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Primary Productivity in Man-Made Lakes of Northwestern Nigeria: A Review of Recent Evidence, Environmental Drivers and Research Gaps

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Abstract

Primary productivity is a fundamental ecological process through which aquatic autotrophs convert inorganic carbon into organic matter and introduce energy into freshwater food webs. Northwestern Nigeria contains numerous man-made lakes and reservoirs that support domestic water supply, irrigation, livestock production and fisheries. However, information on primary productivity in these systems remains fragmented, and many investigations have focused on phytoplankton composition and physicochemical characteristics rather than direct measurements of productivity. This review synthesizes evidence published principally between 2016 and 2026 on primary productivity and related environmental conditions in man-made lakes and reservoirs of Northwestern Nigeria, with comparative evidence from other Nigerian and international freshwater systems. Particular attention was given to gross primary productivity (GPP), net primary productivity (NPP), phytoplankton composition and abundance, nutrients, light availability, turbidity, temperature, dissolved oxygen, seasonality, spatial variation and anthropogenic influences. Direct evidence from Nasarawa Reservoir demonstrates seasonal and spatial variation in GPP and NPP, while studies of Ajiwa, Kalgwai, Kazaure, Zobe and CAAS reservoirs demonstrate substantial variation in phytoplankton communities and environmental conditions. Comparative studies from southern Nigeria further show the importance of depth, reservoir zonation, nutrient availability and light penetration in determining productivity. The review identifies a major research gap: direct measurements of primary productivity remain relatively scarce in Northwestern Nigerian reservoirs. Future investigations should integrate GPP, NPP, respiration, chlorophyll-a, phytoplankton biomass, nutrients, underwater light and hydrological characteristics across seasons, depths and reservoir zones. Such integrated studies will improve understanding of reservoir ecosystem functioning and provide a stronger scientific basis for fisheries and water-resource management.

Introduction

Freshwater lakes and reservoirs are important components of the Nigerian environment because they provide water for domestic use, irrigation, livestock production, fisheries and other socioeconomic activities. Unlike natural lakes, man-made lakes are generally created by impounding rivers or streams, thereby altering water residence time, flow velocity, sediment deposition, nutrient retention and biological communities (Vari et al., 2022; Liu et al., 2021)

Primary productivity is central to the functioning of these systems because it represents the production of organic matter by autotrophic organisms, principally phytoplankton in open-water habitats. Through photosynthesis, phytoplankton convert solar energy into chemical energy that becomes available to zooplankton, benthic organisms and fish. Consequently, variation in primary productivity can have implications for aquatic food-web structure and fisheries potential (Naselli-Flores & Padisak, 2022; Deng et al., 2025).

In reservoir ecosystems, however, productivity is not determined by a single environmental factor. Light availability, nutrients, temperature, water-column stability, turbidity, hydrological conditions and grazing pressure may interact to regulate phytoplankton growth. Hydrodynamics can also alter plankton distribution along a reservoir, demonstrating that reservoirs should not necessarily be regarded as homogeneous water bodies (Liu et al., 2021).

Northwestern Nigeria presents an especially interesting setting for studying these relationships. The region experiences pronounced wet and dry seasons, and reservoirs may receive substantial quantities of sediment and nutrients during periods of runoff. Conversely, the dry season may be associated with reduced inflow, increased water residence time and changes in water transparency and nutrient availability. (Yusuf, 2020; Ghali et al., 2020).

Despite the importance of these systems, direct information on primary productivity in Northwestern Nigerian reservoirs remains limited. One of the most important direct studies is that of Yusuf et al. (2019), who investigated primary production in Nasarawa Reservoir, Katsina State, using the light-and-dark bottle dissolved-oxygen method.

Primary Productivity in Freshwater Ecosystems

Primary productivity can broadly be divided into gross primary productivity (GPP) and net primary productivity (NPP).

GPP is the total amount of organic matter produced through photosynthesis. NPP represents the portion remaining after respiratory losses by the primary producers:

NPP = GPP − autotrophic respiration

Community respiration may include respiration by organisms within the community and therefore provides additional information about the balance between production and respiratory consumption. The distinction is important because phytoplankton abundance alone does not indicate how rapidly organic matter is being produced. A water body may contain many phytoplankton cells but experience relatively low productivity if light, nutrients or other environmental factors restrict photosynthetic activity. Yusuf et al. (2019) provide direct evidence of this distinction in Northwestern Nigeria. Their Nasarawa Reservoir study measured GPP, NPP and community respiration at five sites and at different depths. They reported seasonal variation in several environmental variables and NPP and concluded that high suspended solids during the wet season could reduce light penetration and photosynthetic activity.

