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Decomposition of macroalgae and the release of nutrient in Admiralty Bay, King George Island, Antarctica

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Abstract: On land and in the shore zone macroalgae are a source of organic matter and of nutrients. A crumbled mixture of macroalgae and 10 selected species of macroalge were used in investigations. In long (22–69 days) and short (11–52 hours) term experiments the quantities of released nutrients per 1 kg of dry mass of identified macroalgae were: for nitrogen 7.4–93.7 mg NO_2^--N, 12.9–406 mg NO_3^--N, 74.0–7890 mg NH_4^+-N, and 1110–22000 mg total-N; for phosphorus the figures were: 718–6110 mg reactive-P and 1370–13400 mg total-P. The amounts of ammonium-N, total-N, reactive-P and total-P, released from the mixture of disintegrated algae collected on the beach, were lower than those from fresh algae. Nitrate-N, reactive-P and total-P were liberated most readily. From the total amounts of nutrients in the long and short term experiments about 80% were released during the first 3 days and the first 3 hours respectively. The decomposition of macroalgae may improve the fertility of poor soils and inland water as well as of sea water, being a source of nutrients.

key words: Antarctica, macroalgae, decomposition, nutrients

Introduction

An important source of organic matter in the maritime Antarctic coastal ecosystem is benthic thallophytic algae (Zieliński, 1981; Dieckmann *et al.*, 1985; Rakusa-Suszczewski and Zieliński, 1993). In Admiralty Bay (Fig. 1) they cover over 30% of the bottom surface. The algae are the source of both organic matter released from live cells into the bay water (Dawson *et al.*, 1985) and matter liberated as a result of dying and decomposing of algae in water. The wet weight of macroalgae in Admiralty Bay has been estimated at 74000 tons (Zieliński, 1990). This corresponds to about 296 tons of chlorophyll *a* (Rakusa-Suszczewski, 1995). Macroalgae reach the shore due to waves, tides and wind. After being deposited on land, they are subject to decomposition and join the material cycle between sea and land (Rakusa-Suszczewski, 1980; Zieliński, 1981). Benthic algae dispersed over land may enrich weak soils in organic matter, nutrients and some microelements like Cu or Zn (Rakusa-Suszczewski and Zieliński, 1993). The mass of the macroalgae mixture deposited on the Admiralty Bay shore from February till November 1979 was estimated to be about 244 tons dry weight, corresponding to about 104 kg of macroalgae per meter of accessible beach (Rakusa-Suszczewski, 1995). The mass of macroalgae produced in the shore zone is much greater than that reaching the shore. No one has done a reliable quantitative evaluation in this region (Zieliński, 1981; Reichardt and Dieckmann, 1985).

The aim of the present paper is the experimental examination of the decomposition of marine macroalgae deposited on the shore and quantitative evaluation of the process of leaching of nitrite, nitrate, ammonium and total nitrogen as well as of reactive and total phosphorus.

Materials and methods

The investigations were carried out at Arctowski Station and in the region of the Admiralty Bay in 2001 (Fig. 1). The following materials were used for the experiment: 1) the mixture of macroalgae irrespective of their species composition deposited on the shore and disintegrated in a natural way, 2) fresh specimens of macroalgae sampled from the sea, of the species listed below: Phaeophyta: *Himantothallus grandifolius*, *Cystosphaera jacquinotii*, *Desmarestia menziesii*, *Desmarestia anceps*, *Desmarestia ligulata*, *Adenocystis utricularis*, *Ascoseira mirabilis*, Rhodophyta: *Curdiea racovitzae*, *Myriogramme mangini* and *Sarcodia antarctica.*

The experiment of the first type consisted of long term exposure of macroalgae in distilled water for several days (22–69 days). The determination of nutrients in aqueous solutions was carried out after 24 hours of exposure; after nutrient analyses the water was replaced by fresh water. The second type of experiment involved short exposure of macroalgae in distilled water for several hours (11–52 hours). The determination of nutrients was carried out after one hour of water exposure. After particular determinations take a place 48 hours interval during which deprive macroalgae of water were kept at about $+4°C$ to simulate the natural conditions on the shore.

The water exposures were carried out in both types of experiments (long and short term) at a constant temperature of $+4°C$, in an open polyethylene bottle, in a dark room. The water volume was 1 dm^3 and the amount of macroalgal mixture or of particular species of macroalgae was 100 ± 2 g of wet weight.

