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Primary Production in Freshwater Bodies of the Sub-Antarctic Island Marion

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Primary production was, for the first time, determined in freshwater bodies of Sub-Antarctic islands. Production was determined of the phytoplankton, benthic algal felts, and *Potamogeton* plants covered with masses of epiphytic filamentous algae. ^{14}C tracer techniques and O_2 changes were used to measure the production *in situ* in isolated samples. Primary production of the phytoplankton in non-biotically influenced water was minimal and is among the lowest recorded in the world. The benthic algal felt and *Potamogeton* with epiphytic algae contributed most to the trophic status of the water bodies. Biological fertilization stimulated production in contaminated water.

Die primêre produksie in varswatermeertjies op Sub-Antarktiese eilande is vir die eerste keer bepaal. Die produksie van die fitoplankton, bentiese algmatte en Potamogeton*-plante wat oortrek is met epifitiese alge is bepaal.* ^{14}C*-isotooptegnieke en* O_2*-veranderinge is op geïsoleerde monsters gebruik om die primêre produksie* in situ *te meet. Die primêre produksie van die fitoplankton in water wat nie bioties beïnvloed is nie, was minimaal en is van die laagste ter wêreld tot nog toe bepaal. Die produksie van die bentiese algmatte en* Potamogeton *met epifitiese alge het die meeste tot die trofiese stand van die meertjies bygedra. Biologiese verryking het die primêre produksie in die gekontamineerde water gestimuleer.*

Introduction

Limnological research was undertaken during the Second (1971-72) and Third (1972-73) Biological Expeditions to the volcanic Sub-Antarctic island Marion, which is situated at 46° 53′ S and 37° 45′ E. Limnological research in the Antarctic and Sub-Antarctic is of recent origin, and rates of primary production have been recorded as yet only in water bodies of Antarctica. This was the first investigation to determine rates of primary production in freshwater habitats of the Sub-Antarctic.

Armitage & House (1962) recorded primary production rates of 326-1008 mgC m^{-3} day^{-1} in the shallow Skua and Coast lakes of Ross Island in Antarctica. *Goldman* (1970) reported primary production rates of 47-3 630 mgC m^{-2} day^{-1} for water bodies on Cape Evans, Ross Island, and 29 and 31 mgC m^{-2} day^{-1} respectively for Lakes Vanda and Bonney in Victoria Land. A benthic algal felt is typical of the lakes and pools of Antarctica *(Heywood,* 1972). *Goldman et al.* (1963) found that the periphyton production was more than 20 times that of the phytoplankton in Algal Lake, Ross Island. In the lakes of Signy Island production differences of 25 times between the periphyton and phytoplankton have been recorded (Horne & Fogg unpublished, cited in *Fogg & Horne*, 1970).

Apparatus and Methods

Irradiance was measured with a Kipp and Zonen recording solarimeter. The data on the chart records were reduced by the South African Weather Bureau in Pretoria, which provided computer charts with hourly, daily and monthly values of total and diffused radiation in cal cm^{-2} $time^{-1}$. A relative recording lightmeter which was calibrated with the meteorological instruments was used to make light recordings at the site of a production experiment.

Water transparency was determined with a Secchi disc and an underwater electronic lightmeter.

Water temperature was measured with a thermister thermometer/ oxygen meter (YSI Model 54) and mercury-in-glass thermometers. The YSI meter was also used for measurements of dissolved oxygen.

