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Potentially harmful microalgae in coastal waters of the Algiers area (Southern Mediterranean Sea)

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Abstract – A series of seasonal, monthly and short-term samplings was conducted in open and confined waters of the Algiers area in 2001-2002 and summer 2003 in order to detect potentially harmful microalgae species (HAB). A total of 14 potentially toxic and 18 bloom-forming species were recorded, of which some were found for the first time in Algerian coastal waters: the potential toxin producers *Alexandrium minutum, Dinophysis sacculus* (dinoflagellates) and *Pseudo-nitzschia calliantha* (diatom), as well as the bloom-forming species *Lepidodinium chlorophorum (*dinoflagellate)*, Cyclotella meneghiniana* (diatom) and *Holococcolithophora sphaeroidea* (holococcolithophorid). The latter produced a very important bloom with considerable water discoulouration. The occurrence and duration of this event in the Algiers Harbour underline the importance of this enclosed structure as a growth area for HAB species. The transport of a *H. sphaeroidea* bloom toward off-shore waters by an anticyclonic eddy demonstrates the effect of Algerian current mesoscale instabilities on the spatial distribution of phytoplankton communities.

Algiers Harbour / Harmful algal blooms (HAB) / Southern Mediterranean / *Holococcolithophora sphaeroidea*

Résumé – **Microalgues potentiellement nocives dans les eaux côtières algéroises.** Une série d'échantillonnages annuels, saisonniers et ponctuels a été réalisée en 2001-2002 et pendant l'été 2003 dans les eaux côtières de la région d'Alger, dans le but d'y détecter les espèces de phytoplancton potentiellement nocives et toxiques. 14 espèces potentiellement toxiques et 18 espèces génératrices d'efflorescences ont été identifiées. Les espèces potentiellement toxiques *Alexandrium minutum, Dinophysis sacculus* (dinoflagellés) et *Pseudo-nitzschia calliantha* (diatomée) ainsi que les espèces génératrices d'efflorescences *Lepidodinium*

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chlorophorum (dinoflagellé), *Cyclotella meneghiniana* (diatomée) et *Holococcolithophora sphaeroidea (*holococcolithophoride) ont été récoltées pour la première fois sur la côte algéroise. *H. sphaeroidea* a été à l'origine d'une efflorescence très importante ayant causé une intense coloration des eaux. L'apparition et la durée de cet évènement dans le port d'Alger mettent en évidence l'importance de cette structure enclavée en tant qu'aire de développement des espèces potentiellement nocives. Par ailleurs, l'exportation vers les eaux du large de l'efflorescence de *H. sphaeroidea* par un tourbillon anticyclonique montre l'impact des instabilités à moyenne échelle du courant algérien sur la distribution spatiale des communautés phytoplanctoniques.

Efflorescences de microalgues nocives / *Holococcolithophora sphaeroidea* / Méditerranée du sud / Port d'Alger

INTRODUCTION

Since the 1980s there has been a worldwide increase in Harmful Algal Blooms (HAB) (Honsell *et al.*, 1995; Smayda, 1990; Masó & Garcés, 2006). The term HAB includes a wide range of events caused by an heterogeneous group of microorganisms that may directly or indirectly affect human health, economics and/or the biota of the region. Harmful microalgae species can be classified into two categories according to their respective effects on human health and/or the environment: potential toxin producer and bloom-forming species (GEOHAB, 2001). Some microalgae fall into both of these. Toxic events can be produced at very low concentrations of the causative microalgae. On the other hand, non-toxic high-biomass events can cause great economic losses to aquaculture activities due to fish mortality caused by mechanical damage or suffocation (Hoagland *et al.*, 2002). In addition, these types of events can also originate economic or social problems in tourist areas as a result of the degradation of recreational waters (Garcés *et al.*, 1999; Giacobbe *et al.*, 2004).

In the last decade, HAB events have been detected increasingly in the Mediterranean Sea (Vila *et al.*, 2001; Zingone *et al.*, 2006; Nikolaidis *et al.*, 2005). HAB monitoring programs mainly associated with aquaculture activities have been developed mainly in northern Mediterranean coastal waters, but also in some southern countries (Turki & Balti, 2005; El Madani, 2004). However, little is known about the phytoplankton communities along the 1200 Km-long Algerian coasts in the S-W Mediterranean Sea, and what data are available are mainly relative to off-shore waters. Previous works have focused on the relationships between primary production and the dynamic physical structure of the Algerian current. After leaving the Alboran Sea, the Atlantic current flows along the Algerian coasts forming turbulent structures such as eddies and meanders (Millot, 1985; Benzohra & Millot, 1995). These instabilities generate high phytoplankton biomass (Taupier-Letage, 1988; Raimbault *et al.*, 1993; Morán *et al.*, 2001; Taupier-Letage *et al.*, 2003). Illoul *et al.* (2005) hypothesised that the toxic dinoflagellate *Gymnodinium catenatum* Grah. is transported from the western to the eastern Mediterranean by the Atlantic current. However, a local population is already established in Algerian waters and resting cysts have been isolated from sediments of Bou-Ismaïl Bay (Illoul *et al.*, 2005). Although previous floristic lists also established the presence of several harmful species of microalgae (Lecal, 1957; Pincemin, 1966; Gaumer, 1981; Illoul, 1991; Frehi *et al.*, 2007), neither HAB monitoring programmes nor extended temporal phytoplankton sampling have

