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On the annually recurrent of green macroalgal bloom phenomenon in Timsah Lake, Suez Canal, Egypt

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Key words: El Taawen area, green macroalgal blooms, physico-chemical parameters, spring season, Timsah Lake.

Abstract

Consequence macroalgae blooms phenomenon annually in Timsah Lake, the green macroalgal blooms phenomenon was increased in spring 2014 than the previous study in spring 2004 spring 2005 in order to cover large parts of El Taawen area at the south of Timsah Lake. Macroalgal species were growing firstly on the lakebed in the late winter then separated from the bottom to cover large areas in spring season as mats on the surface of the lake. Massive macroalgal mats, composed primarily of *Enteromorpha clathrata* and *Ulva lactuca* and formed the principal predominant green mats in the studied seasons. Water and sediment samples were determined at the blooming time. The physico-chemical analysis of water and sediment specimens showed increasing in the nutrients. In contrast, dissolved oxygen was declined at the selected sites (anoxic conditions). Total Nitrogen, total phosphorus and organic matters recorded high levels in the sediments. Morphologically, the characteristic length and diameter of *Enteromorpha clathrata* and *Ulva lactuca* reached more than one meter in comparison with its natural size. Human activities on the Lake elevated the nutrients levels to the extent of stimulating algal blooms. Negatively impacts were interfered with economic uses such as fisheries in the Lake.

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Introduction

Timsah Lake is a significant event for the local community, since the lake has an economic importance to Ismailia city and its fishermen. The southern region of the lake, called ElTaawen beach, exposes regularly to annual recurrent of green macroalgal blooms forming algal mats in spring season. This phenomena was studied for the first time during late winter-spring 2004 and 2005 by El Shoubaky and Hamed (2006).

Annual algal bloom phenomenon increased in spring 2014 in comparison to those recorded in the previous study in El Taawen area at the south of Timsah Lake. Rapid and temporary increases in the abundance of a species are considered one of the consequents from multiple drivers of human-induced environmental changes experienced by coastal marine ecosystems (Richardson *et al.* 2009, Condon *et al.* 2011, Lyons *et al.* 2012). Nutrient inputs to coastal waters have increased in coastal environments worldwide as a direct consequence of the growing human population and increased settlement and use of coastal areas (Valiela 2006). These changes in nutrient availability lead to increased eutrophication, a growing threat facing coastal ecosystems (Bricker *et al.* 2008). Mass growth of macroalgae in shallow coastal waters is one of the most conspicuous results of eutrophication (Nelson *et al.* 2008, Choi *et al.* 2010).

The algal blooms are associated with elevated nutrient levels (Sfriso *et al.* 2001, Romano *et al.* 2003). Nitrogen and phosphorus are the main nutrients required for algal growth. In freshwater, phosphorus is usually the nutrient that limits algal growth while in marine waters it is often nitrogen. Both nutrients occur naturally, but human activities can give rise to excess nutrients contributing to exceptionally large algal blooms. Anthropogenic nutrient inputs include point sources such as treated sewage from wastewater treatment plants and septic systems, and diffuse sources such as run-off from agricultural land (Teichberg *et al.* 2010).

Generally, macroalgal mats, usually of the green genera *Enteromorpha*, *Cladophora*, *Chaetomorpha* and *Ulva*, cause the underlying sediments to become more reducing, often leading to anoxia and the accumulation of toxic hydrogen sulphide (Reise 1985). By virtue of their simple morphology and broad physiological tolerances, the rapid and extensive growth of *Enteromorpha* and *Ulva* is therefore commonly used as an indicator of nutrient enrichment and eutrophication of shallow-water systems (Kamer *et al.* 2002).

The importance of sediments as a source of nutrients to macroalgae is critical in understanding nutrient dynamics in estuaries and factors controlling algal blooms (Valiela *et al.* 1997). Lavery and McComb (1991) found that estuarine sediments increased the growth of *Chaetomorpha linum* over a three-week period. Estuarine sediments may also be a significant source of nutrients to macroalgae. The release of nitrogen and phosphorus from sediments is well established (Clavero *et al.* 2000, Grenz *et al.* 2000). In 2014, macroalgal bloom phenomenon was increasing in Timsah Lake. Therefore; the objective of this study was to consequence and assessment of macroalgal bloom phenomenon at the southern region in Timsah Lake, in addition to evaluate the accompanying physico-chemical parameters of the water and sediment.

