The Status and Seasonality in the Physico-chemical Hydrology of a Nigerian Rainforest Pond

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Abstract

Monthly and Seasonal regimes in the physico-chemical status of Mfangmfang pond, Uyo, Nigeria, were studied. Meteorological conditions depicted a short dry (November–February) and a prolonged wet (March–October) season. From the trends in hydrological variables, it was inferred that the integrated impact of precipitation, changes in pond level, input of surface runoff and municipal effluents played an overriding role in determining the absolute levels and temporal patterns in the water quality attributes. The physico-chemical parameters were assigned to three categories according to the types of seasonal and anthropogenic influences:

(1) Dry-season maximum (transparency, dissolved oxygen, free CO₂, nitrate-nitrogen), resulting from low precipitation with concomitant reductions in input of surface runoff/municipal effluents and pond level.

(2) Wet-season maximum (suspended solids, conductivity, phosphate-phosphorus), resulting from increased precipitation with concomitant increases in the input of surface runoff/municipal effluents and pond level.

(3) No substantial seasonality (surface temperature, pH, total alkalinity) due to absence of significant influences of the wet-dry season cycle and surface runoff/municipal effluents.

Key words: tropical pond, seasonality, physico-chemical parameters, water quality

1. Introduction

Small freshwater ponds are common features of Nigerian inland waters. They support subsistence and artisanal fisheries, provide water for domestic purposes and are important spawning and nursery grounds for many fishes. Although a great deal has been documented on the water quality of Nigerian inland waters (HOLDEN and GREEN, 1960; EGBORGE, 1971, 1979; ADEBISI, 1981; KHAN *et al.*, 1983; CHIDOBEM and EJIKE, 1985; OLUSANYA 1988), there is still a lacuna of information on the physico-chemical status of small ponds in the country. Studies on the water quality of ponds are important in evaluating the suitability of the water for aquatic biota, domestic, industrial and agricultural uses. This knowledge is important in the integrated development of good water quality/

fisheries management and conservation strategies.

This paper provides information on the status, monthly and seasonal regimes in some physico-chemical attributes of a rainforest pond (Mfangmfang pond) in Uyo, Akwa Ibom State, Nigeria, during the period, November 1986–October 1987 inclusive. It also examines the role of the dry-wet season cycle and anthropogenic influence (city runoff) on the seasonality regimes of the water quality parameters. The results are collated with those of other tropical lentic and fluvial systems.

2. Study area

Mfangmfang pond (Fig. 1) was formed in 1980 by partially impounding the headwater of Iba-Oku stream by a weir during a gully erosion/landslide control exercise. It is located at

Fig. 1. Map of Iba-Oku stream basin, showing the location of Mfangmfang pond. Inset: (a) Map of Nigeria showing the location of Uyo; (b) Mfangmfang pond, showing the water quality station.

an altitude of less than 15 m above MSL and has an area of c. 29 ha; maximum length and width are c. 1500 and 575 m, respectively; mean depth is 3.9 m. The pond consists of a small northern basin and a larger southern basin. The bottom is predominantly (79.2%) fine

sand/mud while gravel and coarse sand form 20.7% and decaying macrophyte debris, 0.1% of the substratum (IKOTIDEM, 1987). About 90% of the water surface of the southern basin is covered with floating leaves of *Nymphaea* while the northern basin is relatively more open.

The littoral macrophytes comprise *Nymphaea*, *Utricularia*, *Azolla*, *Echinochloa* and *Cyrtosperma*. The fringing swamps have semi-aquatic ferns and *Cyrtosperma* as dominant macrophytes; others include *Raphia vinifera*, *R. hookeri*, *Elaeis guineensis*, *Pandanus candelabrum* and *Musanga* sp.

The riparian zone is dominated by *Hevea brasiliensis*, *Oxytenanthera abyssinica*, *E. guineensis* and grasses. The soil of the catchment area is predominantly laterite. The pond is fed principally by ground seepage from aquifers and secondarily by precipitation, surface runoff and municipal effluents from Uyo metropolis. The unregulated outflow is through a ring culvert into Iba-Oku stream which subsequently discharges into Ikpa River at c. 7 km from the pond. The entire pond-stream system drains a catchment area of c. 12.7 km² and constitutes the main drainage system in Uyo metropolis (5.01° N, 7.56° E).

