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Freshwater Fisheries Resource Potential Estimation: The case of Lake Ardibo, Northern Ethiopia

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Abstract

The study investigates aspects of the fresh water fish resource potential estimation by considering Lake Ardibo, a Crater Lake in the northern highland of Ethiopia. The general aim of this study was to produce a scientific guidance paper on the estimation of fish resource potential of Lake Ardibo and to show the practical applicability of the different fish resource potential estimations models in Lake Ardibo. And this research was done by taking seasonal data from the selected three sampling sites i.e. some limnological parameters (physico-chemical parameters) in the period from February 2009 till January 2010. The sampling sites were located the first one near the shore (littoral site-SS1), the other the vegetated-SS2, one with a relatively dense macrophyte vegetation and the 3rd site was pelagic-SS3. The locations of the sites were identified by the Global Positioning System (GPS). And also series year of catch effort data were collected from Woreda livestock and fishery office and fishery cooperatives. Based on the collected data analysis were made using empirical and Schaefer production models. Hence the empirical models estimation shows 98.1 kg per hectare per year or 206 tons per year; whereas the Schaefer production model gives maximum sustainable yield (MSY) of 3452.5 kg per hectare per year or 3.45 tons per hectare which means 7250 tons per year from the lake and f_{MSY} is 416 standard boats. Results of the Schaefer-Fox model were higher than the empirical estimates. Thus, the Lake can provide sustainable a production of fish, i.e., MSY on average 98.1 kg/ha per year or 206 tons per year from empirically found relationships.

Keywords Ethiopia; Lake Ardibo; Fish; Potential; Estimation; MSY

Introduction

The world fresh water resource is very small, around 2.5% of the global water. From this Lakes cover 0.4% of the global freshwater, however together swamps/wetlands it accounts around 8% and holds 40% of all fish species. In fisheries production and the economic benefit of the lakes, rıvers, dams, and swamps is nearly 15% of our globe fisheries production [1]. Fresh waters are very important ecosystems for human being and gives many economic benefits for the day to day living of the society like drinking water, harvesting of human food and animal feed (fish, algae and other grasses), water for their agricultural land, supporting and serve as habitat for many birds and fish species and gives more than this values and today those ecological benefits are altered by different factors such as over use of the resource, degradation, pollution, climate change and other [2,3].

Fishery is the industry in which the inputs (the application of boats and gillnets and/or other fishing methods) are changed into an output (harvesting and processing of fishes); simply the functionality of any fishing activity in the water body and at the same time harvesting of fish is called fishery. Currently the demand and supply of fish are not balanced, on the supply side there is high technology advancement like fishing equipment's (boats, nets, and gears advancement), processing utilities, cold chain as well as artificial fish production (the aquaculture sector advancement and high market oriented fish production), on the other hand high population growth, demanding protein rich foods, high demanding market throughout the world and also fish is the best animal in food and nutrition security [4-6].

According to Food and Agriculture Organization of the United Nations [7], knowing of specific water body fisheries potential is a big question for resource managers like fish utilization and administrator/manager officers especially in developing countries than fish biologists or researchers. Because ones the potential is known, then it is very easy to put in place fisheries resource management options for that water body. The understanding of the fisheries capability is vital for the management requirements to limit how many fishers and their families could be supported by the fish resource sustainable without collapsing the resource.

Fisheries have an important socio-economic role in many developing countries. An estimated 55 million peoples are directly participated in capture fishery (fishing activity) and aquaculture development in 2010 and the number may reach as high as above this (including the post-harvest sector). Altogether about 1 billion people relay on aquatic products for their main source of animal protein. Not surprisingly, over the last 30 years fisheries have been the focus of various development initiatives sponsored by international organizations like UN FAO, World Bank and others [4,5].

Ethiopia has vast water resource and commonly known as, water tower of east Africa and has so many lakes, rivers, reservoirs, wetlands, springs and untouched underground waters including above 20 natural lakes, 12 large river basins, over 15 big dams/reservoirs, more than 75 wetlands/marshes. And those water bodies are rich in fish diversity and abundance, but most of the water bodies are not well studied and therefore no organized surveys of their potential have been done. Current studies show that the country can produce maximum sustainable yield (MSY) of fish around 95,000 tons per year from the natural water bodies i.e. capture fishery and huge aquaculture potential in all agro-ecologies from cold to warm water species [8-10].

