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WHALE BONES AND MACROALGAE AS SOURCE OF NUTRIENTS AND CATIONS IN THE NEARSHORE GEOECOSYSTEM OF ADMIRALTY BAY (KING GEORGE ISLAND, ANTARCTICA)

ABSTRACT: In the area of the western shore of Admiralty Bay (SSSI No. 8), the remains of 52 whale skulls were found; along the shores of the entire bay 175 skulls were reported. These skulls of whales caught in the area at the beginning of the 20th century are now considered as protected elements of the landscape. Whale bones provide a continuous source of chemical elements and nutrients that are released into the environment; they also cumulate elements of anthropogenic origin, e.g. Pb. The bones of whales as well as macroalgae and penguin feathers might be the source of calcium, phosphorus, carbon, nitrogen and sulphur for the land ecosystem.

KEY WORDS: whale bones, mineral composition, nutrients

1. INTRODUCTION

The presence of whale bones at the shores of Admiralty Bay is due to whale exploitation in the area of the South Shetland Islands and the use of King George and Deception Islands as convenient bases for the whaling industry (Tonnessen and Johnsen 1982). In the years 1904–1908 increasing numbers of whales were killed in this area; 183, 791, 930, and 1743, respectively (International Whaling Statistics 1930, 1931). The unused remains of bodies and bones were carried over the bay by waves and currents. Thus as the result of man's activity there was an additional transport of matter from the sea to the shore (Rakusa-Suszczewski 1987, 1993b, 1995).

The first counting of bones in the area of Admiralty Bay was done in 1997. The count found 158 well preserved whale skulls and 17 fragments of the craniums (Kittel 2001). At the western shore of Admiralty Bay between Point Thomas and Blue Dyke, 58 skulls were observed; 89 at the Keller Peninsula; 9 at Hennequin Point; and 2 at the shore of Ezcurra Inlet. The numbers of vertebrae and ribs are unknown. In 1977 at the time of the building of Arctowski station there were thousands of such bones (Photo 1) usually lying over the storm ridge farther from the sea than the heavier skulls and their fragments. At the time of station's building and during the subsequent years of station occupation

Photo 1. The whale bones make an important component of the Admiralty Bay area landscape

many bones, mainly vertebrae and ribs, were either destroyed or taken away, while the skulls remained in place.

The purpose of the present work was the assessment of the numbers of skulls in the area of Arctowski base, the Site of Special Scientific Interest No. 8 (presently; Antarctic Specially Protected Area Fig. 1). Although bones comprise a component of a protected landscape, we must also consider them as sources of cations and nutrients that are being presently released into the land environment.

2. STUDY AREA

Whale skulls were counted along the shores of Admiralty Bay in the vicinity of the Polish Arctowski station (62°09'41" S; 58°28'10" W) from Point Thomas in the north to Patelnia Point in the south. Numbers (Fig. 1) shown in the squares express the counts of skulls found over particular distances.

Admiralty Bay is the largest in the South Shetlands archipelago. The length of its shore line amounts to ca. 84 km (Rakusa-Suszczewski 1993a). The western shores are flat with either sandy or rocky beaches. In addition, they still are, and have been, the place of accumulation of the whale bodies and skeletons. Winds prevailing from the NW towards the SW and tides generate currents along the western shores of Admiralty Bay (Madejski and Rakusa-Suszczewski 1990, Robakiewicz and Rakusa-Suszczewski 1999). Winds from SE and S cause large waves especially in the area of Point Thomas. Admiralty Bay is located in a Maritime Antarctic zone of low temperatures with the annual air temperature mean of –1.8°C (Martianov and Rakusa-Suszczewski 1990). Water temperature in the near shore zone during summer reaches a maximum of 5.3°C (Rakusa-Suszczewski 1993a). Low air and water temperatures provide conditions suitable for slow decomposition of bones.

