Factors affecting the occurrence of algae on the Sopot beach (Baltic Sea)*

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Abstract

The occurrence of algae on the Sopot beach was investigated from 2004 to 2006 from the beach management point of view. Various methods were applied in an attempt to understand the mechanisms underlying the accumulation of

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algae on the shoreline. They included daily observations of the occurrence of macrophyta on the beach, absorption measurements of acetone extracts of the particulate matter in the seawater, the collection of macrophyta and phytoplankton samples for biomass and taxonomic identification, and determination of the degree of decomposition on the basis of chloropigment analyses. The results were related to the environmental conditions: meteorological data and the physico-chemical parameters of the seawater. The biomass recorded on the beach consisted mainly of macroalgae and a small proportion of sea grass (*Zostera marina*). The phytoplankton biomass consisted mainly of dinoflagellates, diatoms, cyanobacteria, euglenoids and cryptophytes.

The conclusions to be drawn from this work are that the occurrence of huge amounts of macrophyta amassing on the Sopot beach depends on the combined effect of high solar radiation in spring and summer, high-strength (velocity $\times$ frequency) south-westerly winds in May-September, followed by northerly winds, bringing the macrophyta from Puck Bay on to the Sopot beach. At the same time, their abundance along the beach varies according to the shape and height of the shore, the wind strength and the local wind-driven seawater currents. According to estimates, from 2.2–4.4 $\times$ 10^2 tons (dry weight) of macrophyta can be moved on to the Sopot beach in one hour. In October, strong south-easterly winds can also transport huge amounts of decomposing biomass onshore. The phytoplankton content in the total biomass is negligible, even though at low concentrations its biological activity may be considerable. The intensive phytoplankton blooms observed on the Sopot beach in summer are not always caused by cyanobacteria.

1. Introduction

At some times, especially during the summer, macrophyta are a nuisance on the Sopot beach, as they are in other areas around the Baltic Sea (Lotze et al. 1999, Berglund et al. 2003). Dense mats of macroalgae and their decomposition induce hypoxia or anoxia, and consequently faunal mortality (Raffaelli 2000, Salovius and Bonsdorff 2004). But the other side of this problem is that drifting algae are also a refuge for some species of invertebrates and small fish (Norkko et al. 2000). The drifting algae may sink to the bottom, be transferred to other locations by waves and currents, and/or accumulate on the shore.

In recent decades the taxonomic composition of the macrophytobenthos in the Gulf of Gdańsk has changed, especially in its inner, shallow part – Puck Bay – where eutrophication has led to the dominance of filamentous brown algal species from the genera *Ectocarpus* and *Pilayella* (Kruk-Dowgiałło 1996, 1998). Though macrophyta grow on the sea bed in other parts of the Gulf of Gdańsk (Ciszewski et al. 1991, Kruk-Dowgiałło 1996), they may become detached from the sea bed at some stage in their growth or as a result of violent wave action, after which they float

Figure 1. Sopot beach on 24.08.2005

in the water, eventually accumulating on the shore-line, for example, on the Sopot beach. Because of the heaps of decomposing plant material on the beach (Figure 1) and in the near-shore water, and also the blooms of cyanobacteria which occur there in summer, the Sopot beach has to be closed to holidaymakers right in the middle of the tourist season by the services responsible for its maintainence. As the beach is very close to the Sopot town centre, eutrophication of the Gulf of Gdańsk, manifested by the excessive proliferation of macroalgae and intensive phytoplankton blooms, is a serious problem not only for tourists and visitors to this health resort but also to its inhabitants and the authorities responsible for coastal management. According to the legal obligations imposed by the Water Framework Directive (DzU Nr 183, EU WFD 2000), the Sopot Municipal Council is responsible for cleaning the beach and monitoring the occurrence of algae in the coastal waters. Therefore, it is very important for the council and the cleansing services to be able to predict when algae are likely to occur in great abundance, so as to be able to take the necessary remedial action in good time. Apart from a few reports on the distribution of macrophytobenthos in the Gulf of Gdańsk (e.g. Kruk-Dowgiałło 1998), however, the problem of floating algae accumulating on the shoreline of the Gulf of Gdańsk and

elsewhere along the Polish coast has not been addressed (Martin 2005). Neither multiparameter models nor models of suitably small grid size are available, so other methods have had to be applied.

To study the macrophyta on the Sopot beach and the methods of forecasting its occurrence, a range of activities were undertaken over a three-year period (2004–06). These included beach observations, periodic monitoring of the physico-chemical parameters of seawater, sample collection for taxonomic identification of algae, evaluation of taxon composition, determination of biomass and degree of decomposition; the last two were based on absorption in the visible range of particulate matter extracts and chloropigment analyses. The macrophyta and phytoplankton data were correlated with meteorological data and the physico-chemical parameters of the seawater.

2. Experimental

2.1. Observations

Daily seawater and beach observations were carried out at seven coastal sites – Grodowy Stream, Babidolski Stream, Kuźniczy Stream, 'Balbina', Viva Club, Grand Hotel and the Pier (see Figure 2) – during six months (May–October) on every weekday for three years (2004–06). The amounts of algae were expressed on a numerical scale: none – 0, small – 1, average – 2, large – 3, very large – 4, huge – 5, separately for the beach sand and the near-shore water.

2.2. Meteorological data

The following meteorological data – wind velocity and direction, temperature, air humidity and solar radiation – were kindly supplied by the ARMAAG Foundation (Agency of Regional Air Quality Monitoring in the Gdańsk Metropolitan Area) for May–October 2004, 2005 and 2006. All the data were calculated on the basis of half-hourly measurements made at ARMAAG station AM6 in Sopot. In these shallow coastal waters, the wind is responsible for the hydrological conditions – wave action and currents. At depths up to 15 m the strong surface and bottom currents flow in the same direction; when winds are weak there are no bottom currents (IMGW 2000).

2.3. Monitoring

2.3.1. Field measurements and sampling

Each year once a month (in June, July and August) temperature, salinity and oxygen content in the seawater were measured using a portable

field meter (ProfiLine Multi 197i; WTW, Germany) at five sites on the beach (stations 1–5 – see the map in Figure 2). At the same sites and times water samples were collected (c. 6 dm^3 at each station) for determinations of biomass, taxonomic analysis of phytoplankton, nutrients (NO_3^-, NO_2^-, PO_4^{3-}) and chloropigment content, the last-mentioned for estimating the degree of decomposition and evaluating species groups. Plant material samples for taxonomic analysis and chloropigment content determination were collected during the monthly monitoring and also whenever macrophyta occurred in great abundance (stations 2I, 2II, 3I, A–E, T).