Materials and methods

Study area

Timsah Lake is characterized as brackish shallow water. The southern region of the lake, (El Taawen beach) exposes to the agriculture drainage and domestic wastewater from clubs along the shore. The present study was conducted in spring 2014, the season of the green algal blooms as previously described in late winter-spring 2004-2005 (El Shoubaky and Hamed 2006). The study area lies between 30° 32.880'N & 30° 35.700'N latitude and 32° 15.600'E & 32° 19.200'E longitude (Fig. 1). The selected area was divided to three sites. Site I is located directly in front of El Taawen beach, site II is situated at the middle island opposite to the beach and site III is located at the other side of the island.

(A)

(B)

(C)

Fig. 1. Satellite images: A) Location of Suez Canal in Egypt, (B) Location of Timsah Lake in Suez Canal, (C) Timsah Lake and El Taween study area showing the position of the study sites.

Physico-chemical water parameters

Water samples were collected and some parameters were taken *in situ* during blooming time. Surface water temperature was measured by glass mercuric thermometer and pH was determined by Digital pH-meter (Cole-Parmer, model 5938-50). Water samples for chemical analysis were collected in polyethylene bottles of one liter capacity, and laboratory analysis started within few hours from the time of collection. The chemical analysis in addition to salinity, conductivity and dissolved oxygen was determined according to the methods of Dewis and Freites (1970) and Standard Methods (APHA 1992).

Field sediment samples

Sediment samples (approximately 2 kg each) were collected from the selected sites at the same time and region of the macroalgae collection. The wet sediment samples were stored in separate air-sealed plastic containers in the dark at 4°C until analysis. Physical and chemical analyses of Timsah Lake sediment was determined by the methods of Baruah and Barthakur (1997), where as organic matter, Na^+ and K^+ by flame photometry method (Stewarte *et al.* 1974). Total nitrogen was by the conventional micro-Kjeldahl method (Pirie, 1956) and total phosphorus was according to the methods described by Parsons *et al.* (1984).

Macroalgal collection

The macroalgae were collected from the blooms and the settlement algae. The algae were preserved in 4% formalin. The percentage cover of macroalgae was measured quantitatively using quadrate method (Russell and Fielding, 1981). The abundance of each species was assessed using the following seven numerical scales: 0.1<1, 1=1-10, 2=10-15, 3=15-25, 4=25-50, 5=50-75 and 6=75-100. The identification was accomplished using the taxonomic keys provided by Womersley (1984, 1987) and Aleem (1993).

Data statistics

All statistical analyses were performed using Minitab (version 16.1). Statistical significance of differences among different sites and classes (counts) of species was evaluated by Cross Tabulation and Chi- Square at $\rho \leq 0.05$. Analysis of variance (ANOVA) was tested for significant variations and frequency between physico-chemical parameters of water and sediment ($\rho \leq 0.05$). Multivariate descriptive analyses were processed employing to Pearson's correlation coefficients. The resulting similarity matrix was used for a Cluster Analysis to discern Variables between spring 2004, spring 2005 and spring 2014.

Results and discussion

Physico-chemical parameters

El-Taween area still exposed to human activities outflow of agriculture drainage poured through the lake, in addition to domestic wastewater and clubs beside the shoreline. The eutrophication process in Timsah Lake was increasing according to the elevation of nutrients and organic elements levels. Measurements of the physico-chemical parameters of water and sediment showed increasing of nutrients and decreasing in dissolved oxygen at the studied sites.

The environmental conditions showed variation at the selected sites (Table, 1). One-way ANOVA was used to analyze the environmental conditions (ρ value= 0.000 and Frequency= 76.20). Mean and Standard deviation (Mean±StDev) were determined at the selected sites as shown in Table 1. The physical parameters showed that water temperatures in the study period ranged between 26-28°C (M±SD=27.00±1.00). The pH value varied from 7.43 at site III and 7.96 at site I (M±SD= 7.71±0.27). Dissolved oxygen was declined at the selected sites and ranged between 6.0mg/l at site I and 5.0mg/l at site III (M±SD=25.20±5.25). Conductivity recorded increasing at site I (46.3dsm^{-1}) then decreased at sites II and III (M±SD=44.37±1.68). Salinity slightly changed between the sites (28-30‰) (M±SD=29.33±1.40). Timsah Lake has stratification variations in salinity. Decreases in salinity were noted as early as 1871 following Suez Canal construction and subsequent enlargement of the channel from the Nile and other construction projects increased the inflow of fresh water to the lake (Gollasch and Cohen, 2006).

