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# EVALUATION AND MAPPING OF SOIL SALINITY HAZARD IN RAMHORMOZ AREA (KHUZESTAN) USING DISJUNCTIVE KRIGING

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## ABSTRACT

To evaluate the soil salinity hazard in Ramhormoz area located in Khuzestan province, disjunctive kriging was used. Assessment was made through a series of salinity risk map. Disjunctive kriging is a non-linear geostatistical estimation technique which provides minimum estimation variance. Moreover, it allows to calculate the conditional probability that some critical threshold is exceeded. The results of mapping soil salinity at depth 0-50 cm indicate that about 45% of the interpolated sites shows an EC higher than 16 dS $m^{-1}$. About 18% of the whole area was interpolated with an EC less than 4 dS $m^{-1}$ The lowest EC values were found mainly in the areas around and along the river occupied by soils of river alluvial origins, while, the areas with very high EC values are the places situated in the lowlands where two patches of marshes exist. To estimate the conditional probability some salinization thresholds, critical thresholds of 2, 4 and 8 dS $m^{-1}$, were selected. Considering the threshold value of 2 dS $m^{-1}$, almost the entire area shows the conditional probabilities of more than 0.5. It indicates that there is a severe salinity limitation in the entire

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area. Assuming that a probability level of 0.6 is acceptable, for about 40% of the entire area the EC was found to be more than 4 dS $m^{-1}$

**Keywords:** Disjunctive Kriging, Geostatics, Mapping, Soil Salinity, Spatial Variability.

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# ارزیابی و پهنه بندی خطر شوری خاک در منطقه رامهرمز (خوزستان) با استفاده از کریجینگ گسسته

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## چکیده

بمنظور ارزیابی خطر شوری خاک در منطقه رامهرمز واقع در استان خوزستان از روش کریجینگ گسسته استفاده شد. ارزیابی شوری از طریق پهنه بندی ریسک شوری صورت پذیرفت. کریجینگ گسسته عبارت از روش برآورد غیر خطی ژئواستاتیستیکی است که به تخمین آماری با حداقل واریانس می انجامد. افزون بر این از این روش می توان برای محاسبه احتمال شرطی استفاده نمود که مقادیر محاسبه شده از حدود آستانه مشخصی بیشتر باشد. نتایج حاصل از پهنه بندی شوری خاک در عمق ۵۰ -۰ سانتیمتر نشان داد که حدود ۴۵٪ نقاط برآورد شده دارای قابلیت هدایت الکتریکی بیش از ۱۶ دسی زیمنس بر متر ($dS\ m^{-1}$) بود. حدود ۱۸٪ کل منطقه مطالعاتی دارای قابلیت هدایت

الکتریکی کمتر از ۴ دسی زیمنس بر متر تخمین زده شد. کمترین مقادیرقـابلیت هدایـت الکـتریکی بـرآورد شده در اراضی اطراف و به موازات رودخانه، که دارای خاک های با منشاء رسـوبی رودخانـه ای اسـت، دیده شد. در حالی که مقادیر شوری زیاد متعلق به اراضی پست و در مجاورت دو قطعه باتلاق واقع شدهٔ است. به منظور محاسبه احتمال شـرطی چندین حدآستانه، ۲، ۴ و ۸ دسی زیمنس بر متر، انتخاب شـد. بـا در نظر گرفتن حد آستانه ۲ دسی زیمنس بر متر، دبده شد که تقریباً کل منطقه بـر آورد شـده بـا احتمـال ۰/۵ دارای شوری مساوی و یا بیشتر از حد آستانه مزبور است. نتایج، حاکی از محدودیت شدید شوری در منطقه مورد مطالعه است. چنانچه حد احتمال مورد قبول ۰/۶ در نظر گرفته شود در این صورت حدود ۴۰٪ از مناطق برآورد شده دارای قابلیت هدایت الکتریکی بیشتر از ۴ دسی زیمنس بر متر است.

## INTRODUCTION

Salinization is the most harmful and extended environmental problem in arid and semi-arid regions. This phenomenon is caused by either natural processes (primary salinization) or human actions (secondary salinization). The extension of the soil salinity in Iran is estimated at more than 25 million hectares (5). It is also known, from the FAO reports (6) and the work of Kovda (7), that more than 50% of the irrigated soils in Iran are affected by secondary salinization. The first step in the optimization of the management of these salt-affected soils is their inventory in order to investigate their extension and characterize the degree and type of salinization.