Also in Ethiopia the spread of using new technology of fishing is gradually increasing since the introduction of motorized boats since 1986 by the Dutch NGO, LFDP and others. Continuous technological change may cause the catch to increase up to Maximum Sustainable Yield (MSY) level of that stock, but after Maximum Sustainable Yield (MSY) the increase in technology will not bring any increase in output instead there will be a decrease in catch leading the collapse of the stock in the long-run. So early warning is important before this situation is going to occur. In this regard, limiting the effort level is very important.

According to Reyntjens et al. [11] the primary question that comes first is how much can we harvest without collapsing/eroding the fisheries stock? Scientists developed different techniques to answer this question call models. There are three key models (empirical, surplus production and analytical) each having particular pre requests regarding data as well as ability to do the analysis. Evaluating whether the suppositions are logically convened is a very significant concern.

In Ethiopian highland lakes like Lake Ardibo; fishery is the best way to fill their food and nutrition gap and protein source. However, Lake Ardibo is not well and deeply studied particularly their ichthyofauna, how much can provide the lake without eroding the productive nature of the ecosystem and the number of fishermen and families engaged in this business (fishery). Therefore, this study was conducted to know about the fish potential status of the lake so that appropriate management measures would be put in place to sustainably utilize the aquatic resources in the Lake.

Materials and Methods

Description of the area

Lake Ardibo is situated in the north eastern part of Ethiopia, South Wollo administration zone of the Amhara regional state. It is located at 110 10' 26.9'' N, 390 45' 19.2'' E at an altitude of 2000 m asl (Figure 1). The lake area and its watersheds are about 21 km^2 and 52.6 km^2 in that order. Lake Ardıbo watershed is relatively well protected as compare to the nearby Lake, Lake Haik and the area is over all high elevation/altitude described by spread trees and bushes as well as natural-grazing field. The climate is sub humid with regular yearly temperature and precipitation of 18°C and 1158 mm, respectively. Lake Ardibo has utmost depth of 65 m. The Lake has almost similar pH with that of Lake Hayq (8.5). The surface oxygen is about 4.15 mg/L and surface temperature is relatively colder than Lake Hayq (16.3°C). The lake is more turbid with vertical visibility of 1.4 m. Ankerka River flows out of Lake Ardibo and drain into Lake Hayq [12].

Lake Ardibo is one of the most important bird areas of Ethiopia. Still now 73 bird species were recognized in this water body and its surroundings. The fish species found in this lake are not indigenous. The lake harbors two fish species introduced for fisheries and weed control which are Nile tilapia (*Orechromis niloticus*) and Carp (*Cyprinus carpio*), respectively.

In general, the lake ecosystem supports fish species; different birds and aquatic algae and grass species. The lake is majorly used for fishery, irrigation and other societal needs including for animal drinking. Lake Ardibo has more infringing papyrus swamps, which support a unique habitat for freshwater biodiversity and source of animal feed during the dry season. Fisheries resource contributes a lot in food and nutrition security in this area. For Lakes Ardibo, there are registered fishermen in which their livelihood is dependent on it. There is one fisher cooperative working on production and marketing; and the fish produced from Ardibo is transported to and marketed at Haik, Kombolcha, Dessie, Woldia, Debre Brehan and Addis Ababa cities.

Sampling sites

Three sampling sites were identified and selected for seasonal data sampling of some physico-chemical parameters from February 2009 till January 2010. Lake Ardibo is a crater lake in the northern highland of Ethiopia and also collection of many series years catch-effort data from Tehuldery Woreda former agriculture office now livestock and fisheries development office. The sampling sites were located the first one near the shore (littoral site-SS1), the other the vegetated-SS2, one with a relatively dense macrophyte vegetation and the 3rd site waspelagic-SS3. The locations of the sites were identified by the Global Positioning System (GPS).

