CHARACTERIZE THE SIZE OF SHALLOW LANDSLIDES MAPPED WITH SATELLITE IMAGES

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Abstract: Shallow landslides triggered by typhoon events are the major source of sediments of Shimen Reservoir in north Taiwan, with a watershed area of 763.4 km^2 and a water surface area of 8.0 km^2 at full storage. The purpose of this study is to understand the landslide size features obtained by satellite images of SPOT-5 and Formosat-2 after severe rainfall events, and, thus, to give a reference for image selection for landslide inventory. Six times of images were used in this study for representing four major typhoon events from 16 August 2004 to 3 September 2005. Images of SPOT-5 and Formosat-2 for both standard spatial resolution and enhanced-mode resolution are used to understand the effect of spatial resolution on the results of manual interpretation of landslides. It is concluded that (1) More landslides are mapped with images of higher resolution than with lower resolution for the same event; (2) Images of higher resolution give more smaller sizes of landslides; (3) Variations of landslide occurrences are due to triggering factors, especially the magnitude of the event and the temporal apart of two consecutive events.

1. INTRODUCTION

Shimen Reservoir (Figure 1), which has a watershed area of 763.4 km^2 and a water surface area of 8.0 km^2 at full storage, supplies water to more than three million people in northern Taiwan. Shallow landslides triggered by typhoon events are the major source of sediments of Shimen Reservoir. Both aerial photographs and satellite images have been used for estimating the sources of sedimentation from landslides (Huang et al., 1998; Rau et al., 2006 & 2007). In this study, a comparison of the results of sizes and numbers of landslides using different satellite images of SPOT and Formosat-2 is made to know the characteristics of landslide sizes by two different sensors and two sensing modes, and, thus to know the advantages of different types of images such as the interpretability, resolution, and timeliness.

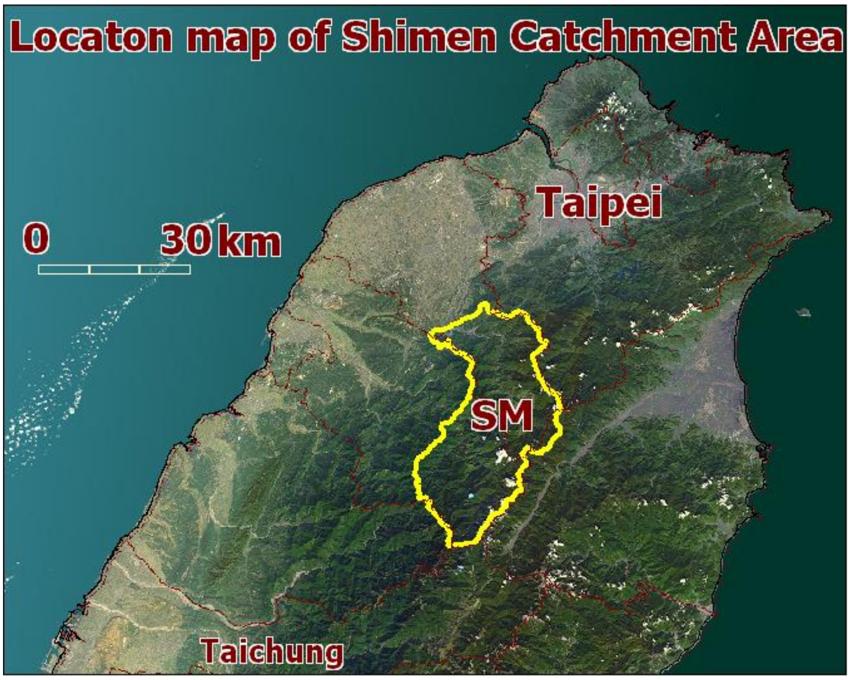

Figure 1: Location of the study area.

2. METHODS

2-1 Research Materials

Six times of images for covering major typhoon events in 2004 and 2005 are used in this study (Table 2, .Figure 2) Taiwan is prone to Typhoons, similar to countries such as the Philippines, Japan, China (the southeastern coastal region), the Pacific and the Caribbean countries. Table 1 shows a list of Typhoon events that hit Taiwan in 2004 and 2005 (CWB, 2012). Four major events which caused serious rainfalls and damages are considered in this study, namely Aere on 26 August 2004, Haitang on 20 July 2005, Matsa on 6 August 2005 and Talim on 1 September 2005. Table 2 and Figure 2 show the satellite images and their corresponding typhoon events.

