Journal of the Marine Biological Association of the United Kingdom, 2011, 91(3), 715–725.
doi:10.1017/S0025315410000330

A study on phytoplankton following 'Volgoneft-248' oil spill on the north-eastern coast of the Sea of Marmara

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Following the 'Volgoneft-248' oil spill, phytoplankton distribution within the affected area was investigated for two years. Simultaneously measured physical variables such as salinity, temperature, Secchi disc, current speed and direction, and total petroleum hydrocarbons (TPH) were evaluated together with phytoplankton data. At the time of the accident, the TPH concentration in surface water was measured as 2.17 mg l^{-1} and decreased to 88.5 μg l^{-1} after five days. In the first sampling period, no diatoms were detected in surface water, while dinoflagellates were dominant in the phytoplankton community. The species composition of phytoplankton changed rapidly in two months and the diatoms increased in terms of abundance and diversity. This indicated that the diatoms might be more sensitive to oil pollution than the dinoflagellates. In comparison with the historical datasets, the low phytoplankton abundance following the oil spill should be considered as the small effect of oil on the phytoplankton rather than natural variability of the ecosystem. High oil concentration in the water column caused stress on the phytoplankton and influenced the species composition negatively depending on the sensitivity of groups and the natural variability of the ecosystem.

Keywords: phytoplankton, diatom, dinoflagellate, oil pollution, 'Volgoneft-248', Sea of Marmara

Submitted 19 May 2009; accepted 25 September 2009; first published online 30 June 2010

INTRODUCTION

As the primary producers of marine ecosystems, i.e. phytoplanktonic organisms, are sensitive to water pollution and hydrological conditions, they have been considered as an indicator of water quality. Many environmental variables influence the distribution of the phytoplankton community. The oil contamination imposes various effects on the phytoplankton (Kühnhold, 1978; Lännergren, 1978; Johansson *et al.*, 1980; Dahl *et al.*, 1983; Goutz *et al.*, 1984; Ostgaard *et al.*, 1984; Tomajka, 1985; Skjoldal & Thingstad, 1987; Batten *et al.*, 1998; Varela *et al.*, 2006). The effect of oil spill on the marine life have been proved by tankers such as the 'Torrey Canyon' (Nelson-Smith, 1970), the 'Santa Barbara' (Straughan, 1972), the 'Argo Merchant' (Kühnhold, 1978) the 'Amoco Cadiz' (Marchand, 1980; Dauvin, 1998), the 'Tsesis' (Johansson *et al.*, 1980), the 'Sea Empress' (Batten *et al.*, 1998) and the 'Exxon Valdez' (Rice *et al.*, 1996; Boehm *et al.*, 1997).

Some of the researchers reported an increase in phytoplankton biomass in the oil spill area (e.g. Dahl *et al.*, 1983; Goutz *et al.*, 1984; Gray *et al.*, 1990; Batten *et al.*, 1998), but it was not clearly demonstrated whether this was caused by an increase in photosynthetic activity or a decrease in zooplankton grazing due to the oil (Lännergren, 1978; Johansson *et al.*, 1980). Varela *et al.* (2006) emphasized the importance of the natural variability on the plankton and stated that the effect of oil decreased if the oil spill occurred in winter. Further, some authors reported that the petroleum hydrocarbons caused a decrease in photosynthesis up to 36–40% (Goutz *et al.*, 1984; Tomajka, 1985), stress occurred an increase in biomass and some changes in species composition (Elmgren *et al.*, 1980) and oil spills inhibited the growth of phytoplankton (Castro & Huber, 2000). However, Gordon & Prouse (1973) mentioned that the degree of inhibition was related to the type and amount of oil. According to Dunstan *et al.* (1975), the low-molecular weight aromatic hydrocarbon compounds could be the growth stimulator of particular species and a major growth inhibitor at high concentrations.

The waterway between the Mediterranean and Black Sea, including the Strait of Istanbul (Bosphorus), Sea of Marmara and the Strait of Çanakkale (Dardanelles) has an intense maritime traffic. The ship-originated pollution caused by mainly dense navigation and maritime accidents is one of the most important problems in this marine environment and the surrounding coastal areas (Doğan & Burak, 2007). In winter this region is affected by continuous passage of cyclonic systems with typical southerly winds posing the highest pollution risk along the northern Marmara coasts (Alpar *et al.*, 2003).

The accident of the Russian oil tanker 'Volgoneft-248' was caused by a strong southerly gale which broke the ship into two parts, approximately 1 km off the coasts of Florya (north-eastern Sea of Marmara) on 29 December 1999. The bow part sank at once and the aft side of the vessel drifted and grounded at shore, while the 'Volgoneft-248' was carrying 4365 tons of heavy fuel oil, and 1579 tons of fuel oil was spilled into the Sea of Marmara. The spilt oil was carried ashore by

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the strong south-westerly winds and waves within a very short time of the accident. The oil was 2–10 m wide and 5 cm thick. A great amount of fuel oil drifted on the shore covered up with sand and then spread in sheets over the sea bottom. Barriers were laid around the vessel in order to avoid leakage of the remaining fuel oil. The clean-up operations were carried out rapidly to remove environmental pollution. The oil was removed and delivered to the receivers. Most of the oil in the sunken bow tanks was recovered in February 2000 (Alpar & Ünlü, 2007). Seasonal phytoplankton distribution on the north-eastern coast of the Sea of Marmara was studied by several researchers (e.g. Uysal, 1996; Balkıs, 2003, 2004; Okuş & Taş, 2007; Deniz & Taş, 2009). This work has a significant importance because the phytoplankton community has been investigated following the oil spill.

The aim of this study is to evaluate the effect of the 'Volgoneft-248' oil spill on the local phytoplankton community. Firstly, we assume that the low phytoplankton abundance in the affected area by oil spill might be related to the effect of oil on phytoplankton. Also, the effect of oil on phytoplankton might be limited due to the natural hydrological conditions in winter. Secondly, the sensitivity of phytoplankton groups to the high oil concentrations may indicate some differences.

MATERIALS AND METHODS

The study area and sampling design

The study area was located at the north-east margin of the Sea of Marmara; including the entire region affected by the 'Volgoneft-248' oil spill offshore Florya. This region was connected to Küçükçekmece Lake with a channel. The sampling depths at Stations A5 and A5C were about 6 m and 78 m, respectively. The coasts of the accident area were composed of beaches, restaurants and recreational spots. The study area consisted of 7 sampling stations. Although the sampling regions presented some geographical differences, the nearest stations to the current study area were chosen for comparison (Figure 1).

Temperature and salinity were measured by the SBE-9 CTD system. Current speed and directions were measured with RDI broad band ADCP (150 kHz). Niskin bottles (5 l) were used for all seawater samples. Secchi depth was measured using a standard Secchi disc. The wind speed and direction data were provided from Kandilli Meteorological Station. The sampling periods were carried out depending on the stages of the clean-up operations in the first year and monitoring samples were collected in winter and summer of the second year. During the study period, 7 sampling periods were planned from January 2000 to January 2002. The first seawater samples were taken a few hours after the accident (30 December 1999). Unfortunately, these samples could not be examined for phytoplankton analysis due to very intense oil contamination. Therefore, first seawater samples for phytoplankton analysis were taken on 3 January 2000. The sampling stations were planned as the surface current system and hydrographical structure of this region. At the beginning of the current study, the chlorophyll-*a* and nutrient analyses could not be performed because the water column contained a very high contamination level of the oil as it was affected severely by the continuing clean-up operations.

