INTRODUCTION

Amongst the living microscopic algae in the oceans, a few thousands cells can at times cause harm to humans and to marine ecosystems. The negative effects of harmful algae are many and diverse, ranging from economical losses in aquaculture, fisheries and tourism industry to major environmental and human impacts.

Attending the problems that they cause, harmful algae can be categorized into three major groups. The first group is formed by “harmless” organisms that discolor the water due to their massive occurrence. However, under certain conditions, oxygen depletion caused by bacterial respiration during the decay of the algal biomass, results in killing of both fish and invertebrates. Examples of such algae are some dinoflagellates included in the genera Gonyaulax, Scripsiella, Prorocentrum and Noctiluca and some diatoms of the genera Skeletonema, Rhizosolenia and Leptocylindrus (Hallegreaff et al., 2003). The second group, recently recognized, because of the increased interest in intensive aquaculture systems for finfish, includes algae that can damage fish gills either mechanically or chemically through the release of exogenous substances with hemolytic action (Yasumoto, 1989). Examples of algae belonging to this group are the diatoms Chaetoceros convolutus and C. concavicornis; the dinoflagellates Karenia mikimotoi, K. brevisulcata and Karlodinium micrum; the prymnesiophytes Prymnesium spp. and Chrysochromulina polylepis and some raphidophytes species such as Heterosigma akashiwo and Chattonella spp. The third and most important algal group includes microalgal species that produce potent toxins which can cause serious gastrointestinal and neurological illnesses.
and death to humans, after contaminated seafood consumption and deaths to other organisms (fish, marine mammals, birds) (Scholin et al., 2000). The occurrence of toxic microalgae represents a significant threat to human health, aquaculture, fishery resources and marine ecosystems throughout the world (Hallegraeff et al., 2003). Based on the symptoms observed in humans, having consumed contaminated shellfish, five types of poisoning due to marine biotoxins are distinguished; Paralytic Shellfish Poisoning (PSP), Diarrhetic Shellfish Poisoning (DSP), Amnesic Shellfish Poisoning (ASP), Neurotoxic Shellfish Poisoning (NSP), Azaspiracid Poisoning (AZP) and Ciguatera Fish/Shellfish Poisoning (CFP/CSP). The latter is transferred to humans also by consuming contaminated coral reef fish.

The first publication related to harmful algae impacts in Greece goes back to the sixties. Anagnostidis (1968) has reported a “red tide” phenomenon along the coastline of Thessaloniki city resulting in mass fish mortalities. Recently, mass finfish mortality (Veterinarian Authorities, personal communication) was recorded in Amvrakikos Bay (December 1998), probably due to the massive presence of the raphidophyte Chattonella veruculosa.

Water discoloration due to massive growth of microalgae (algal blooms), with no fish mortality, has been reported for the inner part of Thermaikos Bay by Nikolaidis (1994), Nikolaidis & Evangelopoulos (1997) and Nikolaidis et al. (1997). Causative organisms for these events were mainly species of the genus Prorocentrum (P. micans, P. triestinum, P. obtusidens and P. rostratum), the photosynthetic ciliate Mesodinium rubrum, the heterotrophic unarmored dinoflagellate Erythropsidinium sp. and the phagotrophic dinoflagellate Noctiluca scintillans. The occurrence of several potentially harmful phytoplanktonic species was reported, apart from Thermaikos Bay, also in other Greek coastal waters (Ignatiades, 1976; Pagou & Ignatiades, 1990; Ignatiades et al., 1995).

The massive growth of the toxins producer (DSP), dinoflagellate Dinophysis cf. acuminata, that was observed on January 2000 in Thermaikos Bay (Koukaras & Nikolaidis, 2004), was the first documented toxic outbreak in Greece (Mouratidou et al., 2004), which resulted in economical losses of about 5 million Euros in the shellfish industry. This toxic episode was the reason for establishing a monitoring program for marine biotoxins. This program is focused on the occurrence of toxic and potentially toxic microalgae in the shellfish production areas of Greece. In the frame of this phytoplankton monitoring program a number of harmful algal episodes have been recorded. The aim of this paper is to present a survey of harmful algae associated with these episodes in Greek coastal waters during the last five years (2000-2004).

