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Influence of Water Quality on the Diversity and Distribution of Macro-Invertebrates in Hiwane Second Order Stream, Northern Ethiopia

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Abstract: Understanding the pattern and process related to biodiversity is a greatest challenge to the science of biological conservation. Furthermore, diversity of tropical aquatic ecosystems is severely threatened by anthropogenic activities. What is more, the continuum of most of the tropical river is interrupted by several man-made activities contributing to adverse effects which hamper provision of good quality of water. Traditionally the quality of water is assessed by physico-chemical means but recent studies have focused on the use of organisms (biota) in water quality assessment for streams and lakes. Here we assessed the influence of water quality on the diversity and distribution of macroinvertebrates in Hiwane second order stream with primary objective to determine the ecological water quality status of Hiwane stream at different sampling sites using rapid field assessment screening methodology. A total of 5 sites (stream sections) were selected and 4 of the sampling sites were within the city Hiwane. However, a reference site outside of the city of Hiwane was included. There were 29 taxa of benthic invertebrates belonging to ephemeroptera, odonata, plecoptera, coleoptera, trichoptera, diptera and hirudenia, among others, recorded from the river. Among these, members of Trichoptera and Ephemeroptera were predominant in density. Furthermore, species diversity is positively correlated with water quality. Since, man-made activities has lead to depletion of biota, any human activity in the drainage area which may cause changes among physico-chemical parameter could lead to a severe impact on the benthic invertebrates of Hiwane stream river. Thus, we recommend that effluent from the town should be carefully managed.

Key words: Macroinvertebrates, water quality, hiwane, pollution

INTRODUCTION

One of the common resources for all life forms on the planet is water. Water is critical for sustainable livelihoods and it is impossible for a single life to live without water. Furthermore, there is a pressure to use these resources with max effort to feed the fast growing population and to improve the standard of living of citizens. However, It is argued that the physical and chemical condition of many streams in tropical countries is deteriorating as a result of human population explosions, changes in land use, intensified agricultural practices and increased industrialization all of which cause changes to natural flow regimes directly or indirectly (Pringle *et al*., 2000; Wishart *et al*., 2000). In different parts of the world streams and rivers are the major sources of water to satisfy human needs. Such a use are clearly manifested and magnified in developing countries where streams and rivers are the main supply of water for domestic uses, agriculture, transport, industries, power production and recreation. Their importance becomes more pronounced in developing countries especially in rural areas where they are major sources of drinking water without any form of treatment. In contrary in urban areas of most developing countries, they serve as receivers of untreated industrial, municipal, clinical and other types of liquid wastes, dumping sites of solid wastes with different constituents from residential areas and are sites for open air urination. The situation is not different in Ethiopia where organic pollution from residential, agricultural and industries are damped into rivers and streams (Zinabu and Elias, 1989). Furthermore, there is a pressure to use these water resources with max. Effort to feed the fast growing population and to improve the standard of living of citizens. Thus, in order to use this huge water resource for the benefit of the citizen in sustainable manner, developing easily applicable biological monitoring system for assessment of aquatic ecosystems is very crucial. Moreover, Macroinvertebrate diversity in Ethiopia in general and Tigray in particular is known little. Only few studies Harrison and Hynes (1988) described the distribution of benthic fauna in the mountain streams and rivers of Ethiopia. Besides, (Seyoum *et al*., 2003) characterized the wastewater and downstream pollution profiles Mojo River in the rift valley portion of Ethiopia. However, this are studies with sporadic sampling of small section of streams. Thus there is a need to develop identification keys and characterization of