In the aqueous solutions thus obtained the analyses were performed for: nitrite-N, nitrate-N, ammonium-N, total-N, reactive-P and total-P. The chemical colorimetric analyses were applied in conformity with Standard Methods (1995). The nutrient contents were spectrophotometrically measured by a Carl Zeiss Specol-1100. Nitrite-N was determined with sulfanilic acid ($\lambda = 543$ nm), nitrate-N after reducing to nitrite on a Cu-Cd column, was found again as nitrite, ammonium-N was analyzed based on indophenol blue method ($\lambda = 630$ nm). Total nitrogen after mineralization with potassium persulfate was determined as nitrate. The amount of reactive-P was found by reaction with molybdate, ascorbic acid being used as the reducing agent ($\lambda = 882$); the same method was used for total-P after mineralization with potassium persulfate. The spectrophotometric readings were converted into mg of nitrogen or of phosphorus liberated from 1 kg dry weight of macroalgae. The dry weight of macroalgae was established by drying at $65°C$ to a constant mass at the beginning and at the end of the experiment.

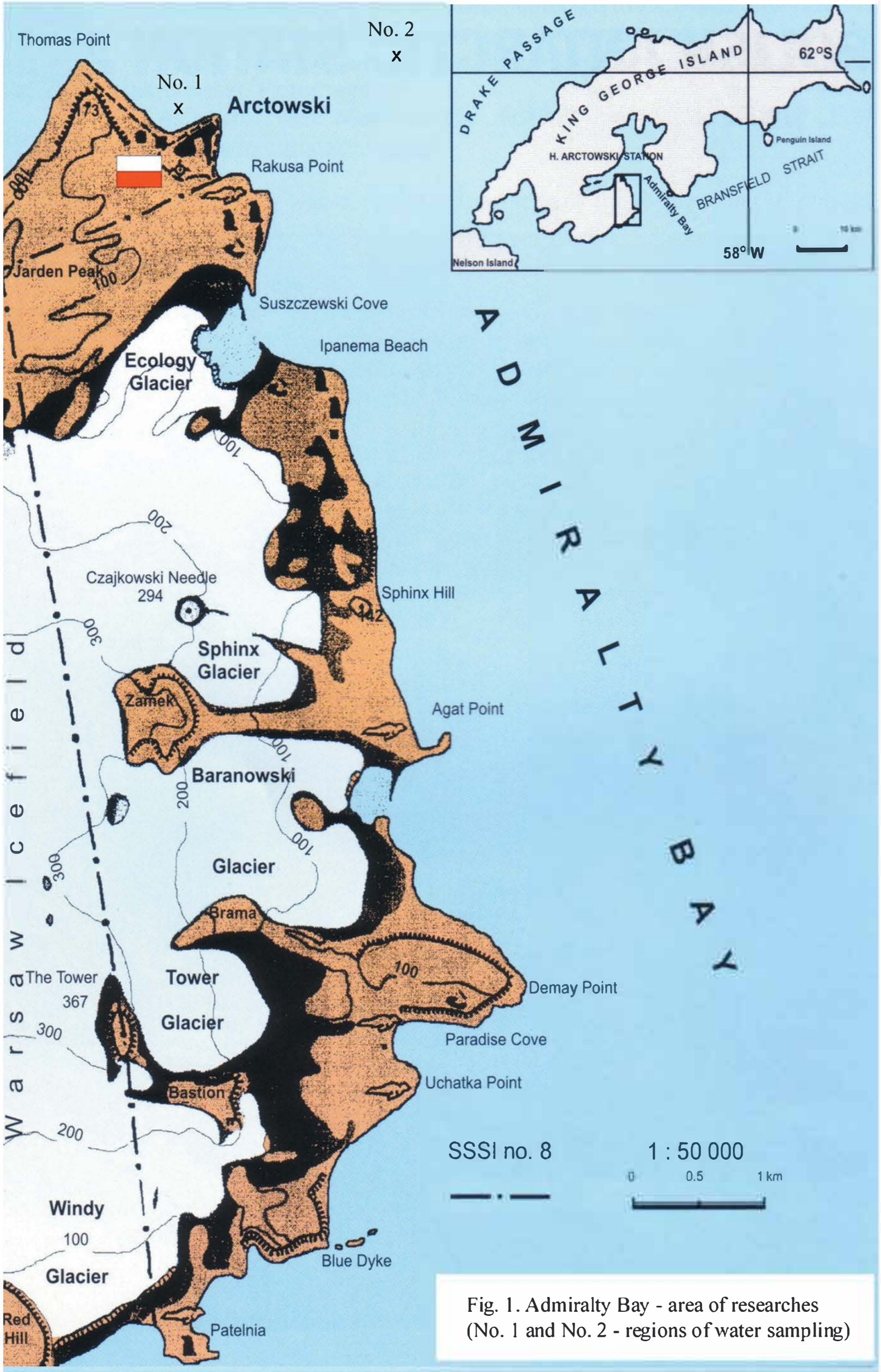

Fig. 1. Admiralty Bay - area of researches
(No. 1 and No. 2 - regions of water sampling)

Fig. 1. Admiralty Bay—area of researches (No. 1 and No. 2—regions of water sampling).

Between January and December 2001 the nutrient content was measured in the near shore zone of Admiralty Bay (about 5 m offshore) and in the surface layer of open water. The water was sampled every 3 weeks. Water samples were collected into 250 m*l* polyethylene bottles which were rinsed before each use with 2 M HCl solution. Samples were analyzed on the day of collection.

Results

In natural conditions the mass of algae reaching the coast is crushed and disintegrated in water by stones, ice, waves and tides. Also complete thalli separated from the substratum were thrown on the shore. The dry weight of individual species of macroalgae before the experiment was between 54 g (*Adenocystis utricularis*) and 248 g