Seawater analysis

The unfiltered seawater samples were analysed by UV-fluorescence for dissolved/dispersed hydrocarbons according to the MARPOLMON protocol (UNESCO, 1984). To determine the pollution belonging to the 'Volgoneft-248',

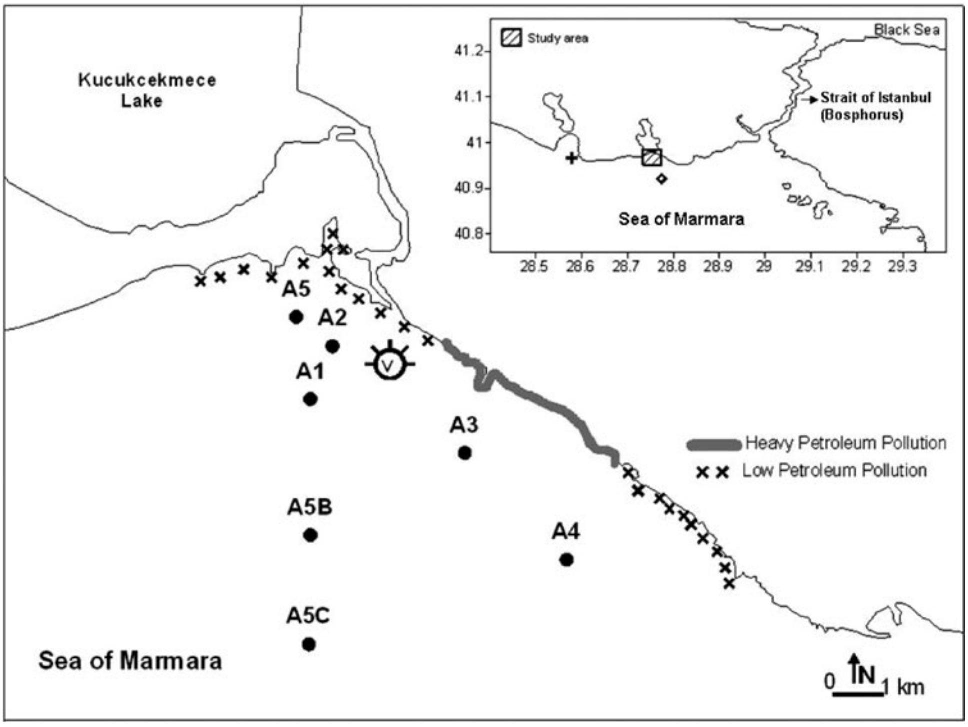

Fig. 1. The study area. Symbols used: shipwreck area (V); seawater sampling stations (A); the sampling stations from the previous studies (∀,%) (″,%).

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approximately 2.8 l seawater was extracted 100 ml dichloromethane (DCM, Lab-Scan, and HPLC Grade) for three times to the separation funnel. Phases of separated DCM were put together and onto some waterless sodium sulphate added, filtered and distilled at 36°C, 310/360 nm (ex/em) was read in UVF and the amount of fuel oil was determined from the standard curve belonging to the fuel oil of 'Volgoneft-248'. A standard curve drawn by the petroleum of the tanker, which had the accident, was used. Thus, standard curve was drawn according to the fuel-oil sample taken from 'Volgoneft-248'. The sample was resolved in 0.005, 0.01, 0.02, 0.03, 0.04 and 0.05 μg/ml concentrations in hexane. The standard curve and its equation were obtained depending on the intensities obtained from the ultraviolet fluoro-spectrophotometer (UVF, Shimadzu, RF-1501) 310/360 nm (ex/em).

The phytoplankton water samples were collected from the surface and 10 m depth using Niskin bottles and transferred into 1 l PVC containers. The water samples were immediately fixed with neutralized formaldehyde in the final concentration of 0.4%. Samples were allowed to settle in the laboratory for a week. Then, the water in the upper part was removed by siphoning and concentrated to 100 ml (Sukhanova, 1978; Throndsen, 1978) and stored in dark coloured glass bottles until microscopic examination. Phytoplankton cells were counted using a Sedgewick–Rafter counting chamber under a light microscope (Guillard, 1978). For the species identification the following references were used: Cupp (1943), Hendey (1964), Drebes (1974), Dodge (1985), Delgado & Fortuna (1991) and Hasle *et al.* (1997). In the Appendix, to show the frequency of appearance of phytoplankton species at the different sampling periods, occurrences of each species in the region were categorized using a modified Soyer's frequency index (f%) (Soyer, 1980). Then, the index values were categorized into the frequency groups as the following: R, rare (1–15%); C, common (16–40%); A, abundant (41–60%); and V, very abundant (61–100%).

RESULTS

Hydrological data

The Sea of Marmara which is an inland basin between the Black Sea and the Aegean Sea, has a two-layered structure separated by a strong pycnocline at a depth of about 25 m (Figure 2). The upper layer water comes from the Black Sea having salinity of 18 psu via the Strait of Istanbul (Bosphorus) and its renewal time is estimated as 4–5 months. The lower layer comes from the Aegean Sea having