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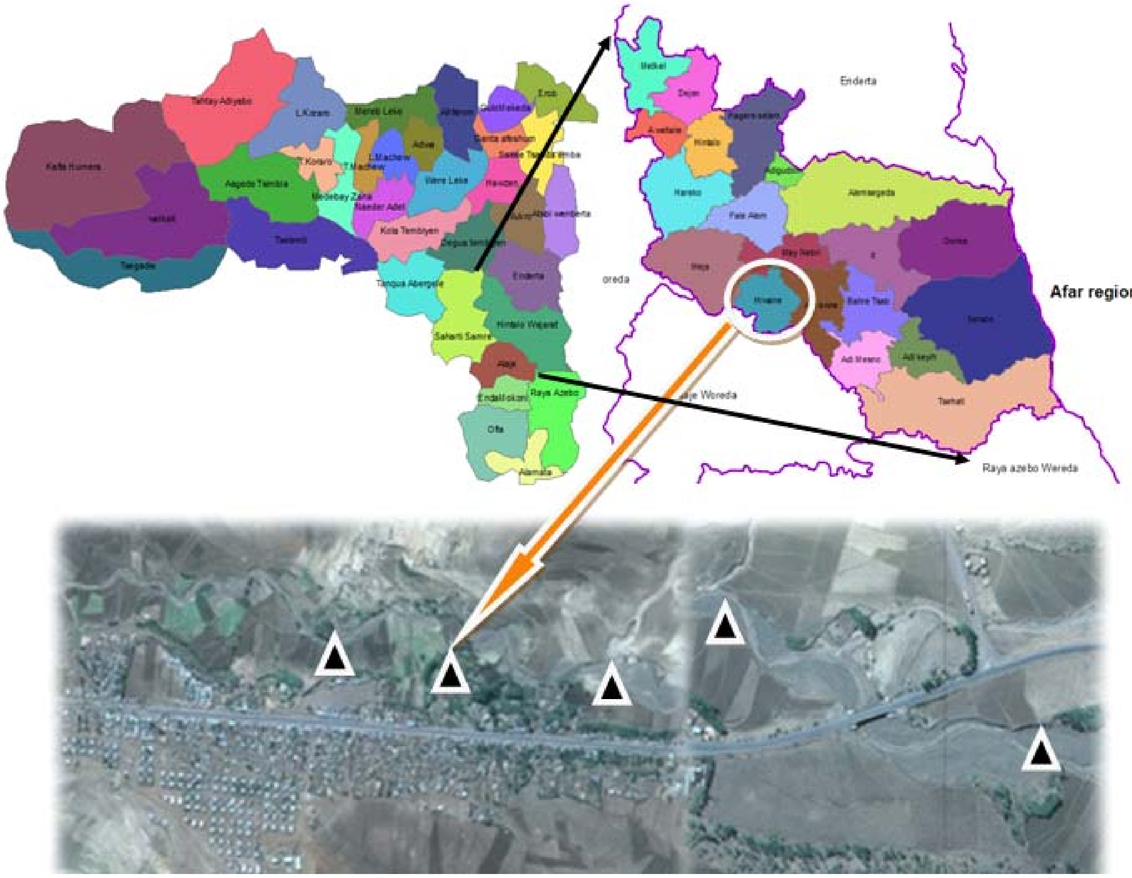

Fig. 1: Map of Tigray (Top right) and Hintalowejerat (top left) and google picture of the study sites indicated with triangle (bottom)

(a) (b)

Fig. 2: Different water use in the stream (a) people washing close b) collecting water for house hold consumption

macroinvertebrate communities based on the countries biota after individual studies are conducted from the different water bodies of the region. Apart from this, it is well established fact that the activity in the watershed affects the quality of water resource in which humans and animals with in the watershed depends on. Thus one would consider streams and rivers as mirrors of the landscape reflecting the 'health' of their catchments. A study by Tesfaye (1988) indicated that benthic macroinvertebrate composition and abundance varies along river kebena as pollution gradient increases. This clearly indicates that macro invertebrates in Ethiopia could be good evidence for developing bio-assessment methodology especially using macroinvertebrate as indicators. Furthermore, most of the European researchers use non-systematic units such as fish, macrophytes, phytoplankton and diatoms for regular observations and determination of ecological statuses of the streams (De Pauw and Vanhooren, 1983). Among which the most frequently used community to determine the water quality in the streams is the macroinvertebrates. However, such study is lacking in Tigray region of Northern Ethiopia. Thus, this study was conducted to assess Influence of water quality on the diversity and distribution of macro invertebrates in Hiwnae of Tigray region

MATERIALS AND METHODS

Description of the study site: Hiwane (13º6′10″ North, 39º29′35″ East) is a small town, in Southern Zone of Tigray, northern Ethiopia (Fig. 1). Hiwane is under the administrative district of Hintalowejerat. It is located about 60 km south of Mekelle, the capital of Tigray region. There is a municipal water system in Hiwane, but it is insufficient and does not serve all the people living in the town or round about. As a result a lot of people depend on the stream running past the town for household water consumption (Fig. 2). Furthermore, people use the stream water to wash their close in the stream itself and as source of water for their livestock drinking as well (Fig. 2b).