3. METHODS

Whale skulls were counted in November and December 2000 at the western shore of Admiralty Bay (Fig.1). Samples for the analyses of mineral composition were obtained from the occipital condyle of 7 skulls found at Point Thomas (Table 1). Localiza-

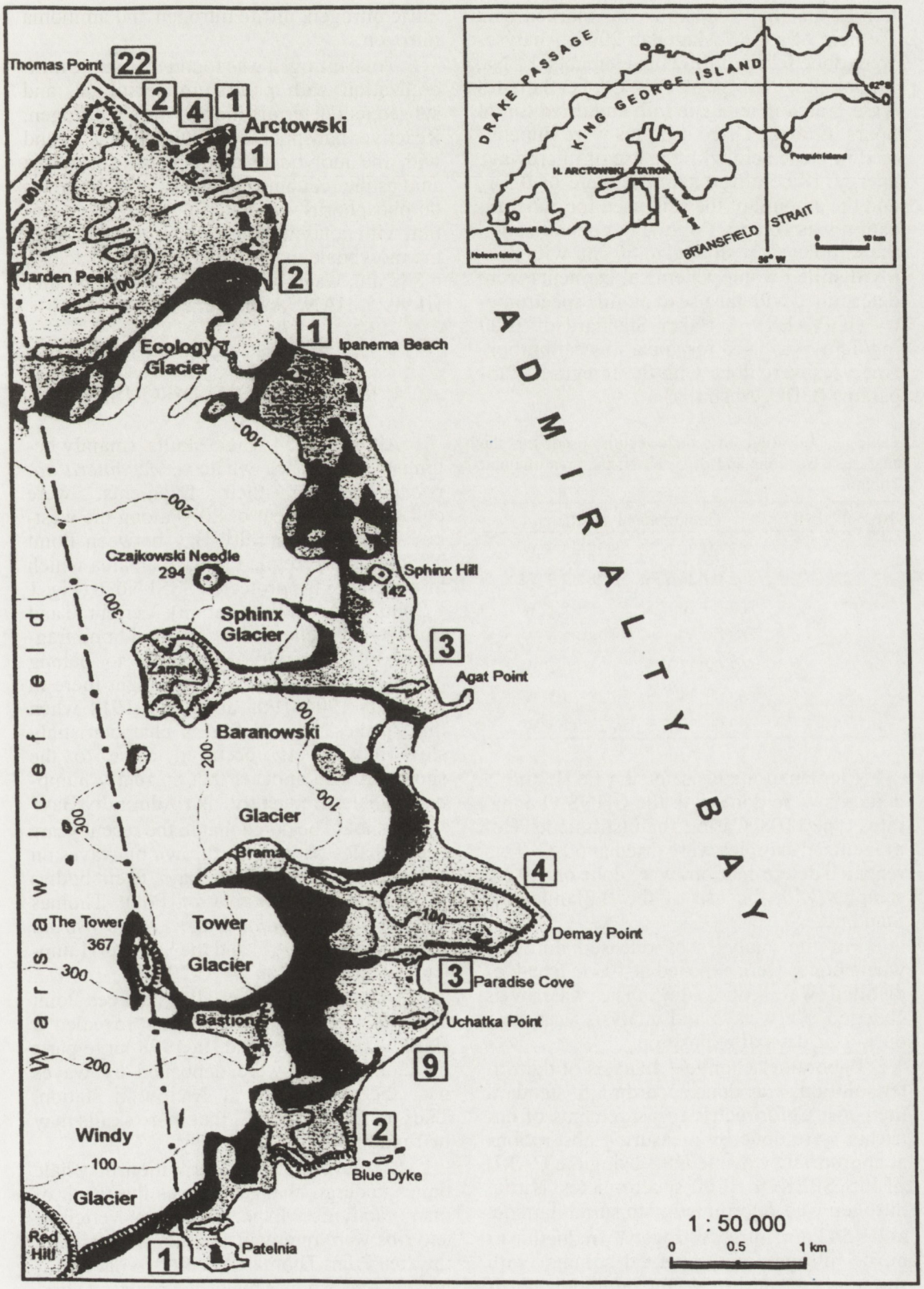

Fig. 1. Western shore of Admiralty Bay. Numbers shown in the squares express the counts of skulls found over particular distances

tion of the analyzed skulls was marked with the help of a GPS Magellan 2000. Analyses were done for the following elements: K, Na, Mn, Ni, Zn, Pb, Mg, Al, P, S, Ca, Fe. Samples were grated in an agate mill and dried for 24 hours at 60°C. Dried samples were mineralized in nitric acid with the use of microwave energy. Mineralized samples were of 0.5 g, and the amount of the acid used for mineralization was 10 cm^3. Following mineralization the samples were diluted to 50 cm^3 with doubly distilled water. Chemical elements were determined with the use of atomic spectrometry (ICP-AES). A Baker Standard of 1000 mg/dcm^3 was used for apparatus calibration. Analyses were done with the Integra XL apparatus (GBC, Australia).

