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CHARACTERIZATION OF COARSE PARTICULATE ORGANIC MATTER (CPOM) STANDING CROP AND ITS RETENTIVE STRUCTURES ALONG A LOW ORDER TROPICAL STREAM: SAGANA RIVER, KENYA.

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Abstract

Retention capacity of coarse particulate organic matter (CPOM) was studied in a low order forested tropical stream, Sagana River, Kenya from February to October 2003. Sampling was carried out bi-weekly along a 100 metres stream stretch. Retentive features were examined for their abundance, types, sizes, and distribution along the stream reach. The characteristics (length, breadth, height, area and volume) of the retentive features were measured and related to the amount of CPOM retained. A Hess sampler (area = $0.0299m^2$) was used for collecting the benthic organic matter (BOM), which was then sorted into leaves, barks, twigs, fruits, roots, wood debris and others. Materials from retentive features were ashed and weighed. The horizontal projection area (HPA) ranged from $0.64m^2$ to $3.76m^2$ and the volume of debris dam from $0.38m^3$ to $3.76m^3$. At the exposed riffle gravel bar (ERGB) site, the HPA varied greatly from 0 to $32.62m^2$. Large woody debris (LWD) retained the highest amount of BOM totalling 68.89g $AFDWm^{-2}$ followed by ERGB with 65.34 g $AFDWm^{-2}$ and debris dam with a total of 58.83g $AFDWm^{-2}$. Leaf litter dominated the BOM inputs accounting for over 47% at the debris dam site. *Ficus thorningii* leaves dominated the leaf inputs accounting for up to 44% of the total BOM. Correlation analysis showed that the most important factor influencing the accumulation of leaf litter was the volume of the debris dam ($r = 0.83$; $P<0.01$). Organic debris dams and LWD, therefore, are extremely important components of the stream ecosystem. They retain and regulate the size and amount of organic matter input within the system, thereby allowing it to be processed into finer size fractions rather than transported downstream in a coarse particulate form, which in turn affects the community structure of the stream ecosystem.

Key words: Characterization, relentive, features, tropical stream.

Introduction

Since Fisher and Likens (1973) estimated that allochthonous coarse particulate organic material (CPOM) was the source of 99.8% of the energy in Bear Brook, it is now recognized that headwater streams draining forested watersheds are dependent upon allochthonous (CPOM) as a source of energy for stream biota (Cummins, *et al.*, 1983; Webster 1983; Webster, *et al.*, 1994).

The retention of organic matter in the bed sediment is of primary importance in the understanding of the stream bioenergetics since the retention capacity dictates what amount of allochthonous organic matter is available in that particular stream reach in time and space (Mathooko, 1995). Speaker *et al.* (1984) reported that the main retentive features in high gradient streams include debris dams, cobbles, blocks, and bedrock while at low gradient streams mid-channel bars covered by small cobbles and gravel form the main retentive features.

Once the organic matter falls within the stream channel, it can either be entrained by the water current or retained in the "dry-store zone" and the "wet-store zone" or the overflown zone of the stream. Dry zones are channel areas that are characterized by periodic flooding and whose retention capacities depend on flood frequency and development of terrestrial vegetation (Bretschko, 1993).

Large accumulations of woody debris and organic matter (debris dams) are common within natural low order tropical streams. They greatly modify the abiotic framework of the streams such as water velocity patterns, sedimentation processes, and retention of particulate dissolved organic matter (Dobson *et al.,* 1992; Borchardt, 1993; Webster et al., 1990). In addition, they increase the retention of organic matter up to 75% of the standing stock in the stream (Bilby and Likens, 1980).

One of the most important contributions of forests to streams is the addition of large wood (Vannote *et al.,* 1980; Likens and Bilby, 1982; Hedin *et al.,* 1982). In fact, almost the entire large woody debris originates from the riparian zone (Webster, 1977; Sedell & Frogart, 1984; Harmon *et al.,* 1986; Keller & MacDonald, 1995).

High retention by cobbles and boulders has been shown to slow downstream transport of organic matter resulting into short spiraling distance (Minshall *et al.,* 1983; Naiman *et al.,* 1987). Jones and Smock (1991), reported increased leaf retention with low flow in high gradient, cobble-dominated stream.