(a)

(b)

Fig. 3: Laboratory procedures a) sieving samples and b) sub sampling of sieved sediment

Data collection methods: Five sampling sites were selected along the second order stream that pass through the town Hiwqane (sampling site 1 (above the city) site 2, 3, 4 and 5 are stream sections that lie with in the town's vicinity.

Both (semi) quantitative sampling Multi-Habitat Sampling approach (MHS) of 25*25 cm area was used and total of 20 sampling units per sampling site were taken and samples per site were combined and preserved in 4% Formaldehyde for later identification in the laboratory. During field sampling a rapid field assessment method for sensory features, chemical processes and composition of biota in the stream were assessed using the Austrian screening protocol (Appendix) and Samples were brought to Biology laboratory and sieved (Fig. 3a) and sorted from sub sample sediments of known area (Fig. 3b)

Macroinvertebrate communities along the second order stream in Hiwane were sampled during July 2010 to June 2011 at the five stations, using d-frame dip net and Multi-Habitat Sampling approach (MHS) was used in order to include all possible microhabitats at each sampling stations. In some areas with the presence of large stones, these were first picked out and washed into the net to remove pupae and other attached macro invertebrates. In addition, macroinvertebrate samples were separated from the macrophytes and the sediment using sieves of different mesh size at Biology department, Mekelle University, Ethiopia. The macro invertebrates were sorted, identified to the lowest possible taxon (species, genus or families) and counted under a stereomicroscope. Furthermore, at the time of sampling water temperature (ºC), pH, dissolved oxygen (DO mg/L) and electrical conductivity (EC µS/cm) were measured in the field using portable equipments.

Data analysis: All data collected were subjected to statistical analysis appropriate for the multimetric approach, which is used to expresses the ecological quality of the water body as a number using:

- **Richness measures** (Number of EPT taxa, total taxa),
- **Composition measures** (like % EPT-Taxa, % EP abundance, % Oligochaeta + Diptera taxa and % shredder & grazer)
- **Diversity measures** (Diversity and species evenness)

Thus, this study is restricted to indices focused on the determination of water quality. Family Biotic Index (Hilsenhoff, 1975), i.e., number of Ephemeroptera, Plecoptera and Trichoptera (EPT%) taxa, number of EPT/Chironomus (EPT/Chr %) and of Shannon and Weaver Diversity Indices (SWDI) which is calculated as:

$$H = -\sum_{i=1}^{n} p * Inp$$

where p is relative abundance and lnp is natural log. of relative abundance.

RESULTS AND DISCUSSION

Macroinvertebrate composition and abundance: A total of 1139 individuals composed of 8 order of insects and 4 orders of non insects were collected during the study time. The most dominant orders of taxa belong to 26 insect families and 3 families of the order Oligochaeta (Table 1 and Fig. 4). Among the insect orders Trichoptera and Diptera are the most dominant with 34 and 27% of the macroinvertebrate community followed by pleocoptera with 10% of the total taxa of insect order (Fig. 4). Furthermore, it is found out that more than 60% of the individuals collected belong to insect orders (Fig. 5) while less than 40% belong the non insect order like Gastropoda and Oligichaetae among others. Among the non Insect order Oligochaetae is the most dominant with 50% of total composition of non insect orders. However, Gastropoda, Planariidae and Hydracarina have the percentage composition of 16.7% each.