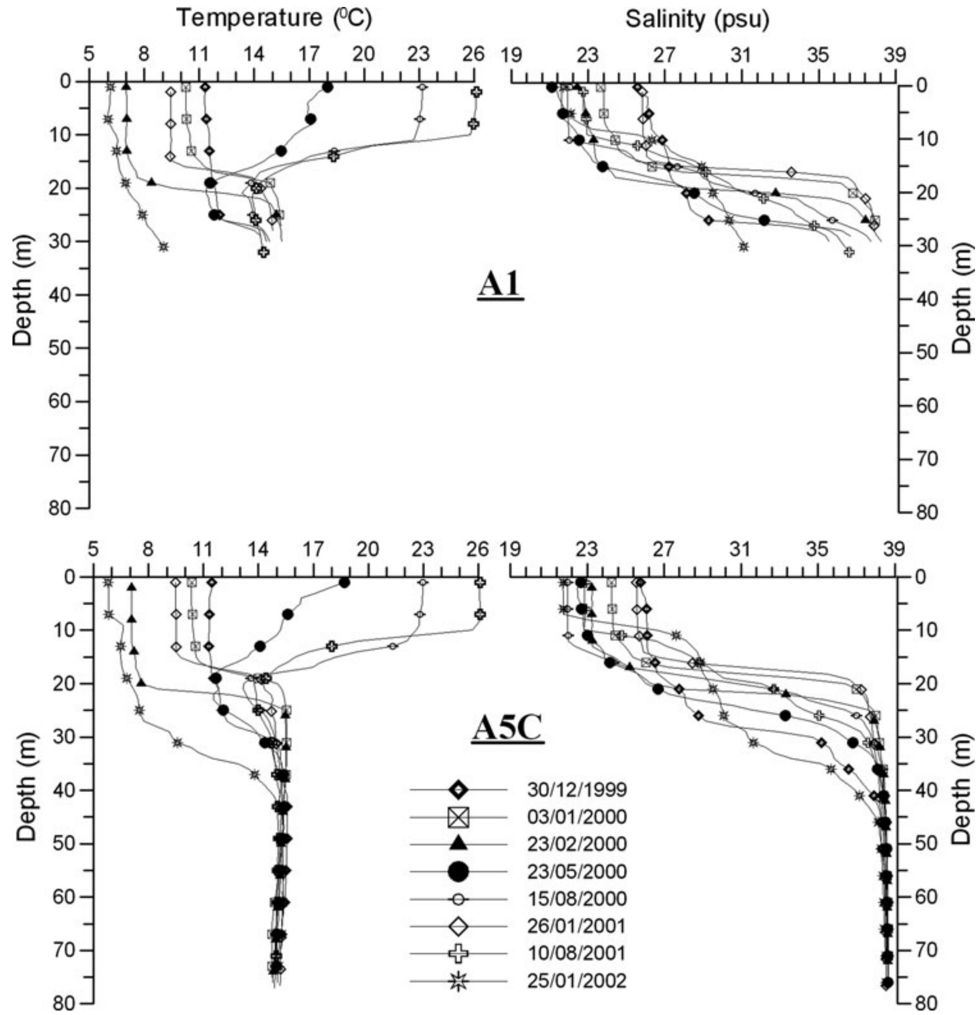

Fig. 2. Temperature and salinity profiles at the coastal (A1) and offshore (A5C) stations.

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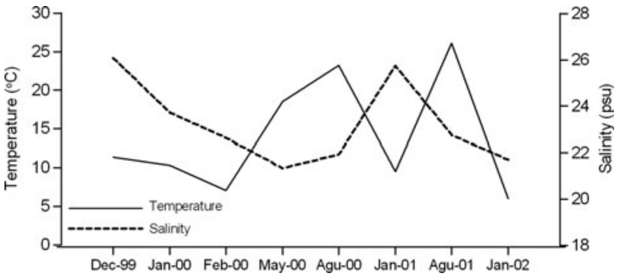

Fig. 3. Mean values of temperature and salinity from the sea surface during the study period.

salinity of 38.5 psu via the Strait of Çanakkale (Dardanelles) and its renewal time is about 6–7 years (Ünlüata *et al.*, 1990; Beşiktepe *et al.*, 1994). Depending on the temperature and salinity profiles for all CTD casts, there was a two-layered structure in the study region. The upper layer salinity was between 21.5 and 26 psu and its temperature was in the range of 6–26°C during the measurement periods. In general, the temperature and salinity of the lower layer below 40 m depth were 14.5°C and 38.5 psu, respectively, as shown in profiles at Station A5C. On the other hand, the interface was not well established at Station A1 (Figure 2).

The physical parameters were related to the environmental and atmospheric conditions. The temperature and salinity values indicated the natural variability depending on the meteorological conditions (Figure 3).

The atmospheric conditions can easily affect the physical parameters of the upper layer and the depth to the interface layer. On the basis of the rapid changes of wind speed and direction, the temperature and salinity profiles on 30 December 1999 indicated the effects of the southerly winds. After five days, the surface salinity decreased and the interface layer was very thin due to the effects of northerly winds (Figure 4).

Depending on the atmospheric conditions, hydrographic structure in the Sea of Marmara can change within several days. The surface salinity is higher in winter when the southerly winds cause mixing of water layers along the northern coasts of the Sea of Marmara. In summer, surface salinity decreases due to the influx of fresh water from the Black Sea via the Strait of Istanbul. The changes in current velocity and directions also indicate the variability of the atmospheric conditions. The dynamic characteristics of the water masses in the affected area can easily change during the continuous passage of cyclonic systems in winter (Alpar *et al.*, 2003). The temporal variations of the dynamic structure at the affected area can be seen clearly in Table 1. The calculated mean values from the surface data in each station are given in Table 1. Meanwhile, the Secchi disc depth measurements showed the variation in the range of 3.7–8.8 m (Table 1).

Total petroleum hydrocarbons (TPH)

At the time of the accident the oil concentration was measured at the highest level (2.17 mg/l) at Station A5. Five days later from the accident, the oil concentration was measured as 88.5 μg l^{-1} at the surface offshore Florya (A1). The oil concentrations at the surface and 10 m depth were in the ranges 0.11–121.5 μg l^{-1} and 0.11–88.5 μg l^{-1}, respectively during the study period. The oil concentrations gradually decreased within one year in accordance with the cleaning operation. The petroleum settled to the sea bottom was disturbed and surface water contamination increased during the cleaning operations carried out in August 2001. Thus, in this period of time, the oil concentrations at the surface reached to 121.5 μg l^{-1} at Station A5C. After one year, the oil levels in the seawater decreased to their normal values (0.3–1.5 μg l^{-1}) following the clean-up operations.

Phytoplankton succession

In the phytoplankton abundance some temporal variation was observed in accordance with the regional characteristics. The abundance of phytoplankton varied from 2 × 10^3 to 195 × 10^3 cells l^{-1} at the surface during the study period. The cell density was mostly as low as in the previous studies carried out in the same region except for January 2002. In January 2000, when the phytoplankton density was poor, there were not any diatoms while the dinoflagellates remained. In February 2000 an increase in diatoms was observed and their abundance reached to 38 × 10^3 cells l^{-1}, and they dominated over the phytoplankton (84%). A significant increase in the dinoflagellates was detected in May 2000 caused by *Prorocentrum micans* and its cell density reached to 70 × 10^3 cells l^{-1}. In August 2000, prokaryot cyanobacterium *Anabaena* sp. appeared and its density was calculated as 450 × 10^3 cells l^{-1} which formed the dominant species in the whole study area. Eukaryotic forms had a very low abundance in that month. There was low phytoplankton abundance in January 2001 that was similar to January 2000 and the maximum abundance of eukaryotic phytoplankton reached to 29.5 × 10^3 cells l^{-1} at the surface.

During the removing of the bottom settled petroleum by divers in August 2001, the oil concentrations in the water column reached to 121.5 μg l^{-1} at Station A5C due to mixing of oil in the seawater. Eukaryotic phytoplankton had the lowest abundance (3 × 10^3 cells l^{-1}) at this time (Figure 5). In addition, the prokaryot cyanobacterium

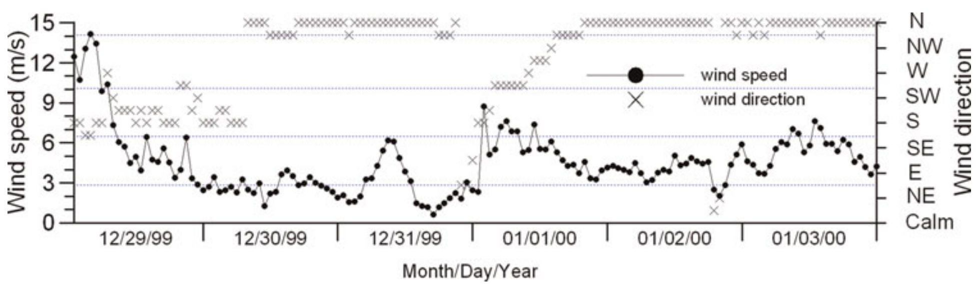

Fig. 4. Wind direction and speed throughout the 6 days following the 'Volgoneft-248' oil spill.