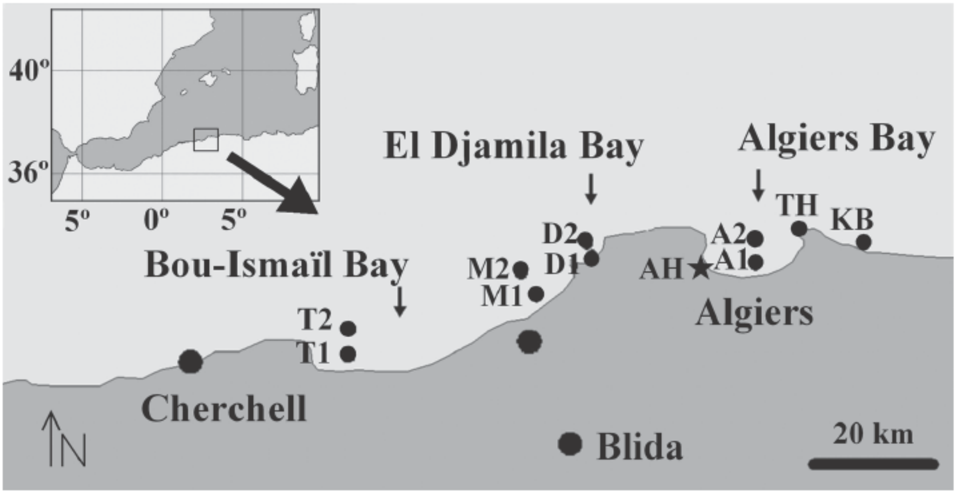


Fig. 1. Location of the sampling stations in the Algiers area.

been implemented on the Algerian coasts. It is known that one of the main difficulties in assessing the expansion of harmful phytoplankton species is the lack of knowledge of their distribution (Zingone & Wyatt, 2005).

The aim of this work is to investigate the occurrence of HAB species in the Algiers coastal area and to detect areas and seasons when the risk of HAB occurring is higher, based on phytoplankton analyses from: a) seasonal sampling in two embayments of the Algiers coast (Algiers Bay and Bou-Ismaïl Bay); b) a monthly sampling in El Djamila Bay during an annual cycle; and c) a short-term sampling in the Algiers Harbour and El Kadous beach during summer conditions (Fig. 1).

METHODS

The Algerian coast extends for some 1200 Km along the S-W Mediterranean Sea. The study area (36°30'-36°50' N, 2°25'-3°18' E) includes Algiers Bay, Bou-Ismaïl Bay, Algiers Harbour and El Kadous beach (see Fig. 1 and Table 1 for sampling frequency and periods).This area is the most densely populated one one the Algerian coast (3 million inhabitants in Algiers = 10% of the Algerian population), Bou-Ismaïl Bay being the most important fishing area of the region. The surroundings of Algiers have intense industrial activity (25% of national companies are located in this part of the country). Algiers Harbour is the biggest harbour of Algeria with 34% of its total commercial activity. The main oueds (temporary rivers) of the area are the Oued El-Harrach in Algiers Bay (flow 6 $m^3 s^{-1}$) and the Oued Mazafran in Bou-Ismaïl Bay (flow 6.88 $m^3 s^{-1}$).

Water samples (250 ml) were collected with a van Dorn sampling bottle and net (20 µm mesh) hauls were obtained horizontally. For phytoplankton investigations, water samples were preserved in acidic Lugol's solution giving the

Table 1. Area and sampling period characteristics

Area	*Station code*	*Sampling depths (m)*	*Station depths (m)*	*Coast distance (miles)*	*Sampled period*
Algiers Bay	A1	0-10	15	< 0,5	October 2001 January, April, July 2002
	A2	0-10-20-30-40	50	1	
El Djamila Bay	D1	0	10	< 0,5	October 2001 January, April, July 2002
	D2	0-10-20	30	0,5	Annual cycle 2001-2002
Bou-Ismaïl Bay	M1	0-10	15	< 0,5	October 2001 January, April, July 2002
	M2	0-10-20-30-40	50	1	
	T1	0-10	15	< 0,5	
	T2	0-10-20-30-40	50	1	
Algiers Harbour	AH	0			July, August 2003
Tamenfoust Harbour	TH	0			
El Kadous Beach	KB	0			

sample a weak brown colour at final fixing concentr Buffered formaldehyde with hexamethylenetetramine was used for fuixing net and coccolithophore bloom samples. Depending on the cell concentration, water sample aliquots of 50, 10 or 2.5 ml were settled in counting chambers for analysis on an inverted microscope (Nikon Diaphot 200) following the Utermöhl method (Throndsen, 1995). Generally, four transects were counted for the smaller cells at 400x and the complete chamber for the bigger ones at 200x.

Taxonomic identifications to species or genus were carried out based on Balech (1988), Dodge (1982), Tomas (1997) and the IOC list (2002). Sanning electron microscopy (SEM) was used for detailed observations when necessary. Aliquots (1-3 ml) of net or water samples were filtered, washed in distilled water, dehydrated in a graded ethanol series, critical point-dried with CO_2 and sputter-coated with gold/palladium (Maugel *et al.*, 1980). For observation of *Pseudo-nitzschia* species, frustule cleaning was carried out beforehand (Hasle, 1978). Critical point-drying with hexamethyldisilazane (HMDS) was used for naked dinoflagellates (Botes *et al.*, 2002). After dehydration in ethanol, samples were immersed in pure HMDS and then air dried. Samples were observed using an Hitachi S-3500N SEM. In order to improve visualization, SEM images of cells were digitally cut from the background using Adobe Photoshop CS2 software (version 9.0) but they images were not transformed in any other way.

In order to follow the expansion of a coccolithophore bloom detected from the analysed samples, satellite images from SeaWiFS/Orbview-2 and granules from MODIS/Aqua covering the Algerian coast for the period 1st-20th August 2003 were obtained from the NASA Goddard Space Flight Centre

DAAC. High-resolution level 1 (L1) SeaWiFS ocean color radiances were atmospherically corrected and processed to level 2 (L2) and a coccolithophore bloom mask was generated using SeaDAS version 4.4p5 (Brown, 1995). The sea surface temperature (SST) was recorded using AVHRR (Advanced Very High Resolution Radiometer) NOAA 16 and 17 from data acquired by the receiving station at the Institut de Ciències del Mar, Barcelona.

RESULTS

The spatial distribution of the potentially harmful species detected in the study area shows that most species are ubiquitous along the Algiers coast (Table 2). Their maximum concentrations, frequency and temporal distribution are shown in Table 3 together with the southern Mediterranean areas where harmful events of the species were previously detected.