Although there has been much interest in the role of riparian vegetation on stream bioenergetics, there is still little information about organic matter-riparian vegetation interaction. In Kenya, studies have been carried out on the organic matter and the invertebrate drift of Naro Moru River (Mathooko, 1994; Mathooko and Mavuti, 1992), the retention of coarse particulate organic matter in Njoro River (Mathooko, 1995) and on the Inputs and retention of particulate organic matter in a tropical stream, Njoro River (Magana, 2000). Mwangi (2000) studied the inputs of coarse organic matter and the distribution and composition of macrobenthos among sites differing in their land use characteristics along the upper reaches of Sagana River. These studies paid no attention to organic matter-retentive feature interaction. Therefore, the aim of this study was to assess the retention capacity of coarse particulate organic matter in a low order forested tropical stream; in addition, the study attempted to characterize the retentive features and to determine the content, distribution and composition of organic matter standing stock along the river.

Materials and Methods

Sagana River occurs in Nyeri District, Central Province, Kenya. It is a second order stream (Strahler, 1957), originating from the South-Eastern slopes of Mt. Kenya at about 4000 m asl. Its catchment stretches from latitude 0^0 13'S to 0^0 22'S and from longitude 37^0 16'E to 37^0 03'E draining a watershed area of approximately 2256 Km^2 (Mwangi, 2000). The length of the river from the source to the confluence point with Nairobi River is approximately 43 km. The river is ephemeral throughout its course. Sampling of CPOM standing stock and its retention features was carried out along a 100 metres stretch along Sagana River. Sampling was carried out every fortnight between February 2003 and October 2003.

Riparian Vegetation

The dominant species were subjectively assessed in the field (Canfield and Hoyer, 1988) and their presence noted along the study reach. Additionally, quantitative samples of vegetation were collected for further identification.

Characterization of retentive features.

Various instream organic matter structures were characterized in physical nature (Mathooko, 1995). This was made in terms of type, length, width, area, volume and the structural components. Enumeration was also carried out and the number of each noted.

Benthic Organic Matter Standing Stock

Benthic Organic Matter (BOM) was estimated among different types of retentive features by collecting all the litter materials occurring within the Hess Sampler with an area of $0.0299m^2$. Twigs, small branches, leaves, fruits, roots, grass and barks were trapped. At least five samples of BOM from each type of retentive feature (most dominant types) was collected. At least 10 samples from the wet zone and 10 samples from the dry zone was also collected. Hess Sampler was placed and all the coarse particulate organic matter (CPOM) enclosed therein were collected, placed in an enamel tray, put into the polythene bags (12x18 inch in size) and then transported to the laboratory for analysis. In the laboratory, the materials were sorted into leaves, bark, twig, wood debris, fruit, and roots. The fragmentary materials that could not be identified was designated "others" or "miscellanous" and then put into separate khaki bags. Leaves were then identified to species. Each component of the materials was then dried at 85^0C in an oven to a constant weight, measured to the nearest 0.01g. Materials were further ashed at 550^0 C for 4 hours and the ash free dry weight (AFDW) taken to the nearest 0.01g. Data was recorded and expressed as g AFDW m^{-2} for the organic detritus of each component.

Data analysis

The Statistical Package for Social Sciences (SPSS version 9.0) was used for statistical analysis of the data. The probability values of $P< 0.05$ was used for all the two tailed tests to show statistical significance of mean values for all the parameters that were analyzed. All means were reported with $\pm$ 95% CL. Data were transformed with $\log_{10}$ (x+1) before carrying out parametric test (t-test and ANOVA) and satisfied for normality and homogeneity tests of variance (Elliot, 1977). The association of various characteristics of retention structures with BOM distribution was assessed using the Pearson Correlation Coefficients. To determine the distribution pattern of the various BOM categories, Green's Coefficient of dispersion (Green, 1966) computed as follows was used:

$$\text{Dispersion index} = \frac{S^2/\bar{X} - 1}{\sum x - 1} \quad \text{where,}$$

S^2 = Sample variance

$\bar{X}$ = Sample mean

$\sum x$ = Total number in the sample

Negative values of this index indicated uniform pattern and positive values indicated clumped pattern.

