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Original Article

Investigation on slope and canopy closure effects to minimize sediment movement in riparian buffer zone

Tampon zonlarda sediment üretimini en aza indirmek için eğim ve meşcere kapalılığının etkisi üzerine bir araştırma

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ABSTRACT

In this study, factors affecting the width of buffer zone used to minimize the sediment movement in the productive forests, have been evaluated. For this purpose, sediment traps were constructed in İstanbul University Education Research and Practice Forest. Sediment data was obtained from sample plots established depending on the different canopy closure, slope length, slope area, rainfall and slope. In this context, a statistical model was developed to estimate the sediment yield depending on slope and canopy closure. The accuracy of the model was tested with various statistical analyses. According to the results, sediment value can be highly estimate depending on slope classes. According to results, in the developed regression models to estimate effects of slope percentage on sediment values, the smallest R2 value was found as 0.79 on 20 % slope area and the highest R2 value was found as 0.97 on 80 % and 100 % slope area. Also, as the slope increases, the accuracy of the regression model of sediment yield increases. And it is concluded that there is a very close relationship between 80 % and 100 % slope. In the developed regression models to estimate effects of canopy closure effects on sediment values, it is seen that the lowest R2 value was calculated on canopy closure 71-100 %, and the highest R2 values were calculated on canopy closure 41-70 % and cutting areas. Sediment yield increases with the decrease of the canopy closure and the accuracy of the model increases.

Keywords: Sediment movement, buffer zone, forest area

ÖZ

Bu çalışmada, üretim ormanlarındaki sediment hareketini en aza indirgemek için kullanılan tampon zon alanlarının genişliğini etkileyen faktörler değerlendirilmiştir. Bu amaçla, İstanbul Üniversitesi Eğitim Araştırma ve Uygulama Ormanı'nda sediment kapanları tesis edilmiştir. Farklı meşcere kapalılığı, yamaç uzunluğu, yamaç alanı, yağış ve eğime bağlı olarak tesis edilen deneme alanlarından sediment verisi alınmıştır. Bu kapsamda, sediment verimini hesaplamak amacıyla istatiksel bir model ortaya konmuştur. Modelin doğruluğu çeşitli istatistiksel analizlerle sınanmıştır. Sonuçlara göre, eğim sınıflarına bağlı olarak sediment değeri yüksek oranda tahmin edilebilmektedir. Elde edilen sonuçlara göre, eğim yüzdesine bağlı olarak olarak sediment tahmini için geliştirilen regresyon modeli sonuçlarında en düşük R2 değeri %20 eğim sınıfında 0.79, en yüksek R2 değeri %80 ve %100 eğim sınıflarında 0,97 olarak bulunmuştur. Ayrıca eğim arttıkça regresyon modelinin doğruluğu arttığı görülmüş ve %80 ile %100 eğim sınıfları arasında çok yakın bir ilişki bulunmuştur. Ayrıca meşcere kapalılığının sediment üretimi üzerindeki etkisini araştırmak için üretilen regresyon modelinde en düşük R2 değeri %71-100 meşcere kapalılığında, en yüksek R2 değerleri ise %41-70 kapalılıkta ve traşlama kesimlerinin yapıldığı alanlarda hesaplanmıştır. Meşcere kapalılığının azalmasıyla birlikte sediment üretimi ve modelin doğruluğu artmaktadır.

Anahtar Kelimeler: Sediment taşınması, tampon zon, ormanlık alan

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INTRODUCTION

Riparian zone is a type of ecotone, or boundary between ecosystems like many other ecotones. Riparian buffer zones are exceptionally rich in biodiversity (Gregory et al, 1991, Malanson, 1993, Naiman et al., 1993).