Among the potential toxin producers, seven species of the dinoflagellate genus *Dinophysis* (DSP) were encountered during the annual cycle and seasonal cruises. *Dinophysis* cf. *acuminata* Clap. & Lach. (Fig. 2), *D. sacculus* Stein (Fig. 3), *D. fortii* Pav. (Fig. 4), *D. tripos* Gourr. (Fig. 5) and *D. rapa* (Stein) Bal. appeared only seldom in the study area, whereas *D. rotundata* Clap. & Lach. (Fig. 6) and *D. caudata* Saville-Kent (Fig. 7) were regularly recorded in all stations. *D. caudata* showed an apparent seasonality with occurrence taking place essentially in July. All species mentioned previously appeared at low concentrations (< 10^2 cells l^{-1}). Other potentially toxic dinoflagellates, namely *Alexandrium minutum* Halim (PSP), *Ostreopsis* sp. (palitoxin producer), *Prorocentrum minimum (*Pav.) Schiller (NTX), *P. lima* (Ehr.) Stein (DSP) and *P. mexicanum/rhathymum* (DSP), appeared at low frequencies (% Np: 0.7-8.7) and low concentrations (< 10^3 cells l^{-1}). Another *Alexandrium* species was detected at very low concentrations in the study area but it could not be identified down to species level. The potentially ASP-producing diatom, *Pseudo-nitzschia calliantha* Lundholm, Moestrup & Hasle (Figs 8-9), identified in November during the annual cycle sampling series, reached 4×10^3 cells l^{-1}. Among the potentially bloom-forming species, *Prorocentrum triestinum* and *Scrippsiella* spp. Occurred at relatively high concentrations (1.8×10^4 and 2.6×10^4 cells l^{-1}) in Algiers Bay. *Chaetoceros* spp., *Cyclotella* sp. and *Cerataulina pelagica* were recorded in the A1station in July with 8×10^5, 3×10^5 and 2.6×10^5 cells l^{-1}, respectively. Other potentially bloom-forming species such as *Ceratium fusus* (Ehr.) Dujard., *Gonyaulax* spp., *Noctiluca scintillans* (Macartney) Kof. & Swezy, *Prorocentrum balticum* (Lohm.) Loebl., *P. dentatum* Stein and *P. micans* Ehr. were frequently recorded (% NP: 11.1-34%) but at concentrations lower than 10^4 cells l^{-1}.

Most of the species that appeared in the Algiers Harbour were also present in open waters. However, the potential okadaic acid producers *Dinophysis sacculus* and *D.* cf. *acuminata* reached their highest concentrations in Algiers Harbour and El Kadous beach. The former reached 3.6×10^3 cells l^{-1} in Algiers Harbour, whereas the latter reached $1.2\ 1 \times 0^3$ cells l^{-1} in El Kadous beach. Blooms caused by several species, including diatoms, dinoflagellates and a coccolithophorid, were detected during the summer sampling in Algiers Harbour. The causative species were, in decreasing order of importance, *Chaetoceros* spp., *Cyclotella meneghiniana* Kütz. (Fig. 10) and *Leptocylindrus minimus* Gran (Figs 11-12). By contrast, in El Kadous beach diatoms were completely absent.

Table 2. Spatial distribution of potentially harmful species in Algiers area

Species \ *Stations*	*A2*	*D2*	*M2*	*T2*	*A1*	*D1*	*M1*	*T1*	*AH*	*TH*	*KB*
Holococcolithophora sphaeroidea	*				*				+++	+++	
Alexandrium minutum	+										
Ceratium fusus	+	+	+	+			+	+	+		
Dinophysis cf. *acuminata*		+							+		+
Dinophysis caudata	+	+	+	+	+		+	+			
Dinophysis fortii		+		+							
Dinophysis rapa	+										
Dinophysis rotundata	+	+	+	+	+			+			
Dinophysis sacculus					+				+		+
Dinophysis tripos		+									
Gonyaulax spp.	+	+	+	+	+			+	+		+
Gymnodinium catenatum	+	+	+	+				+			
Lepidodinium chlorophorum									+++		
Noctiluca scintillans	+	+	+	+	+	+		+			
Ostreopsis sp.		+									+
Prorocentrum balticum	+	+	+	+	+		+	+			
Prorocentrum dentatum	+	+	+	+	+			+			
Prorocentrum lima		+		+				+			+
Prorocentrum mexicanum/ rhathymum		+						+			
Prorocentrum micans	+	+	+	+	+	+	+	+			
Prorocentrum minimum	+	+	+	+				+			
Prorocentrum triestinum	+	+	+	+	+	+	+	+	+	+	+++
Protoperidinium quinquecorne	+	+		+	+						+
Scrippsiella spp.	+	+	+	+	+	+	+	+	+	+	+++
Cerataulina pelagica	+	+			+++		+		+++		
Chaetoceros spp.	+	+	+	+	+	+	+	+	+++		
Cyclotella meneghiniana		+			+				+++		
Cyclotella sp.		+			+++						
Leptocylindrus danicus	+	+	+	+	+		+	+			
Leptocylindrus minimus									+++		
Pseudo-nitzschia calliantha		+									
Pseudo-nitzschia spp.	+	+	+	+	+		+	+	+		
Dictyocha fibula	+	+	+				+				

See Table 1 and Fig. 1 for stations code and location.
+++: > 10^5 cells l^{-1}
*: Coccolithophore bloom mask (MODIS/Aqua datas).

