Soda Lakes of the Rift Valley (Kenya)

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Contents

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Alkaline lakes • Hydrochemistry • Biodiversity • Kenya • Rift valley lakes • Soda lakes

Introduction

Soda lakes are alkaline with pH values ranging from 8 to 12 and characterized by high concentrations of principal ions such as Na+, HCO^-, CO_3^{2-} and Cl^-. Kenya is endowed with many soda lakes forming part of the East African Rift Valley system

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and includes lakes Bogoria, Nakuru, Elementeita, and Magadi (Fig. 1). In addition, Lake Turkana is located on the Kenya-Ethiopian border further north and is described in a separate chapter in this volume. These lakes are characterized by steep fault escarpments, deep gorges, canyons, and craters on the rift floor, some of which have gushing geysers and hot springs (Grant et al. 1990). Historically, the lakes were thought to have been one continuous system called Lake Kamatian (Gregory 1921). Reconstruction of the history of the four lakes based on dated sedimentary time-series data reveal unique hydrological, ecological, and species richness trends that have fluctuated through time between alkaline and freshwater conditions (Grant et al. 1999).

In spite of their apparent hospitality, these soda lakes are among the most productive aquatic environments on earth and support a great diversity of species, some which are endemic, rare, and endangered (Melack and Kilham 1974; Grant et al. 1999). This apparently unique phenomenon has been attributed to the virtually unlimited availability of dissolved carbon dioxide. Other ecosystem services provided by the lakes include habitats for biota including the famous populations of flamingos and rare and threatened mammals, supply of water for domestic use and irrigation, thermal energy, pasture, and recreational and cultural contributions. Currently, Kenya's soda lakes face various challenges, ranging from climate change and water extraction to direct habitat modification, all of which may have significant impacts on existing biodiversity.

Even though the lakes are generally referred to as soda lakes, each has its distinct qualities in terms of biogeochemical attributes.

Lake Bogoria

Lake Bogoria (00° 15′N 36° 05′E) lies within Lake Bogoria National Park at an altitude of 990 m above sea level. The lake has a surface area of 34 km^2 and a catchment area of 930 km^2. It is shallow with an average and maximum depth of 10 m and 14 m respectively. Sediment cores indicate freshwater conditions existed at various times during the past century, and the lake level was up to about 9 m higher than its present level (Tiercelin and Vincent 1999).

Its wetland ecosystems include Lake Bogoria and shoreline, Loburu and Loboi swamps, hot spring marshes, geysers, springs, and mouths of the Emsos River and Sandai River. Some of the services provided by these ecosystems include production of cyanobacteria such as *Arthrospira fusiformis* that is an important food for lesser flamingo (*Phoenicopterus minor*); bee honey, wild fruits, and vegetables which are important human food; salt lick and trona (soda ash) used for livestock fodder; Cyperus macrophytes used for making mats and baskets; and sand and stones used for buildings and murram (laterite) used for road making. It also supports wildlife such as the greater kudu (*Tragelaphus strepsiceros*) and birds such as the lesser flamingo (*Phoenicopterus minor*). The recreational activities include archaeological and contemporary historic sites, landscape, and tourism.