An *in situ* light and dark bottle ^{14}C tracer technique was used to determine primary production in a vertical series of samples of the phytoplankton in the water bodies on the island. Pyrex narrow-neck Erlenmeyer flasks with screw caps (250 ml) were used as incubation flasks. The dark bottles were darkened with a layer of black paint and thick black adhesive tape, and before incubation with aluminium foil. A volume of $NaH^{14}CO_3$ (1-2 μCi/100 ml sample) was added to each flask which was then filled with water from the water body. The flasks were suspended by means of a rod-and-clamp device for a four-hour incubation period in the water bodies. After withdrawal of the samples, they were kept in a dark box (for a period never longer than three hours, but usually less than an hour), and then 50-100 ml aliquots were filtered through Millipore HA membrane filters. Extracellular ^{14}C was removed by washing the filters with 5 ml 0,01 N HC1 and 10 ml distilled water. The wet filters were placed in scintillation vials with 10 ml Insta-Gel (Packard) scintillation liquid. The assimilated radio-activity was subsequently counted in a Packard Tri Carb Scintillation Counter at the University of the O.F.S. in Bloemfontein. The counts were converted to absolute disintegrations per minute and primary production calculated according to *Goldman et al.* (1969). Production values of the four-hour incubation period were converted to daily rates by multiplying by a factor equal to the ratio of irradiance measured during the day and that of the incubation period.

Primary production of the benthic algal felt was measured *in situ* using oxygen changes and ^{14}C tracer techniques.

Light and dark plexiglass boxes, approximately 15 × 15 × 7 cm in size, were placed over the felt during skin-diving operations. The dark boxes were covered with aluminium foil to limit heat buildup due to the absorption of radiant energy by the black boxes. Samples for oxygen analysis were taken with a 50 ml syringe through ampoule stoppers in the sides of the boxes. Production of the benthic algal felt was calculated in mgC m^{-2} day $^{-1}$ from the differences in the oxygen contents *(Strickland & Parsons*, 1965).

Small portions (5 × 5 cm) of the algal felt were removed and placed in light and dark incubation flasks. A volume of $NaH^{14}CO_3$ (2,0 μCi/100 ml sample) was added to each flask, which was then filled with water from the water body. The samples were incubated for 4 hours on the periphyton from which the samples were taken. After withdrawal the flasks were kept in a dark box until they were filtered through Whatman qualitative filter paper. The portions of the algal felt were washed with 10 ml 0,01 N HCl and 50 ml distilled water to remove the extracellular ^{14}C. The samples were dried at 105°C for 10 hours and the dry mass determined. The assimilated radioactivity was determined after combustion of a portion of the samples in a Thomas Ogg Oxygen Flask Igniter at the University of the O.F.S. in Bloemfontein. The produced $^{14}CO_2$ was absorbed in either phenethylamine or ethanolamine. These were mixed with scintillation liquid and the activity assessed in the scintillation counter. The remainder of the samples was dissolved in Soluene 100 and 350 which was mixed with scintillation liquid and counted. Primary production of the algal felt was determined in mgC m^{-2} day $^{-1}$ from the counts.

Primary production of *Potamogeton* and the masses of epiphytic filamentous algae was assessed *in situ* using a ^{14}C tracer technique. Portions of the plants with algae were placed in incubation flasks and suspended over a vertical profile for a 4 hour incubation period. The treatment of the flask and samples was the same as for the benthic algal felt production experiments and the results were calculated in mgC m^{-2} day $^{-1}$.

Results

Primary production was assessed in several water bodies over consecutive days (2-10) to determine daily variations and average production rates.

Skua Lakes

Results of the primary production experiments together with the meteorological data for the period 11 – 21.1.1973 of Skua Lakes 3 and 4 are presented in Table 1. Skua Lakes 3 and 4 are situated on Skua Ridge on the eastern side of the island.

It is evident from the results that the primary production of Skua Lake 4 was much higher than that of Lake 3. A large group of non-breeding skuas *(Stercorarius skua)* colonizes the southern shore of Lake 4, where they bathe and wash in the shallow water of the lake. The result of their fertilization was not chemically detectable, yet the minute enrichment stimulated primary production.

In both lakes primary production of the benthic algal felt was higher than the phytoplankton production. The specific production rates were extremely low and ranged from 0,01 – 0,03% in both lakes. The only significant correlation between the parameters was found between irradiance and O_2-estimated littoral felt production in Lake 3 (r = 0,85).

Albatross Lake 1

Results of the primary production experiments as well as the meteorological data for a few consecutive days of Albatross Lake 1 are presented in Table 2. This lake is the northernmost of the Albatross Lakes which are situated on the eastern side of the island.