Table 3. Maximum concentrations and temporal distribution of potentially harmful species in Algiers area

Species	*Harmful effects*	*Max. Conc. (cells l^{-1})*	*Station Max. Conc.*	*Month Max. Conc.*	*Np*	*% Np*	*Months of presence in study area*	*Year of presence in study area*	*Location of HAB events in SW Mediterranean (toxic or bloom events)*
Prymnesiophyceae ***Holococcolithophora sphaeroidea*** (Schiller) Jordan *et al.*	Bf Disc	$4.7\ 10^8$	TH	August	5	3.3	July-Aug	2003	**Present work**
Dinophyceae ***Alexandrium minutum*** Halim	PSP, Bf	< 20			1	0.6	July	2002	Tunisia (Romdhane *et al.*, 1998), Egypt*, Morocco*
Ceratium fusus (Ehrenberg) Dujardin	Fk	$< 10^3$			49	32	wide distribution	2001-2002	
Dinophysis cf. ***acuminata*** Claparède & Lachmann	DSP	$1.2\ 10^3$	KB	July	7	4.6	Feb-July-Aug	2002-2003	**Present work****, Morocco*
Dinophysis caudata Saville-Kent	DSP	$< 10^2$			11	7.2	Feb-Apr-June-July	2001-2002	Morocco*, Tunisia*, Egypt*
Dinophysis fortii Pavillard	DSP	< 20			2	1.3	Apr-June	2002	
Dinophysis rapa (Stein) Balech	DSP	$< 10^2$			2	1.3	July	2002	
Dinophysis rotundata Claparède & Lachmann	DSP	$< 10^2$			14	9.1	wide distribution	2001-2002	
Dinophysis sacculus Stein	DSP	$3.3\ 10^3$	AH	July	6	3.9	July-Aug	2002-2003	**Present work****, Tunisia*, Morocco*
Dinophysis tripos Gourret	DSP	< 20			1	0.6	June	2002	
Gonyaulax spp.	Bf	$5\ 10^3$	KB	Aug	36	23.5	wide distribution	2001-2002-2003	
Gymnodinium catenatum Graham	PSP	$3.2\ 10^3$	T2	October	22	14.4	Apr-July-Sept-Oct- Nov	2001-2002	Morocco (Tahri Joutei, 1998), Annaba Bay (Frehi *et al.*, 2007)

ASP: amnesic shellfish poisoning, DSP: diarrhetic shellfish poisoning, PSP: paralytic shellfish poisoning, NTX: neurotoxic, Bf: bloom-forming; Fk: fish kill, Disc: discoloration, Tmf: toxic for marine fauna, Hhp: human health problems. Max. Conc.: maximal concentration. The stations and months with concentrations $< 10^3$ cells l^{-1} are omitted in the table. See Table 1 and Fig. 1 for stations code and location. Np: number of occurrence in all samples (total of samples, T = 153), % Np = Np*100/T.
*: information source: http://ioc.unesco.org/hab/HANA/events.htm.
**: for DSP producers concentrations higher than 10^3 cells l^{-1} are considered potential harmful events.

Table 3. Maximum concentrations and temporal distribution of potentially harmful species in Algiers area *(continued)*

Species	*Harmful effects*	*Max. Conc. (cells l^{-1})*	*Station Max. Conc.*	*Month Max. Conc.*	*Np*	*% Np*	*Months of presence in study area*	*Year of presence in study area*	*Location of HAB events in SW Mediterranean (toxic or bloom events)*
Lepidodinium chlorophorum (Elbrächter & Schnepf) Hansen *et al.* **comb. nov.**	Bf , Disc	2.6 10^6	AH	July	3	2	July-Aug	2003	**Present work**
Noctiluca scintillans (Macartney) Kofoid & Swezy	Bf Disc Fk	< 10^2			17	11.1	Jan-Feb-Apr-Oct	2001-2002	Morocco*, Tunisia*
***Ostreopsis* sp.**	Tmf Hhp	< 10^3			4	2.6	July-Aug	2002-2003	
Prorocentrum balticum (Lohmann) Loeblich	Bf	3.5 10^3	T2	Oct	52	34	wide distribution	2001-2002	
Prorocentrum dentatum Stein	Bf Disc	< 10^3			18	11.8	wide distribution	2001-2002	
Prorocentrum lima (Ehrenberg) Stein	DSP	< 10^3			11	7.2	Jan-Apr-Aug-Sep-Oct	2001-2002-2003	
Prorocentrum mexicanum/ rhathymum	DSP	< 10^2			2	1.3	Feb-Oct	2001-2002	
Prorocentrum micans Ehrenberg	Bf	1.6 10^3	A2	April	31	20.3	Jan-Feb-Apr-July-Oct	2001-2002	Egypt*
Prorocentrum minimum (Pavillard) Schiller	NTX, Bf	1.6 10^3	T2	April	13	8.5	Jan-Apr-July-Sep-Oct	2001-2002	Egypt*
Prorocentrum triestinum Schiller	Bf Disc	10^5	KB	May	44	28.8	wide distribution	2001-2002-2003	**Present work,** Annaba Bay (Frehi *et al.*, 2007), Egypt*

ASP: amnesic shellfish poisoning, DSP: diarrhetic shellfish poisoning, PSP: paralytic shellfish poisoning, NTX: neurotoxic, Bf: bloom-forming; Fk: fish kill, Disc: discoloration, Tmf: toxic for marine fauna, Hhp: human health problems. Max. Conc.: maximal concentration. The stations and months with concentrations < 10^3 cells l^{-1} are omitted in the table. See Table 1 and Fig. 1 for stations code and location. Np: number of occurrence in all samples (total of samples, T = 153), % Np = Np*100/T.