Table 1. Physico-chemical parameters of water in El Taawen area at the selected sites in spring 2014 (Mean±SD).

Sites Parameters	Site I	Site II	Site III	Mean±SD
Water Temperature (°C)	27	28	26	27.00±1.00
pH	7.96	7.73	7.43	7.71±0.27
Dissolved oxygen (mg/l)	6.0	5.2	5.0	5.40±0.53
E.C. Conductivity (dsm^{-1})	46.3	43.3	43.5	44.37±1.68
Salinity (‰)	30.8	29.2	28.0	29.33±1.40
Na^+ (meg.l^{-1})	640	409	452	500.33±122.85
K^+ (meg.l^{-1})	18.0	18.0	16.0	17.33±1.15
Cl^- (meg.l^{-1})	475	513	534	507.33±29.91
Ca^{+2} (meg.l^{-1})	33.0	37.0	53.0	41.00±10.58
Mg^{+2} (meg.l^{-1})	109	116	79.0	101.33±19.66
HCO_3^- (meg.l^{-1})	5.00	8.00	6.00	6.33±1.53
SO_4^{-2} (meg.l^{-1})	61.0	59.0	60.0	60.00±1.00
Total nitrogen (mg/l)	16.8	19.6	28.0	21.47±5.83
Total phosphorus (mg/l)	0.193	0.171	0.192	0.19±0.01

The chemical parameters of the water samples registered that, the highest level of Na^+ was at site I (640 meg.l^{-1}) whereas site II was the lowest one (409meg.l^{-1}) (M±SD=500.33±122.85). The K^+ values were equal at sites I and II (18meg.l^{-1}) while the little decreasing at site III (16meg.l^{-1}) (M±SD=17.33±1.15). Site III recorded the maximum levels of Cl^-, Ca^{+2}, total nitrogen recording 534 meg.l^{-1}, 53 meg.l^{-1} and 28 mg/l (M±SD=507.33±29.91 & 41.00±10.58) respectively. while the minimum ones at site I recording 475meg.l^{-1}, 33meg.l^{-1} and 16.8mg/l correspondingly. Site II showed an increase of Mg^{+2} (116meg.l^{-1}) (M±SD=101.33±19.66) and HCO_3^- (8meg.l^{-1}) (M±SD=6.33±1.53). The concentration of SO_4^{-2} was little difference between the selected sites (59-61meg.l^{-1}) (M±SD=60.00±1.00). Total phosphorus ranged between 0.171mg/l at site II (M±SD=21.47±5.83) and 0.193mg/l at site I (M±SD=0.19±0.01).

Sediment analysis

The physicochemical parameters of the surface sediment were determined in El Taween area at the selected sites in spring 2014 (Table, 2). The properties of the sediment at the selected sites were similar where the texture grade was characterized by sand and the color was black. Measurements of pH and conductivity recorded the maximum levels at Site I (7.77 and 25.6dsm^{-1}) whereas the minimum ones were at site III (7.67 and 18.1dsm^{-1}) respectively. The chemical analysis of the sediment at the selected sites showed that the highest values of Na^+, K^+, Cl^- and Mg^{+2} were registered at site II (225, 11, 210 and 56meg.l^{-1}) while the lowest values were at site III of K^+, Cl^- and Mg^{+2} (9, 138 and 34meg.l^{-1}) correspondingly . Mean ± standard deviation of Na^+, K^+, Cl^- and Mg^{+2} was as the follows: 166.00±55.05, 9.67±1.15, 181.00±37.99 and 45.33±11.02 in that order. Site I recorded highly levels of HCO_3^- (10meg.l^{-1}) and SO_4^{-2} (135meg.l^{-1}) whereas the low levels of HCO_3^- (7meg.l^{-1}) was at site II (M±SD=8.33±1.53) and SO_4^{-2} (74 meg.l^{-1}) was at site III (M±SD=100.67±31.21). The concentration of Ca^{+2} varied between 20meg.l^{-1} at site III and 18meg.l^{-1} at site II (M±SD=19.00±1.00). Site III represented highest values of total nitrogen (14%), total phosphorus (3.19%), $CaCO_3$ (6.85 %) and organic matter (10.8%). Mean ± standard deviation of the last parameters was 11.53±2.32, 2.15±0.91, 5.14±1.71 and 10.80±2.70 respectively. One-way ANOVA of the physico-chemical parameters of sediment showed significantly different (p value= 0.000 and Frequency= 27.31).