3. Materials and methods

Monthly meteorological records were obtained from the University of Cross River State (Uyo, Nigeria) weather station (No. 0507. 05B) sited within Mfangmfang pond basin at an altitude of 65 m above MSL. A dry month was defined as one with an aridity index of less than 30 and a wet month as one with an aridity index equal to or greater than 30. Aridity index was calculated according to the formula (EWER and HALL, 1978):

$$\text{Aridity index} = \frac{12P}{T + 10}$$

where P is mean monthly rainfall (mm) and T , mean monthly air temperature (°C). Temporal changes in pond water level were measured (cm) with a simple gauge.

Ten water physico-chemical parameters (surface temperature, transparency (TR), suspended solids (SS), hydrogen ion concentration (pH), conductivity (CD), total alkalinity, dissolved oxygen (DO), free carbon dioxide (CO_2), nitrate-nitrogen (NO_3-N), phosphate-phosphorus (PO_4-P)) were determined monthly based on records and samples taken from

station X (Fig. 1).

All *in situ* determinations and collection of surface water samples were made during mid-morning (10-11 a. m. local time). Water samples were collected with 125 ml bottles for DO and large-mouthed 2-litre plastic vessels for other parameters. Water samples were analysed in the laboratory within 1 hr of collection.

Surface temperature was measured *in situ* by a mercury-in-glass thermometer and TR , with a 25 cm (diameter) Secchi disc. The concentration of SS was estimated by filtering (under suction) 1 litre of water sample through a pre-weighed GF/C Whatman filter paper and oven-drying at 120°C for 12 hr; it was reweighed after cooling in a dessicator to obtain the amount of non-filtrable residue. The coefficient of coarseness (CC) of suspended solids was estimated by dividing the concentration of SS by TR (cf. SCHLOSSER and KARR, 1981a). Hydrogen ion concentration (pH) was measured with a battery powered PHJ-250-F Griffin meter and conductivity (CD), with a Gensway digital meter. Other determinations were based on methods described in APHA (1976): dissolved oxygen was fixed in the field and the concentration estimated in the laboratory by Winkler method. Free CO_2 was estimated in the field titrimetrically using 0.0027 N NaOH and phenolphthalein indicator. Total alkalinity was estimated by titration with 0.02 N H_2SO_4 , using phenolphthalein and methyl orange indicators. NO_3-N and PO_4-P were determined colorimetrically using a Gallenkamp Colorimeter.

To evaluate the differences in physico-chemical attributes between the dry (November-February) and wet (March-October) seasons, the effect of monthly variation was smothered by averaging the levels of each parameter for each season. Intra-season variability in each water quality parameter was evaluated by coefficient of variation (standard deviation $\times$ 100/mean: Lowentine, 1966).

4. Results

The meteorological conditions in Mfangm-

fang pond basin (Fig. 2) depicted a typical tropical seasonality regime with a short dry-season and a prolonged wet-season. The dry-season was characterized by prevalence of hot-dry northeasterly winds from the Sahara desert which resulted in low mean monthly rainfall

(0.3–9.9 cm) and high mean air temperature (29.1–31.1°C); aridity index ranged from 0.9 to 28.9; peak dry-season occurred in December–January. The dry-season was considered mild due to its brevity and the fact that there was always some precipitation in every month.

Fig. 2. Monthly variations in pond water level and meteorological conditions in the study area (November, 1986–October, 1987).

The wet-season was characterized by prevalence of moist tropical maritime winds from the Atlantic Ocean and high mean rainfall (13.1–28.4 cm) with a double maximum, in July and September; air temperature varied between 27.8 and 30.2°C and the aridity index was 41.6–86.9. Annual rainfall was 197.3 cm (with 183 rainy days), 92.7% of which was received during the wet-season.

The water level (Fig. 2) started falling in November with the recession of the rains and reached its minimum in March. With the onset of heavy rains in May, it began to rise, reaching its first peak in July and the second in September, both of which coincided with the first and second rainfall maxima, respectively. There was an inverse relationship between rainfall and water level in November–April, probably due to the lag between the recession of the rains and the decrease in water level. However in May–October, when the soil of the riparian grounds must have been waterlogged, a positive relationship ensued. Annual range in water level was 37 cm.

