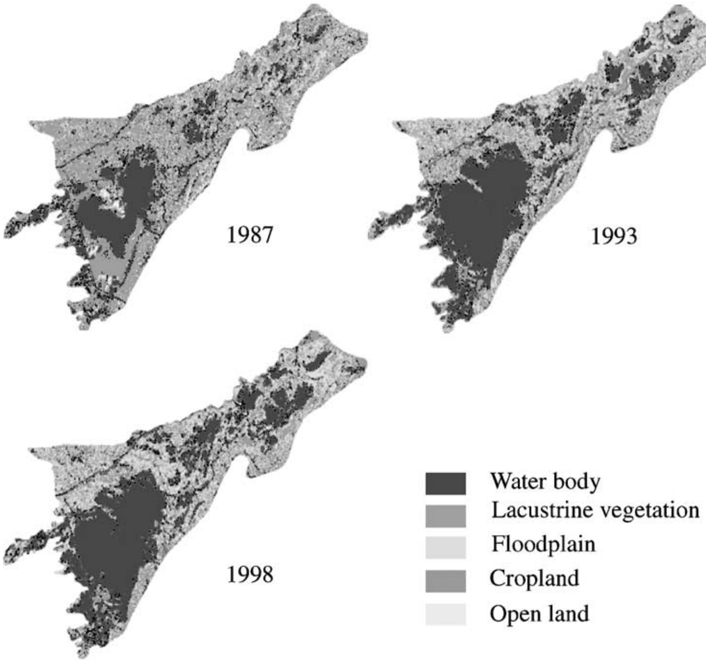

Fig. 2. Land cover types of the study area in 1987, 1993 and 1998.

the *i*th land cover type, n_i the patch numbers of the *i*th land cover type.

Patch density (PD) as an index has the same basic utility as the number of patches, except that it expresses the number of patches based on a unit area. When total landscape area remains constant, patch density is the index of heterogeneity, because a landscape with a higher patch density shows greater spatial heterogeneity (Hietala-Koivu, 1999).

$$\mathrm{PD} = \frac{n_i}{A} \qquad (2)$$

where n_i is the same as the above-mentioned, and A the total area (km^2) of all land cover types.

Frequency distribution of patch size classes can also serve as an indicator for landscape fragmentation. In order to classify distribution of patch size for each land cover type, the patches were grouped into twelve classes according to the number of pixel, pixel 1, 2, 3–4, 5–8, 9–16, 17–32, 33–64, 65–128, 129–256, 257–512, 513–1024, and more than 1024 pixels. Then these patch size classes were converted into an area unit in hectare according to the pixel size of TM image (30 m × 30 m).

3. Results and discussion

3.1. Land cover type transition

The data analysis indicates that the lake restoration projects implemented around the early and mid 1980s significantly increased water body and floodplain coverage while reducing other land types. The area of the water body in 1987 was only 54% of that in 1993 (Table 3 and Fig. 3a). Similarly, the coverage of the floodplain increased from 432.1 km^2 in 1987 to 669.0 km^2 in 1993. Both the water body and the floodplain showed insignificant variations during the period from 1993 to 1998 (Table 3 and Fig. 3a). This land change pattern suggests that the restoration projects caused the lake (water body and floodplain) to reach its relatively stable status in a relatively short period of time. As shown by Table 3 and Fig. 3a, the restoration caused a sharp decrease in cropland from 23.5% of the study area in 1987, 18.9% in 1993, to 7.7% in 1998. Open land also dropped from 3.6 to 0.6% of the total area from 1987 to 1998. However, lacustrine vegetation changes showed a different pattern: coverage decreased by 18.6% for the period from 1987 to 1993