The very low phytoplankton primary production values of 1,32 – 9,38 mgC m^{-2} day $^{-1}$ are evident from the results. Primary production of *Potamogeton* and of the epiphytic filamentous algae was extremely high and production rates of up to 1 269,8 mgC m^{-2} day $^{-1}$ were recorded. Low specific production rates were measured (0,01 – 0,03%).

Lava-lakelet in Study Area 1

Results of the measurements of primary production together with meteorological data of the lava-lakelet in Study Area 1 are presented in Table 3. This lava-lakelet is the larger of the two lakelets in Study Area 1, which is situated west of the Meteorological Station.

The phytoplankton primary production rates in the lava-lakelet were relatively high and values of up to 40,57 mgC m^{-2} day^{-1} were recorded over the 4 day investigation period. Production of the periphyton was not as high as in the Skua Lakes and the ratio between the algal felt and the phytoplankton production was much less than in the Skua Lakes. The production values obtained from the algal felt with the O_2-method were of the same order of magnitude as those obtained with the ^{14}C-method. Very low specific production rates were recorded.

Gentoo Lake

Gentoo Lake is a biotically fertilized lake and results of the primary production experiments are given in Table 4. This lake is situated directly below the Meteorological Station on the eastern side of the island and is frequented by elephant seals and penguins.

The effect which the biotic enrichment has on the primary production of Gentoo Lake is evident from the results. A maximum phytoplankton production value of 793,29 mgC m^{-2} day^{-1} was recorded on 7.2.1973. The primary production values determined on 6 – 8.2.1973 were appreciably higher than those of 22 – 23.3.1973. Since the water was extremely turbid it curtailed biomass estimations and therefore specific production rates could not be determined.

Wallows

Results of primary production experiments in two wallows near Gentoo Lake are given in Table 5. The extremely high primary production rates of up to 6 004 mgC m^{-2} day^{-1} in wallows are evident. Increases in the dissolved oxygen content of the water of up to 4,3 mg O_2/l which was due to marked photosynthesis in the wallows, were measured over the 4 hour incubation period. Chlorophyll contents of the phytoplankton of up to 2,75 mg/l were determined and were the highest recorded in water bodies on the island.

Table 1

Primary production results from Skua Lakes 3 and 4

Water	Date 1973	Water temp. °C	Percentage light penetration 25 cm	50 cm	bottom*	Wind direction and force km h^{-1}	Irradiance J $cm^{-2} day^{-1}$	Irradiance during incubation J cm^{-2} $4h^{-1}$	Cloudiness	Phytoplankton primary production mg C m^{-2} day^{-1}	Bottom algal felt primary production (O_2 estimated) mg C $m^{-2} day^{-1}$	Shore algal felt primary production (^{14}C estimated) mg C m^{-2} day^{-1}	Specific production rate %
Skua Lake 3	11 Jan	14,0	93	—	82	SSW 21	2554	1230	cloudy	4,13	261	—	—
Skua Lake 3	12 Jan	11,0	92	83	71	E 11	1792	933	overcast	6,15	149	—	—
Skua Lake 3	13 Jan	10,0	71	50	39	E 7	2177	849	overcast	6,74	269	316	0,02
Skua Lake 3	14 Jan	11,0	82	65	55	NE 7	1708	808	overcast	9,93	164	411	0,03
Skua Lake 3	15 Jan	12,0	89	78	62	NNW 23	2445	1168	cloudy	6,67	332	397	0,03
Skua Lake 3	16 Jan	9,0	60	40	27	NW 30	1277	473	overcast	15,51	242	422	0,02
Skua Lake 3	17 Jan	11,0	87	75	72	ENE 15	2721	1327	partly cloudy	10,58	295	265	0,02
Skua Lake 3	18 Jan	10,0	92	85	78	WNW 37	1218	782	cloudy	5,97	20,6	187	0,02
Skua Lake 3	21 Jan	9,0	70	45	20	NNE 23	996	360	overcast	11,08	—	556	0,03
Skua Lake 4	11 Jan	14,0	92	—	70	SSW 21	2554	1230	cloudy	12,81	—	—	—
Skua Lake 4	12 Jan	11,0	84	71	44	E 11	1792	933	overcast	15,23	86	—	—
Skua Lake 4	13 Jan	10,0	79	56	36	E 7	2177	849	overcast	24,65	61	91	0,01
Skua Lake 4	14 Jan	11,0	83	68	46	NE 7	1708	808	overcast	51,02	221	217	0,02
Skua Lake 4	15 Jan	11,0	88	80	64	NNW 23	2445	1168	cloudy	15,92	194	138	0,01
Skua Lake 4	16 Jan	9,0	41	19	6	NW 30	1277	473	overcast	101,66	56	91	0,01
Skua Lake 4	17 Jan	11,0	90	85	72	ENE 15	2721	1327	partly cloudy	27,51	43	158	0,01
Skua Lake 4	18 Jan	10,0	90	85	70	WNW 37	1218	782	cloudy	33,93	16	110	0,01
Skua Lake 4	21 Jan	9,0	62	45	30	NNE 23	996	360	overcast	52,89	—	247	0,01