Table 1. Location of whale skulls used for the analyses of cations and of C, H, N; the area of Point Thomas

No. of skull	Geographical position
1.	62°09'30.0"S, 58°28'84.9"W
2.	62°09'28.7"S, 58°28'87.9"W
3.	62°09'26.8"S, 58°28'95.1"W
4.	62°09'32.2"S, 58°28'82.6"W
5.	62°09'33.1"S, 58°28'80.2"W
6.	62°09'34.2"S, 58°28'75.3"W
7.	62°09'35.2"S, 58°28'74.3"W

Elemental analysis for the C, H, and N contents were done with the CHNS-O apparatus type 1108, Carlo Erba Instruments. Homogenized samples were dried at 60°C. Two repeated determinations were done on 4.0 mg samples with the use of the Sulfanilamide Standard.

For the analyses of released nutrients whale bones were exposed at 4°C in a bath of distilled water of 2 dm^3. The water was changed every days and analysis was done during 22 days of exposition.

Laboratory chemical analysis of the water solutions was done according to standard methods. Colorimetric measurements of nutrients were done by measuring absorptions at appropriate wave lengths using the CARL ZEISS SPEKOL 1100 spectrometer. Nitrite nitrogen was determined with sulfanilamide, at $\lambda = 543$ nm; nitrate nitrogen by reduction to nitrite nitrogen in the Cu-Cd column, with sulfanilamide, at $\lambda = 543$ nm; ammonia nitrogen with the Korelef method using indofenol blue, at $\lambda = 630$ nm; organic nitrogen from the difference of total nitrogen and the sums of nitric nitrogen, nitrite nitrogen and ammonia nitrogen.

Total nitrogen was found by sample mineralization with potassium persulfate, and subsequent determination of nitrate nitrogen. Reactive phosphorus ($P\text{-}PO_4^{3-}$) was found with the molybdate method using ascorbic acid as the reducing agent, at $\lambda = 882$ nm; total phosphorus was determined by oxygenation with potassium persulfate, and then with the molybdate method using ascorbic acid, $\lambda = 882$ nm; water pH with the Microcomputer HI 9025, HANNA Instruments.

4. RESULTS AND DISCUSION

Altogether 54 whale skulls, (mainly belong to Humpback whale – *Megaptera novaeangliae*) or their fragments, were collected in the year of 2000 along the western shore of Admiralty Bay between Point Thomas and Patelnia Point, in an area which also includes the protected SSSI No. 8 (Fig. 1 – South of Arctowski station). Vertebrae and ribs were not counted. Bones and bone fragments in Admiralty Bay seem to belong mainly to humpback whales caught there in the years 1904–1905 and 1913–1914 when this species, known for its characteristicly slow movements, occurred close to the shores. It also appears that currently humpback whales frequently visit Admiralty Bay.

It should be noted that in the recent years dead whales were twice thrown by waves on the western shore of the bay. Their bodies were found in the area of Point Thomas (Minke whale – *Balaenoptera acutorostrata* noted on 30.01.1987) and the Sphinx (Humpback whale found on 24.03.2001).

A change in the shore line between Point Thomas and Arctowski station revealed a skull hidden in the sand. In 1998 large parts of another skull were deposited by waves near the sea lantern at Arctowski station. Thus it can be expected that more skulls may be found in waters of the bay.

The numbers and distribution of whale bones undergo changes also as the result of man's activities. Especially many vertebrae and ribs were removed and taken away from the area Point Thomas – Ecology Glacier. At present whale bones make an important component of the Admiralty Bay area landscape (Photo 1) and they are being protected by the interior regulations set up for Arctowski station.