In most environmental studies, data are collected, as several discrete sampling points, in space. To extend point data to area, a spatial interpolation is required. The aim is to estimate the value of an environmental variable at any unsampled location from observations and to map it.

One of the common properties of environmental data is their spatial dependence: observations close to each other are more similar than observations separated by a larger distance. Therefore, when a spatial estimation is performed, this spatial dependence should be taken into account. In many environmental applications not only the estimations themselves do matter, but also the uncertainties associated with the estimated values. A conventional statement such as "the cadmium content which is 2 mg $kg^{-1}$ " is likely to become less acceptable than " the content of cadmium has a probability of 90% of being greater than 2 mg $kg^{-1}$". Therefore, the aim would be to quantify the associated uncertainties. Rather than focusing on particular contents, we may have to characterize probabilities that certain thresholds are exceeded. This will result in a probability map on which probabilities of exceeding given threshold values are represented. The user can then choose which probability of exceedance is acceptable and so which risk he is willing to take. This is preferable to the traditional approach where values are either higher (unsafe) or lower (safe) than a given threshold.

A coherent body of theory, the theory of regionalized variables (8), already exists to achieve this goal. The practical application of this theory is commonly known as geostatistics which includes estimation techniques under the general heading of kriging (4). Kriging is an estimation method which takes several factors like i) number of samples and quality of observations at each location, ii) distance between the samples and the location to be estimated, and iii) spatial continuity of the variable under study, into consideration. It was named after D.G. Krige, a South African mining engineer, who had developed a kind of regression technique for estimating the gold grades in the 1950's. Later, G. Matheron improved and completed this new approach in a comprehensive theory. The new method of estimation was then called kriging (8).

The principle attraction of kriging algorithm is that it allows soil properties to be estimated without bias and with minimum, and known variance by taking into account the spatial dependence. This is the sense in which the method is sometimes known as BLUE (Best Linear Unbiased Estimator). In many instances, however, we need more powerful, nonlinear techniques, especially when we wish to decide what to do in the light of our estimates. In general, decisions are easy where the estimated values are very much less or much greater than a defined critical threshold. Obviously, decisions are difficult where values are close to the threshold since the estimates themselves are subject to error. What is needed is some means of assessing the probability that the true value exceeds or falls short of the threshold, given the estimated value and the data in the neighborhood. This is what disjunctive kriging can do. It provides both estimates of the property and of the conditional probabilities. From theoretical point of view, since disjunctive kriging is a nonlinear estimator, in general, it provides a more accurate estimate of the property than linear estimator like ordinary kriging (2, 3).

The advantages of such a tool in soil science are clear enough. The estimated conditional probability can be used as an input to a management decision making model to provide a quantitative means for determining whether management actions are necessary (13).

The purpose of this paper is to map the probability that the salinity exceeds certain accepted tolerable thresholds. By this mean, one can show where people should attempt to counteract the salinity, where they should be on their guard to prevent its increase and where, for the present at least, they need not worry.

## MATERIALS AND METHODS

### Theory of Disjunctive Kriging

Examples of the application of kriging to soil can be found in the papers written by Yost *et al.* (16), Webster and McBratney (12), and Tao (11). Most of these studies used ordinary kriging. Procedure of ordinary kriging (OK) is carried out in two steps. The first step involves modeling the spatial structure of the regionalized variable (i.e., electrical conductivity of soil extract) through the variogram calculation. It is a function that measures the average dissimilarity between two points x and x+h as a function of their distance h :

$$\gamma(h) = \frac{1}{2}\operatorname{var}\left[Z_{(i)} - Z_{(i+h)}\right] \quad [1]$$

Either linear, spherical, exponential, or Gaussian models are generally used to describe the spatial variability of a regionalized variable (9). In the second step of the ordinary kriging, the selected model for the spatial structure is applied to the data set to estimate values at unsampled locations. The value of unobserved point at location x is estimated by a linear combination of the values of n neighboring data points :

$$Z^{*}_{OK}(x) = \sum_{i=1}^{n} a_i Z(x_i) \quad [2]$$

where $a_i$ is the weight of the $i^{th}$ neighboring value and $Z(x_i)$ is measured value.