Phytoplankton and Primary Production

Phytoplankton constitute an important component of freshwater primary producers. Major groups commonly encountered in Nigerian reservoirs include Chlorophyceae, Bacillariophyceae, Cyanophyceae, Euglenophyceae, Dinophyceae and related groups. Their composition can provide useful information about environmental conditions. However, phytoplankton abundance or diversity should not be equated directly with primary productivity. Productivity is a rate process, whereas abundance represents the quantity of organisms present at a particular time. This distinction is particularly relevant to Northwestern Nigeria because several recent studies have documented phytoplankton communities without directly measuring GPP or

NPP. For example, Ibrahim and Thliza (2023) found Chlorophyta to be the dominant phytoplankton group in Ajiwa Reservoir, followed by Bacillariophyta and Cyanophyta. Sani and Ibrahim (2024) similarly recorded substantial seasonal changes in phytoplankton composition and abundance in Ajiwa Reservoir. These studies are valuable indicators of the primary-producer community but do not, by themselves, quantify the rate of carbon fixation.

Materials and Methods

A narrative review design was adopted to synthesise recent evidence concerning primary productivity, phytoplankton communities and environmental factors affecting productivity in man-made lakes and reservoirs. The evidence was divided into three categories:

(1) Direct productivity studies — studies measuring GPP, NPP or respiration.

(2) Biological indicator studies — studies examining phytoplankton abundance, diversity, biomass or chlorophyll-a.

(3) Environmental studies — studies investigating physicochemical and hydrological factors affecting primary producers.

This classification was used to prevent phytoplankton abundance from being incorrectly treated as a direct measurement of productivity.

Literature Period

The principal literature period was January 2016 to August 2026.

Older literature was considered only when necessary to provide methodological or historical context.

Geographical Scope

The principal geographical focus was Northwestern Nigeria, particularly: Katsina State; Jigawa State; Kaduna State; Kano State; Sokoto State; and Zamfara State. Relevant studies from other Nigerian regions were included for comparison, particularly where they contained direct measurements of primary productivity.

Sources of Information

The literature search used several scholarly information sources and databases, including, Google Scholar; Web of Science; Scopus; ;ScienceDirect; Directory of Open Access Journals (DOAJ); Institutional repositories; Reference lists of relevant publications.

Google Scholar was used for broad scholarly discovery, while Web of Science and Scopus were considered for peer-reviewed literature and citation tracking. ScienceDirect and DOAJ were used to identify additional scientific and open-access literature. Institutional repositories were consulted where relevant academic publications or manuscripts were available.

Using several sources was intended to reduce the likelihood of missing relevant studies. The search was done using the combinations of terms such as "primary productivity" AND reservoir AND Nigeria; "primary production" AND lake AND Nigeria;; phytoplankton AND reservoir AND Northwestern Nigeria; phytoplankton AND Ajiwa Reservoir; primary productivity AND Nasarawa Reservoir; phytoplankton AND Kalgwai Dam; primary productivity AND Owalla Reservoir; primary productivity AND Dandaru Lake; phytoplankton AND Jebba Lake; phytoplankton AND Nigerian reservoirs; chlorophyll-a AND reservoir AND Nigeria; and nutrients AND phytoplankton AND Nigeria.Reference lists of relevant articles were also examined to identify additional studies.

Inclusion Criteria

Studies were included if they:

(1) Investigated freshwater lakes, dams or reservoirs;

(2) Focused on Northwestern Nigeria or provided useful Nigerian comparative evidence;

(3) Were principally published between 2016 and 2026;

(4) Addressed primary productivity, phytoplankton or environmental factors influencing productivity; and

(5) Contained sufficient information for interpretation.

Exclusion Criteria

Studies were excluded if they:

(1) Dealt exclusively with marine systems;

(2) Were unrelated to aquatic productivity;

(3) Did not contain adequate information concerning the study system; or

duplicated another source.