The importance of the water column and sediment as sources of nutrients to macroalgal blooming varied with the magnitude of the different sources. The importance of sediments as a nutrient supply to macroalgae is critical in understanding nutrient dynamics in estuaries and factors controlling algal blooms (Valiela *et al*., 1997; Trimmer *et al*., 2000). Timsah Lake sediment holds highest content of nitrogen, phosphorus and organic matter. This may attributed to the different sources of fresh water in addition to, partially treated or untreated sewage from Ismailia city and drainage water from the agricultural fields (Dowidar & Abdel-Monem, 1990; Peckol *et al.,* 1994).

Table 2. Physico-chemical parameters of sediment in El Taawen area at the selected sites in spring 2014 (Mean±SD).

Sites Parameters	Site I	Site II	Site III	Mean±SD
pH	7.77	7.76	7.67	7.73±0.06
E.C. Conductivity (dsm^{-1})	25.6	24.0	18.1	22.57±3.95
Na^+ (meg.l^{-1})	116	225	157	166.00±55.05
K^+ (meg.l^{-1})	9.00	11.0	9.00	9.67±1.15
Cl^- (meg.l^{-1})	195	210	138	181.00±37.99
Ca^{+2} (meg.l^{-1})	19.0	18.0	20.0	19.00±1.00
Mg^{+2} (meg.l^{-1})	46.0	56.0	34.0	45.33±11.02
HCO_3^- (meg.l^{-1})	10.0	7.00	8.00	8.33±1.53
SO_4^{-2} (meg.l^{-1})	135	93.0	74.0	100.67±31.21
Total nitrogen %	9.4	11.2	14.0	11.53±2.32
Total phosphorus %	1.75	1.51	3.19	2.15±0.91
$CaCO_3$ %	3.43	5.14	6.85	5.14±1.71
Organic matter %	8.1	13.5	10.8	10.80±2.70

Site III was showed high nutrient contents of nitrogen, phosphorus and organic matters than the other sites. This is maybe attributed to that the side of site III mostly associated with agricultural drainage. El-Shoubaky and Salem (2009) showed that serial concentrations of Timsah Lake sediment was rich in the content of nitrogen, phosphorus and organic matter and affected on the plant growth lengths. Macroalgae can utilize nutrients stored in estuarine sediments (Kamer *et al*., 2002).

Macroalgal blooms

Green macroalgal bloom phenomenon in Timsah Lake especially El-Taween area happens annually. The total taxa of macroalgal species (14sp.) was recorded in spring 2014 at the site I followed by site II (11sp.) and the lowest one at site III (8sp.). Chlorophyta formed the dominant macroalgae than red and brown algae as in Table 3. *Enteromorpha clathrata* and *Ulva lactuca* were visible as predominant lush mats of green seaweeds (50-75%). Algal distributions were created from late of winter through beginning of March, but large blooms of the filamentous species *Ulva lactuca* and *Enteromorpha clathrata* were notable on March and April. The filamentous species blooms declined dramatically in May and June. As the patches of macroalgae grow, separate, float then join and they gradually move with the wind driven surface currents (Fig., 2).

Table 3. The macroalgal species recording at the selected sites in spring 2014 in comparison with 2004 and 2005.