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Table 1. Mean surface values of selected physical variables during the study period.

Date of cruises	T (°C)	S (psu)	Current speed V (cm/s)	Current direction (°)	Secchi depth (m)	Wind speed (knot)	Wind direction
30/12/99	11.40	26.08	4.64	141	7.1	2.74	N
03/01/00	10.31	23.72	17.77	79	6.3	5.37	N
23/02/00	7.02	22.62	22.90	113	5.3	3.34	N
23/05/00	18.53	21.34	13.65	254	3.7	2.54	NNW
15/08/00	23.24	21.93	13.16	187	4.1	3.46	N
26/01/01	9.51	25.75	26.92	73	8.0	2.02	ESE
10/08/01	26.06	22.75	18.77	199	8.8	3.70	N
25/01/02	6.03	21.70	18.56	302	4.5	2.35	SE

Anabaena sp. appeared again in August 2001. One of the most important events in this study was a diatom increase observed in January 2002. During this increase, *Pseudo-nitzschia* spp. reached to 186×10^3 cells l^{-1} at the surface of Station A5C. This was the highest abundance level detected throughout the study period. The maximum abundance of some important species are given in Table 2. The dinoflagellates were generally more abundant than the diatoms except for the cases in February 2000 and January 2002.

Phytoplankton distributions in the affected area have shown little differences between the near shore and offshore stations. These differences were related to the distance of the stations to the shipwreck. For instance, in the short-distance stations (A1 and A2) the phytoplankton abundance was relatively lower than other stations although they were more near to coast (Figure 5).

The dinoflagellates formed all of the total phytoplankton in the first samples.The most abundant species were *Ceratium furca, C. fusus and Prorocentrum* spp. while there was no diatom species in the surface water. However, the diatom species composed of 84% of the total phytoplankton in February 2000 (Figure 6) and *Ditylum brightwellii*, *Rhizosolenia setigera* and *Thalassiosira rotula* were the most abundant species. The diatom abundance decreased while the dinoflagellates increased in May 2000. The diatom rate started to increase gradually since August 2000; however, a relative decrease was observed in dinoflagellates. In January 2002, the diatoms dominated in the phytoplankton community.

Species composition

A total of 72 species belonging to 5 taxonomic classes were identified in the seawater samples during the whole study period. Most of these species (93%) were composed of diatoms (35 species) and dinoflagellates (32 species) and the others were cyanobacteria, silicoflagellate and euglenophyte.

The checklist of species and the frequency of occurrence of phytoplankton species are given in the Appendix. The checklist of species explains the frequency of occurrence and

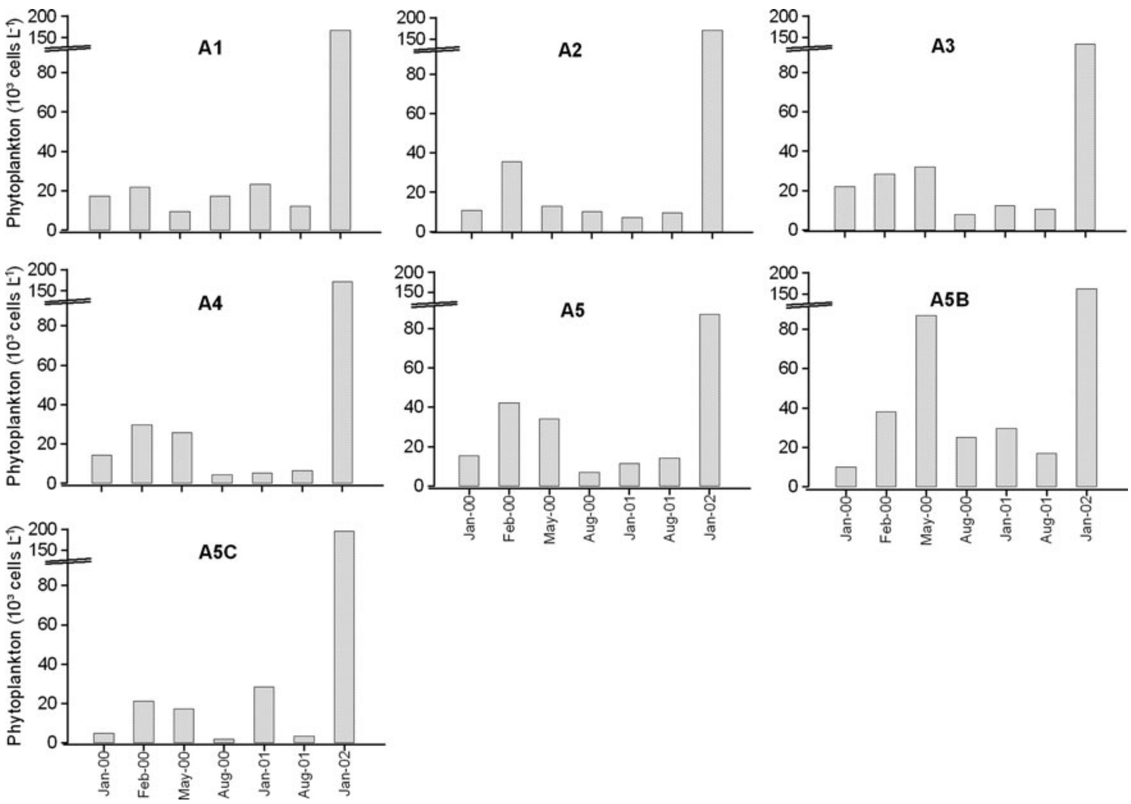

Fig. 5. Spatial and temporal variation of phytoplankton abundance in surface water.

Table 2. Maximum abundances (cells l^{-1}) of the most frequent phytoplankton species at the sea surface and frequency of occurrence (f %) during the study period.

Species	Jan 00	Feb 00	May 00	Aug 00	Jan 01	Aug 01	Jan 02	f %
Dinophyceae								
Ceratium furca	8200	1500	200	0	500	0	250	71
Ceratium fusus	1400	3000	3600	4250	4500	750	1250	100
Prorocentrum micans	3675	1500	70000	1500	6500	1000	1500	100
Prorocentrum scutellum	7350	1600	400	1000	5250	500	500	100
Prorocentrum triestinum	3600	250	13500	250	2000	1000	500	100
Protoperidinium sp.	207	800	1250	250	250	500	750	100
Bacillariophyceae								
Chaetoceros sp.	0	4800	6000	0	2500	0	5750	57
Ditylum brightwelli	0	9500	0	0	1500	0	3750	43
Pseudo-nitzschia delicatissima	0	0	0	0	0	1250	155000	29
Pseudo-nitzschia pungens	0	1000	0	1500	0	0	51750	43
Rhizosolenia hebetata	0	1750	0	700	1000	1500	250	71
Thalassionema nitzschioides	0	1750	0	1000	0	7000	5000	57
Thalassiosira rotula	0	5900	0	0	6500	0	3750	43

temporal distribution of phytoplankton species at the affected area. When the oil concentration was at the highest level, almost no diatoms were detected in the first samples, except *Coscinodiscus* sp. and *Rhizosolenia hebetata*. In contrast, the dinoflagellates *Ceratium furca, C. fusus, Prorocentrum micans, P. scutellum, P. triestinum* and *Protoperidinium* spp. were frequently observed in and all the study area.