In disjunctive kriging (DK) the weights are replaced by the functions $f_i$, i=1,2,…,n, to give :

$$Z^{*}_{DK}(x) = \sum_{i=1}^{n} f_i Z(x_i) \quad [3]$$

These functions are found to minimize the estimation variance. To obtain DK estimator, the original data must be transformed into a new variable, Y(x), with a standard normal distribution where pairs of sample values are bivariate normal (15). If the original data do not follow any simple distribution (multimodal Gaussian or lognormal) disjunctive kriging provides a nonlinear, distribution-dependent estimator. When the data are not normally distributed then the data are transformed to normality by a linear combination of Hermite polynomials. The transformation can be written as :

$$Z(x_i) = \Phi\{Y(x_i)\} \quad [4]$$

where $Y(x_i)$ is the transform of $Z(x_i)$ and $\Phi$ is linear combination of Hermite polynominals such that :

$$\Phi\{Y(x_i)\} = \sum_{k=0}^{\infty} C_k H_k\left[Y(x)\right] \quad [5]$$

**where the values for Y(x) are obtained by taking the inverse,**

**$Y(x) = \Phi^{-1}[Z(x)]$, $H_k[Y(x)]$ is a Hermite polynominal of order k, and $C_k$ are Hermitian coefficients which can be evaluated by Hermite integration (1). The DK estimator is then linear combination of the estimates of the Hermite polynominals of the transformed sample values**

$$Z^*_{DK}(x) = \sum_{k=0}^{k} C_k H^*_k[Y(x)] \qquad [6]$$

**and**

$$H^*_k[Y(x)] = \sum_{i=1}^{n} b_{ik} H_k[Y(x_i)] \qquad [7]$$

**where the series in Eq. [6] has been truncated to k terms and $b_{ik}$ are disjunctive kriging weights.**

**The DK method utilizes the autocorrelation function in determining the weighting coefficients for a series of Hermite polynominals, Eq. [7], :**

$$\rho(h) = 1 - \frac{\gamma(h)}{\sigma^2} \qquad [8]$$

**where $\rho(h)$ is the autocorrelation function and $\sigma^2$ is the variance.**

**One of the interesting features of disjunctive kriging is that an estimate of the conditional probability that the value at an estimation site is greater than an arbitrary threshold value, $Z_c$, can be calculated. The conditional probability is obtained by defining an indicator variable that is equal to unity if $Z^*(x) \geq Z_c$ and zero otherwise (15). This conditional probability is a useful means for determining the risk of different soil hazards. In such a way, a series of useful maps may be realized for soil salinity risk analysis (13, 14).**

## Investigation Area

**The study area is located around the city of Ramhormoz in the Khuzestan province located in the south-west of Iran. It is situated**

between 49°25′ and 49°43′ E longitude and 31°05′ and 31°22′ N latitude. Fig. 1 shows the location of the study area in Iran. The extent of the study area is about 45000 ha. The region shows an average elevation of 110 m above sea level. The annual average temperature is about 24 °C, with an average maximum temperature of 49 °C in June and an average minimum of 3 °C in January. The annual average rainfall is about 330 mm. Most of the rain falls between November and March. The primary cause of salinization in the study area is the parent materials. However, poor irrigation practice, including a shallow groundwater table and saline seeps, have led to a secondary salinization in some parts of the study area. There are four major physiographic regions in the study area including plateau remnants, piedmont alluvial plain, river alluvial plain, and lowlands. Rainfed and irrigated wheat and barley are the major crops cultivated in the area. About 60% and 25% of the whole cultivated lands are devoted to wheat and barley, respectively. Only 5.6% of the total cultivated land is used to grow vegetables and fruit trees.