*Depth at Skua Lake 3 was 70 cm and at Skua Lake 4 it was 90 cm.

Table 2

Primary production results from Albatross Lake 1

Date 1973	Water temp. during incubation start °C	end °C	Percentage light penetration 25 cm	50 cm	100 cm	200 cm	Wind direction and force km h^{-1}	Irradiance J cm^{-2} day^{-1}	Irradiance during incubation J cm^{-2} 4 h^{-1}	Cloudiness	Phytoplankton primary production mg C m^{-2} day^{-1}	Primary production of *Potamogeton* and epiphytic algae mg C m^{-2} day^{-1}	Specific production rate %
31 Jan	9,0	12,0	81	63	46	6	SSW 23	2428	1117	partly cloudy	1,32	—	—
1 Feb	9,0	10,0	69	46	17	4	WSW 11	1712	937	overcast	2,47	658,6	0,02
2 Feb	11,0	11,2	75	46	18	2	NW 23	1984	996	overcast	9,38	1269,7	0,03
3 Feb	10,7	11,8	75	51	18	3		1201	360	overcast	5,35	958,1	0,02
4 Feb	9,5	9,5	47	25	10	2	NW 17	*	*	overcast	1,69	445,6	0,01

*Radiation data not recorded due to instrument failure

Table 3

Primary production results from the lava-lakelet in Study Area 1.

Date	Water temp. during incubation		Percentage light penetration					Wind direction and force	Irradiance	Irradiance during incubation	Cloudiness	Phytoplankton primary production	Algal felt primary production (O_2 method)	Algal felt primary production (^{14}C method)	Specific production rate
1973	start °C	end °C	25 cm	50 cm	100 cm	200 cm		km h^{-1}	J cm^{-2} day^{-1}	J cm^{-2} 4 h^{-1}		mg C m^{-2} day^{-1}	mg C m^{-2} day^{-1}	mg C m^{-2} day^{-1}	%
26 Feb	12,0	12,0	77	62	40	30		NNW21	2374	1080	partly cloudy	34,00	52,3	50,51	0,02
27 Feb	10,5	10,0	80	65	39	27		N21	*	523	overcast	19,83	10,6	17,36	0,01
28 Feb	11,0	12,0	75	54	30	21		N15	996	594	overcast	32,76	31,6	61,05	0,03
1 Mar	12,5	13,6	64	47	28	19		N14	724	280	overcast	40,57	46,7	45,91	0,02