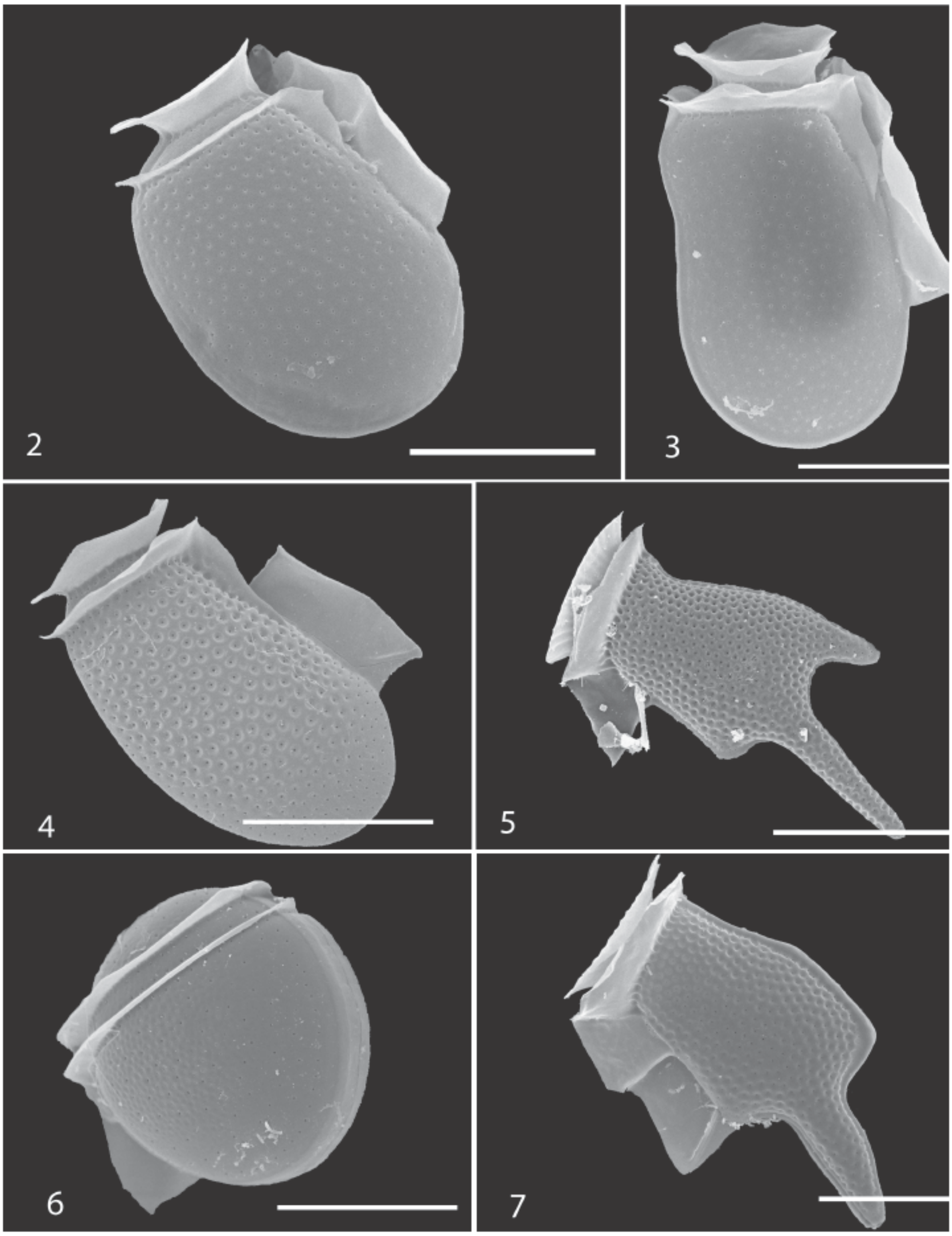
*: information source: http://ioc.unesco.org/hab/HANA/events.htm.

**: for DSP producers concentrations higher than 10^3 cells l^{-1} are considered potential harmful events.

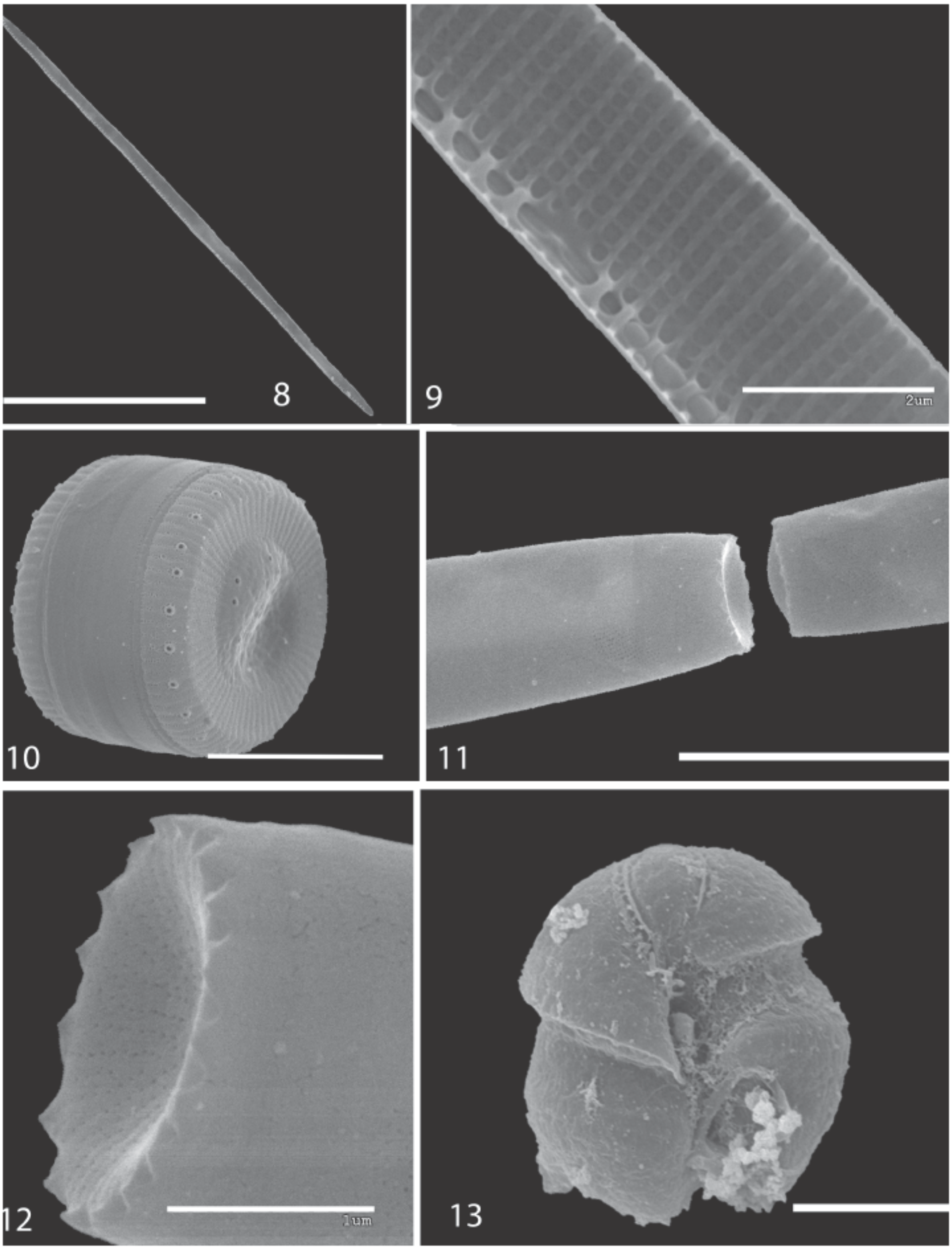
Table 3. Maximum concentrations and temporal distribution of potentially harmful species in Algiers area *(continued)*