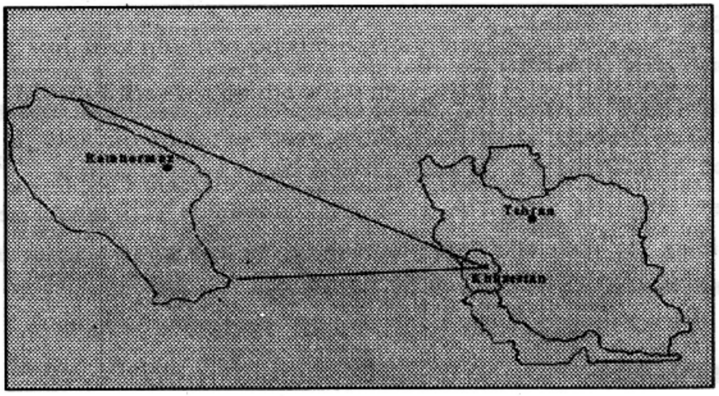

**Fig. 1. Schematic map of Iran and location of the study area.**

The soil survey and land classification study was carried out at a semi-detailed level by the Soil Science Institute of Iran, between 1985 and 1986 (10). This survey was intended to assess the relative suitability of the land for irrigated agriculture.

During the soil survey, about 600 point samples were analysed for electrical conductivity (EC) of the saturated soil extract which weighed for three soil depths: 0-50, 50-100, and 100-150 cm. In the current study only the data on the first depth was used. Such an intensive sampling provided the opportunity to use a geostatistical analysis for evaluating salinity hazard in the study area.

## RESULTS AND DISCUSSION

The summary statistics of the EC data at depth 0-50 cm are summarized in Table 1 and as histogram in Fig. 2. There is a strong positive skewness for EC data. This is confirmed by the summary statistics which the mean value is three times greater than the median.

Table 1. Summary statistics of the original and Ln-transformed salinity data (dS $m^{-1}$).

| | Original EC data | Ln-transformed EC data |
|---|---|---|
| Number of samples | 616 | |
| Mean | 22 | 2.3 |
| Median | 7.4 | 1.9 |
| Variance | 750 | 1.6 |
| Minimum | 1 | 0 |
| Maximum | 109 | 4.7 |
| Stnd. Skewness | 15.37 | 3.65 |
| Stnd. Kurtosis | 6.14 | -6.24 |
| Coefficient of variation (%) | 124 | |

So the mean is not estimated efficiently, and clearly they should be transformed to stabilize the variance. In the ordinary way one would take logarithms. Table 1 also shows that transforming EC data to logarithms removes most of the skewness. In disjunctive kriging the data wre normalized using Hermite polynominals. We did this and then computed the variogram on the transformed values (Fig. 3). In the graph the sample values are plotted as points, and the line is the model fitted. The calculated variogram is clearly bounded and the best fitted model was spherical. The coefficients of the model are given on the graph.

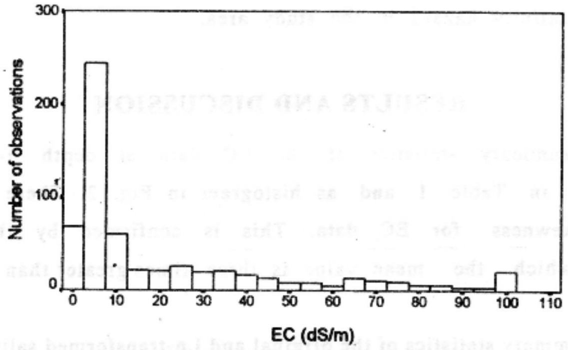

Fig. 2. Histogram of the original EC data (dS $m^{-1}$).

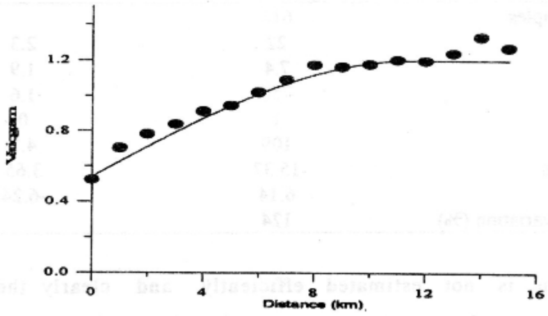

Fig. 3. Variogram of electrical conductivity after normalization by Hermite transformation with the model fitted. The curve is a spherical model with a nugget of 0.54, a sill of 1.20, and a range of 11.5 km.