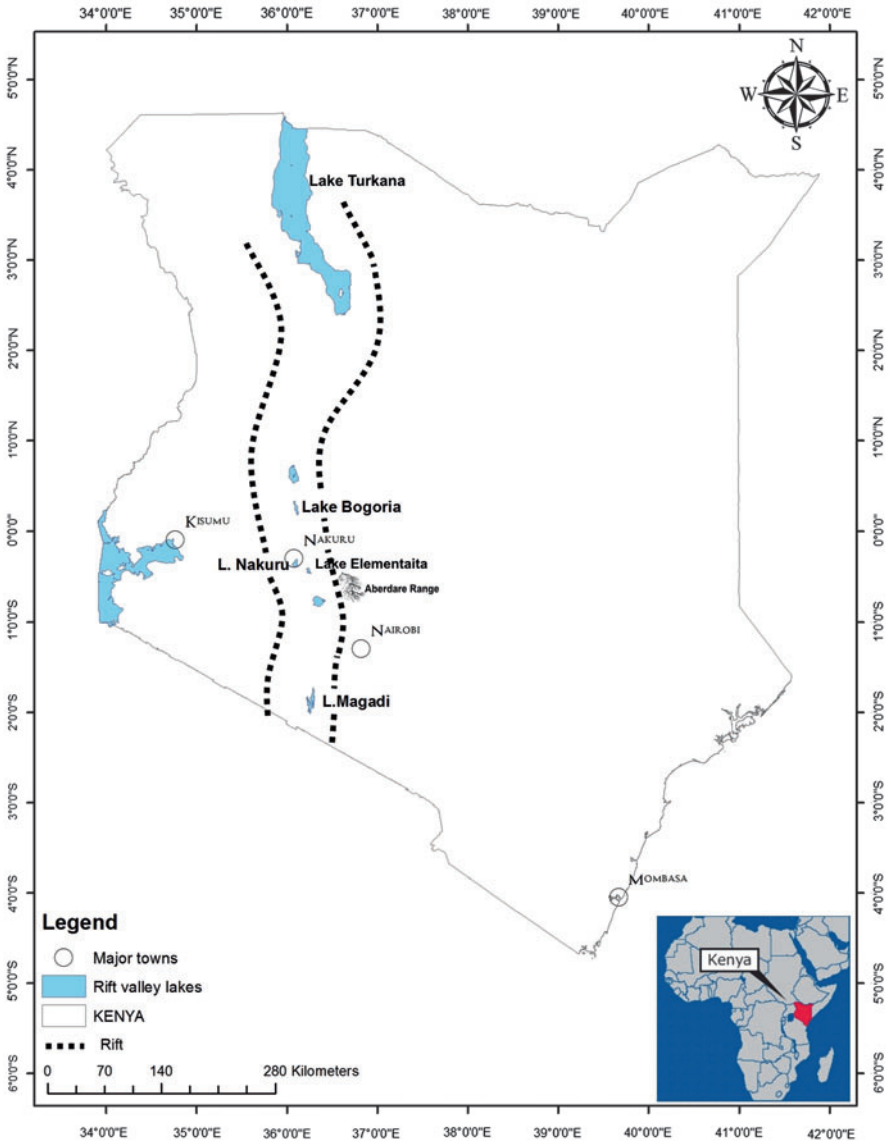

Fig. 1 Map of the Soda Lakes of the Rift Valley in Kenya (Lakes Bogoria, Nakuru, Elementeita, and Magadi). Lake Turkana (furthest north) is covered by a separate chapter in this volume

In 1970, Lake Bogoria was first declared a national reserve because of its biodiversity, scenery, and hydrologic features. The status was later changed to a National Park in 1990 and subsequently designated as a Wetland of International Importance under the Ramsar Convention in 2001. The lake region has continued to

have significant sociocultural, sacred, and economic (pastoral) meaning to the local ethnic groupings of Endorois and Illchamus people.

The hydrology of Lake Bogoria is primarily influenced by the inflows from the Sandai, Loboi, and Emsos Rivers during the wet season (April to August), discharges from the lake floor, and from approximately 200 alkaline hot springs nearby. The lake affects the local hydrological cycle with its evaporation and subsequent condensing as rainfall in the Mochongoi Hills and runoff from the lake's 930 km^2 drainage basin. During the April to August wet season, the increased flow from the catchment coupled with geysers along the banks of Lake Bogoria raise the water level which subsequently declines through December to March (Renault and Owen 2005). It also regulates hydrologic cycle, through evapotranspiration, condensation in Mochongoi Hills, and subsequent rainfall and runoff to Lake Bogoria drainage system of 930 km^2 and into the lake itself. During wet season in the months of April to August, the increased runoff flows from the catchments' area coupled with geysers in the banks of Lake Bogoria cause inundations and rise in the lake level, while during dry season in the months of December to March, the lake level falls (Renault and Owen 2005). Lake Bogoria has no known surface outlet and is located on a semiarid belt within a region, otherwise exhibiting a tropical climate and receiving approximately 50 mm of rainfall per month and a precipitation of 400–600 mm per year with high rates of evapotranspiration at 1500 mm per day. Temperatures range from 18 °C to 35 °C during wet and dry seasons, respectively.