Table 2. The contents of cations (mg/kg) and C, H, N (%) in the vertebrae and skulls of whales

Cation	Bone	Skull								
		1	2	3	4	5	6	7	$\bar{x}$	S.D.
S	5400	5230	4440	5310	390	3940	3820	4710	4155	1530
P	107000	110800	101700	96930	88720	87770	84980	95390	96661	8750
Ca	245000	237900	263000	250700	226900	230200	220000	255100	241100	13950
Mg	4700	5530	4740	4500	4600	4150	4030	4850	4637.5	43050
Na	8100	7440	7420	6390	5890	7030	6960	8770	7250	852
K	740	350	660	280	810	360	320	470	498.7	194
Zn	165	155	164	132	134	152	138	208	156	23
Cu	7.6	5	2.3	3.4	4.6	3.8	3.8	13	5.4	3.2
Mn	39	15	7.8	16.7	17.9	21.7	22.8	33.8	21.8	9.5
Ni	<3	<3	<3	<3	<3	<3	<3	4.0	<3	
Pb	<10	<10	18	212	23	10	<10	<10		
Fe	640	590	180	690	600	1050	950	1920	827.5	479
Al	920	800	290	700	630	880	970	1270	807.5	266
N (%)	3.42	3.64	3.61	3.65	4.25	3.71	3.25	3.72	3.65	0.27
C (%)	11.43	12.25	12.36	12.67	14.75	12.9	11.03	12.12	12.43	1.05
H (%)	2.00	2.17	2.17	2.21	2.37	2.13	1.91	2.10	2.13	0.13

Whale bones contain 50% dry weight, 15% water, 35% fat (Tonnessen and Johnson 1982), and proteins, mainly in the form of collagen. As shown by our own analyses, the major chemical elements found in whale bones include: carbon, nitrogen, and hydrogen, and also calcium, phosphorus, sodium, sulphur and manganese; together they make 55% of dry bone weight (Table 2).

Sea water contains mainly Na, Mg, Ca, K in the respective amounts of ca. 10500, 1350, 400 and 380 mg/kg (Goldberg 1963). The contents of sodium, manganese, and potassium in bones is in the same order of magnitude as in sea water. The highest differences occur for calcium, phosphorus, and for the cations such as Fe, Al, Zn, Mn, Cu, which occur in greater concentrations in bones. High concentration of Pb in bones no. 3, and also 2 & 4 (Fig. 1; Table 2) has probably resulted from gasoline pollution and gasoline transfer to Arctowski base from the main oil-tank, along the route in the vicinity of Point Thomas, which the bones are located.

Land flora contains mainly K, Ca, Mg, Na and all species sampled in biotically enriched habitats have higher concentration of Na and K (Fabiszewski and Wojtuń 2000). there is also much of Fe, Al, Zn, Cu, Mn. Ratios of the amounts of various elements in whale bones (Table 3) are significantly different from those found in the grass, and they are more similar, in the case of Na and K, to those reported for krill, *Euphausia superba*, (Janes 1997, Juchnowicz-Bierbasz and Rakusa-Suszczewski 2002).), or mammals such as dogs, cows, rabbits or rats (Harrow and Mazur 1958). Bones might provide the potential source of various elements which are being also concentrated by land flora.

Table 3. Values of elements ratios in whale bones, are given with exactness 1 (e.g. Ca:P = 2, at left side directed down)

	Ca	P	Na	Mg	S	Fe	Al	K	Zn
Ca		–	–	–	–	–	–	–	–
P	2		–	–	–	–	–	–	–
Na	33	13		–	–	–	–	–	–
Mg	51	20	1		–	–	–	–	–
S	58	23	1	1		–	–	–	–
Fe	291	116	8	5	5		–	–	–
Al	298	119	8	5	5	1		–	–
K	483	193	14	9	8	1	1		–
Zn	1545	619	46	29	26	5	5	3	

Table 4. Release of nutrients (mg/kg) into solution during 22 days water exposure of whole bones at 4°C