The phytoplankton species composition indicated a rapid change within two months after the oil spill and the number of species increased from 24 taxa to 38 taxa. One of the most important results was the increase in the number of diatom species (from 2 to 21), which constituted 55% of the total number of phytoplankton (Figure 7). The number of dinoflagellate species reached to 21 in May 2000, and this formed 70% of the number of total species. The number of diatom species started to increase gradually from August 2000 to the end of the study period parallel to the decreasing oil concentration. The number of diatom species reached to 24 (63% of total species) in January 2002 (Figure 7). On the contrary to the diatoms, no significant changes were detected in the number of dinoflagellates throughout the sampling periods. They were always observed during the study period, although their numbers were relatively decreased. In January 2002, when the oil concentration decreased remarkably (from 0.11 to 1.34 $\mu g\, l^{-1}$) in the affected area, the number of diatoms increased to 24. As a result, most of the regional characteristic species were found again two months later following the accident. Other phytoplankton groups such as silicoflagellates and euglenophytes were also observed starting from May 2000 (Figure 7).

The Shannon diversity index (H') values were measured between 0.58 and 3.65 bits in surface and 0.49 and 3.38 bits in 10 m depth. In the first samples following the oil spill, the diversity values (H') were very low (from 1.92 to 2.36 bits), however H' rapidly increased and reached to 3.51 bits in February 2000.

DISCUSSION

Many studies generally report that there is no significant effect of oil on the phytoplankton; even our results present many discrepancies. The effects of oil on the marine life have been shown by the previous oil spills by tankers. The dynamic characteristics of water masses in the affected area may help both the dispersion of oil and the ultimate decrease in the effects on plankton. Although the impact of oil spill on the benthic organisms by the settled oil to the sea bottom is well known, it is not easy to explain direct effect of the oil spill on the phytoplankton due to the natural variability of the ecosystem which has a direct effect on the phytoplankton. Some authors (Brown & Searl, 1976; Coates *et al.*, 1986) report that the background levels for TPH in the sea are in the range of 0.3–1.5 µg/l. According to Tsvetnenko (1998) TPH concentration must not exceed 7 µg/l as the final advisory water quality criterion.

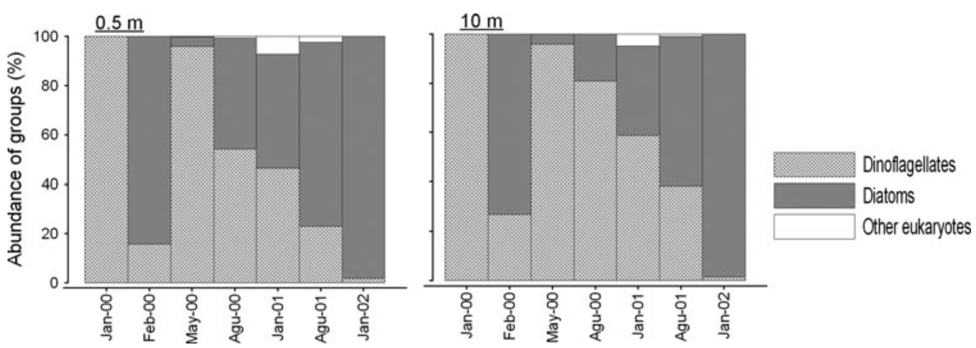

Fig. 6. Change of phytoplankton group composition in terms of abundance.

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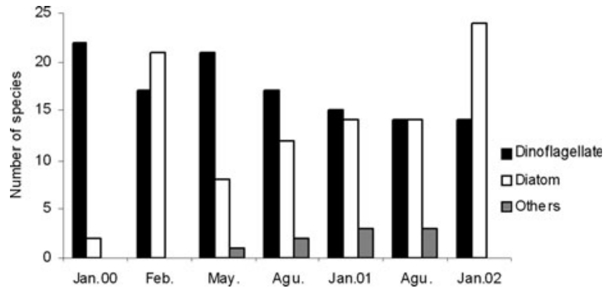

Fig. 7. Temporal variation of phytoplankton species composition.

After the 'Volgoneft-248' oil spill, the oil concentration in seawater was measured much higher than the accepted values for the water quality criterion and it reached to the highest level (2.17 mg/l) at Station A5. This result is the highest level contamination recorded after the 'Gotia' tanker accident according to the data given in the literature (Table 3). The short and medium term effects of oil pollution caused by oil spills on the marine systems have been investigated in various parts of the world and found significant in the eastern Baltic, Black Sea, Sea of Marmara, Bosphorus, English Channel and Alaska. The heavy oil pollution can effect the photosynthesis due to the blocking of sunlight by the oil covering in coastal stations. On the other hand, the oil sedimentation also adversely affected the cell abundance since the phytoplankton settled down together with the tar ball formation. Alpar & Ünlü (2007) explained how the tar balls could have been stranded on the Florya shoreline. A considerable part of the spilled oil sank to the seafloor and mixed with sand by suspended sediment particles in the water column.

The hydrological conditions in mid-winter (cold water and strong water movements) after the 'Volgoneft-248' oil spill limited the development of phytoplankton on a large scale. In the first samples taken following the oil spill, the absence of diatom species in the surface water may indicate the negative effect of oil on diatoms. Two months later from the oil spill diatoms formed the bulk of the phytoplankton community and also the phytoplankton species composition changed rapidly in favour of diatoms. Therefore, diatoms could be more sensitive to oil pollution than the dinoflagellates. Dahl *et al.* (1983) verified that crude oil inhibits the growth of diatoms.

The winter diatom increase detected in January 2002 was one of the most important biological events when the oil concentration ranged between 0.19 and 0.44 μg/l. Based on the previous studies (Uysal, 1996; Balkıs, 2003; Okuş & Taş, 2007; Deniz & Taş, 2009) which were carried out on phytoplankton in the Sea of Marmara, the abundance of diatoms was higher during late winter and autumn, and the dinoflagellates especially in late spring and summer. Balkıs (2003) and Deniz & Taş (2009) reported that the dinoflagellates increased in May as stated in this work. Balkıs (2003) revealed that total phytoplankton abundance reached to its maximal level in

Table 3. The tanker accidents in various parts of the world.

Tanker accident	Oil spilled (t)	Pollution level (μg/l)	References
'Thesis' (1977)	1000	50	Johansson, 1980
'Amoco Cadiz' (1978)	223,000	100	Marchand, 1980; Dauvin, 1998
'Exxon Valdez' (1989)	37,000	6.24	Boehm *et al.*, 1997; Rice *et al.*, 1996
Aegean Sea (1992)	73,000	79.1–257	González *et al.*, 1997
North Cape (1996)	2700	50	Reddy & Quinn, 1998
'Braer' (1995)	86,825	1000–5000	Newey & Seed, 1995
'Nassia' (1994)	9000	24.9	Güven *et al.*, 1996
'TPAO' (1997)	214.3	33.2	Ünlü *et al.*, 2000
'Erika' (1999)	19,800	560–750	Benoit & Haeseler, 2004
'Volgoneft-248' (1999)	1579	88.5–2.17*	This study
'Prestige' (2002)	77,000	0.1–570	González *et al.*, 2006
'Gotia' (2002)	25	813.5*	Güven *et al.*, 2004

*, mg l^{-1}.