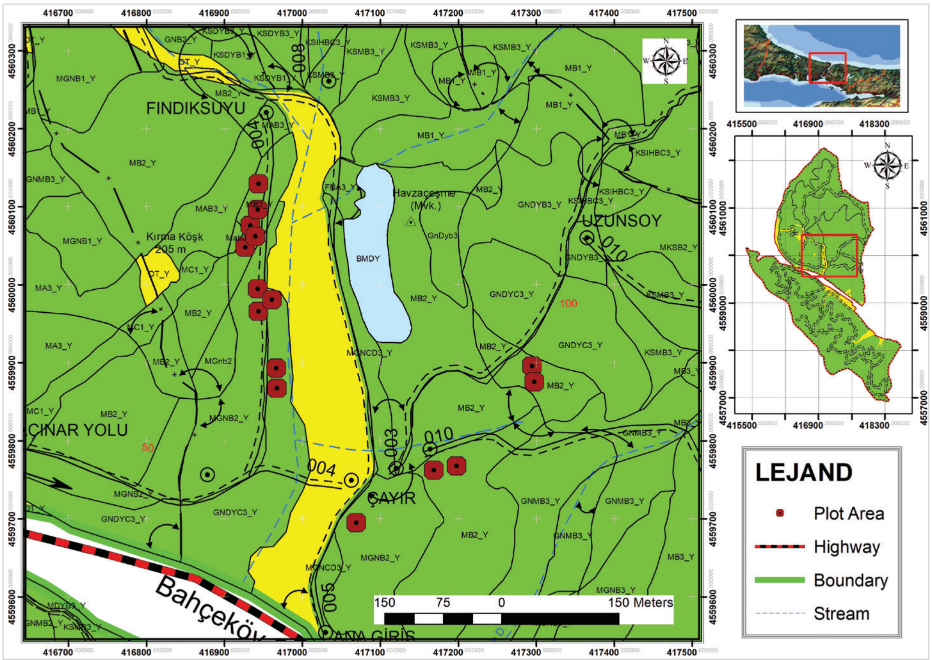

Figure 1. The location of study area and sediment traps (Akgul, 2012)

A riparian zone that is afforded to some degree of protection is a riparian buffer zone. The Word "buffer" is used because one of the functions of the protected area is to buffer the stream from the impact of human land use activities, such as farming and construction (Wenger, 1999). Depending on this various activities, the natural structure is deteriorating and there is accumulation of sediment in the streams.

Trapping and/or removing sediment from runoff is one of the important functions of Riparian buffers (Wood and Armigate, 1997; Malanson, 1993; Wenger and Fowler, 2000; Bentrup, 2008; Schueler, 1995, Rudeck et al, 1998, Akgul, 2012).

Some of the first research on riparian buffers was initiated to determine logging road setbacks (Trimble and Sartz, 1957). Sediment trapping efficiency of riparian buffer zones depends on many factors. The buffer width is one of the most important aspects of the effectiveness. Large buffers generally remove more pollutants than smaller ones. The effectiveness of buffer zone width is influenced by various factors, e.g. slope, vegetation type, soil type, rainfall etc. (Mayer et al, 2005)

One of the greatest factor is the slope to minimize the sediment movement in the riparian buffer zone. The slope factor is used in many formulas which is developed for calculating the effective buffer width to prevent the sedimentation and other pollutants. Some of these formulas are based on only slope factors.

Another factor is the soil type which is not recommended because of determining soil characteristics on wide scale somewhat is problematic and expensive (Wenger, 1999).

Vegetation type is also effective factor. Both forested and grass buffers are effective to trapping sediment. The combination of vegetation types (trees, grass and shrubs) helps maximize the efficiency and diversity of benefits that the buffer provides. Removal sediment efficiency range from 70-90% forested area, 53-97 % of the vegetated filter strip, 92-96 % of forested and vegetated filter strips (Krumine, 2004).

In this study, slope and canopy closure factors were investigated to effectiveness of buffer zone on sediment trapping/production rate.

MATERIALS AND METHODS

Study Area

Field monitoring study was done in İstanbul University Education Research and Practice Forest which is located in northern part of İstanbul. The research field is at Thracian side of Marmara Region, between 28° 59′ 17″-29° 32′ 25″ east longitudes and 41° 09′ 15″–41° 11′ 01″ north latitudes according to Greenwich (Figure 1).

Construction of Plot Areas and Sediment Traps

In the study, plot areas and the sediment traps were constructed in research forest to determine riparian buffer zone effectiveness ratio for minimize the sediment and calculating the sediment yield. While sample plots are choosing, canopy closure, slope and slope length were considered. The sediment traps are constructed in 4 different plot areas (Pa) which have different canopy closure. Plot areas' canopy closures range from 0% of clear cutting area (Pa1), 10-40% of Pa2, 41-70% of Pa3, 71-100% of Pa4. Totally 120 sediment traps were estab-

Figure 2. Sediment traps in plot areas (Akgul, 2012)

lished at 5 different slopes (20%-40%-60%-80%-100%), and 10 different slope lengths (1-10 meters), in each plot areas (Figure 2) (Akgul, 2012).