Lake Bogoria National Park supports a range of wetland and terrestrial biodiversity. The hypersaline nature of Lake Bogoria provides an optimal environment for primary production of the populations of algae such as cyanobacteria. Cyanobacteria populations in the lake are dominated by *Arthrospira fusiformis* but also include other species such as *Anabaenopsis arnoldii*, *Anabaenopsis* spp., *Microcystis flos-aquae*, *Raphidiopsis* sp., and *Haloleptolyngbya alcalis* (Vareschi 1978; Kaggwa et al. 2013). Other phytoplankton groups in the lake include *Cryptomonads* and green algae, e.g., *Ankistrodesmus* sp., *Crucigenia* sp., and *Monoraphidium minutum.* Species of diatoms include *Nitzschia* sp. and *Navicula* sp., and euglenoids, *Euglena* spp. *Anabaenopsis arnoldii* and *Microcystis flos-aquae.*

Several higher plant species are found within the lake's vicinity. These include the following Poaceae species: *Dactyloctenium aegyptium*, *Sporobolus ioclados*, *Digitaria velutina*, and *Chloris virgata*; while shrubs include *Grewia tenax*, *G. bicolor*, and *Acacia mellifera*; and the trees *Balanites aegyptica*, *Combretum* spp., *Ficus* spp., *Terminalia* spp., and *Acacia tortilis*; cactus (*Opuntia sp.*); and *Prosopis juliflora*. The shoreline of the lake is vegetated with *Cyperus laevigatus*, *Sporobolus spicatus*, and *Cynodon dactylon.*

The zooplankton community in Lake Bogoria is dominated by the monogonont rotifer species *Brachionus plicatilis* and *Hexathra jenkinae*. Insect communities in the area include Diptera such as tsetse fly (*Glossina morsitans*) that causes nagana illness in cattle and sleeping sickness in humans, and odonata larvae adapted to cope with extreme alkaline conditions.

While over 120 bird species occur in Lake Bogoria, its status as a National Park is based on the presence of several key bird species. The lesser flamingo

(*Phoeniconaias minor*) does not breed in the lake but migrates here in large numbers to feed, specifically on *Arthrospira fusiformis* (Vareschi 1984). Between the months of October and March, at least 10,000 lesser flamingos occur on the lake and decline to less than 5000 birds during the months of April to September. Other bird species include the common ostrich (*Struthio camelus*), grey heron (*Ardea cinerea*), hamerkop (*Scopus umbretta*), little egret (*Egretta garzetta*), white-faced whistling duck (*Dendrocygna viduata*), African fish-eagle (*Haliaeetus vocifer*), tawny eagle (*Aquila rapax*), yellow-billed stork (*Mycteria ibis*), common sandpiper (*Actitis hypoleucos*), African citril (*Serinus citrinelloides*), and the Brubru bushshrike (*Nilaus afer*).

Besides birds' species, the status of Lake Bogoria as a National Park is further supported with the occurrence of more than 20 mammal species including the threatened Greater Kudu (*Tragelaphus strepsiceros*), the East African Impala (*Aepyceros melampus rendilis*), and the rare Vervet Monkey (*Cercopithecus pygerythrus*) Lake Bogoria National reserve (2007).

Lake Nakuru

The lake is situated within the Nakuru National Park at 00°20′ S 36°05′ E and at 1759 m above sea level. It has a surface area of 40 km^2 and a catchment area of 800 km^2 (Vareschi 1982; Tiercelin and Vincens 1987). The lake has gradually developed alkaline conditions over the last several decades, creating harsh conditions and consequent ecological limitations for various flora and fauna (Shivoga 2001).

Lake Nakuru wetland ecosystems include the lake shoreline and Baharini springs. The lake has a mean depth of 2 m, and surface water temperature ranges between 25° and 27 °C (Vareschi 1982). The wet season in the region fall between April and August, while the dry season occurs between October and March. The mean annual rainfall is 95.1 mm. Rivers draining Lake Nakuru include Njoro, Makalia, Lamuriak, and Enderit. Sources of water into the lake include rainfall, surface runoff, and treated wastewater from two sewage treatment plants in the nearby town of Nakuru. In 1997, the lake was almost completely dry, partly as a result of drought and large volumes of water being extracted upstream by farmers.