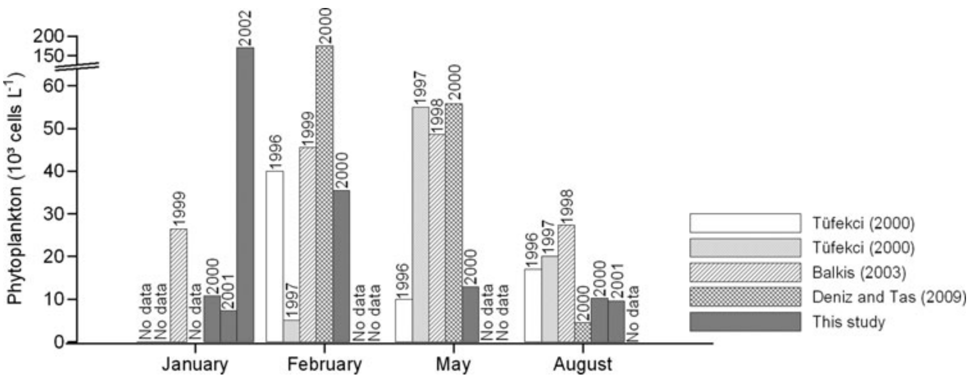

Fig. 8. Comparison of phytoplankton abundance with the historical datasets.

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March and diatoms dominated the phytoplankton community. The winter diatom increase was reported by Okuş & Taş (2007) in February. Results obtained on phytoplankton succession were generally similar to the historical findings. The phytoplankton species identified in the current work were available in the checklist of the Sea of Marmara collated by Balkıs (2004). The dinoflagellates were observed in the whole study period in the affected area, while the diatoms were not observed in the first sampling (Appendix).

The historical data on phytoplankton composition of the north-eastern Sea of Marmara (Uysal, 1996; Tüfekçi, 2000; Balkıs, 2003; Deniz & Taş, 2009) could be useful to evaluate the effects of oil pollution and the surface values of Station A2 were used in comparisons. The low phytoplankton abundance following the oil spill should be considered as the negative effects of oil pollution on phytoplankton compared to the historical data (Figure 8), although the sampling points are not the same. The sampled area in the current study is located at a very shallow region and very close to the connection of Kucukcekmece Lake with the Sea of Marmara (Figure 1). Thus, one can expect a higher productivity in this coastal area as a consequence of freshwater input to the region. The low phytoplankton densities following the oil spill should be taken as an indicator of pollution stress on phytoplankton communities.

CONCLUSION

The effect of the 'Volgoneft-248' oil spill which occurred in winter on the phytoplankton was limited because of the natural meteorological conditions. The oil spill was dispersed rapidly due to the dynamic structure in the water column, consequently, the adverse effect on phytoplankton was relatively decreased. However, the phytoplankton abundance was very low compared to the historical datasets. Low phytoplankton abundance was mostly related to the high hydrocarbon concentrations. This may indicate that there is little adverse effect of oil on phytoplankton. Nevertheless, the absence of diatoms in January 2000 indicates that diatoms might be more sensitive to the oil pollution than the dinoflagellates. Thus, the effect of oil on phytoplankton varies depending on the sensitivity of species and the natural environmental conditions.

ACKNOWLEDGEMENTS

This study is dedicated to Professor Dr Erdoğan Okuş, who passed away on 9 April 2006 following a tragic accident during an oceanographic cruise in the Black Sea. We are grateful to him for his contributions to Turkish marine sciences. We thank Professor Dr Bedri Alpar and Dr Necip Ünlü for correcting the English text and the captain, scientists and technicians of RV 'ARAR' for their efforts in the monitoring programme.

REFERENCES

Alpar B., Yüce H. and Türker A. (2003) Water exchange in the Golden Horn. *Turkish Journal of Marine Sciences* 9, 51–68.

Alpar B. and Ünlü S. (2007) Petroleum residue following *Volgoneft-248* oil spill at the coasts of the suburb of Florya, Marmara Sea (Turkey). *Journal of Coastal Research* 23, 515–520.

Balkıs N. (2003) Seasonal variations in the phytoplankton and nutrient dynamics in the neritic water of Büyükçekmece Bay, Sea of Marmara. *Journal of Plankton Research* 25, 703–717.

Balkıs N. (2004) List of phytoplankton of the Sea of Marmara. *Journal of Black Sea/Mediterranean Environment* 10, 123–141.

Batten S.D., Allen R.J.S. and Wotton C.O.M. (1998) The effects of the Sea Empress oil spill on the plankton of the southern Irish Sea. *Marine Pollution Bulletin* 36, 764–774.

Benoit Y. and Haeseler F. (2004) *Weathering of tanker Erika's fuel oil no. 6 in marine environment*. Institut Français du Pétrole. Interspill 2004, Presentation no. 460.

Beşiktepe Ş.T., Sur H.İ., Özsoy E., Latif M.A., Oğuz T. and Ünlüata Ü. (1994) The circulation of hydrography of the Marmara Sea. *Progress in Oceanography* 34, 285–334.

Boehm P.D., Douglas G.S., Burns W.A., Mankiewicz P.J., Page D.S. and Bence A.E. (1997) Application of petroleum hydrocarbon chemical fingerprinting and allocation techniques after the Exxon Valdez oil spill. *Marine Pollution Bulletin* 34, 599–613.

Brown R.A. and Searl T.D. (1976) Nonvolatile hydrocarbons in the Pacific Ocean. In *Proceedings of the Symposium on Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environments*. Washington, DC: American Institute of Biological Sciences, pp. 240–255.

Castro P. and Huber M.E. (2000) *Marine biology*. 3rd edition. New York: McGraw-Hill Companies, Inc.

Coates M.D., Connel W. and Bordero J. (1986) Aliphatic hydrocarbons in Great Barrier Reef organisms and environment. *Estuarine, Coastal and Shelf Science* 23, 99–114.

Cupp E.E. (1943) *Marine plankton diatoms of the west coast of North America*. Berkeley, CA: University of California Press.

Dahl E., Laake M., Tjessem K., Eberlein K. and Boehle B. (1983) Effects of Ekofisk crude oil on an enclosed planktonic ecosystem. *Marine Ecology Progress Series* 14, 81–91.

Dauvin J.C. (1998) The fine sand *Abra alba* community of the Bay of Morlaix twenty years after the Amoco Cadiz oil spill. *Marine Pollution Bulletin* 36, 669–676.

Delgado M. and Fortuna J.M. (1991) Atlas de Fitoplancton del Mar Mediterraneo. *Scientia Marina* 55, 1–133.

Deniz N. and Taş S. (2009) Seasonal variations in the phytoplankton community in the north-eastern Sea of Marmara and a species list. *Journal of the Marine Biological Association of the United Kingdom* 89, 269–276.

Dodge J.D. (1985) *Atlas of dinoflagellates. A scanning electron microscope survey*. London: Farrand Press.

Doğan E. and Burak S. (2007) Ship-originated pollution in the Istanbul Strait (Bosphorus) and Marmara Sea. *Journal of Coastal Research* 23, 388–394.