Collecting Sediment Data

Sediment data were collected from the sediment traps within after each heavy rainfall. Totally 19 different rainfalls occurred during study between first data collection and last data collection. First sediment data was collected in November 28, 2010, last sediment data was collected May 8, 2011. After each heavy rainfall, sediment data were collected from sediment traps and labelled in sample container to be analyzed in the laboratory (Akgul, 2012).

Sediments which collected from sediment traps were separated from materials such as branches, leaves in the laboratory. During the study, totally 4544 sediment data which were taken from sediment traps and they were weighted after dried at 150°C in laboratory (Figure 3).

Meteorological Data

Weather data was continuously recorded at the adjacent weather station at the Green Roof Research Site located in İstanbul University Faculty of Forestry. Weather data was measured by an automated weather station (DeltaOhm HD2003). Three axis Ultrasonic Anemometer, Delta OHM S.r.L., Padova/Italy, measurement accuracy ±1°C) and precipitation measurements were collected using a rain gauge (DeltaOhm HD 2003 tipping bucket, measurement accuracy ±1%). All meteorological data was collected by hourly.

Statistical Evaluation of Sediment Data

In the study, all statistical analysis was performed using Minitab 16.0 statistical package. Multiple linear regression analysis was used to find the statistical relationship between dependent (sediment) variables and independent variables (slope, slope length, slope area, canopy closure, precipitation). Simple linear regression analysis was used to bilateral relations between parameters to mathematically.

To evaluate and examine statistically the relationship between the independent variables and the dependent variable with its relationship correlation analysis was used. To evaluate accuracy of developed mathematical model by regression analysis, total number of variables (n=4544) were randomly selected and used as calibration data, while approximately 25% of them (n=1136) were also used as test data. And also paired sample T Test and

Figure 3. Evaluation of the sediment data (Akgul, 2012)

Table 1. Rainfall data of sediment data collection

	Rainfall			
Data No	Date	Month	Year	Rainfall (mm)
1	23-27	November	2010	25
2	5-6	December	2010	13.4
3	10-11	December	2010	58.4
4	13-17	December	2011	13.3
5	3-7	January	2011	33.4
6	16-17	January	2011	16.4
7	22-27	January	2011	50.3
8	29-30	January	2011	11.1
9	15-20	February	2011	10.8
10	22 - 2	February-March	2011	43.8
11	6-11	March	2011	13.1
12	17-19	March	2011	11.5
13	20-21	March	2011	15.2
14	27 - 2	March-April	2011	31.4
15	3-6	April	2011	9.7
16	8-15	April	2011	17.3
17	18-19	April	2011	28.1
18	20-29	April	2011	13.4
19	30 - 7	April-May	2011	46.1

correlation analysis were used to calculate the significance level of the models.

RESULTS

Results of Meteorological Data

During sediment data collection totally 19 different rainfalls occurred. The lowest rainfall occurred in April 3-6, 2011 with 9.6 mm. The highest rainfall occurred in December 10-11, 2010, with 58.4 mm (Table 1).

Results of Sediment-Slope

In order to estimate effects of slope percentage on sediment values, five different multiple regression models were developed. In all regression models sediment value ln(Sed) was consider as dependent variable. Also, in all models; slope length [ln(Sl)], canopy closure [ln(Ccl)], total precipitation [ln(Tp)] and area [ln(Ar)] were considered as independent variables. According to model 1 which developed to estimate [ln(sed)] value Adjusted R^2 found as 0.79 for 20% slope value, in model 2 found as 0.88 for 40% slope value, found as 0.93 for 60% slope value, found as 0.97 for 80% slope value and Adjusted R^2 found as 0.97 for 100% slope value. The results were showed that sediment value can be highly estimate depending on slope classes (Table 2, 3).