The surface temperature (Fig. 3a) was consistently lower than air temperature except in April and June when surface temperature was higher by 0.8 and 0.3°C, respectively. Annual mean surface temperature was 27.4°C; it ranged from 25.5°C in July to 29°C in November, these coinciding with the months of minimum and maximum air temperatures, respectively. There was no appreciable difference in mean surface temperature between the dry and wet seasons.

Transparency varied from 30 cm in June to 101.5 cm in January (Fig. 3b). The monthly changes showed high TR (>80 cm) in November–April and August–October and low TR (<65 cm) in May–July. Mean TR was higher in the dry than wet season.

Annual mean SS was $216.8 \mu\text{g}\cdot\text{l}^{-1}$ and ranged from $10 \mu\text{g}\cdot\text{l}^{-1}$ in November, December and September to $200 \mu\text{g}\cdot\text{l}^{-1}$ in June (Fig. 3c). The monthly cycle in levels of SS showed a bimodal regime, with peaks in March and June. Mean concentration in the wet-season was appreciably higher than that of the dry-season.

Levels of SS and reciprocal of TR were positively related ($r=0.873$, $df=10$, $P<0.002$), with SS accounting for 76.2% of the variation (r^2) in TR ; linear regression equation for this relationship is:

$$\frac{1}{TR} = 0.011743 + 0.0000108SS$$

The CC of suspended solids (Fig. 3d) ranged from 0.1 in December and September to 131.6 in June, the latter coinciding with the month of maximum SS and minimum TR . Monthly variation in CC depicted a bimodal pattern with peaks in March and June, a regime analogous to that of SS (cf. Fig. 3c). Coefficient of coarseness of SS was inversely correlated with TR ($r=-0.695$, $df=10$, $P=0.02$), indicating that TR decreased during periods of increasing levels of small particles of SS and *vice-versa*; about 48.3% of the variation in TR was associated with coarseness of the SS . The linear regression equation for this relationship is:

$$TR = 103.03033 - 1.12771CC.$$

The wet-season mean CC was higher by a factor 16.8 than the dry-season value; this indicates that large suspended solids constituted the bulk of the suspended load during the wet-season.

The pond, with an annual mean pH of 6.9, may be considered neutral. pH was slightly less than 7 throughout the study period except in May, June and August, when values slightly exceeded neutrality (Fig. 3e). The monthly pH regime showed two main peaks, in May and August. pH ranged between 6.5 and 6.8 in the dry-season and 6.4–7.7 during the rains; there was no marked variation in mean pH for the two seasons.

Mfangmfang pond, with an annual mean CD of $47.7 \mu\text{S}\cdot\text{cm}^{-1}$ was low in ionic content; CD ranged from $40.7 \mu\text{S}\cdot\text{cm}^{-1}$ in January to $61.8 \mu\text{S}\cdot\text{cm}^{-1}$ in June (Fig. 3f). Average wet-season CD was higher than that of the dry-season by $7.2 \mu\text{S}\cdot\text{cm}^{-1}$. The CD of Mfangmfang pond was significantly related to SS ($r=0.734$, $df=10$, $P<0.01$), with SS accounting for 53.9% of the variation in CD ; linear regression equation

Fig. 3. Monthly and seasonal variations in surface temperature (a), transparency (b), suspended solids (c), coefficient of coarseness of suspended solids (d), pH (e), and conductivity (f) in Mfangmfang pond (November, 1986–October, 1987); ds=dry-season mean; ws=wet season mean.

for this relationship is:

$$CD = 45.98614 + 0.00806SS.$$

The reciprocals of CD and CC were negatively correlated ($r = -0.635$, $df = 10$, $P < 0.05$)

according to the expression:

$$\frac{1}{CD} = 0.02183 - 0.00018CC.$$

About 40.3% of the variation in CD was

associated with the coarseness of suspended solids in the water.