*Radiation data not recorded due to instrument failure

Table 4

Primary production results from Gentoo Lake

Date	Water temp. during incubation		Percentage light penetration			Secchi depth	Wind direction and force	Irradiance	Irradiance during incubation	Cloudiness	Phytoplankton primary production
1973	start °C	end °C	10 cm	25 cm	50 cm	cm	km h^{-1}	J cm^{-2} day^{-1}	J cm^{-2} 4 h^{-1}		mg C m^{-2} day^{-1}
6 Feb	10,0	12,0	20	3	1	9,6	SSW 29	1963	820	partly cloudy	152,45
7 Feb	9,0	11,0	20	4	1	9,5	NNW 25	1214	113	overcast	793,29
8 Feb	12,0	16,0	60	15	1	12,5	N 15	*	*	cloudy	299,31
22 Mar	8,0	11,0	33	5	1	14,7	~11	1277	611	cloudy	46,28
23 Mar	9,3	10,8	30	3	1	12,4	NW 38	686	456	overcast	58,66

*Radiation data not recorded due to instrument failure

Table 5

Primary production results from two wallows near Gentoo Lake

Water	Date	Water temp. during incubation		O_2 content during incubation		Secchi depth	Wind direction and force	Irradiance	Irradiance during incubation	Cloudiness	Total chlorophyll content of water	Phytoplankton primary production	Specific production rate (%)
	1973	start °C	end °C	start mg/l	end mg/l	cm	km h^{-1}	J cm^{-2} day^{-1}	J cm^{-2} $4h^{-1}$		mg/l	mg C m^{-2} day^{-1}	mg C mg Chl^{-1}
Wallow 1	6 Feb	10,0	16,0	14,3	18,6	4,7	SSW 29	1963	820	partly cloudy	2,010	3494,2	1,74
Wallow 1	7 Feb	7,5	13,0	11,2	15,4	4,9	NNW 25	1214	113	overcast	1,960	5622,6	2,87
Wallow 1	8 Feb	19,0	23,0	17,6	19,4	5,5	N15	*	*	cloudy	2,750	4785,4	1,74
Wallow 2	6 Feb	10,0	16,0	7,5	11,0	5,7	SSW 29	1963	820	partly cloudy	0,821	4457,6	5,43
Wallow 2	7 Feb	7,5	12,0	6,6	8,6	4,4	NNW 25	1214	113	overcast	1,135	6003,9	5,29
Wallow 2	8 Feb	16,0	21,0	13,3	15,9	4,0	N 15	*	*	cloudy	1,674	5548,7	3,31

*Radiation data not recorded due to instrument failure

Pronounced animal fertilization, especially N and P enrichment were responsible for the eutrophic nature of wallows. Wallow 2 was slightly more productive than wallow 1 and the concentrations of ammonia nitrogen, nitrate nitrogen and total dissolved phosphate phosphorus were 55,2; 20,4; 4,28 and 33,8; 21,4; 3,64 mg/l respectively. The chlorophyll contents were used as a measure of the organic mass *(Wetzel & Westlake*, 1969) and the specific growth rates of 1,74 – 5,43% were the highest recorded on the island.

Discussion

The primary production rates recorded in the non-biotically influenced water bodies are amongst the lowest determined in the world. The production results are summarized in Fig. 1, showing:

(a) a lake with no biotic influences (Skua Lake 3),
(b) a lake with little biotic enrichment (Skua Lake 4),
(c) a lava-lakelet with no biotic influences (Study area 1),
(d) a lake with no biotic influences and a dense stand of *Potamogeton* (Albatross Lake 1),
(e) a biotically enriched lake (Gentoo Lake), and
(f) a wallow.

Efford (1967) reported average annual production values of only 22 mgC m^{-2} day^{-1} for Marion Lake, British Columbia. In the Arctic, primary production values of 0 – 200 mgC m^{-2} day^{-1} with an average June, July and August production of 7 – 82 mgC m^{-2} day^{-1} were recorded *(Kalff*, 1970).

The rigorous climate, poor water quality and scarcity of truly planktonic algae could account for the low production rates on Marion Island. No detailed algal survey was made, but the dominance of the Zygnemataceae as the main component of the water flora was well established. During windy conditions the filamentous algae and gelatinous blue-green algae were stirred into suspension and, as a result, high phytoplankton production rates were usually recorded on such days (see Skua Lakes 3 and 4 on 16.1.1973, Table 1).