Lake Nakuru has been designated as a Bird Sanctuary since 1960, declared a National Park in 1968, as well as the first rhino sanctuary and the first Ramsar Site in Kenya in 1987 and 1990, respectively. It was identified as an Important Bird Area in 1999, and lastly in 2011, it was designated as a World Heritage Site by UNESCO.

The conservation status of Lake Nakuru signifies its importance as a habitat for key biodiversity including its signature species, the lesser flamingo, and over 56 species of mammals including the near-threatened white rhinoceros *Ceratotherium simum cottoni* and endangered Rothschild's giraffe *Giraffa camelopardalis rothschildi*, buffalo, lion, zebra, eland, and waterbuck.

The lake is world famous for its bird fauna, with over 450 species, dominated by the lesser flamingo. Home to over a million flamingos, flocks of lesser and greater

flamingos (*Phoenicopterus roseus*) line the shores of the lake, giving it a pinkish appearance. The total flamingo count varies year to year and season to season, but frequently stands at about two million with lesser flamingo being more than greater flamingo. A cichlid fish, *Alcolapia grahami*, introduced into the lake in 1960, is the main herbivore (Vareschi 1979). Other biota found in the lake includes dense populations of Cyanobacteria *Anabaenopsis magna* and *Arthrospira fusiformis* which dominate the phytoplankton community (Finlay et al. 1987). The surrounding vegetation is mainly wooded and bushy grassland with wide ecological diversity. It has about 550 different plant species, including the unique euphorbia (*Euphorbia candelabrum*) forest and acacia (*Acacia tortilis*) woodlands.

The lake is fringed by alkaline swamps with areas of sedge and typha marsh along the river inflows and springs. The surrounding areas support a dry transitional savanna with lake margin grasslands of *Sporobolus spicatus* salt grass moving into grasslands of *Hyparrhenia hirta* and Rhodes grass *Chloris gayana* in the lower areas. More elevated areas have dry forest with *Acacia xanthophloea*, olive *Olea hochstetteri*, and *Euphorbia candelabrum* forest. The bushland is dominated by the composites, Mulelechwa *Tarchonanthus camphoratus* and *Psiadia arabica*.

Because of its incredible biodiversity, the lake's natural resources continue to contribute considerably to the country's economy through tourism activities in the area. It supports the livelihoods of cosmopolitan (i.e., Nakuru town) and diverse multiethnic communities (predominantly Kikuyus, Maasais, and Kalenjins) through provision of water for domestic and agricultural uses, recreation, employment in the tourism sector, and other values that are hardly appreciated such as local climate modulation and aesthetics.

Lake Elementeita

Lake Elementeita was formed through tectonic and volcanic activities and lies approximately 30 km south of Lake Nakuru. The lake derives its name from the Maasai word *muteita*, meaning "dust place" in reference to the dry and dusty conditions of the area, especially between January and March. It lies at 00°27′ S 36°15′ E and an altitude of 1782 m above sea level (Melack 1988; Mwaura and Moore 1991). The lake has a surface area of 20 km^2 and a catchment area of 500 km^2. Lake Elementeita is fed by three seasonal streams, the Mbaruk to the north and Kariandusi and Memeroni to the south. Some hot springs along the southern end also supply the lake with a minimal amount of water (Mwaura and Moore 1991). Annual rainfall in the area is low and highly variable, mostly concentrated between April and July for long rains and in October and November for the short rains. The water budget is strongly influenced by precipitation, evaporation, and highly seasonal small inflows. Air temperatures are highly variable, ranging from 25 °C to 32 °C during the day, while at night temperatures fall below 15 °C. The lake is extremely shallow and shows a pan-like characteristic that makes it lose water rapidly through evaporation exacerbated by rapid heating of its sediments (Oduor and Schagerl 2007).

Similar to the other soda lakes, Lake Elementeita hosts a diversity of flora and fauna. In recognition of its importance as a critical habitat, Lake Elementeita was formally recognized as a Ramsar Site in 2005. The lake hosts Kenya's only breeding colony of Great White Pelicans *Pelecanus onocrotalus* and Great Crested Grebes *Podiceps cristata*. Gray-crested helmet-shrike *Prionops poliolophus* and Jackson's widowbird *Euplectes jacksoni* reside around the lake. At the southern end of the lake lies the "Kekopey" hot springs, which is a key breeding area for the alkali-tolerant tilapia, *Alcolapia graham*. In addition, the Soysambu Wildlife Conservancy (a nonprofit organization) covering 19,424 ha, which is located within the lake and covering two-thirds of its shoreline, is also a Ramsar Site. Soysambu is home to over 12,000 large mammals including Rothschild's giraffes, giant eland *Taurotragus derbianus*, Dik-diks *Madoqua* sp., cliff-dwelling klipspringers *Oreotragus oreotragus*, impalas, lions and buffalos, as well as over 450 bird species.