RESULTS

Retentive features

The main instream organic and in-organic retentive structures identified along the study area were debris dams, large woody debris, exposed riffle gravel bars and aquatic macrophytes with large woody debris being the most common feature.

Debris dam

The number of debris dams ranged from 0 to 2. Measurements of the greatest breadth ranged from 0.52 m to 1.68 m with a length of 0.79 m to 2.24 m and a height ranging between 0.43 m to 1.2 m. The mean for the greatest breadth, length and height were 0.99 $\pm$ 0.18 m, 1.39 $\pm$ 0.26 m to 0.66 $\pm$ 0.13 m, respectively. The horizontal projection area ranged from 0.64 m^2 to 3.76 m^2, with a mean of 1.55 $\pm$ 0.46 m^2. The total dam volume ranged from 0.38 m^3 to 3.76 m^3 with a mean of 1.25 $\pm$ 0.52 m^3. The average density of accumulation was 1.7 dams per 100 m. The main structural component of the dams was leaf material, which made up 47.8 % of the total detrital standing stock.

Large woody debris

A total of 18 large woody debris (LWD) were observed within the study site. Occurrence ranged from 1 to 3 with a mean of 1.8 $\pm$ 0.42. The diameter ranged from 0.17 m to 0.49m, while the length varied between 7.2 m to 13.1 m.

Exposed riffle gravel bar

Twelve (12) exposed riffle gravel bars were observed. The occurrence was relatively stable with a range of 0 to 2. The average density of accumulation was 1.2 gravel bars per 100 metres of the study site. Greatest breadth and length varied from 0.79 m to 3.78 m and 1.64 m to 10.38 m respectively. The horizontal projection area ranged from 0 to 32.62 m^2 averaging 16.02 $\pm$ 6.32 m^2.

Effectiveness of organic matter retention

Debris dam

Quantitative and Qualitative constituents of retained organic matter

Total ash free dry weight (AFDW) of retained organic matter averaged 58.83g. Leaf litter was the largest fraction accounting for 47.8% of the total detrital standing stock at the site. Barks, twigs, roots and wood debris amounted to 18.7%, 16.7%, 6.4% and 1.6% AFDW respectively. The leafy BOM component was dominated by *Ficus thorningii* and *Croton macrotachyus*. BOM distribution was aggregated as evidenced by the positive values of the dispersion index (table 1) except for twigs.

Relationship between retained organic matter and the characteristic of debris dam

The total amounts of leaves showed a positive significant correlation with height and breadth of the debris dam ($r = 0.74$; $P < 0.05$ and $r = 0.75$; $P < 0.05$) respectively. The amount of leaves retained correlated strongly with the volume of debris dam ($r = 0.833$; $P < 0.001$) and the horizontal projection area ($r = 0.75$; $P < 0.05$).

Large Woody Debris (LWD)

Quantitative constituents of retained organic matter

The total amount of organic detritus was 68.89g AFDW m^{-2} with leaf litter contributing the highest amount (19.35g AFDW m^{-2}). Twigs, barks, and roots amounted to 15.77g, 9.56g, 7.81g and 1.25g AFDW m^{-2} respectively. The distribution of all the accumulated organic detritus with the exception of leaf litter was aggregated as evidenced by the positive values of the dispersion index. The total leaf litter showed a negative value of the index depicting a uniform distribution pattern where Green's coefficient of dispersion was used determining the distribution (table 1).

Table 1. The dispersion index values for benthic detrital standing stock at different sites along the study reach between February 2003 and October 2003, Sagana River, Kenya.

	Sites				
BOM category	**Wet zone**	**Dry zone**	**Debris dam**	**LWD**	**Exposed riffle gravel bar**
Bark	-	-	0.33	0.12	0.40
Twig	-0.02	0.31	-0.04	0.08	-0.20
Fruit	1.22	0.94	1.07	1.00	1.02
Root	-	1.00	1.00	1.00	-0.12
Wood debris	0.27	0.22	1.00	-	1.00
Leaves	0.04	0.17	0.05	-0.01	0.16
Miscellaneous	1.00	-0.43	0.09	0.11	1.00

+ Values indicate clumped pattern
- Values indicate uniform pattern
Relationship between retained organic matter and characteristics of LWD

The diameter showed no significant relationship with the retained organic matter standing stocks. The length was positively and highly correlated with the leaf litter AFDW ($r = 0.767$; $P < 0.001$). However, the length was negatively correlated with the bark AFDW ($r = -0.665$; $P < 0.05$). Volume showed no relationship ($P > 0.05$) with the AFDW of detrital organic matter ($p > 0.05$).