Biotic enrichment stimulates primary production, the magnitude of which is dependent on the extent of fertilization. Skua Lake 4 is subjected to enrichment by a few non-breeding skuas and has a significantly higher phytoplankton production than Skua Lake 3 which is not fertilized. Gentoo Lake, on the other hand, is subjected to marked biological enrichment and has correspondingly high production rates. Wallows, which represent extreme degrees of biotic fertilization, have the highest primary production rates recorded on the island.

Primary production in the benthic algal felt was up to 42 times higher than that of the phytoplankton in the overlying water. In Skua Lake 3 the bottom littoral zone produced approximately 25 times as much as the phytoplankton and the shore littoral zone about 42 times as much. Production in the algal felt of Skua Lake 4 was only 2 – 4 times more than that of the phytoplankton. In the study area lava-lakelet production of the algal felt and of the phytoplankton was of the same order. In Albatross Lake 1 production of the phytoplankton compared with that of *Potamogeton* and the epiphytic algal mass was minimal, the latter producing approximately 200 times as much as the phytoplankton.

From these results it is evident that the algal felts and *Potamogeton* contribute most to the trophic status of the non-biotically influenced water bodies. Because factors such as wind, temperature and biotic enrichment greatly influence production rates, no correlations could be found between parameters such as irradiance, phytoplankton