Data Extraction

The following information was extracted where available:

author and year; study location; reservoir/lake; sampling period; sampling frequency; productivity measurements; phytoplankton composition; phytoplankton abundance; nutrients; temperature; turbidity; dissolved oxygen; seasonal patterns; spatial patterns; depth-related patterns; and anthropogenic influences.

Data Synthesis

The evidence was synthesised according to:

Direct primary productivity; phytoplankton abundance and diversity; seasonal variation; spatial and vertical variation; nutrients; light and turbidity; temperature; dissolved oxygen; anthropogenic activities; fisheries implications; and research gaps.

Evidence from Nasarawa Reservoir

Nasarawa Reservoir in Katsina State provides the strongest directly relevant evidence currently available for primary productivity in Northwestern Nigeria. Yusuf et al. (2019) sampled five sites near the dam wall from February to November 2018 and collected samples at one-metre depth intervals. GPP, NPP and community respiration were determined using the light-and-dark bottle dissolved-oxygen method. The authors reported seasonal variation in pH, temperature, conductivity, transparency, dissolved oxygen, nitrate, phosphate and NPP. GPP and NPP were highest at site C, whereas community respiration was highest at site E. An important interpretation from this study is that wet-season runoff may have contradictory effects. Runoff can introduce nutrients that potentially stimulate phytoplankton growth, but it can also increase suspended solids and turbidity. When sediment reduces light penetration, the stimulatory effect of nutrients may be offset by light limitation. Thus, the relationship can be represented conceptually as:

Rainfall → runoff → nutrients ↑ + suspended solids ↑ → potential stimulation of growth but reduced light → variable productivity

This interaction deserves greater attention in Northwestern Nigerian reservoirs. Yusuf (2020) subsequently investigated phytoplankton as indicators of water quality in Nasarawa Reservoir, further demonstrating the value of combining biological and physicochemical information when evaluating reservoir condition.

Results and Discussion

Evidence fromAjiwa Reservoir

Ajiwa Reservoir in Katsina State has received considerably more recent attention than many other reservoirs in the region. Usman et al. (2017) examined the effects of physicochemical parameters on phytoplankton composition and abundance in Ajiwa Reservoir. The study, conducted from September 2014 to August 2015, recorded 40 phytoplankton species belonging to five major classes, with Chlorophyceae being dominant. Suleiman et al. (2021) subsequently investigated environmental parameters and plankton assemblages in the reservoir. Their results demonstrated relationships between physicochemical conditions and plankton communities, providing further evidence that environmental variability influences biological communities in Ajiwa Reservoir.

Ibrahim and Thliza (2023) examined Ajiwa Reservoir over a 12-month period and reported Chlorophyta as comprising 57.66% of the phytoplankton composition, followed by Bacillariophyta (25.70%), Cyanophyta (14.73%) and Dinophyta (1.91%). More recently, Sani and Ibrahim (2024) sampled Ajiwa Reservoir from December 2022 to September 2023. They reported significant seasonal differences in temperature, pH, dissolved oxygen, electrical conductivity, turbidity, nitrate and phosphate. Chlorophyceae accounted for the largest proportion of phytoplankton individuals in their study. When considered together, these studies demonstrate that Ajiwa Reservoir has a dynamic phytoplankton community responding to changing environmental conditions. However, they also illustrate the distinction between phytoplankton studies and direct productivity studies. Direct measurements of GPP and NPP would be required to establish the actual rate of primary production.

Evidence from Kalgwai Dam

Kalgwai Dam provides another important example from Northwestern Nigeria. Ghali et al. (2020) investigated phytoplankton community structure and physicochemical conditions at Kalgwai Dam in northwestern Nigeria. Sampling was conducted monthly at three stations for six months. The study documented substantial phytoplankton diversity and found spatial variation in environmental variables including dissolved oxygen, phosphate, pH and turbidity. Bacillariophyta was an important component of the community, and the authors related changes in phytoplankton structure to environmental conditions and anthropogenic pressures. The study is significant for the present review because it shows that reservoir condition can vary substantially among sites within the same water body. Therefore, a single sampling point may not adequately represent the productivity or ecological condition of an entire reservoir.