Exposed Riffle Gravel Bar (ERGB)
Quantitative and Qualitative constituents of retained organic mater
Total estimated detrital standing stock amounted to 64.34g AFDW m^{-2}. Leaves were the most important component constituting 35.3% (22.87g AFDW m^{-2}) of the total. Other components included barks (31.7%), twigs (12.3%), roots (2.8%), woody debris (1.4%), and fruits (0.1%). The contribution of the leaf litter to the total detrital standing stock was relatively high (35%) with *Ficus thorningii, Cussonia holstii, Calodendrum capense* and *Trichocladus elliptium* being the main species. The other species occurred in small quantities. The BOM accumulation for all the component categories was highly variable. There was variation in the quantity and dynamics of stored detritus among different sampling occasions. The dispersion index showed leaves, barks, wood debris, fruits and grass to be aggregated while twigs and roots were uniformly distributed (Table 1).

Relationship between retained organic matter and characteristics of the exposed riffle gravel bar (ERGB)
AFDW of twigs at the exposed riffle gravel bar showed a positive and significant correlation with breadth ($r = 0.650$; $P < 0.05$) and length ($r = 0.650$; $P < 0.05$). Similarly, breadth was positively correlated with the quantity of leaves ($r = 0.704$; $P < 0.05$). The amount of leaves was significantly correlated with the area of exposed riffle gravel bar ($r = 0.696$; $P < 0.05$). In addition, a positive and significant correlation was discerned between the area and amount of twigs ($r = 0.747$; $P < 0.05$) .

Benthic organic matter standing stock
Composition of BOM
The main BOM standing stock components identified at the wet and dry zone sites are summarized in Table 2 and Table 3 respectively. Barks, twigs and woody debris constituted over 72% of the detrital benthic organic matter standing stock at the wet zone site. Moreover, the leaf litter comprised over 60% of the total BOM standing stock accumulation.

Quantity of benthic organic matter
The main components constituting BOM at the wet zone were leaves (13.1g AFDWm^{-2} followed by barks (12.9g AFDWm^{-2}), woody debris (11.9g AFDWm^{-2}) and twigs (11.7g AFDWm^{-2}). The leafy BOM component was dominated by *Cussonia holstii* (30.1%) followed by *Ficus thorningii* (18.5%) and *Newtoinia buchanani* (5.1%). At the dry zone, BOM was dominated by leaves (52.2g AFDWm^{-2}) followed

by twigs (13.2g AFDWm^{-2}), barks (6.4g AFDWm^{-2}), woody debris (4.4g AFDWm^{-2}) and fruits (4.4g AFDWm^{-2}). The leafy BOM component was dominated by *Ekebergia capensis* (33.3%) followed by *Ficus thorningii* (20.7%) and *Calodendrum capense* (3.2 %).

The dispersion index (Table 1) showed all the identified BOM categories to be aggregated while unidentifiable was uniformly distributed. Overall, more BOM occurred at the dry zone (83.5g AFDWm^{-2}) as compared to the wet zone (50.6 g AFDWm^{-2}) although the two were not statistically significantly different ($P > 0.05$).

Discussion

Retention structures

Debris dam

Piegay and Gurnell (1997), while carrying out a study on low order streams of Southern England bordered by a managed riparian forest, found the volume of debris dam ranging from 1.02m^3 to 1.96m^3 per 100m of the stream length. In the present study, the mean dam volume for the entire study period was 1.25 ± 0.52 m^3 per 100m of the reach. This is well within the range limit given by Piegay and Gurnell (1997). The main structural components of debris dam for the entire study period were the leaves, bark and twigs. The result agrees with the findings of Weigelhofer and Waringer (1999) who reported leaf packs and twigs as important prerequisites for dam formation.