Table 1: Typhoon events hit Taiwan in 2004 and 2005 (CWB, 2012).

Year	Number	Name	Warning period	Maximum wind speed (m/s)	Radius of the 7_{th} level wind speed (km)	Radius of the 10_{th} level wind speed (km)
2005	519	Longwang	09/30～10/03	51	200	80
2005	518	Damrey	09/21～09/23	25	200	--
2005	515	Khanun	09/09～09/11	43	200	80
2005	513	Talim	08/30～09/01	53	250	100
2005	510	Sanvu	08/11～08/13	25	200	--
2005	509	Matsa	08/03～08/06	40	250	80
2005	505	Haitang	07/16～07/20	55	280	120
2004	427	Nanmadol	12/03～12/04	38	250	80
2004	424	Nock-ten	10/23～10/26	43	250	100
2004	421	Meari	09/26～09/27	40	200	80
2004	420	Haima	09/11～09/13	18	100	--
2004	417	Aere	08/23～08/26	38	200	50
2004	413	Rananim	08/10～08/13	40	250	100
2004	409	Kompasu	07/14～07/15	20	100	--
2004	407	Mindulle	06/28～07/03	45	250	100
2004	404	Conson	06/07～06/09	33	150	50

Table 2: The satellite images and their corresponding typhoon events

number	Satellite image	resolution	Before the event of	After the event of
1	SPOT5 2004/08/16	10 m	Aere	
2	SPOT5 2005/03/16	10 m and 2.5 m		Aere
3	Formosat-2 20050404	8 m and 2 m		Aere
4	Formosat-2 2005/07/25	8 m		Haitang
5	Formosat-2 2005/08/16	8 m		Matsa
6	Formosat-2 2005/09/03	8 m		Talim

2-2 Manual Interpretation of landslides

Manual interpretation of landslides was conducted in this study. Two geologists experienced with field survey of landslides were trained to read and delineate shallow landslide features under 2D GIS environment and thus to enter the attributes of each individual landslides when one landslides are recognized on satellite images. Main procedures for the landslide mapping conducted include following steps:

(1) Acquisition of standard products of ortho-rectified images from Center for Space and Remote Sensing Research (abbr. CSRSR), National Central University.
(2) Image enhancement for landslide-enhanced false color composite (Figure 3).

(3) Manual interpretation of landslides on GIS interface with fixed scale of on-screen images at 1/500.
(4) Enter additional attributes for the delineated landslide including a priority classification of ABCD based on the relevance to protected objects such as houses and public facilities.
(5) Field survey of landslides for landslides classified as A and B classes.
(6) Database installation of landslides with field-checked attributes.
(7) Statistical analyses and presentation of final report.

For general application of satellite images, spectral features of objects are usually used for automatic classification to recognized different classes of land cover types (Liu et al, 2002; Chang and Liu, 2004; Chang et al., 2010). Automatic classification is useful for recognizing the bare ground of new landslides. However, bare lands are not necessary landslides. For practical consideration, manual method is adopted in Taiwan for almost all governmental projects in general survey of landslides using either aerial photography or satellite images. In addition to the fixed scale and image enhancement used on GIS screen, criteria for the trained interpreter include: (1) Tonal criterion- such as brown, deep brown, and green brown. (2) Relative location criterion- landslides should usually be found on steep slopes, upper stream reach, road cut side, and river attacking side. (3) shape criterion- elongated, spoon-shaped, or rectangular-shaped in river-side, and dendritic shape for quick flows on steep tributaries. (4) Directional criterion- sliding direction should conforms to direction of gravity. (5) Shadow criterion- on 2D images, interpreter should bear in mind that illumination source of the image may cause false vision due to the shadow effect. Care should be paid on knowing the valley and the ridges on the images.

