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Wild Rice (*Oryza* Spp.) Germplasm Collections from Gangetic Plains and Eastern Region of India: Diversity Mapping and Habitat Prediction using Ecocrop Model

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Abstract

Wild rice collections form the priority target group among rice germplasm for characterization, evaluation, conservation and utilization. So far 889 accessions of wild rice (*Oryza* spp.) germplasm were collected by ICAR-NBPGR from Gangetic Plains and eastern region of India in last four decades. Passport information on assembled germplasm was used to know habitat specificity and diversity pattern to predict their distribution; this will help execution of explorations. Germplasm accessions belonging to six different wild rice taxa–*Oryza meyeriana* var. *granulata* (4), *O. nivara* (484), *O. officinalis* (50), *O. rufipogon* (367), *O. sativa* var. *spontanea* (18) and *Porteresia coarctata* (10) were collected from Gangetic Plains and eastern region of India. GIS mapping had shown that maximum numbers of wild rice species were collected from north-western and north-eastern regions of Odisha. In this study, we used current (1950-2000) and projected climate data for 2050 through 'EcoCrop' model to predict habitat suitability areas for wild rice. Predicted habitat suitability map (1950-2000) had shown that at present >80% area of Gangetic Plains and eastern region of India are suitable for wild rice occurrence. Projection for 2050 indicated that nearly 47.7% areas becoming less suitable for wild rice distribution, indicating urgent need for exploration in prioritized areas for wild rice, particularly in these regions of India.

Keywords

Climate change; Diversity mapping; EcoCrop model; Gangetic Plains; Wild rice

Introduction

Genus *Oryza* L. belonging to family Poaceae has two cultivated species (*O. sativa* L. and *O. glaberrima* Steud.) and 22 wild species predominantly occurring in the tropics [1]. Rice is the staple food for more than 50% world and 85% Indian population, and accounts for 35 to 60% of calories consumed by three billion Asians [2]. However, ensuring food and nutrition security for the burgeoning population under shrinking land resources and mitigating adversities arisen due to climate change through increase in rice production is a challenge to the nation for the future.

Wild relatives having desirable traits/genes, which are generally not available in crops, are increasingly recognized as valuable resource for crop improvement. Wild rice species have provided many valuable traits/genes such as disease and pest resistance, high yield, abiotic stress tolerance and cytoplasmic male sterility [3-6]. Survey and exploration of wild rice species form a priority, notably after the success achieved in the utilization of annual species *O. nivara*; its germplasm collection from eastern Uttar Pradesh served as a novel source of resistance to *Rice grassy stunt virus* (RGSV) and *Rice tungro virus* (RTV) [3,7]. This indicates the significance of wild rice germplasm collections from the Gangetic Plains and eastern region of India**,** which fall under the broader region considered as centre of origin/diversity for rice. Recent advances in tissue culture have enabled production of wide hybrids and molecular marker technology has aided precise detecting of introgression of chromosome segments from wild into cultivated species [3,8].

The Gangetic Plains comprises of most parts of Uttar Pradesh, Bihar and West Bengal while eastern region of India encompasses the states of Chhattisgarh, Jharkhand and Odisha; both the regions are among the most intensively cultivated ones in the world and are crucial for food security of India [9]. This region has been remarkable with a great diversity in wild rice populations growing in its natural habitats. Five wild taxa of *Oryza* - *Oryza meyeriana* (Zoll. and Moritzi) Baill. var. *granulata* (Nees and Arn. ex G. Watt) Duist, *O. nivara* S.D Sharma & Shastry, *O. officinalis* Wall. ex G. Watt (syn. *O. minuta* sensu Bor non J.Presl & C.Presl), *O. rufipogon* Griff. (syn. *O. jeyporensis* Krishnasw. & Chandras.) & *O. sativa* var. *spontanea* Roshev are reported in these regions [10,11]. Apart from these, *Porteresia coarctata* (Roxb.) Tateoka, the only species of genus *Porteresia* often suggested to be treated as member of *Oryza* owing to its phylogenetic affinities, is also found in this region. Wild rices are used by the tribal inhabiting the Jeypore tract of Odisha as supplementary food, for medicinal purposes and during festivals; this tract is often considered as one of the secondary centers of origin of rice [12]. Genetic structure within and among natural populations of *O. nivara* and *O. rufipogon* has been discussed [13,14] indicating the role of introgression in shaping genetic diversity patterns of these two important wild relatives.