Kazaure, Zobe and CAAS Reservoirs: Recent Evidence

An especially important development is the publication by Maaruf et al. (2026), which examined phytoplankton diversity in Zobe Reservoir in Katsina State, Kazaure Reservoir in Jigawa State and CAAS Reservoir in Kaduna State. The investigation covered June 2023 to April 2024 and therefore provides some of the most recent evidence available for reservoirs in Northern Nigeria.

During the dry season, 484 phytoplankton individuals were recorded at Zobe, 300 at Kazaure and 252 at CAAS. Bacillariophyceae was particularly prominent at Zobe and Kazaure, whereas Chlorophyceae was prominent at CAAS. During the rainy season, Bacillariophyceae remained prominent in all three reservoirs. Maaruf et al. (2026) concluded that phytoplankton were more abundant during the dry season than the rainy season. This finding is particularly interesting when compared with other Nigerian reservoirs where wet-season abundance has sometimes been greater. The apparent differences among reservoirs demonstrate that seasonal effects are context-dependent. They may depend on local rainfall, runoff, turbidity, water level, nutrient inputs, reservoir morphology and residence time. Importantly, the Maaruf et al. (2026) study measured phytoplankton diversity rather than GPP or NPP. Therefore, it should be interpreted as recent evidence about the primary-producer community, not as a direct measurement of primary productivity.

Kazaure Reservoir as a Case of Biological Indication

Hussain (2024) examined phytoplankton as bioindicators of water quality in Kazaure Reservoir, Jigawa State. Thirty phytoplankton species representing four major groups were recorded, with Chlorophyta, Bacillariophyta, Cyanophyta and Euglenophyta forming the major groups. The study also identified pollution-tolerant genera and interpreted the reservoir as experiencing substantial organic enrichment. The study is useful because it demonstrates how phytoplankton composition can indicate environmental stress. Nevertheless, the presence of pollution-tolerant species should not automatically be interpreted as evidence of high primary productivity. A reservoir can be nutrient-rich and environmentally degraded while experiencing variable or even low productivity if other factors, particularly light, temperature or hydrological disturbance, restrict photosynthesis.

Comparative Evidence from Other Nigerian Reservoirs

Owalla Reservoir

Comparative evidence from southwestern Nigeria is useful because direct productivity studies are scarce in Northwestern Nigeria. Omoboye and Adeniyi (2017) investigated primary productivity in Owalla Reservoir, Osun State, during rainy and dry seasons. Seven sampling stations were used, with measurements taken at different depths at several stations. Primary productivity was determined using the oxygen method. GPP ranged from 17.28 to 126.72 Kcal m^{-3} day^{-1}. The study demonstrates the importance of vertical sampling. Productivity is unlikely to remain constant with depth because light decreases as water depth increases. This has direct implications for Northwestern Nigeria: future productivity studies should avoid relying exclusively on surface-water measurements.

Dandaru Lake

Ayoade and Izah (2019) investigated Dandaru Lake in southwestern Nigeria using monthly sampling at five stations for six months. The study directly measured GPP, NPP and community respiration alongside physicochemical parameters and phytoplankton assemblages. The reported mean GPP was 1.23 ± 1.68 g C m^{-2} day^{-1}, while NPP was 0.78 ± 1.48 g C m^{-2} day^{-1} and community respiration was 0.45 ± 0.72 g C m^{-2} day^{-1}. The study also found low phosphate and nitrate concentrations and a phytoplankton community dominated by Euglenophyceae and Bacillariophyceae. Dandaru Lake illustrates the value of measuring productivity, water chemistry and phytoplankton simultaneously. Such an integrated approach would be particularly useful in Northwestern Nigeria.

Eko-Nde Reservoir

Akinyemi et al. (2022) investigated physicochemical parameters and phytoplankton community structure in Eko-Nde Reservoir, Osun State. Their study examined relationships between environmental variables and phytoplankton composition. Although the study did not directly measure GPP or NPP, it provides comparative evidence that phytoplankton community structure can respond to physicochemical changes within Nigerian reservoirs.

Opa Reservoir Wetlands

Adebayo et al. (2021) investigated planktonic flora and fauna in the wetlands associated with Opa Reservoir, southwestern Nigeria. They recorded 68 phytoplankton species and 36 zooplankton species. Bacillariophyta had the highest occurrence among the phytoplankton. The authors also reported evidence of anthropogenic influence on the wetland ecosystem. The study demonstrates that wetlands associated with reservoirs can contain substantial primary-producer diversity and should not necessarily be ignored when assessing reservoir productivity.