In the GIS environment, after the delineation of the landslide boundary and close the boundary as a polygon, attribute of the landslide should be entered. Attributes adopted in this study include ID number, political unit 1 (county), political unit 2 (township), political unit 3 (village), National Map Series Number, watershed designation, sub-watershed designation, land-cover type, landslide size, coordinates of center points of landslide polygon, elevation of landslide crown, and slope of the landslide. The size of each individual landslides is used in the analyses of this study.

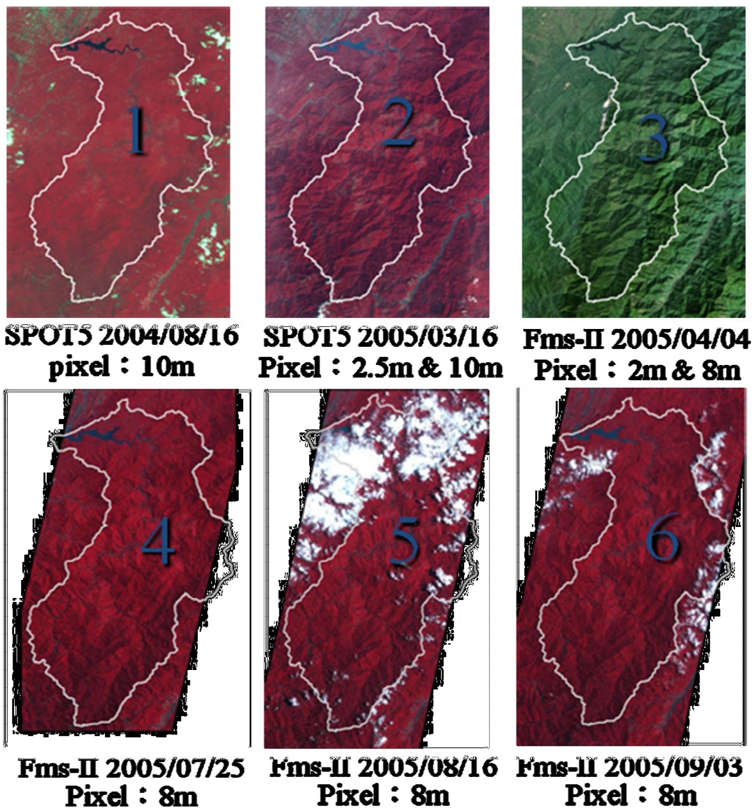

Figure 2: The satellite images used in this study

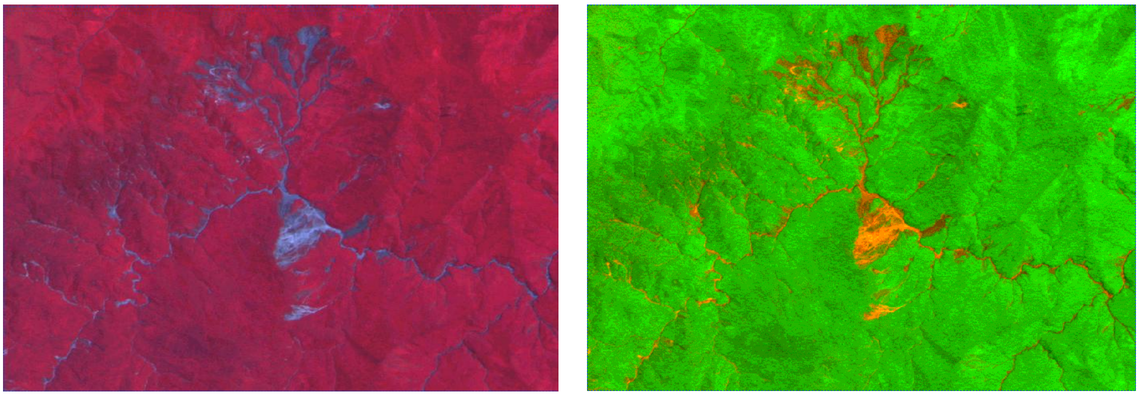

Figure 3: Ordinary false color composite image (Left) and landslide-enhanced FCC image (Right) that make the non-vegetated area with brown color for visual interpretation.