MATERIALS AND METHODS

Study area and sampling stations

Water samples for identification and enumeration of harmful, toxic and/or potentially toxic microalgae were collected from a wide network of fixed points within the separated geographical areas as they are shown in Fig. 1. The number of sampling stations of each area is presented in Table 1.

Sampling and analyses

Water samples from the whole water column (integrated water samples) were taken with a PVC tube equal in length to the depth of each station. Subsamples of 500 ml were placed in plastic bottles and fixed immediately with Lugol’s solution. Species were identified according to the official guidelines of UNESCO (Hallegraeff et al., 2003) and additional specific monographs such as those by Schiller (1933), Hustedt (1962), Sournia (1986) and Tomas (1993, 78

1996). Cells were counted with an inverted microscope, by applying the Utermöhl’s sedimentation method (Utermöhl, 1958). The potentially toxic species were counted using 25 ml (blooming period) and 50 ml (non-blooming period) sedimentation chambers by scanning the whole bottom of the chamber (magnifications \( \times 63, \times 100 \)). Scanning electron microscope (SEM, ZEISS DSM 940A) was additionally used for species identification.

RESULTS

During the last five years (2000-2004), water discoloration due to massive occurrence of microalgae has been observed mostly in the inner part of Thermaikos Bay (Fig. 2a). The most common organism was Noctiluca scintillans (Fig. 2b), a heterotrophic dinoflagellate mainly observed in late winter (February) and at the beginning of spring (March-April) reaching high abundances, between \( 2.0 \times 10^6 \) and \( 5.4 \times 10^6 \) cells l\(^{-1}\). Another organism, the massive growth of which in the inner part of Thermaikos Bay caused water discoloration during spring (April-May) in the years 2001-2003, was the raphidophyte Chattonella cf. globosa (Fig. 2c). Its abundance ranged between \( 2.0 \times 10^4 \) and \( 4.0 \times 10^4 \) cells l\(^{-1}\). Chattonella cf. globosa cells are yellowish brown, spherical in shape with two unequal flagella; one long and the other extremely short, almost invisible. Gymnodinium sp. (Fig. 2d), an unarmored dinoflagellate, also occurred in the inner part of Thermaikos Bay (mainly in September 2002) reaching abundances up to \( 65.4 \times 10^3 \) cells l\(^{-1}\). Its massive occurrence caused yellow-greenish water discoloration.

Discoloration of water was also caused by species of the genus Prorocentrum in different regions of Greece. Prorocentrum cf. obtusidens (Fig. 2e) occurred in the inner part of Thermaikos Bay during the winter 2000-2001 at abundances of about \( 1.2 \times 10^6 \) cells l\(^{-1}\) and was responsible for water discoloration in January 2001. Water discoloration in the same region was similarly caused by another species of this genus (P. redfeldii, Fig. 2f) with an abundance ranging between \( 1.2 \times 10^5 \) and \( 6.0 \times 10^6 \) cells l\(^{-1}\). Prorocentrum minimum (Fig. 2g) mass occurrence (up to \( 11.8 \times 10^4 \) cells l\(^{-1}\)) was observed in April 2003 in Elefsis Bay and also along the coasts of Thrace (Porto-Lagos and Alexandroupolis). In Amvrakikos Bay, P. minimum reached high abundances every year during autumn.

Another species in Amvrakikos Bay that caused water discoloration mainly during spring was Alexandrium insuetum (Fig. 2h). In April 2003 (Fig. 3), mass occurrence (\( 2.54 \times 10^6 \) cells l\(^{-1}\)) of this species caused brownish water discoloration without toxic episodes.