Within the scope of the study, to validation of developed regression models test datasets were used. Scatter plot model 1 for 20% slope, was demonstrated a linear correlation with R^2=0.88 between observed and predicted ln(sed) (225 observations), model 2 for 40% slope was demonstrated linear correlation with R^2=0.88 between observed and predicted ln(sed) (228 observations), model 3 for 60% slope was demonstrated linear correlation with R^2=0.94 between observed and predicted ln(sed) (228 observations), model 4 for 80% slope was demonstrated linear correlation with R^2=0.97 between observed and predicted ln(sed) (228 observations), while model 5 for 100% slope was demonstrated linear correlation with R^2=0.96 between observed and predicted ln(sed) (228 observations) (Figure 4) (Akgul, 2012).

Results of Sediment-Canopy Closure

In order to estimate effects of canopy closure percentage on sediment values, three different multiple regression models were developed. In all regression models sediment value ln(Sed) was consider as dependent variable. Also, in all models; slope length ln(Sl), slope ln(P), total precipitation ln(Tp) and area ln(Ar) were considered as independent variables. According to model 1 which developed to estimate ln(sed) value depending on canopy closure 71-100%, Adjusted R^2 found as 0.92. In model 2 which developed to estimate ln(sed) value depending on canopy closure 41-70%, Adjusted R^2 found as 0.96 while in model 3 which developed to estimate ln(sed) value depending on canopy closure 41-70%, Adjusted R^2 calculated as 0.96 (Table 4, 5) (Akgul, 2012).

In the scope of the study, to validation of developed regression models test datasets were used. Scatter plot model 1 for 71-100% canopy closure, was demonstrated a linear correlation with R^2=0.914 between observed and predicted ln(sed) (381 observations), model 2 for 41-70% canopy closure was demonstrated linear correlation with R^2=0.914 between observed and predicted ln(sed) (380 observations), model 3 for canopy closure 0% (clear cutting area) was demonstrated linear correlation with R^2=0.940 between observed and predicted ln(sed) (376 observations) (Figure 5).

Table 2. Statistical summary of regression models

Model No	Slope Constant	N	Adjusted R2	Std. Error of the Estimate	F	Sig.
1	20	896	0.79	0.58	844.71	0.000
2	40	912	0.88	0.35	1659.37	0.000
3	60	912	0.93	0.25	2987.81	0.000
4	80	912	0.97	0.16	7302.61	0.000
5	100	912	0.96	0.20	4956.39	0.000

Table 3. Summary of regression model coefficients

Model no	Slope %	Model	B	Regression Model
Model 1	20	Constant	-0.340	$Y=e^{-3.40-0.602*\ln(Sl)-2.030*\ln(Ccl)+0.765*\ln(Tp)+1.011*\ln(Ar)}$
		ln(Sl)	-0.602	
		ln(Ccl)	-2.030	
		ln(Tp)	0.765	
		ln(Ar)	1.011	
Model 2	40	Constant	0.118	$Y=e^{0.118+0.773 *\ln(Sp)-1.254*\ln(Ccl)+0.469*\ln(Tp)+1.020*\ln(Ar)}$
		ln(Sl)	-0.773	
		ln(Ccl)	-1.254	
		ln(Tp)	0.496	
		ln(Ar)	1.020	
Model 3	60	Constant	0.394	$Y=e^{1.020-0.80 *\ln(Sp)-1.045*\ln(Ccl)+0.422*\ln(Tp)+1.020*\ln(Ar)}$
		ln(Sl)	-0.800	
		ln(Ccl)	-1.045	
		ln(Tp)	0.422	
		ln(Ar)	1.020	
Model 4	80	Constant	0.583	$Y=e^{0.583-0.77 *\ln(Sp)-1.088*\ln(Ccl)+0.461*\ln(Tp)+1.021*\ln(Ar)}$
		ln(Sl)	-0.774	
		ln(Ccl)	-1.088	
		ln(Tp)	0.461	
		ln(Ar)	1.021	
Model 5	100	Constant	0.680	$Y=e^{0.680-0.736 *\ln(Sp)-1.224*\ln(Ccl)+0.567*\ln(Tp)+1.021*\ln(Ar)}$
		ln(Sl)	-0.736	
		ln(Ccl)	-1.224	
		ln(Tp)	0.567	
		ln(Ar)	1.021	

DISCUSSION AND CONLUSION

Sediment trapping efficiency of riparian buffer zone is one of the most important factor of buffer zone effectiveness to determine optimum buffer width. Many factors were investigated to determine effectiveness of buffer zones. Especially, slope factor has been studied in many studies. In the scope of the study, slope factor and canopy closure factor were evaluated to investigate the effects of closure and slope on sediment production in the study.