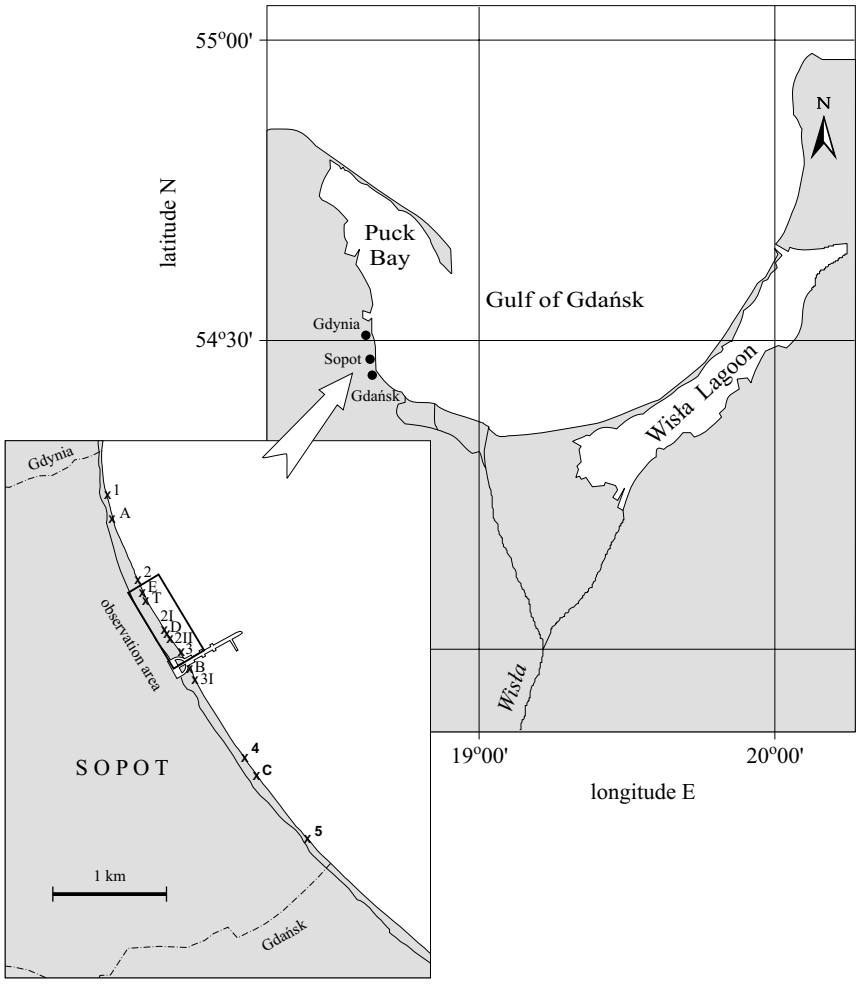

Figure 2. Study area

2.3.2. Laboratory analyses

• Biomass

Biomass of plant material was estimated as follows: seawater (3 dm^3) was filtered through sterile gauze (maximum mesh size 1 mm). The plant material was then dried (at 60°C), weighed and the biomass calculated per litre of seawater.

• Taxonomic analyses

Macrophyta samples were identified to species or genus level under a binocular microscope (Pankow et al. 1990). Abundance of taxa was estimated on a three-point scale (1 – sporadic occurrence, 2 – common, 3 – dominant) and presented as a percentage.

The phytoplanktonic organisms were conditioned after collection with Lugol's solution and studied under an inverted microscope fitted with phase contrast and differential interference contrast (Hällfors 2004). Phytoplankton counts were carried out in accordance with the COMBINE programme of HELCOM (HELCOM 1997). The volume of each cell was calculated by measuring its morphometric characteristics. Volumes were converted to biomass, assuming 1 μm^3 to be equivalent to 1 pg (Edler 1979).

• Absorption measurements

Absorption in the visible range was measured in the seawater samples collected at sites 1–5 in 2004–06, and additionally in those collected twice a week at one selected station (No. 2) in 2005 and 2006. The seawater samples were filtered through GF/C filters. These filters were then extracted with acetone and absorption ($\lambda = 660$ nm) of the extracts was measured with a spectrophotometer and calculated per 100 cm^3 of seawater.

• HPLC chloropigment analyses

Chloropigment composition of seawater and macrophyta samples was determined. The following pigments were determined in all samples: chlorophyll *a*, chlorophyllide *a*, allomer and epimer of chlorophyll *a*, phaeophytin *a*, allomer and epimer of phaeophytin *a*, phaeophorbides *a*, pyrophaeophytin *a*, sum of steryl chlorines, chlorophyll *b*, phaeophytin *b* and chlorophylls *c*. Extraction and analysis of chloropigments were carried out according to procedure described previously (Kowalewska 2005, Szymczak-Żyła et al. 2008).

The decomposition of plant material was estimated on the basis of the percentage of chlorophyll *a* (Chl *a*) in the sum of chloropigments *a* (sum of chlorophyll *a* and its derivatives = $\sum$ Chlns *a*).

• Determination of nutrients

Inorganic phosphate in the seawater samples was determined according to Koroleff's procedure (Grasshoff 1976). This method is based on the reaction of phosphate ions with an acidified molybdate reagent with the addition of trivalent antimony ions to yield a phosphomolybdate complex, which is then reduced by ascorbic acid to a compound of the highly-coloured blue compound.

Nitrite in the seawater samples was determined photometrically according to the procedure described by Grasshoff (1976). This method is based on the reaction of nitrite with an aromatic amine (sulphanilamide hydrochloride) leading to the formation of a diazonium compound followed by coupling with a second aromatic amine (n-(1-naphthyl)-ethylenediamine dihydrochloride) to form a coloured azo dye.

The determination of nitrate in the seawater samples was based on the reduction of nitrate to nitrite, which was then determined as described above. Nitrate was reduced in a reductor filled with copper-coated cadmium granules (Grasshoff 1976).

2.4. Statistical analysis

The results were subjected to statistical analysis using STATISTICA 6.0 software. Before analysis, tests were carried out to check whether the condition necessary for using parametric methods had been satisfied. The normal distribution of the characteristics in each group was tested with the Shapiro-Wilk test. Correlation analysis was used to evaluate the relationships between the occurrence of macrophyta on the beach (observations), biomass of plant material (filtration), absorption of the seawater samples, phytoplankton and macrophytobenthos taxonomy, nutrient and pigment contents, meteorological data, and the physico-chemical parameters of the seawater. Since the basic conditions for using the R-Pearson parametric linear correlation were not fulfilled, its non-parametric equivalent – the R-Spearman correlation – was applied to the data sets. The calculated correlation coefficient is a measure of the strength of the linear relationships between variables. A correlation with $p < 0.05$ was regarded as significant.

3. Results and discussion

3.1. Macrophyta and phytoplankton

3.1.1. Observations

Generally, the abundance of macrophyta on the beach during the whole three-year period was greatest in summer, i.e. from June to August

Table 1. Sum of monthly mean quantities of macroalgae for seven observation sites. Amounts of macroalgae at each site expressed on a numerical scale (none – 0, small – 1, average – 2, large – 3, very large – 4, huge – 5)

	In seawater (A)	On sand (B)	A + B
2004			
May	7.3	5.5	12.8
June	15.4	14.6	30.0
July	11.9	10.3	22.1
August	10.6	8.5	19.1
September	7.6	4.6	12.2
October	8.3	12.7	21.0
May–October	10.5	9.8	20.3
2005			
May	5.6	6.1	11.7
June	7.1	5.3	12.4
July	8.0	7.4	15.4
August	12.0	10.1	22.1
September	14.1	9.3	23.4
October	6.7	3.6	10.3
May–October	9.1	7.0	16.1
2006			
May	6.9	3.5	10.4
June	14.1	9.5	23.5
July	10.7	8.0	18.7
August	11.6	9.2	20.8
September	4.1	4.0	8.1
October	7.3	5.3	12.7
May–October	9.2	6.6	15.8

(Table 1), although in different years the maximum occurred in different months. Sometimes there was not just one maximum. In the water, in 2004 the maximum was in June (15.4 points), after which the abundance dropped, rising again in October to 8.3; in 2005 there was just one maximum, in September (14.1); in 2006 there was one maximum in June (14.1), another smaller one in August (11.6), and a slight increase in October (7.3). On the sand, the maximum in 2004 was reached in June (14.6) with a small increase in October (12.7); in 2005, quantities decreased from May to June but rose to a maximum in August (10.1); in 2006 there was a maximum in June (9.5), another one of similar height in August (9.2), and a small increase in October (5.3). There were greater differences in total macrophyta abundance (the sum for water and sand)

during each year and between years than between the respective values for water and sand. This was due to the generally higher amounts in the water than on the sand, except on two occasions – in October 2004 and May 2005. The total macrophyta abundance was greatest in June 2004 (30.0), in August/September 2005 (22.1/23.4), and in June (23.5) and August (20.8) 2006. Of the three years, the macrophyta abundance was the highest in 2004; the values in 2005 and 2006 were comparable. These data were in part distorted by beach cleansing activities, but their scale was such that their influence was not great. Also, the distribution of the macrophyta along the beach was different at particular stations. Distinct spatial and temporal variations were observed, e.g. in 2006 (Figure 3). In August 2006 the largest amounts of macrophyta in seawater were recorded in the vicinity of the Grand Hotel (54), whereas during the same period significantly lower quantities were found near the 'Balbina' station (20).