Macroalgal species	Spring 2004	Spring 2005	Spring 2014
Chlorophyta			
Chaetomorpha indica Kutz.	+	+	+
Chaetomorpha linum (Mull.) Kutz.	+	+	+
Cladophora glomerata (L.) Kutz.	+		
Cladophora rupestris (L.) Kutz.	+	+	+
Enteromorpha clathrata (Roth) Greville		+	+
Enteromorpha compressa (L.) Greville		+	+
Enteromorpha flexuosa (Wulf.) J. Agard	+	+	+
Enteromorpha intestinalis (Linnaeus) Link			+
Enteromorpha linza Linnaeus			+
Enteromorpha prolifera (Mueller) Agardh			+
Ulva fasciata Delile			+
Ulva lactuca Linnaeus	+	+	+
Ulva rigida Agardh			+
Rhodophyta			
Polysiphonia variegata (Ag.) Zanardini	+		+
Phaeophyta			
Giffordia indica (Sonder) Papenfuss &Chihara			+
Ectocarpus sp		+	

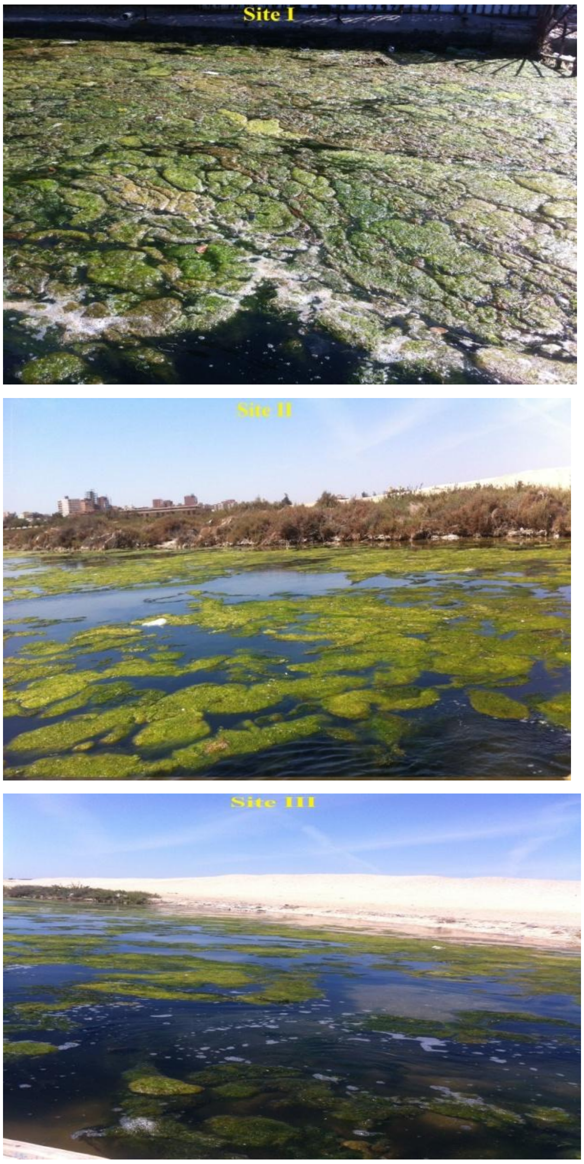

Fig. 2. Green macroalgae blooms at the selected sites in spring 2014.

Table 4. The Pearson Chi-Square between sites and counts (classes) of species in Timsah Lake.

Count Site	0	1	2	3	4	5	All
I	0 42.00 42.000	56 46.67 1.867	**70** 42.00 18.667	42 28.00 7.000	0 14.00 14.000	28 23.33 0.933	196 196.00 *
II	42 42.00 0.000	**56** 46.67 1.867	28 42.00 4.667	28 28.00 0.000	28 14.00 14.000	14 23.33 3.733	196 196.00 *
III	**84** 42.00 42.000	28 46.67 7.467	28 42.00 4.667	14 28.00 7.000	14 14.00 0.000	28 23.33 0.933	196 196.00 *
All	126 126.00 *	**140** 140.00 *	126 126.00 *	84 84.00 *	42 42.00 *	70 70.00 *	588 588.00 *

Bold numbers indicate maximum frequency of counts in sites. The first value in rows is the count, the second one is expected count and the third one is the contribution to Chi-square.