Species	*Harmful effects*	*Max. Conc. (cells l^{-1})*	*Station Max. Conc.*	*Month Max. Conc.*	*Np*	*% Np*	*Months of presence in study area*	*Year of presence in study area*	*Location of HAB events in SW Mediterranean (toxic or bloom events)*
Protoperidinium quinquecorne (Abé) Balech	Bf	$< 10^3$			5	3.3	July-Aug-Oct	2001-2002-2003	Egypt*, Tunisia*
***Scrippsiella* spp.**	Bf Disc	$1.2\ 10^6$	KB	July	72	47.1	wide distribution	2001-2002-2003	
Bacillariophyceae ***Cerataulina pelagica*** (Cleve) Hendey	Bf	$2.6\ 10^5$	A1	July	17	11.1	July-Oct-Nov-Aug	2001-2002-2003	**Present work**, Egypt*
***Chaetoceros* spp.**	Bf	$3.5\ 10^7$	AH	July	29	18.9	wide distribution	2001-2002-2003	
Cyclotella meneghiniana Kützing	Bf	$1.1\ 10^6$	AH	July	6	3.9	July-Aug	2003	**Present work** Egypt (Ismael & Dorgham, 2003)
***Cyclotella* sp.**	Bf	$8\ 10^5$	A1	July	2	1.3	July	2001-2002	
Leptocylindrus danicus Cleve	Bf	$7.9\ 10^4$	A1	April	16	10.5	Jan-Apr-Sep-Oct-Nov	2001-2002	
Leptocylindrus minimus Gran	Bf Fk	$2.2\ 10^6$	AH	August	4	2.6	July-Aug	2003	**Present work** Egypt (Mikhail, 2001)
Pseudo-nitzschia calliantha Lundholm, Moestrup et Hasle	ASP	$4\ 10^4$	D2	Nov	1	0.6	November	2001	**Present work** Tunisia (Sahraoui *et al.*, 2006)
***Pseudo-nitzschia* spp.**	ASP	$3.8\ 10^4$	AH	August	19	12.4	Jan-Mar-July-Aug-Sep-Nov	2001-2002-2003	
Chrysophyceae ***Dictyocha fibula*** Ehrenberg	Bf Fk	$< 10^3$			7	4.6	Jan-June-Sep-Oct-Dec	2001-2002	

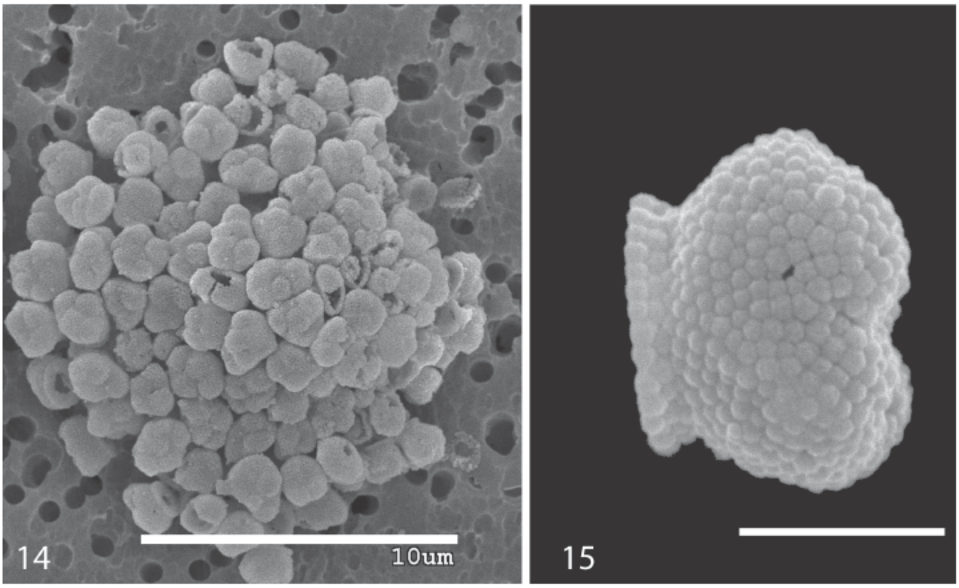
ASP: amnesic shellfish poisoning, DSP: diarrhetic shellfish poisoning, PSP: paralytic shellfish poisoning, NTX: neurotoxic, Bf: bloom-forming; Fk: fish kill, Disc: discoloration, Tmf: toxic for marine fauna, Hhp: human health problems. Max. Conc.: maximal concentration. The stations and months with concentrations $< 10^3$ cells l^{-1} are omitted in the table. See Table 1 and Fig. 1 for stations code and location. Np: number of occurrence in all samples (total of samples, T = 153), % Np = Np*100/T.
*: information source: http://ioc.unesco.org/hab/HANA/events.htm.
**: for DSP producers concentrations higher than 10^3 cells l^{-1} are considered potential harmful events.



Figs 2-7. **2.** *Dinophysis* cf. *acuminata*, SEM. Scale bar: 20 µm. **3.** *Dinophysis sacculus*, SEM. Scale bar: 20 µm. **4.** *Dinophysis fortii*, SEM. Scale bar: 30 µm. **5.** *Dinophysis tripos*, SEM. Scale bar: 50 µm. **6.** *Dinophysis rotundata*, SEM. Scale bar: 30 µm. **7.** *Dinophysis caudata*, SEM. Scale bar: 30 µm.