TABLE 1. Spatial distribution of the main harmful algae recorded in the Greek coasts and the number of sampling stations in each area during the present study

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+++ : >10^6 cells l\(^{-1}\); ++ : 10^4 – 10^6 cells l\(^{-1}\); + : 10^3 cells l\(^{-1}\); +— : 10^2 cells l\(^{-1}\); — : abundances below detection level
A. insuetum was observed also in May 2004 at high cell densities (4.71 × 10^5 cells l^-1) in Amvrakikos Bay and its bloom lasted approximately three weeks (Fig. 3).

Microalgae related to toxic episodes have been reported only in Thermaikos and Amvrakikos Bays. These belonged to the genera *Dinophysis* and *Alexandrium* which caused DSP and PSP intoxication. High cell densities (up to 85.4 × 10^3 cells l^-1, middle depth water sample, February 2000) of *Dinophysis* species were recurrently recorded in the inner part of Thermaikos Bay between February and April during the study period (Fig. 4). 98% of the *Dinophysis* population was occupied by the species *D. cf. acuminata* (Fig. 2i). The bloom always initiated in the inner part of the Bay and expanded after 3-4 weeks to the southern part along the coast of Pieria in relation to the water masses circulation in Thermaikos Bay. *Dinophysis cf. acuminata* cells were also observed in Maliakos and Amvrakikos Bays in low abundances. The dominant species within the *Dinophysis* population, either in Maliakos or in Amvrakikos Bays, were *D. sacculus* (Fig. 2j) and *D. caudata* which reached abundances up to 3.0 × 10^3 cells l^-1 (Fig. 4). *Dinophysis* species in lower cell densities (<200 cells l^-1) were further observed in Lesbos and Limnos islands without DSP episodes. In coastal waters of Thrace, Kavala, Evoikos and Elefsis Bays, *Dinophysis* species were sporadically observed in low abundances (<80 cells l^-1).

*Pseudo-nitzschia* species (*P. cf. pungens* [Fig. 2k], *P. pseudodelicatissima*) were recorded throughout the year in all monitored areas. Blooms of the above species were mainly observed during the period March to May (Fig. 5) reaching a maximum abun-
Another potentially toxic, small-sized species of the genus *Alexandrium* (Fig. 2l), probably *A. minutum*, was recorded particularly during spring and early summer in Maliakos and Amvrakikos Bays. Specifically, in Maliakos Bay, this species reached abundance up to $2.7 \times 10^3$ cells l$^{-1}$ (Fig. 3).

The spatial distribution of the main harmful phytoplankton species detected in the Greek coast during the present study is presented in Table 1.

**DISCUSSION**

Greece is one of many countries affected by harmful algae. During the present study, the majority of algal blooms were observed in Thermaikos and Amvrakikos Bays. It is generally accepted that one of the most important factors promoting the development of algal blooms in coastal waters is the nutrient supply from terrestrial sources (Cadée, 1986; Radach et al., 1990; Smayda, 1990). Thermaikos and Amvrakikos Bays are strongly influenced by different human activities and the development of recurrent algal blooms could be explained by the continuous nutrient discharging from rivers and urban sewage. High levels of nutrients could promote algal blooms, but this is not the only factor for bloom development. Nutrient imbalance could also be a parameter that favors certain species versus others (Hodgkiss & Ho, 1997; Bulgakov & Levich, 1999). Because of the increase of nitrogen and phosphorous inputs due to eutrophication, the ratio of these nutrients to silicate becomes very high. This could favor non diatom species including several harmful and toxic species (Smayda, 1989).

During the last five years, silicate concentration in Thermakos Bay seems to decrease (Koukaras & Nikolaidis, 2004) compared to previous measurements (Nikolaidis & Moustaka-Gouni, 1992; Nikolaidis et al., 1995). In Thermakos Bay, the majority of algal blooms are formed by flagellates, mostly dinoflagellates, that dominate over diatoms as they have specialized behaviors, like mixotrophy (Granéli & Carlsson, 1998; Stoecker, 1999) and capability for vertical migration (Hasle, 1950; Villarino et al., 1995).