Asejire Reservoir

Asibor and Adeniyi (2022) examined the phytoplankton flora of Asejire Reservoir in southwestern Nigeria. They identified 154 phytoplankton taxa and reported spatial differences in phytoplankton distribution, with the riverine zone contributing substantially to total phytoplankton abundance. The importance of the riverine zone supports the idea that reservoir productivity can vary according to longitudinal position. Nutrient-rich inflow areas may differ markedly from the clearer, more lacustrine portion near the dam.

Agba Reservoir and the Importance of Siltation

Mustapha and Abodunrin (2021) examined the effects of siltation on Agba Reservoir, Ilorin. They found reduced depth, low transparency and high turbidity, particularly during the rainy season. Although Agba Reservoir is outside Northwestern Nigeria, its findings are highly relevant to the region because sedimentation is also an important issue in reservoirs receiving catchment runoff. Siltation can influence primary productivity in two opposing ways. Nutrient-rich sediments may contribute nutrients to the water column, but suspended particles can reduce light penetration and therefore limit photosynthesis. The Nasarawa Reservoir findings provide a Northwestern Nigerian example of this same general ecological mechanism.

Environmental Drivers of Primary Productivity

Light Availability and Turbidity

Light is fundamental to photosynthesis. In reservoirs, light availability is influenced by depth, water colour, suspended sediment, algal biomass and dissolved organic matter. The Nasarawa Reservoir study provides direct evidence that high suspended solids during the wet season may reduce productivity by restricting light penetration (Yusuf et al., 2019). The same principle is supported by evidence from Agba Reservoir, where turbidity increased during the rainy season in association with siltation (Mustapha & Abodunrin, 2021).Therefore, future Northwestern Nigerian productivity studies should measure not only turbidity but also: Secchi depth; photosynthetically active radiation; light attenuation; and depth of the euphotic zone.

Nutrient Availability

Nitrogen and phosphorus are major nutrients supporting phytoplankton growth. Ajiwa Reservoir demonstrates substantial seasonal variation in nitrate and phosphate (Sani & Ibrahim, 2024). However, high nutrient concentration should not automatically be interpreted as high primary productivity. Nutrients can accumulate in water while another factor, such as insufficient light, restricts phytoplankton growth. Cai et al. (2019), working in a subtropical reservoir, demonstrated the importance of phytoplankton in reservoir nitrogen cycling, illustrating that phytoplankton are active participants in nutrient transformation rather than simply passive indicators of water quality.

Temperature

Temperature affects photosynthetic enzymes, metabolic activity, respiration and phytoplankton growth. Seasonal temperature changes are therefore likely to contribute to productivity differences between rainy and dry periods. The Ajiwa studies provide evidence of seasonal temperature variation alongside changes in phytoplankton communities (Ibrahim & Thliza, 2023; Sani & Ibrahim, 2024). Nevertheless, temperature should be interpreted together with nutrients and light rather than treated as an isolated control.

Hydrodynamics and Water Residence Time

Reservoir hydrodynamics influence nutrient distribution, sedimentation, mixing and plankton retention. Liu et al. (2021) demonstrated that hydrodynamics can regulate longitudinal plankton community structure in cascade reservoirs. This is particularly relevant to Northwestern Nigerian reservoirs because differences between inflow, transitional and dam zones may influence productivity. The recent Zobe, Kazaure and CAAS study further demonstrates that phytoplankton composition differs among reservoirs situated in different ecological settings (Maaruf et al., 2026).

Seasonal Variation

Seasonality is one of the most frequently observed patterns in Nigerian freshwater ecosystems.

However, the direction of seasonal change is not uniform. Nasarawa Reservoir showed relatively lower wet-season productivity, which the authors associated partly with suspended solids and reduced light penetration (Yusuf et al., 2019). Conversely, recent phytoplankton studies in Ajiwa and the Zobe–Kazaure–CAAS reservoirs have demonstrated different seasonal patterns in phytoplankton abundance and composition (Sani & Ibrahim, 2024; Maaruf et al., 2026). This apparent inconsistency is not necessarily contradictory. It emphasizes that seasonality acts through several interacting mechanisms rather than functioning as a single ecological variable.