The most extensive investigations of the relationship between slope factor and sediment production to determine buffer width effectiveness have been conducted by forestry

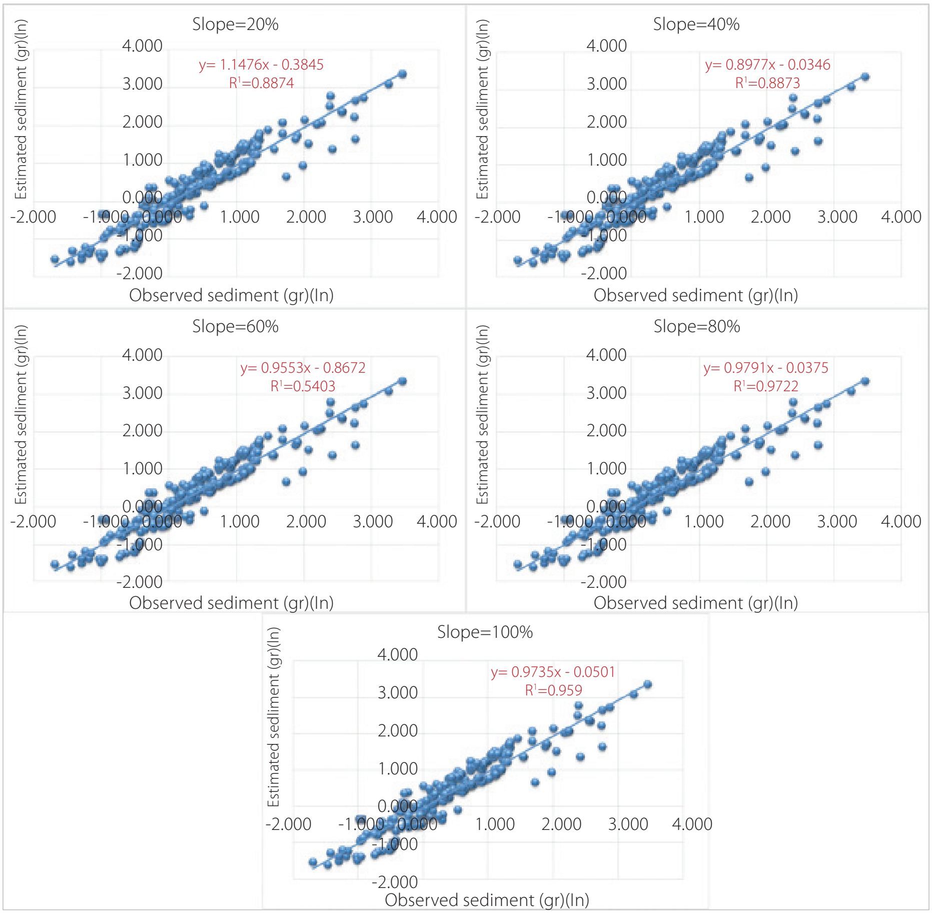

Figure 4. Validation of estimated and observed sediment values according to slope

Table 4. Statistical summary of regression models

Model No	Canopy Closure %	N	Adjusted R2	Std. Error of the Estimate	F	Sig.
1	71-100	1520	0.92	0.31	441.207	0.000
2	41-70	1520	0.96	0.18	9230.914	0.000
3	0-40	1504	0.96	0.19	8216.685	0.000

researchers. Trimble and Sartz (1957) found a high correlation between slope and buffer width in the formula they developed. This formula also shows a strong relationship between slope and sediment production. Dillaha et al. (1988, 1989) indicated that as buffer slope increase from 11% to 16%, sediment trapping of buffer zone declined by 7-38%. According to results, in the developed regression models to estimate effects of slope percentage on sediment values, the smallest R^2 value was found as 0.79 on 20% slope area and the highest R^2 value was found as 0.97 on 80% and 100% slope area. According to these results, as the slope increases, the accuracy of the regression model of sediment yield increases (Akgul, 2012). And it is concluded that there is a very close relationship between 80% and 100% slope. Also, R^2 values and the normal R^2 values are close to each other reveal the correctness of the model. It was showed that it can be highly estimate depending on slope class.