The pond was moderately oxygenated, with an annual mean concentration and percentage saturation of $5.7 \text{ mg}\cdot\text{l}^{-1}$ (range $2.6\text{--}8.3 \text{ mg}\cdot\text{l}^{-1}$) and 72.1% (range 32.2–104.9%), respectively. The DO did not attain 100% saturation level throughout the year except in December when it was slightly supersaturated (Figs. 4a, b). The months of maximum and minimum DO (December and September, respectively) coincided with that of minimum and maximum levels of SS (Fig. 3c). Mean concentration of DO was higher by $1.6 \text{ mg}\cdot\text{l}^{-1}$ (21% saturation) during the dry than wet season; this was the converse of the seasonal regime in SS levels.

Phenolphthalein alkalinity was zero throughout the study period. It can therefore be inferred that OH^- and CO_3^{2-} ions made insignificant contributions to total alkalinity (*cf.* HALL *et al.*, 1977). This implies that total alkalinity was produced principally by HCO_3^- ion. Annual average total alkalinity was $9.9 \text{ mg}\cdot\text{l}^{-1}$ CaCO_3 ; it varied from $4 \text{ mg}\cdot\text{l}^{-1}$ in May–June to $15 \text{ mg}\cdot\text{l}^{-1}$ in July (Fig. 4c). Average total alkalinity was not markedly different in the dry and wet seasons.

Free dissolved CO_2 was consistently higher than DO except in May when equal concentrations ($6 \text{ mg}\cdot\text{l}^{-1}$) were recorded. Annual mean free CO_2 was $12.7 \text{ mg}\cdot\text{l}^{-1}$ and ranged from $6 \text{ mg}\cdot\text{l}^{-1}$ in May to $24.4 \text{ mg}\cdot\text{l}^{-1}$ in January (Fig. 4d). Mean concentration of free CO_2 was slightly higher in the dry than wet season.

The overall average concentration of $\text{NO}_3\text{--N}$ was $68 \text{ }\mu\text{g}\cdot\text{l}^{-1}$. Levels were low ($<100 \text{ }\mu\text{g}\cdot\text{l}^{-1}$) in most months of the year, except February–April, when they were high ($>100 \text{ }\mu\text{g}\cdot\text{l}^{-1}$) (Fig. 4e). Maximum concentration ($400 \text{ }\mu\text{g}\cdot\text{l}^{-1}$) was attained in February while in May, it was below the limit of detection. Higher mean $\text{NO}_3\text{--N}$ occurred in the dry-season than during the rains.

Annual mean $\text{PO}_4\text{--P}$ ($29.7 \text{ }\mu\text{g}\cdot\text{l}^{-1}$) was lower than that of $\text{NO}_3\text{--N}$ by 56.3% ($38.3 \text{ }\mu\text{g}\cdot\text{l}^{-1}$). Monthly regime in $\text{PO}_4\text{--P}$ in Mfangmfang pond (Fig. 4f) showed three peaks (December, March and August respectively). Maximum

concentration ($60 \text{ }\mu\text{g}\cdot\text{l}^{-1}$) occurred in August and minimum ($12.5 \text{ }\mu\text{g}\cdot\text{l}^{-1}$), in June. Mean $\text{PO}_4\text{--P}$ was slightly higher during the wet than dry season.

The intra-season variability in each physico-chemical attribute of Mfangmfang pond (Table 1) indicates that $\text{NO}_3\text{--N}$ and $\text{PO}_4\text{--P}$ were more variable in the dry-season while all other parameters were more variable during the rains.

5. Discussion

The low surface temperature in Mfangmfang pond may be ascribed to the floating leaves of *Nymphaea*/overhanging macrophytes which preclude the effect of sun's insolation and the fact that temperature readings were taken during mid-morning. The absence of a marked seasonality in surface temperature in this pond is in consonance with the reports of ARMITAGE (1984) for tropical regulated streams and KRAMER (1978) for unregulated streams. However, it contradicts the regime in many tropical aquatic systems in which temperatures are higher in the dry-season than during the rains (WELCOMME, 1979, 1985; OLUSANYA, 1988).