Geographic information system (GIS) tools, global positioning system (GPS) and crop models were used frequently in diversity mapping and predicting suitable sites for future collection of crop wild relatives (CWR) using data on different climatic variables. Utility of crop models and GIS in germplasm collection and management of CWR has been widely recognized through various studies, e.g. wild potato [15] beans [16] and *Brassica* spp. [17]. In the present study results are based on geo-referencing of collecting sites, mapping of collected diversity and generating prediction maps for thriving of wild rice in current and future climate, thereby pinpointing existing gaps pertaining to unexplored/less explored areas for wild rice.

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Material and Methods

Study area and climate data of the regions

A total of 22.5 million hectare fertile plain area extending from 17.49° to 31.0°N latitude and 77.6° to 91.5°E longitude, comprising 214 districts-Uttar Pradesh (75), Bihar (38), Jharkhand (24), Chhattisgarh (27), Odisha (30) and West Bengal (19) forms the study site (Figure 1). Though known for high population density, different forest types mainly tropical dry deciduous, moist deciduous and moist semi-evergreen forest types to sub-montane forest types occur in these states. While alluvial soil is found in all the six states, laterite soil in Chhattisgarh, Jharkhand and Odisha, and coastal alluvial soil in Odisha and West Bengal [18] all the soil types host suitable habitat for wild rice. This regions experience extreme variability in the climate over the annual seasonal cycle. Average annual rainfall from study area is 1,319 mm while maximum rainfall (1349.81 mm) while state-wise maximum rainfall (1,489 mm) was recorded from Odisha state. Variation in mean temperature (min. & max.) was ranged between 11.21-26.5°C and 24.94-38.01°C (Figure 2) during last 65 years.

Wild rice germplasm and scrutiny of passport data

A total of 1,102 accessions of wild rice (*Oryza* spp.) germplasm were augmented by the ICAR-National Bureau of Plant Genetic Resources (NBPGR) from various parts of the country (from 1976 to March 2016) through crop-specific/ multi-crop explorations (in collaboration with crop-based institutes and State Agricultural Universities). Of them, 889 accessions augmented from the Gangetic Plains and eastern regions of India formed the base for this study. Scrutiny of passport data for these accessions was done on botanical names, geo-coordinates of places/sites of collection (village/block/ tehsil, district and state) using GIS tools.

Diversity analysis, mapping and 'EcoCrop' modeling

Diversity analysis using DIVA-GIS technique was done based on geo-coordinates (latitude and longitude) and additional attributes (species name, locality information) of point data; points represent locations where a sample was collected [19]. EcoCrop model uses information on climatic requirements for different crops considering optimal conditions and limits to adaptation [15,5]. According to International Centre for Environmental Management, USA, this model can also be adapted where ecological information is available on related/similar species within the group [20]. EcoCrop is implemented in DIVA-GIS [15] and has been interfaced with climate data for temperature suitability (**Ktmp:** absolute temperature that will kill the plant, **Tmin:** minimum average temperature at which the plant will grow, **Topmin:** minimum average temperature at which the plant will grow optimally, **Topmax:** maximum average temperature at which the plant will grow optimally, **Tmax:** maximum average temperature at which the plant will cease to grow); for rainfall suitability (**Rmin:** minimum rainfall (mm) during the growing season, **Ropmin:** optimal minimum rainfall (mm) during the growing season, **Ropmax:** optimal maximum rainfall (mm) during the growing season, **Rmax:** maximum rainfall (mm) during the growing season); length of the growing season (**Gmin:** minimum days of growing season, **Gmax:** maximum days of growing season) to predict suitability of a particular region to a particular crop/CWR. We apply 'EcoCrop' model to wild *Oryza* species using the current climate data (1950-2000) derived from WorldClim (http://www.worldclim.org; consisting of climate grids with a spatial resolution of 5 km^2) [21] as a baseline, and future climate data used from downscaled global climate model (GCM) outputs for the year 2050 [22].