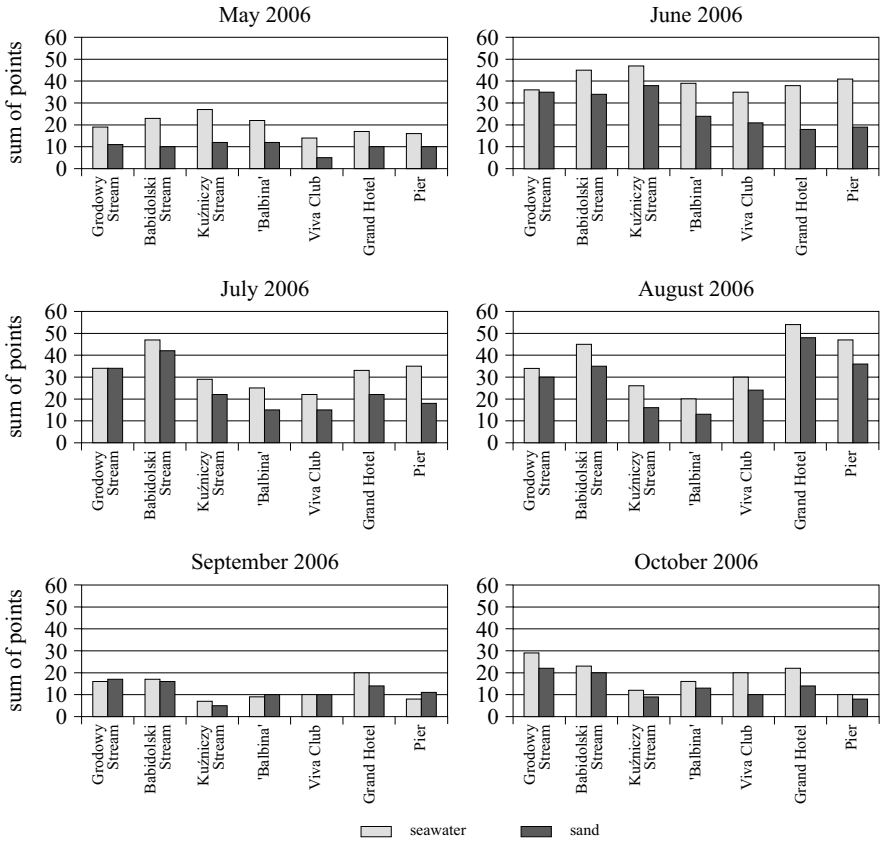

Figure 3. Abundance of macrophyta at different sites based on observations on the Sopot beach in 2006

In September 2006 macroalgae in the seawater were more evenly distributed, their abundance varying from 7 to 20 points.

3.1.2. Biomass

The biomass determined during the summer monitoring period averaged over all five sites, was highest in August (2004, 2005 and 2006) and in June (2006), though at particular stations it could be quite different, even at the same time, e.g. c. 21 000 mg (d.w.) dm^{-3} at site 1 (most sheltered from the wind) and 3–4 mg (d.w.) dm^{-3} at sites 4 and 5 (more exposed to the wind) in August 2004 (Table 2). Monitoring was carried out once a month.

Both the biomass determined from the average summer month observations and the mean absorption in the visible range of the particulate matter extract corresponded well with the amounts of plant material collected from the beach by the Sopot municipal cleansing services (Figure 4). The relevant ratios of macrophyta biomass in August 2005 to that in July 2005 were 1.57, 1.42 and 1.50 – for water only, sand only and water + sand, respectively (Figure 4a), 1.88 – for absorption measured twice a week (i.e. for water) (Figure 4b), and 1.63 – for the Sopot Municipality data (i.e. for sand) (Figure 4c). Only in October was there a clear difference between the first two methods owing to the decomposition of the floating material. Consequently, the observed amounts decreased and absorption of the extract increased.

Assuming that 1) the beach is 4.5 km long, 2) the near-shore seawater zone covered with macrophyta is 50 m wide, 3) macrophyta in the seawater are present down to a depth of 1 m, and 4) the biomass equal to the average monthly values obtained by filtering the water through gauze, the average macrophyta biomass in this volume of seawater was c. 4.4, 2.2 and 2.5×10^2 t (dry weight) in the summer seasons of 2004, 2005 and 2006, respectively. Of course, this is a very rough estimate, but compared with the amounts of material collected from the beach by the cleansing services (100 t in July and August 2005), it seems reasonable. Also, the macrophyta biomass was not evenly distributed along the coast. The next and even more difficult problem regarding the estimation of quantity relates to the speed of algae transport to the beach. Assuming the average wind velocity to be 1.5 m s^{-1} and the velocity of seawater moved by such a wind to be 100 times slower (Massel 2007), these amounts of algae contained in that seawater volume will be transported to the shore in one hour.

3.1.3. Taxonomy

The macrophyta included green, brown and red macroalgae species with a small proportion of sea grass *Zostera marina* (Table 3). These are

Table 2. Seawater samples collected from the Sopot beach – absorption, biomass, physico-chemical parameters, nutrient and pigment content

	Absorption [$\lambda = 660$ nm]	Biomass [mg d.w. dm^{-3}]	Salinity [PSU]	Oxygen [mg dm^{-3}]	Temperature [°C]	NO_3^- [mg dm^{-3}]	NO_2^- [mg dm^{-3}]	PO_4^{3-} [mg dm^{-3}]	Chl *a* [nmol dm^{-3}]	Chl *b* [nmol dm^{-3}]	Chls *c* [nmol dm^{-3}]	$\sum$Chlns *a* [nmol dm^{-3}]	Chl *a* [%]
24.06.2004													
station 1	0.017	5957	5.0	2.8	20.6	0.027	0.006	0.010	63.48	6.53	2.60	108.83	58.3
station 2	0.042	401	7.0	11.0	15.8	0.016	0.001	0.022	9.83	2.97	1.47	43.85	22.4
station 3	0.145	178	7.0	10.4	15.0	0.016	< d.l.*	< d.l.	1.45	0.48	6.16	53.16	2.7
station 4	0.064	1468	6.9	9.8	15.3	0.023	< d.l.	0.037	2.10	0.39	5.36	31.32	6.7
station 5	0.072	191	6.9	10.1	17.3	0.019	< d.l.	0.118	0.16	0.15	5.80	39.12	0.4
29.07.2004													
station 1	0.055	99	6.5	9.32	20.0	0.024	0.001	< d.l.	24.01	3.40	2.41	36.52	65.7
station 2	0.021	< 1	5.0	9.70	17.8	0.884	0.008	0.057	8.48	0.65	0.35	10.68	79.4
station 3	0.034	87	6.6	9.83	19.4	0.069	0.003	0.043	19.74	1.63	1.42	26.17	75.4
station 4	0.056	< 1	6.8	9.44	21.2	0.054	0.004	0.077	14.93	0.62	0.89	18.68	79.9
station 5	0.050	10	6.9	9.54	21.7	0.146	< d.l.	0.060	31.23	0.43	0.57	35.79	87.3
25.08.2004													
station 1	1.536	20 896	5.6	0.19	18.0	0.074	0.012	0.558	393.85	44.74	76.98	577.85	68.2
station 2	0.119	74	6.8	7.75	18.2	0.023	0.003	< d.l.	57.33	5.98	7.69	85.35	67.2
station 3	0.046	23	6.7	8.46	18.4	0.069	0.007	< d.l.	18.92	1.30	1.77	28.24	67.0
station 4	0.077	3	7.0	5.69	18.3	0.093	0.022	0.114	24.65	1.67	2.42	41.97	58.7
station 5	0.054	4	6.4	8.00	19.1	0.212	0.020	0.049	18.08	0.81	1.91	28.88	62.6

Table 2. (*continued*)