Days	$N\text{-}NO_2^-$		$N\text{-}NO_3^-$		$N\text{-}NH_4^+$		$N_{org.}$		N_{total}		$P\text{-}PO_4^{-3}$		P_{total}		pH	N:P
	mg/kg	$\%NO_2$	mg/kg	$\%NO_3$	mg/kg	$\%NH_4$	mg/kg	$\%N_{org.}$	mg/kg	$\%N_{total}$	mg/kg	$\%PO_4$	mg/kg	$\%P_{total}$		
1	0.059	15.2	0.62	16.6	3.81	15.8	1.29	3.3	5.78	8.6	4.54	5.4	4.97	4.8	6.94	2.6
2	0.044	11.3	0.16	4.2	1.37	5.7	4.19	10.6	5.75	8.5	5.97	7.1	6.26	6.1	7.12	2.0
3	0.039	10.0	0.35	9.4	1.04	4.3	2.30	5.8	3.73	5.5	5.44	6.5	6.08	5.9	7.00	1.4
4	0.020	5.1	0.16	4.3	0.88	3.7	1.07	2.7	2.14	3.2	4.43	5.3	5.13	5.0	6.90	0.9
5	0.019	4.9	0.21	5.6	0.93	3.9	0.96	2.4	2.12	3.1	3.21	3.8	4.65	4.5	6.92	1.0
6	0.016	4.1	0.18	4.8	0.83	3.4	1.24	3.2	2.26	3.3	2.65	3.2	4.01	3.9	6.78	1.2
7	0.015	3.9	0.24	6.4	1.02	4.2	1.09	2.8	2.36	3.5	4.11	4.9	5.01	4.9	6.94	1.0
8	0.015	3.9	0.29	7.9	0.74	3.1	1.47	3.7	2.51	3.7	5.43	6.5	6.21	6.0	6.82	0.9
9	0.014	3.6	0.17	4.4	0.93	3.9	1.55	3.9	2.65	3.9	3.65	4.4	4.65	4.5	6.78	1.3
10	0.015	3.9	0.14	3.6	1.09	4.5	2.39	6.1	3.63	5.4	3.21	3.8	4.12	4.0	6.72	1.9
11	0.015	3.9	0.11	3.0	1.09	4.5	4.08	10.4	5.30	7.8	6.08	7.3	6.91	6.7	6.84	1.7
12	0.012	3.1	0.12	3.2	0.99	4.1	2.53	6.4	3.65	5.4	3.69	4.4	4.13	4.0	6.78	2.0
13	0.012	3.1	0.12	3.3	1.00	4.1	1.75	4.4	2.88	4.3	4.21	5.0	5.49	5.3	6.81	1.2
14	0.010	2.6	0.15	3.9	0.78	3.3	2.46	6.2	3.40	5.0	5.39	6.4	5.92	5.7	6.95	1.3
15	0.010	2.6	0.19	5.0	0.93	3.9	3.02	7.7	4.15	6.1	4.32	5.2	5.38	5.2	6.89	1.7
16	0.011	2.8	0.10	2.7	0.88	3.7	2.55	6.5	3.54	5.2	3.21	3.8	4.12	4.0	6.92	1.9
17	0.009	2.3	0.09	2.3	0.99	4.1	1.57	4.0	2.65	3.9	2.69	3.2	3.59	3.5	6.98	1.6
18	0.007	1.8	0.08	2.1	1.00	4.2	1.10	2.8	2.18	3.2	2.15	2.6	3.01	2.9	7.00	1.6
19	0.011	2.8	0.08	2.0	0.96	4.0	0.94	2.4	1.98	2.9	2.65	3.2	3.21	3.1	7.02	1.4
20	0.009	2.3	0.06	1.6	0.86	3.6	0.66	1.7	1.59	2.4	2.34	2.8	3.70	3.6	7.05	1.0
21	0.013	3.3	0.07	1.8	0.96	4.0	0.65	1.7	1.69	2.5	2.11	2.5	3.25	3.2	6.85	1.1
22	0.014	3.6	0.07	1.9	0.98	4.1	0.58	1.5	1.64	2.4	2.25	2.7	3.30	3.2	6.77	1.1
Sum	0.389	100	3.75	100	24.03	100	39.41	100	67.58	100	83.72	100	103.10	100		
Mean	0.018		0.17		1.09		1.79		3.07		3.81		4.69		6.9	