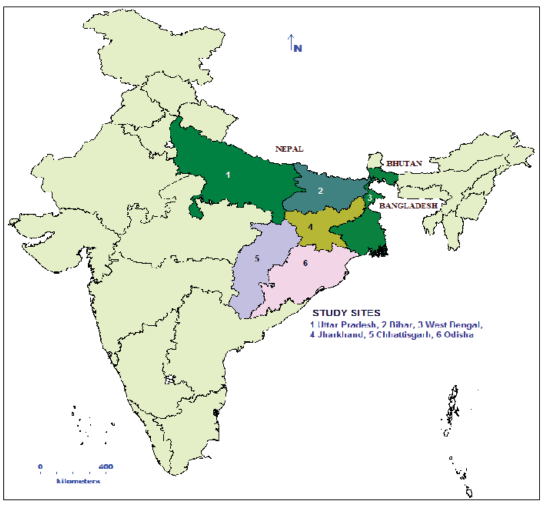

Figure 1: Map of Gangetic Plains (1, 2 & 3) and eastern region of India (4, 5 & 6).

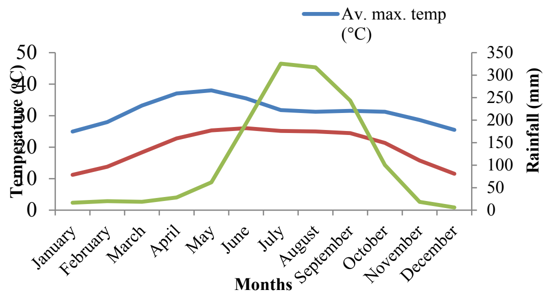

Figure 2: Climate pattern (Av. 1950-2015) of Gangetic Plains and eastern region of India (source- www.imd.gov.in).

Results and Discussions

Wild rice germplasm status and geo-referencing

Explorations conducted from the past forty years (1976-2016) revealed the collection of six wild rice taxa *viz.*, *O. meyeriana* var. *granulata*, *O. nivara*, *O. officinalis*, *O. rufipogon*, *O. sativa* var. *spontanea* and *Porteresia coarctata* (syn. *Oryza coarctata*) in the Gangetic Plains and eastern region of India. Study regions constituted more than three-fourth of wild rice germplasm (889 acc.) collections across the country. Species-wise account shows that maximum accessions were collected in *O. nivara* (484) followed by *O. rufipogon* (323), *O. officinalis* (50), *O. sativa* var. *spontanea* (18), *Porteresia coarctata* (10) and *O. meyeriana* var. *granulata* (4) from this region and all the accessions were geo-referenced (Figure 3a). State-wise, total collections were from Odisha (335) followed by Uttar Pradesh (263), West Bengal (154), Chhattisgarh (69), Jharkhand (39) and Bihar (29). Maximum collections (>80%) were made during the execution of World Bank-funded National Agricultural Technology Project on Plant Biodiversity (1999 to 2005) at the Bureau. Bihar state is poorly represented by wild rice germplasm collections as compared to other states (Table 1). Interestingly, *Oryza nivara* was collected from all the six states while *O. meyeriana* var. *granulata* and *P. coarctata* were collected only from Odisha (Table 1). However, literature survey revealed the distribution of latter *O. meyeriana var. granulata*

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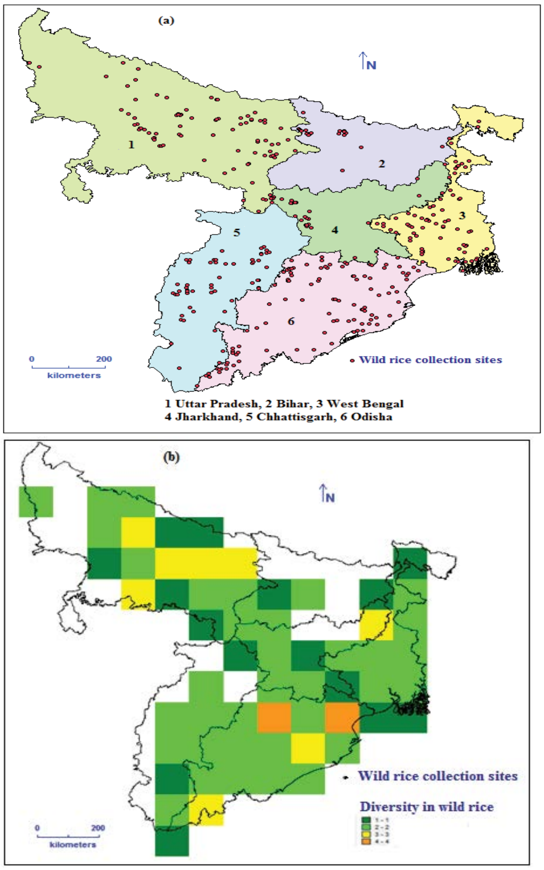