**Combining this model and the transformed data one can estimate the electrical conductivity at depth 0-50 cm. Fig. 4 shows the result. The estimated EC map clearly illustrates the salinization-landscape relation. It is clear that the lowest EC values can be found mainly in the areas around and along the river occupied by soils of river alluvial origins, while, the areas with very high EC values are the places situated in the lowlands where two patches of marshes exist.**

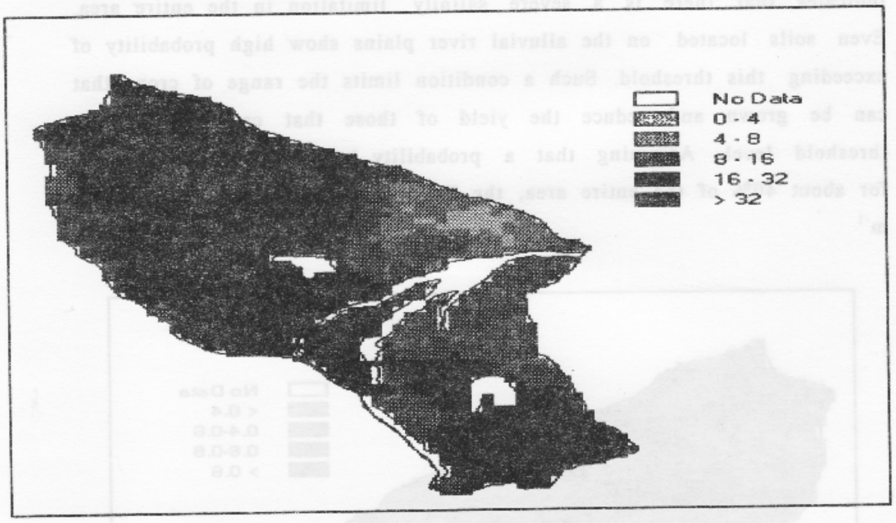

Fig. 4. Kriged map of electrical conductivity, EC, in dS $m^{-1}$.

The kriged map indicates that more than 80% of the interpolated sites shown an EC of more than 4 dS $m^{-1}$ In these areas one could expect losses of yield or even no germination of plants.

To estimate the conditional probability that the true values exceed salinization thresholds some well established critical values for the electrical conductivity were used. These thresholds were 2, 4 and 8 dS

$m^{-1}$. The resulting probability maps are shown in Figs. 5 to 7. All probability maps illustrate the same general patterns of soil salinity as those obtained for EC estimates. They clearly demonstrate the large probability of exceeding the threshold values in areas where lowlands occur. On the other hand, soils located on the alluvial river plains show a smaller probability of exceedance.

Considering the threshold value of 2 dS $m^{-1}$, almost the entire area shows the conditional probabilities of more than 0.5. It implicitly indicates that there is a severe salinity limitation in the entire area. Even soils located on the alluvial river plains show high probability of exceeding this threshold. Such a condition limits the range of crops that can be grown and reduce the yield of those that can tolerate this threshold level. Assuming that a probability level of 0.6 is acceptable, for about 40% of the entire area, the EC was found to be more than 4 dS $m^{-1}$