Table 5. Comparison of chemical elements contents (mg/kg) in materials of different origin in the near shore zone of Admiralty Bay. Values are given with exactness 0.1%

	Cations										
	S	P	Ca	Na	Mg	K	Fe	Al	N	C	H
Whale bones n = 8	0.4	9.6	24	0.7	0.4				4	12	2
Himantothallus grandifolius & its rizodia n = 4	1.2	0.2	1.7	1.3	0.9	0.1	0.1	0.2	3	38	5
Feather of pinquines n = 3	3.5	0.1	0.4	0.3	0.1				15	48	7
Nacella concinna (shell) n = 1			35	0.1					0.1	12	0.2
Soil near Arctowski n = 3	0.1	0.3	1.6	0.6	0.8		3.7	3	0.5	6.3	1
Stones-kaolin n = 1			5.6	1.8	0.3	0.3	0.7	7.4			1
Deschampsia antarctica n = 8	0.1	0.2	0.3	0.5	0.2	0.9	0.3	0.2	2.1	38	6
Colobanthus quitensis n = 1			1				1.2	1.3	2	31	4
Mosses n = 1	0.1	0.3	0.7	0.6	0.5	0.6	1	1	1.7	36	5.4
Usnea antarctica n = 1			2.3		0.1	0.1	0.2	0.2	0.6	40	6.1

Twenty two days exposure of vertebrae fragments in distilled water had caused a release of primarily ammonia nitrogen and organic nitrogen and phosphorus (Table 4). We think that bones are the best source of organic nitrogen which is mineralized in the process of ammonification to the easily absorbed ammonium form.

Rain and snow precipitation may wash out various elements from whale bones that fertilize the near shore ecosystem. The bones of whales as well as macroalgae and penguin feathers (Table 5) might be a primary source of calcium, phosphorus, carbon, sulphur and nitrogen for the land ecosystem.

It is a long-lasting process related to the low temperatures. As reported by Olech (1993), whale bones were observed to provide a substrate for the growth of one species of Cyanophytes, 5 species of Chlorophytes, 13 species of lichens, and 2 species of mosses. Bones provide a barrier against wind, and are the places of increased humidity. Finally, they sometimes provide nesting areas for birds that lead to the development of vascular plants in their vicinity (Zarzycki 1993, Fabiszewski and Wojtuń 2000), and enrich the near shore land ecosystem.

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5. SUMMARY

Altogether 52 whale skulls, or their fragments, were collected in the year of 2000 along the western shore of Admiralty Bay between Point Thomas and

Patelnia Point, in an area which also includes the protected SSSI No.8 (Fig. 1). Vertebrae and ribs were not counted. Bones and bone fragments in Admiralty Bay seem to belong mainly to humpback whales caught there in the years 1904–1905 and 1913–1914. The numbers and distribution of whale bones undergo changes also as the result of man's activities. At present whale bones make an important component of the Admiralty Bay area landscape (Photo 1).The contents of sodium, manganese, and potassium in bones is in the same order of magnitude as in sea water. The highest differences occur for calcium, phosphorus, and for the cations such as Fe, Al, Zn, Mn, Cu, which occur in greater concentrations in bones (Table 2).As shown by our own analyses, the major chemical elements found in whale bones include: carbon, nitrogen, and hydrogen, and also calcium, phosphorus, sodium, sulphur and manganese; together they make 55% of dry bone weight (Table 2).Land flora contains mainly K, Ca, Mg, Na and all species sampled in biotically enriched habitats have higher concentration of Na and K there is also much of Fe, Al, Zn, Cu, Mn. Ratios of the amounts of various elements in whale bones (Table 3) are significantly different from those found in the grass. Bones might provide the potential source of various elements which are being also concentrated by land flora. Twenty two days exposure of vertebrae fragments in distilled water had caused a release of primarily ammonia nitrogen and organic nitrogen and phosphorus (Table 4). Rain and snow precipitation may wash out various elements from whale bones that fertilize the near shore ecosystem. The bones of whales as well as macroalgae and penguin feathers (Table 5) might be a primary source of calcium, phosphorus, carbon, sulphur and nitrogen for the land ecosystem.

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