Figure 3: a Geo-referenced and b species richness map of wild rice collections from Gangetic Plains and eastern region of India.

in foothills of Uttar Pradesh, Bihar and Jharkhand (Sahibganj, Hazaribagh and Giridih) and West Bengal [23,24] indicating the need for locating and collecting germplasm of this taxon.

Collection database showed that these wild species were mainly collected from habitats – swamps, marshes, open ditches, riverbanks, lake-sides, forest areas, adjacent to agricultural fields and from margins of rice fields. Species-wise preferences recorded were: *O. meyeriana* var. *granulata* - swampy and shaded area in forest floor; *O. nivara* - open habitat, swampy areas, ditches, edges of ponds in or around rice fields; *O. officinalis* - partial shade, seasonally dry; marshes, open ditches; *O. rufipogon* - swamps, marshes, open ditches, ponds, riverbanks, lakesides, and at the margins of rice fields; *P. coarctata* - along the riverside creeks of the estuaries where high tides are common.

In Odisha, a total of 335 germplasm accessions from 241 sites lying in 29 out of total 30 districts were collected (Figure 3a). Maximum germplasm accessions were collected from Mayurbhanj (49) followed by Sundargarh (45), Kendujhar (24), Kalahandi (19), Jharsuguda (17) and Ganjam (17) districts. Considerable variability has been noticed in *O. nivara* collections from this state for various morphological characters (leaf length, leaf width, plant height and width and 100 seed weight), and biotic (bacterial leaf blight) and abiotic (moisture) stresses [25]. Likewise, some explorers [26] had reported variability in *Porteresia coarctata* (vern. name: *dhanidhan*) collections from Bhadrak, Jagatsingh Pura and Kendrapara for growth habit, maturity duration, panicle type, leaf size and leaf colour. ICAR-National Rice Research Institute, Cuttack, Odisha also made some precious collections of this species from Bhitarkanika National Park located in Kendrapara district [26].

In Uttar Pradesh, out of 75 districts, wild rice germplasm (263 acc.) was collected from 182 locality sites of 29 districts spreading over central and eastern regions (Figure 3a). Maximum germplasm were collected from Faizabad (76) followed by Kanpur (26), Bareilly (21), Barabanki (20), Fatehpur (17) and Gorakhpur (13) districts. However, Basti district and adjoining areas deserve attention for more collections, as evident from a germplasm collection of *O. nivara* showing resistance to *Rice grassy stunt virus* (RSTV) biotype-1 [7] from this area [27]. This Suggested the need for detailed characterization of wild rice (*O. nivara* and *O. rufipogon*) collections from eastern parts of this state, as they may provide some novel/important genes in rice improvement.

In West Bengal wild rice germplasm (154 acc.) has been collected from 126 locality sites of 14 districts (out of 19) covering northern, western and central region (Figure 3a). Maximum germplasm were from Bankura (26) followed by Birbhum (23), South 24 Parganas (21), West Medinipur (12) and Purulia (10) districts. This indicates the need to collect germplasm from eastern regions of this state adjoining Bangladesh. Location and collection of *Porteresia coarctata* from coastal and Sunderbans region [10] of this state requires urgent attention.