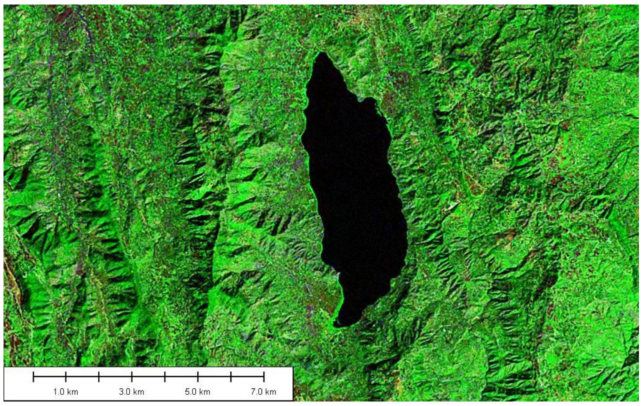

Figure 1: Satellite image of Lake Ardibo [12].

Physico-chemical parameters

The physico-chemical parameters, biological sampling were done two times in the study year, i.e. at dry and wet seasons, that includes temperature of the water, pH, dissolved oxygen, conductivity, Secchi reading, phytoplankton and zooplankton using thermometer, pH meter, oxygen meter, conductivity meter, Secchi disk and zoo and phytoplankton nets respectively.

Empirical model

According to LFDP et al. [13-15] estimations based on empirically found relationship between fish yield and other parameters like Morpho-Edaphic-Index (MEI) of the lake were also used to estimate potential yield of the lake as presented in Table 1 by different scholars. The advantage of this method is that they require very little data which are either available or can be quickly collected at a relatively minor cost and they give a quick estimate of potential yields.

Author	Equation	Yield
Marshal	$\ln(Yt)=3.57+0.57\ln(A_o)$	Tons
Henderson and Welcome	$Y=14.3136MEI^{0.4681}$	kg/ha/year
Toews and Griffith	$Log(Y)=1.4071+0.3697Log(MEI)-0.00004565A_oLog(Y)$	kg/ha/year
Schlesinger and Regier	$0.050T_m+0.280Log(MEI)+0.236$	kg/ha/year

Table 1: Empirical models used to estimate MSY [13].

Symbols used: Yt: Total yield in tons/year; Y: Yield in kg/ha/year; Ao: Area in km2; $\bar{Z}$: Mean depth in meters; Tm: Mean annual air temperature; MEI: Morpho-Edaphic-Index calculated as conductivity over $\bar{Z}$.

Catch and effort data

The fish catch and fishing effort data were collected from the former Tehuledere Woreda agriculture and rural development office now Tehuledere Woreda livestock and fisheries resource development office and fishery cooperative of lake Ardibo. Therefore data from 2002 to 2009 G.C. were collected and organized for further analysis using Schaefer harvest (production) model to calculate maxımum sustainable yield (MSY) and the corresponding effort (f_{MSY}) from catch and effort data of series years [7,16]. AS

$$MSY = \frac{a^2}{4.b} \qquad MSY = \frac{a^2}{4.b}$$

Where, MSY - Maximum Sustainable Yield; f_{MSY} - Effort of Maximum Sustainable Yield; a and b are constants parameters estimated through a simple linear-regression analysis from catch and effort data.

According to LFDP [16] the upper limit sustainable yield, i.e., MSY is achieved when the biomass is half the biomass of the un-fished stock. Because catch per unit effort is directly proportional to the biomass, this also means that at MSY, the catch per unit effort is half what it was at the beginning of the development of the fishery. The parameters a and b were estimated through a simple linear regression analysis of the catch per unit effort on the effort. It has to be stressed, however, that these equations were derived for a situation of equilibrium when the net growth rate of the stock is zero.

Descriptive statistic was used to analyze the data.