Table 1. Dry mass of macroalgae before and at the end of the experiment.

No.		Dry weight in 1000 g of wet weight of algae						
		Before the experiment	After long exposure			After short exposure		
		g dry weight	Exposure time (days)	g dry weight	%	Exposure time (hours)	g dry weight	%
1	*Himantothallus grandifolius*	187	58	62.5	33.4	46	92.4	49.4
2	*Cystosphaera jacquinotii*	194	69	80.3	41.4	52	85.1	43.9
3	*Desmarestia menziesii*	185	58	122.6	66.3	46	113.9	61.6
4	*Desmarestia anceps*	227	69	152.5	67.2	52	159.3	70.2
5	*Desmarestia ligulata*	192	30	89.1	46.4	25	76.4	39.8
6	*Adenocystis utricularis*	54	30	14.2	26.3	25	17.6	32.6
7	*Ascoseira mirabilis*	165	30	89.3	54.1	25	47.7	28.9
8	*Curdiea racovitzae*	248	47	160.7	64.8	33	173.8	70.1
9	*Myriogramme mangini*	182	30	82.3	45.2	25	35.7	19.6
10	*Sarcodia antarctica*	121	30	57.8	47.8	25	37.0	30.6
11	Average 1-10	176	45	86.8	49.3	35.4	78.7	44.7
12	Disintegrated mixture of unidentified algal species collected from the beach	158	22	78.5	49.7	11	84.4	53.4

(*Curdiea racovitzae*) in 1000 g of wet weight (Table 1). The average dry weight of 10 species under study amounted to 176 g in 1000 g wet weight, and that of unidentified algal mixture deposited on the beach was 158 g in 1000 g wet weight. The decrease of dry weight of known algal species and of unknown mixture after long immersion in water was about 49% (Table 1). Short exposure resulted in a residual dry weight of 45 to 53 % (Table 1). The experiment has indicated that nitrite-N, nitrate-N, ammonium-N, total-N, reactive-P, and total-P were released in the following proportions per 1 kg dry weight: 7.4–93.7 mg, 12.9–406 mg, 74.0–7890 mg, 1110–22000 mg, 718–6110 mg and 1370–13400 mg respectively (*cf.* Tables 2 and 3). These results showed that the amounts of ammonium-N, total-N, reactive-P and total-P released from the disintegrated mixture of algae from the beach were lower than the average values for nutrients released from 10 species of fresh macroalgae.

Table 2. Amount of released nutrients from fresh macroalgae and from their mixture in the course of long exposure in distilled water.