Drebes G. (1974) *Marines Phytoplankton, eine Auswahl der Helgoländer Planktonalgen (Diatomeen, Peridineen)*. Stuttgart: Georg Thieme Verlag.

Dunstan W.M., Atkinson L.P. and Natoli J. (1975) Stimulation and inhibition of phytoplankton growth by low molecular weight hydrocarbons. *Marine Biology* 31, 305–307.

Elmgren R., Vargo G.A., Grassle J.F., Grassle J.P., Heinle D.R., Langiois G. and Vargo S.L. (1980) Trophic interactions in experimental marine ecosystem perturbed by oil. In Giesey J.R. (ed.) *Microcosms in eolgical research*. Washington, DC: USA Technical Information Center, US Department of Energy, pp. 779–800.

González J.J., Schultze F., Escánez J. and Cerqueira E.M. (1997) Distribución espacial y evolución anual en el agua submareal de los hidrocarburos poliaromáticos vertidos por el *Mar Egeo*. In Prego R.

and Fernández J.M. (eds) *Procesos biogeoquímicos en sitemas costeros Hipano-Lusos*. Galicia, Espana: Diputation Provincial de Pontevedra y Consejo Superior de Investigaciones Cientificas, pp. 137–141.

González J.J., Viñas L., Franco M.A., Fumega J., Soriano J.A., Grueiro G., Muniategui S., López-Mahía P., Prada D., Bayona J.M., Alzaga R. and Albaigés J. (2006) Spatial and temporal distribution of dissolved/dispersed aromatic hydrocarbons in seawater in the area affected by the *Prestige* oil spill. *Marine Pollution Bulletin* 53, 250–259.

Gordon D.C. and Prouse N.J. (1973) The effects of three oils on marine phytoplankton photosynthesis. *Marine Biology* 22, 329–333.

Goutz H.M., Berland B., Leveau M. and Bertrand J.C. (1984) Effect of petroleum biodegredation products on phytoplankton growth. *Second International Colloguium on Marine Bacteriyology*. Paris: IFREMER, pp. 621–627.

Gray J.S., Clarke K.R., Warwick R.M. and Hobbs G. (1990) Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk Oilfields North Sea. *Marine Ecology Progress Series* 66, 285–299.

Guillard R.R.L. (1978) Counting slides. In Sournia A. (ed.) *Phytoplankton manual*. Paris: UNESCO, pp. 182–189.

Güven K.C., Yazıcı Z., Ünlü S., Okuş E. and Doğan E. (1996) Oil pollution on seawater and sediments of Istanbul Strait, caused by Nassia Tanker accident. *Turkish Journal of Marine Sciences* 2, 65–89.

Güven K.C., Ünlü S. and Çetintürk K. (2004) Oil pollution in Bosphorus, Golden Horn and Sea of Marmara from M/V GOTIA ship accident occurred in 2002. *Journal of Black Sea/Mediterranean Environment* 10, 85–102.

Güven K.C., Okuş E., Sur H.İ., Gazioğlu C., Yüksek A., Ünlü S., Altıok H., Taş S., Müftüoğlu A.E., Yılmaz N., Aslan Yılmaz A., Karhan Ü. and Yalçın A. (2006) *Petroleum pollution of Volgoneft-248 tanker accident in the Florya–Küçükçekmece area*. Final Report. Istanbul University, Institute of Marine Sciences and Management, Istanbul, Turkey.

Hasle G.R., Syvertsen E.E., Steidinger K.A., Tangen K., Throndsen J. and Heimdal B.R. (1997) *Identifying marine phytoplankton*. Edited by Tomas C.R. San Diego, CA: Academic Press.

Hendey N.I. (1964) *An introductory account of the smaller algae of British coastal waters. Part V: Bacillariophyceae (diatoms)*. Her Majesty's Stationery Office: London.

Johansson S., Larsson U. and Boehm P. (1980) The Tsesis oil spill. Impact on the pelagic ecosystem. *Marine Pollution Bulletin* 11, 284–293.

Kühnhold W.W. (1978) Impact of the Argo Mechant oil spill on macrobenthic and pelagic organisms. In *AIBS Conference Assessment Ecological Impact of Oil Spill, 14–17 June 1975, Keystone, Colorado, USA*, pp. 152–179.

Lännergren C. (1978) Net- and nanoplankton: effects of an oil spill in the North Sea. *Botanica Marina* 21, 353–356.

Marchand M.H. (1980) The Amaco Cadiz oil spill. Distribution and evolution of hydrocarbon concentrations in seawater and marine sediments. *Environment International* 4, 421–429.

Nelson-Smith A. (1970) The problem of oil pollution of the sea. In Russell F.S. and Yonge M. (eds) *Advances in Marine Biology* 8, 215–306.

Newey S. and Seed R. (1995) The effects of the Braer oil spill on rocky interdial communities in south Shetland, Scotland. *Marine Pollution Bulletin* 30, 274–280.

Okuş E. and Taş S. (2007) Diatom increase in phytoplankton community observed in winter in the North-eastern Marmara Sea (Beylikdüzü). *Journal of Black Sea/Mediterranean Environment* 13, 7–17.

Ostgaard K., Eide I. and Jensen A. (1984) Exposure of phytoplankton to Ekofish crude oil. *Marine Environmental Research* 11, 183–200.

Reddy C. and Quinn J.G. (1998) GC-MS analysis of total petroleum hydrocarbons and polycyclic aromatic hydrocarbons in sea water samples after the North Cape oil spill. *Marine Pollution Bulletin* 38, 126–135.

Rice S.D., Spies R.B., Wolfe D.H. and Wright B.A. (1996) Chemical sampling and analysis of petroleum hydrocarbons in near surface seawater of Prince William Sound after the Exxon Valdez oil spill. In *Proceedings of the Exxon Valdez oil spill Symposium*, pp. 17–28.

Skjoldal H.R. and Thingstad T.F. (1987) Oil pollution and plankton dynamics. Summary of enclosing experiments in Lindaaspollene Norway with special emphasis on the balance between autotrophic and heterotrophic processes. In J. Kuiper and W.J. van den Brink (eds) *Fate and effects of oil in marine ecosystems*. Dordrecht: Martinus Nijhoff Publishers, pp. 159–172.

Soyer J. (1980) Bionomic benthique du plateau continental de la Cote catalane française III. Les peuplements de Copepodes harpacticoides (cruestaceae). *Vie et Milieu* 21, 337–511.

Straughan D. (1972) Biological effects of oil pollution in the Santa Barbara Channel. In Ruivo M. (ed.) *Marine pollution and sea life*. London: Fishing News Books Ltd, pp. 355–359.

Sukhanova I.N. (1978) Settling without the inverted microscope. In Sournia A. (ed.) *Phytoplankton manual*. Paris: UNESCO, p. 97.

Throndsen J. (1978) Preservation and storage. In Sournia A. (ed.) *Phytoplankton manual*. Paris: UNESCO, pp. 69–74.

Tomajka J. (1985) The influence of petroleum hidrocarbons on the primary production of the Danube River plankton. *Acta Hydrochemie–Hydrobiology* 13, 615–618.

Tüfekçi A.V. (2000) *Phytoplankton distribution in the Bosphorus junction of the Sea of Marmara and Black Sea with the Bosphoru*. PhD thesis. Institute of Marine Sciences and Management, University of Istanbul. [In Turkish.]