3. RESULTS AND DISCUSSION

Table 3 shows the results of landslide interpretation. There are two satellite imaging sensors, namely SPOT5 and Formosat-2. And, there are two imaging modes used, namely enhanced mode of SPOT5 with ground sampling distance (GSD) of 2.5 m and pan-sharpened mode of Formosat-2 withGSD of 2 m. Landslides of Matsa are not included in this analyses due to that the cloud cover was serious and the landslides are not covering the whole Shimen Reservoir catchment. The general average size of a landslide on all the images ranges from 1.05 ha to 1.66 ha. Table 4 shows the statistics of landslide size in percentages of five classes on basis of landslide size. In general, landslides smaller than 1 hectare have 63% whereas total area coverage of this class of size has 24%. And, 99% of total landslide count is smaller than 10 hectares with total area coverage of 85% in these 2 classes. Some further observations of the size of landslides are given in the following discussion.

Table 3: Results of landslide interpretation

	images	GSD (m)	Event	Total no. of landslides	Total area of landslides (Ha.)	Average area of a landslide (Ha.)
1	SPOT5 on 20040816	10	before Aere	215	225.85	1.050
2	SPOT5 on 20050316	10	after Aere	379	629.25	1.660
3	SPOT5 on 20050316	2.5	after Aere	477	693.33	1.454
4	Formosa-2 on 20050404	8	after Aere	424	689.56	1.626
5	Formosa-2 on 20050404	2	after Aere	473	723.74	1.530
6	Formosa-2 on 20050725	8	after Haitang	549	745.73	1.358
7	Formosa-2 on 20050903	8	after Talim	535	776.93	1.452

Table 4: Statistics of landslide size

Class of landslide size	1	2	3	4	5	1	2	3	4	5
Range of landslide size (Ha.)	0~1	>1~10	>10~50	>50~100	>100	0~1	>1~10	>10~50	>50~100	>100
s20040816-10M	67.9%	31.6%	0.5%	0.0%	0.0%	32.4%	62.9%	4.6%	0.0%	0.0%
s20050316-10M	57.5%	41.4%	0.8%	0.3%	0.0%	19.4%	63.4%	6.3%	10.9%	0.0%
s20050316-25M	63.7%	35.4%	0.6%	0.2%	0.0%	23.6%	60.7%	5.7%	9.9%	0.0%
f20050404-8M	58.5%	40.3%	0.9%	0.2%	0.0%	20.3%	62.2%	7.5%	10.0%	0.0%
f20050404-2M	61.5%	37.4%	0.9%	0.2%	0.0%	22.1%	61.2%	7.2%	9.5%	0.0%
f20050725-8M	67.8%	31.2%	0.9%	0.2%	0.0%	25.8%	56.5%	8.4%	9.2%	0.0%
f20050903-8M	64.7%	34.0%	1.1%	0.2%	0.0%	23.7%	57.7%	9.8%	8.9%	0.0%
Average	63.1%	35.9%	0.8%	0.2%	0.0%	23.9%	60.7%	7.1%	8.4%	0.0%

3-1 Landslides induced by Typhhon Aere

AS shown in Table 3 and Table 4, the image s20040816-10M of SPOT5 before Typhoon Aere gave 215 landslides with total landslide area of 225.85 hectares. And, the image s20050316-10M after Typhoon Aere gave 379 landslides with total landslide area of 629.25 hectares. Obviously, Typhoon Aere is a major event which caused double the number and coverage of landslide occurrences. In addition, when the event becomes more serious, the average size of a landslide becomes larger. As shown in Table 3, the general average size of a landslide before Aere was 1.05 hectares whereas that after Aere was 1.66 hectares.