According to our results, a temporal pattern for algal blooms does not seem to exist, since bloom development was observed throughout the year. However, the majority of blooms were recorded during spring when thermal stratified conditions in the water column begin to establish. Massive growth of dinoflagellates associated with water discoloration was observed in Amvrakikos Bay, where *A. insuetum* population reached high cell densities during spring 2003 and 2004, respectively. *Alexandrium insuetum*, which has been first described by Balech (1985) in Korean Pacific waters, is not a common species of the genus. This species was found in Japanese waters (Yuki & Yoshimatsu, 1990) and recently in the Mediterranean Sea (Daly Yahia-Kefi et al., 2001), but bloom of this species has never been reported. According to our findings, the first bloom of *A. in-
due to the variability of toxin production among those of Maliakos Bay. These results are probably of Sato al. harmful algae with worldwide distribution (Fryxell minutum Grigoriadou only in Amvrakikos Bay (March 2004) (Kaniou-bioassay) in one mussels-sample has been detected Maliakos and Amvrakikos Bays. PSP toxicity (mouse and it was also observed during the present study in mainly in confined areas of the Mediterranean Sea al. (Chang, 1996) and the Mediterranean Sea (Lassus minutum species were recorded only in Amvrakikos Bay (Kan-episodes associated with the presence of Dinophysis kikos Bays the most abundant species of the genus al. (Maestrini, 1998; Godhe, 1995). In Maliakos and Amvra-kikos Bays the most abundant species of the genus Dinophysis were D. sacculus and D. caudata. DSP episodes associated with the presence of Dinophysis species were recorded only in Amvrakikos Bay (Kaniou-Grigoriadou et al., 2005), whereas cell densities of Dinophysis species ranged at similar levels with those of Maliakos Bay. These results are probably due to the variability of toxin production among Dinophysis species concerning regional and season-al morphotypes of one species (Johansson et al., 1996; Sato et al., 1996; Giacobbe et al., 2000).

Another harmful algal species which has been world widely related to PSP events is Alexandrium minutum (Delgado et al., 1990; Honsell, 1993; Vila et al., 2005). This species has been well documented, mainly in confined areas of the Mediterranean Sea and it was also observed during the present study in Maliakos and Amvrakikos Bays. PSP toxicity (mouse bioassay) in one mussels-sample has been detected only in Amvrakikos Bay (March 2004) (Kaniou-Grigoriadou et al., 2004) during the occurrence of A. minutum (<500 cells l⁻¹) along with high abundances of marine cyanobacteria.

The genus Pseudo-nitzschia is a further group of harmful algae with worldwide distribution (Fryxell et al., 1997). The ubiquitous distribution of the genus and its association with domoic acid (DA) production has brought serious attention to this phytoplankton group (Bates et al., 1998). Nine species of Pseudo-nitzschia have been documented to produce DA (P. multiseries, P. australis, P. seriata, P. pseudodelicatissima, P. delicatissima, P. multistriata, P. turgidula, P. fraudulenta and P. pungens) (Hallegraff et al., 2003). In Greek coastal waters, Pseudo-nitzschia species are important component of the phytoplankton community and only two of the previous mentioned DA producers were recorded (P. pseudodelicatissima and P. pungens). However, ASP toxicity in mussels (above the regulatory level of DA: 20 µg g⁻¹) has not been detected (Kaniou-Grigoriadou et al., 2005) in areas where Pseudo-nitzschia species were observed in high abundance. These findings are supported by the results of other re-searches who have found non-toxic clones of P. pseudodelicatissima from around the world and a low amount of DA in P. pungens (Bates et al., 1998; Rhodes, 1998).

The potential hazard of future toxic blooms requires further investigation for harmful algae distribu-tion in Greek coastal waters in order to provide additional information and improve our understand-ing of these phenomena.

ACKNOWLEDGE MENTS

This work was supported by the Prefectures of Thessaloniki, Imathia, Pieria, Kavala, Rodopi, Evros, Preveza, Attiki, Euboia, Lesvos and Fthiotida. The authors would also like to thank the Veterinarian Authorities of each Prefecture for the assistance in the samplings.

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