Anthropogenic Influences

Reservoirs in Northwestern Nigeria are frequently surrounded by agricultural land, settlements and livestock activities. These activities can introduce nutrients, organic matter and sediment into water bodies. Ghali et al. (2020) identified anthropogenic pressures around Kalgwai Dam and linked environmental deterioration to human activities. Ibrahim and Thliza (2023) similarly noted that agricultural runoff and human activities around Ajiwa Reservoir may influence future water quality. The ecological consequences of nutrient enrichment are not necessarily straightforward. Moderate nutrient enrichment may stimulate primary production, while excessive enrichment can promote eutrophication, alter phytoplankton composition and contribute to oxygen depletion. Consequently, management should focus not simply on increasing productivity but on maintaining balanced and sustainable productivity.

Primary Productivity and Fisheries

Primary productivity is fundamental to aquatic food webs because phytoplankton form the first major biological pathway through which solar energy enters the system. A simplified pathway is:

Sunlight → phytoplankton → zooplankton → fish

Therefore, changes in primary productivity may influence food availability for higher trophic levels. However, greater productivity does not automatically mean better fisheries. Excessive nutrient enrichment can produce undesirable algal conditions and deterioration of water quality.

Consequently, the objective of reservoir management should be to understand the relationship among: primary productivity → plankton biomass → fish-food availability → fish production

This relationship remains insufficiently investigated in Northwestern Nigeria.

Research Gaps and Future Directions

The literature reviewed reveals several important gaps.

Scarcity of direct productivity measurements: The most important gap is the limited number of studies directly measuring GPP, NPP and respiration in Northwestern Nigerian reservoirs.

Nasarawa Reservoir provides valuable evidence, but comparable measurements are needed in Ajiwa, Kalgwai, Zobe, Kazaure, CAAS and other major reservoirs.

Limited long-term monitoring: Many studies cover one year or less. Long-term monitoring would make it possible to determine whether observed seasonal patterns are consistent between years.

Inadequate vertical measurements: Productivity should be measured at multiple depths because light availability decreases with depth.

Insufficient spatial coverage: Future studies should distinguish: riverine/inflow zone; transition zone; and lacustrine/dam zone.

Limited integration of productivity and phytoplankton biomass: Future research should combine: GPP; NPP; respiration; chlorophyll-a; phytoplankton abundance;phytoplankton biomass; nutrient concentrations; and light availability.

Limited connection with fisheries: Studies should investigate whether changes in primary production correspond to changes in zooplankton abundance, fish-food organisms and fish production.

Need for standardized methodology: Use of consistent productivity methods and reporting units would make comparisons among Northwestern Nigerian reservoirs much easier.

Recommended Framework for Future Studies

This review observed that most studies reviewed reported fragmented results and left out the measurement of some important drivers of primary productivity. Therefore the following is recommended.

Future research should adopt an integrated approach comprising of measurements such as Primary productivity including GPP, NPP and respiration while, the taxonomy, abundance, biomass, biovolume of Phytoplankton should be studied more elaborately. Similarly, pigments like Chlorophyll-a should be looked into. In the same vein, other factors such as nutrients content like nitrate, nitrite, ammonium, phosphate; Light attenuation; and human activities are also important measurements that should studied simultaneously.

Sampling should be undertaken during both rainy and dry seasons beyond one year and across multiple depths and reservoir zones.

Conclusion

The available evidence demonstrates that man-made lakes and reservoirs of Northwestern Nigeria support diverse and environmentally responsive phytoplankton communities.

However, the evidence also reveals an important distinction between phytoplankton community studies and direct measurements of primary productivity. The strongest direct evidence from Northwestern Nigeria comes from Nasarawa Reservoir, where the measurement of GPP, NPP and community respiration demonstrated seasonal and spatial variation in productivity.

The central conclusion of this review is therefore that primary productivity in man-made lakes of Northwestern Nigeria remains inadequately quantified. Existing phytoplankton and water-quality studies provide valuable indirect evidence concerning the ecological processes controlling productivity, but direct GPP and NPP measurements remain comparatively scarce.

Conflict of Interest

The Author declares no conflict of interest.

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