Lake Elementeita's littoral areas have patches of reeds. The lake is characterized by mass developments of filamentous cyanobacteria including *Arthrospira fusiformis* and *Anabaenopsis* spp. (Vareschi 1978, 1982; Melack 1988; Owino et al. 2001). Some of these algae and crustaceans are preferred prey for the visiting flamingos and other bird species, and as such the lake provides an important refuge for flamingos (*Phoenicopterus ruber*) and other birds and an important breeding ground for the pelican.

Lake Magadi

The lake gets its name from a Swahili word, meaning sodium bicarbonate, and is the southernmost in the soda lake series in Southern Kenya. It lies at 1°52′ S 36° 16′ E and 579 m above sea level and has a surface area of 104 km^2. Several thousand years ago, during the late Pleistocene to mid-Holocene, the lake had freshwater with many fish species, whose remains are preserved in the High Magadi Beds, a series of lacustrine and volcaniclastic sediments preserved in various locations around the present shoreline (Fig. 2).

Lake Magadi is mainly fed by hot springs around its edges, with relatively minor additions from the monsoonal rains. The main part of Lake Magadi is only covered by water for a short period of the year. A relatively thin layer of water accumulates during wet seasons, which then evaporates exposing a vast pan of trona (sodium sesquicarbonate) during the dry seasons. The lake is 80 % covered by trona (Jones et al. 1977). Seasonal runoff, mainly from the valley floor north of the lake, is considered the major groundwater recharge (Jones et al. 1977).

Lake Magadi is a popular destination for wading birds during the dry season including flamingos, heron, pelicans, and spoonbills. The lake is one of the few places in Kenya where the chestnut-banded plover *Charadrius pallidus* can be seen regularly; and the endemic tilapiine *Alcolapia grahami* is reported by Seegers and Tichy (1999) to be the only fish species in the lake.

Other biota inhabiting the lake includes many species of the microbial alkaliphile community: *Habmonas campisalis*, *Haloalkaliphilic archaea*, *Tindallia magadii*,

Fig. 2 Lake Magadi – Courtesy Jacob E. Ojuok (KMFRI)

Natronococcus amylolyticus, *Methylohalomonas lacus*, *Methylonatrum kenyese*, *Amphibacillus fermentum*, *Amphibacillus tropicus*, Desulfonatronovibrio hydrogenovorans, *Halonatronum saccharophilum*, *Natronoincola histidinovorans*, *Natrionella acetigena*, *Spirochaeta alkalica*, *Spirochaeta africana*, and *Spirochaeta asiatica*.

Lake Magadi is not a protected ecosystem in Kenya (Nyamasyo and Owuor 2009). The ecosystem services in Lake Magadi include recreation (it is a tourism attraction). The lake's trona is used for glass manufacturing, fabric dyeing, and paper production. Chert is a sodium silicate sedimentary mineral rock that was discovered at Lake Magadi during the 1960s (Behr 2002). Magadi Chert with high fluoride deposits is drawn from the lake and used as a meat tenderizer by the local community, thereby ingesting high levels of fluorine, which is harmful to the bones and other body tissues. Alkaliphilic bacteria obtained from the lake are used in manufacturing of alkali-tolerant enzymes (Jones et al. 1988). The local community comprises mainly of the indigenous Maasai living within the rural hinterlands and the nearly 1000 residents from diverse ethnic backgrounds living in the town of Magadi.

Threats and Future Challenges Facing the Kenyan Soda lakes

The soda lakes of the Rift Valley are facing myriad threats and challenges, including an increase in human population and poor land use practices, land tenure conflicts, catchment degradation, pollution, conflicts over water rights and uses, cultural

erosion due to influences from tourism activities, human-wildlife conflicts, and the impacts of invasive species and climate change.