Table 1: The most dominant order of macro invertebrates in Hiwane stream

Ephemeroptera	Order: Tricoptera	
Rhyacophilidae	Order: Plecoptera	Perlidae
Glossosomatidae		Nemouridae
Hydropsychidae		Leuctridae
Polycentropodidae	Order: Oligochaeta	Lumbricidae
Psychomyiidae		Tubificidae
Limnephilidae		Lumbriculidae
Leptoceridae		
	Order: Diptera	Pediciidae
Sericostomatidae		Chironomidae
Beraeidae		Simuliidae
Odontoceridae		Athericidae
Baetidae		Empididae
Heptageniidae		Limoniidae
Leptophlebiidae		Tabanidae
Ephemeridae		Tipulidae
Ephemerellidae		

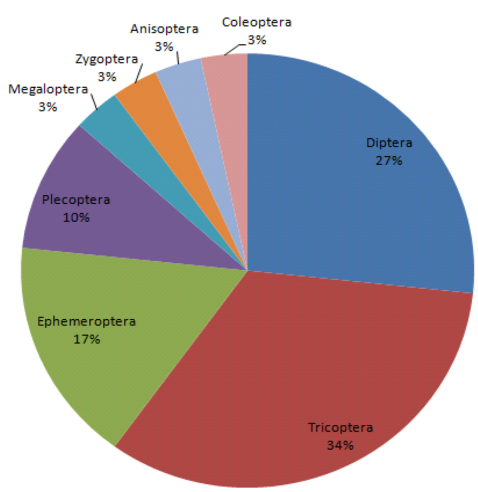

Fig. 4: Composition of insect orders in Hiwane stream

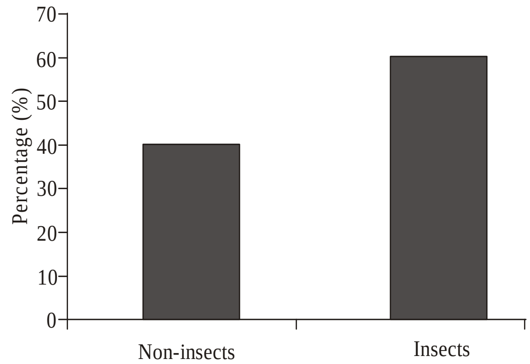

Fig. 5: Category to which the individual macro invertebrates belong

The different stream sections were preclassified using expected values for disolved oxygen (Table 2). Accordingly sampling site 1 falls under quality class I (with 98 mg/L DO) where as stream sections 2,3,4 and 5 falls under quality class II with DO given in Table 2.

Changes in physicochemical structure also affected the diversity of species at each sampling stations. Furthermore, the great majority of the existing taxa at 1st, 2nd, sampling stations have not been observed at 4th and 5th sampling stations. As a result of the water quality assessment using biotic indices (Table 4), the 4th and 5th sampling stations were determined as the polluted part of the stream, fitting in exactly with the water quality classification done according to the physico-chemical parameters (Table 2) Furthermore, diversity indices values of these sampling stations (i.e., 4 and 5) are lower than either of the other sampling stations (i.e., 1 and 2). This clearly supports the data from Dissolved Oxygen (DO) and oxygen saturation (%) (Table 2).

In this study fluctuation of pH (Fig. 6) between reference sites (mean value of 7.7) and impacted site was not statistically significant (T-test, n = 2, $p<0.05$). Thus, the influence of pH on the evaluation of the quality status of sampling sites can be excluded that means these parameters were not selected to support the classification of quality classes. However, it is know that the pH is an important variable that can influence chemical and biological processes in the stream water (Resh, 1995; Rosenberg and Resh, 1993); Dow and Zampella, 2000). Besides, it is reported that variations in pH within 24 h time can be caused by the photosynthesis and respiration cycles of algae in eutrophic waters (Hawkins, 1978).

The water temperature fluctuation during the sampling time in all sampling site was insignificant (Mean = 23.78, $p<0.05$ n = 5). As can be seen from Fig. 1 the values under reference condition were lower (Mean 22.9ºC) than at impacted sites 4 and 5 (mean = 25ºC). This observation may be due to the fact that reference sites were located in the head water section of the river having relatively more shading such a result have been reported by Kalyoncu and Zeybek (2011).