Also several studies were conducted to investigate effectiveness of vegetation type to sediment trapping on riparian buffer zone. Some of researchers suggested grass buffer while other researcher suggested forested buffers. Also, Welsch, 1991, Lowrance et al, 1997 strongly suggest a combination of grass and forested buffers to increase effectiveness of buffer zone to minimize sediment production. Krumine in 2004 stated that removal sediment efficiency range from 70-90% forested area, 53-97% of the vegetated filter strip, 92-96% of forested and vegetated filter strips. According to results, in the developed regression models to estimate effects of canopy closure effects on sediment values, it is seen that the lowest R^2 value

Table 5. Summary of regression model coefficients

Model no	Slope %	Model	B	Regression Model
Model 1	71-100	Constant	-7.486	$Y=e^{-7.486-0.645*ln(Sl)+1.237*ln(P)+0.683*ln(Tp)+1.028*ln(Ar)}$
		ln(Sl)	-0.645	
		ln(P)	1.237	
		ln(Tp)	0.683	
		ln(Ar)	1.028	
Model 2	41-70	Constant	-3.335	$Y=e^{-3.335-0.777*ln(Sl)+0.594*ln(P)+0.476*ln(Tp)+1.007*ln(Ar)}$
		ln(Sl)	-0.777	
		ln(P)	0.594	
		ln(Tp)	0.476	
		ln(Ar)	1.007	
Model 3	0-40	Constant	-2.839	$Y=e^{-2.839-0.790*ln(Sl)+0.605*ln(P)+0.465*ln(Tp)+1.019*ln(Ar)}$
		ln(Sl)	-0.790	
		ln(P)	0.605	
		ln(Tp)	0.465	
		ln(Ar)	1.019	

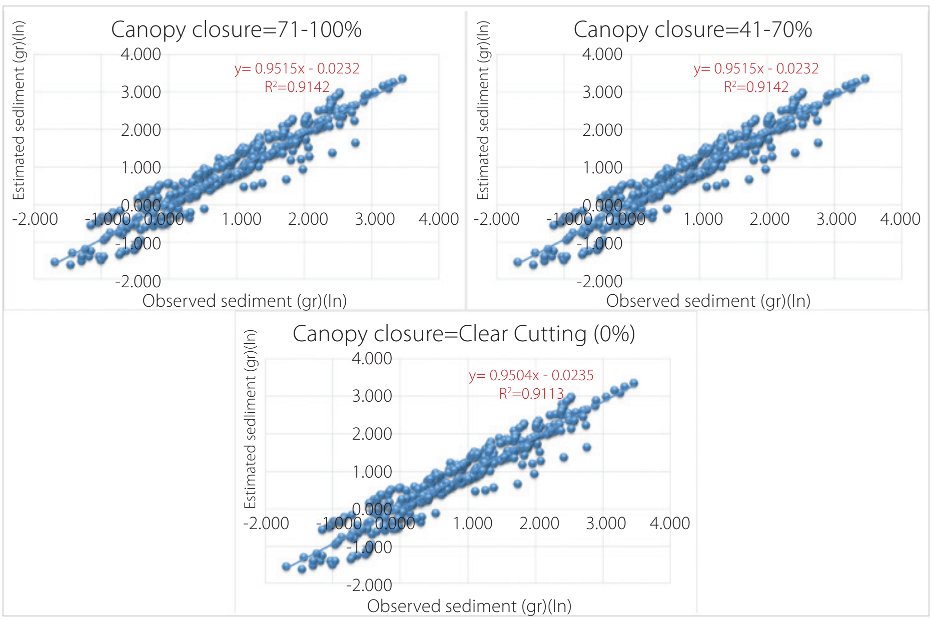

Figure 5. Validation of estimated and observed sediment values according to canopy closure

was calculated on canopy closure 71-100%, and the highest R^2 values were calculated on canopy closure 41-70% and cutting areas. Sediment yield increases with the decrease of the canopy closure and the accuracy of the model increases. As is also implied, according to test data, the generated regression model is statistically acceptable.

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