In other states *viz.* Bihar, Jharkhand and Chhattisgarh, only a total of 137 germplasm accessions were collected. In Chhattisgarh (69 acc.), maximum accessions were collected from Raigarh and Raipur districts with 17 accessions each. In Jharkhand (39 acc.), maximum germplasm accessions have been collected from Palamu (11) followed by Garhwa (10), Latehar (6) and Lohardaga (5) districts (Figure 3a). In Bihar, out of 38 districts, germplasm accessions were assembled from only five districts- East Champaran (6), Samastipur (4), Sheohar (2), Sitamarhi (9) and West Champaran (7). At the same time, [27] observed good variability in *O. nivara* and *O. rufipogon* in south-western part of Bihar particularly Buxar, Kaimur and Rohtas areas, indicating the necessity for survey and explorations in the diversity rich localities under this state.

Diversity mapping in wild rice

Diversity map generated in DIVA-GIS through geo-referenced data vis-à-vis species richness was aimed at identifying species rich areas/ niches, from where more number of wild rice species and diversity could be collected. Dark orange colour (grid no. 4) on the map is showing maximum number of wild species collections from the north-western and north-eastern region of Odisha. The next species-rich area belongs to grid no. 3 (yellow colour), displayed in central and north-eastern region of Uttar Pradesh and central parts of West Bengal, and south-eastern and south-western parts of Odisha (Figure 3b). This revealed that some areas/districts of Odisha adjoining to the well collected districts Jharsuguda, Koraput and Mayurbhanj would form the target for more number of species collection through fine grid survey in the future. It is to be noted that species concept has an impact on this diversity map. For example during 1950s, a new species *O. jeyporenenis* Govindasw and Krishnam was described from Jeypore tract of Koraput district (grid no. 3) in Odisha; this is now reduced or synonymized under O. *rufipogon* complex, thereby resulting into reduction in species number from this area.

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Table 1: Wild rice collections in Gangetic Plains and eastern region of India.

Species	Germplasm accessions collected from different states						Total accn.
	Bihar (29)	Chhattisgarh (69)	Jharkhand (39)	Odisha (335)	Uttar Pradesh (263)	West Bengal (154)	
O. nivara	24	49	13	169	165	64	484
O. rufipogon	1	-	-	149	85	88	323
O. officinalis	4	19	25	2	-	-	50
O. sativa var. *spontanea*	-	1	1	1	13	2	18
O. meyeriana var. *granulata*	-	-	-	4	-	-	04
Porteresia coarctata (syn. *Oryza coarctata*)	-	-	-	10	-	-	10

Habitat prediction mapping in wild rice

The habitat suitability map for wild rice species in the current context based on 'EcoCrop' model is shown in Figure 4a. Mainly five categories were recognized based on current climate data: 'very high suitable area' (67.89%) and high suitable area' (17.83%) has been shown through light green and orange colour respectively, 'moderate suitable area' (9.61%, dark green), 'low suitable area' (pink) (1.55%) and 'unsuitable area' (3.11%, brown) in the Gangetic Plains and eastern region of India (Figure 4a). Model predicted that most of the areas of Gangetic Plains form either sui or highly conducive habitat for wild rice. Generally 'not suitable areas' are located on mountains areas with slope >30% and elevations above 1500 m msl. Also collected germplasm as well as literature inputs matched well with habitat suitability map generated using current climate data (Figure 4a).

The model projected that by 2050, there will be only 52.3% area of favorable habitat (very high suitable) for wild rice from current (68% area) (Figure 4b). Similar trend would be expected in wild rice habitats distributed across South Asia. These predictions indicate that changes in precipitation and temperature can influence the habitat suitability of wild rice. Prediction map shows that Chhattisgarh and Jharkhand states will lose >50%, 'very high suitable area' by 2050, as both the states have significant areas under hill ecosystem, which is more vulnerable to climate change than the plain areas. Studies suggested that warming in the hills/high altitude ecosystems has been greater than the global average of 0.74°C over the last 100 years [28]. Also ever-increasing anthropogenic and grazing pressures would shrink wild rice population and their niche area, indicating the need for earliest possible collection of the precious germplasm.

Gaps in germplasm collection and conservation

Based on Passport data of wild rice germplasm collections, distribution, mapping of diversity using GIS grid method and habitat suitability maps based on current and future climate, with further inputs from floristic and relevant literature, following gaps were identified.