Large Woody Debris (LWD)

Forest productivity and management largely determines the amount of LWD supplied to the streams. However, the amounts and frequencies of LWD, which should heavily influence the morphology of streams under potentially natural conditions, are unknown. According to Harmon *et al.,* (1986), the volume of LWD present in 83 stream sections of unmanaged forests throughout North America ranged from 2.5 to 4500m^3/ha. In Canadian boreal forest streams, LWD (>10cm in diameter) standing stock ranged from 0.2 to 794m^3/m^2 (Naiman *et. al.,* 1986). In France along the alluvial floodplains, Piegay and Gurnell (1997) found LWD volume ranging from 0.28 to 743.4m^3/ha. Similarly, Hering *et al.* (2000) while carrying out a study on the quantity and distribution of LWD in central European streams reported that LWD volume related to stream length was 1.44m^3/100 meter reach.

In this study, the volume of LWD (≥10 cm in diameter) related to the study reach length was 1.25m^3/100 meter reach. Considering results from other rivers in some parts of the world, the present LWD volume is slightly lower predominantly because logs of size class category (≥10 cm in diameter) is lacking due to historical alterations of the channel and the floodplain along the riparian zone. It is apparent that virtually all forests along the catchment areas in Kenya have been managed and used in the past. These results regularly in the lack or low numbers of old, dying trees, which potentially could provide most of the LWD.

BOM retention in wet and dry zones

In the present study, the dry zone site accumulated higher BOM detrital standing stock (83.51g AFDWm^{-2}) than the wet zone (58.83g AFDWm^{-2}) possibly due to the presence of abundant retention structures such as large cobbles and boulders. Similarly, the leaves were stored more at the dry zone (51.89g AFDWm^{-2}) than at the wet zone (28.11g AFDWm^{-2}). The results are consistent with observations made by Bretschko (1990) and Mathooko (1995) that the dry zone store more leaves than the wetted zone. Bretschko (1990) noted that at any time of the year, amounts of deposited leaf material are four (4) times greater in dry channel areas than in wet areas. In this study, leaf litter at the dry zone was four times higher than that at the wetted zone. This is partly explained by the fact that leaf materials falling on the water surface at the wet zone are quickly transported downstream. The idea is supported by Mwangi (2000) who found higher total detrital standing stock at the cultivated dry zone than at the wetted zone along the upper reaches of Sagana River (Kenya). However, contrary to the present results, he noted that the leaf litter at the dry zone was only higher by almost twice than that of the wetted zone.

The riparian plant vegetation composition reflected the qualitative characteristics of the benthic organic matter standing stock. The difference in leaf litter accumulation at the dry and wet zones is attributed to species composition and density of the riparian vegetation. A very dense canopy closure of *Ekebergia capensis*, *Ficus thorningii* and *Calodendrum capense* covered the stream channel at the dry zone site. This introduced large quantities of leaves into the stream through direct inputs. The dominance of these species in the detrital standing stock was consistent with the trends that the surrounding riparian vegetation constitutes the main source of allochthonous CPOM inputs (Vannote *et al.,* 1980). These results support the observations made by Moser (1994) that the aerial inputs at the Oberer Seebach (Austria) were significantly correlated with the canopy closure. The findings further agree with the observations made by Webster *et al* (1990) and Bilby and Bisson (1992) that clear cutting of riparian vegetation drastically reduce litter inputs to streams.

BOM retention at the debris dam

The total BOM at Sagana River are not comparable to that of tropical and sub-tropical rivers draining watersheds. For example, Winkler (1991) recorded 13 Kg DWm^{-2} of standing stock of BOM in a dam structure situated in a secondary branch of the Oberer Seebach in Lunz (Austria). Smock *et al.,* (1989) collected standing stock of benthic organic matter ranging between 922 and 3356g AFDW m^{-2} in Oberer Seebach, Austria. The highest standing stock of benthic organic matter were recorded by Weigelhofer and Waringer (1999) in Weidlingbach, lower Austria, with 22 kg DWm^{-2}. These values are higher than the ones of the present study (i.e. 566.36g DWm^{-2} or 49.99g AFDWm^{-2}). The low values are possibly due to lack of thick un-impacted riparian vegetation undergrowth particularly along the bank of the study reach. It can also be apparently related to discharge. An increase in discharge as a result of high rainfall during study period flushed organic material from the debris dam. This is in agreement with observation made by Maridet *et al.,* (1995) that the seasonality of benthic organic matter standing stock is related to discharge in streams adjacent to catchments in the French granitic central mountains. They further noted that the low amount of BOM stored in certain months of the year was due to the flushing flows during peak leaf fall.