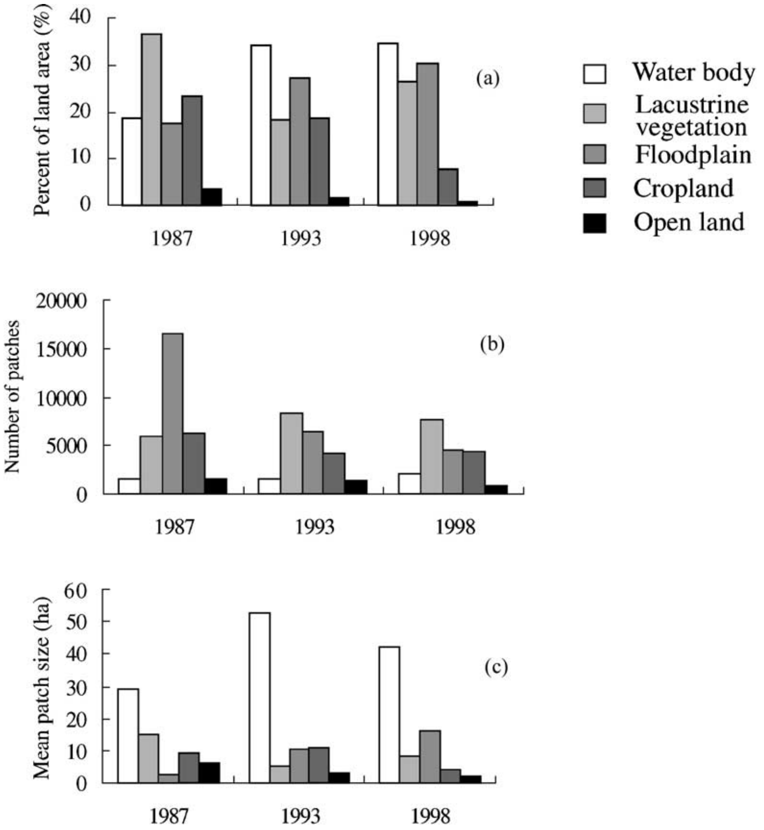

Fig. 3. Percent of land area (a), number of patches (b), and mean patch size (c) for the land cover types during the period of 1987–1998.

and then increased by 8.5% for the period from 1993 to 1998. According to the classified satellite images (Fig. 2 and Table 2), the later gain of the vegetation coverage mainly occurred in abandoned croplands that were not inundated. This suggests that the lake restoration could affect riparian land conversion in two ways: by inundation due to increased water coverage and by land adaptation for changing land uses.

Table 2
Land cover transition proportion (%) between 1987–1993 and 1993–1998 in the study area

Land cover	Water body	Lacustrine vegetation	Flood plain	Cropland	Open land
1987–1993					
Water body	82.8	11.0	3.2	3.0	0.0
Lacustrine vegetation	29.6	25.6	30.7	13.4	0.7
Floodplain	7.6	15.5	41.6	32.0	3.3
Cropland	23.3	15.1	30.9	27.7	2.9
Open land	31.0	9.7	21.2	34.5	3.6
1993–1998					
Water body	74.4	17.9	5.7	1.9	0.1
Lacustrine vegetation	27.8	38.9	27.8	4.9	0.7
Floodplain	10.3	31.4	49.1	8.1	1.1
Cropland	7.8	24.2	48.4	19.0	0.7
Open land	1.9	21.2	57.7	17.3	1.9

A transition matrix (Table 2) was calculated to help understand the land cover transitions among land types. The water body had the highest retention rate while the lowest went to the open land for both periods of 1987–1993 and 1993–1998. During the period of 1987–1993, the highest change rate (i.e. 34.5%) was for the land type transition from the open land to the cropland; from 1993 to 1998, the highest change rate (i.e. 57.7%) was for the open land to the floodplain. The cropland retention rate decreased from 27.7% between 1987 and 1993 to 19.0% between 1993 and 1998. It was noted that during the periods of 1987–1993 and 1993–1998 the human population in Honghu Lake area continued to grow at rates of 12 and 4%, respectively (Statistical Bureau of Hubei Province, 1988, 1994, 1999). It would certainly have placed a high demand on agricultural lands, which could modify the land cover transition process caused by the restoration. High transition rates for the open land might indicate that the open land was increasingly utilized by local residents after the restoration as the alternative to compensate the cropland loss from the restoration.