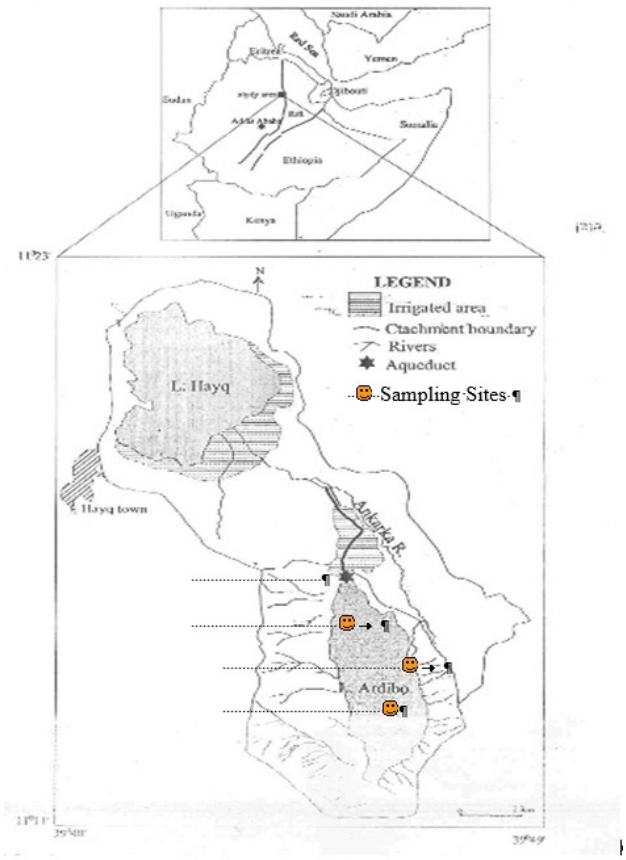

Figure 2: Map of Ethiopia and sampling sites at Lake Ardibo [12].

Results and Discussion

Metrological data

Lake Ardibo area monthly temperature, rainfall both the minimum and maximum were taken from Ethiopian Federal Metrological agency. According to the data, which plotted in Figures 1 and 2, mean-monthly minimum air temperature ranged from 4.6°C to 15.1°C, while the maximum mean monthly atmosphere temperature fluctuated from 23.9°C to 31.4°C. Monthly total precipitation ranged from 1 mm (May, 2009) to 344 mm (May 2007).

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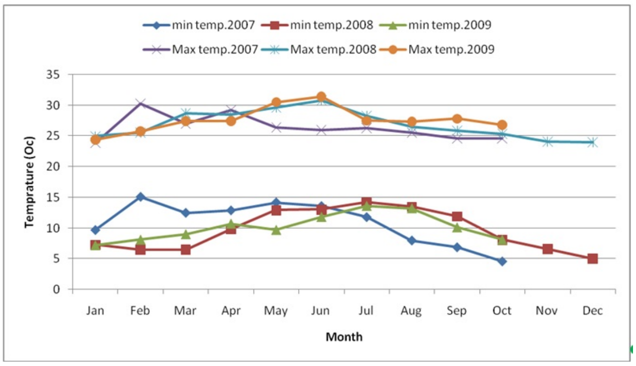

Figure 3: Mean monthly minimum and maximum atmospheric temperature of the Lake region (Federal Metrological agency, 2010).

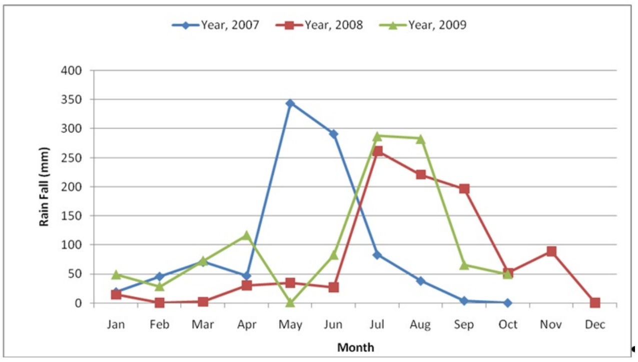

Figure 4: Mean monthly rainfall of the lake region (Federal Metrological Agency, 2010).

Physico-chemical parameters

The physic-chemical parameters taken from Lake Ardibo Littoral, vegetated and pelagic sites include dissolved oxygen (parts per million), temperature (°C), conductivity (µs/cm), PH and secchi depth (meters) both in wet and dry season of the year. As indicated below in Table 2, the maximum dissolved oxygen and secchi depth reading registered in vegetated site of the lake (17.53 ppm and 4.5 m respectively) due to the aquatic plants photosynthesis process in dry season, whereas the highest temperature i.e. 23.7°C was taken in the wet season, pelagic sites of the water. As well as Conductivity and PH was high in dry season, 1806 and 8.5 respectively in littoral and pelagic sites.