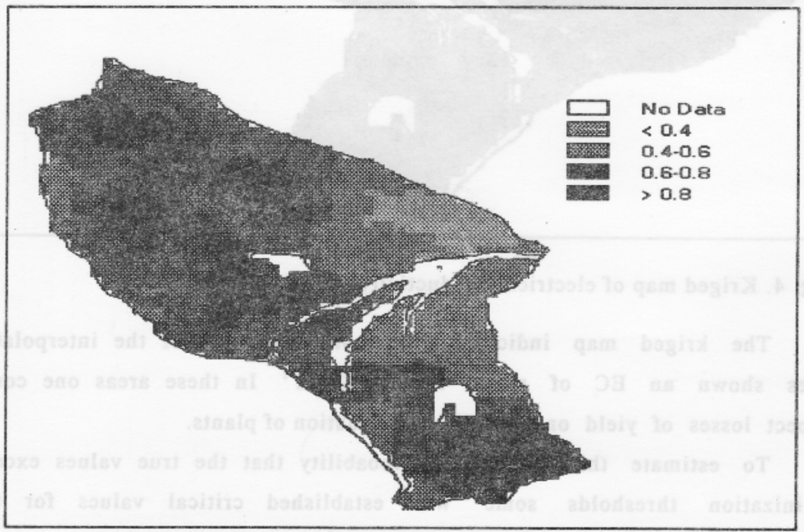

Fig. 5. Map of the conditional probability that EC ≥ 2 dS $m^{-1}$

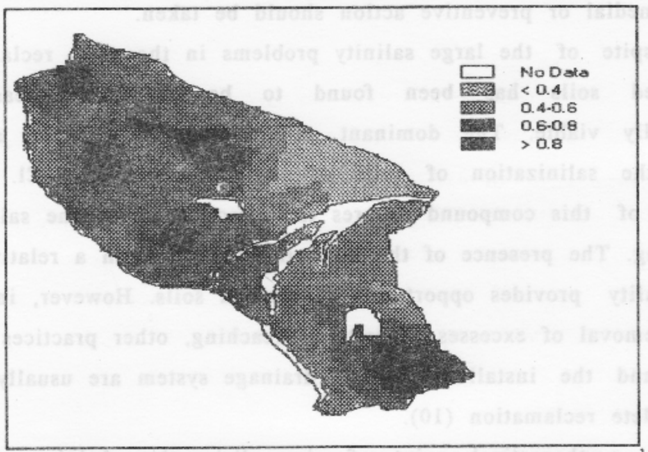

**Fig. 6. Map of the conditional probability that EC ≥ 4 dS m$^{-1}$**

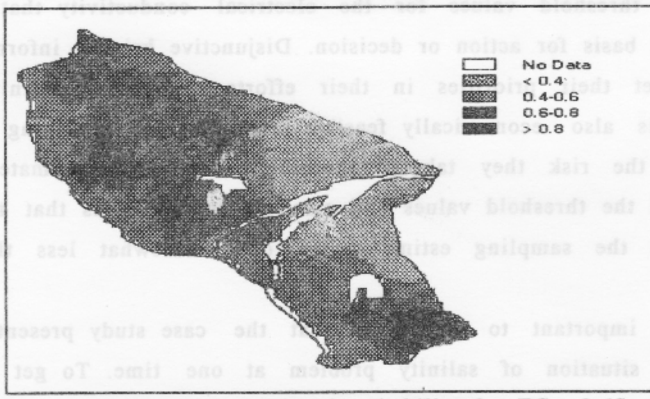

**Fig. 7. Map of the conditional probability that EC ≥ 8 dSm$^{-1}$**

**A threshold value of 8 dS m$^{-1}$ indicates the value at which most crops suffer seriously from salinization but some crops, like barley, can still be grown with an acceptable yield. The results show that there is a chance of 0.5 for about 50% of the whole area that the first depth contains EC of less than 8 dS m$^{-1}$. It is clear from the resulting maps**

that all these areas are located near the river. Such results indicate where remedial or preventive action should be taken.

In spite of the large salinity problems in the area, reclamation of salt-affected soils has been found to be technically feasible and economically viable. The dominant salt compounds that play a decisive role in the salinization of soils of the study area is NaCl. The high solubility of this compound ensures the effectiveness of the salt removal by leaching. The presence of the river in the area with a relatively good water quality provides opportunity to reclaim soils. However, in addition to the removal of excesses of salts by leaching, other practices like soil leveling and the installation of a drainage system are usually required for complete reclamation (10).

From a theoretical point of view disjunctive kriging seems well suited for monitoring and controlling soil salinity. There are well established threshold values for the electrical conductivity that can be used as a basis for action or decision. Disjunctive kriging informs them how to set their priorities in their efforts to combat salinity. The technique is also economically feasible since disjunctive kriging informs people of the risk they take by ignoring the sampling estimates where they exceed the threshold values and also the smaller risks that they still run where the sampling estimates are only somewhat less than the thresholds.

It is important to emphasize that the case study presented here shows the situation of salinity problem at one time. To get a better understanding of the salinity hazard in terms of both spatial and temporal variability, it would be better to survey soil salinity during different seasons and also during a period of several years. Disjunctive kriging allows an investigation of the temporal dynamics of soil salinity by producing a series of maps showing the seasonal motion of the salinity front.

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