3.2. Landscape characteristics change

As indicated by the landscape indices (Table 3 and Fig. 3), the restoration projects had modified landscape characteristics, and this process varied according to land cover types. After the restoration, both the MPS values (Fig. 3c) and the coverage percentages (Fig 3a) of water body and floodplain were greatly increased. This suggests that the impoldering-related restoration process not only restored the lake (water body and floodplain) from croplands and other land covers, but also made the lake less fragmented. As more water patches developed, the lacustrine vegetation became more fragmented after the restoration, which was indicated by a significantly decreased mean patch size (Fig. 3c) for an increased number of patches (Fig. 3b). Greatly reduced in coverage area, both the cropland and the open land showed no meaningful changes in other landscape characteristics (Fig. 3b and c).

The PD value of floodplain dropped sharply after the restoration, suggesting that significant modification of lake hydrology by the restoration projects had generated more homogenous floodplain landscapes (Table 3). The decrease in PD values for the cropland and the open land might be simply caused by the reduction of their total coverage, resulting in smaller but more homogenous land covers. Unlike other land covers, the water body and lacustrine vegetation became more heterogeneous after the restoration, as indicated by increased PD values (Table 3). The number of patch showed the same trends as those of the PD values for all land cover types (Fig. 3b).

Table 3
Landscape characteristics for land cover types over time

	Area (km^2)	Patch density[a] (number/km^2)
Water body		
1987	457.5	0.6
1993	840.4	0.7
1998	854.1	0.8
Lacustrine vegetation		
1987	903.5	2.4
1993	445.3	3.4
1998	653.6	3.1
Flood plain		
1987	432.1	6.7
1993	669.0	2.6
1998	747.3	1.9
Cropland		
1987	577.6	2.6
1993	463.6	1.7
1998	188.6	1.8
Open land		
1987	89.8	0.6
1993	41.4	0.6
1998	14.8	0.3

[a] Patch density is the ratio of patch numbers of different land cover types to the total areas.

Classified satellite images showed that more patches of water and vegetation covers developed in 1993 and 1998 than in 1987, while the number of patches of other land cover types decreased from 1987 to 1998 (Fig. 2). Most of the patch-related landscape indices for the study area varied less from 1993 to 1998 than from 1987 to 1993, indicating that the lake restoration caused some relative stability in landscape characteristics in a quite short period of time.

To illustrate the relationship between the number of patches and the patch size (indicated by the median of a given area range), the frequency distribution of patch size classes was calculated (Fig. 4). The frequency distribution curves for all the land cover