Plankton

The identified zooplankton species were *Trichocerca species., Anuraepsis species., Keratella species, Cyclopoid species, Mytilia species, Nuplie species, Brachionus species, Moina species, Polyarthra species*. Phytoplankton species of *Cosmarium species, Peridinium species, Cymbella species, Synedra species, Nitzschia species, Navicula species, Microcystis species, Cyclotella species, Surirella species, Scenedesmus species, Oscilatoria species, Staurastrum species, Cymatopleura species, Oocystis species, Elakatothrix species, Pediastrum species, Schroederia species* were also identified in this study. And from the result shown in Figure 3, the number of phytoplankton and zooplankton across sites were in direct relation with the abundance and distribution of the fish in Lake Ardibo. In addition they are high in littoral and vegetated zone of the lake; whereas DO were high in vegetated zone of the lake in both seasons this is due to photosynthesis processes of the grasses or vegetation whereas other parameters were more or less similar in both seasons. The zooplankton species composition of Lake Ardibo is similar with that of Lake Hayq, which is dominated by Cyclops, Bosmina, Keratella, Brachionus and Diaphanosoma (Figure 4) [17]. Since Lake Hayq and Ardibo are connected by river Ankerkeha they have similar zooplankton species like *Thermocyclops ethiopiensis* and *Mesocyclops aequatorialis*. The phytoplankton species identified so far are *Closterium, Microcysts, Oscillatoria, Cellerna, Melosira* and *Consmarium*.

Sites	Station depth (m)	Parameters									
		Dissolved oxygen (ppm)		Temperature (°C)		Conductivity (µs/cm)		pH		Secchi depth (m)	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dy	Wet
Littoral site (SS1)	2.5	12.06	2.88	23.4	23.2	1806	1585	8.5	7.46	2	1.1
Vegetated site (SS2)	27	17.53	3.54	21.7	23.2	1491	1600	7.54	8.09	4.5	3.8
Pelagic site (SS3)	47	12.6	2.78	22.4	23.7	1712	1559	8.51	7.75	4	3.6

Table 2: Physico-chemical parameter of Lake Ardibo.

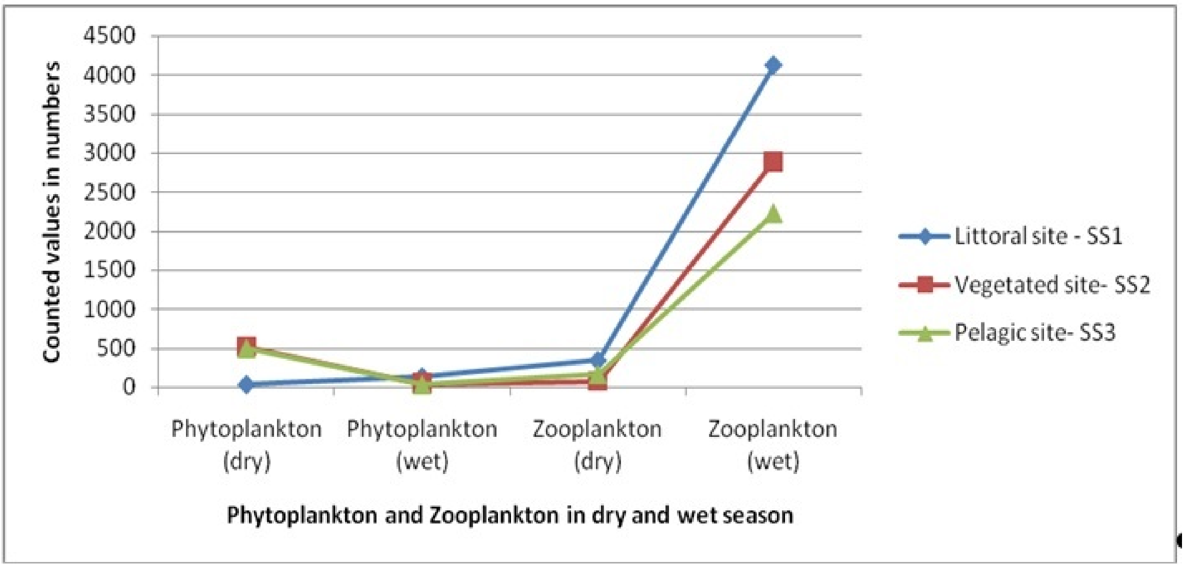

Figure 5: Phytoplankton and zooplankton in dry and wet season in Lake Ardibo.