The patterns of seasonal variation in transparency and suspended solids in Mfangmfang pond are consistent with those in Opa reservoir, Nigeria (OLUSANYA, 1988) and rivers Zambezi (HALL *et al.*, 1977) and Ogun, Nigeria (ADEBISI, 1981). The decrease in transparency during the rains can be attributed to increased input of fine silt and particulate organic debris from the riparian zone through surface runoff while the high transparency during the dry-season may be due to sedimentation of suspended solids and decrease in the input of surface runoff (*cf.* THOMAS and RATCLIFFE, 1973–Nunguna reservoir Ghana; CHIDOBEM and EJIKE, 1985–Shen reservoir, Nigeria). The positive relationship between transparency and suspended solids indicates the role of the latter in determining the patterns of water clarity. The inverse relationship between the coefficient of coarseness of suspended solids and transparency is probably because large suspended particles scatter less light than an equal concentration of

Fig. 4. Monthly and seasonal variations in dissolved oxygen (a), % saturation of oxygen (b), total alkalinity (c), free carbon dioxide (d), nitrate-nitrogen (NO₃-N) (e), and phosphate-phosphorus (PO₄-P) (f) in Mfangmfang pond (November, 1986–October, 1987); ds=dry-season mean; ws=wet-season mean.

small particles (GRASSY in SCHLOSSER and KARR, 1981a).

The absence of a marked seasonality in the pH of Mfangmfang pond is probably due to the

fact that most of the H⁺ ions are not derived from external sources; thus the pond pH is unresponsive to increases in the input of precipitation, surface runoff and municipal effluents

Table 1. Intra-season variability in the physico-chemical parameters of Mfangmfang pond.

Parameter	Coefficient of variation (%)	
	Dry-season	Wet-season
Water level	3.9	14.1
Surface temperature	3.1	4.6
Transparency	10.5	34.8
Suspended solids	85.7	222.8
Coefficient of coarseness of suspended solids	81.2	268.6
Hydrogen ion concentration	1.9	6.5
Conductivity	3.6	14.6
Dissolved oxygen	15.4	41.6
Percentage saturation of oxygen	15.8	41.4
Total alkalinity	3.2	44.1
Free carbon dioxide	16.0	26.2
Nitrate-nitrogen	176.7	102.0
Phosphate-phosphorus	54.4	48.1

during the rains. It is also possible that the pond water is strongly buffered resulting in undetectable seasonal pH changes. The seasonality regime in the pH of Mfangmfang pond agrees with the observations of HALL *et al.* (1977) in Zambezi river and OLUSANYA (1988) in Opa reservoir but contradicts the trend in many African rivers in which pH is lower in the wet-season but rises during the dry-season (EGBORGE, 1971; WELCOMME, 1975; ADEBISI, 1981; WRIGHT, 1982).

The low ionic content of Mfangmfang pond is comparable to that of Lake Kainji, Nigeria, with a conductivity of $46-99 \mu\text{S}\cdot\text{cm}^{-1}$ (WELCOMME, 1986). The wet-season conductivity in Mfangmfang pond, which was higher than the dry-season value, is attributable to ionic enrichment of the pond through the input of municipal effluents and surface runoff from the riparian zone and/or 'solution effect' (WELCOMME, 1979) whereby ions bound in previously semi-dry land by decaying macrophytes, dissolved as the water level increased and inundated fringing swamps and riparian zone. The seasonality regime in the conductivity of the pond contrasts with the pattern in tropical freshwater lagoons and rivers which are characterized by higher values in the dry-season (WELCOMME, 1969, 1979, 1985; ADEBISI, 1981; WRIGHT, 1982). The positive relationship between conductivity and suspended solids in

Mfangmfang pond suggests that a large proportion of the ions in the pond exist in loosely adsorbed forms on the surfaces of suspended solids (*cf.* ADEBISI, 1981). The inverse relationship between conductivity and coarseness of suspended solids indicates that small suspended particles are more effective in the transportation of ions than larger ones. The role of suspended solids as vehicles for the transport of ions in aquatic systems is discussed by DUDLEY and KARR (1978) and SCHLOSSER (1978).

The inverse relationship between dissolved oxygen and suspended solids levels in the pond may be because a large proportion of the suspended solids comprised particulate organic matter whose decomposition resulted in depressed dissolved oxygen levels. Reduced dissolved oxygen levels may also be due to the flushing out of deoxygenated stagnant swamp water into the pond (*cf.* WELCOMME, 1975) and the decomposition of drowned macrophytes and other organic debris (*cf.* HALL *et al.*, 1977) during the high water period of the wet-season. Increased dissolved oxygen concentration in the pond during the dry-season was probably induced by photosynthetic activity of aquatic macrophytes (WELCOMME, 1975) and a decrease in the level of organic suspended solids. The seasonality regime in dissolved oxygen in Mfangmfang pond contrasts with the records of CAREY (1971), EGBORGE (1971), WELCOMME (1975)

and HALL *et al.* (1977) that dissolved oxygen in tropical African aquatic systems is generally lower in the dry-season than during the rains.