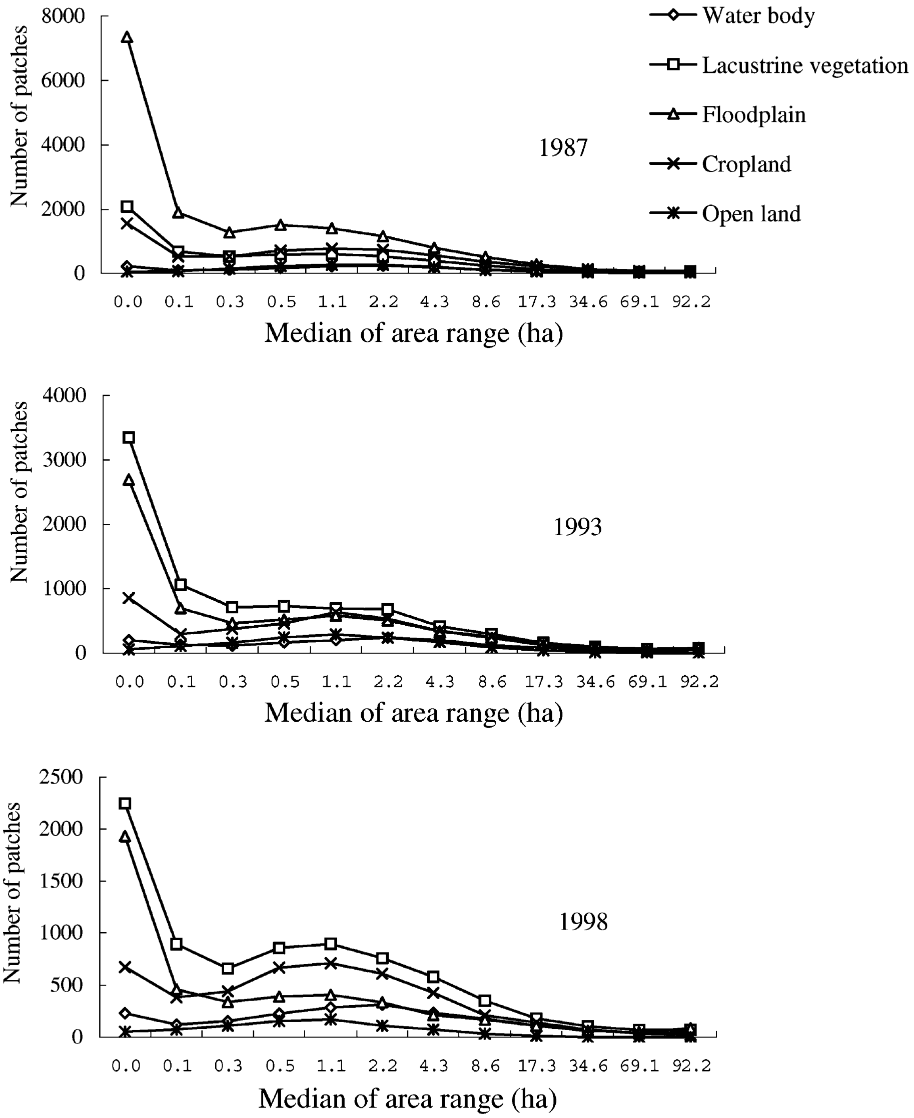

Fig. 4. Frequency distribution of the land cover types for periods of 1987, 1993 and 1998.

types showed similar trends for 1987, 1993 and 1998. For the lacustrine vegetation, the floodplain, and the cropland, the number of patches decreased as the area range increased. This decrease was significant when the area was smaller than 0.1 ha and moderate in the range from 0.1 to 34.6 ha, but showed no clear variation after 34.6 ha. For the water body and the open land, the distribution curves were relatively flat, although more patches occurred near the middle of all area ranges. Except for the water body and open land, a rapid drop in the number of smaller patches for all other land types from 1987 to 1998 (Fig. 4) suggests that the restoration effects made the riparian landscape less fragmented.

4. Conclusions

The study suggests that the lake restoration from impoldering could greatly change the land cover and land use types and modify riparian landscapes in a considerably short period of time. However, the lake and riparian landscapes could soon establish relatively stable conditions, thus presenting clearly two distinct periods of the lake and landscape development after the restoration, namely, the changing phase (1987–1993 for this study case) and the stabilizing phase (1993–1998). The changes in landscape characteristics caused by the restoration varied according to land cover types. Generally, as the lake hydrology was significantly modified by the restoration projects, floodplain landscapes became more homogenous while the lacustine vegetation tended to be more fragmented. The analysis also indicates that the lake restoration could affect riparian land conversion in two ways: by inundation due to increased water coverage and by land adaptation for changing land uses. Alternative land uses by local residents to compensate the cropland loss from the restoration could modify this land cover transition process.

Although remote sensing and landscape indices are appropriate technical means to detect and describe the changes in land cover and landscape features, more on-site data collections, such as hydrological and biological data, and analyses would better help understand the restoration process and the effects. It would be especially beneficial to analyze the impacts of land cover and landscape changes on wildlife population dynamics and biodiversity.

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