No.		Exposure time	NO_2^--N	NO_3^--N	NH_4^+-N	total-N	reactive-P	total- P
		Days	mg N/kg dry weight				mg P/kg dry weight	
1	*Himantothallus grandifolius*	58	11.4	20.7	1010	9590	2670	5050
2	*Cystosphaera jacquinotii*	69	10.6	38.1	382	3980	2310	3530
3	*Desmarestia menziesii*	58	32.6	31.5	836	8040	2550	3730
4	*Desmarestia anceps*	69	13.2	24.9	415	5530	1230	8300
5	*Desmarestia ligulata*	30	21.9	16.9	817	7470	4140	12000
6	*Adenocystis utricularis*	30	28.9	406	693	17900	3010	5110
7	*Ascoseira mirabilis*	30	18.1	24.0	421	6830	3050	6480
8	*Curdiea racovitzae*	47	11.2	347	1500	10900	4160	5950
9	*Myriogramme mangini*	30	25.7	45.6	437	7760	6110	9120
10	*Sarcodia antarctica*	30	26.6	110	339	9940	3930	7990
11	Average 1-10	45	20.0	106	685	8790	3320	6730
12	Disintegrated mixture of unidentified algal species collected from the beach	22	51.1	35.3	74.0	2980	842	1760

Table 3. Amount of released nutrients from fresh macroalgae and from their mixture in the course of short exposure in distilled water.

No.		Exposure time	NO_2^--N	NO_3^--N	NH_4^+-N	total- N	reactive-P	total-P
		hours	mg N/kg dry weight				mg P/kg dry weight	
1	*Himantothallus grandifolius*	46	35.3	30.0	1360	8110	3250	5910
2	*Cystosphaera jacquinotii*	52	7.4	12.9	274	2740	2400	3230
3	*Desmarestia menziesii*	46	30.3	23.6	1070	12200	3440	5730
4	*Desmarestia anceps*	52	13.6	18.7	833	4020	1570	2600
5	*Desmarestia ligulata*	25	88.4	25.4	679	11500	5470	13400
6	*Adenocystis utricularis*	25	93.7	240	724	17800	3540	8080
7	*Ascoseira mirabilis*	25	74.4	29.8	304	9200	4470	6620
8	*Curdiea racovitzae*	33	11.3	111	3230	9020	3600	5170
9	*Myriogramme mangini*	25	85.6	37.1	7890	22000	5970	9800
10	*Sarcodia antarctica*	25	93.7	82.6	388	11100	3600	7330
11	Average 1-10	35.4	53.4	64.6	1680	10800	3700	6790
12	Disintegrated mixture of unidentified algal species collected from the beach	11	42.8	23.5	114	1110	718	1370

The amount of released nutrients changed with time (Tables 4 and 5). The nutrients released most readily were nitrate-N, reactive-P and total-P. From the total amount of available nutrients about 80% were liberated during the first 3 days in long exposure and the first 3 hours in short exposure experiments (Tables 4 and 5). The remaining compounds were released during the same time interval in amounts from 15.3% (ammonium-N, short exposure) to 55.4% (nitrate-N, short exposure) (Table 5). The decomposition of the mixture of macroalgae sampled from the beach, disintegrated in a natural way, exhibited a less pronounced differentiation in amounts of the nutrients being released in particular exposures in water (Tables 4 and 5). These data probably reflect results of earlier decomposition of this material in sea water. The direct analyses of nutrients in the water of Admiralty Bay revealed that their concentration near the shore (Table 6) was higher than in open water, particularly as regards ammonium-N

Table 4. Average amounts of nutrients released during long exposure in distilled water (sample No. 1–12 average values for 10 fresh identified species of macroalgae, sample No. 13–24 average values for a mixture of unidentified species, collected from the beach).