The most important variable influencing the accumulation of leaf litter at the debris dam is volume. This is best illustrated by a strong and positive correlation between the total ash fire dry weights of leaf litter and the volume of the debris dam. This suggests that increased amount of leaf litter at the debris dam site may be related to high dam volume.

BOM retention at the large woody debris

The results of this study suggest that large woody debris is an important determinant of the detrital accumulation among patches in Sagana River. Naiman and Sedell (1979) and Bilby and Likens (1980) explained that a large proportion of standing stock of particulate organic matter in streams is often associated with LWD. A similar sentiment was also given by Molles (1982) who showed that streams with no LWD has lower standing stocks of organic matter and support few shredding insects. The results of the present investigation are in general agreement with those of such studies in that the highest accumulation of detrital benthic organic matter standing stock was recorded at the LWD.

The total detrital benthic organic matter standing stock measured in the present study at the LWD is far much higher than that of the debris dam and the exposed riffle gravel bar. The difference is possibly due to trapping of smaller debris by the extensive branches and sticks of the LWD. This is in agreement with the idea that the accumulation of LWD such as branches and sticks greatly increase retention efficiency of streams by trapping smaller debris (Webster *et al.,* 1994; Jones, 1997).

The most important feature of the LWD influencing the accumulation of leaf litter in Sagana River is the length. This is best illustrated by the correlation analysis, which showed very high significant relationship between the ash fire dry weights of detrital leaf litter standing stock and the length of the LWD.

BOM retention at the exposed riffle gravel bar

The large and more stable cobbles and boulders at the exposed riffle gravel beds usually act as sediment retainers. According to Speaker *et al.,* (1984), retention by obstacles in these sites is more efficient than in dead zones at low current velocity. However, Snaddon *et al.,* (1992) shows that the retentive efficiency of riffle decreases with increasing discharge. Discharge regime is regarded as driving variable for CPOM retention (Bretschko, 1990). Similarly, Pozo *et al.,* (1994) posits that when litter inputs coincide with low flow, CPOM tends to accumulate on the streambed but if otherwise, downstream transport is favoured. The detrital material entering the river is thus rapidly exported as the flow increases. The idea is supported by Magana (2000) who reported that the exposure of cobbles, boulders and pebbles increased the relative retentiveness of riffle biotopes during the low discharge period. Similar sentiments were also given by Mwangi (2000) while carrying out a study at the upper reaches of Sagana River. He showed that the storage of allochthonous organic matter inputs into the stream was achieved through retention by the abundant small cobbles and gravel occurring within a large exposed gravel bar. These tenets and the results of the present investigation are in general agreement with such observations. It is, therefore, possible that the high accumulation of the detrital material at the exposed riffle gravel bar site may have been related to the presence of cobbles and boulders and discharge regime.

The composition of the leaf material collected reflected the distribution of plants vegetation along the riparian zone, espousing with the findings of Johnson *et al.,* (1997) that narrow strips of riparian forests (buffer strip) may contribute substantial amounts of allochthonous debris to streams. Similar sentiments were also given by Sedell *et al.* (1978) and King *et al.,* (1987). They asserted that most of the organic matter entering the stream through aerial or lateral input is derived from the immediate adjacent vegetation along the stream channel and the content is largely dependent upon the riparian vegetation density.

Conclusion

From the foregoing discussion based on the data presented, the following conclusions can be made from the study:

- The main retentive features along the mid-reaches of Sagana River are debris dam, large woody debris and exposed riffle gravel bar whose retention efficiency greatly depend on water level and discharge.
- Dam volume and the length of LWD are important parameters that influence the quantity and composition of BOM accumulation at the debris dam and large woody debris respectively. The greatest breadth, length and area of the exposed riffle gravel bar have a significant effect on the BOM accumulation.
- Narrow strip of riparian vegetation is an effective source of allocations of organic matter input into the stream.

The findings of the present study provide pertinent information on the retention capacity and the role of retentive features in the retention of CPOM inputs to the Sagana River. In addition, the role of riparian vegetation as an effective source of allochthonous organic matter input and the building blocks materials for retention structures (debris dams & LWD) is discerned.

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