	Absorption [$\lambda = 660$ nm]	Biomass [mg d.w. dm^{-3}]	Salinity [PSU]	Oxygen [mg dm^{-3}]	Temperature [°C]	NO_3^- [mg dm^{-3}]	NO_2^- [mg dm^{-3}]	PO_4^{3-} [mg dm^{-3}]	Chl *a* [nmol dm^{-3}]	Chl *b* [nmol dm^{-3}]	Chls *c* [nmol dm^{-3}]	$\sum$Chlns *a* [nmol dm^{-3}]	Chl *a* [%]
28.06.2005													
station 1	0.062	92	7.0	9.37	17.4	0.014	< d.l.	0.047	0.40	1.88	0.63	15.19	2.6
station 2	0.054	70	6.5	10.00	17.2	0.066	0.009	0.121	0.14	0.97	0.47	9.43	1.5
station 3	0.070	234	6.8	10.25	17.6	0.017	0.003	0.002	0.21	0.89	1.72	18.22	1.2
station 4	0.052	107	7.1	9.70	18.3	0.016	0.004	< d.l.	0.27	0.76	0.65	11.80	2.3
station 5	0.057	103	7.0	9.62	18.1	0.014	0.002	0.203	0.09	0.57	0.90	11.39	0.8
27.07.2005													
station 1	0.365	27	6.7	10.10	18.7	0.029	< d.l.	0.102	10.43	29.46	6.61	143.19	7.3
station 2	0.294	58	6.7	10.75	18.5	0.027	< d.l.	0.088	3.46	34.73	3.26	128.41	2.7
station 3	0.160	74	6.8	10.10	18.7	0.025	< d.l.	< d.l.	2.28	15.07	2.63	63.51	3.6
station 4	0.118	68	6.8	9.81	19.8	0.030	< d.l.	0.106	1.52	7.87	1.04	39.19	3.9
station 5	0.056	39	6.8	9.11	19.8	0.029	0.001	0.039	3.12	1.52	0.60	18.78	16.6
24.08.2005													
station 1	0.041	111	6.5	10.30	20.6	0.023	0.004	< d.l.	5.78	1.05	0.66	22.44	25.8
station 2	0.325	3 731	5.7	12.34	20.1	0.242	0.009	< d.l.	32.56	5.55	13.36	145.59	22.4
station 3	1.452	7 149	6.6	4.85	22.3	0.035	0.003	0.106	345.53	24.81	42.85	749.10	46.1
station 4	2.562	2 857	4.8	10.47	22.3	0.032	< d.l.	0.121	40.23	19.24	24.89	619.44	6.5
station 5	0.024	29	6.8	9.45	21.5	0.020	0.004	0.219	0.41	0.32	0.33	8.99	4.6

Table 2. (*continued*)

	Absorption [$\lambda = 660$ nm]	Biomass [mg d.w. dm^{-3}]	Salinity [PSU]	Oxygen [mg dm^{-3}]	Temperature [°C]	NO_3^- [mg dm^{-3}]	NO_2^- [mg dm^{-3}]	PO_4^{3-} [mg dm^{-3}]	Chl *a* [nmol dm^{-3}]	Chl *b* [nmol dm^{-3}]	Chls *c* [nmol dm^{-3}]	$\sum$Chlns *a* [nmol dm^{-3}]	Chl *a* [%]
28.06.2006													
station 1	0.249	1118	6.1	10.79	20.7	0.020	0.002	0.017	15.28	2.44	0.8	31.67	7.7
station 2	0.990	2543	5.4	13.45	20.8	0.022	0.001	< d.l.	39.64	4.21	2.65	75.19	5.6
station 3	0.574	3965	6.0	13.84	20.4	0.029	0.006	< d.l.	56.41	3.08	10.96	154.87	2.0
station 4	0.067	221	5.5	11.60	18.9	0.107	0.006	0.007	6.39	0.54	0.42	13.33	4.1
station 5	0.013	73	5.8	9.9	18.8	0.243	0.006	0.139	3.80	0.23	0.22	4.77	4.8
25.07.2006													
station 1	0.018	181	6.2	8.87	23.8	0.022	0.002	0.065	3.23	0.34	0.21	6.74	5.0
station 2	0.021	85	4.8	9.00	21.2	0.549	0.009	0.050	6.34	0.75	0.53	10.53	7.1
station 3	0.052	173	6.1	9.50	23.2	0.030	0.002	0.040	8.19	1.42	1.17	19.87	7.1
station 4	0.065	431	6.2	9.49	22.9	0.028	0.004	0.025	12.51	1.21	2.21	29.30	4.1
station 5	0.034	49	6.2	8.7	22.7	0.022	0.002	0.100	0.79	0.41	0.75	7.26	5.6
21.08.2006													
station 1	0.022	28	6.9	7.32	18.1	0.017	0.003	< d.l.	3.61	0.63	0.95	10.81	5.8
station 2	0.030	41	6.8	7.15	18.0	0.051	0.004	0.045	4.19	0.39	0.74	8.25	4.7
station 3	0.481	3369	6.7	7.10	18.5	0.018	0.004	0.060	28.62	9.88	5.27	125.72	7.9
station 4	0.688	4374	6.5	4.00	18.4	0.021	0.001	0.045	43.98	1.41	5.04	115.79	1.2
station 5	0.017	49	6.7	7.85	18.1	0.023	0.001	0.060	3.76	0.84	0.61	10.16	8.3

* for NO_2^- – < 0.001, for PO_4^{3-} – < 0.002

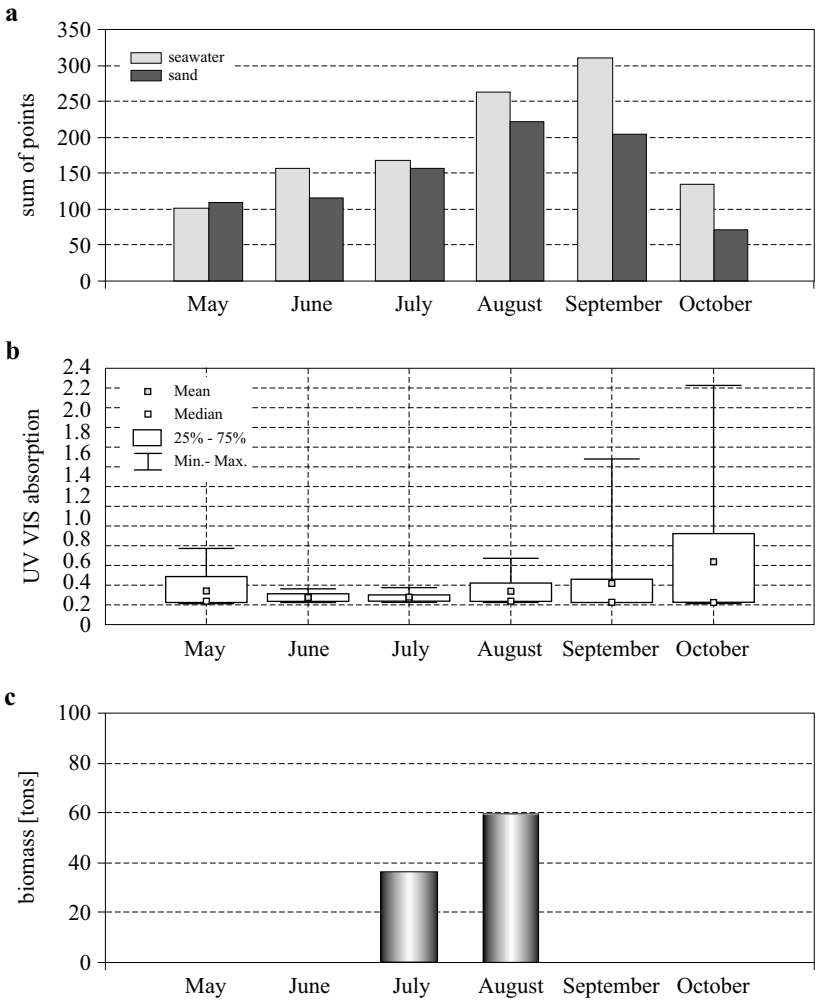

Figure 4. Macrophyta on the Sopot beach in 2005: a) abundance of macrophyta based on observations; b) absorption in the visible range of the particulate matter extract – station 2, twice-weekly measurements; c) amounts of macrophyta collected by the cleaning services – data from the Sopot Municipal Council