No.	Exposure time	NO_2^--N		NO_3^--N		NH_4^+-N		total - N		reactive - P		total - P	
	Day	mgN/kg d.w.	%	mgN/kg d.w.	%	mgN/kg d.w.	%	mgN/kg d.w.	%	mgP/kg d.w.	%	mgP/kg d.w.	%
1	1	2.6	12.9	72.4	68.0	181	26.5	2150	24.5	1770	53.4	3690	54.8
2	2	2.2	10.9	16.3	15.3	69.4	10.1	1080	12.3	973	29.4	1620	24.0
3	3	1.6	8.0	4.5	4.2	21.9	3.2	507	5.8	299	9.0	606	9.0
4	4	2.3	11.4	1.2	1.1	13.8	2.0	246	2.8	101	3.0	293	4.3
5	5	1.2	6.0	1.1	1.0	7.1	1.0	164	1.9	43.3	1.3	141	2.1
6	6	0.5	2.5	0.9	0.8	6.5	0.9	110	1.3	21.6	0.7	56.8	0.9
7	7	0.5	2.5	0.7	0.7	6.0	0.9	94.0	1.1	12.2	0.4	32.1	0.5
8	8	0.4	2.0	0.6	0.6	8.7	1.3	96.9	1.1	6.2	0.2	22.5	0.3
9	9	0.4	2.0	0.5	0.5	9.5	1.4	96.7	1.1	3.6	0.1	14.1	0.2
10	10	0.3	1.5	0.4	0.4	10.1	1.5	81.6	0.9	4.0	0.1	13.7	0.2
11	Sum of exposure days 11-69	8.1	40.3	7.9	7.4	350	51.2	4160	47.3	77.8	2.3	247	3.7
12	**Total**	**20.1**		**107**		**684**		**8790**		**3310**		**6740**	
13	1	2.5	4.9	6.9	19.5	2.8	3.8	180	6.0	90.1	10.7	152	8.9
14	2	7.6	14.9	4.0	11.4	6.0	8.1	465	15.6	92.2	11.0	183	10.7
15	3	3.5	6.8	0.0	0.0	4.3	5.8	15.7	0.6	79.9	9.5	205	11.9
16	4	1.7	3.4	4.9	13.9	2.8	3.8	185	6.2	101	12.0	174	10.1
17	5	3.7	7.2	1.1	3.1	2.5	3.4	245	8.2	90.0	10.7	148	8.6
18	6	3.4	6.7	0.0	0.0	1.5	2.0	35.5	1.2	66.6	7.9	109	6.4
19	7	4.1	8.0	5.9	16.7	3.4	4.6	82.5	2.8	61.0	7.2	119	6.9
20	8	6.1	11.9	4.1	11.6	4.0	5.4	94.4	3.2	48.6	5.8	64.0	3.8
21	9	0.0	0.0	1.7	4.8	4.6	6.2	117	3.9	54.9	6.5	108	6.3
22	10	2.7	5.3	1.3	3.7	4.5	6.1	107	3.6	41.4	4.9	98.4	5.7
23	Sum of exposure days 11-22	15.8	30.9	5.4	15.3	37.6	50.8	1450	48.7	116	13.8	356	20.7
24	**Total**	**51.1**		**35.3**		**74.0**		**2980**		**842**		**1720**	

Table 5. Average amounts of nutrients released during short exposure in distilled water (sample No. 1–12 average values for 10 fresh identified species of macroalgae, sample No. 13–24 average values for a mixture of unidentified species, collected from the beach).

No.	Exposure time	NO_2^- -N		NO_3^- -N		NH_4^+ -N		total - N		reactive - P		total - P	
	Hour	mgN/kg d.w.	%	mgN/kg d.w.	%	mgN/kg d.w.	%	mgN/kg d.w.	%	mgP/kg d.w.	%	mgP/kg d.w.	%
1	1	2.1	3.9	15.7	25.6	119	7.1	1710	15.9	1490	39.8	2430	35.8
2	2	3.4	6.4	11.4	18.6	102	6.2	1680	15.6	1199	32.0	1980	29.2
3	3	6.5	12.2	6.8	11.1	34.3	2.0	688	6.4	513	13.7	763	11.2
4	4	6.6	12.4	3.2	5.2	28.8	1.7	551	5.1	153	4.1	425	6.3
5	5	2.6	4.9	5.2	8.5	23.7	1.4	367	3.4	91.0	2.4	257	3.8
6	6	2.4	4.5	2.8	4.6	24.9	1.5	255	2.4	62.0	1.7	159	2.3
7	7	3.9	7.3	1.9	3.1	21.4	1.3	236	2.2	46.5	1.2	113	1.7
8	8	2.8	5.3	1.5	2.4	20.5	1.2	248	2.3	28.7	0.8	78.0	1.1
9	9	2.1	3.9	1.2	2.0	20.7	1.2	203	1.9	17.8	0.5	69.9	1.0
10	10	1.7	3.2	0.8	1.3	28.9	1.7	188	1.7	13.4	0.4	58.6	0.9
11	Sum of exposure 11-52 hours	19.2	36.0	10.8	17.6	1250	74.7	4630	43.1	127	3.4	454	6.7
12	**Total**	**53.3**		**61.3**		**1670**		**10800**		**3740**		**6790**	
13	1	0.0	0.0	5.7	24.3	1.4	1.2	86.7	7.8	87.3	12.1	146	10.7
14	2	4.9	11.4	0.0	0.0	0.8	0.7	28.8	2.6	81.3	11.3	269	19.7
15	3	5.3	12.4	0.7	3.0	2.2	1.9	60.4	5.4	110	15.3	182	13.3
16	4	6.1	14.3	2.8	11.9	25.0	21.8	135	12.2	142	19.7	191	14.0
17	5	13.1	30.6	4.4	18.7	26.5	23.1	91.1	8.2	125	17.4	192	14.0
18	6	9.0	21.0	2.0	8.5	18.2	15.9	106	9.6	93.5	13.0	131	9.6
19	7	1.4	3.3	0.4	1.7	6.2	5.4	104	9.4	44.9	6.2	82.1	6.0
20	8	0.6	1.4	1.2	5.1	7,0	6.1	122	11,0	15.6	2.2	73.0	5.3
21	9	0.5	1.2	2.0	8.5	6.5	5.7	96.7	8.7	6.2	0.9	13.9	1.0
22	10	1.0	2.3	1.0	4.3	13.4	11.7	199	17.9	12.0	1.7	11.5	0.8
23	11	0.9	2.1	3.3	14.0	7.4	6.5	79.5	7.2	1.3	0.2	76.7	5.6
24	**Total**	**42.8**		**23.5**		**115**		**1110**		**719**		**1370**	