3-2 Landslides induced by After Typhhon Aere with various resolutions

Table 3 shows that image of 10 m resolution of SPOT-5 on 20050316 gave 379 landslides with total landslide area of 629.25 hectares and image of 2.5 m resolution of SPOT-5 on 20050316 gave 477 landslides with total landslide area of 693.33 hectares. There is only 10% increase of landslide coverage though there is an increase of landslide numbers of more than 25%. This indicates that more smaller landslides can be observed. This can be reflected by the change of general size of a landslide from 1.66 to 1.45 hectares. For the purpose of sediment estimation, proper resolution should be considered because high resolution of images may not contribute so much as proportional to spatial resolution. Nevertheless, if engineering measures for traffic routes and building-up areas or public facilities are concerned, a landslide of 10 to 50 m is large enough to endanger life and properties. Similarly, Table 3 shows that image of 8 m resolution of Formosa-2 on 20050404 gave 424 landslides with total landslide area of 689.56 hectares and image of 2 m resolution on the same day gave 473 landslides with total landslide area of 723.74 hectares. There is only 5% increase of landslide coverage though there is an increase of landslide numbers of more than 12%. Both image of 2.5 m resolution of SPOT-5 on 20050316 and image of 2 m resolution of Formosa-2 on 20050404 show that landslides of class 1 and class 2 account for 99% of all landslides.

3-3 Landslides in sequential events

Images of Formosa-2 acquired on 20050404, 20050725, and 20050903 were taken after major typhoon events of Aere, Haitang and Talim, respectively. As shown in Table 3, total number of landslides on 20050404 image was 424 with total landslide area of 689.56 hectares. After three months, total number of landslides on 20050725 image was 549 with total landslide area of 745.73 hectares. Though total number increases nearly 30%, the increase of total area is only 8%. This means that a lot of small landslides were triggered in the event of Haitang, after the major event of Aere. After one and a half months, total number of landslides on 20050903 image was 535 with total landslide area of 776.93 hectares. This indicates event Talim in a later phase triggered some more large landslides with some small landslides are recovered. Therefore, the total number of landslides decreases 3% whereas the total landslide area increases 4%. Table 3 also shows that Formosa-2 image with a resolution of 8 m gives very similar results of landslide interpretability with SPOT5 image with a resolution of 10 m. Similarly, it also shows that the pan-sharpened image of Formosa-2 image with a resolution of 2 m gives very similar results of landslide interpretability with enhanced mode of SPOT5 image with a resolution of 2.5 m.

3-4 The evolution of a selected landslide - Baishisi Landslide

The designed effective capacity of Shimen Reservoir is 252 million cubic meters. The estimated sedimentation per year from 1963 to 2003 is around 0.7 to 1.0 million cubic meters. As shown in Table 4, there is a landslide with a size of 68.82 hectares took place after Typhoon Aere which possesses about 0.2% of total landslide numbers whereas it has about 10% of the total landslide area. The landslides triggered by Aere contributed sediments around 12 million cubic meters. A large landslide in upstream of Baishisi has an area about 68.82 hectares which may contribute sediments of nearly 7 million cubic meters (Figure 4). It is also noted that the width of whitish color in the stream of image on 16 March 2005 became narrower on the image on 25 July 2005. This means the sediments with whitish color were washed down to the bottom of the reservoir. In a later stage, the unconsolidated materials of the landslide body will gradually move to the downstream or even reach the reservoir. Serious damages are thus imposed to the water quality and the sustainability of reservoir.

4. CONCLUSIONS & RECOMMENDATIONS

Taiwan is located on the tracks of typhoons - the tropical cyclones. Heavy rainfall which comes along the typhoon usually triggered a lot of landslides which may endanger the sustainability of water reservoir and the water quality. Shimen Reservoir supplies water to more than three million people in northern Taiwan. Nevertheless, water supply is interrupted very often due to the deterioration of water quality in typhoon period. It is proved in this study that satellite images can be good tools for monitoring the source of sedimentations.

It is noteworthy that more landslides are mapped with images of higher resolution than with lower resolution for the same event and images of higher resolution give more smaller sizes of landslides. Variations of landslide occurrences are due to triggering factors, especially the magnitude of the event and the temporal apart of two consecutive events.

This study also shows that standard product of Formosat-2 gives similar result by standard product of SPOT5, and pan-sharpened product of Formosat-2 gives similar result by enhanced mode product of SPOT5. One special advantage of Formost-2 is the capability of daily visit. The timeliness for emergent assessment of landslide problems in the catchment area becomes important for applying quick measures to counter-act the sources of water turbidity.