Maximum sustainable yield and the corresponding effort

The maximum sustainable yield and corresponding effort were computed empirically and surplus production models using the existing data sources (Tables 2-4).

Area km^2	Mean depth (m)	L_o (km)	Temperature (°C)	Conductivity (µS/m)
21	34	8.33	26.1	1626

Table 3: Data used for estimation MSY of Lake Ardibo using physico-chemical parameters.

Models	Calculated productivity (kg/ha/year)	Estimated potential yield in (tons per year)
Marshal	95.9	201.4
Henderson and Welcome	87.5	183.8
Toews and Griffith	106.4	223.5
Schlesinger and Regier	102.6	215.5
Average	98.1	206

Table 4: Result of potential yield estimate.

Selected but more two empirical models were applied to estimate the potential yield particularly maximum sustainable yield (MSY) of the Lake Ardibo. Based on the calculation different results were registered from 87.5 kg per hectare per year to 106.4 kg/ha per year. Or 183.8 tons to 223 tons per year, and the average is 98.1 kg/ha per year or 206 tons per annum on a sustainable basis (Figure 5). On the other hand, this estimation doesn't indicate stock condition like species composition, growth and recruitment.

Year	Catch (Yt) (tons)	Total Effort (ft) (numbers)	CPUE per boat (U)=Yt/ft
2002	68.5	720	95.14
2003	76.8	1620	47.41

2004	70	1260	55.56
2005	78	1620	48.15
2006	91.2	1980	46.06
2007	82.8	1440	57.5
2008	102.1	2340	43.63
2009	126.4	2520	50.16
		1687.5	55.45

Table 5: Catch and effort data for Gillnet of Lake Ardibo.

However, it is supposed that 2/3 of the average of the different MSY result (or 137.3 tons per year) shows good and sustainable yearly harvesting point. The similar results were obtained by Bahir Dar Fish and other Aquatic Life Research Center progress report; they documented that the lake provides about around 200 tons per year and currently the fishers harvests two fish species *Oreachromis niloticus* and *Cypernus carpio* that fetch good price in the market and also have cultural value in the area (Table 5).

b = 0.02

a = 16.62

Y = a-bf, U = a - bf

Y/f= a-bf, y= af-bf^2

$$U = 16.62 - 2.3 \times 10^{-2} f$$

The straight line that best fits to the data is thus given by this equation.

$$MSY = \frac{a^2}{4.b} \text{ and } fMSY = \frac{a}{2.b}$$

MSY=3452.5 kg/ha/year or 3.4525 tons/ha which means 7250 tons per year from the lake and f_{MSY} is 416 standard boats.

The estimated potential yield from a lake is important information required for fisheries management. It is possible to compare the actual yield of the fisheries with the estimated potential yield. It is on the basis of this comparison that management plans are made. Historical catch and effort data are needed to make predictions about the possible impact of management decisions. It may be very difficult to manage what is not known.

Conclusions

The study showed that Lake Ardibo can provide 98.1 kg/ha/year or 206 tons per annum. And also the zooplankton and phytoplankton distribution and abundance have direct relation with the fish stock population. Finally this resource is limited if everybody catches, the fish stock may collapse so there should be fishery management option in place and fishery officers should work maximum sustainable yield (MSY) limit is practiced as indicated above and should be checked. In line with this there should be limiting the number of boat and nets and also fishing day. And also there should be continuous awareness creation for fishermen and local lake community so that the communities by themselves manage the lake resource and fish in a sustainable manner because fish can recruit and renew itself through the natural reproduction biology. And enactment of the Amhara fishery regulation valid for the water body (Lake Ardibo). Also there should be proper monitoring and evaluation activity together with data re-coding and reporting to concerned bodies (catch, effort, fish species type, length, weight maturity stage, market prices and other physico-chemical data) should be collected at least monthly and reported to line offices.

Acknowledgments

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Author Contributions

A.W. brought the original idea and conducted the experiment. M.M. deigned the experiment.

Conflicts of Interest

No conflicts of interest.

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