Table 2: Expected and observed values of dissolved oxygen (concentration and saturation) among pre-classified classes

Expected values**			Observed values**		
Quality class	DO (mg/L)	DO saturation (%)	DO (mg/L)	DO saturation (%)	Stream section
I	8 or more	95-110	8	119	1
II	>6	70-125	7.74	112	2
III	4 or less	50-150	7.11	109	3
IV	2 to 4	25-200	7.81	121.8	4
V	<1	<10 (deficit),	7.01	107.8	5

**: The expected values are from Moog and Sharma (2005) for different quality classes and observed values are avaerage values taken for the stream sections we measure in-situ

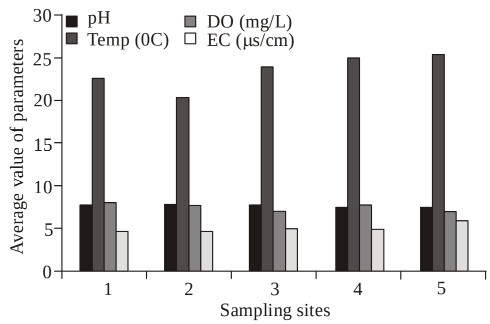

Fig. 6: Mean values of phyicochemical parameters of Hiwnae river

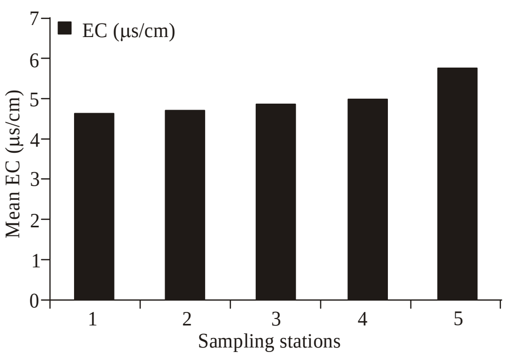

Fig. 7: Mean Electrical Conductivity (EC) of different sampling stations/sites in the Hiwane River

As indicated Table 2 and Fig. 7, sites, which were classified as quality class II (based on DO and O_2%) accounts high levels of conductivity (with 4.8 µS/cm and 5.4 µS/cm at sampling site 5 and 4 respectively). All sites under this quality class were located downstream of a grinding mill, which uses the streams as main waste (effluent) dumping site. On the contrary the reference sites have relatively low conductivity reflecting the normal ions present in the water (mean 4.6 Fig. 7). Therefore, in a direct comparison with an existing reference site or in the case of stable basic natural conductivity conditions, conductivity could be used as a good discriminating parameter for quality classes in this study conductivity can excellently discriminate the reference sites from impacted sites (Fig. 7). This is in agreement with reports by Kalyoncu and Zeybek (2011). Furthermore it is argued elsewhere that conductivity can

Table 3: Diversity index and species richness and evenness of sampling sites

Sampling site	Shannon diversity index (H)	Species richness (S)	Species evenness (J)
Site 1	1.80044566	11	0.75084416
Site 2	1.77199568	10	0.76956795
Site 3	1.5788514	9	0.71856624
Site 4	1.43984147	9	0.65530009
Site5	1.37894238	9	0.62758372

Table 4: Comparison of predicted response of different biometric index and response calculated based on data from Hiwane stream

Biometric indecx	Predicted response	Response meet
Total No. taxa	Decrease	Variable
No. EPT taxa	Decrease	Yes
No. Ephemeroptera	Decrease	Yes
No. Chironomidae	Decrease	Yes
No. Coleoptera taxa	Decrease	Variable
No. of Intolerant taxa	Decrease	Yes
Shannon-wiener index	Decrease	Yes
% Trichoptera	Decrease	Yes
% Ephemeroptera	Decrease	Yes
% EPT	Decrease	Yes
% Diptera taxa	Increase	Yes
% Tolerant organisms	Increase	Yes
% Odonata	Increase	Yes
% Diptera	Increase	Yes
% Red chironomids	Increase	Yes

be influenced largely by geology since it is highly influenced by mineral salts (Kalyoncu *et al*., 2009a, b). However, an increase in conductivity possibly occurs when additional wastes containing ions enter the stream section (Kalyoncu *et al*., 2008). Thus, it is highly probable that the increase in conductivity in the stream from sampling site 1 down to sampling 5 is due to the additional waste from residence as well as the mill

Macroinvertebrate diversity and species richness: We have calculated the diversity index for each sampling sites given and as indicated in Table 3, the species diversity increases with water quality (i.e. the highest diversity is observed in the sampling site with a good water quality). This result is in line with Washington (1984). Besides, we have compared the different richness and composition measures with predicted response for each biometric index with calculated responses (each metric calculated based on data we collected) and we found that a good correspondence (Table 4) between the two. This is in agreement with the generally accepted principle that macro-invertebrate community structure can be used as an