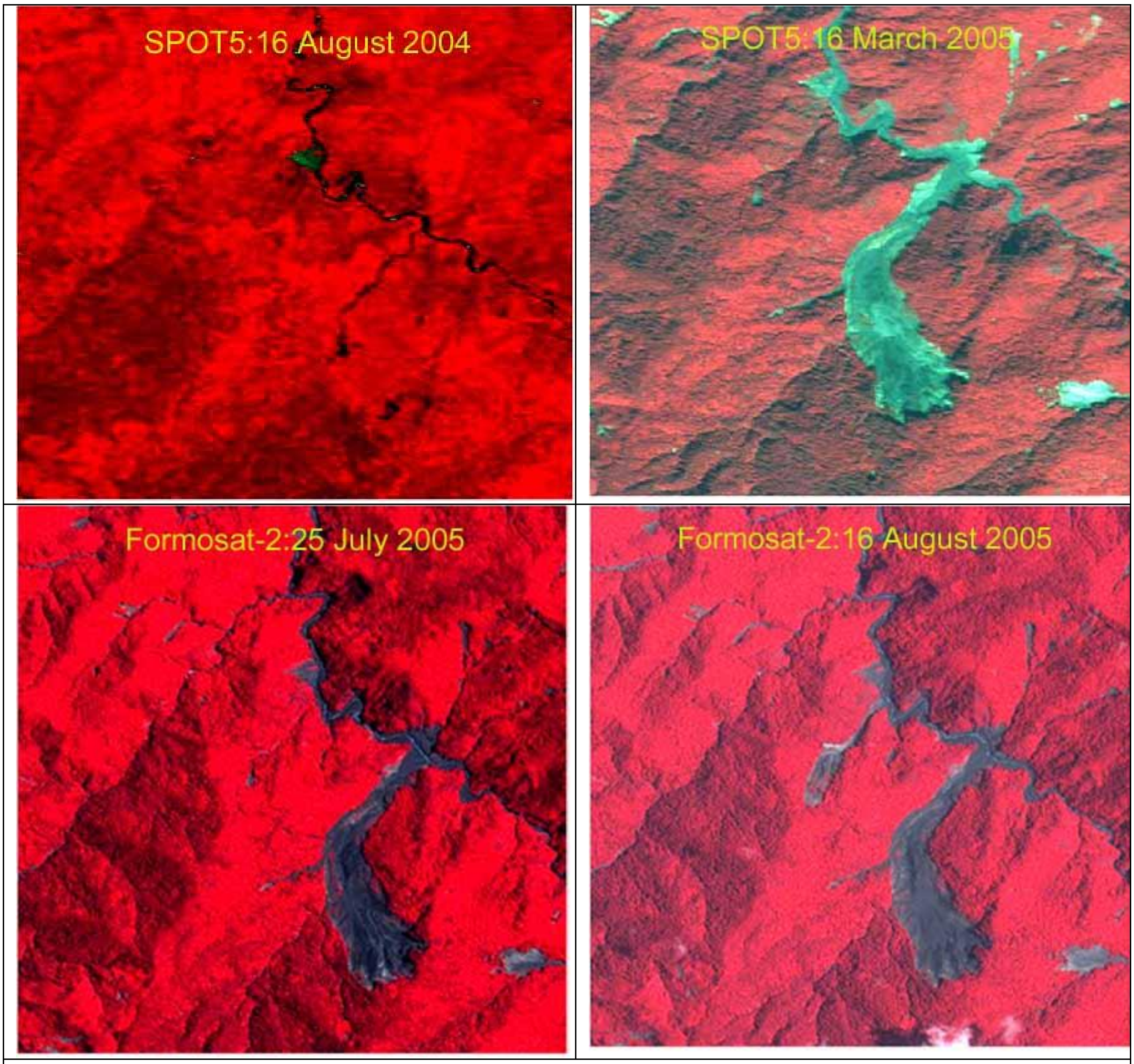

Figure 4: False color composite images acquired on 16 August 2004, 16 March 2005, 25 July 2005 and 16 August 2005. A large landslide (Baishisi landslide) at the lower center of the image which was developed after Typhoon Aere. There were some more large landslides developed in the neighbourhood of this one

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