Figs 8-13. **8.** *Pseudo-nitzschia calliantha* (entire cell), SEM. Scale bar: 30 µm. **9.** *Pseudo-nitzschia calliantha* (detail), SEM. Scale bar: 2 µm. **10.** *Cyclotella meneghiniana*, SEM. Scale bar: 5 µm. **11.** *Leptocylindrus minimus*, SEM. Scale bar: 5 µm. **12.** *Leptocylindrus minimus* (detail), SEM. Scale bar: 1 µm. **13.** *Lepidodinium chlorophorum*, SEM. Scale bar: 5 µm.



Figs 14,15. **14.** *Holococcolithophora sphaeroidea*, SEM. Scale bar: 10 µm. **15.** A coccolith of *Holococcolithophora sphaeroidea*, SEM. Scale bar: 1 µm.

The bloom-forming dinoflagellates *Scrippsiella* spp. and *Prorocentrum triestinum* were present in all samples collected in Algiers Harbour (respective maxima: 4.2×10^5 and 6.5×10^4 cells l^{-1}, 22nd July). On 25th July, in El Kadous beach these species reached 1.2×10^6 and 10^5 cells l^{-1}, causing green discolouration of the water. During the same period, another discolouration-producing dinoflagellate, *Lepidodinium chlorophorum* (Elbrächter & Schnepf) Hansen, Botes & De Salas (Fig. 13), bloomed in Algiers Harbour on 29th July with 2.6×10^6 cells l^{-1}.

In August 2003, a massive bloom of the holococcolithophorid *Holococcolithophora sphaeroidea* (Schiller) Jordan, Cros &. Young (Figs 14, 15) caused a strong yellowish discolouration in Algiers waters. Cell concentration reached 4.7×10^8 cells l^{-1} in Tamentfoust Harbour (a small fishing harbour in the eastern part of Algiers Bay). Satellite imagery showed that this invasive population covered almost the whole of Algiers Bay and was transported toward off-shore waters by an anticyclonic eddy (Fig. 16).

DISCUSSION

The near-coastal waters of the study area (inner part of Algiers Bay, El Kadous beach and Algiers Harbour) are characterised by the presence, high frequency and abundance of several potentially harmful microalgal species, especially bloom-forming ones like *Scrippsiella* spp., *Prorocentrum triestinum* and *Chaetoceros* spp.

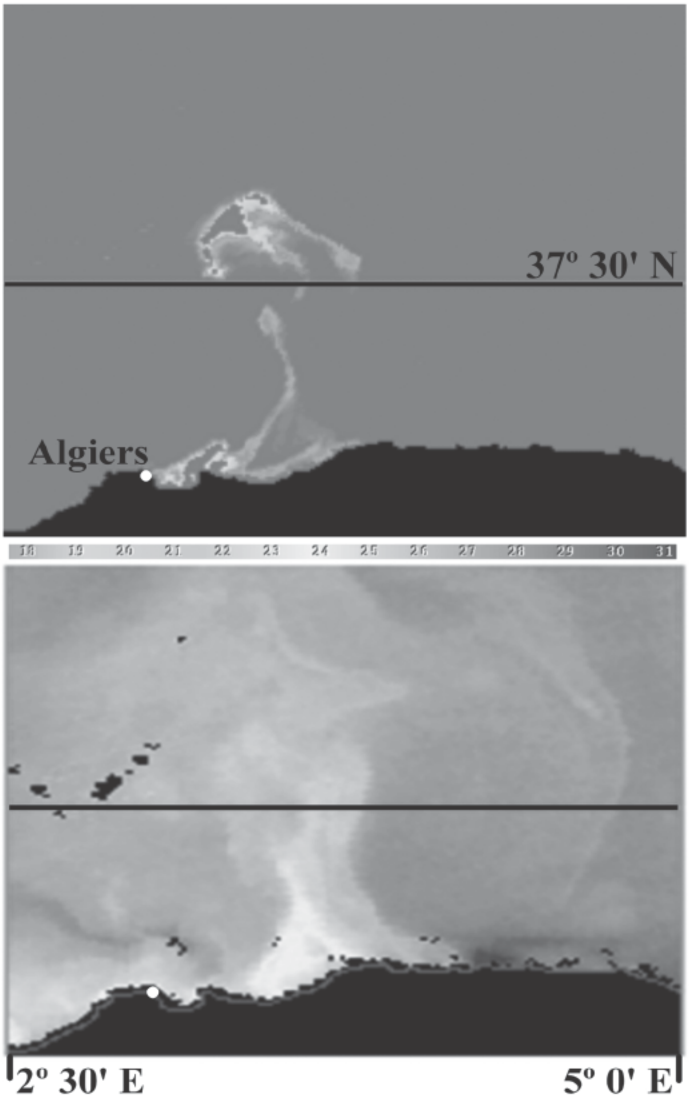


Fig. 16. Satellite imagery of coccolithophorid bloom. Coccolithophorid bloom mask (13-08-2003) from MODIS/Aqua (above). SST with temperature scale (13-08-2003) from AVHRR data (below).

Two potentially toxic species of the genus *Dinophysis* found at high concentrations in the study area were *D.* cf. *acuminata* and *D. sacculus*. Only *D. acuminata* had already been found in Algerian waters (Lecal, 1957; Pincemin, 1966; Gaumer, 1981; Illoul, 1991; Samson-Kechacha & Touahria, 1992). According to Blanco *et al.* (1998), the densities of *D.* cf. *acuminata* which were recorded are higher than the minimal concentrations capable of producing intoxication. In the Mediterranean Sea, harmful effects have been observed for both species. In the northern part, okadaic acid contamination of mussels caused by *D. sacculus* in the Tyrrhenian Sea and Spanish waters has been reported (Giacobbe *et al.*, 1995; Delgado *et al.*, 1996; Vila *et al.*, 2001). In the Aegean Sea, *D. acuminata* caused a DSP event (Koukaras & Nikolaidis, 2004). The detection of DSP was related to *Dinophysis acuminata* and *D. sacculus* in a Moroccan lagoon, in the southern Mediterranean Sea (Tahri Joutei *et al.*, 2003) whereas DSP contamination of clams was found in Tunisian shellfish areas (Turki, 2004). Among the seven species of *Dinophysis* identified in the present study, six of them were recorded in the Campania region of Italy (Tyrrhenian Sea) (Zingone *et al.*, 2006). *Dinophysis caudata, D. fortii, D. rapa, D. rotundata* and *D. tripos* were also detected recently in Annaba Bay, eastern coast of Algeria (Frehi *et al.*, 2007).