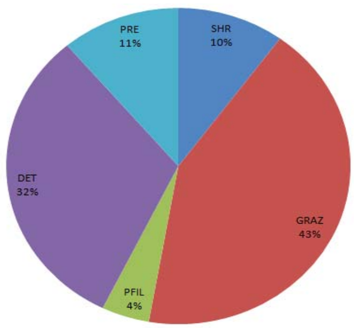

Fig. 8: Composition of functional feeding groups of macroinvertebrate in Hiwane stream PFIL: Filter feeders; GRAZ: Grazers; DET: Detritus feeders; PRE: Predacious; SHR: Shredder

indicator of the condition of an aquatic system as stated in different literatures (Armitage *et al*., 1983; Friberg *et al*., 2006; Ortiz and Puig, 2007).

We further categorized the macroinvertebrate community into different feed groups using Moog (1995) functional feeding groups (Fig. 8). Over all the macroinvertebrate community of Hiwane stream is highly dominated by grazers (43%) while the filter feeder are the least represent feeding groups.

CONCLUSION

In summary, the macroinvertebrate community of highland stream-Hiwane is dominated by Grazers. And there is a good correspondence between macroinvertebrate diversity and water quality.

Appendix: Decision support table used in field

	Water quality classes				
Decision support table	--				
Multiple choices possible	I	II	III	IV	V
Sensory features	To beticked/counted if not in accordance with natural river type				
Non natural turbidity ,suspended solids			+	+	++
Non natural colour		+	+	+	++
Foam		+	+	+	+
Odour (water)		+	++	++	++
Weste dumping		+	+	+	++
Ferro-sulphide reduction - (water velocity<0,25 m/s)	-				
Mud reduced but with aerobic surface		+	+++	++	
Mud reduced but aerobic surface				++	+++
Lower surface of stones (% cover black dots)		<25%	25–75%	75-100%	100%++
Upper & lower surface of stones (% cover black dots)					
Ferro-sulphide reduction - (water velocity<0,25-75 m/s)					
Mud reduced but with aerobic surface			+	+++	+
Mud reduced but aerobic surface				+	++
Lower surface of stones (% cover black dots)			<50%	50-100%	100%
Upper & lower surface of stones (% cover black dots)					+++
Ferro-sulphide reduction - (water velocity<0,75 m/s)					
Lower surface of stones (% cover black dots)			<25%	25-50%	50-100%+++
Upper & lower surface of stones (% cover black dots)					
Bacteria ,fungi, periphyton					
Sewage fungi & bacteria (visible to the naked eyes)	-	-	few	medium	many ++++
Sulphur bacteria (visible to the naked eyes)		-	-	-	++++
Cleanwater algae (e.g. *Chamaesiphon*)	+++	+			
Stones with algal vegetation (perihyton) in the layers	++	+			
% of thick, sigificart layers of algae	<25%	25-75%	75-100%	75-100 %	few+
filamentous green algae	none to few	filaments, tufts	large tufts	(large) ufts	
Algal bloom			+++	++	+
Benthic maero-invertedrates					
Katharobic indicatores	+++	+			
Syn(-Agapetus) sp	+++	+			
Perlidae	++	+			
Plecoptera	++	+			
Epeorus asssimilis	+	++			
Philopotamus sp.	+++	++			
Odontocerum sp.	++	++			
Rhthrogena ssp.	+++	++			
Heptagenildae	+++	++	+		
Ephemerelidae	+	++	+		
Lepi dostomatidea	+	++	+		
Potamanthus		++	+		
Simuliidae		+	++	++	
Hydropsyche spp. (medium to many)		+	++	++	
Phy sa ssp.(medium To many)			+	++	+
Potamopyrgus antipodarum (>medium)			+	+++	+
Aselius aquaticus (more than naturally occurring)	-	-	+	+++	+
Leeches (more than naturally occurring)		-	-	+	++++
Chironomids with red colour		very few	few	medium	+++many[t]
Bezzia-Group				+	++
Psychodidae animals, e. g. rat -tail maggots					+++
Oil gochaeta / Tubificidae (mud - worms)	0to very few	few	few medium	medium/many	+++many[t]
Sum of columns					

*)abundances may decline to 0 if oxygen depletes

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