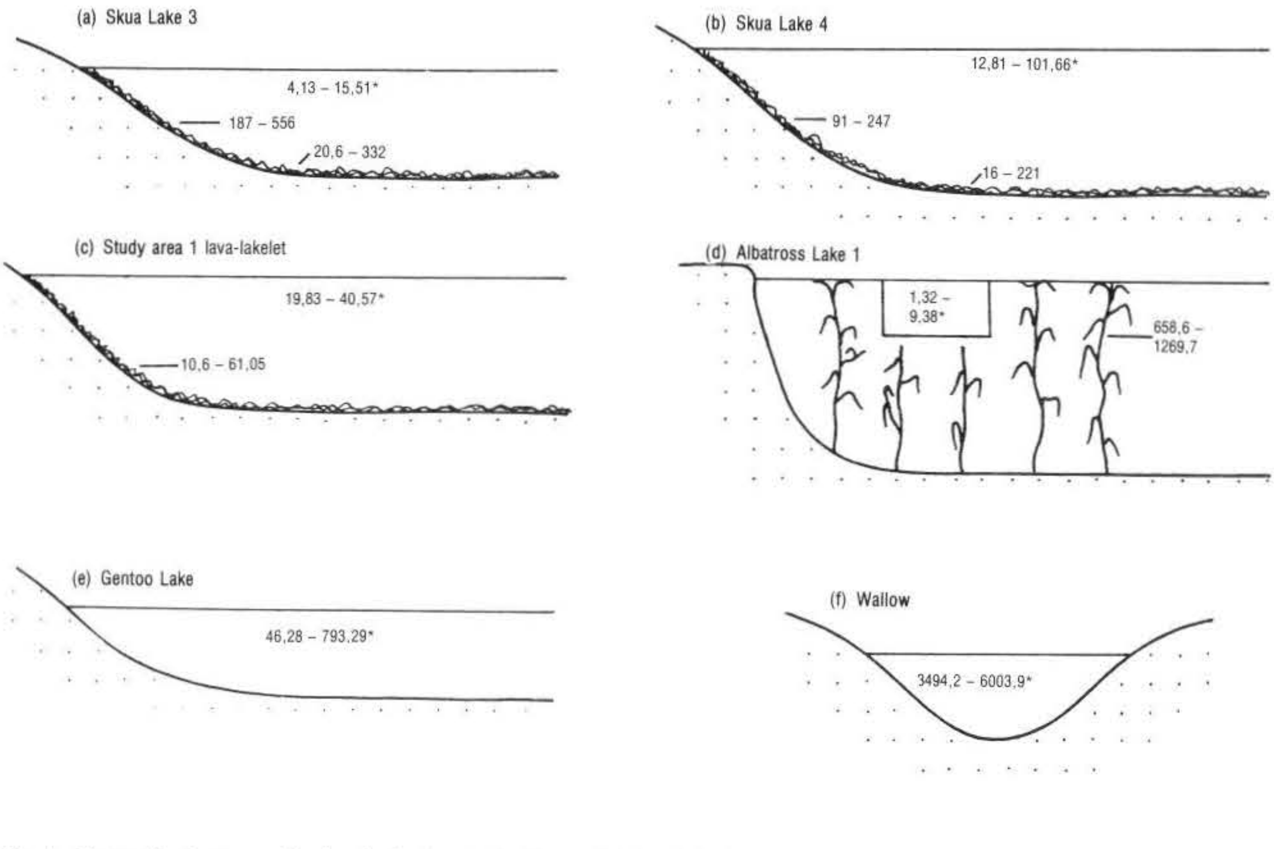

Fig. 1. Rates of primary production in freshwater bodies on Marion Island (* Phytoplankton primary production).

and periphyton production. The low specific production rates indicate extremely inactive algal populations in the water bodies. The poor water quality is mainly responsible for this, as high specific production values were recorded in biologically contaminated water (5,43% in wallows).

In discussing the biota of Marion and Prince Edward Islands, *Van Zinderen Bakker* (1971) stresses their small species diversity and ascribes it mainly to the relatively young geological age of the islands. As a consequence of this the food chains and food webs in the ecosystems of the island are fairly simple. In the freshwater habitats a maximum of only two trophic levels can be found. The first trophic level, the procedures, comprises the phytoplankton and benthic algal felts and the second, the herbivores, which are represented only by zooplankton (Entomastraca). In wallows, only the first trophic level may be present.

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References

Armitage, K.B. & House, H.B. A limnological reconnaissance of the area of McMurdo Sound, Antarctica. *Limnol. Oceanogr.*, **7**, 36-41, 1962.

Efford, J.A. Temporal and spatial differences in phytoplankton of Marion L., British Columbia. *J. Fish. Res. Bd Can.*, **24**(2), 2283-2307, 1967.

Fogg, G.E. & Horne, A.J. The physiology of Antarctic freshwater algae. In *Antarctic ecology*, edited by M.W. Holdgate, 632-638. London and New York, Academic Press, 1970.

Goldman, C.R. Antarctic freshwater ecosystems. In *Antarctic ecology*, edited by M.W. Holdgate, 609-627. London and New York, Academic Press, 1970.

Goldman, C.R., Mason, D.T. & Wood, B.J.B. Light injury and inhibition in Antarctic freshwater phytoplankton. *Limnol. Oceanogr.*, **8**, 313-322, 1963.

Goldman, C.R., Steemann Nielsen, E, Vollenweider, R.A. & Wetzel, R.G. The ^{14}C light and dark bottle technique. In *A manual on methods for measuring primary production in aquatic environments*, edited by R.A. Vollenweider, 70-73. Oxford and Edinburgh, Blackwell, 1969.

Heywood, R.B. Antarctic limnology: a review. *British Antarctic Survey Bulletin*, no. 29, 35-65, 1972.

Kalff, J. Arctic lake ecosystems. In *Antarctic ecology*, edited by M.W. Holdgate, 651-663. London and New York, Academic Press, 1970.

Strickland, J.D.H. & Parsons, T.R. A manual of sea water analysis. *Fisheries Research Board of Canada Bulletin*, no. 125, 167-170, 1965.

Van Zinderen Bakker, E.M. Sr. Introduction. In *Marion and Prince Edward Islands*. Report on the South African Biological and Geological Expeditions, 1965-66, edited by E.M. van Zinderen Bakker Sr., J.M. Winterbottom & R.A. Dyer, 1-15. Cape Town, A.A. Balkema, 1971.

Wetzel, R.G. & Westlake, D.F. Periphyton. In *A manual on methods for measuring primary production in aquatic environments*, edited by R.A. Vollenweider, 33-40. Oxford and Edinburgh, Blackwell, 1969.

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