Alexandrium minutum, first described in the Alexandria Harbour (Halim, 1960), was another potentially toxic species collected in the Algiers area. It is widely distributed in the northern Mediterranean Sea, where it causes recurrent blooms and shellfish toxicity (Honsell *et al.*, 1996; Nikolaidis *et al.*, 2005; Vila *et al.*, 2005). In the southern Mediterranean, specifically in the Alexandria Harbour, *A. minutum* was related to massive fish and invertebrate mortality in 1994 (Labib & Halim, 1995) and to shellfish toxicity in Nador Lagoon, Morocco (El Madani, 2004). Another PSP causative species, *A. catenella,* has been detected recently in Annaba Bay (Frehi *et al.*, 2007).

Another potentially toxic species, the diatom *Pseudo-nitzschia calliantha* (ASP), was found in the study area. This is the first detection of this species on the Algerian coast. A toxic clone of *P. calliantha* had already been identified in the Bizerte Lagoon, Tunisia, in the southern Mediterranean (Sahraoui *et al.*, 2006).

The bloom-forming species *Lepidodinium chlorophorum (*originally described as *Gymnodinium chlorophorum,* which was transfe to the genus *Lepidodinium* by Hansen *et al., 2007*), reached very high cell densities in the Algiers Harbour (> 10^6 cells l^{-1}), causing a conspicuous green discolouration of the water. This is the first time that a *Lepidodinium chlorophorum* bloom has ever been detected in the southern Mediterranean. This species has been detected recently also in recreational waters of the Balearic Islands (Illoul *et al.*, in press). In the Mediterranean Sea, the first invasive bloom caused by this symbiont-containing gymnodinioid dinoflagellate was recorded in the Adriatic Sea in 1984 (Honsell & Talarico, 2004). *L. chlorophorum* recurrently generates green discolourations in European coastal waters (Sournia *et al.*, 1992; De Jong *et al.*, 1999; Mouritsen & Richardson, 2003). Blooms reported in Atlantic French and southern Chilean coasts have been related to fish mortality, probably by anoxia (Belin & Raffin, 1998; Sournia *et al.*, 1992; Iriarte *et al.*, 2005). *L. chlorophorum* was also efound at very high concentrations in the German Wadden Sea (De Jong *et al.*, 1999) and Danish waters (Ærtebjerg *et al.*, 2003; Mouritsen & Richardson, 2003) but without noxious effects on fish.

In El Kadous beach, *Scrippsiella* spp. bloomed with > 10^6 cells l^{-1} in July. Within the widely ditributed genus *Scrippsiella*, *Scrippsiella trochoidea* is known to cause fish and invertebrate mortality induced by oxygen depletion at high concentrations (Hallegraeff, 2003).

The bloom-forming diatoms *Leptocylindrus minimus* and *Cyclotella meneghiniana* were recorded during a summer sampling in the Algiers Harbour. Both species occurred at high concentrations (> 10^6 cells l^{-1}). The former was related to fish mortality in Chilean trout and salmon farms (Clément, 1994), while the latter is an indicator of eutrophication (Kauppila *et al.*, 2005).

The *Holococcolithophora sphaeroidea* bloom reported in the present work is the second event of its kind in the Mediterranean Sea. The first Mediterranean bloom of this species was recorded in 2001 in Tarragona Harbour, Catalan coast, Spain (Cros *et al*., 2002). Since 2001, *H. sphaeroidea* blooms have occurred recurrently on the Catalan coasts (L. Cros, personal communication).

CONCLUSIONS

The present study reports on the occurrence of many harmful microalgae identified in the Algerian area. A series of seasonal, monthly and short-term samplings was conducted in open and confined waters of the Algiers area in 2001-2002 and summer 2003 in order to detect harmful phytoplankton species. A total of 14 potentially toxic and 18 bloom-forming species were identified. Most species are ubiquitous along the coast. In general, the species that appeared in open waters were also present in Algiers Harbour at higher concentrations. Potentially toxic species such as *Dinophysis* cf. *acuminata* and *D. sacculus* were found in the Algiers coastal area and collected at high concentrations in the Algiers Harbour and El Kadous beach. The short-term sampling conducted in the Algiers Harbour during summer 2003 revealed the occurrence of several bloom events caused by dinoflagellates (*Lepidodinium chlorophorum*), diatoms (*Leptocylindrus minimus*) or coccolithophores (*Holococcolithophora sphaeroidea*). The transport of the extended *H. sphaeroidea* bloom in the Algiers area during the summer sampling shows the strong effect of mesoscale Algerian eddies on the spatial distribution of phytoplankton biomass. In addition, the case of *H. sphaeroidea* bloom highlights the importance of confined water areas for HAB studies. Indeed, the bloom of this species had already been detected in Algiers Harbour waters several days before the appearance of its visible patches in Algiers Bay. This event agrees with the observations of Vila *et al.* (2001), who consider that the monitoring of harmful phytoplankton in confined waters can act as an alarm system for possible occurrence of HAB's in the open waters. No toxic events or fish mortality events have ever been reported along the Algerian coasts. However, the high number of potentially harmful species detected in this study underlines the need to establish a regular HAB monitoring programme. Aquaculture activities are not developed in the area, although there are indications for investment plans in this field (MPRH, 2006). Overall, the results of the present work suggest that harmful events are more likely to occur in near-shore areas (harbours and beaches) during summer conditions.

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