the main groups of macrophyta occurring in the whole Gulf of Gdańsk (Kruk-Dowgiałło 1998). The dominant species were *Cladophora* spp., *Enteromorpha* spp. (green algae), *Pilayella littoralis* (brown algae) and *Ceramium* spp. (red algae). 22–75% of the biomass consisted of green algae, 17–71% of red algae and 0–50% of brown algae (Filipkowska et al. 2008). Macrophyta abundance reached a maximum in June 2004 and 2006, when the three groups of algae were in equal proportions, whereas in 2005 maximum abundance was in August, when the three groups were also

present in comparable proportions in most samples. The percentage of green algae was highest in the samples collected in July 2004 (60%), June and July 2005 (75%) and August 2006 (up to 75%), that of brown algae was highest in June 2004 and 2006 ($\sim$30%) and August 2005 (up to 50%), and that of red algae highest in August 2004, 2005 and 2006 (up to 50, 60 and 100%, respectively). The abundance of sea grass also peaked in August 2004, 2005 and 2006 (up to 100, 22.2 and 28.6%, respectively); in the June 2006 samples its percentage was high compared to the same period in the other years (Table 3). The brown filamentous macroalgae (*Pilayella* and *Ectocarpus* spp.) and the green algae (*Enteromorpha* spp.) that dominated the biomass, like the numerous epiphytes on the sea grass, provide evidence for the intensive eutrophication of the Gulf (Kruk-Dowgiałło 1996, Salovius & Bonsdorff 2004, Scanlan et al. 2007). The ratio of the sum of red algae and sea grass to the sum of brown and green algae was highest in August. This tallies with the growth cycle of these species (Kruk-Dowgiałło 1998). The abundance of brown algae peaked during the maximum abundance of macrophyta in each year, although their percentage in the total biomass during the whole season was not the highest.

Macroalgae have already been shown to be good indicators of the state of the marine environment (e.g. Alström-Rapaport & Leskinen 2002, Arévalo et al. 2007, Ballesteros et al. 2007, Sfriso et al. 2009). Though recommended for monitoring by EU WFD, they have not been monitored in the Polish coastal zone in recent years (WIOŚ 2008). The majority of the macroalgae reported from the Sopot beach are classified as opportunistic species abundant in eutrophic environments (Kruk-Dowgiałło 1998, Lotze et al. 1999, Raffaelli 2000, Scanlan et al. 2007).

Table 4 lists the classes and cell numbers of phytoplankton determined in the samples, and Figure 5 shows the biomass and taxon percentages. The groups of phytoplankton were those normally present in the southern Baltic (Pliński 1995, IMGW 1998, 2000). Both the biomass and composition of the phytoplankton population differed considerably, according to year, season and sampling site location. Phytoplankton was the most abundant in the samples collected in 2005, less abundant in 2004 and least abundant in 2006. In 2004 and 2006 its biomass reached a maximum in June; in 2005 it peaked in July. In June 2004 and 2005 dinoflagellates were distinctly dominant, mainly the brackish-water species *Heterocapsa triquetra*. The blooms of this marine dinoflagellate usually occur in June under intensive solar radiation (Wasmund et al. 1998). In June 2006, however, both the qualitative and quantitative composition of the phytoplankton was diversified, and diatoms, dinoflagellates or cyanobacteria were dominant at different sites.

Table 3. Macroalgae and sea grass collected on the Sopot beach – composition of plant material and pigment content (Filipkowska et al. 2008)

		Green algae [%]	Brown algae [%]	Red algae [%]	Sea grass [%]	Chl a [1)] [nmol g^{-1}]	Chl b [2)] [nmol g^{-1}]	Chls c [3)] [nmol g^{-1}]	$\sum$Chlns a [4)] [nmol g^{-1}]	Chl a [5)] [%]
2004										
2	21.06.2004	–	–	–	–	71.29	84.87	98.61	908.03	7.85
1	24.06.2004	33.3	33.3	33.3	0.0	198.91	171.85	37.36	1044.52	19.04
2	24.06.2004	33.3	33.3	33.3	0.0	107.07	159.46	56.36	1105.96	9.68
2'	24.06.2004	33.3	33.3	33.3	0.0	49.80	168.12	51.98	1189.67	4.19
2I	29.07.2004	60.0	20.0	20.0	0.0	192.94	118.69	53.27	905.55	21.31
T	02.08.2004	0.0	0.0	0.0	100	1925.57	430.96	8.01	2265.32	85.00
1	25.08.2004	41.4	13.8	41.4	3.4	878.62	289.19	101.92	2127.30	41.30
2II	25.08.2004	50.0	0.0	50.0	0.0	1201.80	417.25	113.72	2712.99	44.30
2005										
3	28.06.2005	75.0	0.0	25.0	0.0	6.86	54.84	46.15	499.57	1.37
A	29.07.2005	75.0	0.0	25.0	0.0	48.48	84.57	36.48	456.32	10.62
B	05.08.2005	48.0	32.0	16.0	4.0	284.39	998.89	171.19	3385.42	8.40
C	11.08.2005	27.6	27.6	41.4	3.4	160.08	271.86	81.61	1508.63	10.61
2'	22.08.2005	33.3	50.0	16.7	0.0	669.14	282.86	272.09	3720.66	17.98
2	24.08.2005	40.0	0.0	60.0	0.0	656.93	260.20	359.10	4048.10	16.23
3	24.08.2005	28.6	28.6	42.9	0.0	637.38	348.69	213.15	3011.83	21.16
3I	24.08.2005	32.4	32.4	32.4	2.7	480.23	462.64	157.76	2681.49	17.91
4	24.08.2005	28.6	42.9	28.6	0.0	588.87	110.02	202.45	3207.34	18.36
D	27.08.2005	22.2	22.2	33.3	22.2	394.05	306.74	150.38	2882.54	13.67

Table 3. (*continued*)

2006		Green algae [%]	Brown algae [%]	Red algae [%]	Sea grass [%]	Chl a [1)] [nmol g^{-1}]	Chl b [2)] [nmol g^{-1}]	Chls c [3)] [nmol g^{-1}]	$\sum$Chlns a [4)] [nmol g^{-1}]	Chl a [5)] [%]
2'	14.06.2006	33.3	22.2	22.2	22.2	73.10	98.63	120.58	1418.97	5.15
2'a	14.06.2006	100.0	0.0	0.0	0.0	390.27	182.75	7.68	740.06	52.73
2'b	14.06.2006	0.0	100.0	0.0	0.0	59.55	18.02	276.86	2336.96	2.55
1	28.06.2006	30.0	30.0	30.0	10.0	556.03	159.20	134.51	1544.21	36.01
2	28.06.2006	30.0	30.0	30.0	10.0	512.81	105.33	88.63	1445.80	35.47
3	28.06.2006	30.0	30.0	30.0	10.0	375.54	208.53	185.55	3273.71	11.47
3I	28.06.2006	30.0	30.0	30.0	10.0	300.70	117.83	171.76	2782.75	10.81
E	17.07.2006	0.0	0.0	100.0	0.0	234.62	114.21	102.48	1474.74	15.91
1	21.08.2006	75.0	0.0	25.0	0.0	284.24	539.23	134.14	2944.91	9.65
3	21.08.2006	28.6	0.0	42.9	28.6	1103.02	522.17	174.23	3842.18	28.71
4	21.08.2006	23.5	0.0	70.6	5.9	670.51	581.43	113.34	3259.65	20.57