The absence of a marked difference in mean total alkalinity between the dry and wet seasons in Mfangmfang pond sharply contrasts with the seasonality regimes in Opa reservoir (OLUSANYA, 1988) and some tropical rivers (BALON and COCHE, 1974; HALL *et al.*, 1977; ADEBISI, 1981) which are characterized by higher alkalinity during the dry-season. The level of free carbon dioxide in Mfangmfang pond was slightly higher in the dry-season than during the rains. This disagrees with ADEBISI (1981) and WRIGHT (1982), who recorded lower concentrations of free carbon dioxide during the dry-season in Ogun and Jong rivers, respectively.

The seasonal variation in nitrate-nitrogen concentration in Mfangmfang pond showed a higher value in the dry-season than during the rains. This can be ascribed to the slow enrichment of the pond through mineralization of organic matter discharged into the pond through surface runoff and municipal effluents during the wet-season. This seasonality regime is the converse of that in Lake Asejire, Nigeria (EGBORGE, 1979) and Shen reservoir (CHIDOBEM and EJIKE, 1985), where levels are higher in the wet-season. The seasonal pattern in levels of phosphate-phosphorus in the pond is consistent with the observations of HALL *et al.* (1977), EGBORGE (1979) and OLUSANYA (1988) for Zambezi river, Lake Asejire and Opa reservoir respectively.

The higher wet-season variability in most of the water quality parameters of the pond may be linked to the impacts of extrinsic factors (*e. g.*, rainfall, input of surface runoff and municipal effluents) which are more prominent during the rains than in the dry-season. Conversely, the higher dry-season variability in nitrate-nitrogen and phosphate-phosphorus indicates that the seasonal regimes in these attributes are influenced by subtle intrinsic factors which predominate during this season.

The physico-chemical hydrology of Mfangmfang pond revealed that the integrated impact

of rainfall, accompanying fluctuations in pond level and discharge of municipal effluents and surface runoff from the riparian zone into the pond, tend to play an overriding role in determining the absolute levels and monthly/seasonal regimes in the water quality parameters. The physico-chemical attributes can be assigned to three categories according to the types of seasonal and anthropogenic influences:

- (1) Dry-season maximum, resulting from low rainfall and concomitant reductions in pond level and input of surface runoff/municipal effluents; transparency, dissolved oxygen, free carbon dioxide and nitrate-nitrogen are in this category.
- (2) Wet-season maximum, resulting from increased rainfall, with concomitant increases in pond level and input of surface runoff/municipal effluents; suspended solids, conductivity and phosphate-phosphorus is in this group.
- (3) No substantial seasonal variation; parameters in this category (surface temperature, pH and total alkalinity) are not significantly influenced by the tropical wet-dry cycle or influx of surface runoff and municipal effluents.

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摘 要

あるナイジェリア多雨林池の 物理化学的水文状態と季節性

ナイジェリア・Uyo の Mfangmfang 池の物理化学的状态につき、その季節性を調べた。気象状況は、短い乾季（11月—2月）と長い雨季（3月—10月）に分けられた。水文の変動の傾向から、降水・池水位・表流水の流入・都市排水などの総合された影響が水質の絶対的基準と一時的な型を決定していると解釈された。物理化学的パラメータは、その季節性と人間活動の影響をもとに、以下の3つに分類された。

- (1) 乾季に最大となるもの(透明度・溶存酸素・遊離 CO₂・硝酸性窒素)。これらは、低い降水量とそれに伴う表面流出・都市排水流入量の減少および池水位の低下に起因する。
- (2) 雨季に最大となるもの(SS・電導度・リン酸性リン)。これらは、高い降水量とそれに伴う表面流出・都市排水流入量の増加および池水位の上昇に起因する。
- (3) 季節性の無いもの(表面温度・pH・全アルカリ度)。これらは、雨季—乾季のサイクルおよび表面流出・都市排水の大きな影響を受けないことによる。

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