- Areas representing deficit collection: *Odisha*: Kendrapara, Kandamal, Rayagada; *Uttar Pradesh*: Basti, Ambedkar Nagar, Sant Kabir Nagar, Chandauli, Gazipur, Ballia, and adjoining areas; *Bihar*: barring the north-western side, all the districts more particularly Buxar, Kaimur and Rohtas; *Jharkhand*: northern, southern and eastern districts; *Chhattisgarh*: most of the districts except Raipur and Raigarh; *West Bengal*: eastern districts adjoining Bangladesh. As prediction map showed that the states of Chhattisgarh and Jharkhand will heavily lose 'very high suitable area' in 2050, it may be worthy to prioritise these states for germplasm collection in the near future.

- Species-wise least collection: *O. meyeriana* var. *granulata*: foothills of Uttar Pradesh, Bihar and Jharkhand (Sahibganj, Hazaribagh and Giridih) and West Bengal; *O. nivara*: to be collected from all areas listed in 'areas representing deficit collection'; *O. officinalis*: niche-specific areas in all states, especially Odisha, West Bengal, Uttar Pradesh and Bihar; *O. rufipogon*: Bihar, Chhattisgarh and Jharkhand, and *O. jeyporensis* forms in Odisha; *O. sativa* var. *spontanea*: it represents the weedy form of rice, as poorly collected, it may be a target for throughout the region; *Porteresia coarctata*: from mangrove forests in Odisha and West Bengal (Sundarbans). Exact location details of all their distribution obtained from renowned herbaria would be of useful in exploration and their germplasm collection.

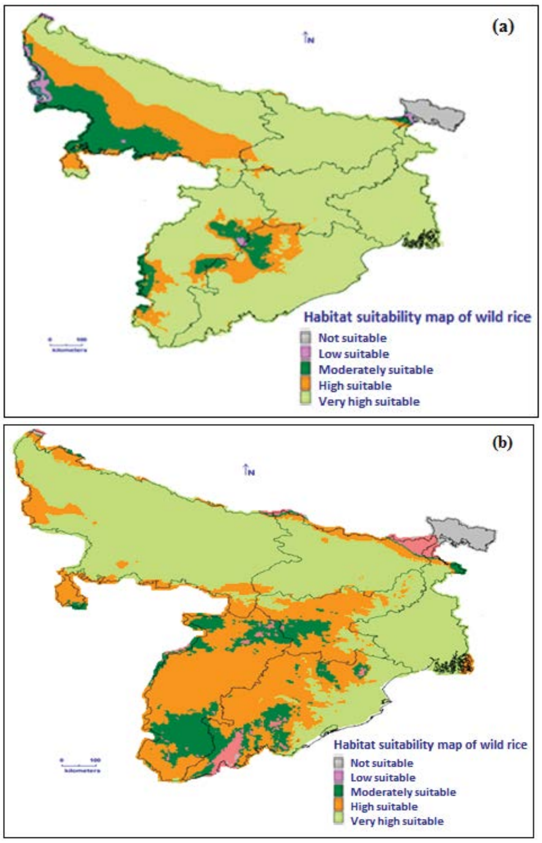

Figure 4: a. Wild rice habitat suitability map (1950-2000), b habitat prediction map for 2050 in Gangetic Plains and eastern region India.

Conclusions

Significant germplasm collections of wild rices have been

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assembled in the Gangetic Plains and eastern region of India in comparison to other phyto-geographical zones. However, considerable collection gaps still exist in this zone comprising of six states in terms of areas as well as species, as revealed through DIVA-GIS tools. Analysis had shown that maximum number of wild rice species was collected from north-western and north-eastern region of Odisha. Predicted habitat suitability map had shown that at present >80% area of Gangetic Plains and eastern region of India are suitable for wild rice occurrence. Leaving aside some limitations while using the EcoCrop models, projection for 2050 indicated that nearly 47.7% areas becoming less suitable for wild rice distribution, indicating the urgent need for systematic exploration in prioritized areas and protecting major sites allowing for adaptation, evolution and *in-situ* conservation.

Addressing the problems of wild species collection for conservation (seed shattering, collecting in muddy/swampy areas; niche-specificity in case of *O. meyeriana* var. *granulata*; less number of seeds/panicle, recalcitrance in *Porteresia*) will pave way for effective management, utilization and collections of these precious germplasm.

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