[1)] chlorophyll a
[2)] chlorophyll b
[3)] chlorophylls c
[4)] sum of chloropigments a (chlorophyll a and transformation products of chlorophyll a)
[5)] percentage of chlorophyll a in the sum of chloropigments a

Table 4. Qualitative and quantitative [items dm^{-3}] determination of phytoplankton in seawater

	Cyanobacteria	Dinoflagellates	Diatoms	Euglenoids	Green algae
24.06.2004					
station 1	n.d.	n.d.	n.d.	n.d.	n.d.
station 2	n.d.	n.d.	n.d.	n.d.	n.d.
station 3	18 400	29 142 100	4 000	400	0
station 4	387 300	19 806 200	49 800	447 300	0
station 5	197 100	22 775 320	102 500	519 500	14 400
29.07.2004					
station 1	545 040	808 200	279 600	93 800	45 200
station 2	269 870	216 434	183 230	7 200	15 300
station 3	126 400	527 100	541 800	297 300	0
station 4	215 400	39 400	336 500	371 700	44 900
station 5	591 700	50 400	774 700	115 400	21 400
25.08.2004					
station 1	n.d.	n.d.	n.d.	n.d.	n.d.
station 2	345 860	21 620	674 640	0	72 900
station 3	617 020	900	234 640	0	78 520
station 4	135 350	1 480	47 620	0	30 400
station 5	251 100	7 400	272 400	0	268 820
28.06.2005					
station 1	314 460	8 263 000	45 830	14 430	14 900
station 2	196 600	10 853 990	130 670	0	14 430
station 3	244 400	9 746 700	281 340	74 430	59 000
station 4	294 060	4 446 500	7 700	14 200	29 600
station 5	590 100	14 583 910	24 020	14 800	22 000
27.07.2005					
station 1	1 957 130	3 038 480	161 700	13 361 600	387 200
station 2	1 258 350	2 502 100	593 860	7 662 000	327 000
station 3	3 742 300	2 360 700	988 050	19 802 400	59 400
station 4	2 508 400	990 700	562 700	1 529 500	253 200
station 5	2 290 060	3 463 400	513 300	4 697 900	237 900
24.08.2005					
station 1	237 880	1 547 300	131 710	0	0
station 2	0	747 910	2 329 830	0	89 200
station 3	43 300	0	9 797 530	0	0
station 4	321 500	0	14 675 210	0	0
station 5	0	800	193 210	0	327 000
28.06.2006					
station 1	2 086 340	673 860	367 340	0	906 420
station 2	378 930	1 866 770	120 560	28 860	29 660
station 3	773 060	288 600	2 681 660	0	490 060

Table 4. (*continued*)

	Cyanobacteria	Dinoflagellates	Diatoms	Euglenoids	Green algae
28.06.2006					
station 4	2 587 590	506 600	30 000	29 700	94 710
station 5	4 428 920	649 300	100 520	0	314 560
25.07.2006					
station 1	6 115 070	416 700	244 470	0	416 500
station 2	1 729 630	535 600	582 390	0	300
station 3	5 025 380	29 930	678 540	0	497 330
station 4	13 047 230	59 460	1 933 850	59 500	0
station 5	8 844 510	59 400	584 340	0	892 000
21.08.2006					
station 1	21 400	628 060	1 327 500	0	29 730
station 2	74 140	538 800	3 110 180	0	31 330
station 3	149 700	29 730	4 942 160	0	0
station 4	35 200	0	2 942 320	29 730	59 500
station 5	852 450	0	4 143 830	0	90 400

n.d. – not determined.

In July 2004 no taxon was dominant, with cyanobacteria, dinoflagellates and diatoms being present in comparable proportions. However, in July 2005 euglenoids made up a considerable share of the phytoplankton biomass, a further indication of the eutrophication of the environment. In July 2006 cyanobacteria (*Nodularia spumigena*, *Anabaena* sp., *Merismopedia* spp.) constituted a substantial proportion of the phytoplankton biomass: their blooms occur at high temperatures, intensive solar radiation, and under stagnant conditions (Wasmund 1997, Finni et al. 2001). That they can also survive anoxia is also demonstrated by the results, because cyanobacteria were present in huge numbers, precisely when the seawater temperature was high (e.g. 25.07.2006, station 4 – about 13 million items dm^{-3} (Table 4) and 22.9°C (Table 2)). Cryptophytes occur in stagnant water but need less light (Mackiewicz 1991, IMGW 2000, Pająk 2003). In August 2004–06 the majority of the phytoplankton assemblage consisted of dinoflagellates of the genus *Heterocapsa* (*H. triquetra* and *H. rotundata*) and diatoms, mainly of the genera *Syndera*, *Licmophora*, *Rhoicosphenia* and *Cocconeis*, all of the marine origin. Like dinoflagellates, diatoms need lower temperatures but intensive solar radiation. Green algae, representative of freshwater microorganisms, were generally in the minority. Conspicuous proportions of green algae in the phytoplankton biomass were recorded only in July 2004 and 2005. The phytoplankton composition can change in a relatively short time in response to numerous factors, e.g. the time of day, temperature, sunlight, nutrient availability, salinity (freshwater inflow), wind. Obviously,

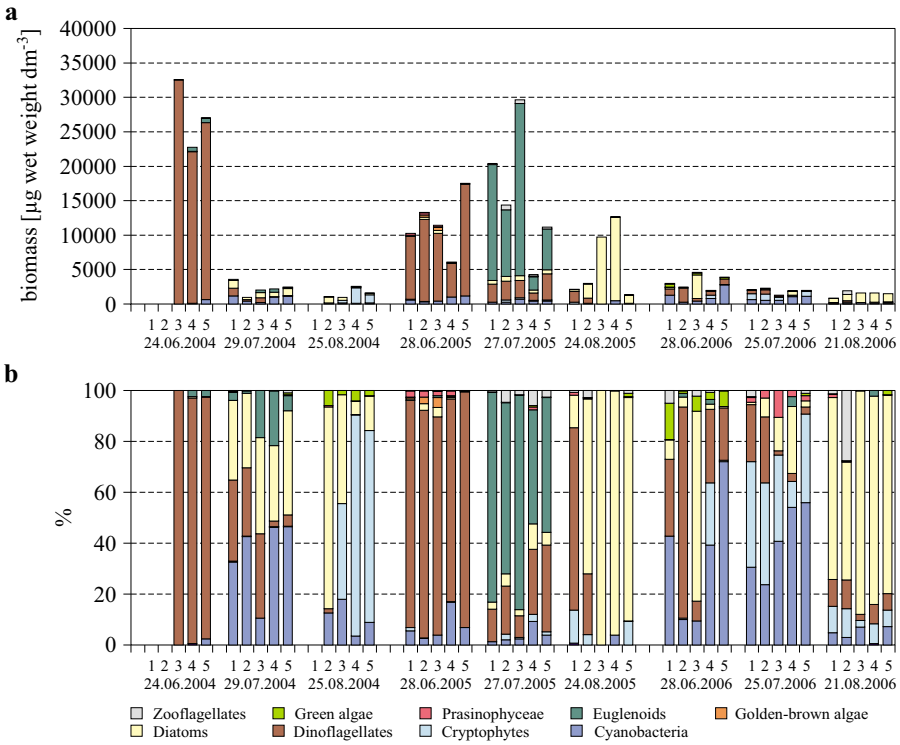

Figure 5. Phytoplankton samples: a) biomass [μg wet weight dm^{-3}]; b) percentage composition of phytoplankton in biomass

there were too few samples to compare these three summer seasons in greater detail, but it is clear that the local conditions were not the only influence on the biomass and phytoplankton composition at the study sites.