The human population density is currently 20 people per square kilometer, but the growth rate of 3.5 % per annum has resulted in higher demand for settlement and agricultural land. Subdivision of land has encouraged encroachment and general reclamation of wetlands in the riparian areas surrounding the soda lakes. The latter is more apparent in semiarid areas (especially in Lake Bogoria) where agricultural activities and pastoralism are practiced in the fragile habitats.

A cultural system that glorifies high livestock numbers rather than their quality has led to an increase in the livestock, and this has led to uncontrolled grazing around lakes Bogoria and Elementeita. In addition, poor land management practices among these communities has impacted negatively on land cover. Extraction of forest resources for medicinal purpose, fuel wood, charcoal burning, and timber has led to catchment degradation and forest loss. The foregoing anthropogenic activities have led to soil erosion and consequently sedimentation in the lakes. This is more evident in the major water towers such as the Aberdare Range and Mau Escarpment, which are important in recharging aquifers and the maintenance of wetlands. It has been predicted that with continuous increase in human population and settlement within the lakes' subdrainage, the demand for water will outstrip supplies with barely minimal amounts left to support wildlife populations. Land tenure and land use systems around the soda lakes have also changed over the years, from nomadic pastoralism (surrounding lakes Bogoria, Elementeita, Magadi) to communal sedentary grazing and currently individual holdings. This has accelerated catchment degradation resulting in the drying up of rivers, encroachment of riparian areas, and subdivision of land leading to unsustainable livelihood prospects.

In addition, the general disruption of hydrological regimes, impacts on water quality and quantity due to cultivation along streams and riverbanks, and clearing of forests in the upper parts of the catchment and diversion of water to support settlement, agriculture, and industrial activities have caused serious conflicts in water rights and use.

On the other hand, the increasing use of chemicals such as fertilizers, herbicides, and pesticides in agricultural practices around the lakes has led to the accumulation of these chemicals in the lakes, thus compromising the aquatic life and the well-being of those whose lives depend on the waters of the soda lakes. Increased use of fertilizers in the catchment areas has also led to eutrophication of the soda lakes, hence the high primary production in these lakes. Besides the foregoing, tourism activities also contribute to the pollution of these lakes, as most of the hotels mushrooming along the shores of Lakes Nakuru and Bogoria empty their wastes into the lakes. Other sources of pollution in the lakes include effluents from municipal (e.g., Nakuru) and industrial sources (Magadi).

In spite of economic gains from tourism, the industry has continued to impact negatively on the general lifestyle of riparian communities. Tourism encourages practices which are inconsistent with traditional norms and contribute to cultural erosion. These may include influences on dress codes among other social practices.

Lakes Bogoria, Nakuru, and Elementeita are national protected reserves. However, there are numerous occasions when wild animals stray out of the park boundaries. This has resulted in the destruction of properties, and in some cases, human lives have been lost. These human-wildlife conflicts have resulted in standoffs between the wildlife managers and local communities. Conflict arises when animals from the national parks invade communities' farms, and the authorities concerned hardly compensate them adequately for their losses. The communities seek revenge by killing the animals, which results in retaliation by park managers by arresting the persons responsible for killing the animals.

There are two invasive plant species found within the proximity of the soda lakes. These include prickly pear cactus (*Opuntia* sp.) from the family Cactaceae and Mesquite *Prosopis juliflora* locally known as "Mathenge." The impact of these on the local environment and biodiversity is not yet apparent, but they certainly have some competitive ecological advantages over the local biota.

The soda lakes of Kenya have limited capacity to mitigate the impacts of global warming and climate change. Lake salinity levels have fluctuated over the years but clearly exhibit an increasing trend. Together with other climate change factors including the increased variability of local temperature, rainfall and wind patterns could negatively impact on the lakes' biogeochemistry with adverse effects on the biodiversity. For instance, recent reports indicate a shift in preferences and reduction of flamingo populations in some of the soda lakes as a result of environmental vicissitudes. Changes in climatic conditions may also result in trophic interruption.

Cross-References

- ▶ Lake Turkana, the World Largest Permanent Lake
- ▶ Lakes Baringo and Naivasha, Endorheic Freshwater Lakes of the Rift Valley, Kenya

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