Comparison spring 2014 with 2004 & 2005

Consequence to the macroalgal blooms annually, the number of algal species was increased in spring 2014 (14sp.) than in spring 2004 (7sp.) and spring 2005 (8sp.) at the same time (El Shoubaky and Hamed, 2006). This study little differed than in temperate regions, which the growth of mat forming algae occurs mainly in the early spring and may persist at high densities throughout the summer before disappearing in the late autumn (Kim *et al.*, 2004; Liu *et al.* 2009 and Zhao *et al.*2011).

The Pearson correlation between spring 2014 and spring 2004 & 2005 showed that there was highly significant between spring 2004 and 2005 (ρ = 0.000) but there was no significance between spring 2014 and either of 2004 or 2005. Cluster Analysis of spring 2004; spring 2005 and spring 2014 Variables showed the high similarity level between spring 2004 and 2005 (68.90%) in the number of algal species whereas the similarity level in spring 2014 was 50.00% as shown in Fig. 3. *Enteromorpha clathrata* and *Ulva lactuca* were the principal predominant green mats in the studied seasons.

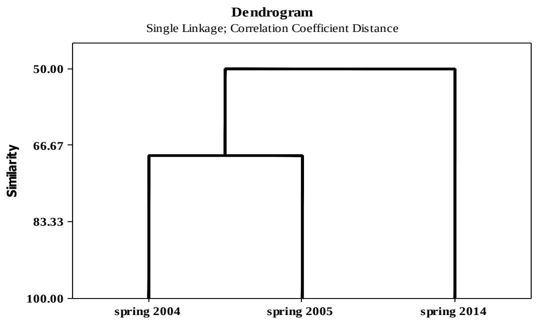

Fig. 3. Dendrogram showing the similarity levels between spring 2014, 2004 and 2005.

Guidone and Thornber (2013) reported that the formation of blooms of filamentous and/or thin foliose macroalgae is frequently a consequence of coastal eutrophication (Morand & Merceron, 2005; Ye *et al.*, 2011). Macroalgae with these morphologies have a high surface area to volume ratio that enables them to rapidly uptake nutrients for greatly increased growth (Pedersen and Borum 1996), provided favorable bathymetric, temperature, and light conditions exist (Sousa *et al.*, 2007; Liu *et al.*, 2010). Nitrogen and phosphorus are the two most common nutrients that limit macroalgal growth (Kamer *et al.*, 2002). Both nutrients occur naturally, but human activities can give rise to excess nutrients contributing to exceptionally large and stimulate algal blooms. El-Shoubaky and Abdel-Kader (2007) recorded high levels of total nitrogen and phosphorus in the brackish *Ulva lactuca and Enteromorpha intestinalis* tissues than in marine species which indicating to the eutrophic character. Valiela *et al.* (1997) mentioned that the macroalgal blooms are generated by nutrient loading to shallow waters where the bottom is within the photic zone. *Ulva* is an opportunistic alga, capable of causing green tides in nutrient-rich environments due to its high rate of nutrient uptake (Villares & Carballeira 2004). If the role of *Ulva* as temporary nutrient sink is significant, its planned removal may help to control eutrophication.

Morphologically, the characteristic length and diameter of *Enteromorpha clathrata* and *Ulva lactuca* reached to be more than one meter in comparison with its natural size. El-Shoubaky and Abdel-Kader (2007) showed that *Ulva lactuca* in the eutrophic brackish Timsah lake habitat increased more than the normal size in marine habitat. This is agreeing with Van Den Hoek *et al.* (1995) who mentioned that *Ulva lactuca* grow up to ~30 cm high, the thallus is broad (exceeding 1 meter if attached to large stable objects) with rounded lobes and smooth undulating margins without denticulations. *Ulva lactuca* take up nutrients 4-6 times faster than slower growing perennial species (Pedersen and Borum, 1996). This results in fast production of new biomass (Altamirano *et al.,* 2000).

Conclusion

Timsah Lake still exposed to more of anthropogenic impacts and this lead to excess of nutrient eutrophication contributing to exceptionally large and stimulates green algal blooms from year to year especially *Enteromorpha clathrata* and *Ulva lactuca* in spring season. The physico-chemical analysis showed increasing in the nutrients. In contrast, dissolved oxygen was declined at the selected sites (anoxic conditions). Total Nitrogen and total phosphorus were considerable rising in the sediments in addition to organic matters. The green macroalgal biomass can exploit in economic uses response to the phenomenon.

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