3.1.4. Chloropigment content

Table 3 lists the chloropigment concentrations in the macrophyta. The ratio of chlorophyll *a* to the sum of total chloropigments *a* expressed as a percentage was assumed to be a measure of the degree of decomposition of the plant material (Filipkowska et al. 2008). The lower the proportion of chlorophyll *a*, the greater the decomposition of the sample. Accordingly, the most decomposed were the samples collected in June 2004 (4–19% Chl *a*) and 2005 ($\sim$1.4% Chl *a*), and also in July 2005 ($\sim$11% Chl *a*). But the differences in pigment composition also depended on species. The richest in chlorophyll *a* were the samples collected in August 2004–2006 (up to 85%, 21% and 29% Chl *a*, respectively) and in June 2006 (36% Chl *a*). The chlorophyll *b* content indicates the presence of green macro- and microalgae

or sea grass, and chlorophylls *c* are marker pigments of brown and red algae (Jeffrey et al. 1997). Individual species were selected from the total biomass for the pigment composition to check these regularities: green and brown algae (samples 2'a and b from sample 2, June 2006), red algae (sample E, July 2006). However, interpretation of the pigment results is not easy, because the chloropigment composition depends not only on the mixture of species but also, as mentioned above, on the degree of decomposition of the plant material; moreover, chlorophyll *b* and chlorophylls *c* are even less stable than chlorophyll *a*. For example, the sea grass sample T (02.08.2004) and sample No. 3 collected in June 2005 (75% of green algae) should have been rich in chlorophyll *b*, but the content of this pigment was not at the same level in either case (431 and 55 nmol g^{-1} respectively). This will have been due to the overlapping influence of different factors: these were different species, and besides, sample 'T' was fresh (85% Chl *a*), while sample No. 3 (28.06.2005) was decomposed ($\sim 1.4\%$ Chl *a*). It should be borne in mind that these pigments will also have been derived from phytoplankton, even though the proportion of chloropigments originating from phytoplankton is small compared to that in macrophyta at their greatest abundance, and also that absorption methods (including HPLC) determine the chloropigments in phytoplankton, detritus and some macrophyta, whereas the weight biomass method using gauze determines mainly the macrophyta and only some phytoplankton.

Table 2 sets out the chlorophyll *a* content in the phytoplankton species. Chlorophylls *c* in phytoplankton samples are markers of diatoms, dinoflagellates, as well as cryptophytes, golden-brown algae and haptophyte algae; chlorophyll *b* is a marker of green algae and euglenoids, whereas chlorophyll *a* occurs in all the photosynthetic microalgae, and is the sole chlorophyll in cyanobacteria (Jeffrey et al. 1997). The concentration of chloropigments *a* in the surface seawater samples ranged from 5 to 750 nmol dm^{-3}. These values were definitely higher than the pigment content presented for the Gulf of Gdańsk by Szymczak-Żyła & Kowalewska (2007) and other authors (Ochocki et al. 1995, Witek et al. 1999, Stoń & Kosakowska 2000, Wasmund et al. 2000). Moreover, as much as 78% of the seawater samples exceeded the HELCOM target level of summer chlorophyll *a* concentration for the Baltic Proper (< 1.5 μg dm^{-3}) (HELCOM 2007). The high concentration of chloropigments is due to the eutrophication of the coastal waters in the Gulf of Gdańsk and leads to the mass occurrence of macroalgae and phytoplankton. Comparison of the absorption maxima of the acetone extracts with the intensive blooms of phytoplankton species shows that the most intensive maxima correspond to

macroalgae abundance. Even the most intensive phytoplankton blooms are barely reflected in the absorption of extracts from the seawater samples.

3.1.5. Nutrients

It is a well-known fact that high concentrations of nutrients in seawater stimulate the growth of algae, while an excess of macroalgae and phytoplankton blooms are signs that the functioning of the aquatic ecosystem is imbalanced (HELCOM 2006, 2007). That is why nutrient concentrations (PO_4^{3-}, NO_3^-, NO_2^-) were also monitored as part of this study. The content of phosphates varied from < 0.002 to 0.558 mg dm^{-3}, although in the majority of cases levels were < 0.200 mg dm^{-3}. The highest phosphate content (station No. 1, 25.08.2004) differed distinctly from the rest of the results. Moreover, about 25% of all results were determined as concentrations below the detection limit. Concentrations of nitrates varied from 0.014 to 0.884 mg dm^{-3}, but exceeded 0.20 mg dm^{-3} only in a few samples. The highest nitrite content was 0.022 mg dm^{-3} but, as in the case of phosphates, almost 25% of the levels were below the detection limit. Although the nutrient content data are not numerous, they do seem to indicate that maximum levels were accidental rather than typical; it should be remembered that monitoring at each location was infrequent and the maximum values measured were not repeated. It is significant that there are as many as 12 streams crossing the Sopot beach, each of them discharging its own load of nutrients to the sea. Nutrient concentrations are strongly affected by seasonality, so it is difficult to compare these data with any requirements. The phosphorus and nitrogen concentrations stipulated by both the relevant Polish Government order (DzU Nr 162) and HELCOM targets (HELCOM 2007) relate to the surface water concentrations of nutrients in winter; at this time of year biological activity is at its lowest, and inorganic nutrients reach their highest concentrations in the Baltic Sea. This is the result of remineralisation, vertical mixing in the water column, the small amount of sunlight and consequently the lack of phytoplankton activity (Feistel et al. 2008, HELCOM 2007). The period of high biological activity occurs from early spring to late autumn (when the seawater samples were taken), and then the nutrient contents decrease to around the detection limit. In any case, in only one sample (station No. 2, 29.07.2004) was the nitrogen concentration higher ($C_{N(nitrate+nitrite)} = 3.270$ μmol dm^{-3}) than the HELCOM targets for the Baltic Proper (< 2.9 μmol dm^{-3}). In the case of the phosphorus concentrations, 18% of all samples exceeded the HELCOM target level for the Baltic Proper (< 0.38 μmol dm^{-3}). Note that the HELCOM requirements involve the open sea of the different Baltic sub-regions, in this case the Baltic Proper.

3.2. Relation to environmental conditions

The average annual solar radiation was highest in 2005 ($\sim 245 \times 10^3$ W m^{-2}), somewhat less in 2006 ($\sim 238 \times 10^3$ W m^{-2}), and lowest in 2004 ($\sim 232 \times 10^3$ W m^{-2}). The maximum solar radiation in 2004 was in June ($\sim 311 \times 10^3$ W m^{-2}), and in 2005 and 2006 in July ($\sim 334 \times 10^3$ and $\sim 358 \times 10^3$ W m^{-2}, respectively) (Table 5).

2004 was the coolest of the three years and had the coolest May–July period (mean temp. 14.8°C). Maximum air temperatures were recorded in August 2004 (19.3°C), and July 2005 and 2006 (19.7 and 22.3°C, respectively) (Table 5).

Table 5. Meteorological data* – monthly means for 2004–06

	Wind velocity [m s^{-1}]	Air temperature [°C]	Air humidity [%]	Mean 24 h solar radiation [W m^{-2}]	Sum of solar radiation [W m^{-2}]
2004					
May	2.1	11.6	77.3	199.9	297 501
June	1.8	15.5	76.1	216.0	311 031
July	1.6	17.1	80.7	184.4	274 435
August	1.5	19.3	82.4	169.4	251 793
September	1.9	15.0	78.5	122.9	176 935
October	1.7	10.6	85.2	52.3	77 770
May–October	1.8	14.8	80.1	157.5	231 577
2005					
May	1.7	12.7	76.5	191.3	284 694
June	1.8	15.6	76.3	223.1	310 598
July	1.6	19.7	78.2	224.3	333 690
August	1.6	17.6	80.2	167.4	249 143
September	1.4	16.3	81.1	128.4	184 876
October	1.6	10.1	83.0	71.7	106 741
May–October	1.6	15.3	79.2	167.7	244 957
2006					
May	1.6	13.3	72.6	199.5	296 891
June	1.5	16.8	78.0	230.0	298 118
July	1.6	22.3	72.5	240.9	358 444
August	1.4	18.7	84.7	130.2	193 702
September	1.1	17.0	83.2	140.6	202 456
October	1.6	12.6	85.0	52.3	77 757
May–October	1.5	16.8	79.3	165.6	237 894

* – values calculated on the basis of data supplied by the ARMAAG Foundation.