Table 6. Concentration of nutrients in Admiralty Bay water from January to December 2001 ($n = 17$).

Region of water sampling		NO_2^- - N	NO_3^- -N	NH_4^+ -N	total - N	reactive -P	total - P
		mgN/dm³				mgP/dm³	
No 1 - near-shore water	Average	0.011	0.321	0.069	0.977	0.089	0.141
	SD	0.004	0.095	0.048	0.356	0.024	0.050
No 2 - open water	Average	0.007	0.354	0.056	0.935	0.081	0.118
	SD	0.003	0.110	0.043	0.334	0.013	0.025

and total-N, as well as phosphorus in various forms.

Discussion

The fertility of land bordering on Admiralty Bay depends upon the input of organic matter from Admiralty Bay and Bransfield Strait, in the form of feces of penguins and flying birds and algal debris deposited on the shore (Rakusa-Suszczewski, 1980). The kinetics of macroalgae decomposition in seawater and on the bay shore was examined by Zieliński (1981). These investigations have shown that the loss of 50% of macroalgal dry matter occurs after about 20 days of exposure. The decomposition rate was higher in macroalgae exposed on the shore, the state of the thallus also having an effect. In our experiments analogous results were obtained (Tables 1 and 2). A higher rate and greater amount of nutrients were released from fresh macroalgae, identified as to species (Tables 4 and 5), than from their disintegrated mixture that had gone through a decomposition process. In experimental conditions the algae were placed in distilled highly hypotonic water, that leads to cell decay (Komis *et al.*, 2002; Morbach and Kramer, 2002). This simulates the natural conditions on the sea shore, where the macroalgae have contact with fresh water.

In the region of Admiralty Bay, taking into account the amount of macroalgae deposited per meter of beach was estimated to be 104 kg dry weight (Rakusa-Suszczewski, 1995), and the nutrients may be released from the macroalgae at average rates of 404 mg nitrite-N, 22.0 mg nitrate-N, 1100 mg ammonium-N, 10500 mg total-N, 6800 mg reactive-P and 12900 mg total-P. In the region of Arctowski Station the main sources of nutrients for surface waters are the penguin guano and relict ornithogenic soils (Juchnowicz-Bierbasz and Rakusa-Suszczewski, 2002) and, to a small degree, whale bones (Rakusa-Suszczewski and Nędzarek, 2002).

The transport of algal material far inland by wind may increase the fertility of surface fresh water and may enrich the soils situated far away from regions fertilized with guano and nutrients present in water flowing down stream from penguin colonies. The near-shore water in Admiralty Bay, in spite of being highly dynamic, exhibits a somewhat higher concentration of particulate and dissolved organic matter (Pęcherzewski, 1980) and a higher content of biogenic compounds (Samp, 1980) as compared with open water, as confirmed also by our observation (Table 6). The macroalgae of Admiralty Bay therefore are a source of organic matter and nutrients and their decomposition may generate an increase of fertility of poor soils and of terrestrial water, and locally of the water in the coastal zone of Admiralty Bay.

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