Tsvetnenko Y. (1998) Derivation of Australian tropical marine water quality criteria for the protection of aquatic life from adverse effects of petroleum hydrocarbons. *Environmental Toxicology and Water Quality* 13, 273–284.

UNESCO (1984) *Manual for monitoring oil and dissolved/dispersed hydrocarbons in marine waters and on beaches*. Intergovernmental Oceanographic Commission, Manuals and Guides No. 13, 35 pp.

Uysal Z. (1996) A net-plankton study in the Bosphorus junction of the Sea of Marmara. *Turkish Journal of Botany* 20, 321–327.

Ünlü S., Güven K.C. and Doğan E. (2000) Oil pollution in Tuzla Bay after TPAO tanker accident. *Turkish Journal of Marine Science* 6, 139–155.

Ünlüata U., Oğuz T., Latif M.A. and Özsoy E. (1990) On the physical oceanography of the Turkish Straits. In Pratt L.J. (ed.) *The physical oceanography of sea straits*. The Netherlands: Kluwer Academic Publishers, pp. 25–60.

and

Varela M., Bode A., Lorenzo J., Álvarez-Ossorio M.T., Miranda A., Patrocinio T., Anadón R., Viesca L., Rodríguez N., Valdés L., Cabal J., Urritia A., García-Soto C., Rodríguez M., Álvarez-Salgado X.A. and Groom S. (2006) The effect of the 'Prestige' oil spill on the plankton of the N–NW Spanish Coast. *Marine Pollution Bulletin* 53, 272–286.

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https://doi.org/10.1017/S0025315410000330 Published online by Cambridge University Press

APPENDIX

List and frequency distribution of phytoplankton (abbreviations used: R, rare, 1–15%; C, common, 16–40%; A, abundant, 41–60%; V, very abundant, 61–100%).

Taxonomic groups and species	Jan 00	Feb 00	May 00	Aug 00	Jan 01	Aug 01	Jan 02
Prokaryota							
Cyanophyta							
Cyanophyceae							
Anabaena sp.				V		V	
Eukaryota							
Chromophyta							
Dinophycaea							
Ceratium furca (Ehrenberg) Claparède & Lachmann	V	V	C	R	C	R	C
Ceratium fusus (Ehrenberg) Dujardin	V	V	V	V	V	V	V
Ceratium horridum (Cleve) Gran					R		R
Ceratium trichoceros (Ehrenberg) Kofoid	C		R			V	
Ceratium tripos (O.F. Müller) Nitzsch	R	C	C	R			
Dinophysis acuminata Claparède & Lachmann	R						
Dinophysis acuta Ehrenberg	R	R		R	R	R	
Dinophysis caudata Saville-Kent	R						R
Diplopsalis lenticula Bergh					R	R	
Gymnodinium sanguienum Hirasaka					V		
Gymnodinium sp.	C	C	A	C	C		
Heterocapsa triquetra (Ehrenberg) Stein				R			A
Noctiluca scintillans (Macartney) Kofoid & Swezy	R	C	R	A			
Oxytoxum oxytoxoides Kofoid						R	
Oxytoxum sp.	C	C	C		C		
Phalocrama rotundatum (Claparède & Lachmann) Kofoid & Mich.	C	R		R			
Prorocentrum compressum (Bailey) Abé	C			R		R	R
Prorocentrum gracile Schütt			C		C		
Prorocentrum micans Ehrenberg	V	V	V	V	V	A	V
Prorocentrum scutellum Schröder	V	V	A	A	V	C	C
Prorocentrum triestinum Schiller	V	R	A	C	A	A	R
Protoperidinium claudicans (Paulsen) Balech			R	R			
Protoperidinium conicum (Gran) Balech			R				C
Protoperidinium depressum (Bailey) Balech	C	C	R	R		R	
Protoperidinium divergens (Ehrenberg) Balech	R		A	R	R		
Protoperidinium pallidum (Ostenfeld) Balech	C		C				
Protoperidinium pellucidum Bergh	R		C			C	A
Protoperidinium pentagonum (Gran) Balech		R					C
Protoperidinium punctulatum (Paulsen) Balech	R	R	C				
Protoperidinium sp.	A	V	V	A	R	R	R
Protoperidinium steinii (Jörgensen) Balech	C	R	V	R			
Scrippsiella trochoidea Stein Löblich III		C	R	V	R	V	C
Dictyochophyceae							
Dictyocha fibula Ehrenberg					A	R	
Dictyocha speculum Ehrenberg			R		A		
Octactis octonaria (Ehrenberg) Hovasse					C		
Bacillariophyceae							
Chaetoceros affinis Lauder		R	R				C
Chaetoceros curvisetus Cleve			R			R	C
Chaetoceros diadema (Ehrenberg) Gran		C					
Chaetoceros holsaticus Schütt		R	R				R
Chaetoceros sp.		R	R		R		R
Chaetoceros tortissimus Gran							R
Coscinodiscus concinnus W. Smith		R		R	R		C
Coscinodiscus perforatus (Forti) Hustedt					C		
Coscinodiscus radiatus Ehrenberg		R			A		R
Coscinodiscus sp.	R	R	R	A	V		A
Dactyliosolen fragilissimus (Bergon) Hasle				R		A	C
Detonula confervacea (Cleve) Gran			R	C	R		

Continued

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Appendix. Continued

Taxonomic groups and species	Jan 00	Feb 00	May 00	Aug 00	Jan 01	Aug 01	Jan 02
Ditylum brightwellii (T. West) Grunow in Van Heurck		V			C		V
Guinardia delicatula (Cleve) Hasle					R	R	
Guinardia flaccida (Castracane) H. Peragallo					V		
Hemiaulis hauckii Grunow in Van Heurck						R	
Leptocylindirus danicus Cleve		C		R	R	R	R
Leptocylindirus minimus Gran		A			R	R	
Navicula sp.			R		R		R
Nitzschia longissima (Brébison, in Kützing) Ralfs in Pritchard		V			R		
Proboscia alata (Brightwell) Sundström		R				A	C
Pseudo-nitzschia delicatissima (Cleve) Heiden in Heiden & Kolben							V
Pseudo-nitzschia fraudulenta (Cleve) Hasle							C
Pseudo-nitzschia pungens (Grunow *ex* P.T. Cleve) Hasle		R		C			V
Pseudosolenia calcar-avis (Schultze) Sundström				R		R	
Rhizosolenia hebetata (Hensen) Gran	R	C		C	V	A	R
Rhizosolenia setigera Brightwell		V			A		
Skeletonema costatum (Greville) Cleve		C				R	A
Stellarima stellaris (Roper) Hasle & Sims							R
Thalassionema nitzschioides (Grunow) Mereschkowsky		C		R		V	V
Thalassiosira decipiens (Grunow in Van Heurck) Jörgensen		R					
Thalassiosira eccentrica (Ehrenberg) Cleve		R		C	R		
Thalassiosira rotula Meunier		V	R	R	V		V
Thalassiothrix frauenfeldii Grunow						R	R
Thalassiothrix longissima Cleve & Grunow		C					A
Chlorophyta							
Euglenophyceae							
Eutreptiella sp.				R		C	

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