Humidity was greatest in May–October 2004. In 2005, the average monthly humidity rose from May to October and was generally lower than in 2004. The humidity in 2006 (79.3%) was less than in 2004 (80.1%) and on average similar to that in 2005 (79.2%). The period from May to July was drier than the corresponding one in 2005. In 2006 there were three humidity maxima: a small one in June (78.0%), a higher one in August (84.7%), and the highest one in October (85.0%).

The average annual wind velocity was highest in 2004 (1.8 m s^{-1}), and lowest in 2006 (1.5 m s^{-1}) (Table 5). The prevailing wind direction in all three years was south-westerly. Winds from this direction were strongest in 2004, much less strong in 2005 and weakest in 2006 (Figure 6). The wind strength was defined as the product of its velocity and frequency of occurrence. The greatest differences in particular months were in the strength of north-easterly, south-easterly and southerly winds: the first in June–August, the other two in October. South-westerly winds were strongest in June and September 2004, in August 2005, and in May, September and October 2006.

Table 2 lists the salinity, oxygen content and temperature of the seawater. Salinity at the shoreline was usually close to 7, but in the vicinity of local watercourses it fell even to 4.8 PSU. Water temperature (15–23.8°C) was similar to the air temperature during stagnant periods at particular locations, but differed during strong winds and wave-action. Oxygen concentrations varied from 0.19 mg dm^{-3} (anoxia) to 13.84 mg dm^{-3}. Oxygen depletion was recorded in only a few cases and was most probably caused by the accumulation of macrophyta at the water's edge, which sometimes form a kind of stagnant water belt in which huge amounts of organic matter decompose at the sampling sites.

There were no significant correlations between the parameters studied for the data sets collected during three years. This was most probably due to the great variety of factors studied and to the small number of data sets. Other authors have also noted that the occurrence, persistence and impacts of macroalgal blooms are often difficult to characterise and understand fully because of a number of physical, chemical and biological factors, which may interact in a complex way (Scanlan et al. 2007). In case of the Sopot beach additional factors are involved: those causing macroalgae to be detached and to float over long distances across the sea.

Nevertheless, the factors affecting accumulation of plant material on the Sopot beach can be divided into two groups: one includes factors affecting the growth of macrophyta – temperature and solar radiation; we assume that the concentrations and ratios of nutrients, trace elements, salinity, etc. were on average similar in all three years 2004–06. The other group of

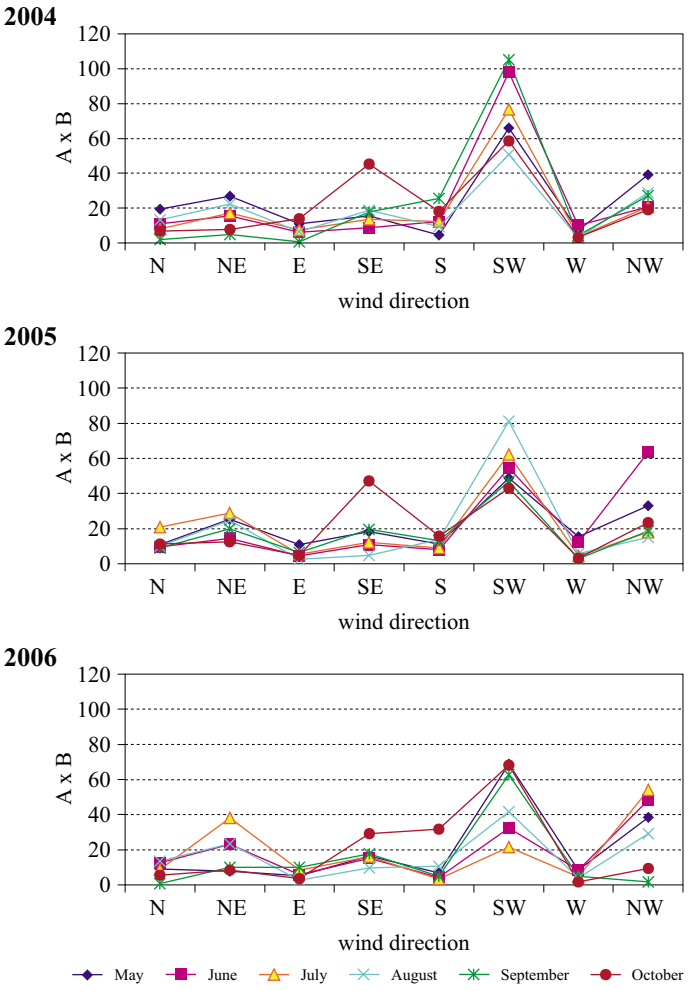

Figure 6. Wind strength (A × B) in 2004–2006; A – frequency of occurrence, B – wind velocity

factors includes winds, waves and currents, which cause macrophyta to be detached from the sea bed, transport the biomass to the Sopot beach and relocate it along the shoreline. Taking into account the fact that the weather conditions, which may speed up or slow down the growth and proliferation of macrophyta, were the worst in 2004 and the best in 2006, while the biomasses were the reverse (the highest in 2004), one may say that the most important factors were the velocity, frequency of occurrence, and direction of the wind, which in these shallow coastal waters is the principal driver of water currents and water exchange. Especially important seems to be the prevailing south-westerly wind, which when strong generates offshore surface

currents (IMGW 2000). This water circulation is particularly significant for macrophytobenthos transport from Puck Bay: this is sheltered from the open sea by the Hel Peninsula, so the macrophyta, released and moved from the bottom to the surface water, do not then float out to the open sea but are shifted by the wind-driven currents towards the Gulf of Gdańsk. Moreover, filamentous brown macroalgae are more abundant in Puck Bay than elsewhere in the Gulf (Ciszewski et al. 1991, Kruk-Dowgiałło 1996). Taking into account the fact that during the three-year study, the maximum abundance of algae accumulating on the beach coincided with the highest proportion of filamentous brown algae in the macrophyta biomass and a strong south-westerly wind followed by northerly wind moving the biomass shorewards, we can conclude that these heaps of macroalgae accumulating on the Sopot beach originated from Puck Bay. Such a conclusion is supported by the high, positive correlation between the northerly wind and the observation data recorded only in 2006 ($r = 0.88$ in water), when south-westerly winds were the weakest in the three years and the amounts of macroalgae material accumulating on the Sopot beach were the smallest.

4. Conclusions

Shore monitoring is definitely a less expensive method than aerial photography (Berglund et al. 2003), and so long as it is regular and frequent, the observations give reliable results. Absorption of an acetone extract of seawater is a good measure of the algal biomass in seawater, provided the content of macroalgae is low.

Three significant factors acting in combination are responsible for the huge amounts of macrophyta amassing on the Sopot beach: 1) high solar radiation in spring and summer, 2) very strong (velocity $\times$ frequency) south-westerly winds from May to September, which move macrophyta from Puck Bay to the Gulf of Gdańsk, and 3) the strength of the northerly winds shifting these macrophyta towards the beach. It was estimated that from 2.2. to 4.4. 10^2 t of macroalgae (dry weight) can be moved onto the Sopot beach in one hour. In October, the southerly and south-easterly winds also transport decomposing plant material towards this shore. The biomass recorded on the beach consists mainly of macroalgae with a small proportion of sea grass; the phytoplankton content in the total biomass is negligible, even though at low concentrations their biological activity may be considerable. The intensive phytoplankton blooms observed from the Sopot beach are not always caused by cyanobacteria, and the phytoplankton abundance varies along the beach according to the wind

and the local currents it gives rise to. The main taxa making up the phytoplankton biomass are dinoflagellates, diatoms, cyanobacteria, euglenoids and cryptophytes.

This pilot project has been insufficient to enable a full understanding of the factors governing the occurrence of algae on the Sopot beach. Neither the rather small number of some data nor the variety of physical, chemical and biological factors permit an exhaustive explanation of the accumulation of algae on the sea-shore at present; only general conclusions can be drawn.

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